Beverage Packaging

A Comparative Life Cycle Assessment

On behalf of
Ball Corporation

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List of Acronyms

ACE	Alliance for Beverage Carton and the Environment
ADP	Abiotic Depletion Potential
AP	Acidification Potential
ATB	AlumiTek aluminum bottle
BR	Brazil
CFF	Circular Footprint Formula
CML	Centre of Environmental Science at Leiden
CN	China
DQI	Data Quality Index
EF	Environmental Footprint
ELCD	European Life Cycle Database
EoL	End-of-Life
EP	Eutrophication Potential
eq.	Equivalents
EU	European Union
EU	European Union (used to define the scope of regionalization in GaBi)
FEVE	The European Container Glass Federation
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
GPI	Glass Packaging Institute
GWP	Global Warming Potential
ILCD	International Cycle Data System
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MCI	Material Circularity Indicator
MSWI	Municipal Solid Waste Incinerator
NMVOC	Non-Methane Volatile Organic Compound

ODP	Ozone Depletion Potential
PEF	Product Environmental Footprint
PET	Polyethylene terephthalate
PET (C)	PET bottle for carbonated beverage
PET (NC)	PET bottle for non-carbonated beverage
POCP	Photochemical Ozone Creation Potential
SFP	Smog Formation Potential
STD	Standard aluminum can
TPA	Tetra Prisma Aseptic
US	United States of America
VOC	Volatile Organic Compound

Glossary

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)

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.

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)

Comparative assertion

"Environmental claim regarding the superiority or equivalence of one product versus a competing product that performs the same function." (ISO 14044:2006, section 3.6)

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).

Foreground system

"Those processes of the system that are specific to it … and/or directly affected by decisions analysed 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.

Functional unit

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

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 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)

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)

Packaging efficiency

In this report, this term refers to packaging-to-product ratio, i.e. the less packaging material required to provide the functional unit of fill volume, the more efficient the packaging is in delivering the product.

Recycling and collection rates

Recycling and collection rates are both referred to in this report. The significant difference between the two terms in practice is that recycling rates tend to be lower than collection rates because of material losses during the sorting process (contamination and process inefficiencies). However, these losses are not quantifiable by the authors of this study due to lack of available data. Recycling rates themselves may also be variable depending on whether they are measured as the *input* of recycling material into the recycling plant, or the *output* of recycled material from that plant. Unless specified otherwise, collection and recycling rates as used in this report both refer to material inputs into the recycling plant.

Sensitivity analysis

“Systematic procedures for estimating the effects of the choices made regarding methods and data on the outcome of a study.” (ISO 14044:2006, section 3.31)

System boundary

“Set of criteria specifying which unit processes are part of a product system.” (ISO 14044:2006, section 3.32)

Value of scrap

Estimated environmental burdens associated with the provision of secondary material prior to recycling (i.e. scrap). Calculated as the environmental impact of primary material minus the impact of recycling.

Executive Summary

The goal of the study is to conduct a Life Cycle Assessment (LCA) analyzing the environmental performance of single-use, small-to-medium size aluminum cans and bottles compared to competing alternative packages: PET bottles, glass bottles and beverage cartons in three different markets: EU, US and Brazil. One focus of the study is on varying degrees of recycling rates and recycled content to understand interdependencies between circular product design and environmental impacts of different beverage packaging options.

The study has been commissioned by Ball Corporation. As the study includes comparative assertions of different beverage packaging systems a Critical Review by an external panel was performed.

The primary intended application of the study is to provide up-to-date and objective results in various sustainability metrics of specific beverage packaging alternatives.

The main reason for carrying out the study is to identify the environmental hotspots of the aluminum can's life cycle and related optimization potential. The secondary reason is to compare and contrast various beverage packaging alternatives, with the intention of comparative assertions intended to be disclosed to the public (except for confidential primary data), in three regional settings, using different End of Life methods.

The study is intended for publication to beverage producers as the primary audience, but also to provide credible communication material for retailers and other interested parties.

This study meets the requirements of the international standards for Life Cycle Assessment (LCA) according to ISO 14040 (ISO, 2006) / ISO 14044 (ISO, 2006).

In three regional contexts, four beverage packaging alternatives in various sizes are compared. The assessment includes raw material extraction and manufacturing of primary and secondary packaging but excludes the beverages themselves. The system boundaries are cradle to grave, thus including transports to filling and distribution, as well as end of life of the packaging materials.

In the EU, the political context made the Product Environmental Footprint Circular Footprint Formula (PEF CFF) method the most up-to-date and relevant approach to handling secondary material inputs and recycling credits. In the US, the cut-off approach is considered the most widely accepted and practiced, whereas in Brazil the substitution approach is applied for baseline scenarios. Alternative approaches were considered as scenarios for the EU and US.

In each region, a specific selection of 2-4 products per packaging material were purchased, measured and weighed. Ball Corporation supplied primary data on can manufacturing, while all other background and foreground data were based on industry averages and association datasets from the GaBi Databases 2019.

To make the study an overarching reference material for today's and tomorrow's decisions, sensitivity analyses are not only considered for data uncertainty but also to display variability in:

- Collection/recycling rates 0-100%
- Recycled content 0-100%
- Lightweighting 5-10%
- Glass bottle refill scenarios 0-20x

- Methodology (PEF CFF vs substitution, substitution vs. cut-off)

The LCIA includes global warming potential (EF 3.0 for Europe, TRACI for US and ReCiPe for Brazil), acidification, eutrophication and other environmental impact categories. These traditional LCA considerations are complemented by the material circularity indicator (MCI), developed by the Ellen MacArthur Foundation and Granta Design. MCI measures how restorative the material flows of a product are. While it does not consider material efficiency, it is a socio-economic metric which is increasing in popularity and leverage among private and public stakeholders. It should be used in conjunction with the LCA results to enable a more comprehensive understanding of product sustainability.

Figures 1-1 to 1-3 provide an overview of the baseline performance of each packaging alternative per region, showing the potential for variation in the climate change based on the influence of each sensitivity analysis and scenario performed. This allows the user to easily see the potential minimum climate change impact and the maximum worst recorded climate change impact, assessed in this study. Further impact categories need to be considered as well, and can be found in chapters 4.1.1, 4.1.2, 4.1.3 for the EU region, in chapters 5.1.1, 5.1.2, 5.1.4 for the US region and in chapters 6.1.1, 0 and 6.1.4 for the Brazil region.

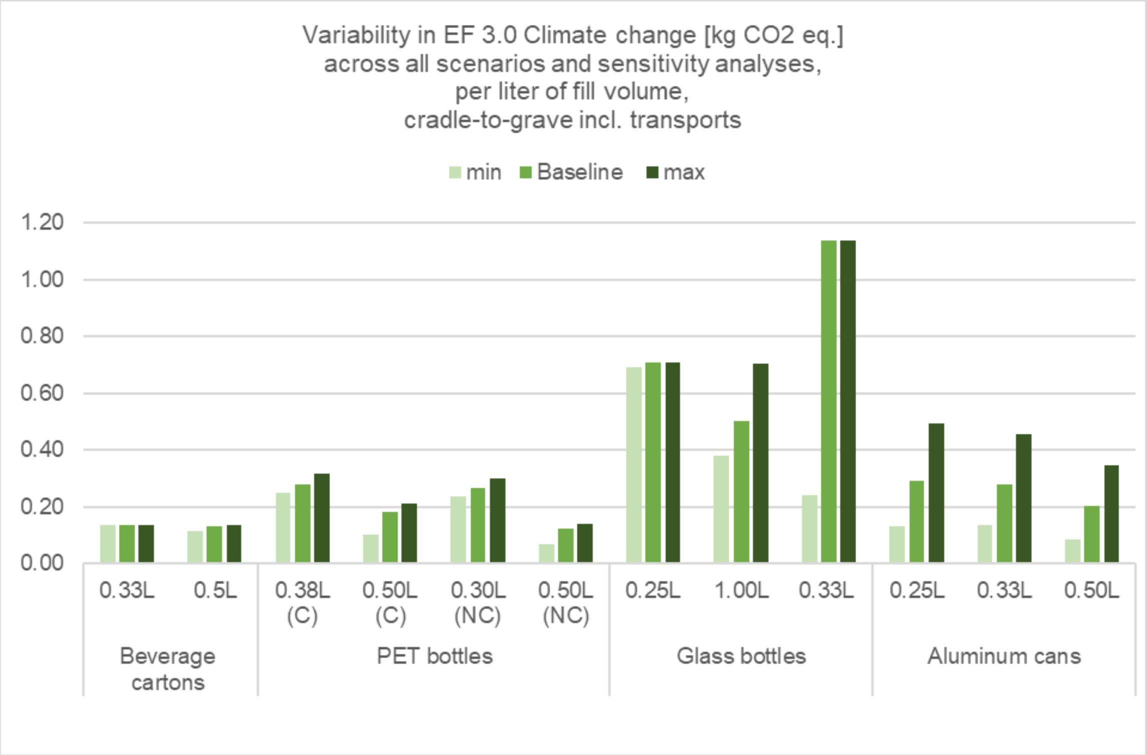

Figure 1-1:Variability of the EF 3.0 Climate change [kg CO2 eq.] impact of products scaled to 1 liter of fill volume, cradle-to-grave incl. transports, across all scenarios and sensitivity analyses in the EU.

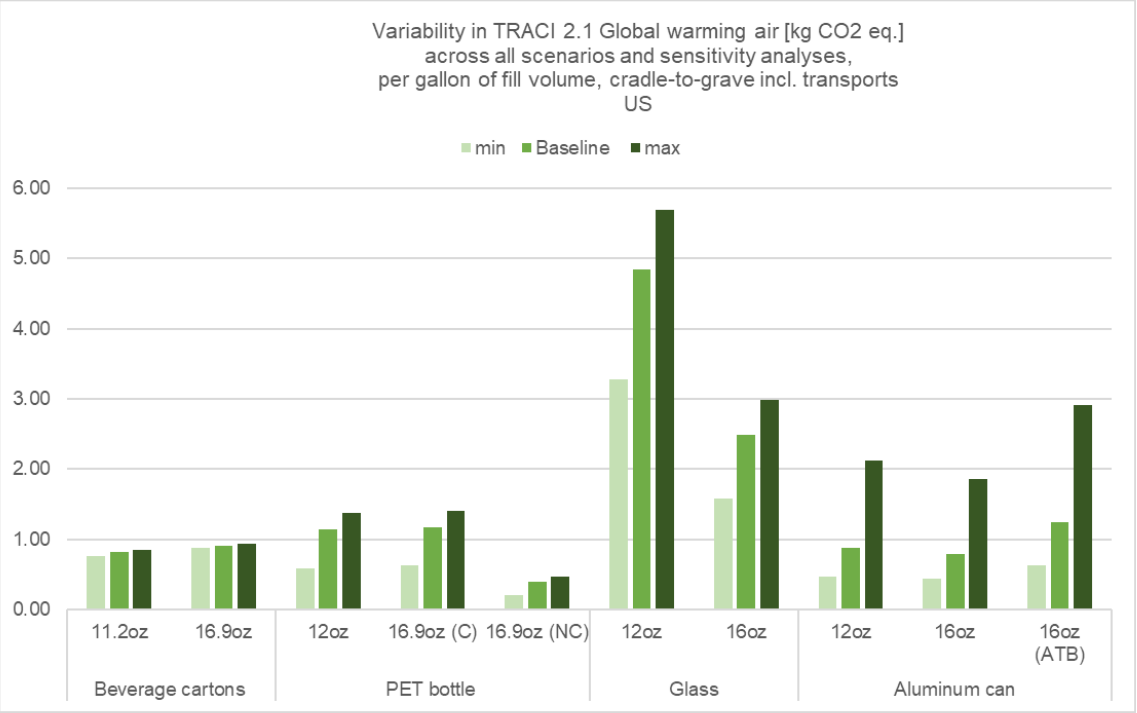

Figure 1-2:Variability of the TRACI 2.1 Global Warming Air [kg CO2 eq.] impact of products scaled to 1 gallon of fill volume, cradle-to-grave incl. transports, across all scenarios and sensitivity analyses in the US.

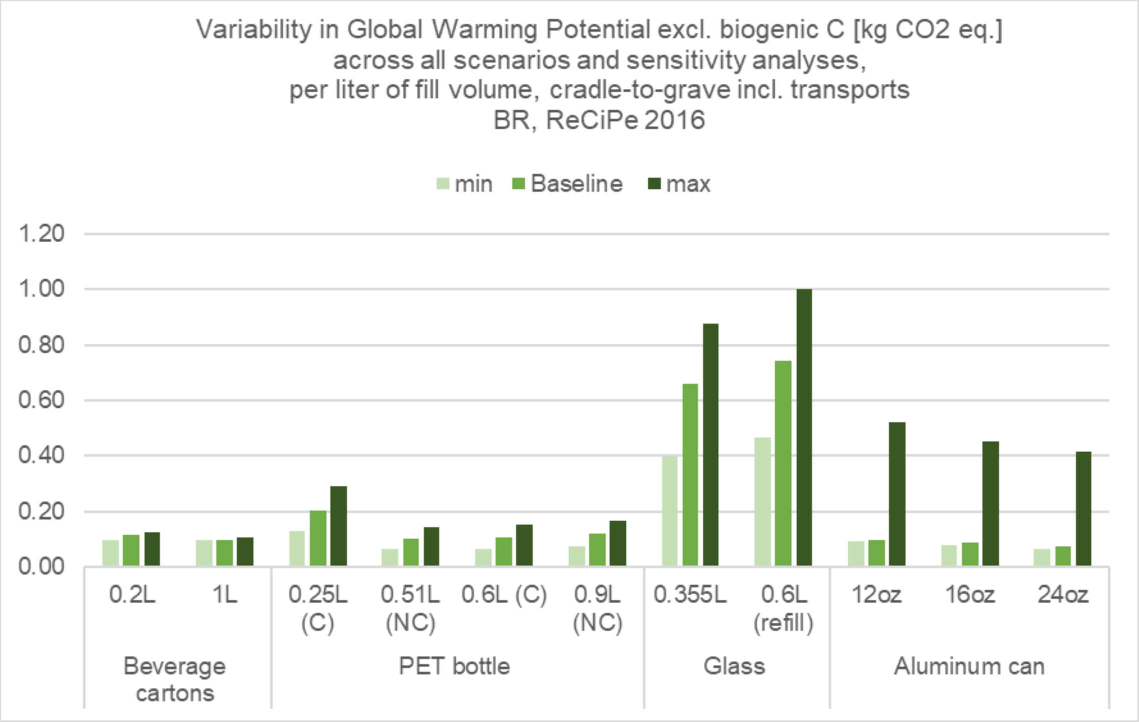

Figure 1-3:Variability of the Global Warming Potential excl. biogenic C [kg CO2 eq.] of products scaled to 1 liter of fill volume, cradle-to-grave incl. transports, across all scenarios and sensitivity analyses in Brazil.

Conclusions from this study include:

- Packaging efficiency has a significant impact on the environmental burdens of the packaging. A packaging container with a larger volume requires relatively less material to provide a given quantity of product. This is an important factor to consider when making comparisons across different packaging formats and sizes. It is important to note here, that the study focused on small-to-medium sized products, not all beverage packaging types and formats such as 2 liter or 1 gallon bottles.
- Among non-carbonated beverages, the best performers in Europe and the US tend to be PET bottles for water, where thin wall designs result in relatively small impacts. In Europe, where non-carbonated PET bottles also covered a juice bottle, beverage cartons in fact perform more consistently well. In Brazil, the 97% recycling rate of aluminum beverage cans make them the best performer in all but one impact categories.
- Among carbonated beverages, aluminum cans and PET bottles compete for most favorable LCA results. In Europe, PET bottles tend to have somewhat more consistently high performance, whereas in the US aluminum cans have a lower global warming potential and acidification, while PET performs better in other impact categories. In Brazil, aluminum cans are the best performers across all but one impact categories.
- The regional variation in rankings has mostly to do with differences in recycled content and recycling rates, but is also impacted by the choice of methodology: in the EU, the PEF CFF method generates markedly higher impacts for aluminum cans with medium recycled content and high recycling rates compared with lower impacts when other methodologies are applied. With high recycled content and medium recycling rates, the US applies a slightly more favorable method for aluminum cans (cut-off vs substitution). By contrast, in Brazil both recycling and recycled content are at their highest among all regions and the methodology most favorable to aluminum cans (substitution) has been applied.
- Single-use glass bottles consistently show the highest environmental burdens across all impact categories due to their high mass and energy intensive manufacturing process. However, extensively reused bottles outperform single-use bottles..
- Aluminum cans have the second highest improvement potential in terms of their environmental footprint (see Figure 1-1 through Figure 1-3), which can be achieved, in particular, by further increasing recycling rates and average recycled content.
- Cartons show no potential to improve by increasing recycling rates. This is because recycled paper most often relies on external (fossil) energy sources, whereas virgin paper when produced in integrated mills benefits from renewable energy carrier by-products. However cartons can benefit from lightweighting.
- The material circularity scores tend to correlate with findings on global warming potential for aluminum cans, glass bottles and cartons. A notable exception are PET bottles. Aluminum cans tend to outperform other packaging materials, as a result of the well-developed infrastructure for collection, sorting and recycling, the extremely low yield losses during recycling, and very high levels of recycled content, closing the material loop very well. Despite the fact that fiber, polymer and aluminum layers in beverage cartons are difficult and costly to separate, cartons achieve decent MCI scores. This is due to their renewable main raw material, paperboard, which the MCI methodology assumes to be circular. Other circularity methodologies do not equate renewable content as circular, rather look at whether a material is recycled in reality. A near-perfect MCI can be achieved by refillable glass bottles, if refilled many times. The notable differences between MCI scores and LCA results (especially on climate change) stem from the fact that material and energy efficiency are not taken into account by the MCI methodology. Therefore, it is strongly recommended that any statement or decision should consider findings from environmental impact data from LCAs in conjunction with MCI scores.

Key limitations and considerations include:

- Due to access to more granular and more recent aluminum and beverage can manufacturing data, there is a data quality difference between the primary data used for aluminum cans and the secondary data used for packaging alternatives. However, using conservative assumptions and a range of scenarios and sensitivity analyses , results have been checked for robustness and uncertainties highlighted to avoid any false conclusions.
- While Brazilian baseline results include a refillable glass bottle, the European study considers product refill and reuse as part of the sensitivity analyses. Other refill options and deposit return schemes (DRS) have not been considered as part of this study because market shares of refillable packaging alternatives in the regions considered are relatively low, and because there is no reliable data available for the actual number of refill trips per bottle. As far as DRS for recycling is concerned, the statistics used for this study does not differentiate different types of collection systems. Excluding refill systems from the scope has meant that only a part of the aspects of benefits and challenges of circular economy could be explored. Refill systems have the theoretical potential to distribute manufacturing impacts of all materials across several life cycles and thereby reduce impacts considerably. However, the logistics are not to be underestimated and assessing the sustainability potential of these systems requires more focus than was allotted in this study.
- Production of the actual beverages is not included because this study focuses on beverage packaging only, and it is assumed the beverage would have a comparable impact on the LCA of each packaging type. If included and depending on the beverage considered, it is expected that the beverage could significantly increase the absolute environmental impact results and will put the packaging assessment and its conclusions into a different perspective.
- MCI scores should be considered when evaluating the sustainability credentials of different packaging options, while recognizing that they do not account for material and energy efficiency. Circularity scores should be understood as complementary to the main LCA results to help interested stakeholders understand the bigger picture of product sustainability in the context of economic, environmental and social considerations.

Key recommendations include:

- The study findings indicate the paramount importance of enhancing circular systems, especially for materials that have a high level of embedded energy such as aluminum and glass. This entails:
    - Increasing collection rates and real recycling of the collected materials,
    - Increasing recycled content,
    - Maximizing the number of refills for refillable bottles,
    - Supporting the logistics of closing the product loop, i.e. providing the scrap input in the quality and quantity that is required by the recycling system and those that intend to incorporate recycled material in their packaging.

Given the different characteristics of packaging materials, each substrate can improve its sustainability profile through a set of different optimization measures. As shown by this study and the variability graphs above, some substrates have a higher potential to effectively reduce environmental impacts than others. Lightweighting and energy-related measures, in particular energy efficiency improvements and the use of renewable energy, are additional optimization measures that can benefit different packaging options to varying degrees.

1. Goal of the Study

The goal of the study is to conduct an LCA analyzing the environmental performance of single-use, small to medium-size aluminum cans and bottles compared to competing alternative beverage packages (i.e. PET bottles, glass bottles and beverage cartons) in three different markets: Europe, US and Brazil. One focus of the study is explicitly on varying degrees of recycling rates and recycled content to understand interdependencies between circular product design and environmental impacts of different beverage packaging options.

The study has been commissioned by Ball Corporation and is intended to be disclosed to the public. This excludes confidential primary data. As the study includes comparative assertions of different beverage packaging systems, a panel of independent experts was assigned to carry out a critical review of the study.

The intended applications of the study are

- to provide up-to-date and objective results of various environmental metrics for specific beverage packaging alternatives;
- to provide a comprehensive overview of product sustainability and potential for overall improvement by complementing life cycle assessment results with the material circularity (MCI) methodology, a socio-economic metric;
- to apply the learnings of regional results to develop communication and/or product marketing strategy, and in the medium term, further optimize product design;
- to pinpoint the advantages and disadvantages of specific aluminum packaging types over alternatives, and to provide a benchmark between most common beverage packaging alternatives in the three regions (EU, US and BR).

The reasons for carrying out the study are

- to identify the environmental hotspots of the aluminum can’s life cycle and related optimization potential;
- to understand the environmental advantages/drawbacks of beverage cans and bottles in the specific context of each investigated region (EU, US and BR);
- to understand sensitivity to End-of-Life methodology in general and recycling rates across the span of 0-100% (all four materials, one EoL method, one region);
- to compare the environmental impacts of various beverage packaging alternatives, with the intention of comparative assertions intended to be disclosed to the public (except for confidential primary data);
- to provide comparative environmental impact information to brands and other interested parties that may result in further market share growth of aluminum beverage cans;
- to understand product material circularity;
- to inform and improve the commissioner’s corporate sustainability strategy.

The study is intended for publication, to beverage manufacturers as the primary audience, but also to provide credible communication material for retailers and other interested parties. By disclosing it to the public, end-consumers are also potential audience, though not directly targeted by the commissioner.

This study meets the requirements of the international standards for Life Cycle Assessment (LCA) according to ISO 14040 (ISO, 2006) / ISO 14044 (ISO, 2006).

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 to be studied are single-use, small to medium-size beverage packaging alternatives for carbonated (c) and non-carbonated drinks (nc). Beverages are not included (see chapter 2.3). A scenario overview for each region is given in Table 2-1, Table 2-2 and Table 2-3. Details regarding the choice of EoL Scenarios can be found in chapter 2.4.2.

The sample product systems are treated as single use, however the PET bottles, glass bottles and beverage cartons are resealable except for the beverage carton with straw. Aluminum cans are not resealable except for the 16oz AlumiTek bottle (ATB) manufactured in the US. The consequences of resealability are not considered in this study because of uncertainties related to the beverage contents and consumption patterns. Representative products have been selected by the commissioner of this study as they are considered to be competing products in each of the three regions.

Table 2-1: Packaging products and scenarios under study for the EU region (C: carbonated, NC: non-carbonated)

EU					
Baseline			**Additional scenarios**		
Material	**Sizes**	**EoL / Treatment of secondary materials**	**EoL / Treatment of secondary materials**	**Collection rate**	**Others**
Beverage cartons	0.33L	PEF CFF	Substitution	Substitution, Collection rate 0-100%	-
	0.50L				
PET bottle (C)	0.38L	PEF CFF	Substitution	Substitution, Collection rate 0-100%	PET bottle weight reduction by 5-10% Manufacturing energy for blow molding
	0.50L				
PET bottle (NC)	0.30L				
	0.50L				
Glass bottle (single use)	0.25L	PEF CFF	Substitution	Substitution, Collection rate 0-100%	-
	1.00L				
Glass bottle (refillable)	0.33L	-	-	-	Reuse bottle 0.33L (20x)
Aluminum can	0.25L	PEF CFF	Substitution	Substitution, Collection rate 0-100%	Renewable energy for can manufacturing
	0.33L				
	0.50L				

Table 2-2: Packaging products and scenarios under study for the US region

US				
Baseline			**Additional scenarios / sensitivity analyses**	
Material	**Sizes**	**EoL / Treatment of secondary materials**	**EoL / Treatment of secondary materials**	**Others**
Beverage cartons	11.2oz (0.33L)	Cut-off	Substitution	Beverage carton weight reduction by 5-10% Recycled content 0-100%
	16.9oz (0.50L)			
PET bottle (C)	12.0oz	Cut-off	Substitution	PET bottle weight reduction by 5-10% Manufacturing energy for blow molding Recycled content 0-100%
	16.9oz			
PET bottle (NC)	16.9oz			
Glass bottle (single use)	12.0oz	Cut-off	Substitution	Glass bottle weight reduction by 5-10% Recycled content 0-100%
	16.0oz			
Aluminum can	12.0oz	Cut-off	Substitution	Renewable energy for manufacturing Aluminum can weight reduction by 5-10% Recycled content 0-100%
	16.0oz			
	16.0oz (AlumiTek)			

Table 2-3: Packaging products and scenarios under study for the BR region

Brazil				
Baseline			**Additional scenarios**	
Material	**Sizes**	**EoL / Treatment of secondary materials**		
Beverage cartons	0.20L	Substitution	Collection rate 0-100%	
	1.00L			
PET bottle (C)	0.25L	Substitution	Collection rate 0-100% Manufacturing energy for blow molding	
	0.6L			
	0.51L			
PET bottle (NC)	0.90L			
Glass bottle (single use)	0.355L-	Substitution	-	Collection rate 0-100%
Glass bottle (refillable)	0.60L		5, 10, 15, 20 refills	
Aluminum can	12oz (0.355L)	Substitution	Collection rate 0-100%	
	16oz (0.473L)			
	24oz (0.71L)			

2.2. Product Function(s) and Functional Unit

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

The LCA results are not meant to be compared between regions due to differences in the product portfolios, regional waste management infrastructure, supply chains and preferred methodologies for LCIA. As such, the functional unit is defined separately for each region under study,

- 1 liter fill volume of small to medium-size, single-use beverage packaging at point of sale for the EU region;
- 1 gallon fill volume of small to medium-size, single-use beverage packaging at point of sale for the US region;
- 1 liter fill volume of small to medium-size, single-use beverage packaging at point of sale for the BR region.

Primary beverage packages under study are assumed to be technically equivalent regarding the mechanical protection of the packaged beverage during transport, the storage and at the point-of-sale.

It has to be mentioned that while the protective function regarding mechanical stress is comparable among the different packaging systems, they differ in terms of physicochemical influences, i.e., UV-transmittance and airtightness. While transparent packaging systems (PET, glass) are UV-transmittant, tinted glass bottles, aluminum cans and beverage cartons are not. The shelf life of certain beverages can be negatively influenced by the UV-permeability of the packaging. Furthermore, aluminum cans are 100 % airtight while e.g. packaging systems with screw caps or crown corks are not, which can also influence the shelf life of beverages. However, usually for the choice of the ideal packaging system for a beverage regarding all potential protective functions, those factors are already considered. Therefore, this study neglects potential differences in protective performance.

For simplicity, products are assumed to be fully emptied and consumed[1] as consumer behavior is not foreseeable, meaning the impacts of beverage residues cannot be taken into account. Beverage manufacturing, cooling for quality and losses at any part of the chain are not considered in this study.

Furthermore, the aluminum cans compete with packaging products that only cover part of the product palette aluminum cans may provide packaging for: from beer to juices and water, carbonated and non-carbonated, the same aluminum can may be used. By contrast, cartons are typically only used for non-alcoholic, non-carbonated beverages and PET bottles require different

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[1] The different packaging systems may differ slightly regarding the amount of beverage remaining in the packaging at the end-of-life, e.g., bottles can be emptied easier than beverage cartons and aluminium cans. Even non-resealable product design may create differences from the product shape and material. Increased product residues in the packaging lead to decreased amounts of beverage consumed compared on a same volume base. However, these differences are not taken into consideration in this study because they are expected to be very small and can therefore be cut off.

design when used for carbonated and non-carbonated contents (weights and layers change). Therefore, a spectrum of packaging alternatives is compared with aluminum cans to cover the most market-relevant applications and competing products.

The reference flow for the product systems is *Beverage container (packed)*, including both the primary and the secondary packaging. The flow has the reference quantity 'mass' measured in kilograms. For each product, the reference flow was defined based on individual product mass and volume, to arrive at the functional unit specified above.

Table 2-4: **Reference flows (beverage container, packed) per product in the EU region.**

Packaging material	Sizes	Reference flow (kg) per functional unit (liter)	Pieces of product per functional unit (liter)
Beverage cartons	0.33L	0.05	3.03
	0.50L	0.08	2
PET bottle (c)	0.38L	0.08	2.63
	0.50L	0.05	2
PET bottle (nc)	0.30L	0.07	3.33
	0.50L	0.03	2
Glass bottle (single-use)	0.25L	0.73	4
	1.00L	0.52	1
Glass bottle (re-fillable)	0.33L	0.59	3.03
Aluminum can	0.25L	0.07	4
	0.33L	0.08	3.03
	0.50L	0.04	2

Table 2-5: **Reference flows (beverage container, packed) per product in the US region.**

Packaging material	Sizes	Reference flow (kg) per functional unit (gallon)	Pieces of product per functional unit (gallon)
Beverage cartons	11.2oz	0.42	11.5
	16.9oz	0.62	7.57
PET bottle (c)	12oz	0.28	10.7
	16.9oz	0.29	7.57
PET bottle (nc)	16.9oz	0.09	7.57
Glass bottle (single-use)	12oz	3.97	10.7
	16oz	1.97	8
Aluminum can / bottle	12oz	0.22	10.7
	16oz	0.28	8
	16oz (AlumiTek)	0.28	8

Table 2-6: Reference flows (beverage container, packed) per product in the BR region.

Packaging material	Sizes	Reference flow (kg) per functional unit (liter)	Pieces of product per functional unit (liter)
Beverage cartons	0.20L	0.06	5
	1.00L	0.05	1
PET bottle (c)	0.25L	0.08	4
	0.51L	0.05	1.96
	0.6L	0.04	1.67
PET bottle (nc)	0.90L	0.05	1.11
Glass bottle (single-use)	0.355L	0.63	2.82
Glass bottle (re-fillable)	0.60L	0.74	1.67
Aluminum can	12oz	0.05	2.82
	16oz	0.04	2.11
	24oz	0.04	1.41

2.3. System Boundary

The study considers cradle-to-grave systems from production of raw materials up to end-of-life, including:

- raw material manufacturing;
- transport of raw materials to bottle/can manufacturing - these were only included for main raw materials, whenever data was available (aluminum cans and beverage cartons) (see details in section 3.2);
- transport of final packaging systems to filling plant;
- transport of final packaging (empty) to retailer; secondary packaging (e.g. corrugated carton boxes and/or trays, shrink foil);
- in some specific cases reuse is considered in the use phase; this includes bottle washing and additional logistics (see details in 3.3.1 and 3.5.1)
- End-of-Life (incineration, landfill and recycling).
  Details to the specific system boundaries can be found in the corresponding descriptions of the regions of the different product systems (chapter 3.3, chapter 3.4 and chapter 3.5).

Excluded are

- Packaging materials except the final beverage packaging under study (primary and secondary packaging) because they are expected to have a negligible influence on the overall results and because they were not consistently available. In detail, this includes the following packaging materials:
  - packaging of pre-products used for the manufacturing of packaging systems
  - packaging used to transport empty beverage containers to filling plant
  - tertiary packaging (e.g. wood pallets and shrink foil) .To justify this exclusion a scenario has been calculated for a beverage carton including tertiary packaging in Annex G: Tertiary Packaging.
- the filling process as there are not many differences expected between the compared products and the energy consumed is not expected to make a significant difference;

- cooling of beverages because not all products require cooling and therefore, overall results would not be comparable. Aluminum is expected to benefit from the cooling requirements compared with other materials, see (ICF International , 2016). Besides the fact that aluminum could benefit from an inclusion of the cooling process, other beverages requiring little or no cooling would also benefit in a direct comparison of total LCA results;
- the beverage manufacturing including its ingredients and additives, as this study is intended to compare beverage packages[2];
- any wasted beverage products as there are not many differences expected in terms of e.g. spillages etc.;
- consideration for the durability and protective capabilities of the packaging, as the use phase and shelf life are not focal points for this study. One should note that aluminum's intrinsically protective properties are thus not taken into consideration, making the study results very conservative;
- capital goods such as processing machines, trucks and buildings are excluded in the foreground system. For industrialized production of goods in high volumes, the impact of this infrastructure is commonly negligible for most impact categories when applied to fast moving consumer goods;
- while product re-use is considered in sensitivity analyses, refill schemes are excluded because the market share for refillable packaging alternatives in the regions considered is generally very small. For instance, the UK is a key consumer of the beverage packaging systems considered in this study and had a market share of <10% refillable beverage packaging in 2017 (FEVE, 2018). Excluding refill systems from the scope has meant that only a part of the aspects of benefits and challenges of circular economy could be explored. Refill systems have the theoretical potential to distribute manufacturing impacts of all materials across several life cycles and thereby reduce impacts considerably. However, the logistics are not to be underestimated and assessing the sustainability potential of these systems requires more focus than was allotted in this study.

The system boundaries are depicted for each product system in the Life Cycle Inventory in section 3.2 and summarized in Table 2-7.

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[2] Beverage production was not included in this study because it is assumed that the influence to the overall LCA results to all packaging systems under study would be comparable. Beverages usually contribute to the largest share (>60 %, expert judgement based on a variety of internal, non-official studies) to the carbon footprint of a packaged beverage. It can be expected that the overall LCA results would increase significantly for many of the environmental impacts under study if beverages were included.

Table 2-7: System boundaries

Included	Excluded
✓ Manufacturing of raw materials ✓ Transport of raw materials to manufacturing, if available ✓ Transport to filling station ✓ Secondary packaging ✓ Distribution to retailer ✓ Reuse, if applicable ✓ End of Life (incineration, landfill and recycling)	× Packaging of raw materials/pre-products × Production of beverages × Tertiary Packaging × Packaging to filling station × Filling and refilling process × Cooling of filled beverage containers × Capital Goods

2.3.1. Time Coverage

- The time reference for primary data collected for the aluminum cans is 2018.
- The time reference for all other beverage containers is also 2016-2019, as the products were purchased, weighed and measured in 2019 July through September.
- It is assumed that the results are valid at least/at most for the next 5 years or for as long as no significant technological changes occur in the manufacturing of the compared products;
- The collection data is documented in detail in chapter 3.
- The actual temporal representativeness and overall data quality has been assessed in chapter 7.4.

2.3.2. Technology Coverage

- The intended technology reference is the most current available industry average; even though Ball has provided primary data for can manufacturing, the regional data included averages across various sites;
- The competing packaging products also aim to represent current industry averages. The technological coverage regarding beverage cartons can be considered good based on recent discussions with the corresponding association. The dataset is considered to be up to date and representative. The PET bottle blow-molding process was approximated with blow-molding process of HDPE bottles, and therefore has a lower technological representativeness. In terms of energy consumption, however, the dataset was compared with other datasets (e.g. PlasticsEurope's formerly available PET blow moulding dataset) and has been found a very close match. Sensitivity analyses are performed to account for an uncertainty in both direction, as the exact impact is not known (see more in 4.5.4, 5.5.3 and 6.4.3). For glass bottles, association data for container glass was used, which can be considered representative of the industry average;
- The data collection is documented in detail in chapter 3
- The actual technological representativeness and overall data quality has been assessed in chapter 7.4

2.3.3. Geographical Coverage

- The intended geographical reference of the study is tri-focal: Europe (focus on United Kingdom and France), US and Brazil

- The geographical coverage of the data used is documented in detail chapter 3
- Overall representativeness and quality of the data used has been assessed in chapter 7.4.

2.4. Allocation

2.4.1. Multi-output Allocation

Liquid packaging board (LPB, used to make composite carton beverage containers like those by Tetra Pak or Elopak) has been mass allocated. Multi-output allocation generally follows the requirements of ISO 14044, section 4.3.4.2. In the LCI dataset of liquid packaging board production by ACE (2011) there are two co-products listed, tall oil (19.3kg / 1000kg LPB) and turpentine (1.3kg / 1000kg LPB). Mass allocation has been applied to distribute the environmental burdens between the main and co-products. This approach does not differ from other comparative studies (Ifeu, Comparative Life Cycle Assessment of TetraPak® carton packages and alternative packaging systems for liquid food on the Nordic market, 2017).

Beyond this, there are no significant multi-output processes within the foreground system. As a result, all impacts from the foreground system are fully allocated to the products under study.

Allocation of background data (energy and materials) taken from the GaBi 2019 databases is documented online at http://www.gabi-software.com/deutsch/my-gabi/gabi-documentation/gabi-database-2019-lci-documentation/.

2.4.2. End-of-Life Allocation

End-of-Life allocation generally follows the requirements of ISO 14044, section 4.3.4.3. The text below describes all methods applied in this study, while the next chapter will explain where each of those approaches have been used and why. The decision for which methodological approach should be chosen for each product system were taken in a joint process with the commissioner, based on the regional significance and acceptance of the methodology. In order to also produce comparable results for all product systems, a substitution approach was included in all systems (either as a main scenario or as an additional scenario). The substitution approach is most commonly used as it enables the best observation for the impact of variable recycling rates, which is a focal point for this study.

Material recycling

- *substitution approach:* A value of scrap burden was calculated for the input amount of scrap metal (i.e. recycled content enters the product system with corresponding burdens), while recovered material at the End of Life was assigned a credit. Although common in many metal-focused studies, a net scrap approach was not used here (i.e., scrap collected at EoL is reduced by any scrap inputs to the product system). The original burden of the primary material input is 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 modelled using industry average inventories.
- *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.

- *PEF CFF:* The PEF EoL formula aims to find a market-driven balance between the substitution and the cutoff approach. An allocation factor “A”, which is specific for each material and application (e.g., aluminum cans, PET bottles etc.), can be found in Annex B: of the guidance document. The factor distributes the burdens/credits from the above-named approaches to the product system. An allocation factor of “0” enables the substitution approach whereas a factor of “1” enables the cutoff-approach. In order to apply the PEF CFF, the prescribed values for the factor must be taken from Annex C (European Comission, 2018) and range between 0.2 and 0.8. The lower value of 0.2 is used for recyclates in high demand such as aluminum or glass, whereas the higher value of 0.8 is applied for recyclates that are currently not in high demand.

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 of the avoided burden, while it may not be a conservative assumption specifically for cans, because materials with high energy recovery value receive lower credits when substituted with the cleanest energy source.
- *Cut-off:* see below

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.
- *Cut-off:* see below

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). Power from landfill gas may only be considered in case of biodegradable material included in the product, but not for aluminum, glass or plastics. No credits for power or heat production are assigned.
- *CFF:* The PEF EoL formula aims to find a market-driven balance between the substitution and the cutoff approach. In order to apply the PEF CFF, the prescribed values for incineration with and without energy recovery, and landfill are taken from Annex C (European Comission, 2018) of the PEF Guide.

2.5. Cut-off Criteria

No cut-off criteria for the foreground system are defined for this study within the primary data collection. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. It has to be mentioned that for the US region, the cut-off-method is applied for the EoL whereby credits as well as secondary materials are outside of the system boundaries unlike in other regions. In order to check whether this has a significant effect on the outcome, a substitution approach was also modelled.

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.

The choice of proxy data is documented in Chapter 3. The influence of proxy data on the results of the assessment has been carefully analyzed and is discussed in Chapter 7.4.

2.6. Selection of LCIA Methodology and Impact Categories

Three different markets are in scope of this study. For each market one relevant set of indicators has been identified as representative:

- EU region: Environmental Footprint 3.0,
- US region: TRACI 2.1,
- BR region: ReCiPe 2018,

The impact assessment categories and other metrics considered to be of relevance to the goals of the study are shown in the respective tables. Not every single category will be shown in the result tables of the main report. However, they can be found in Annex F: Extended LCIA Results.

It shall be noted that the below mentioned 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.

2.6.1. **Region: EU**

Various impact assessment methodologies are applicable for use in the European context, including CML, ReCiPe, and selected methods recommended by the ILCD. This assessment is predominantly based on the compilation of impact categories recommended by the Product Environmental Footprint Guidelines. Implementations in the Life Cycle Assessment software, GaBi 9.2, follow the European Commission Joint Research Centre’s characterization factors EF 3.0 published in March 2019.

This collection of indicators applicable to the European context includes some widely used and respected indicators and LCIA methodologies, e.g. from the well-known ReCiPe or CML methodologies, as well as some less known methodologies and others still under debate by the scientific community. However, since the framework has gained broad attention from industry and academia alike due to its potential application in future EU regulations, it was deemed as the right set of impacts to evaluate for a study in the European context.

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-8 and Table 2-9.

Climate change (Global warming potential, impact category) was chosen because of its high public and institutional interest due to their environmental relevance and international acceptance (confirmed by the IPCC). The calculation methods are scientifically and technically valid (Guinée, et al., 2002). The impact category climate change is assessed based on the current IPCC characterization factors taken from the 5th Assessment Report (IPCC, 2013) for a 100-year timeframe (GWP100) as this is currently the most commonly used metric.

The climate change results exclude the photosynthetically bound carbon (also called *biogenic carbon*). Because the products are fast moving consumer goods, the CO2 incorporated by the plants upstream will be degraded predictably within 100 years, and will thus be released back into the atmosphere. Therefore, the biogenic carbon is not sequestered and will be carbon neutral over the life cycle of the product unless this carbon is converted into methane, in which case the impact is considered.

Eutrophication and acidification were chosen because they are closely connected to air, soil, and water quality and capture the environmental burdens associated with commonly regulated emissions such as NO_x, SO_2 and others. Eutrophication, marine and terrestrial, and Photochemical ozone creation potential are reported in the Annex F: Extended LCIA Results, as their trends in the results are expected to be similar to the main results reported in chapters 4-6..

Blue water consumption, i.e., the anthropogenic removal of water from its watershed through shipment, evaporation, or evapotranspiration, as well as the Water scarcity footprint (WSF) according to the AWaRe method (UNEP, 2016), both, have a high political relevance. The UN estimates that roughly a billion people on the planet don’t have access to clean drinking water, which entails a variety of problems around ecosystem quality, health, and nutrition. They are included for reasons of completeness in the Annex F: Extended LCIA Results. Results from the water scarcity footprint are to be interpreted with care as the underlying association data in the study does not allow for a reliable water scarcity assessment.

The *Montreal Protocol on Substances that Deplete the Ozone Layer* was implemented in 1989 with the aim of phasing out emissions of ozone depleting gases. The protocol has been ratified by *all* members of the United Nations – an unprecedented level of international cooperation. With a few exceptions, use of CFCs, the most harmful chemicals, has been eliminated, while complete phase out of less active HCFCs will be achieved by 2030. As a result, it is expected that the ozone layer will return to 1980 levels between 2050 and 2070. In addition, no ozone-depleting substances are emitted in the foreground system under study. For these reasons, ozone depletion potential is not considered in this study. The indicator is, however, included for reasons of completeness in the Annex F: Extended LCIA Results.

Land use is only included in the Annex, as it has little relevance for the production processes in question. Further impact categories were excluded from the report but included in the Annex based on the descriptions provided in (Guinée, et al., 2002) related to their fulfilment of ISO criteria:

Human toxicity and ecotoxicity impact categories have got a high uncertainty and are, similar to ionizing radiation, still being discussed in the scientific community.

Despite 20 years of research, there remains no robust, globally agreed upon method - or even problem statement - for assessing mineral resource inputs in life cycle impact assessment (Drielsmaa, et al., 2016). One may further argue that the concern regarding the depletion of scarce resources is not as much an 'environmental' one, but rather about the vulnerability of markets to supply shortages. These shortages, in return, are driven by various factors that are not captured adequately by current metrics. Accordingly, resource criticality has emerged as a separate tool to assess resource consumption (Nassar, et al., 2012; Graedel & Reck, 2015). However, a complete criticality assessment is out of scope for this work. Therefore, this study simply reports the CML (Institute of Environmental Sciences, Faculty of Science of Leiden University) assessment of abiotic depletion potential (ADP) (van Oers, de Koning, Guinée, & Huppes, 2002), because the implementation of the EF 3.0 impact category in GaBi is not fully in line with the background data of ILCD compliant GaBi datasets[3].

Table 2-8: EF 3.0 impact category descriptions

Impact Category	Description	Unit	Reference	Main report	Annex
Climate change (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	(IPCC, 2013)	✓	
Eutrophication freshwater	EUTREND model, Fraction of nutrients reaching freshwater end compartment (P)	kg P eq.	(Struijs, van Wijnen, van Dijk, & Huijbregts, 2009)	✓	✓
Eutrophication marine	EUTREND model, Fraction of nutrients reaching freshwater end compartment (N)	kg N eq.	(Struijs, van Wijnen, van Dijk, & Huijbregts, 2009)		✓
Eutrophication terrestrial	Accumulated Exceedance (AE). Change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems.	Mole N eq.	(European Commission, 2011)		✓

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[3] The ILCD flowlist allows use of molecules such as NaCl, whereas the EF 3.0 only characterizes single substance flows (i.e. Na, Cl). The GaBi datasets have been built using the ILCD flowlist, and the EF characterisations do not allow to apply them to such molecules/substances. As a consequence, resource flows are not fully characterized and the EF 3.0 impacts are not reliable.

Impact Category	Description	Unit	Reference	Main report	Annex
Acidification terrestrial and freshwater	Accumulated Exceedance (AE). Change in critical load exceedance of the sensitive area in terrestrial and main freshwater ecosystems.	Mole H+ eq.	(European Commission, 2011)	✓	✓
Photochemical ozone formation – human health	Expression of the potential contribution to photochemical ozone formation following the LOTOS-EUROS model. Tropospheric ozone concentration increases as NOx equivalents.	kg NMVOC eq.	(Van Zelm, et al., 2008)		✓
Ozone depletion	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.	kg CFC-11 eq.	(WMO, 2014)		✓
Ionizing radiation - human health	Ionizing Radiation Potentials: The impact of ionizing radiation on the population, in comparison to Uranium 235.	kBq U235 eq.	(Frischknecht, Braunschweig, Hofstetter, & Suter, 2000)		✓
Land use	Soil quality index based on the LANCA methodology	Pt	(Bos, Horn, Beck, Lindner, & Fischer, 2016)		✓
Cancer human health effects	Comparative Toxic Unit for human (CTUh). Estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kg).	CTUh	(Rosenbaum, et al., 2008)		✓
Non-cancer human health effects	Comparative Toxic Unit for human (CTUh). The estimated increase in morbidity in the total human population per unit mass of a chemical emitted (cases per kg).	CTUh	(Rosenbaum, et al., 2008)		✓
Resource use, energy carriers	Abiotic resource depletion fossil fuels (ADP-fossil)	MJ	(van Oers, de Koning, Guinée, & Huppes, 2002)		✓
Resource use, mineral and metals	Abiotic resource depletion (ADP ultimate reserve).	kg Sb eq.	(van Oers, de Koning, Guinée, & Huppes, 2002)	✓	✓
Respiratory inorganics	Disease incidences due to kg of PM2.5 emitted.	Disease incidences	(Fantke, et al., 2016)		✓
Water scarcity	User deprivation potential (deprivation-weighted water consumption)	m³ world eq.	(UNEP, 2016)		✓

Table 2-9: Other environmental indicators for the EU region

Indicator	Description	Unit	Reference	Main report	Annex
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.	Liters of water	(thinkstep, 2014)		✓
CML2001 Abiotic Depletion (ADP elements)	A measure of the depletion of non-living (abiotic) resources such as fossil fuels, minerals, and clay.	[kg Sb eq.]	(van Oers, de Koning, Guinée, & Huppes, 2002)	✓	✓

2.6.2. Region: US

TRACI 2.1 has been selected as it is currently the only impact assessment methodology framework that incorporates US average conditions to establish characterization factors (Bare, 2012) (EPA, Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) – User's Manual, 2012). The impact assessment categories and other metrics considered to be of relevance to the goals of the study are shown in Table 2-10 and Table 2-11.

Global warming potential (GWP) was chosen because it is of high public and institutional interest and deemed to be one of the most pressing environmental issues of our time. The GWP impact category is assessed based on the current IPCC characterization factors taken from the 5th Assessment Report (IPCC, 2013) for a 100-year timeframe (GWP100) as this is currently the most commonly used metric.

As this study is a cradle-to-grave study, the GWP results do not include photosynthetically bound carbon (also called *biogenic carbon*), nor the release of that carbon during the use or end-of-life phase as CO_2.. Biotic CH_4 is taken into consideration with a reduced characterization factor of 22,3. The results shall be summed up to "0" for cradle-to-grave studies. However, GWP results include emissions from direct land use change which are calculated using the *Direct Land Use Change Assessment Tool*[4] . This 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 http://www.gabi-software.com/support/gabi/gabi-modelling-principles/. Emissions from land use change are expected to be of low relevance in this study.

Eutrophication, acidification, and photochemical ozone creation potential were chosen because they are closely connected to air, soil, and water quality and capture the environmental burden

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

associated with commonly regulated emissions such as NO_x, SO_2, VOC, and others. Eutrophication, marine and terrestrial, as well as POCP will be reported in Annex D:

The *Montreal Protocol on Substances that Deplete the Ozone Layer* was implemented in 1989 with the aim of phasing out emissions of ozone depleting gases. The protocol has been ratified by *all* members of the United Nations – an unprecedented level of international cooperation. With a few exceptions, use of CFCs, the most harmful chemicals, has been eliminated, while complete phase out of less active HCFCs is estimated for 2030. As a result, it is expected that the ozone layer will return to 1980 levels between 2050 and 2070. In addition, no ozone-depleting substances are emitted in the foreground system under study. For these reasons, ozone depletion potential is not considered in this study. The indicator is, however, included to improve completeness in Annex D: .

Water consumption, i.e., the anthropogenic removal of water from its watershed through shipment, evaporation, or evapotranspiration, has also been 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. It is included for reasons of completeness in the Annex F: Extended LCIA Results.

Additionally, the study includes an evaluation of human toxicity and ecotoxicity by employing the USEtox™ characterization model. USEtox™ is currently the best-available approach to evaluate toxicity in LCA and is the consensus methodology of the UNEP-SETAC Life Cycle Initiative. The precision of the current USEtox™ characterization factors is within a factor of 100–1,000 for human health and 10–100 for freshwater ecotoxicity (Rosenbaum et al 2008). This is a substantial improvement over previously available toxicity characterization models, but still significantly higher than for the other impact categories noted above. Given the limitations of the characterization models for each of these factors, results are reported as ‘substances of high concern’ but are not to be used to make comparative assertions. Results of these indicators are included for reasons of completeness in the Annex F: Extended LCIA Results.

Despite 20 years of research, there remains no robust, globally agreed upon method - or even problem statement - for assessing mineral resource inputs in life cycle impact assessment (Drielsmaa, et al., 2016). One may further argue that the concern regarding the depletion of scarce resources is not as much an ‘environmental’ one, but rather about the vulnerability of markets to supply shortages. These shortages, in return, are driven by various factors that are not captured well by current metrics. Accordingly, resource criticality has emerged as a separate tool to assess resource consumption (Nassar, et al., 2012; Graedel & Reck, 2015). However, a complete criticality assessment is out of scope for this work. Therefore, the study at hand reports the assessment of abiotic resources out of completeness reasons but gives out the warning to interpret its results carefully.

Table 2-10: TRACI 2.1 impact category descriptions

Impact Category	Description	Unit	Reference	Main report	Annex
Global Warming Air, excl. biogenic carbon	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	(IPCC, 2013)	✓	✓

Impact Category	Description	Unit	Reference	Main report	Annex
Eutrophication	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	(Bare, 2012) (EPA, Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) – User's Manual, 2012)	✓	✓
Acidification	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	As for Eutrophication	✓	✓
Smog Air	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	As for Eutrophication		✓
Ozone Depletion Air	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	As for Eutrophication		✓
Ecotoxicity	A measure of toxic emissions which are directly harmful to the health of humans and other species.	Comparative toxic units (CTUh, CTUe)	(Rosenbaum, et al., 2008)		✓

Table 2-11: Other environmental indicators for the US region

Indicator	Description	Unit	Reference	Main report	Annex
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.	Liters of water	(thinkstep, 2014)	✓	✓

2.6.3. **Region: BR**

As advised by the University of Brasília (Laboratory of Energy and Environment, Department of Mechanical Engineering, Faculty of Engineering), the scientific community in Brazil predominantly uses the ReCiPe methodology. Table 2-12: ReCiPe impact category descriptions below summarizes the applicable references for each of the impact categories evaluated in this report. As for EU and US, the selection of impact categories follows the logic of robustness, relevance and the pattern of results. The latter means that – for the sake of brevity and a clearer focus – impact categories with the same outcome in terms of order of results and underlying reasons (e.g. use of fossil fuels and fossil material resources) will not be discussed in Chapter 4, but will only be listed without interpretation in Annex F: Extended LCIA Results. Selected for inclusion are:

- Climate change (Table 2-12)
- Freshwater eutrophication (Table 2-12)
- Terrestrial acidification (Table 2-12)
- Freshwater consumption (Table 2-12)
- Abiotic depletion, CML (Table 2-13, in place of ReCiPe's Fossil depletion, this methodology can be considered more robustly applied in the GaBi Databases).

The following impact categories are excluded from the interpretation based on lack of robustness:

- All impact categories of Human Toxicity and Ecotoxicity
- Depletion of fossil resources

The following impact categories are excluded from the interpretation based on similarity of patterns to Climate change (driven by energy consumption):

- Photochemical ozone formation – human health
- Photochemical ozone formation – ecosystems
- Fine particulate matter formation
- Ionizing radiation

The following impact category is excluded based on inconsistencies in background data:

Stratospheric ozone depletion – refrigerant use in aluminum association datasets are still contained in some of the datasets, all of which are in fact banned substances and can be safely assumed to be out of use.

Table 2-12: ReCiPe impact category descriptions

Impact Category	Description	Unit	Reference	Main report	Annex
Climate change, default, excl. biogenic carbon	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	(IPCC, 2013)	✓	✓
Freshwater eutrophication	Phosphorus increase in fresh water	kg P eq.	(Helmes, Huijbregts, Henderson, & Jolliet, 2012) (Azevedo, Henderson, van Zelm, Jolliet, & M.A.J., 2013a) (Azevedo, et al., 2013b) (Azevedo, Development and application of stressor – response relationships of nutrients, 2014)	✓	✓
Terrestrial acidification	Ability of certain substances to build and release H+ ions	kg SO_2 eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)	✓	✓
Photochemical ozone formation – human health	Tropospheric ozone population intake increase (M6M)	kg NOx eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)		✓
Photochemical ozone formation, ecosystems	Tropospheric ozone increase (AOT40)	kg NOx eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)		✓
Stratospheric ozone depletion	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.	kg CFC-11 eq.	(Hayashi, Nakagawa, Itsubo, & Inaba, 2006) (De Schryver, et al., 2011)		✓
Ionizing radiation	Absorbed dose increase	kBq Co-60 eq.	(Frischknecht, Braunschweig, Hofstetter, & Suter, 2000) (De Schryver, et al., 2011)		✓

Impact Category	Description	Unit	Reference	Main report	Annex
Human Toxicity – cancer	Risk increase of cancer disease incidence	kg 1,4-DCB eq.	(Van Zelm, Huijbregts, & Van de Meent, 2009)		✓
Fossil depletion	Upper heating value	kg oil eq.			✓
Land use	Occupation and time-integrated transformation	m²×yr annual crop land	(De Baan, Alkemade, & Köllner, 2013) (Elshout, Van Zelm, Karuppiah, Laurenzi, & Huijbregts, 2014) (Köllner & and Scholz, 2007)		✓
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	kg 1,4-DCB eq.	.		✓
Freshwater ecotoxicity	Hazard-weighted increase in fresh waters	kg 1,4-DCB eq.	.		✓
Marine ecotoxicity	Hazard-weighted increase in marine waters	kg 1,4-DCB eq.	(Van Zelm, Huijbregts, & Van de Meent, 2009)		✓
Fine particulate matter formation	PM2.5 population intake increase	kg PM2.5 eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)		✓
Freshwater consumption	Fresh water use	m³	.		✓

Table 2-13: Other environmental indicators for the BR region

Indicator	Description	Unit	Reference	Main report	Annex
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.	Liters of water	(thinkstep, 2014)	✓	✓
Abiotic Depletion Potential	A relative measure derived for the extraction of elements, minerals and fossil fuels.	kg Sb eq.	(van Oers, de Koning, Guinée, & Huppes, 2002)	✓	✓

2.7. Material Circularity Indicator

In addition to the impact categories and LCI metrics discussed above, this report also explores the circularity of the products assessed. Product circularity relates to the concept of a circular economy, an economic and industrial model which designs products and systems to be restorative and regenerative rather than depleting finite virgin materials and creating high levels of waste.

Circularity is increasingly included in political agendas, for example the European Commission put forward the New Circular Economy Strategy to support the EU's transition to a circular economy. An increasing number of companies are also observing opportunity for growing business value by adopting a circular economy strategy, as it theoretically captures additional value from products and materials which might otherwise be discarded as waste. Reducing waste flows and resource depletion can have significant benefits to the environmental performance of products and systems. For these reasons, circularity is considered a critical aspect to capture in this study that goes beyond traditional LCA considerations.

The Material Circularity Indicator (MCI) scores are calculated for each product using the methodology described in *Circularity Indicators - An Approach to Measuring Circularity* (Ellen MacArthur Foundation & Granta Design, 2015). MCI scores are assessed on a scale from 0-1. One represents a theoretical perfectly circular product where all input and output flows are restorative and there are no losses associated with activities such as recycling.

When measuring circularity, the mass of materials consumed is not considered in the MCI score. Further, while the MCI metrics reveal the circularity of product, they do not account for material efficiency nor the overall environmental impacts of the product itself. It is therefore essential that the scores are used in tandem with the impact indicators provided by the LCA impact categories discussed above, to identify whether pursuing product circularity is the best pathway to optimize the environmental performance of the product.

For example, a product with high durability might have a high circularity score because it has an extended number of use cycles, but much higher embodied environmental impacts. If the benefits of pursuing the more circular product do not improve or even worsen the environmental impacts of the original product, then a circular economy may not be the most desirable sustainability strategy in this instance. The results returned from a life cycle assessment (LCA) provide the knowledge to determine whether this is the case.

In this study, material circularity assessment is included alongside the LCA to allow the user to measure the actual environmental performance of products and consider the relevance of circular strategies. The aim is to allow the user to understand how to fully optimize the environmental performance of each packaging option by combining the knowledge provided from both tools.

Three main aspects of the product’s life cycle influence the MCI score:

- Proportion of input material flows that are restorative (i.e. from reused or recycled sources)
- Proportion of waste flows that are used restoratively (i.e. reused or recycled at end of life), including the efficiency of material recycling processes (material losses during recycling).
- Product utility compared to that of an average product in the market. This can relate to use intensity, serviceable lifetime, etc. For packaging applications, the number of refill cycles can be considered a suitable measure of product utility, with single use items being the average situation.

The current MCI methodology has been designed with a focus on non-renewable resources and the report does not go into details regarding how to assess renewable resources (e.g. paper, cardboard, biopolymers) – the Ellen MacArthur Foundation is in the process of further developing the methodology to evaluate how to deal with such materials. In this study it is assumed that renewable resource inputs such as fibers used in beverage cartons and secondary packaging are sourced sustainably. This is because some of the biggest producers of the paper and carton products assessed in this study have declared certified sustainable sourcing by the FSC. As such, the position was adopted that these inputs are completely restorative and so resource scarcity is not of concern. Treatment of such materials at end of life follows the same approach as for non-renewable materials, where recycling results in circularity benefits but landfill and energy recovery do not.

2.8. 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

Since ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, the evaluation of the environmental performance of the packaging systems under study 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.

2.9. 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 of highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all 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 data in this regard.
- Consistency refers to modelling 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 modelling 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 (company-specific) 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.

The datasets used for each region can be found in Chapter 3.3, Chapter3.4 and Chapter 3.5 . An evaluation of the data quality regarding these requirements is provided in Chapter 7.4 of this report.

2.10. 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.

2.11. Software and Database

The LCA model was created using the GaBi 9 Software system and Service Pack 39 for life cycle engineering, developed by thinkstep (now Sphera Solutions). The GaBi 2019 LCI database provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.12. Critical Review

The results of this study are intended to be used by the commissioner (Ball Corporation). Further, results with comparative assertions are intended to be disclosed to the public. A third-party critical review of the study according to ISO 14040 (paragraph 6.3), ISO 14044 (ISO 2006) and ISO/TS 14071 (ISO 2014) will be carried out by a review panel. In this study, the critical review process was done as an accompanying process. Thus, the critical reviewers were able to comment on the project from the time the goal and scope description and preliminary results have been available.

The critical review panel consists of

- **Pere Fullana (Chair)** UNESCO Chair in Life Cycle and Climate Change, ESCI-UPF
- **Angela Schindler**, Umweltberatung und Ingenieurdienstleistung (Environmental consultancy and engineering services)
- **Ivo Mersiowsky**, Quiridium

The Critical Review Statement can be found in Annex A. The Critical Review Report is available upon request from the study commissioner.

Following ISO 14044 clause 6.1, the critical review panel wants to state that, within their knowledge:

- the methods used to carry out the LCA are consistent with the above International Standards,
- 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.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Aluminum cans

Primary data were collected using customized data collection templates from Ball Corporation, which were sent out by email to the regional company representatives for Europe, US and Brazil. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, and internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, thinkstep (now Sphera Solutions) engaged with the data provider to resolve any open issues.

Primary data collected this way covered can body and can end manufacturing for 3 sizes/types in each of the regions. Primary data also extended to the secondary packaging for selected final products that use Ball beverage cans.

PET bottles, glass bottles and beverage cartons

For all other beverage containers secondary data was collected based on sample products selected by Ball for most relevant market shares in the specified regions, adjusted in some instances based on access to those products near thinkstep (now Sphera Solutions) office locations. The final set of specific products is summarized in the sections 3.3.1, 3.4.1 and 3.5.1. The specified products were purchased by thinkstep (now Sphera Solutions), and materials were then identified by consultants, measured and weighed to the precision available in-house at the thinkstep (now Sphera Solutions) offices. In Brazil, the same procedure was applied by collaborators at the University of Brasília (Laboratory of Energy and Environment, Department of Mechanical Engineering, Faculty of Engineering). For most products, the precision of measurements was at least one decimal place (0.1g), giving a relative error of at most 10% by weight in case of caps (1-2g), but well under 1% relative to the entire primary packaging (bottle plus cap). The precision of weighing scales available at the German office, was, on the other hand only ±1g, which affected only 1 PET bottle and 2 glass bottles (potential error up to 5% of the primary packaging as a whole). For carton products produced by Tetra Pak, information on product weight and composition was taken from online resources (Tetra Pak 2019).

3.2. Overview of Product Systems

This chapter outlines the examined product systems insofar as they are relevant for all regions. Further details are provided in the specific regional sub-chapters 3.3, 3.4 and 3.5.

3.2.1. Aluminum cans

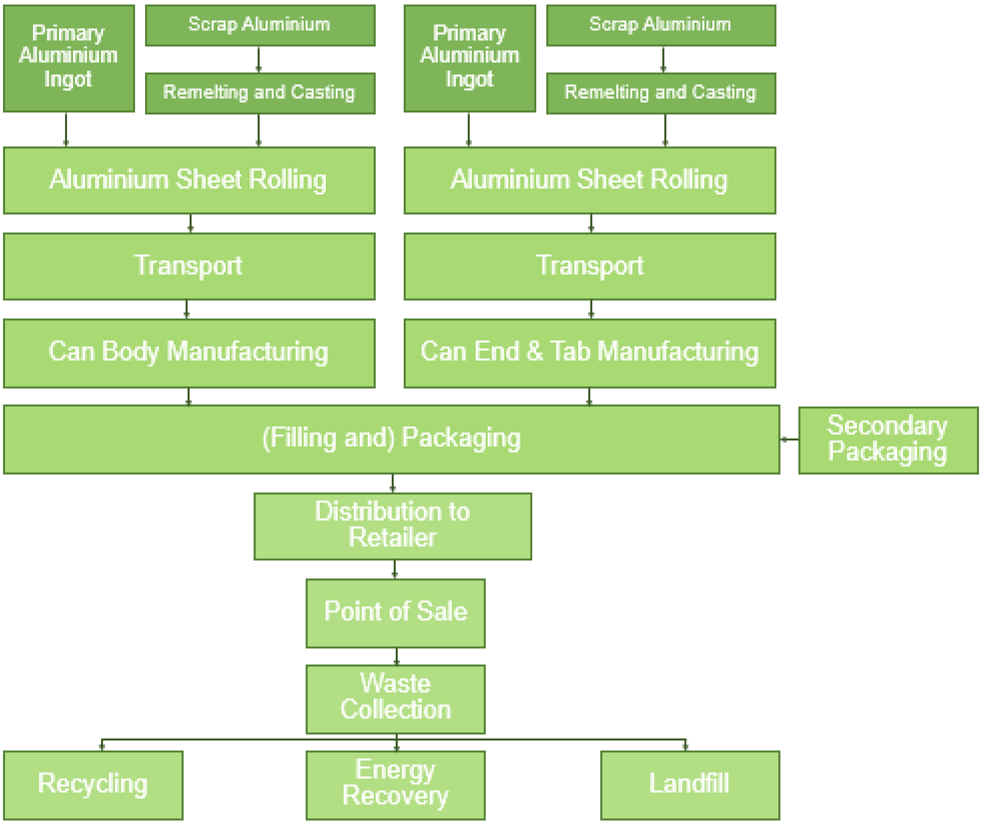

Figure 3-1: Schematic representation of the aluminum can life cycle as modelled in this study.

Aluminum cans at Ball are manufactured from specific alloys, named AA3104 for the body stock and AA5182 for the can end and tab stock. The most dominant alloying elements, albeit in minute quantities, in both specific alloys are magnesium and manganese and they differ only slightly in terms of the remaining elements. Iron was only modelled as part of the Ferro-Manganese mixture dataset used to proxy the Manganese contents, while not adding to the total mass (thus resulting in a minute overestimation of impact). The missing mass has been filled up with aluminum.

The primary aluminum ingot is mixed with the specified alloying elements to form the input mass of primary aluminum ingot required for the sheet making. As shown in Figure 3-1, sheet making uses a mixture of primary and secondary aluminum ingot and varies regionally in terms of the amount of secondary aluminum and energy and material consumption (see details in the region-specific chapters).

Thusly formed aluminum sheets (“can body stock” and “can end stock”) are transported to the can manufacturing sites where further conversions take place, cutting, welding, forming, coating, spraying etc. included in a single black box module filled with primary data from Ball Corporation (Confidential Data). The data has been divided (allocated) to individual can sizes in each region, by Ball, such that some minor variation may take place between the manufacturing impact of different sizes due to separate data collection for some product lines.

After cans and can ends have been manufactured the two are shipped to the beverage producer, where cans are filled, sealed (not included in this study) and put into the respective secondary packaging. The transportation to point of sales is referred to as transport to distribution and is modelled as transport by truck. The end of life considers both the primary packaging (aluminum cans) and the secondary packaging and is modelled based on regional statistics and, whenever available, regional datasets from the GaBi Databases. The specific list of used datasets is detailed later in this chapter.

3.2.2. PET bottles

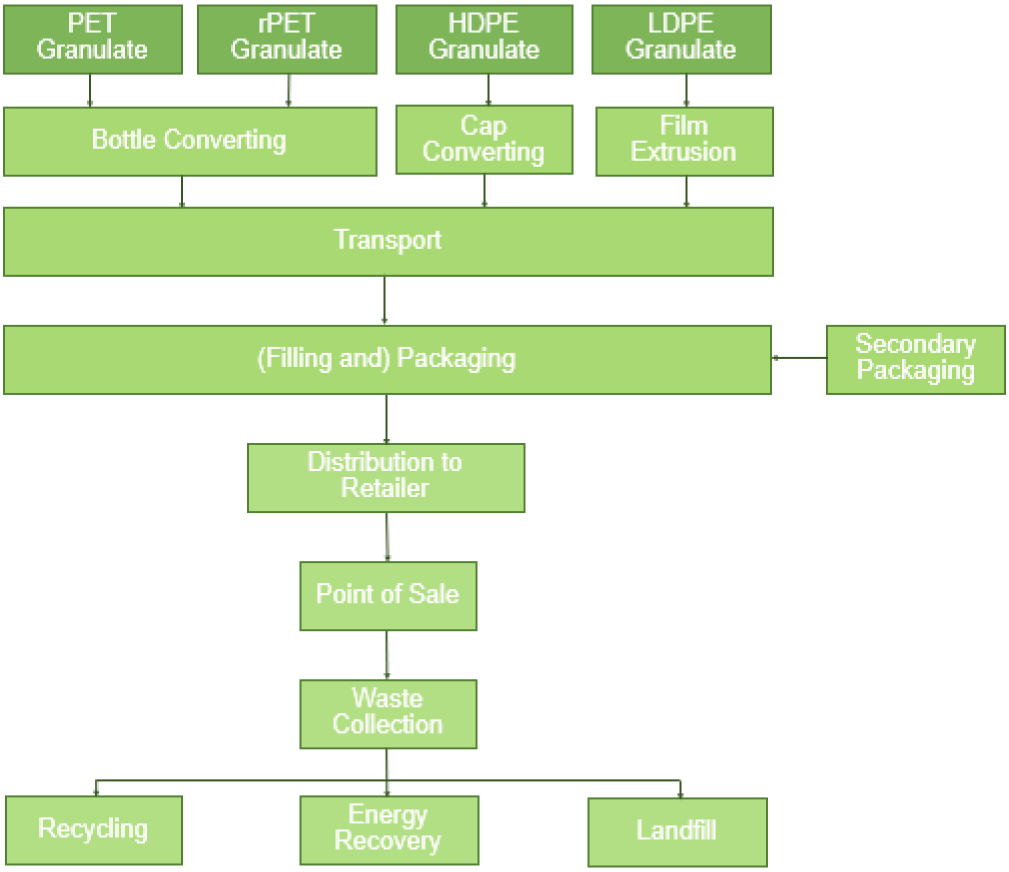

Figure 3-2: System boundaries for the PET bottle system for retail distribution. Filling is only a placeholder for applying the secondary packaging and represents no environmental burdens.

3.2.3. Glass bottles

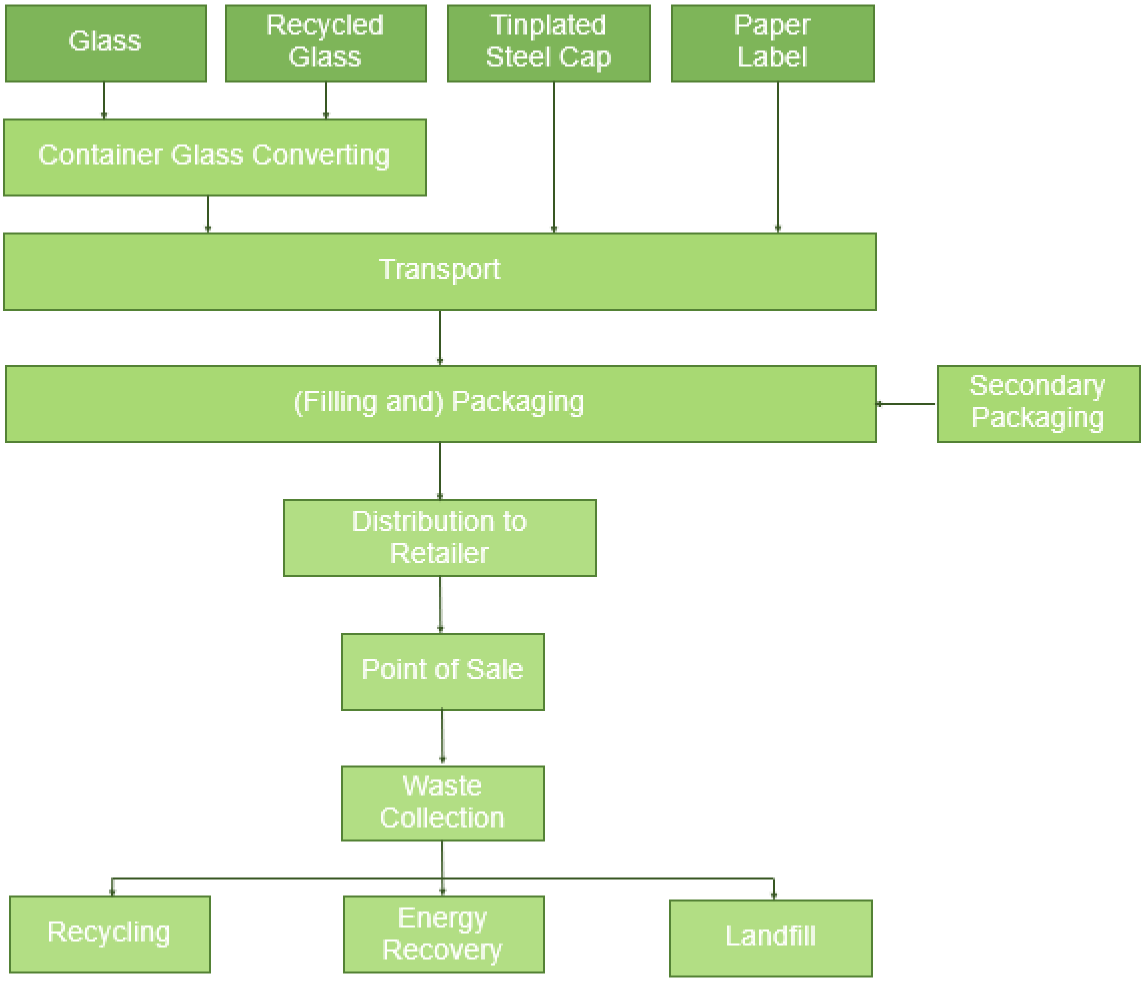

Figure 3-3: Generic system boundaries for the single-use glass bottle system for retail distribution. Filling is only a placeholder for applying the secondary packaging and represents no environmental burdens. Refilling, when relevant, is considered with a washing step and additional logistics not shown here, because it is only relevant in some specific cases.

3.2.4. Liquid beverage cartons

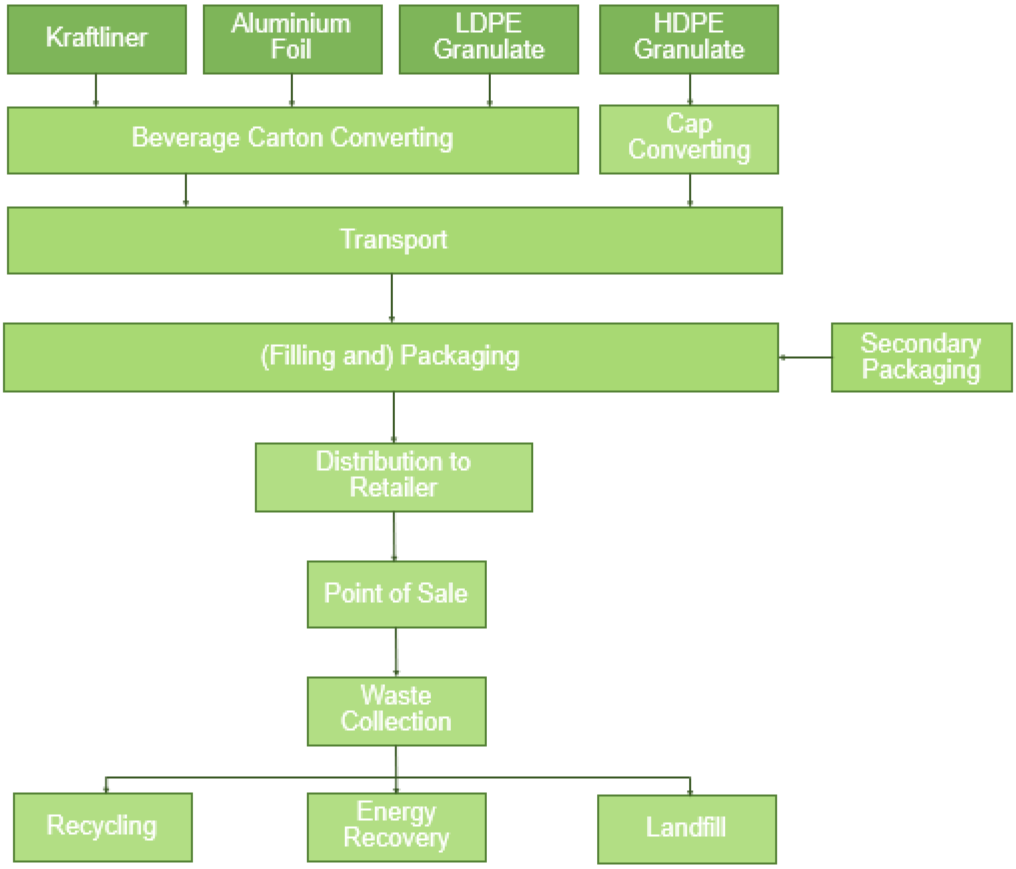

Figure 3-4: System boundaries for beverage carton system for retail distribution. Filling is only a placeholder for applying the secondary packaging and represents no environmental burdens.

3.2.5. Transports to Filling and distribution

As described in section 2.3, filling is not part of the system boundaries. However, transportation to the filling site has been included and estimated at 400km for all products included, for lack of better data. This data stems from the life cycle inventory of liquid beverage board conversion and has been applied consistently for all other products as well.

Transport to distribution represents a similar data gap and was set to a conservative 1,500km, which allows products to be distributed across the full region in each of the studied regions. Although in the US and Brazil, some of the distances may well go beyond this distance, since transportation did not become a hotspot in the assessment, no further investigations were carried out.

3.3. Region: EU

3.3.1. Overview product specifications

Material	Purchased in	Primary												Secondary		
		Container Volume	Container Weight (g)	DQI*	Cap material	DQI*	Cap Weight (g)	DQI*	Label	DQI*	Label Weight (g)	DQI*	Seal Weight (g)	Nesting	Packaging material	Weight (g)
Carton	UK	0.33L	13.00	L	HDPE	L	4.00	L	direct print	-	n/a	-	n/a	4	corrugated board	20
	DE	0.5L	19.00	L	HDPE	L	4.00	L	direct print	-	n/a	-	n/a	8	corrugated board	126
PET (NC)	UK	0.3L	17.20	M	HDPE	E	3.30	M	LDPE	E	0.4	M	n/a	-	-	n/a
	UK	0.5L	12.90	M	HDPE	E	1.60	M	LDPE	E	0.4	M		12	LDPE	16
PET (C)	UK	0.38L	21.70	M	HDPE	E	3.60	M	LDPE	E	1.9	M	n/a	6	LDPE	8
	DE	0.5L	20.00	M	HDPE	E	2.00	M	LDPE	E	<1	M	n/a	12	LDPE	16
Glass	DE	0.25L	170.00	M	tinplated steel	M	2.00	M	direct print	M	n/a	-	<1	4	corrugated board	44
	DE	0.33L	386.00	M	tinplated steel	M	2.00	M	paper	M	<1	M	<1	24	returnable crate (HDPE)	1770
	UK	1L	518.30	M	tinplated steel	M	1.40	M	paper	M	1.2	M	n/a	6	returnable crate (HDPE)	1042
Alu can	-	0.25L	7.64	M	aluminum	M	2.61	M	direct print	M	n/a	M	n/a	4	corrugated board	28.5
	-	0.33L	9.43	M	aluminum	M	2.44	M	direct print	M	n/a	M	n/a	4	corrugated board	46
														4	LDPE	5
	-	0.5L	11.99	M	aluminum	M	2.44	M	direct print	M	n/a	M	n/a	12	LDPE	15
														12	corrugated board	45

*DQI Data Quality Index: M – Measured, E – Estimated, L – Literature, n/a – not applicable

Table 3-1: Recycled content of considered packaging alternatives

Beverage container	Recycled content	Source
Aluminum	55% can body, 3% can ends	R1, PEF Annex C
PET	0%	R1, PEF Annex C
Glass (flint, colorless)	40%	R1, PEF Annex C
Carton	100% virgin aluminum foil, LPB and polyethylene film	R1, PEF Annex C

An evaluation of the used data quality for the region can be found in Annex B:

3.3.2. Aluminum cans

While the generic life cycle is the same in all three regions, there are several important distinctions:

Recycled content and modelling secondary inputs

As shown in Table 3-1, the aluminum can body in Europe has 55% recycled content, while can end and tabs have only 3% scrap input.

Since the baseline scenario in the EU region follows the PEF CFF formula, the method prescribes not only a specific End of Life modelling but also determines the input of secondary materials. Therefore, a fixed portion (known as the allocation factor, A) of the secondary aluminum inputs modelled as primary material. As the formulas below show, 11% of the secondary aluminum is modelled as secondary (scrap) input and 44% as primary. The secondary part of recycled content is modelled using the value of scrap approach, a screenshot of which can be seen in Figure D-0-1.

According to the PEF CFF formula:

*Primary aluminum (**E_V**):* $1-R1=0.45$
Primary part of recycled content (E_recycled_prim): $R1*(1-A)=0.44$
Secondary part of recycled content (E_recycled_sec): $R1*A=0.11$

,where
R1, recycled content = 0.55
A, allocation factor of burdens and credits between supplier and user of recycled materials = 0.2 fixed values provided by the Annex C of the PEF Guidance Document. The factor A is a material-specific value, and moves between 1 (cut-off approach, no credits given) and 0 (substitution approach, full credits given).

Background data

European background data have been applied. As shown in Table 3-2 sheet manufacturing relies primarily on association data from European Aluminum (EA). Net material flows of aluminum can production are described in Figure 3-5.

Foreground data

Data for can manufacturing was collected by the EU representative of Ball from all facilities in this region, for 0.25L, 0.33L and 0.5L cans. The model applied region-specific data wherever possible, as listed in Table 3-3, Table 3-4. Additionally, Figure 3-5 depicts a screenshot from the GaBi model of can making (mass of individual entries are included in the confidential Annex).

Transports

The transport of inbound sheets for both can body and can ends require 84km rail transport, 566km ship transport and 836km truck drive. The outbound scrap aluminum is transported by truck to a recycling facility 1,010km away.

End of life

Annex C of the PEF Guide provides 0.69 as the rate of recycling for aluminum cans (see Table 3-11). Based on this and other constants, the portion that is sent to recycling in the GaBi model is calculated using the PEF CFF Formula as:

E_$_{\text{recyclingEoL}}$ = R2*(1-A)/RecyEoL_yield

where

R2, recycling rate = 0.69

A, allocation factor = 0.2

Recy$_{\text{EoL\_yield}}$, yield of recycling = 0.98

Since the quality of recycled aluminum is as high as primary, given the application (default value PEF guide), the credited amount from 1kg aluminum scrap is equal to 0.551.

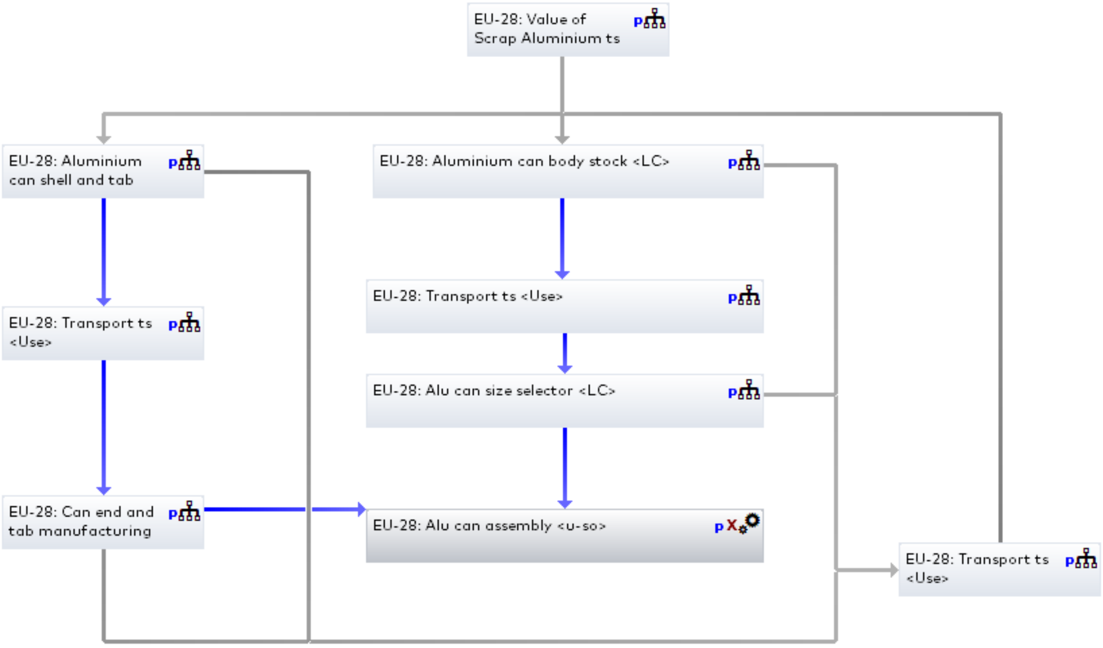

Figure 3-5: **Screenshot of the GaBi model of aluminum can manufacturing in the EU-28.**

Table 3-2: Datasets used to model aluminum sheet production for can body and can end and tab stock

Material/Process	GaBi dataset	Source	Documentation	Reference year
Sheet making	Aluminium sheet (2015)	EA	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1bfa0b24-db14-4785-bf69-35966f2e807e.xml	2015
Primary Aluminum	EU28+EFTA: Primary aluminum ingot consumption mix (2015)	EA	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/05f94d68-6435-4312-9ae2-091abadc5b24.xml	2015
Recycled Aluminium	EU28+EFTA: Aluminum remelting: wrought alloys ingot from scrap (2015)	EA	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/a9aa87f8-2daa-4634-83a4-51659ebfb3d5.xml	2015
Magnesium	CN: Magnesium ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/47cff7c4-6816-4093-a8e4-6a690bde0613.xml	2016
Ferro-Manganese	ZA: Ferro-manganese, refined (Ref. FeMn)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d9a98a56-7065-4277-93cd-aca94a0bf186.xml	2016
Silicon	GLO: Silicon mix (99%) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b356811f-fba4-4faf-9a32-5bfc950b8beb.xml	2016
Zinc	DE: Zinc redistilled mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/19720938-1090-44ee-ad57-6d2be1320d67.xml	2016

Table 3-3: Datasets used to model aluminum can manufacturing (energy datasets covered in the generic background data section), auxiliaries included up to 0.5% mass relative to product mass.

Material	Proxy	GaBi dataset	Source	Documentation	Reference year
Epoxy resin	No	DE: Epoxy Resin (EP) Mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/50125a08-978e-4156-bcc0-2d13ec3b49c7.xml	2016
Conversion Coating	Yes	US: Coatings (for can manufacturing) ts		no online documentation available, relative mass below 1%	
Sulphuric acid	No	DE: Sulphuric acid (96%) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/bf9c0154-1389-4f19-bcc1-15aec086624e.xml	2016
Municipal water	No	EU: Tap water from groundwater ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/db009013-338f-11dd-bd11-0800200c9a66.xml	2016
Solvent/ Cleaning Agent	Yes	DE: Isopropanol ts EU: Aceton ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ef44b6f5-5df4-4490-b485-2cd7d6c18167.xml http://gabi-documentation-2019.gabi-software.com/xml-data/processes/85b900e2-428e-4b18-8886-393f9956317d.xml	2016
GOV Film (Gloss Over Varnish)	Yes	DE: Polyester Resin unsaturated (UP) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b6801f51-3d8e-47d1-96bb-dbbea7b14e16.xml	2016
Hazardous waste	Yes	EU: Hazardous waste (statistic average) (no C, worst case scenario incl. landfil) ts	ts	http://gabi-documentation-2020.gabi-software.com/xml-data/processes/5b9241cb-e2fd-4e3d-bbe5-9285f2d7865d.xml	2016
Commercial waste	No	EU: Commercial waste (AT, DE, IT, LU, NL, SE, CH) on landfill ts		http://gabi-documentation-2020.gabi-software.com/xml-data/processes/e378d67c-a042-413c-a151-6d39f0fa280d.xml	
Municipal waste water	No	EU: Municipal waste water treatment and landfill ts		http://gabi-documentation-2020.gabi-software.com/xml-data/processes/52940380-bb28-4f80-b32f-b73989d79d0b.xml	

Table 3-4: Datasets used for can end manufacturing

Material	Proxy	GaBi dataset	Source	Documentation	Reference year
Ammonia water	Yes	DE: Ammonia water (weight share 25% NH3) ts	ts	http://gabi-documentation-2020.gabi-software.com/xml-data/processes/f2731daa-f2f2-4605-bd5f-8eb6ef4b4746.xml	
Lubricant	No	EU: Lubricants at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/bdfac21c-7415-46af-acbc-8916cb95b9b8.xml	2016
Water	No	DE: Water (desalinated; deionized) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/300e0734-6b74-4225-a078-d64108783da3.xml	2016
Coating	No	US: Coatings (for can manufacturing) ts	ts		

3.3.3. PET bottles

PET share is assumed to derive 70% from EU and 30% from China based on the trade balance between EU exports (worth ca. 20bn EUR) and extra-EU imports (worth ca. 11bn EUR), and China being the largest manufacturer of plastics worldwide (with about 30% market share). Pure PET granulate via DMT route is assumed for China (slightly older technology) and pure PET granulate via purified terephthalic acid (PTA) and ethylene glycol for the EU portion (newer technology). Additives were not considered in this LCA due to the lack of availability of specific data, assuming that their impact is negligible or slightly worse than pure PET. It is likely that this simplification does not affect outcomes significantly, or potentially makes a slightly better case for PET bottles.

Recycled content and modelling secondary inputs

As shown in Table 3-1 and in line with the PEF Guide, PET bottles have been modelled without any recycled content. No secondary inputs have been modelled.

Background data

European background data has been applied.

Foreground data

Product specific data has been collected via sample products (chapter 3.3.1). The model is depicted in chapter 3.2.2. Region-specific datasets are applied wherever possible, as listed in Table 3-5.

Transports

Transports as stated in chapter 3.2.5 have been applied.

End of life

Annex C of the PEF Guide provides 0.42 as the rate of recycling for PET bottles (see Table 3-11). Based on this and other constants, the portion that is sent to recycling in the GaBi model is calculated using the PEF CFF Formula as:

$E\_{\text{recyclingEoL}} = R2*(1-A)/RecyEoL\_yield$

where

R2, recycling rate = 0.42

A, allocation factor = 0.5

$Recy_{\text{EoL\_yield}}$, yield of recycling = 0.86

Since the quality of recycled PET is not as high as primary, only 90% of the recyclate is credited (default value PEF guide). From an input of 1kg PET scrap, 0.19kg virgin PET can be credited.

Table 3-5 Datasets used to model PET bottle production in EU

Material	GaBi dataset	Source	Documentation	Reference year
Bottle: PET granulate	EU: Polyethylene terephthalate bottle grade granulate (PET) via PTA	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4b2420b3-8f56-45f1-984d-173a9298ef4a.xml	2016
Bottle: PET granulate	CN: Polyethylene terephthalate granulate (PET via DMT)	ts	No online documentation available. GUID: {2790464C-5FEC-4CE4-9DAC-B84E303F4679}	2016
Bottle: PET blow molding	DE: Polyethylene (HDPE/PE-HD) blow moulding <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/3979582f-0678-4dfe-8304-1860a797c0b8.xml	2016
Closure: HDPE granulate	EU: Polyethylene high density granulate (HDPE/PE-HD)	ts	No online documentation available. GUID: {5B30A5AB-BC4E-4316-BB18-F6605B382648}	2016
Closure: Injection molding	GLO: Plastic injection moulding (parameterized)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aaf7c3a1-6ecd-459e-a493-3f376507e29b.xml	2016
Label: LDPE granulate	EU: Polyethylene Low Density Granulate (LDPE/PE-LD)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/df6a564c-f46e-4325-9689-022bbfe009db.xml	2016
Label: Film extrusion	GLO: Plastic Film (PE, PP, PVC)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/7094f46a-2202-44e5-a1cc-8e939be9ff6b.xml	2016
Electricity	EU: Electricity grid mix	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/001b3cb7-b868-4061-8a91-3e6d7bcc90c6.xml	2016

Material	GaBi dataset	Source	Documentation	Reference year
Thermal energy	EU: Thermal energy from natural gas ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/cfe8972e-6b51-4a17-b499-d78477fa4294.xml	2016
Compressed air	GLO: Compressed air 7 bar (medium power consumption)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/591678ea-db78-427a-8b62-f0c2a329c5bb.xml	2016
Lubricants	EU: Lubricants at refinery	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/bdfac21c-7415-46af-acbc-8916cb95b9b8.xml	2016
MSWI PET	EU: Polyethylene terephthalate (PET) in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/83963943-31b5-420a-abb6-72be280c1c64.xml	2016
MSWI PE	EU: Polyethylene (PE) in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e0d2ea41-0800-482c-b985-a7dc550ffba6.xml	2016

3.3.4. **Glass bottles**

Recycled content and modelling secondary inputs

As shown in Table 3-1 and in line with the PEF Guide, glass bottles have been modelled 40% recycled content.

Modelling secondary inputs in the baseline scenario follow the circular footprint formula (CFF). The use of glass cullet reduces the input of energies and related emissions in the container glass production. The allocation factor A equals 0.2 and means that 20% of recycled content is treated as secondary material whereas the remaining 80% of recycled content are treated in the model as primary material.

Background data

European background data have been applied.

Foreground data

Product specific data has been collected via sample products (chapter 3.3.1). The model is depicted in chapter 3.2.2. Region-specific datasets are applied wherever possible, as listed in Table 3-6.

Transports

Transports as stated in chapter 3.2.5 have been applied.

End of life

Annex C of the PEF Guide provides 0.66 as the rate of recycling for glass bottles (see Table 3-11). Based on this and other constants, the portion that is sent to recycling in the GaBi model is calculated using the PEF CFF Formula as:

E_$_{\text{recyclingEoL}}$ = R2*(1-A)/RecyEoL_yield

where

R2, recycling rate = 0.66

A, allocation factor = 0.2

Recy$_{\text{EoL\_yield}}$, yield of recycling = 0.919

Since the quality of recycled glass is as high as primary, all of the recyclate is credited (default value PEF guide). From an input of 1kg glass arriving at the recycling plant, 0.528kg virgin container glass can be credited.

Table 3-6: Datasets used to model glass bottle production in EU

Material	GaBi dataset	Source	Documentation	Reference year
Glass, virgin	Production of container glass (100% batch)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/5f88e494-354b-4e7b-b40a-f734f7304642.xml	2016
Glass, recycled	Production of container glass (100% cullet)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/497a4b72-84bf-4ba0-84ef-cf5ed9fd2a5b.xml	2016
Label: Paper, virgin	Kraftliner (2015) - for use in avoided burden EoL scenario cases	FEFCO	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ac37d3c-caeb-4216-9f1d-c78c1b8c772b.xml	2016
Label: Paper, recycled	Testliner (2015) - for use in avoided burden EoL scenario cases	FEFCO	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e1f35758-557e-44de-8d73-28be3c87d43f.xml	2016
Closure: Steel	EU: Steel tinplated	world-steel	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6accaea9-92bd-45ee-816e-1037a7f4deb8.xml	2014

3.3.5. Liquid beverage cartons

Recycled content and modelling of secondary inputs

As per the PEF Guide, no recycled content has been modelled for the beverage carton fractions (Table 3-1).

Background data

European background data has been applied.

Foreground data

Product specific data according to Tetra Pak (2019) has been collected (chapter 3.3.1). The model is depicted in chapter 3.2.4. Region-specific datasets are applied wherever possible, as listed in Table 3-8.

Transports

Transports for the raw materials to manufacturing have been applied according to ifeu (2011). For liquid packaging board, 200km transport by truck, 400km transport by train and 1300km transport by ship has been assumed. For polymers, 200km transport by truck has been assumed. For aluminum foil, 250km transport by truck has been assumed.

End of life

Annex C of the PEF Guide provides 0.43 as the rate of recycling for beverage cartons (see Table 3-11). Based on this and other constants, the portion that is sent to recycling in the GaBi model is calculated using the PEF CFF Formula as:

$E\_{}_{recyclingEoL} = R2*(1-A)/RecyEoL\_yield$

where

R2, recycling rate = 0.43

A, allocation factor = 0.2

$Recy_{EoL\_yield}$, yield of recycling = 0.85

Since the quality of recycled paper is high enough to fulfil the same function as primary paper, all of the recyclate is credited (default value PEF guide). From an input of 1kg paperboard arriving at the recycling plant, 0.547kg virgin paper can be credited.

Table 3-7 Beverage carton composition of sample products in the EU region

	Beverage carton fractions			
	Alu %	LDPE %	LPB %	DQI
0.33L	0.073	0.236	0.691	L
0.5L	0.064	0.214	0.722	L

Table 3-8: Datasets used to model beverage carton production in EU

Material/ Process	GaBi dataset	Source	Documentation	Reference year
Liquid packaging board	EU: Liquid Packaging Board (LPB) production	ACE/ELCD	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/7d580a76-d2a4-46fe-a3a3-c6c8ed585382.xml	2009
LDPE granulate	EU: Polyethylene Linear Low Density Granulate (LLDPE/PE-LLD)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/27b2f25c-ccec-43cf-97b9-bc97f0f95f49.xml	2016
Aluminum ingot	EU+EFTA: Primary aluminium ingot consumption mix (2015)	European Aluminium	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/05f94d68-6435-4312-9ae2-091abadc5b24.xml	2015
Aluminum foil	EU: Aluminium foil (2010) <p-agg>	European Aluminium	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/86c4d1c5-19f9-4d43-9bff-0b88b714b93f.xml	2011
Printing ink	DE: Polyacrylate ink (estimation)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/5732dcc1-d1e7-42b9-8a36-a6214d3abc22.xml	2016
Natural gas	EU: Natural gas mix	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/c6387e19-933f-4726-a7ad-7a8050aa418c.xml	2016
Liquefied Petroleum Gas	EU: Liquefied Petroleum Gas (LPG) (70% propane, 30% butane)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/0ab1ed73-8af0-4fc2-a288-eac53f7ae0f0.xml	2016
Waste water	EU: Municipal waste water treatment (mix)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/9805e7ee-b500-46b4-a0f0-37b09e00a3fa.xml	2016
Waste for incineration	EU: Municipal waste in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aa364db3-52ce-4bee-89eb-b86426753ec2.xml	2016
Waste for landfill	EU: Commercial waste (AT, DE, IT, LU, NL, SE, CH) on landfill	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e378d67c-a042-413c-a151-6d39f0fa280d.xml	2016
Hazardous waste	GLO: Hazardous waste (non-specific) (C rich, worst case scenario incl. landfill)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/64fe47f0-c90b-4e41-8e3e-a6eca3715879.xml	2016
Steam credit	EU: Process steam from natural gas 95%	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/104dbecc-4f6c-456b-9e44-722bc9c41e75.xml	2016

3.3.6. **Background data of energy and transports applicable for all products**

All production processes in Europe are assumed to be supplied by the same energy carriers and energy sources. Table 3-9 summarizes the GaBi datasets used commonly across all production modelled. One generic transport model is used to describe transport options across each product life cycle. The datasets used in this model are summarized in Table 3-10.

Table 3-9: Datasets used to model energy provision for products manufactured in EU.

Material	GaBi dataset	Source	Documentation	Reference year
Electricity	EU: Electricity grid mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/001b3cb7-b868-4061-8a91-3e6d7bcc90c6.xml	2016
Thermal energy from natural gas	EU: thermal energy from natural gas ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/cfe8972e-6b51-4a17-b499-d78477fa4294.xml	2016
Thermal energy from fuel oil	EU: thermal energy from light fuel oil (LFO) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/261369f8-8ad9-4cac-81bc-4f308f2d80be.xml	2016

Table 3-10: Datasets used to model material and product transport in EU.

Transport mode	GaBi dataset	Source	Documentation	Reference year
Truck-trailer	GLO: Truck-trailer, Euro 0 - 6 mix, 34 - 40t gross weight / 27t payload capacity ts <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4e47891c-25ca-4263-8ebd-e1b462c0f4b8.xml l	2016
Rail	Rail transport cargo - average, light train, gross tonne weight 500t / 363t payload capacity	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/0e18387f-9a65-4a6c-87d6-89404f330a10.xml	2016
Motor ship	Motor ship, 1,500t payload capacity / upstream	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/7877b2c6-5772-4555-9806-327ab7ed3f37.xml	2016
Diesel	EU: Diesel mix at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/244524ed-7b85-4548-b345-f58dc5cf9dac.xml	2016

3.3.7. **End of Life**

For each product three possible end of life waste streams are available; recycling, incineration (with energy recovery) and landfill. The statistics for each of these recycling streams is based on PEF Guidance Annex C, November 2019. The recycling yields are calculated using GaBi databases. Table 3-11 below summarizes this information. To be kept in mind is that the cited End of Life shares (%) differ from the recycling rate R2, because the EoL shares include the allocation factor A and the yield of the recycling process.

Table 3-11: End of Life statistics applied for the EU region.

Material	EoL stream	EoL share (%)	Recycling rate (%) R2	R2 Definition	Recycling Yield (%)	Allocation factor A	Qs/Qp
Aluminum can	Recycling	56.3	69	Output recycling plant	98	0.2	1
	Incineration	14.0	-	-	-	-	-
	Landfill	17.1	-	-	-	-	-
PET bottle	Recycling	24.6	42	Output recycling plant	86	0.5	0.9
	Incineration	26.1	-	-	-	-	-
	Landfill	31.9	-	-	-	-	-
Glass bottle	Recycling	57.5	66	Output recycling plant	95	0.2	1
	Incineration	15.3	-	-	-	-	-
	Landfill	18.7	-	-			
	Re-use	0-20 re-uses (scenario only)					
Beverage cartons*	Recycling	40.2	43	Input recycling plant	85	0.2	1
	Incineration	25.7	-	-	-	-	-
	Landfill	31.4	-	-	-	-	-

** Beverage carton indicators apply to the liquid packaging board and not to HDPE and aluminum foils in the layers as per direct communication with the dual system in Germany. Fiber losses are considered in the recycling process, therefore Qs/Qp is set to 1.*

Transport distances to End of Life processing facilities are neglected, as these are expected to be within 100km radius of the disposal site by the end consumer.

The end of life waste streams are split using consistent calculations for all products. Where material or energy is recovered from end of life processes, fixed material credits are applied to compensate the burdens created by the product life cycles. Table 3-12 summarizes the GaBi datasets used commonly across all end of life plans modelled.

Table 3-12: Datasets used to model end of life processes for products manufactured in EU.

Material/Process	GaBi dataset	Source	Documentation	Reference year
End of life selection	GLO: Multi-functionality in End-of-Life Situations (PEF circular footprint formula, End-of-Life) PEF guide <u-so>	ts	No documentation available	2013
Beverage Carton				
Paper waste on landfill	EU: Paper waste on landfill ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/89863fce-3306-11dd-bd11-0800200c9a66.xml	2016

Material/Process	GaBi dataset	Source	Documentation	Reference year
Paper waste for incineration	EU: Paper / Cardboard in waste incineration plant ts <p-agg>		http://gabi-documentation-2019.gabi-software.com/xml-data/processes/0730a97b-bda5-4b9b-8632-8f2c52271f92.xml	2016
Paper waste for recycling	EU: Testliner (2015) - for use in avoided burden EoL scenario cases ts/FEFCO <p-agg>		http://gabi-documentation-2020.gabi-software.com/xml-data/processes/e1f35758-557e-44de-8d73-28be3c87d43f.xml	2016
Product with recycled paper content	BR: Kraftliner 2015 ts/FEFCO, by-products tall oil and turpentine (mass) - avoided burden ts <p-agg>		http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ac37d3c-caeb-4216-9f1d-c78c1b8c772b.xml	
Product with 100% recycled paper content	BR: Testliner 2015 ts/FEFCO - for use in avoided burden Eol scenario cases ts <p-agg>		http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e1f35758-557e-44de-8d73-28be3c87d43f.xml	
PET Bottle				
Plastic waste on landfill	EU: Plastic waste on landfill ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/64197300-3307-11dd-bd11-0800200c9a66.xml	2016
PET for incineration	EU: Polyethylene terephthalate (PET) in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2020.gabi-software.com/xml-data/processes/83963943-31b5-420a-abb6-72be280c1c64.xml	2016
PET for recycling	EU: Polyethylene terephthalate (PET) granulate secondary ; no metal fraction ts <p-agg>	ts	http://gabi-documentation-2020.gabi-software.com/xml-data/processes/60dd82e4-46d0-4735-a8ad-94e708a2b92a.xml	2016
Glass Bottle				
Glass waste for landfill	EU: Glass/inert waste on landfill ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/64197304-3307-11dd-bd11-0800200c9a66.xml	2016
Glass waste for incineration	EU: Inert waste in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6d42b1ce-d6d0-4ad6-b8d2-4ded71770214.xml	2016
Production of glass cullet	EU: Glass cullet, sorted ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ae26c0a4-c43c-4e55-9426-28402256e592.xml	2016
Glass cullet for recycling	EU: Production of container glass (100% cullet) ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/497a4b72-84bf-4ba0-84ef-cf5ed9fd2a5b.xml	2016
Aluminum Can				

Material/Process	GaBi dataset	Source	Documentation	Reference year
Aluminum waste to landfill	EU: Inert matter (Aluminium) on landfill ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/2bb26c32-23c1-459d-929d-f07917830678.xml	2016
Aluminum waste to incineration	DE: Non-ferro metals, aluminium, more than 50µm in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/37d98fd2-cbf5-425d-ae1b-032118a99e7d.xml	2016
Aluminum waste for recycling	EU28+EFTA+Turkey: Aluminium remelting: wrought alloys ingot from scrap (2015) European Aluminium <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/a9aa87f8-2daa-4634-83a4-51659ebfb3d5.xml	2016
Aluminum ingot production	EU28+EFTA: Primary aluminium ingot consumption mix (2015) European Aluminium	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/05f94d68-6435-4312-9ae2-091abadc5b24.xml	2016

3.4. Region: US

3.4.1. Overview product specification

Material	Primary										Secondary		
	Container Volume	Container Weight (g)	DQI*	Cap material	Cap Weight (g)	DQI*	Label	DQI*	Label Weight (g)	DQI*	Nesting	Packaging material	Weight (g)
Carton	11.1oz	13.00	L	HDPE	4.00	L	direct print	-	n/a	-	12	corrugated board	231
	16.9oz	18.60	M	HDPE	2.70	M	Direct print	-	n/a	-	24	corrugated board	386
											1x24	corrugated board	1055
PET (C)	12oz	19.10	M	PP	2.04	M	LDPE	M	0.22	M	8	LDPE	5
											3x8	corrugated board	94
	16.9oz	26.00	M	PP	3.02	M	LDPE	M	0.86	M	6	LDPE	13
											4x6	corrugated board	149
PET (NC)	16.9oz	8.81	M	PP	1.06	M	LDPE	M	0.21	M	12	LDPE	14
Glass	12oz	288.00	M	tinplated steel	2.10	M	direct print	-	n/a	-	12	corrugated board	439
											1x12	corrugated board	532
	16oz	223.00	M	tinplated steel	4.10	M	paper	M	1.39	M	6	corrugated board	69
											4x6	corrugated board	149
Alu can	12oz	10.25	M	aluminum	2.43	M	direct print	M	n/a	M	8	corrugated board	66
	16oz	12.18	M	aluminum	2.43	M	direct print	M	n/a	M	4	corrugated board	50
	16oz (ATB)	21.97	M	aluminum	2.56	M	direct print	M	n/a	M	9	corrugated board	119

*DQI Data Quality Index: M – Measured, E – Estimated, L – Literature, ATB – Alumi-Tek Bottle, n/a – not applicable

Table 3-13: Recycled content of considered packaging alternatives

Beverage container	Recycled content	Source
Aluminum cans	73%[5]	AA 2016 (The Aluminum Association, 2019)
PET bottles	6%	(National Association of PET Container Resources (NAPCOR) and The Association of Plastic Recyclers (APR) , 2018)
Glass bottles	35%	Glass Packaging Institute (GPI) (GPI, 2014)
Beverage carton	0% all virgin materials	ACE (Ifeu, 2011)

An evaluation of the overall data quality for this region can be found in Annex B:

3.4.2. Aluminum cans

Recycled content and modelling secondary inputs

As shown in Table 3-13, the aluminum cans have a very high recycled content of 73%. Modelling secondary inputs in the baseline scenario follows the cut-off methodology, therefore aluminum scrap enters the system burden-free and leaves the system without credit. Certainly, scrap requires re-melting which is included in the partly aggregated can rolling dataset (Table 3-14).

Background data

North American background data have been applied. As shown in Table 3-14, sheet manufacturing relies heavily on association data from The Aluminum Association (AA), which are due to be published. Net material flows of aluminum can production can be gleaned from Figure 3-6.

Foreground data

Can manufacturing was collected by the US representative of Ball from facilities in this region, for 12oz and 16oz standard (STD) cans as well as the 16oz Alumi-Tek bottle (ATB). The model applied region-specific datasets wherever possible, as listed in Table 3-14, Table 3-15, Table 3-16, however several auxiliaries were only available with German or European boundary conditions. For an addition level of detail, Figure 3-6 depicts a screenshot from the GaBi model of can making.

Transports

The transport of inbound can sheet for both can body and can end require 485km ship transport and 1,591km truck drive. The outbound scrap aluminum is transported by truck to a recycling facility 1,476km away.

End of life

At the End of Life, 50.4%[6] of aluminum cans are collected for recycling (see Table 3-23).

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[5] According to the government-approved terminology of recycled content, which excludes run-around scrap. Total scrap input including run-around scrap amounts to 78%.

[6] According to the latest figures (AA 2019) published after the background model in this report was finalized, EoL collection has decreased to 49.8%. The difference is, however is so small that it will not affect outcomes.

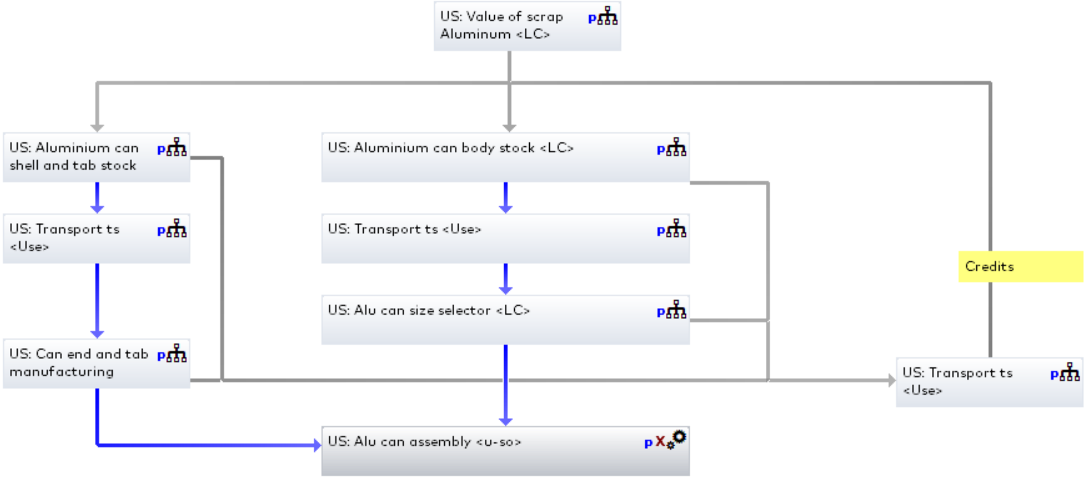

Figure 3-6: **Screenshot of the GaBi model of aluminum can manufacturing in the US.**

Table 3-14: Datasets used to model aluminum sheet production for can body and can ends and tab stock in the US.

Material	GaBi dataset	Source	Documentation	Reference year
Primary Aluminum	RNA: Primary Aluminum Ingot AA/ts	AA/ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/768dd9de-0553-4857-b3ed-a40e0b0f10ef.xml	2010
Recycled Aluminum	RNA: Aluminum scrap remelting and casting AA/ts	AA/ts	Annex I:	2016
Aluminum sheet	RNA: Combined hot and cold rolling	AA/ts	Annex I:	2016
Magnesium	CN: Magnesium ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/47cff7c4-6816-4093-a8e4-6a690bde0613.xml	2016
Ferro-Manganese	ZA: Ferro-manganese, refined (Ref. FeMn)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d9a98a56-7065-4277-93cd-aca94a0bf186.xml	2016
Silicon	GLO: Silicon mix (99%) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b356811f-fba4-4faf-9a32-5bfc950b8beb.xml	2016
Zinc	DE: Zinc redistilled mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/19720938-1090-44ee-ad57-6d2be1320d67.xml	2016

Table 3-15: Datasets used to model can manufacturing in the US, including auxiliaries contributing at least 0.5% by mass relative to the product.

Material	Proxy	GaBi dataset	Source	Documentation	Reference year
Epoxy resin		DE: Epoxy Resin (EP) Mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/50125a08-978e-4156-bcc0-2d13ec3b49c7.xml	2016
Sulphuric acid		DE: Sulphuric acid (96%) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/bf9c0154-1389-4f19-bcc1-15aec086624e.xml	2016
Tap water		US: Tap water from groundwater ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/dc952b0b-97ae-4539-aa07-bd4d76d8cfa9.xml	2018
Cooling agent and solvent combined	Solvent/ Cleaning Agent	US: Isopropanol ts US: Aceton ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ba8ea668-ea63-4404-8a8b-3925d612a637.xml, http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4792d8d7-092b-49a8-85ac-e6995b9039cd.xml	2016
Ink	Water-based coating	DE: Coating water-based (industry; white) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aa21af51-b765-4070-8e79-20107647a29f.xml	2016
GOV Film	Polyester resin	DE: Polyester Resin unsaturated (UP) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b6801f51-3d8e-47d1-96bb-dbbea7b14e16.xml	2016

Table 3-16: Datasets used to model can end and tab manufacturing

Material	GaBi dataset	Source	Documentation	Reference year
Ammonia water	US: Ammonia water (weight share 25% NH3) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d953511f-619a-4871-9fcf-fe0e273b6f0b.xml	2016
Lubricant	EU: Lubricants at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/bdfac21c-7415-46af-acbc-8916cb95b9b8.xml	2016
Metal glue	EU: Metal Glue (Screw sealing) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e36ce59e-49dd-4b4a-8c3c-c206e4442170.xml	2018

3.4.3. PET bottles

Recycled content and modelling secondary inputs

As shown in Table 3-13, PET bottles have an average recycled content of 6% according to the National Association of PET Container Resources (NAPCOR) and The Association of Plastic Recyclers (APR) (2018).

Modelling secondary inputs in the baseline scenario follows the cut-off methodology. Consequently, PET scrap enters the system burden-free, then undergoes recycling before being used as an input to bottle manufacturing. Following processing (recycling) steps are included: grinding, metal separation, washing, pelletization and compounding. These steps are included in the partly aggregated Plastic granulate secondary (PET) dataset (Table 3-17).

Background data

North American background data has been applied.

Foreground data

Product specific data has been collected via sample products (chapter 3.4.1). The model is depicted in chapter 3.2.2. Region-specific datasets are applied wherever possible, as listed in Table 3-17.

Transports

No transport processes other than those stated in chapter 3.2.5 have been applied due to a lack of reliable data. This favors the PET bottles, but is a disadvantage for the cans, where such data is available.

End of life

At the End of Life, PET bottles are collected at a relatively low 29.9% for recycling (EPA 2015, Table 3-23). Due to the lack of more specific data, products collected for recycling are assumed to enter the recycling facility, i.e. losses are only included in the recycling process itself (yield).

Table 3-17: Datasets used to model PET bottle production system in the US region

Material	GaBi dataset	Source	Documentation	Reference year
Bottle: PET granulate, virgin	US: Polyethylene terephthalate granulate (PET) via PTA	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/043fc939-8eff-409b-ac6b-7609312ab447.xml	2018
Bottle: PET granulate, recycled	US: Plastic granulate secondary (PET)	ts	No online documentation available. GUID: {B96CD185-56FB-4C20-B8F5-44AC0714703C} only plan available. No docu	2016
Bottle: PET blow molding	DE: Polyethylene (HDPE/PE-HD) blow moulding <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/3979582f-0678-4dfe-8304-1860a797c0b8.xml	2016
Closure: PP	US: Polypropylene granulate (PP)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/5bb0726a-a44f-4f80-a964-0aeeb947ad41.xml	2016

Material	GaBi dataset	Source	Documentation	Reference year
Closure: Injection molding	GLO: Plastic injection moulding (parameterized)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aaf7c3a1-6ecd-459e-a493-3f376507e29b.xml	2016
Label: LDPE	US: Polyethylene Low Density Granulate (LDPE/PE-LD)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1cab96fb-492d-436a-8f14-fd86df4f7843.xml	2016
Label: Film extrusion	GLO: Plastic Film (PE, PP, PVC)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/7094f46a-2202-44e5-a1cc-8e939be9ff6b.xml	2016
Compressed air	GLO: Compressed air 7 bar (medium power consumption)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/591678ea-db78-427a-8b62-f0c2a329c5bb.xml	2016
Lubricants	US: Lubricants at refinery	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d161bd8f-005c-47af-97fb-82bbcee1f39b.xml	2016
MSWI: PET	US: Polyethylene terephthalate (PET) in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/c0a8ea64-6ce8-46b1-8851-14c57e4a8d3a.xml	2016
MSWI: PP	US: Polypropylene (PP) in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/3c54cba7-33a9-463e-8d07-2e774f6ef833.xml	2016
MSWI: PE	US: Polyethylene (PE) in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/27b8efb0-adae-44d9-8a43-b5e52c24f0ae.xml	2016

3.4.4. Glass bottles

Recycled content and modelling secondary inputs

In 2013, container glass had a recycled content of 33.6 while having had a 50% target for 2014 that has not been reached (GPI, 2014). In 2018, the recycled content has been estimated to be at 35% (Dr.-Ing. Joachim Harder, 2018). This follows the upward trends shown by GPI (2014).

Modelling secondary inputs in the baseline scenario follows the cut-off methodology, therefore glass cullet enters the system burden-free and leaves the system without credits. The use of glass cullet reduces the input of energies and related emissions in the container glass production.

Background data

North American background data has been applied.

Foreground data

Product specific data has been collected via sample products (chapter 3.4.1). The model is depicted in chapter 3.2.3. Region-specific datasets are applied wherever possible, as listed in Table 3-18.

Transports

No other transports than stated in chapter 3.2.5 have been applied due to lack of reliable data working to the advantage of glass bottles.

End of life

At the End of Life, glass bottles are collected at 41.9% for recycling (EPA 2015, Table 3-23).

Table 3-18 Datasets used to model glass bottle production system in the US region

Material	GaBi dataset	Source	Documentation	Reference year
Bottle: Container glass, virgin	US: Container glass 100% virgin	ts	Regionalized to US boundary conditions from the EU-28 dataset http://gabi-documentation-2019.gabi-software.com/xml-data/processes/5f88e494-354b-4e7b-b40a-f734f7304642.xml	2018
Bottle: Container glass, recycled	US: Container glass 35% recycled content	ts	No documentation available, based on the EU-28 dataset http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1251bef4-96ea-4091-ab58-0805050e9102.xml	2018
Label: Paper	US: Kraftliner 2015 ts/FEFCO, by-products tall oil and turpentine (mass) - avoided burden	FEFCO/ts	No online documentation available. GUID: {c679f1d7-bd3c-4542-8c84-c355750dae14} based on the EU-28 dataset http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ac37d3c-caeb-4216-9f1d-c78c1b8c772b.xml	2014
Value of scrap: paper	US: Testliner 2015 ts/FEFCO - for use in avoided burden Eol scenario cases	FEFCO/ts	No online documentation available. GUID: {316e9b60-5982-417c-9897-235161c94d51} based on the EU-28 dataset http://gabi-documentation-2020.gabi-software.com/xml-data/processes/e1f35758-557e-44de-8d73-28be3c87d43f.xml	2014
Closure: tinplated steel	US: Steel tinplated	worldsteel	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4b6095ea-22c3-4509-9a8c-b81297551db4.xml	2014
Ink	US: Inks (for can manufacturing)	ts	No online documentation available. GUID: {E2D3B395-DB2E-45E1-A9A6-AA3E21D62BE7}	2018

3.4.5. Liquid beverage cartons

Recycled content and modelling secondary inputs

No recycled content has been modelled for the beverage carton fractions.

No secondary inputs have been modelled.

Background data

North American background data has been applied.

Foreground data

Product specific data has been collected via samples for the 16.9oz size (chapter 3.4.1). For the 11.1oz size by Tetra Pak, specifications according to Tetra Pak (2019) have been applied. The model is depicted in chapter 3.2.4. Region-specific datasets are applied wherever possible, as listed in Table 3-20.

Transports

Transports for the raw materials to manufacturing have been applied according to ifeu (Ifeu, 2011) or liquid packaging board, 200km transport by truck, 400km transport by train and 1,300km transport by ship has been assumed. For polymers, 200km transport by truck has been assumed. For aluminum foil, 250km transport by truck has been assumed.

End of life

At the End of Life, liquid beverage cartons are collected at 26.4% for recycling (Table 3-23). However, it is assumed that only the paper fraction of beverage cartons is recycled. Aluminum and Polyethylene fractions are assumed to be incinerated or landfilled.

Table 3-19 Beverage carton composition of sample products in the US region

Container	Beverage Carton Fractions			
	Alu%	LDPE%	LPB%	DQI
11.1oz	7.3	23.6	69.1	L
16.9oz	6.0	20.0	74.0	L

Table 3-20: Datasets used for manufacturing cartons in the US

Material	GaBi dataset	Source	Documentation	Reference year
Liquid packaging board	US: Kraftliner	FEFCO	Regionalization of the FEFCO datasets in-house by ts.	2014
LDPE granulate	US: Polyethylene Linear Low Density Granulate (LLDPE/PE-LLD)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1cab96fb-492d-436a-8f14-fd86df4f7843.xml	2016
Aluminum ingot	RNA: Aluminium ingot mix IAI	IAI/ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1861bc3a-c181-4589-8968-88136b2e5e44.xml	2015
Aluminum foil	EU: Aluminium foil (2010) <p-agg>	European Aluminium	http://gabi-documentation-2019.gabi-software.com/xml-	2011

			data/processes/86c4d1c5-19f9-4d43-9bff-0b88b714b93f.xml	
Printing ink	US: Polyacrylate ink (estimation)	ts	http://gabi-documentation-2020.gabi-software.com/xml-data/processes/90ea0337-8006-49cc-a441-55a2ab34153e.xml	2016
Natural gas	US: Natural gas mix	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/90be2ca7-96eb-4949-8e6d-c60dd58018aa.xml	2016
Liquefied Petroleum Gas	US: Liquefied Petroleum Gas (LPG) (70% propane, 30% butane)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/2a8b8c86-7d4b-4bde-a09f-782d4d9b8608.xml	2016
Waste water	US: Municipal waste water treatment (mix)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d0f0306e-74e2-448c-a602-3ad753749a1c.xml	2018
Waste for incineration	US: Municipal waste in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aa364db3-52ce-4bee-89eb-b86426753ec2.xml	2016
Waste for landfill	US: Municipal Solid waste on landfill	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/62ef428a-183b-4448-9396-4d192d7c692a.xml	2016
Hazardous waste	GLO: Hazardous waste (non-specific) (C rich, worst case scenario incl. landfill)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/64fe47f0-c90b-4e41-8e3e-a6eca3715879.xml	2016
Steam credit	US: Process steam from natural gas 95%	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/2cfc6c81-b8ac-4228-aea4-1527abeb922a.xml	2016

3.4.6. Background data of energy and transports applicable for all products

All production processes in the US are assumed to be supplied by the same energy carriers and energy sources. Table 3-21 summarizes the GaBi datasets used commonly across all production modelled. One generic transport model is used to describe transport options across each product life cycle. The datasets used in this model are summarized in Table 3-22.

Table 3-21: Datasets used to model energy use for products manufactured in the US.

Material	GaBi dataset	Source	Documentation	Reference year
Electricity	US: Electricity grid mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6b6fc994-8476-44a3-81cc-9829f2dfe992.xml	2016

Material	GaBi dataset	Source	Documentation	Reference year
Thermal energy from natural gas	US: Thermal energy from natural gas ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/885a8641-0eae-4f2f-b191-cec7335325bc.xml	2016

Table 3-22: Datasets used to model transports for products manufactured in the US.

Material	GaBi dataset	Source	Documentation	Reference year
Truck-trailer	GLO: Truck-trailer, Euro 0 - 6 mix, 34 - 40t gross weight / 27t payload capacity	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4e47891c-25ca-4263-8ebd-e1b462c0f4b8.xml	2016
Rail	GLO: Rail transport cargo - average, light train, gross tonne weight 500t / 363t payload capacity		http://gabi-documentation-2019.gabi-software.com/xml-data/processes/0e18387f-9a65-4a6c-87d6-89404f330a10.xml	2016
Motor ship	GLO: Motor ship, 1,500t payload capacity / upstream		http://gabi-documentation-2019.gabi-software.com/xml-data/processes/7877b2c6-5772-4555-9806-327ab7ed3f37.xml	2016
Diesel	US: Diesel mix at refinery ts		http://gabi-documentation-2020.gabi-software.com/xml-data/processes/452a3926-2850-47db-809d-753095ed7dac.xml	2016

3.4.7. End of Life

For each product three possible end of life waste streams are available: recycling, incineration and landfill. The statistics for each of these end of life streams is sourced from the EPA Report 2015 (EPA, 2015) (annex 3) for all materials except for aluminum. Table 3-23 summarizes these statistics. Collection rates refer to values provided as collected for recycling. Losses due to sorting are not considered, yields refer to the efficiency of the recycling plant to convert a given post-consumer material into secondary materials and reflect data in the corresponding recycling dataset of the GaBi databases shown in Table 3-24. These losses are most likely to affect materials, whose sorting efficiencies are lower, such as plastics and beverage cartons, thereby disadvantaging aluminum and glass, which are easier to sort.

Transport distances to End of Life processing facilities are neglected, as these are expected to be within 100km radius of the disposal site by the end consumer.

Table 3-23: End of life treatment of considered packaging alternatives in the US region

	EoL stream	Collection %	Yield %	Source
Aluminum can	Recycling	50.4	98	AA 2016
	Incineration	0		
	Landfill	49.6		

PET bottle	Recycling	29.9	86	EPA 2015
	Incineration	13.8		
	Landfill	56.4		
Glass bottle	Recycling	41.9	97	
	Incineration	11.5		
	Landfill	46.6		
Beverage cartons	Recycling	26.4	92*	
	Incineration	14.4		
	Landfill	59.1		

*Recycling yield of beverage cartons only refers to the paper fraction, the aluminum and polyethylene fractions have been assumed to have 0% material recycling yield.

Table 3-24: Datasets used to model end of life processes for products manufactured in the US.

Material	GaBi dataset	Source	Documentation	Reference year
Waste to disposal	EOL: Waste to disposal (e.g. landfill, energy recovery) ts <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/8dd8163b-4ea3-4632-ac74-324cc818cecd.xml	2018
Waste for recycling	EOL: Waste to be recycled ts <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/fb9a6418-6716-4ce4-ba0d-0d226e296702.xml	2018
End of life selection	GLO: Multi-functionality in End-of-Life Situations (PEF circular footprint formula, End-of-Life) PEF guide <u-so>	ts	No documentation available	2013
Correction for downcycling	GLO: Correction for downcycling (PEF guide, Annex V) <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/627b42d2-7ce1-47b3-9521-bddc8a619bd0.xml	2019
Beverage Carton				
Paper waste on landfill	US: Paper waste on landfill, post-consumer ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b0635f05-8e3d-4af8-9f9b-32cf1f9b03d1.xml	2018
Paper waste for incineration	US: Paper waste in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/56658f48-f0a5-43ab-8ef7-fb59fa471be8.xml	2018
Product with recycled paper content	US: Kraftliner 2015 ts/FEFCO, by-products tall oil and turpentine (mass) - avoided burden ts <p-agg>	ts	Based on EU-28 dataset http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ac37d3c-caeb-4216-9f1d-c78c1b8c772b.xml	2018

Material	GaBi dataset	Source	Documentation	Reference year
Product with 100% recycled paper content	US: Testliner 2015 ts/FEFCO - for use in avoided burden Eol scenario cases ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e1f35758-557e-44de-8d73-28be3c87d43f.xml	2018
PET Bottle				
Plastic waste on landfill	US: Plastic waste on landfill, post-consumer ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/164a9e96-4707-4a75-acb0-38593e1c044e.xml	2018
PET for incineration	US: Polyethylene terephthalate (PET) in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/c0a8ea64-6ce8-46b1-8851-14c57e4a8d3a.xml	2018
PET for recycling	US: Recycling of polyethylene terephthalate (PET) plastic ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6adcbaef-dd80-41f6-857f-d47904f5a7a5.xml	2018
Glass Bottle				
Glass waste for landfill	US: Glass/inert on landfill ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/78796b81-3df2-443f-a3a0-7028f736e957.xml	2018
Glass waste for incineration	US: Glass/inert waste in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/983b5cc3-5a5f-46ff-bd45-f1fbc0872e17.xml	2018
Production of glass cullet	EU: Glass cullet, sorted ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ae26c0a4-c43c-4e55-9426-28402256e592.xml	2018
Glass cullet for recycling	EU: Production of container glass (100% cullet) ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/497a4b72-84bf-4ba0-84ef-cf5ed9fd2a5b.xml	2018
Aluminium Can				
Aluminum waste to landfill	EU: Inert matter (Aluminium) on landfill ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/2bb26c32-23c1-459d-929d-f07917830678.xml	2018
Aluminum waste to incineration	DE: Non-ferro metals, aluminium, more than 50µm in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/37d98fd2-cbf5-425d-ae1b-032118a99e7d.xml	2018
Aluminum waste for recycling	RNA: Aluminum scrap remelting and DC casting (100% UBC scrap) AA/ts <p-agg>	ts	Annex I:	2018

Material	GaBi dataset	Source	Documentation	Reference year
Aluminum ingot production	RNA: Primary Aluminum Ingot AA/ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/768dd9de-0553-4857-b3ed-a40e0b0f10ef.xml	2010

3.5. Region: Brazil

3.5.1. Overview product specifications

	Primary											Secondary		
Material	Container Volume	Container Weight (g)	DQI*	Cap material	DQI*	Cap Weight (g)	DQI*	Label	DQI*	Label Weight (g)	DQI*	Nesting	Kind of Packaging	Weight (g)
Carton	0.2L	8	L	HDPE	E	0.4**	L	direct print	-	n/a	-	27	corrugated board LDPE	60 10
	1L	32.00	L	HDPE	E	2.00	L	direct print	-	n/a	-	12	corrugated board	228
PET (C)	0.25L	16.00	M	PP	M	2.00	M	PP	E	0.22	M	18	LDPE	18
PET (NC)	0.51L	16.00	M	PP	M	2.00	M	PP	E	0.22	M	12	LDPE	16
PET (C)	0.6L	20.00	M	PP	M	2.00	M	PP	E	0.28	M	15	LDPE	24
PET (NC)	0.9L	28.00	M	HDPE	M	11.50	M	PP	E	0.01	M	6	LDPE	10
Glass	0.355L	206.00	M	tin-free steel	E	2.00	M	paper (met)	L	n/a	-	6 4X6	corrugated board LDPE	38 26
	0.6L	420.00	M	tin-free steel	E	2.00	M	paper	L	n/a	-	12	corrugated board	278
Alu can	12oz	10.66	M	aluminum	M	2.14	M	direct print	M	n/a	-	12	LDPE	21
	16oz	12.85	M	aluminum	M	2.14	M	direct print	M	n/a	-	12	LDPE	23
	24oz	19.85	M	aluminum	M	4.42	M	direct print	M	n/a	-	12	LDPE	19

*DQI Data Quality Index: M – Measured, E – Estimated, L – Literature, n/a – not applicable

** Straw instead of Cap

Table 3-25: Recycled content of considered packaging alternatives

Beverage container	Recycled content	Source
Aluminum can	78% can body, 78% can ends	Pers. Comm. with manufacturers
PET bottle	0%	Pers. Comm. with manufacturers
Glass bottle	45%	CEMPRE (2018)
Beverage carton	100% virgin aluminum foil, LPB and polyethylene film	ACE (Ifeu, 2011)

An evaluation of the data quality of this region can be found in Annex B:

3.5.2. Aluminum cans

Recycled content and modelling secondary inputs

As shown in Table 3-25, the aluminum cans have a very high recycled content of 78%. Modelling secondary inputs in the baseline scenario follows the substitution approach. In estimating the value of scrap, i.e. the burdens associated with the production of scrap aluminum, the impact of the re-melting process was subtracted from the impact of primary ingot production (see Figure D-0-2).

Background data

Brazilian background data have been applied wherever possible from the GaBi Databases 2019. As shown in Table 3-26, sheet manufacturing relies heavily on association data from the European Aluminum Association (EA) (European Aluminium Association, 2013)), that have been regionalized to Brazilian boundary conditions. Net material flows of aluminum can production are shown in Figure 3-7.

Foreground data

Can manufacturing was collected by the Brazilian representative of Ball from facilities in this region, for 12oz, 16oz and the 24oz cans. Two types of can ends are applied, one manufactured in Brazil and one in the US. For the US can ends, the can end manufacturing data in the US data collection has been scaled to the product mass provided by the Brazilian facilities. The model applied region-specific datasets wherever possible, as listed in Table 3-26 and Table 3-27, however most auxiliaries needed to be proxied using US, European or German boundary conditions (in this order of preference) from the GaBi Databases 2019. For an addition level of detail, Figure 3-7 (and Figure D-0-5) depicts a screenshot from the GaBi model of can making.

Transports

The transport of inbound sheets for the can body only require 665km truck transport, whereas can ends require 1,773km ship transport and 1,240km truck drive. In addition, one of the can ends are shipped from the US. For these can ends additional transports of 8,784km shipping and 500km truck were added. The outbound aluminum scrap is transported by truck to a recycling facility 1,476km away (due to lack of data, assumed the same as in the US).

End of life

At the End of Life, aluminum cans are collected at an almost perfect 97.3% for recycling (see Table 3-34).

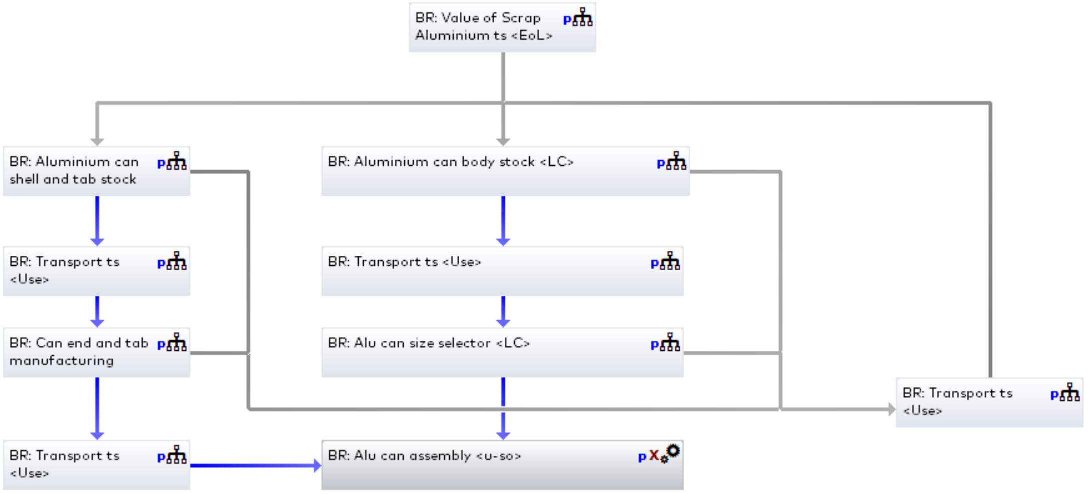

Figure 3-7: **Screenshot of the GaBi model of aluminum can manufacturing in BR.**

Table 3-26: Datasets used to model aluminum sheet production for can body and can end and tab stock in Brazil.

Material	GaBi dataset	Source	Documentation	Reference year
Primary Aluminum	RLA: Aluminium ingot mix IAI 2015	IAI/ts	Region Latin-America, (World Aluminium, 2017)	2015
Aluminum remelting	BR: Remelting & Casting of rolling scrap EAA 2010	EAA/ts	Boundary conditions set to BR; (European Aluminium Association, 2013)	2010
Aluminum sheet making	BR: Aluminium sheet [p-agg] EAA update 2010, excl. ingot ts	EAA/ts	Boundary conditions set to BR; EA2010 (European Aluminium Association, 2013)	2010
Magnesium	CN: Magnesium ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/47cff7c4-6816-4093-a8e4-6a690bde0613.xml	2018
Ferro-Manganese	ZA: Ferro-manganese, refined (Ref. FeMn)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d9a98a56-7065-4277-93cd-aca94a0bf186.xml	2018
Silicon	GLO: Silicon mix (99%) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b356811f-fba4-4faf-9a32-5bfc950b8beb.xml	2018
Zinc	DE: Zinc redistilled mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/19720938-1090-44ee-ad57-6d2be1320d67.xml	2018

Table 3-27: **Datasets used to model aluminum can manufacturing in Brazil. Included in this list are auxiliaries at least 0.5% of mass relative to product output mass.**

Material	Proxy	GaBi dataset	Source	Documentation	Reference year
Internal varnish	Epoxy resin	DE: Epoxy Resin (EP) Mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/50125a08-978e-4156-bcc0-2d13ec3b49c7.xml	2018

Material	Proxy	GaBi dataset	Source	Documentation	Reference year
Hydraulic oil	Lubricants	BR: Lubricants at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/10e9c2eb-cbc0-4848-9fe1-f3766927ed5b.xml	2016
Sulphuric acid		US: Sulphuric acid (75%) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/11b52f5a-5d35-45e0-9a71-3328f4c378ca.xml	2018
Tap water		US: Tap water from groundwater ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/dc952b0b-97ae-4539-aa07-bd4d76d8cfa9.xml	2018
Soluble oil	Paraffins	BR: Wax / Paraffins at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1b88db9c-7830-4b40-a7f8-2e18991586d3.xml	
Solvent/ Cleaning Agent		US: Isopropanol ts US: Aceton ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ba8ea668-ea63-4404-8a8b-3925d612a637.xml http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4792d8d7-092b-49a8-85ac-e6995b9039cd.xml	2018
External varnish	Polyester resin	DE: Polyester Resin unsaturated (UP) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b6801f51-3d8e-47d1-96bb-dbbea7b14e16.xml	2018

Table 3-28: Datasets used to model can end and tab manufacturing in Brazil.

Material	GaBi dataset	Source	Documentation	Reference year
Ammonia water	US: Ammonia water (weight share 25% NH3) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d953511f-619a-4871-9fcf-fe0e273b6f0b.xml	2018
Lubricant	EU: Lubricants at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/bdfac21c-7415-46af-acbc-8916cb95b9b8.xml	2016
Metal glue	EU: Metal Glue (Screw sealing) ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/e36ce59e-49dd-4b4a-8c3c-c206e4442170.xml	

3.5.3. PET bottles

Recycled content and modelling secondary inputs

As shown in Table 3-25, the recycled content of manufactured PET bottles has been modelled with 0%. No secondary inputs have been modelled.

Background data

Brazilian background data have been applied wherever possible from the GaBi Databases 2019. PET granulate has been generated based on the European dataset, exchanging energy carriers for better regional representation.

Foreground data

Product specific data has been collected via sample products (chapter 3.5.1). The model is depicted in chapter 3.2.2. Region-specific datasets are limited to sourcing water and energy carriers. All other datasets have been applied as in the US model (Table 3-17) using US, European or German boundary conditions (in this order of preference) from the GaBi Databases 2019.

Transports

No other transports than stated in chapter 3.2.5 have been applied due to lack of reliable data.

End of life

At the End of Life, PET bottles are collected at 59% for recycling (Table 3-23). Following the substitution approach credits were given wherever necessary.

3.5.4. Glass bottles

Recycled content and modelling secondary inputs

As shown in Table 3-25, the recycled content of manufactured container glass is 45%. Following the substitution approach, all secondary inputs have been treated as virgin material inputs.

Background data

Brazilian background data have been applied wherever possible from the GaBi Databases 2019. The container glass dataset based on European association data was adapted to Brazilian boundary conditions including the use of energy carriers as well as the source of the soda, i.e. the main background material for virgin production. Soda in Brazil is assumed to be produced primarily via synthetic pathways.

Foreground data

Product specific data has been collected via sample products (chapter 3.5.1). The model is depicted in chapter 3.2.3. Region-specific datasets are limited to sourcing water and energy carriers. All other datasets have been applied as in the US model (Table 3-29) using US, European or German boundary conditions (in this order of preference) from the GaBi Databases 2019.

Transports

No other transports than stated in chapter 3.2.5 have been applied due to lack of reliable data.

End of life

At the End of Life, glass bottles are collected at 47% for recycling (Table 3-23). Following the substitution approach credits were given wherever necessary.

Table 3-29: Datasets used for the manufacturing of glass bottles in BR.

Material	GaBi dataset	Source	Documentation	Reference year
Bottle: Container glass, virgin	BR: Container glass 100% virgin	ts	Regionalization of the EU dataset in-house by ts.	2018
Bottle: Container glass, recycled	BR: Container glass 45% recycled content	ts	Regionalization of the EU dataset in-house by ts.	2018
Label: Paper	BR: Kraftliner 2015 ts/FEFCO, by-products tall oil and turpentine (mass) - avoided burden	FEFCO/ts	Regionalization of the FEFCO dataset in-house, by ts.	2018
Value of scrap: paper	BR: Testliner 2015 ts/FEFCO - for use in avoided burden Eol scenario cases	FEFCO/ts	Regionalization of the FEFCO dataset in-house, by ts	2018
Closure: tinplated steel	US: Steel tinplated	worldsteel	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4b6095ea-22c3-4509-9a8c-b81297551db4.xml	2014
Ink	US: Inks (for can manufacturing)	ts	No online documentation available. GUID: {E2D3B395-DB2E-45E1-A9A6-AA3E21D62BE7}	2018

3.5.5. **Liquid beverage cartons**

Recycled content and modelling secondary inputs

As shown in Table 3-25, the recycled content of liquid beverage cartons is 0%.
No secondary inputs have been modelled.

Background data

Brazilian background data have been applied wherever possible from the GaBi Databases 2019. Most relevantly, forestry data supplying the virgin fibers for the main raw material LPB was adapted to the local forestry conditions and energy carriers.

Foreground data

Product specific data has been collected via sample products (chapter 3.5.1). The model is depicted in chapter 3.2.4. Region-specific datasets are applied wherever possible, as listed in Table 3-31, however most auxiliaries needed to be proxied using US, European or German boundary conditions (in this order of preference) from the GaBi Databases 2019.

Transports

Transports for the raw materials to manufacturing have been applied according to ifeu (2011). For liquid packaging board, 200km transport by truck, 400km transport by train and 1300km transport by ship has been assumed. For polymers, 200km transport by truck has been assumed. For aluminum foil, 250km transport by truck has been assumed.

End of life

At the End of Life, liquid beverage cartons are collected at 21% for recycling (Table 3-34). However, it is assumed that only the paper fraction of beverage cartons is recycled. Aluminum and Polyethylene fractions are assumed to be landfilled.

Table 3-30: Beverage carton composition in the BR carton datasets.

	Beverage carton fractions			
	Alu%	LDPE%	LPB%	DQI
0.2L	6.2	21.7	72.1	L
1L	6.4	22.3	71.3	L

Table 3-31: Datasets used in the manufacturing of cartons in BR.

Material	GaBi dataset	Source	Documentation	Reference year
Liquid packaging board	BR: Kraftliner	FEFCO	Regionalization of the FEFCO datasets in-house by ts	2010
LDPE granulate	US: Polyethylene Linear Low Density Granulate (LLDPE/PE-LLD)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1cab96fb-492d-436a-8f14-fd86df4f7843.xml	2018
Aluminum ingot	RLA: Aluminium ingot mix IAI	IAI/ts	Region Latin-America, (World Aluminium, 2017)	2015
Aluminum foil	EU: Aluminium foil (2010) <p-agg>	European Aluminium	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/86c4d1c5-19f9-4d43-9bff-0b88b714b93f.xml	2011
Printing ink	US: Polyacrylate ink (estimation)	ts	http://gabi-documentation-2020.gabi-software.com/xml-data/processes/90ea0337-8006-49cc-a441-55a2ab34153e.xml	2018
Natural gas	BR: Natural gas mix	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4186b579-4691-49b3-913a-572cd76337d0.xml	2016
Liquefied Petroleum Gas	BR: Liquefied Petroleum Gas (LPG) (70% propane, 30% butane)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/eff69ddc-2caa-4594-b1dd-2ffdb41589ef.xml	2016
Waste water	US: Municipal waste water treatment (mix)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/d0f0306e-74e2-448c-a602-3ad753749a1c.xml	2016
Waste for incineration	US: Municipal waste in waste incineration plant	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aa364db3-52ce-4bee-89eb-b86426753ec2.xml	2016
Waste for landfill	US: Commercial waste on landfill	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/62ef428a-183b-4448-9396-4d192d7c692a.xml	2018
Hazardous waste	GLO: Hazardous waste (non-specific) (C rich, worst case scenario incl. landfill)	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/64fe47f0-c90b-4e41-8e3e-a6eca3715879.xml	2016

3.5.6. Background data of energy and transports applicable for all products

All production processes in Brazil were modelled using the country-specific electricity grid mix and other energy provision datasets of the GaBi Databases 2019 listed in Table 3-32. One generic transport model is used to describe transport options across each product life cycle. The datasets used in this model are summarized in Table 3-33.

Table 3-32: Datasets used to model energy provision for products manufactured in Brazil.

Material	GaBi dataset	Source	Documentation	Reference year
Electricity	BR: Electricity grid mix ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ceb36eee-1612-4101-81a8-0fb8aeac9032.xml	2016
Thermal energy from natural gas	BR: Thermal energy from natural gas ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ba90481b-0584-43a1-a047-027a2f85e3b5.xml	2016
Thermal energy	US: Thermal energy from propane ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/9af2af7f-e514-4e25-b398-c7ab380493fe.xml	2016
Thermal energy	BR: thermal energy from LPG ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4555358d-71fb-45e8-a104-7d56b46d13c4.xml	2016
Steam credit	BR: Process steam from natural gas 95%	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/cb4e9740-3a29-47ee-aad4-9d3176877780.xml	2016

Table 3-33: Datasets used to model transport for products manufactured in Brazil.

Material	GaBi dataset	Source	Documentation	Reference year
Truck-trailer*	GLO: Truck-trailer, Euro 0 - 6 mix, 34 - 40t gross weight / 27t payload capacity	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4e47891c-25ca-4263-8ebd-e1b462c0f4b8.xml	2016
Rail*	GLO: Rail transport cargo - average, light train, gross tonne weight 500t / 363t payload capacity	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/0e18387f-9a65-4a6c-87d6-89404f330a10.xml	2016
Motor ship*	GLO: Motor ship, 1,500t payload capacity / upstream	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/7877b2c6-5772-4555-9806-327ab7ed3f37.xml	2016
Diesel	BR: Diesel mix at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ad6b878-05a4-4b8f-9a5d-92f762e80e32.xml	2016

*Proxy datasets are used for these processes in Brazil.

3.5.7. End-of-Life

For each product three possible end of life waste streams are available; recycling, incineration and landfill. The statistics for each of these recycling streams is sourced from CEMPRE (Cempre, 2018) (annex 3). The recycling yields reflect data from the GaBi databases. The table below summarizes this information.

Table 3-34: End of Life treatment of packaging alternatives in Brazil.

	EoL stream	Collection %	Yield %	Source
Aluminum can	Recycling	97.3	99	CEMPRE
	Incineration	0		
	Landfill	2.2		
PET bottle	Recycling	59	86	
	Incineration	0		
	Landfill	41		
Glass bottle	Recycling	47	97	
	Incineration	0		
	Landfill	53		
	Reuse	0 – 20 reuses		Scenario only
Beverage cartons	Recycling	21	92	CEMPRE
	Incineration	0		
	Landfill	79		

Transport distances to End of Life processing facilities are neglected, as these are expected to be within 100km radius of the disposal site by the end consumer.

The end of life waste streams are split using consistent calculations for all products. Where material or energy is recovered from end of life processes, fixed material credits are applied to compensate the burdens created by the product life cycles. Table 3-35 summarizes the GaBi datasets used commonly across all end of life plans modelled.

Table 3-35: Datasets used to model end of life processes for products manufactured in the US.

Material	GaBi dataset	Source	Documentation	Reference year
Waste to disposal	EOL: Waste to disposal (e.g. landfill, energy recovery) ts <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/8dd8163b-4ea3-4632-ac74-324cc818cecd.xml	2016
Waste for recycling	EOL: Waste to be recycled ts <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/fb9a6418-6716-4ce4-ba0d-0d226e296702.xml	2016
End of life selection	GLO: Multi-functionality in End-of-Life Situations (PEF circular footprint formula, End-of-Life) PEF guide <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/dbb118f3-a233-4143-8757-373ec8d520c8.xml	2013

Material	GaBi dataset	Source	Documentation	Reference year
Correction for downcycling	GLO: Correction for downcycling (PEF guide, Annex V) <u-so>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/627b42d2-7ce1-47b3-9521-bddc8a619bd0.xml	2016
Beverage carton				
Paper waste on landfill	US: Paper waste on landfill, post-consumer ts <p-agg	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/b0635f05-8e3d-4af8-9f9b-32cf1f9b03d1.xml	2016
Paper waste for incineration	US: Paper waste in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/56658f48-f0a5-43ab-8ef7-fb59fa471be8.xml	2016
Product with recycled paper content	BR: Kraftliner 2015 ts/FEFCO, by-products tall oil and turpentine (mass) - avoided burden ts <p-agg>	ts	Regionalization of the FEFCO datasets in-house by ts	2015
PET bottle				
Product with 100% recycled paper content	BR: Testliner 2015 ts/FEFCO - for use in avoided burden Eol scenario cases ts <p-agg>	ts	Regionalization of the FEFCO datasets in-house by ts	2015
Plastic waste on landfill	US: Plastic waste on landfill, post-consumer ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/164a9e96-4707-4a75-acb0-38593e1c044e.xml	2016
PET for incineration	US: Polyethylene terephthalate (PET) in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/c0a8ea64-6ce8-46b1-8851-14c57e4a8d3a.xml	2016
PET for recycling	US: Recycling of polyethylene terephthalate (PET) plastic ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6adcbaef-dd80-41f6-857f-d47904f5a7a5.xml	2016
Glass bottle				
Glass waste for landfill	US: Glass/inert on landfill ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/78796b81-3df2-443f-a3a0-7028f736e957.xml	2016
Glass waste for incineration	US: Glass/inert waste in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/983b5cc3-5a5f-46ff-bd45-f1fbc0872e17.xml	2016
Production of glass cullet	EU: Glass cullet, sorted ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/ae26c0a4-c43c-4e55-9426-28402256e592.xml	2016
Glass cullet for recycling	EU: Production of container glass (100% cullet) ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/497a4b72-84bf-4ba0-84ef-cf5ed9fd2a5b.xml	2016
Aluminum can				
Aluminum waste to landfill	EU: Inert matter (Aluminium) on landfill ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/2bb26c32-23c1-459d-929d-f07917830678.xml	2016

Material	GaBi dataset	Source	Documentation	Reference year
Aluminum waste to incineration	DE: Non-ferro metals, aluminium, more than 50µm in waste incineration plant ts <p-agg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/37d98fd2-cbf5-425d-ae1b-032118a99e7d.xml	2016
Aluminum waste for recycling	BR: Remelting & Casting of rolling scrap EAA 2010 ts <Mfg>	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/a9aa87f8-2daa-4634-83a4-51659ebfb3d5.xml	2016
Aluminum ingot production	RNA: Primary Aluminum Ingot AA/ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/768dd9de-0553-4857-b3ed-a40e0b0f10ef.xml	2016

3.6. 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”. The complete inventory is included in the Annex C: Life Cycle Inventory.

4. Life Cycle Impact Assessment: EU

This chapter contains the description of results for the impact categories and additional metrics selected in section 2.6. The full set of assessed indicators are provided in Annex F: Extended LCIA Results. 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.

The LCIA results include contribution analyses, which split the results according to the following life cycle stages: manufacturing, secondary packaging, transport to filling, distribution and end of life. This enables the reader to understand the influence of each life cycle stage on the overall environmental performance of the product.

In order to account for potential variability within the foreseeable future as well as for uncertainties in a few parameter values and methodological choices, scenarios and sensitivity analyses are provided in sections 4.4 and 4.5.

4.1. Overall Results

4.1.1. Acidification terrestrial and freshwater

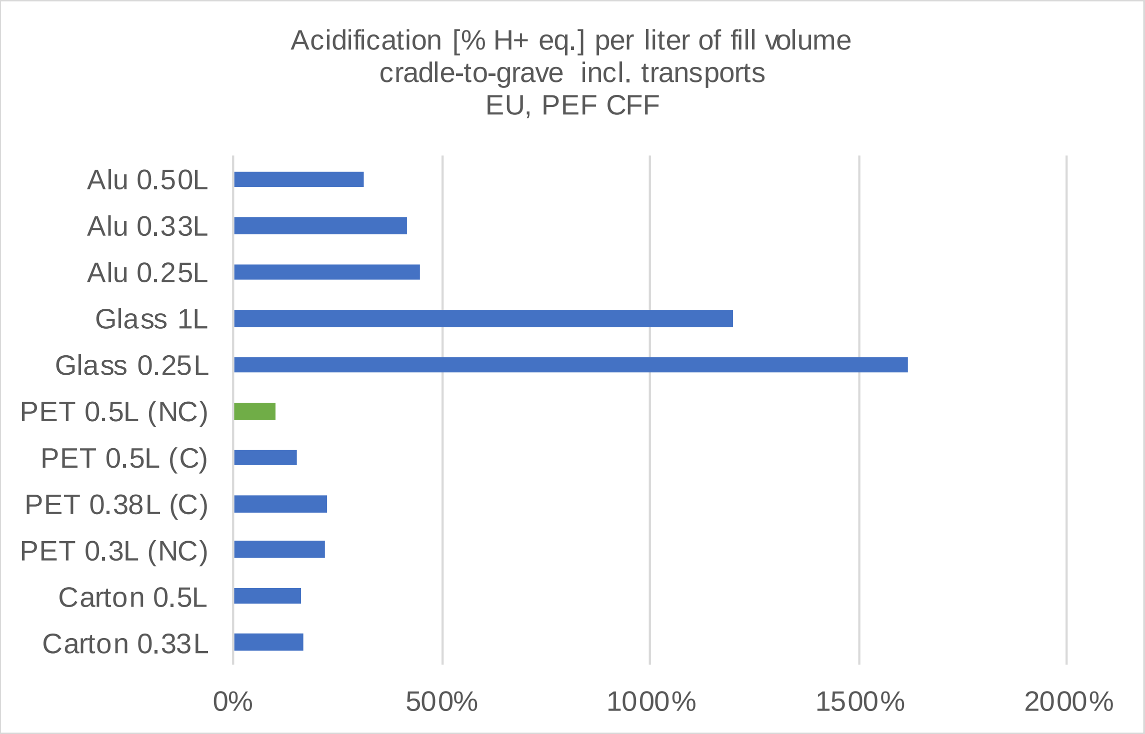

Figure 4-1: **Relative acidification results of each of the compared products, using the PEF CFF method**

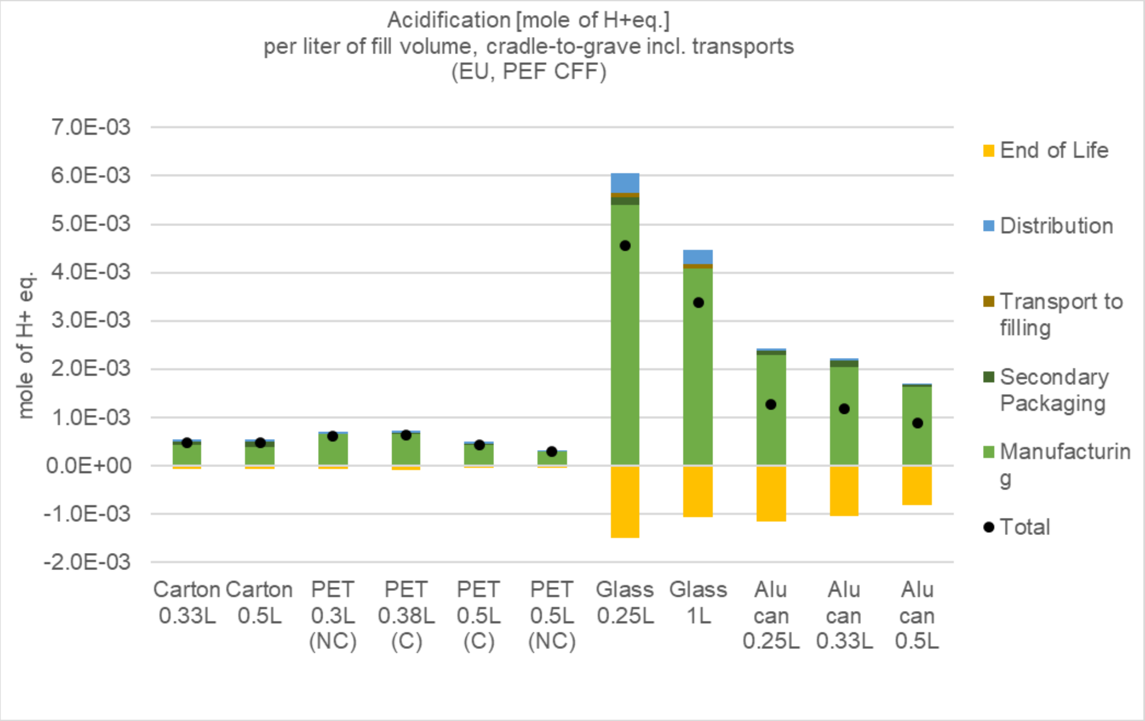

Figure 4-2: **Absolute acidification results of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method**

Acidification of soils and waters mainly occurs through the conversion of air pollutants like SO_2, NO_2 into acids such as H_2SO_4 and HNO_3. These acids can cause ecosystem nutrient imbalances, increase the solubility of metals into soils and corrode calcium carbonate rocks like limestone. The air pollutants are commonly associated with the combustion of fossil fuels when generating electricity or during transport. Accordingly, most acidification impacts are derived from manufacturing processes for the packaging formats.

The overall best performer is the 0.5L PET bottle for non-carbonated water. Because other non-carbonated drinks such as juices, teas or energy drinks come in heavier PET bottles compared to still water, beverage cartons as one material option for non-carbonated beverages perform well more consistently.

PET bottles derive more than 55% of impact from SO_2 emissions, highlighting their fossil origin and reliance largely on fossil fuels. Yet, the low weight of the thin-walled PET 0.5L (NC) water bottle becomes the more relevant factor for these results. Beverage cartons release equal amounts of NO_x and SO_2 emissions, and the acidification impact is mainly associated with the manufacturing stage. Beverage cartons have a low overall acidification impact, mainly because the energy used in manufacturing is generated internally from black liquor and other by-products of pulping virgin fibers, instead of relying on the EU-28 electricity grid mix. The grid mix is largely supplied by fossil fuels which generate large quantities of SO_2 emissions.

Most PET bottles come in second place due to their lower production-phase energy consumption as compared to aluminum cans. Aluminum cans produce almost twice as many SO_2 emissions as they do NO_x emissions, indicating a significant driver of their respective contributions to acidification is derived from reliance on fossil-based electricity sources.

The glass bottles have the highest contribution to acidification because of process-specific emissions of SO_2 related to glass melting and conditioning. Glass manufacturing is also highly energy-intensive and relies on electricity derived from fossil fuels.

4.1.2. Eutrophication freshwater

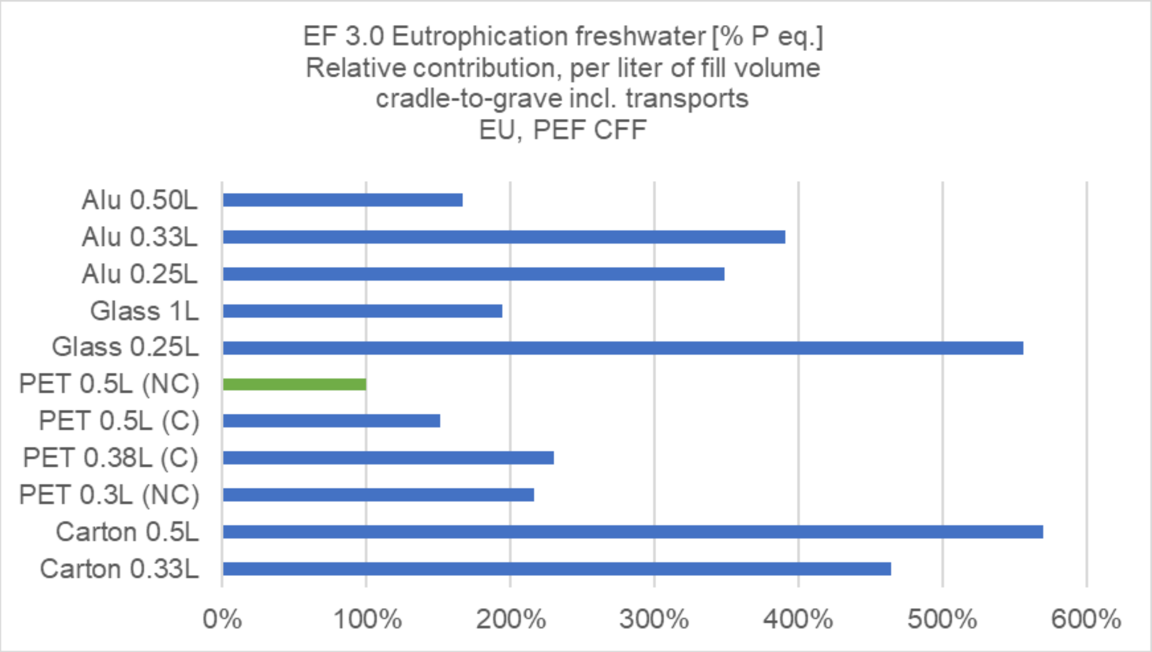

Figure 4-3: Relative freshwater eutrophication results of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method

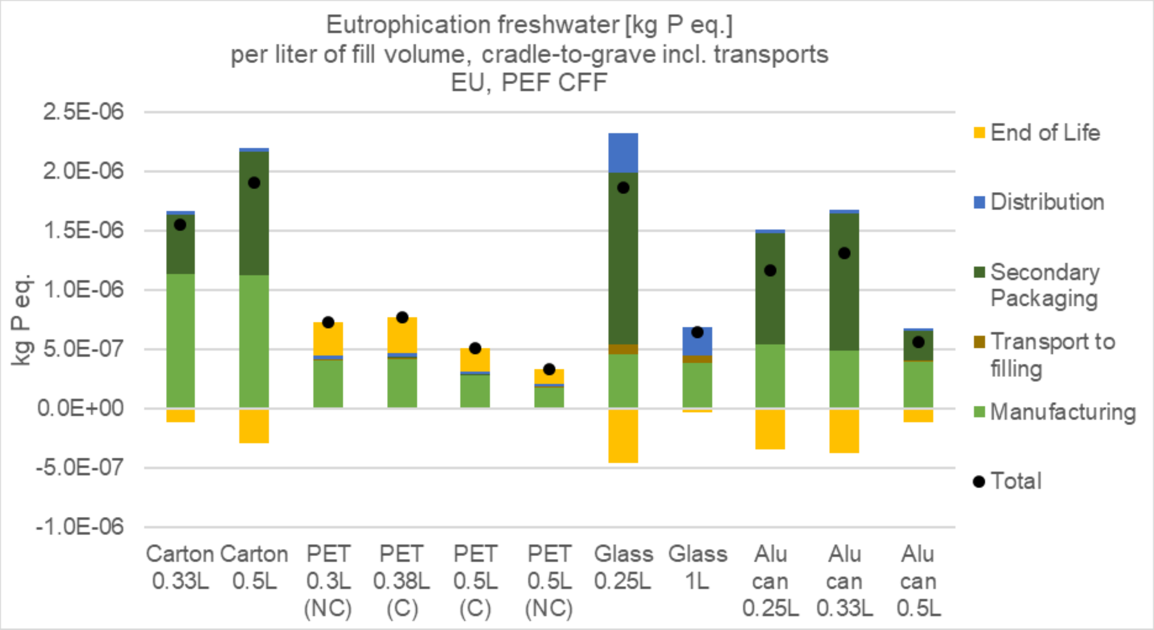

Figure 4-4: Absolute freshwater eutrophication results of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method

Freshwater eutrophication is driven by phosphate emissions, as this is usually the limiting nutrient in freshwater ecosystems. These emissions commonly reach fresh water supplies by leaching into ground water or as direct run-off from agriculture (due to fertilizer use) and can unbalance ecosystems causing algal blooms and fish kills. In this study, phosphate emissions account for just under 90% of the impacts, whereas phosphorus flows total over 10% (~2% to soil and 9% to water).

Products that are in part made of agriculture-derived products, such as beverage cartons and corrugated board in secondary packaging, have the greatest impacts on freshwater eutrophication.

The overall results show the life cycle of the PET bottles has the lowest impact in this category due to relatively little reliance on water during the manufacturing phase and virtually no contribution from the plastic-based secondary packaging. This is because they do not rely on corrugated board material for secondary packaging and use LDPE film instead.

PET bottles are followed by the 0.5L aluminum can, and the 1L glass bottle. Both representative products used in this LCA study, also used little to no corrugated board for secondary packaging.

The results for aluminum cans and PET and glass bottles demonstrate the relevance of packaging volumes, as large containers with a bigger fill volumes demonstrate a better environmental performance per liter compared to smaller fill volumes. This is because the products with a greater fill volume require less material overall for manufacturing and less secondary packaging to provide 1 liter of beverage contents.

4.1.1 Climate change

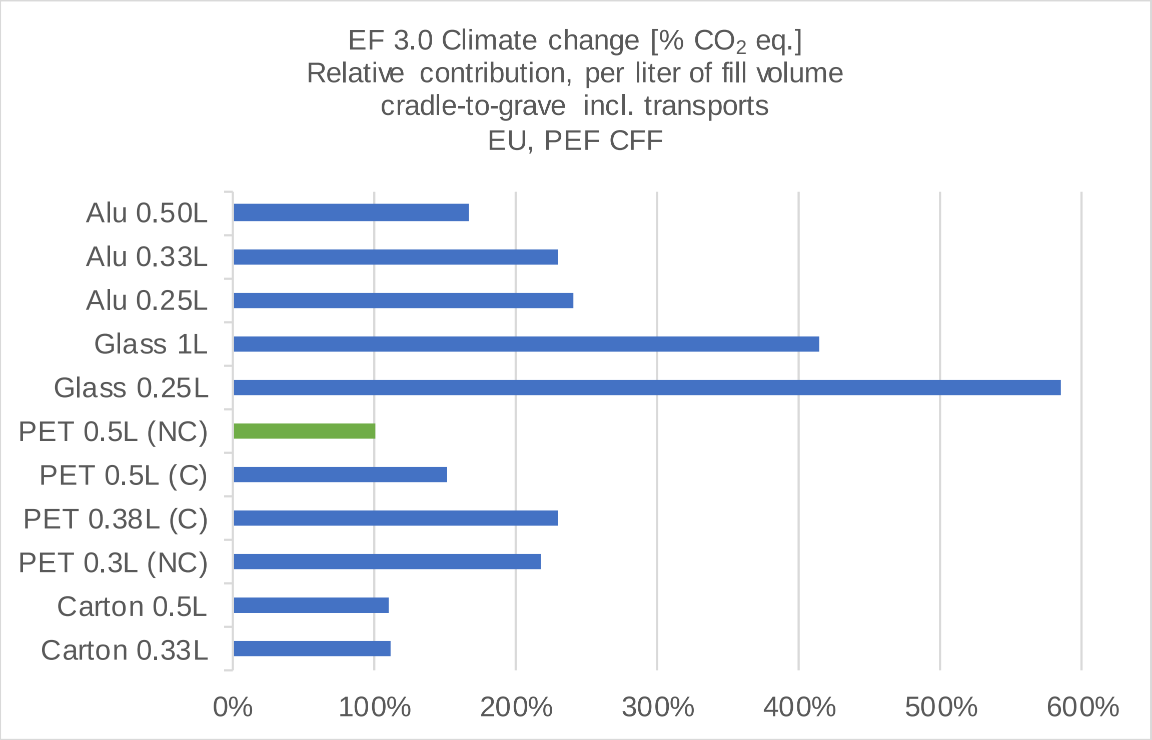

Figure 4-5: **Relative climate change results of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method**

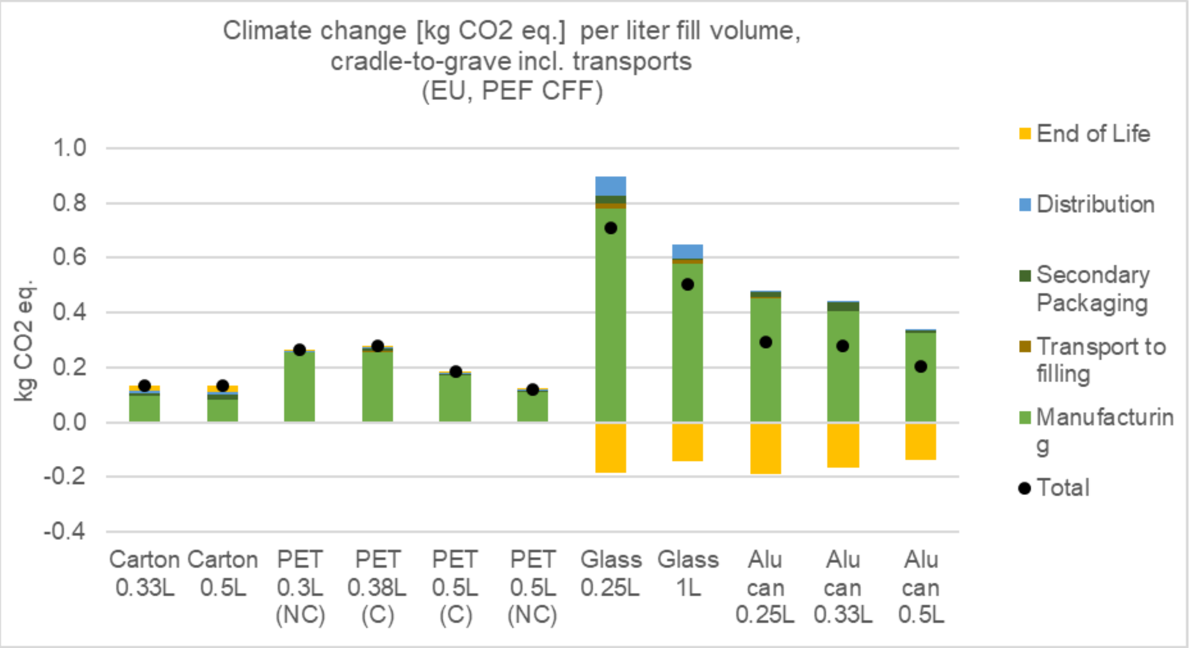

Figure 4-6: **Absolute climate change results of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method**

Climate change is driven by greenhouse gases like CO_2 and CH_4 in the troposphere which trap infrared radiation from and redirect it back towards the Earth's surface. This radically alters the conditions at the Earth's surface and may cause warming or cooling effects which have the potential to alter the Earth's climates. Greenhouse gases are mainly associated with the combustion of fossil fuels which are used in energy generation and manufacturing of fossil-based materials like plastic.

These results demonstrate the importance of packaging efficiency, as containers with bigger fill volumes demonstrate a better environmental performance per liter of beverage than smaller containers. This is because the packaging types with greater fill volume require less material overall for manufacturing and secondary packaging to provide 1 liter of beverage.

Although the 0.5L PET bottle for non-carbonated water has the lowest carbon footprint, due to its very thin walls and consequently low weight, PET bottles for carbonated beverages come with significantly higher carbon emissions. Therefore, beverage cartons show a more consistently low climate change impact, benefitting from the fact that approximately 75% of their mass is composed of virgin paperboard. This is a bio-based material whose side products can be used as a biofuel and provide energy for the pulp and papermaking processes (from bark, forestry off cuts, wood chips, black liquor, etc.). Biogenic carbon dioxide is sequestered during the growth of the trees providing these bio-materials, and is later re-emitted at the end of life which results in a zero overall net emission of greenhouse gases (GHG). The lack of GHG emissions associated with these biomass materials significantly reduces the overall carbon footprint of beverage cartons.

In comparison, PET bottles (except for the above mentioned PET 0.5L bottle for non-carbonated water) have a higher environmental burden associated with their manufacturing stage because they are produced from fossil-based resources, and mainly fossil-fuel derived energy is used during production.

Aluminum cans also have a relatively high impact associated with manufacturing, but this is partly offset at the end of life due to the fact that recycling aluminum saves 95% of the energy compared to the production of virgin aluminum – and because cans have a higher recycling rate compared with other substrates.

Both single use glass bottles show a significantly higher climate change impact than aluminum cans, PET bottles and beverage cartons. This is not surprising given that glass bottle production is very energy intensive and glass bottles are 10x heavier than PET bottles, 15x heavier than beverage cartons and 20x heavier than aluminum cans.

4.1.3. Resource use: elements, minerals and metals

The EF 3.0 impact category for abiotic resource depletion only allows the characterization of single substance flows from the background data of GaBi datasets (e.g. sodium or chlorine), whereas in accordance with ILCD rules, GaBi datasets have many substances in their flow lists, which are thus not characterized in the EF 3.0 impact category. Therefore, to allow a better overview of the consumption of compound molecules such as sodium chloride, the CML Jan 2001 – 2016 Abiotic Depletion Potential impact category is shown for reasons of completeness as a substitute methodology to describe global resource scarcity.

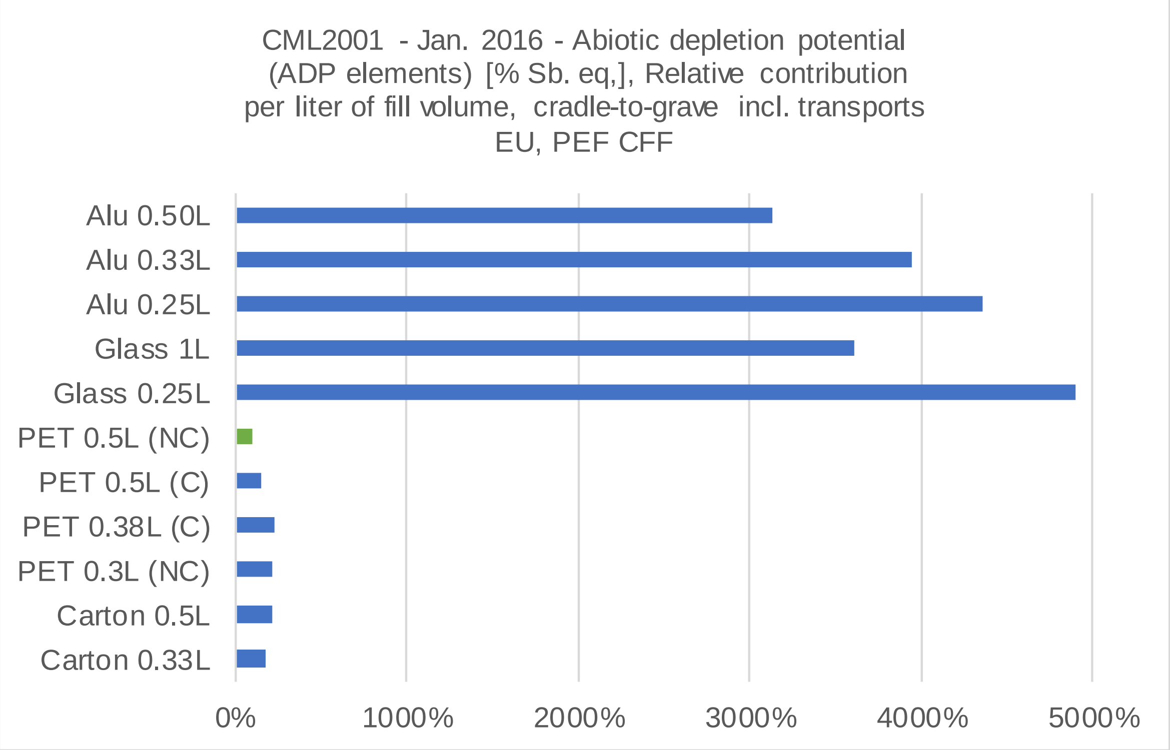

Figure 4-7: The Abiotic depletion potential (elements, CML2001 – Jan. 2016) of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method

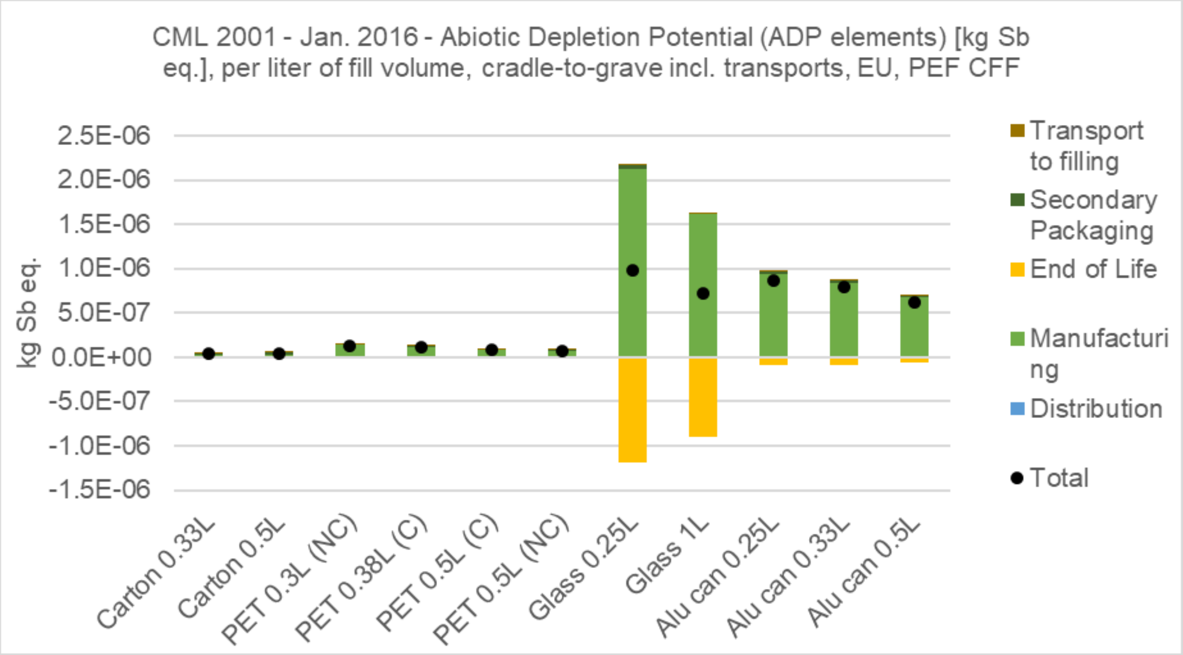

Figure 4-8: Absolute abiotic depletion potential (ADP elements) results of each of the compared products, scaled to 1 liter of fill volume, using the PEF CFF method

The results show that glass bottles and aluminum cans have high impacts on abiotic depletion potential (ADP), while the ADP for PET bottles and beverage cartons is relatively small.

Aluminum is the fourth most abundant element in the Earth's crust. Similarly, the three dominant materials used to manufacture glass bottles – sand, soda and limestone – are also in abundance and not considered a scarce resource. This impact category fails to duly credit the fact that these minerals are not lost or transformed to an unusable format, and their mere extraction is considered as a contribution. For these reasons, the results for ADP should be understood only as an indicator for the demand of abiotic resources.

4.2. Detailed Results – Climate change impact of the aluminum can

In order to understand the hotspots of the 0.25L aluminum can life cycle, a contribution analysis was done for contributing gases shown in Table 4-1. The numbers demonstrate that close to 90% of climate change impact derives from carbon dioxide emissions, while another ca. 8% derives from methane from biotic and abiotic sources, a common distribution for industrial goods. Of significance is the emission of tetrafluoromethane, a common refrigerant gas – without an ozone depletion potential – which is created during the primary aluminum smelting process.

Table 4-1: Contribution analysis – climate change of the 0.25L aluminum can life cycle

Emissions contributing to Climate change	% contribution
Carbon dioxide	88.5
Nitrous oxide (laughing gas)	0.5
Tetrafluoromethane	2.6
Methane	6.9
Methane (biotic)	1.3
Total	**99.8**

In order to gain further insights into hotspots, aluminum can manufacturing was further broken down into the sub-processes shown in Figure 4-9.

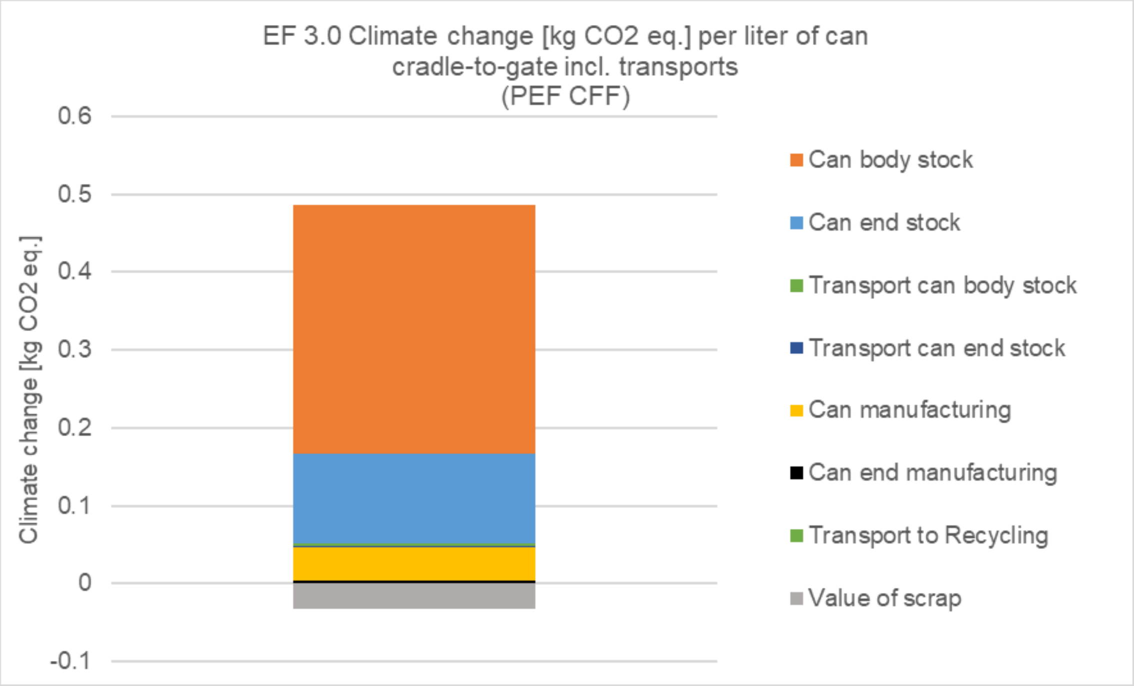

Figure 4-9: Detailed climate change contributions in the manufacturing phase of the 0.25L aluminum can, shown per liter of fill volume, using the PEF CFF method.

The detailed results show the aluminum and can sheet production, captured as "can body stock," contributes to more than 60% of the total impact. Most of the impacts for this process are derived from manufacturing the primary aluminum ingot and rolling the aluminum sheet.

20% of the climate change impact stem from "'can end stock," of which 97% of emissions come from the manufacturing of primary aluminum ingot and rolling the aluminum sheet. While can ends tend to be less than 1/5th of the total can weight, they still represent a significant contribution to the can's overall carbon footprint because it comes with a lower recycled content compared to the can body (see Annex C of the PEF guidance).

'Can manufacturing' contributes 38% to overall climate change impact. This is almost entirely derived from the electricity and thermal energy consumed during these steps. With average European electricity grid mix, energy is largely derived from fossil fuels.

The "value of scrap" aspect refers to the benefits or 'credits' assigned to the scrap material which is recycled and re-used as secondary materials. The aluminum can body stock has a relatively high recycled content, and high recycling rate at end of life. For this reason, environmental credits reduce the overall climate change impact.

4.3. Material Circularity Indicator (MCI) Results

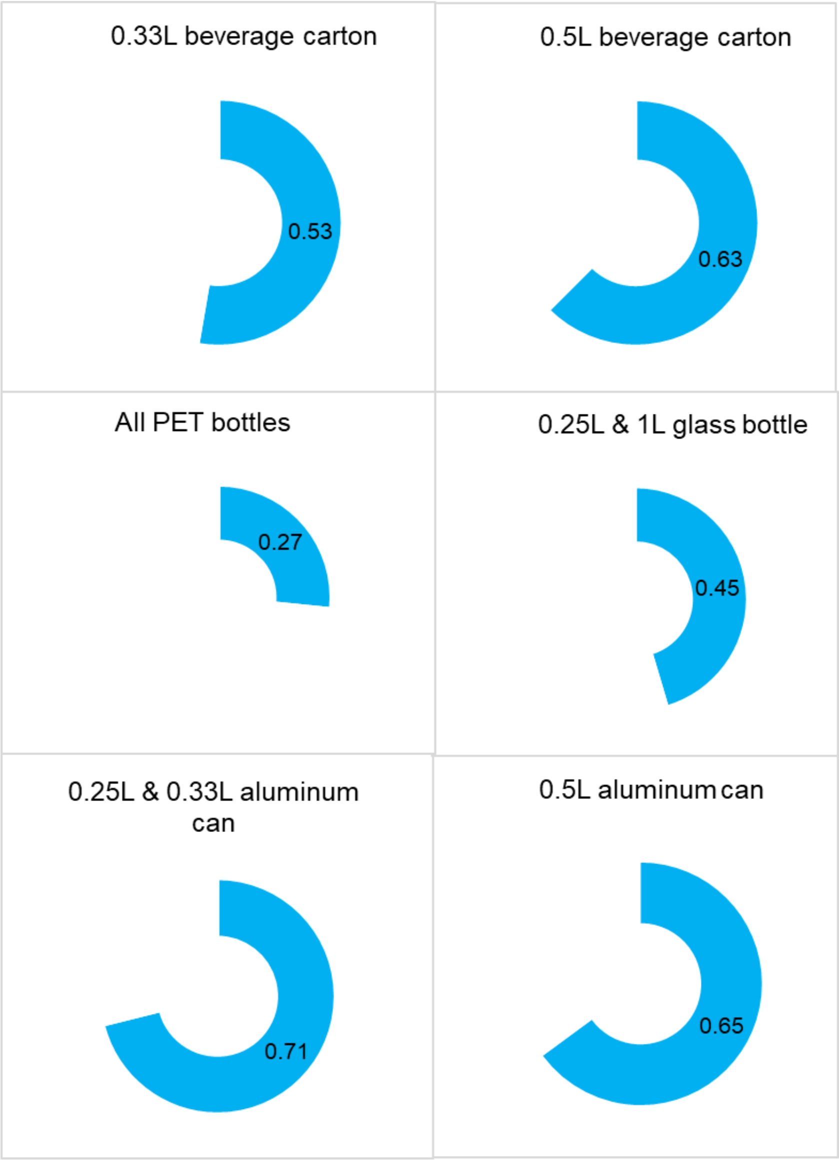

Figure 4-10: **Material Circularity Indicator results for the different packaging options (EU)**

Figure 4-10 shows the results for the material circularity indicator for each of the packaging formats assessed in this study for the EU countries. A score of 1 indicates a completely circular product, and a score of 0.1 indicates a completely linear product. This means that conversely to all previous environmental impact charts, a higher MCI bar indicates a better material circularity performance.

Three main aspects of the product’s life cycle influence the MCI score:

- Proportion of input material flows that are from reused or recycled sources, or from sustainably sourced biological material (e.g. FSC-certified paper)
- Proportion of waste flows that are reused or recycled at end of life

- Product utility measured as the number of reuse cycles compared to the average situation (single use).

Aluminum cans have relatively high MCI scores of ~0.7, which reflects the highest average recycled content (55% of can stock, 3% of end and tab stock) and end of life recycling rate (69%) of all beverage packaging materials. The 0.5L cans have a slightly lower MCI score because the cans chosen for this study came with slightly heavier PE film as secondary packaging.

Beverage cartons have an intermediate MCI score of 0.5-0.6. The cartons have a lower collection rate of 43%, and only the paper fractions are assumed to be recycled. However, the cartons are ~70% paperboard which has 0% recycled content but is assumed to be sustainably sourced and therefore considered completely restorative by the MCI methodology. This greatly benefits their MCI score. The 0.5L carton has a higher MCI score because it requires a greater quantity of cardboard secondary packaging. The secondary packaging used is also assumed to be sustainably sourced and comes with a high recycling rate. Conversely to the basic principles of LCAs, material efficiency considerations and waste treatment, the use of additional material in this case is rewarded in the MCI score, purely because of its renewable origins. Provided that the carton in the primary packaging is not sourced sustainably, the MCI would sink considerably (see note in section 6.3). It is not a matter of this report to discuss this methodological principle, but the authors advise the use of caution when interpreting MCI values and making decisions without additional considerations.

The PET bottles have the lowest MCI score (below 0.3). This reflects the 0% recycled content or re-use. The MCI scores are driven mainly by the relatively low recycling rate at end of life of 42%.

4.4. Scenarios

4.4.1. Scenario: Recycling methodology

As discussed in section 2.4, the baseline results reported in this study for the EU region, use the PEF CFF formula to account for the treatment of secondary materials as well as for the End of Life. This approach is a market-defined mix between the more classical cut-off and substitution approaches. An allocation factor *A* assigns each material and application a share between the two approaches individually, based on the market’s supply and demand of its recyclate. Additionally, a quality indicator provides a value for the recyclate relative to the virgin material.

In order to assess how the choice of this methodology affects the results, an alternative scenario using the substitution approach has been set up, giving credits at the EoL and calculating a value of scrap for recycled content on the input side. For both approaches, the inputs and outputs are treated equivalently. If a product receives the same amount of recycled input as it generates at end of life, both methodologies will yield identical results – when this balance is lost, the results may diverge.

This section presents and contrasts the results of each methodological approach to examine how they influence the study outcomes. The climate change impact category for the PEF CFF and the substitution methodologies is summarized in Figure 4-11. The cradle-to-grave results of an aluminum can are explored in a constitution analysis in Figure 4-12.

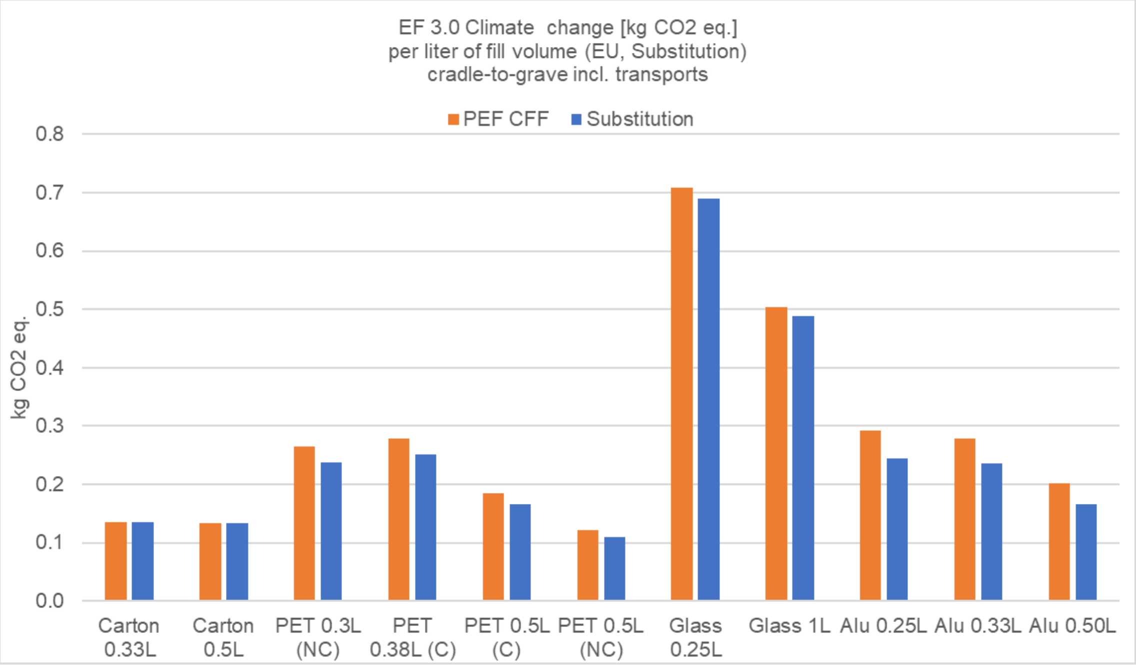

Figure 4-11: Climate change impact results of each of the compared products, scaled to 1 liter of fill volume, using the substitution and the PEF CFF methods.

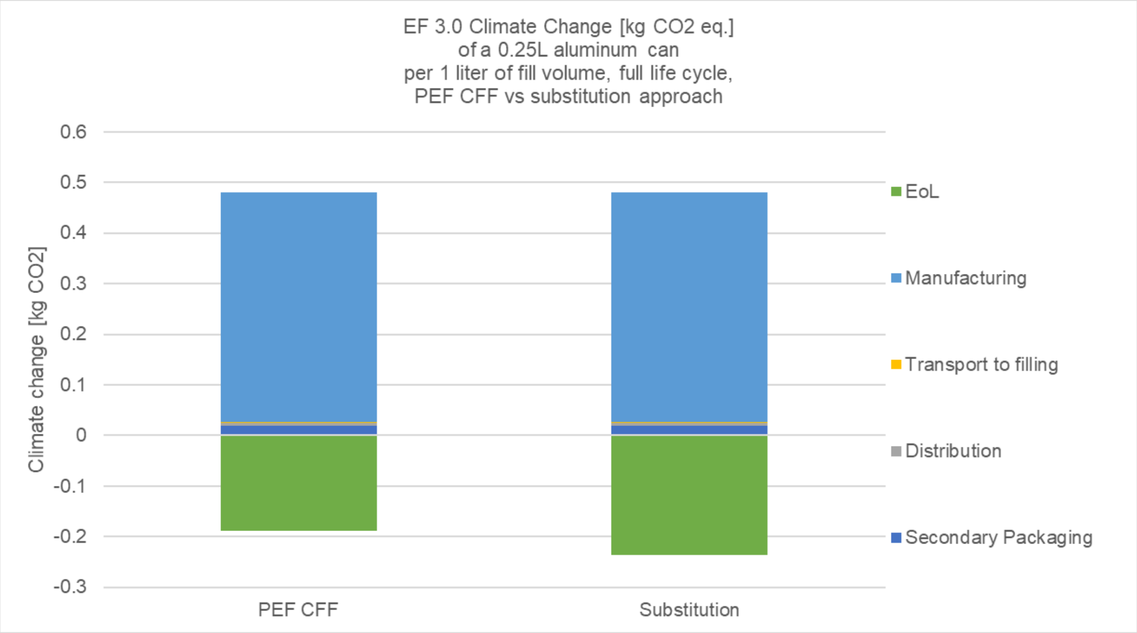

Figure 4-12: Climate change impact results of a 0.25L aluminum can scaled to 1 liter of fill volume, over its entire life cycle, using the substitution and the PEF CFF methods.

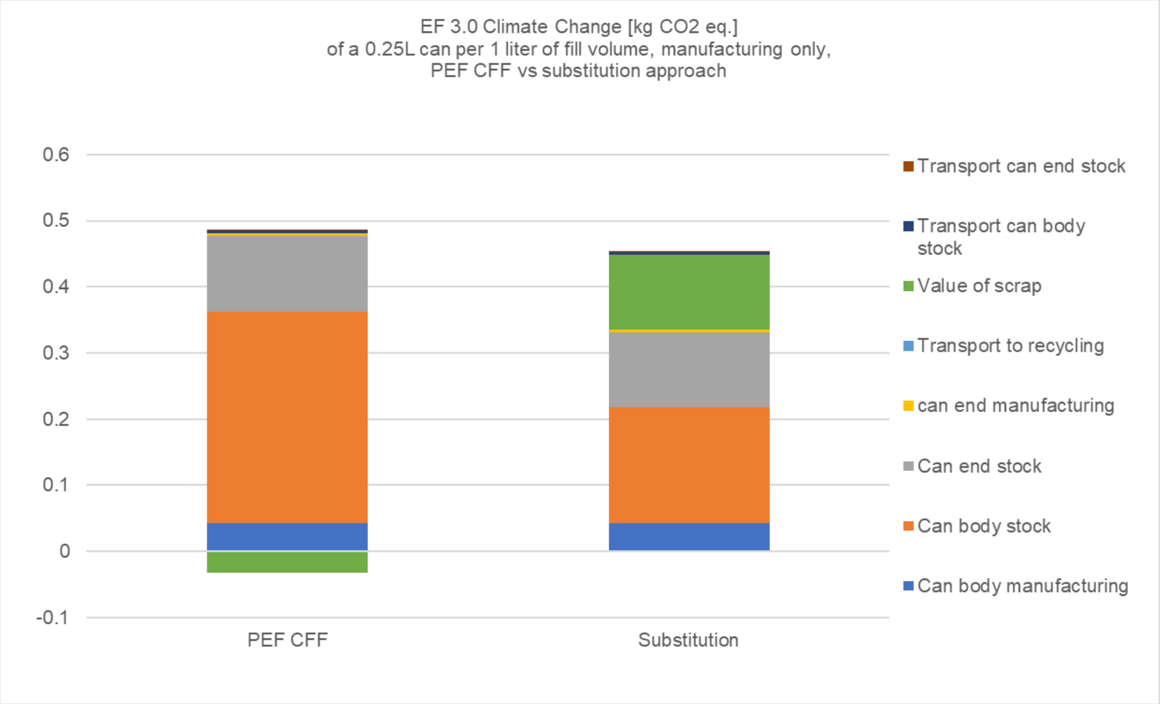

Figure 4-13: Climate change impact results of the 0.25L aluminum cans, scaled to 1 liter of fill volume, cradle to gate, using the substitution and the PEF CFF method.

While the overall picture seems to be rather stable throughout the product range, it is clear that aluminum cans are most impacted by the choice of method. The alternative substitution approach would enable a decrease of about 17% for aluminum cans due to the differentiation of scrap inputs into secondary input "as primary" and "as secondary", at fixed ratios of 0.8 and 0.2, respectively. Using the substitution approach, secondary input was – by contrast – always quantified using the value of scrap dataset for aluminum (primary ingot – recycling).

As shown in Figure 4-12, the main difference in outcomes stems from the End of life credits. These are given using the same 0.8 as primary, 0.2 as secondary principle that applies for the inputs too. These modify the final recycling quota from a 69% collected for recycling down to just above 56% allowed to go into the recycling stream. This results in visibly different results when compared with 69% collected and then recycled at 98% efficiency using the substitution approach.

Figure 4-13 shows the distribution of impacts within manufacturing. While the total impact is quite similar, the distribution is quite different from what was shown in Figure 4-12.

- Value of scrap is a positive figure (unlike a credit in the PEF CFF method, this quantifies the impact of the secondary (scrap) aluminum inputs;
- Can body stock has a distinctly lower impact due to the lack of "secondary input as primary ingot"; here, only the 45% of primary ingot and the sheet making processes are included;
- Can end stock and can manufacturing are largely unchanged.

4.4.2. Scenario: Renewable energy for manufacturing

As Ball Corporation is in the process of finalizing several renewable energy deals which may enable the entirety of their European manufacturing operations to be supplied with a combination of renewable energy mixes, an additional (future) scenario was calculated for 100% wind-energy-powered can manufacturing in Europe. As a result of this transformation, the climate change impacts are expected to be reduced by 9-10%, as shown in Figure 4-14. Although an important move to lower the beverage can’s carbon footprint, emissions from aluminum production are a bigger hotspots in the can’s life cycle compared to can manufacturing.

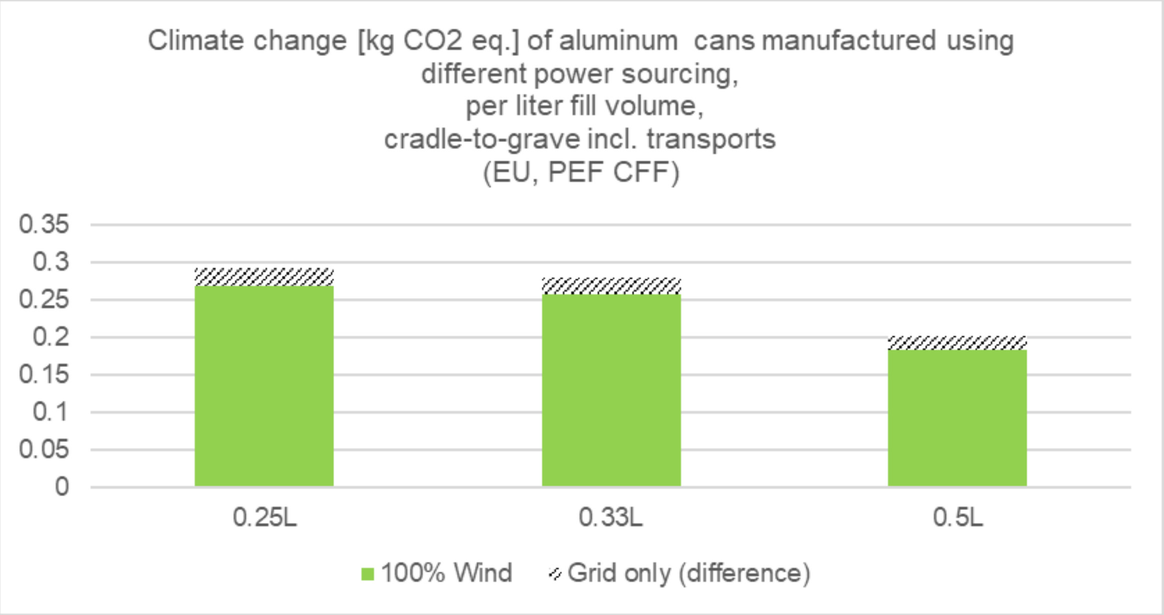

Figure 4-14: **Climate change impact results of each of the compared products, scaled to 1 liter of fill volume, using the substitution and the PEF CFF method.**

4.5. Sensitivity Analyses

In the following sections we explore the sensitivity of the results to parameters whose variation was expected to make significant differences to the outcomes. Parameters were shortlisted based on uncertainty due to data quality and the authors’ expert judgment on relevance to the results.

4.5.1. Sensitivity to PET weight

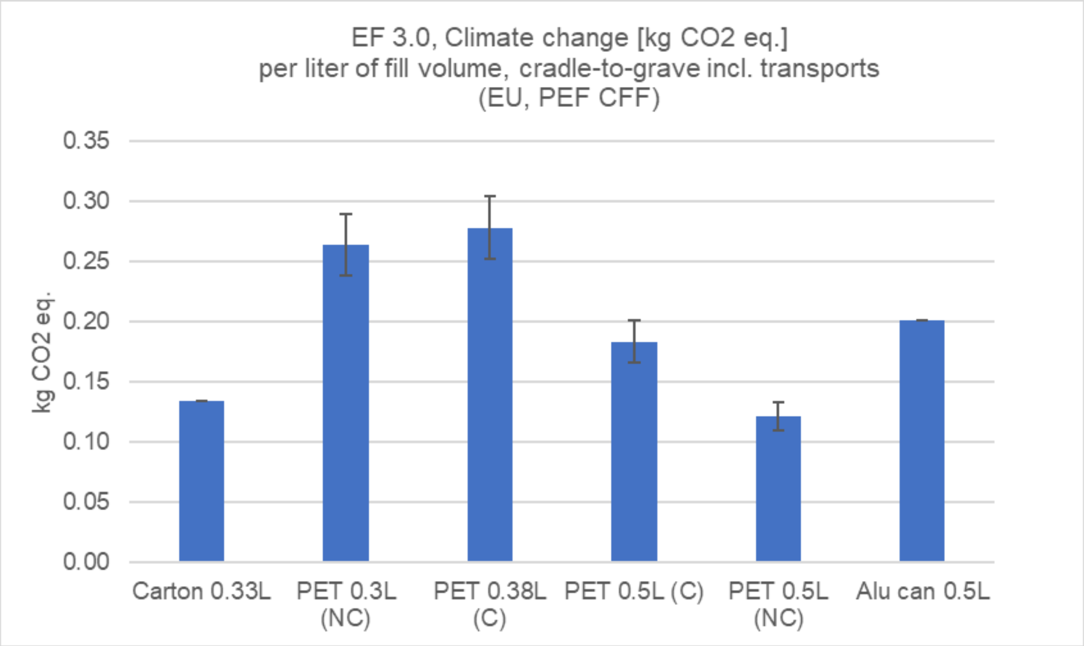

Figure 4-15: Climate change contributions of the life cycle of PET bottles with ±10% variable weight, compared against the baseline climate change contributions of the 0.5L aluminum can and 0.33L beverage carton for reference. Shown per liter of fill volume, using the PEF CFF method.

This sensitivity analysis evaluates the effect of changing the PET bottle weight by ±10% on the overall climate change impact of each product. Among the product selection there was one particularly light-weight product, the PET 0.5L (NC) bottle for water, which had a considerably lower weight than the PET 0.3L (NC) bottle (for juice). Since there are multiple considerations in defining product design, it was deemed important to include these weight variations in the analysis. Figure 4-15 compares the climate change impact of the PET bottles with ±10% variable weight against the baseline climate change impacts of the 0.33L beverage carton and 0.5L aluminum can.. The results are shown through error bars as variation around the climate change impact for each product with its baseline collection rate.

The results show that ±10% weight changes in the PET bottles have the potential to improve/increase the climate change impact of the products, by 9-10%. This is because the PET granulate derived from fossil fuels represents close to 70% of the life cycle impacts.

Overall, weight changes in the PET bottles by up to 10% do not change the rank order for the material as a whole but it can elevate or demote individual bottle designs. This sensitivity analysis suggests it may be more beneficial to focus on improving the 0% recycled content and 42% recycling rate of the PET bottles to significantly improve the climate change impact of these packaging formats (see next section).

It should be noted that weight optimization also influence and improve the performance of other packaging formats. As can be seen in the weight sensitivity analysis performed for US packaging alternatives in Chapter 5.5.1, it is expected that by reducing product weight by up to 10%, the aluminum cans will be affected by ±8%, the glass bottles by ±8-9% and the beverage cartons by ±5-7%.

4.5.2. Sensitivity to recycling rates 0-100% (substitution method)

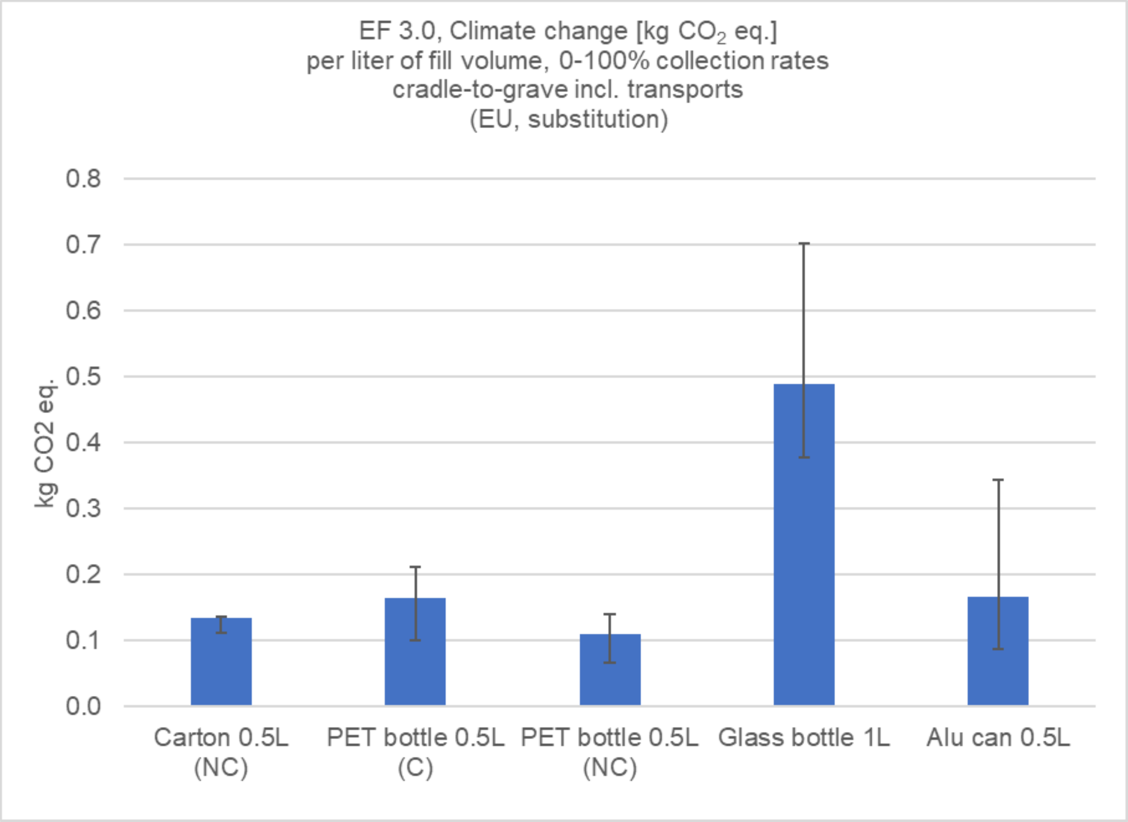

Figure 4-16: Climate change contributions over the life cycle of packaging products, shown per liter of fill volume, using the substitution method.

The analyzed products have different optimization potentials when it comes to increasing real recycling rates. The PEF CFF formula does not allow for this sensitivity assessment, so the substitution method is used as the baseline for this analysis. From each competing packaging material, one product (the most optimal according to their climate change profile) was tested with 0% and 100% collection rates for recycling. The recycling efficiencies remain unchanged (see Table 3-11).

The results are shown through error bars as variation around the climate change impact for each product with its baseline collection rate. The LDPE film fraction of the packaging formats are not collected for recycling in this sensitivity analysis as these are not widely recyclable materials which are generally sent to landfill or incineration.

The beverage cartons display little improvement in climate change impact with a 100% recycling rate. Both the PEF CFF and substitution provide little to no benefit to recycled paper, either as recycled content or as end of life credits[7], and since the mass is primarily defined by this material fraction, there can be little gain here, even with perfect recycling efficiency.

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[7] Recycling paper fibres and using them in paper pulp-making is an energy-intensive process. Additionally, integrated paper mills which use virgin paper are able to source renewable energy from the biomass by-products during paper production, which recycled paper plants generally do not have access to.

Contrary to the case of beverage cartons, aluminum cans, PET and glass bottles can make considerable reductions when collected and recycled at high rates. Aluminum specifically, when achieving recycling rates in the 80-100% recycling rate range, could be at par with beverage cartons and PET bottles for non-carbonated water. This is definitely a point of interest for an industry that is not only capable of achieving some of the highest recycling rates and yields, but also closing the material loop and applying the post-consumer scrap directly as new material input.

4.5.3. Sensitivity to refill of glass bottles

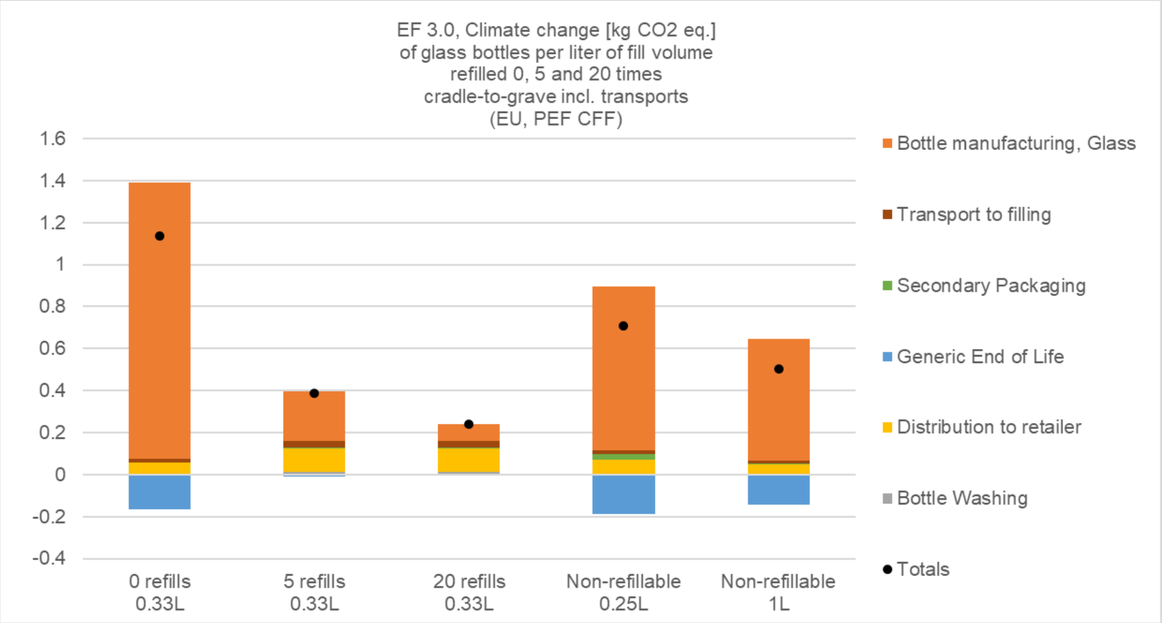

Figure 4-17: Climate change contributions over the life cycle of the 0.33L glass bottle, shown per liter of fill volume, using the PEF CFF method with 0-20 refills.

In Europe, the availability of reusable glass bottles varies drastically among countries. In the main markets that are of interest for this study, UK, France and Spain, refillable bottles have a very small market share. In Germany, for example, glass refills are more widespread. Since one of the purchased products, a 0.33L glass bottle, was a refillable bottle with a thicker wall (heavier weight) for longevity, it was considered to be better if it was not included in the baseline analysis alongside the lighter weight single-use glass bottles. Therefore, this product is considered in this separate sensitivity analysis and single-use glass bottles are shown as references.

For the refill bottle it is assumed that the transports from point of return to washing infrastructure and refilling stations will increase the total transports to 1,500km from the original 400km considered in the base case as transport to filling. The number is a mere estimate on the lower end of expected logistics behind these operations. Washing a maximum capacity of 3,000 bottles per hour consumes 1kWh electricity and 700kg of water. Lacking official statistics for the expected refill cycles of glass bottles in Europe, the number of refills estimated for Brazil was used as a proxy for the maximum number (20) of refills. As shown in Figure 4-17, as the number of refills increase, the impact of manufacturing decreases proportionally, making transports the most relevant phases of the life cycle. This reduction in life cycle impacts (0.24 kg CO_2 eq. with 20 refill cycles) makes glass a lot more competitive with other packaging formats although still showing a higher impact than the best performing PET bottle (0.12 kg CO_2 eq.), beverage carton (0.13 kg CO_2 eq.) and aluminum can (0.20 kg CO_2 eq.).

In addition to the reduced climate change impact, it is worth mentioning that the glass bottle refilled 20 times also achieves an MCI score close to 1, which is the highest score across all packaging options. Both the single-use and the refillable glass bottle options have an assumed recycled content of 40% and a recycling rate of 66% at end of life; however, in comparison, the single-use glass bottle achieves a much lower MCI score of ~0.4. This demonstrates the benefits of reusing packaging on product circularity, if indeed refill systems are set up efficiently with e.g. standardized bottles that can be circulated in a broad pool among all beverage brands.

4.5.4. Sensitivity to energy consumption in PET bottle manufacturing

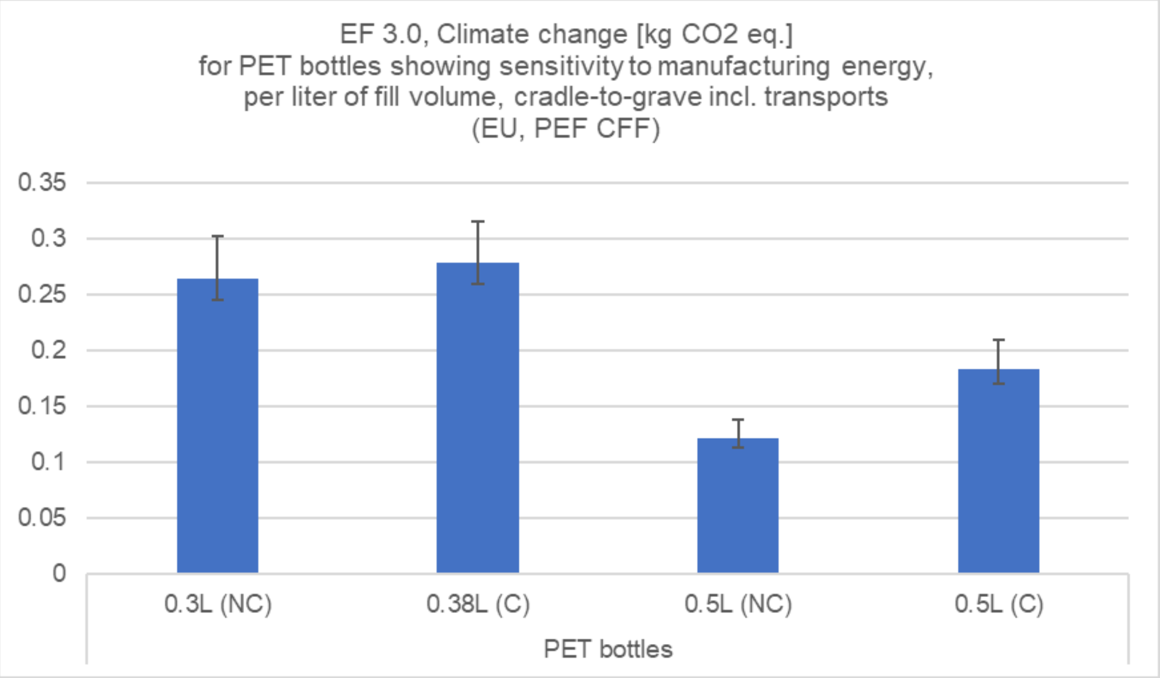

Figure 4-18: The variation in climate change impact for each PET bottle when energy consumption during blow molding is changed between 0.5 and 2x the baseline.

In terms of data quality, an uncertainty rests within the PET bottle manufacturing process. As described previously, a blow molding process was used originally developed for HDPE bottles. The intended application range of this dataset was for bottles in the range of 0.5 to 4kg sizes, which is significantly larger than the bottle weights in this study (>10x). In the baseline study, we applied the lowest end of this range, i.e. 0.5kg, and the associated energy consumption. The resulting energy consumption is fully in line with the - to the authors' and peer reviewers' knowledge - only ever published LCI dataset specifically developed for stretch blow molding of PET bottles, unfortunately no longer supported by PlasticsEurope[8]. Given the uncertainty and missing primary information on the specific stretch blow molding process for small PET bottles, the authors have explored the potential implications of lowering the energy consumption of this process to half the original (0.5x), and double (2x) the original value.

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[8] To the authors' knowledge PlasticsEurope could not maintain the dataset because PET converters did not provide (sufficient) data.

Energy consumption from the product life cycle contributes ~15% of the baseline climate change impacts for PET bottles, so changing the amount of energy consumed will also influence the overall climate change impact of the products by 7-15% (minimum and maximum values, respectively).

4.6. Uncertainty analysis

The following section summarizes two aspects of variation explored in the results of this study. The first aspect describes the uncertainty in climate change impact for each packaging format assessed, with respect to data quality and methodology. The second aspect describes the potential variability of climate change impact of each packaging type based on sensitivity analyses performed to assess *potential for change in the future*. Together, the results are intended to show the maximum potential improvements and worst-case outcomes identified for each packaging type. Ultimately, this chapter is designed to allow the reader to understand the reliability of the results and identify the maximum potential improvement in performance for each packaging type by adopting the changes defined in the sensitivity analyses.

Thus, the uncertainty analysis presented in Figure 4-19 considered the following scenario and sensitivity analyses:

- Methodology of secondary materials and End of Life treatment of waste (Substitution vs PEF CFF) (section 4.4.1)
- Reuse of the refillable glass bottle (section 4.5.3)
- Manufacturing energy of the PET bottle (section 4.5.4)
- PET weight changes (section 4.5.1)

In addition to the above uncertainties, further variability was included in Figure 4-20 to account for potential future change:

- Collection rates for recycling 0-100% (section 4.5.2)
- Renewable energy for can manufacturing (section 4.4.2)

There is little recorded uncertainty for beverage cartons (Figure 4-19), and no significant improvement potential found exploring future directions of change (Figure 4-20). This is because the cartons are not significantly affected by changes to the recycling rate, nor to methodological differences in the underlying recycling methodology for the study.

PET bottles show a considerable degree of uncertainty around the baseline impact recorded (Figure 4-19), which is related to uncertainties in the amount of energy consumed during the PET blow-molding manufacturing process and weight differences. The PET bottles do show a medium response to improvements in the recycling rate (Figure 4-20).

The 0.25L and 1L single-use glass bottles do not show any uncertainty in Figure 4-19, but the larger bottle demonstrates a marked potential for improvement if collected for recycling at higher rates (Figure 4-20). The refillable 0.33L glass bottle shows the highest level of uncertainty out of all packaging formats due to the unknown number of actual refill trips per bottle .

Aluminum cans demonstrate a small degree of uncertainty, which is derived from differences in the climate change impact found for the baseline recycling methodology and alternative (substitution) recycling methodology. Cans have a high potential for improvement based on the recycling rate and switching the electricity grid mix supply used for manufacturing from fossil-based to renewable.

The potential improvements identified for each packaging type may be considered more attainable as recycling and reuse regulations are changing rapidly , driving the packaging sector towards real circularity.

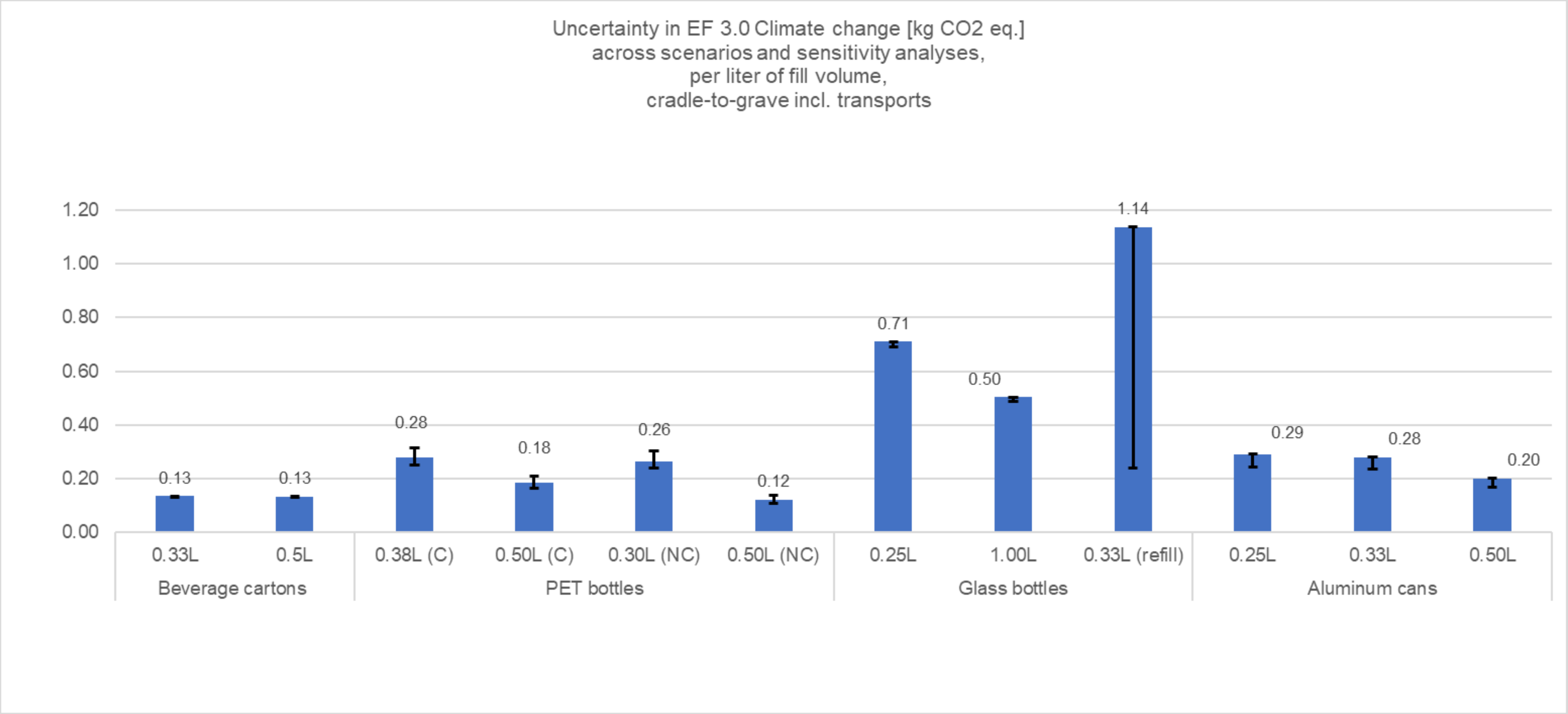

Figure 4-19: **Uncertainty analysis of the EF 3.0 Climate change [kg CO2 eq.] impact of products, scaled to 1 liter of fill volume, based on the results of the recycling methodology scenario and sensitivities to glass bottle refilling, and variation in PET manufacturing energy consumption. Values taken from Table 4-2: baseline - PEF CFF, min – minimum of values from scenario and sensitivity analyses under the column “Uncertainty”, max– maximum of values from scenario and sensitivity analyses under the column “Uncertainty”.**

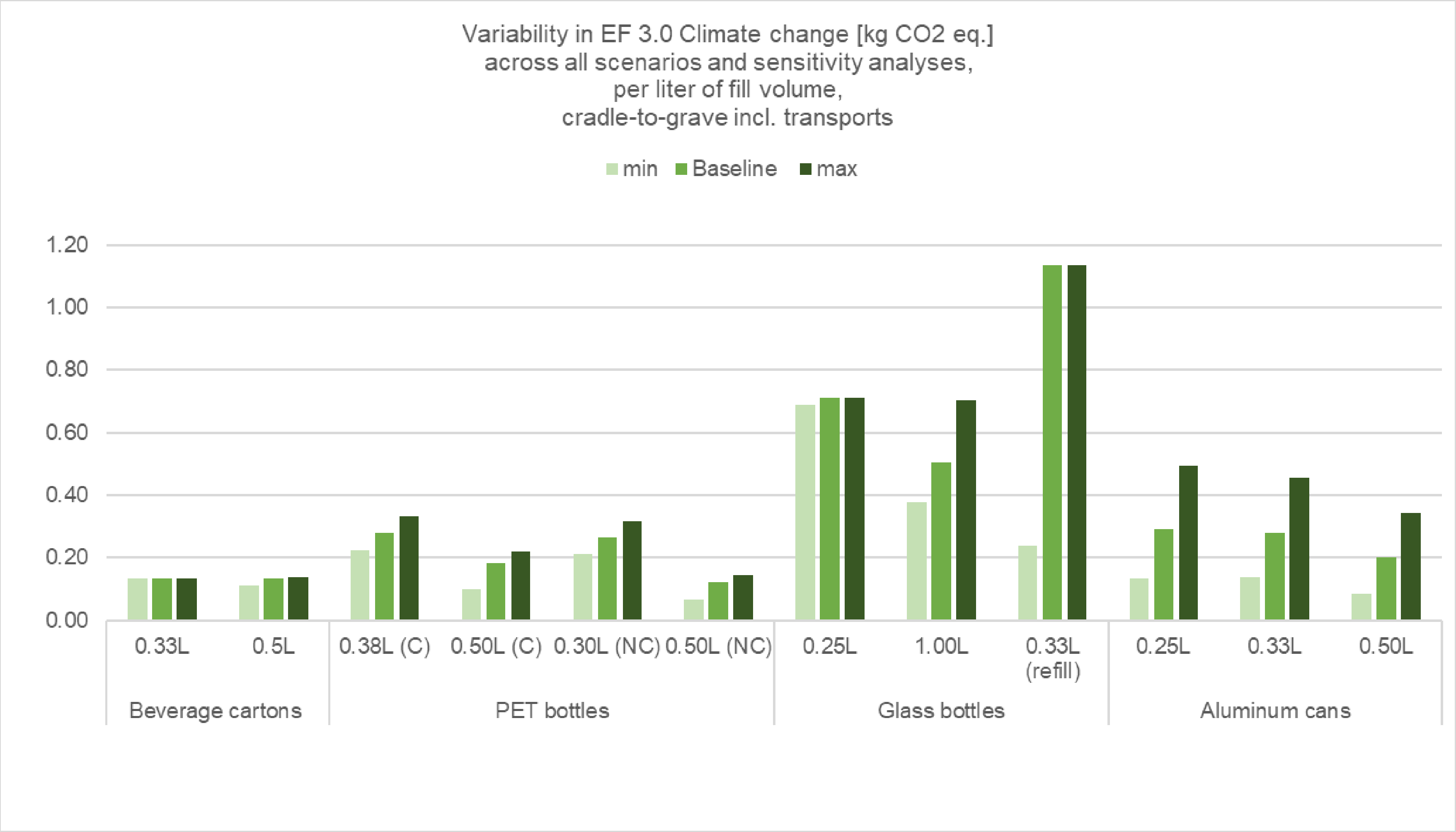

Figure 4-20: **Variability analysis of the EF 3.0 Climate change [kg CO2 eq.] impact of products scaled to 1 liter of fill volume, cradle-to-grave incl. transports, based on the worst-case and best-case performances for each product derived from the sensitivities to changes to PET weight and recycling / collection rate. Values taken from Table 4-2: baseline - PEF CFF, min – minimum of values across all scenarios and sensitivity analyses, max - min – maximum of values across all scenarios and sensitivity analyses.**

Table 4-2: Summary of scenario and sensitivity analyses in EU region for EF 3.0 Climate change [kg CO2 eq.] impact of products scaled to 1 liter of fill volume, cradle-to-grave incl. transports, and calculation of uncertainty by means of minimum and maximum values. Grey cells denote the lack of a corresponding scenario / sensitivity analysis.

			Uncertainty						Future change potential		
		Baseline	Scenario		Sensitivity analyses (uncertainty)				Scenario	Sensitivity analyses (future change potential)	
Beverage packaging type	Sizes	PEF CFF	Substitution	Reuse 20x	PET weight 10% increase	PET weight 10% decrease	PET mfg 2x baseline	PET mfg 0.5x baseline	Renewable mfg	Recycling 0%	Recycling 100%
Beverage cartons	0.33L	0.13	0.13								
	0.5L	0.13	0.13							0.14	0.11
PET bottles	0.38L (C)	0.28	0.25		0.30	0.25	0.32	0.26			
	0.50L (C)	0.18	0.17		0.20	0.17	0.21	0.17		0.21	0.10
	0.30L (NC)	0.26	0.24		0.29	0.24	0.30	0.25			
	0.50L (NC)	0.12	0.11		0.13	0.11	0.14	0.11		0.14	0.07
Glass bottles	0.25L	0.71	0.69								
	1.00L	0.50	0.49							0.70	0.38
	0.33L (refill)	1.14		0.24							
Aluminum cans	0.25L	0.29	0.24						0.27	0.49	0.13
	0.33L	0.28	0.24						0.26	0.46	0.14
	0.50L	0.20	0.17						0.18	0.34	0.09

5. Life Cycle Impact Assessment: US

The overall results have been assessed using four indicators which evaluate the environmental performance of each bottle product, covering acidification, eutrophication, global warming potential (GWP) and freshwater consumption. The cut-off approach has been applied as the primary recycling methodology. The full set of assessed indicators are provided in Annex F: Extended LCIA Results.

The LCIA results include contribution analyses, which split the results according to the following life cycle stages: manufacturing, secondary packaging, transport to filling, distribution and end of life. This enables the reader to understand the influence of each life cycle stage on the overall environmental performance of the product. Two additional scenarios are considered in the LCIA results for the US. The first analysis compares the differences in results yielded from the cut-off approach and substitution approach. The second scenario describes the potential for the aluminum can manufacturing processes to be sourced from renewable energy instead of grid energy and explores how altering the power sourcing affects environmental performance.

Two sensitivity analyses are also considered. The first sensitivity analysis investigates the GWP when reducing the weight of each container by 5% and by 10%. The second sensitivity analysis investigates the GWP when changing the recycled content of each beverage packaging alternative from 0% recycled content, to the average recycled content, to 100% recycled content.

5.1. Overall Results – cut-off approach

5.1.1. Acidification

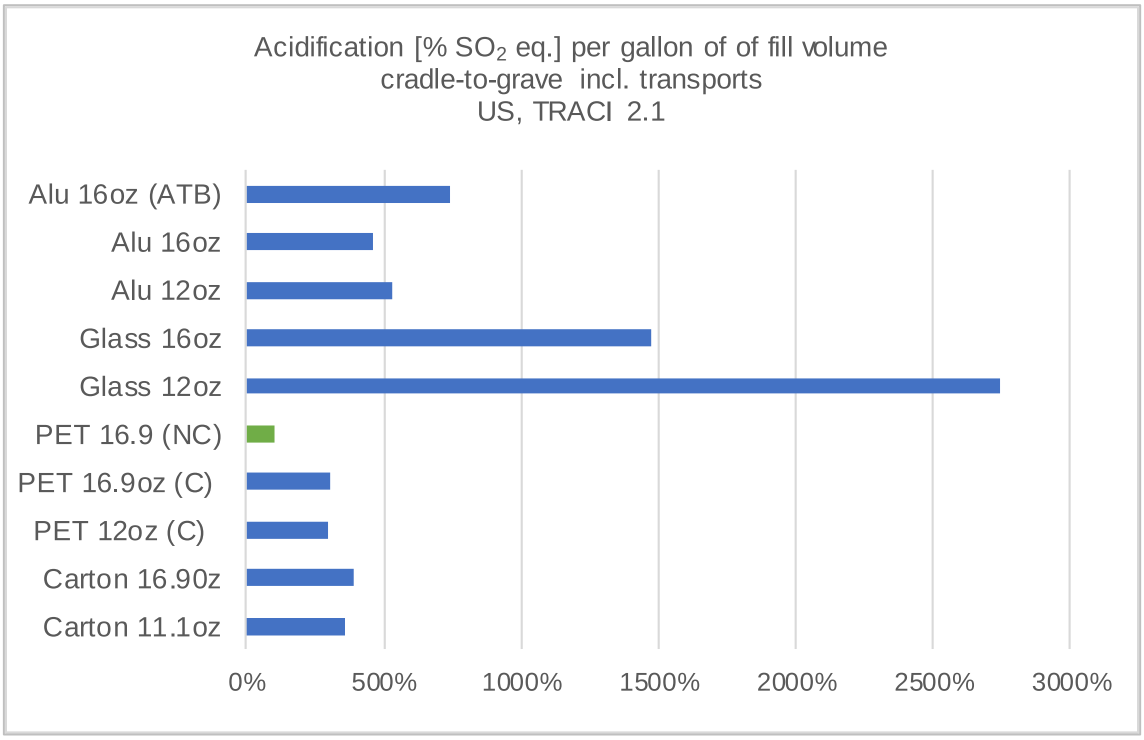

Figure 5-1: Acidification results of each of the compared products scaled to 1 gallon of fill volume, using the TRACI 2.1 method.

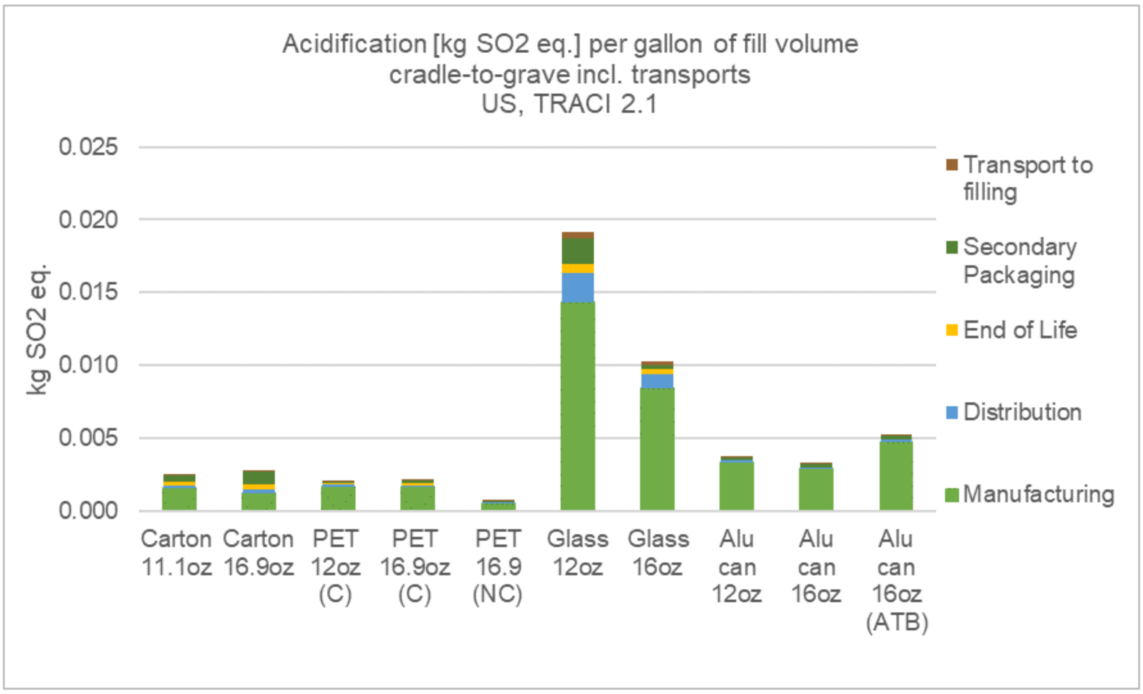

Figure 5-2: The contribution of different life cycle stages/production processes to the overall acidification results, using the TRACI 2.1 method.

Acidification of soils and waters mainly occurs through the conversion of air pollutants like SO_2, NO_2 into acids such as H_2SO_4 and HNO_3. These acids can cause ecosystem nutrient imbalances, increase the solubility of metals into soils and corrode calcium carbonate rocks like limestone.

Sulfur dioxide and nitrogen oxide emissions account for around 90% of the emissions for all the packaging options assessed in this study and are mostly associated with fuel combustion during manufacturing.

Glass bottles exhibit considerably higher burdens for acidification potential than other options. This partly reflects the high mass compared to other packaging formats and the energy intensive production glass manufacturing process. However, the nature of glass production itself also contributes large amounts of nitrogen monoxide, which are generated during the batch formulation step. Nitrogen monoxide accounts for about 30% of the total acidification impact for glass bottles and is a much less significant contributor for the other packaging options.

PET bottles show the best performance in this impact category, just ahead of beverage cartons. Manufacturing drives the majority of impacts for PET bottles, while secondary packaging has a relatively large contribution to the life cycle burdens of cartons, because the mass of secondary packaging is high compared to the mass of the cartons themselves.

Aluminum cans benefit significantly from the high level of recycled content, and impacts are predominantly driven by manufacturing.

For all packaging formats, most of the burdens are associated with raw material production and manufacturing.

5.1.2. Eutrophication

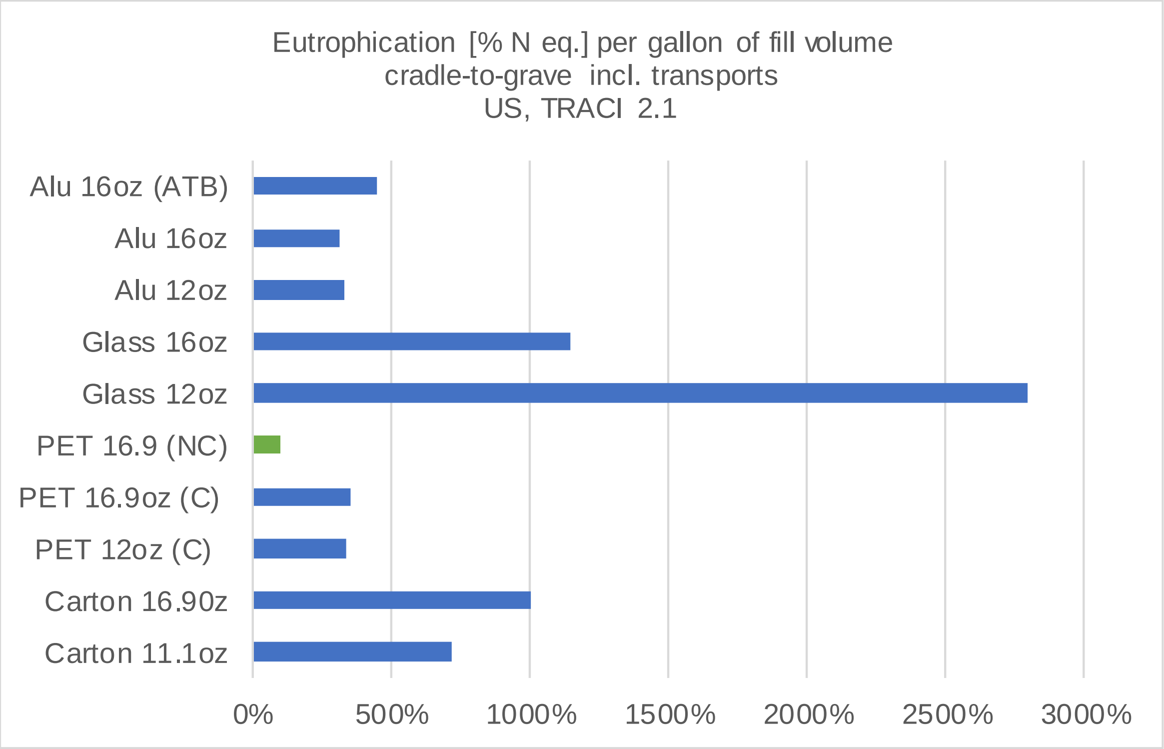

Figure 5-3: Eutrophication results of each of the compared products scaled to 1 gallon of fill volume, using the TRACI 2.1 method.

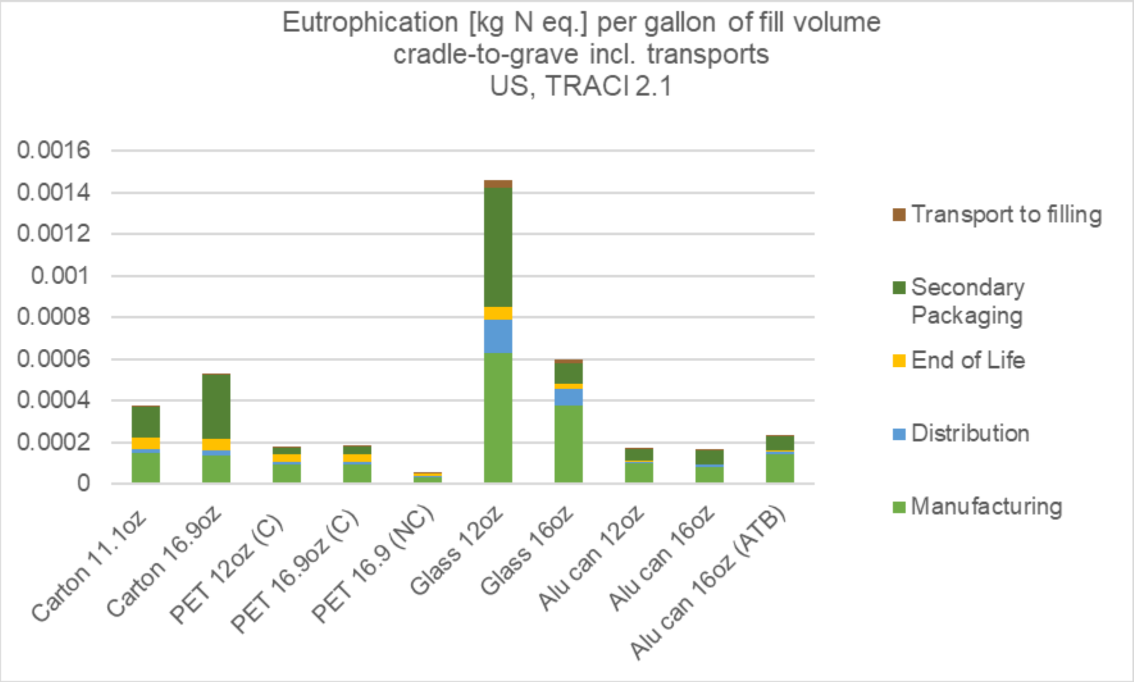

Figure 5-4: The contribution of different life cycle stages/production processes to the overall eutrophication results, using the TRACI 2.1 method.

Eutrophication of aquatic ecosystems describes accelerated algae growth and blooms of bacteria which prevent sunlight penetrating the lower depths of a water body, limiting photosynthesis and oxygen content in the water. This can lead to fish die-off and anaerobic decomposition. Eutrophication is caused by the excessive enrichment of nutrients like nitrogen and phosphorous which drive algal growth.

The 16.9oz PET bottle for non-carbonated water shows the best performance in this category due to combination of thin walls (low weight), lower manufacturing-related water consumption and a more favorable packaging-to-product ratio. Among the packaging options for non-carbonated drinks, aluminum cans get second place, followed by cartons and glass bottles. Among the packaging options suitable for carbonated drinks, aluminum cans take the lead with the lowest impact, followed closely by PET bottles and then, glass. PET and aluminum packaging benefits from relatively little waste water generation during manufacturing (high recycled content for aluminum) and less secondary packaging made from corrugated board.

The 12oz glass bottle demonstrates a considerably worse environmental performance than other packaging types because of the much higher resource demand of the product, and the type and amount of secondary packaging. Both cartons and glass bottles use significant quantities of corrugated board as secondary packaging which drives the overall burden for these packaging formats.

Paper factories require large amounts of water and chemicals and release high amounts of nutrients as waste water, resulting in the proportionally high impact of both beverage carton manufacturing and secondary packaging (mainly cardboard). Because the relative amount of cardboard used as secondary packaging is higher for beverage cartons and glass bottles, these two show the highest eutrophication impacts.

Burdens associated with transport are also noticeable for glass bottles, reflecting their high mass compared to other pack types.

5.1.3. Global Warming Potential

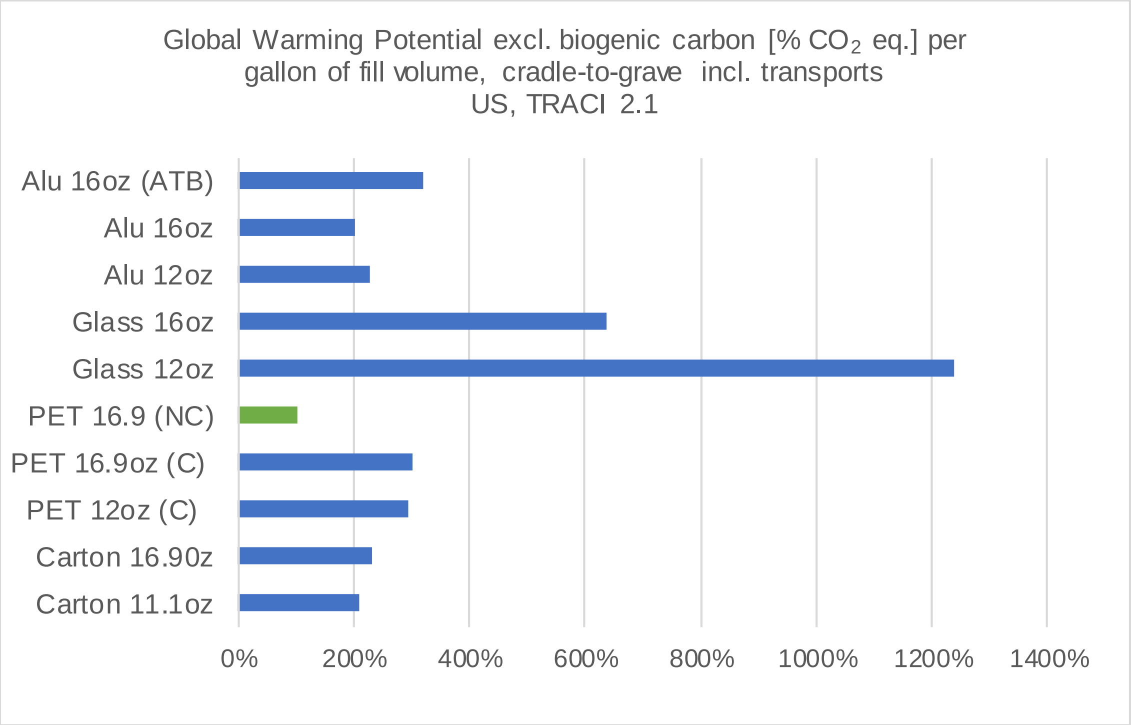

Figure 5-5: GWP results of each of the compared products scaled to 1 gallon of fill volume, using the TRACI 2.1 method.

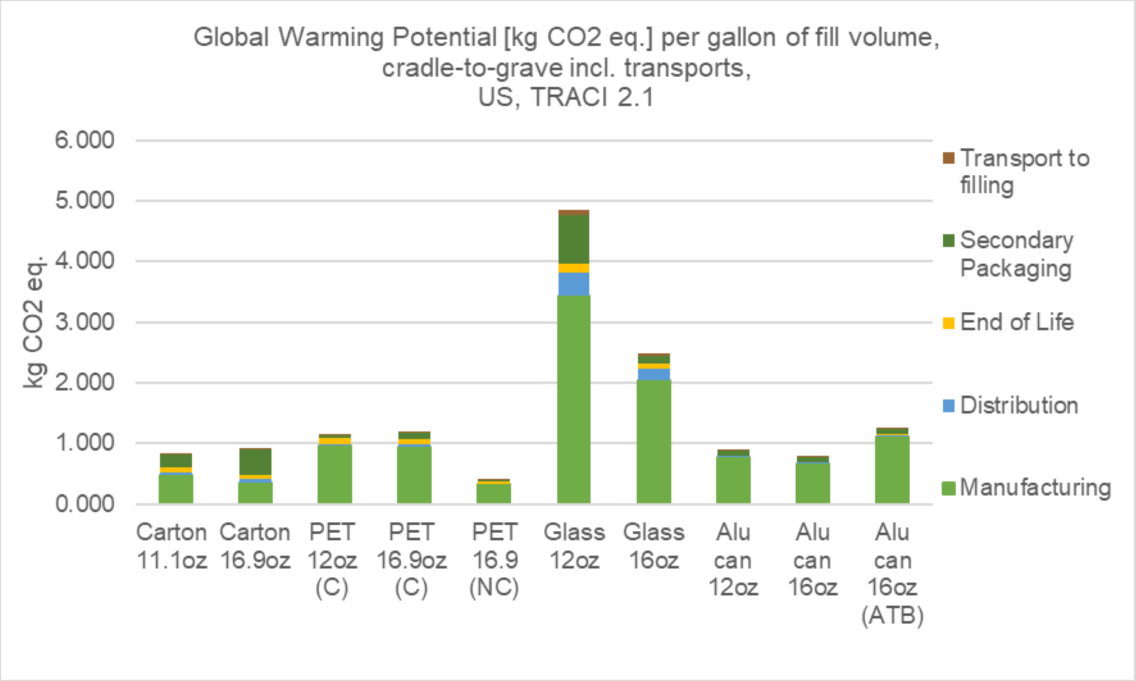

Figure 5-6: The contribution of different life cycle stages/production processes to the overall GWP results, using the TRACI 2.1 method.

Global warming potential (GWP) is driven by greenhouse gases like CO_2 and CH_4 in the troposphere which trap infrared radiation and redirect it back towards the Earth's surface. This radically alters the conditions at the Earth's surface and may cause warming or cooling effects which have the potential to alter weather events, affect ocean current circulation and cause other long-term GWP effects.

The 16.9oz PET bottle for non-carbonated water has the lowest impact overall due to its extremely thin-wall design. The second place among non-carbonated drinks packaging is a close match between aluminum cans and beverage cartons, with very similar overall burdens. Glass bottles, by a large margin, come in last. Among options for carbonated drinks, aluminum performs strongest, followed by PET bottles and finally glass. The low mass and high recycled content of aluminum cans enable consistently low impacts of this packaging format. The lightweight nature of the PET bottles make them a highly efficient packaging format, where the majority of climate change impacts are coming from the fossil-based raw materials.

Cartons show a low GWP because they are predominantly made from virgin paperboard. This paperboard is sourced from biomass and also uses large amounts of biomass as fuel for the pulp and papermaking process (from bark, forestry off cuts, wood chips, black liquor, etc.). Biogenic carbon dioxide is sequestered during tree growth, which is then re-emitted when incinerated (for energy) resulting in a zero overall net emission of greenhouse gases (GHG). The lack of GHG emissions associated with these biomass fuels significantly reduces the overall GWP of beverage cartons.

Glass bottles are the packaging format with the highest GWP. This reflects the energy-intensive manufacturing process and the far larger mass of glass bottles compared to other packaging options. The 12oz bottle has markedly higher burdens than the 16oz bottle. This is due to the increased packaging efficiency per gallon as pack sizes increase (larger packs use less mass per unit of volume than smaller packs). The burdens related to secondary packaging for the 12oz glass bottle are higher for the same reason.

Cartons also show a relatively large contribution from secondary packaging. For the 16.9oz pack this has higher burdens than the carton itself and can be explained by the high proportion of recycled paper in the corrugate boxes. Paper recyclers often do not have access to biomass fuel that is readily available for use by virgin producers, and so have to rely more on fossil fuels. As such, GWP burdens for recycled content can be higher than for virgin material.

Apart from the 16.9oz carton, the manufacturing stage is the dominant contributor to the environmental burdens for GWP for all packaging options assessed in this study.

5.1.4. Blue water consumption

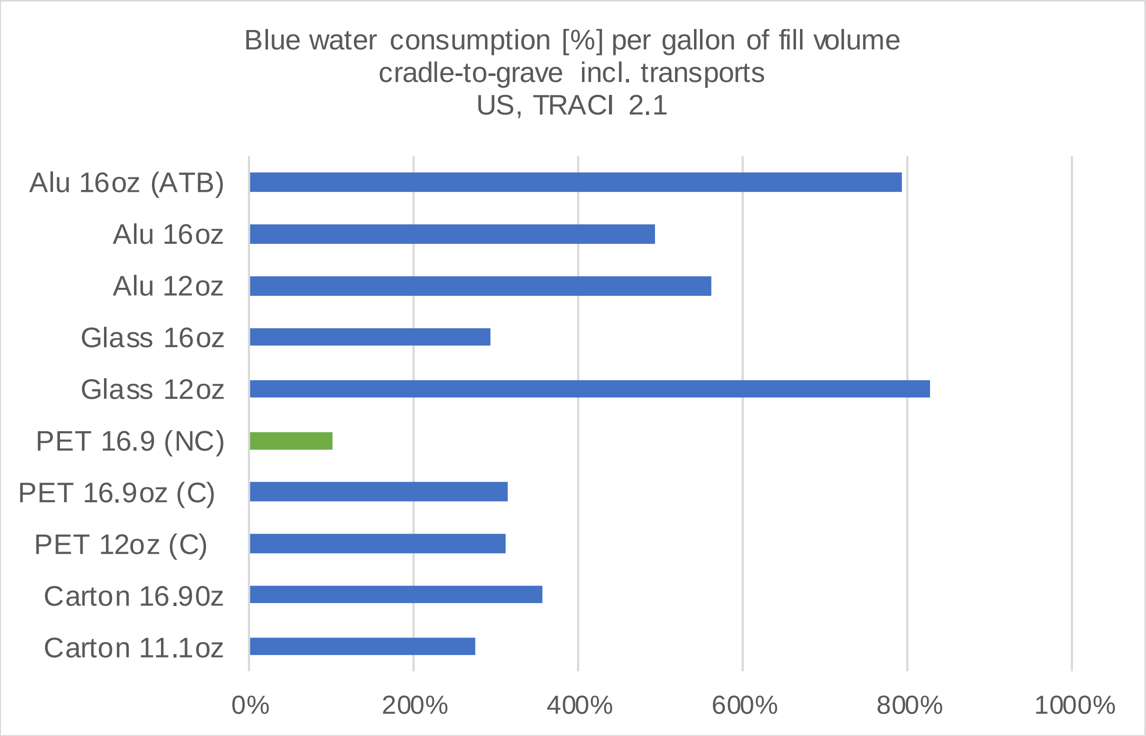

Figure 5-7: **Blue water consumption results of each of the compared scaled to 1 gallon of fill volume, using the TRACI 2.1 method.**

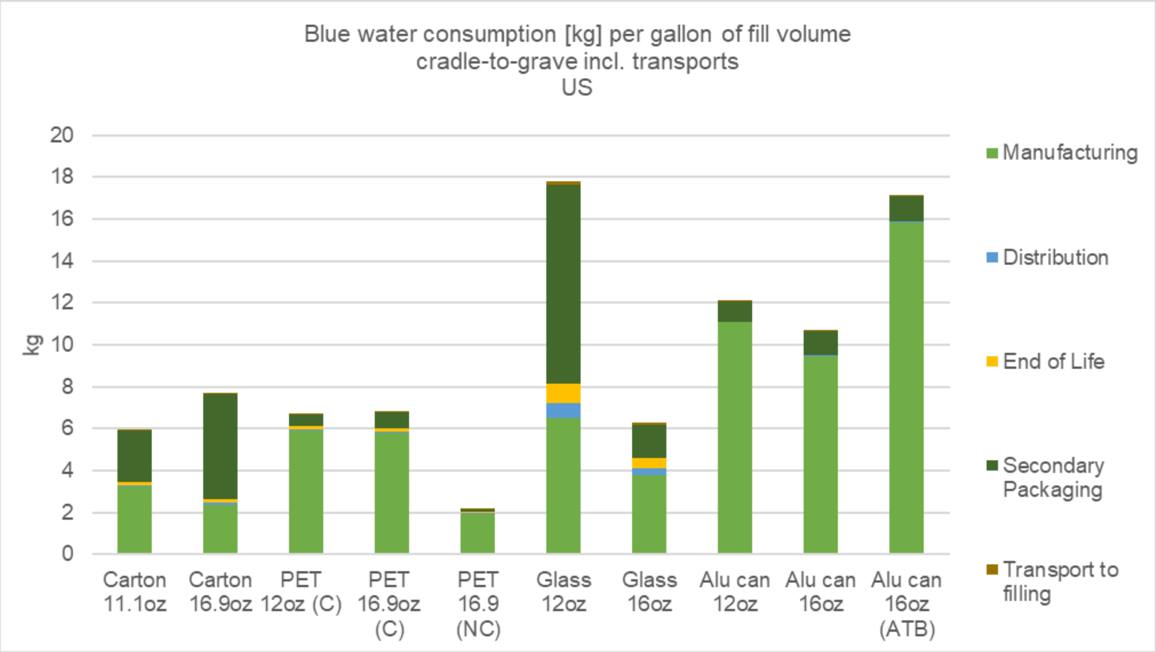

Figure 5-8: **The contribution of different life cycle stages/production processes to the overall blue water consumption results, cradle to grave, per gallon of fill volume using the TRACI 2.1 method.**

Water consumption in manufacturing, electricity generation and other processes can affect the distribution and accessibility of freshwater supplies. In water-scarce areas this can result in increased competition for freshwater resources for irrigation, energy generation, manufacturing, cooking and hygiene, and maintaining ecosystem health.

The difference in water consumption for the manufacturing aspects of the 12oz and 16oz glass bottles is relatively low, at ~2kg. However, the 12oz glass bottle demonstrates the highest blue water consumption overall due to very high contribution from secondary packaging (corrugate boxes). This impact is not seen for the 16oz glass bottle because its greater volume makes it far more efficient at delivering one gallon of product and requires far less secondary packaging. The glass bottles require at least twice as much secondary packaging material as every other product, because the mass of the glass bottles is between 10-20x greater than the mass of the other products.

PET bottles and cartons show the lowest overall blue water consumption, which is related to product manufacturing processes. Here, the PET bottles benefit from the lightweight nature and relatively little water consumed during manufacturing.

Cartons have a relatively low blue water consumption but also show a large contribution from secondary packaging. The paper manufacturing process is quite water-intensive as large volumes of water are required to turn fiber pulp into slurry. However, the overall burden is small as cartons have relatively low mass and as long as water is returned to the same watershed, this impact will be rather small.

Aluminum cans consume relatively large quantities of freshwater associated with the background datasets (ingot and can rolling processes). As noted previously, aluminum cans benefit from high levels of recycled content used in the pack.

5.2. Detailed results

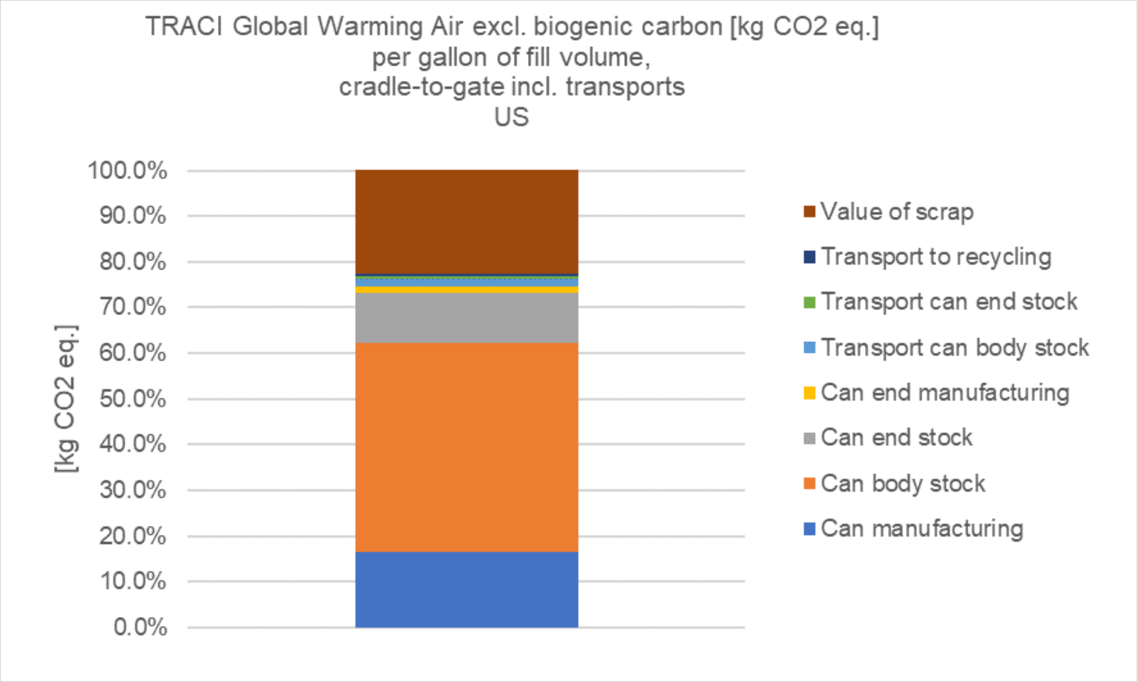

Figure 5-9: Detailed global warming potential contributions in the manufacturing phase of the 12oz aluminum can, shown per liter of per fill volume, using the TRACI 2.1 method (substitution method).

The results presented in this section have been run using the substitution methodology to account for the environmental impact of recycled content. The contribution analysis shows the “can body stock” or smelting process accounts for just under 50% of the total GWP derived from cradle-to-gate, due to this being a very energy-intensive process. The GWP related to the remaining manufacturing processes are predominantly derived from the mining and processing of raw bauxite material used to manufacture aluminum and turn it into can end and body stock. The can manufacturing process accounts for ~19% of the overall burdens of production. Burdens from transport processes are <1%.

The high end of life recycling rate and the credits received for recycling at end of life will, to a large extent, be offset by the burdens of the input scrap when the full cradle-to-grave scope is assessed using the substitution approach.

5.3. Material Circularity Indicator (MCI) Results

Figure 5-10 shows the results for the material circularity indicator for each of the packaging formats assessed in this study for the US. A score of 1 indicates a completely circular product, and a score of 0.1 indicates a completely linear product.

Three aspects of the product’s life cycle influence the MCI score, as follows:

- Proportion of input material flows that are from reused or recycled sources, or from sustainably sourced biological material (e.g. FSC certified paper)
- Proportion of waste flows that are reused or recycled at end of life
- Product utility measured as the number of reuse cycles compared to the average situation (single-use).

Aluminum cans have the highest MCI scores of ~0.8, which reflects the high rate of recycled content (73%) and recycling rate at end of life (49.8%). Variability in the MCI scores for different can sizes derive from differences in the secondary packaging used.

Beverage cartons have an intermediate MCI score of around 0.7-0.8. This is because cartons contain 69-74% paperboard, which is assumed to be sustainably sourced and therefore (based on the MCI methodology) restorative (circular) in nature. Tetrapak beverage cartons in the US are manufactured using paperboard, of which 100% is derived from Forestry Stewardship Council (FSC) certified or controlled sources (Tetra Pak, 2018). Additionally, relatively large quantities of secondary packaging made of cardboard are applied for these products, which are also assumed to be restorative (circular) and have a high recycling rate at end of life, thus further increasing the total MCI. Provided that the carton in the primary packaging is not sourced sustainably, the MCI would sink considerably (see note in section 6.3). As explained before, the MCI is calculated based on material fractions independent of total amounts, therefore some results go contrary to principles of waste and material efficiency as well as results of traditional LCIA.

Glass bottles have an intermediate MCI score of around 0.5 because both options have an assumed recycled content of 35% and a recycling rate at end of life of 42%.

PET bottles have the lowest MCI scores among the packaging formats assessed in this study, with values from 0.2 to just over 0.3. This is because the PET bottles use 94% virgin material and have a relatively low recycling rate of 30% at end of life.

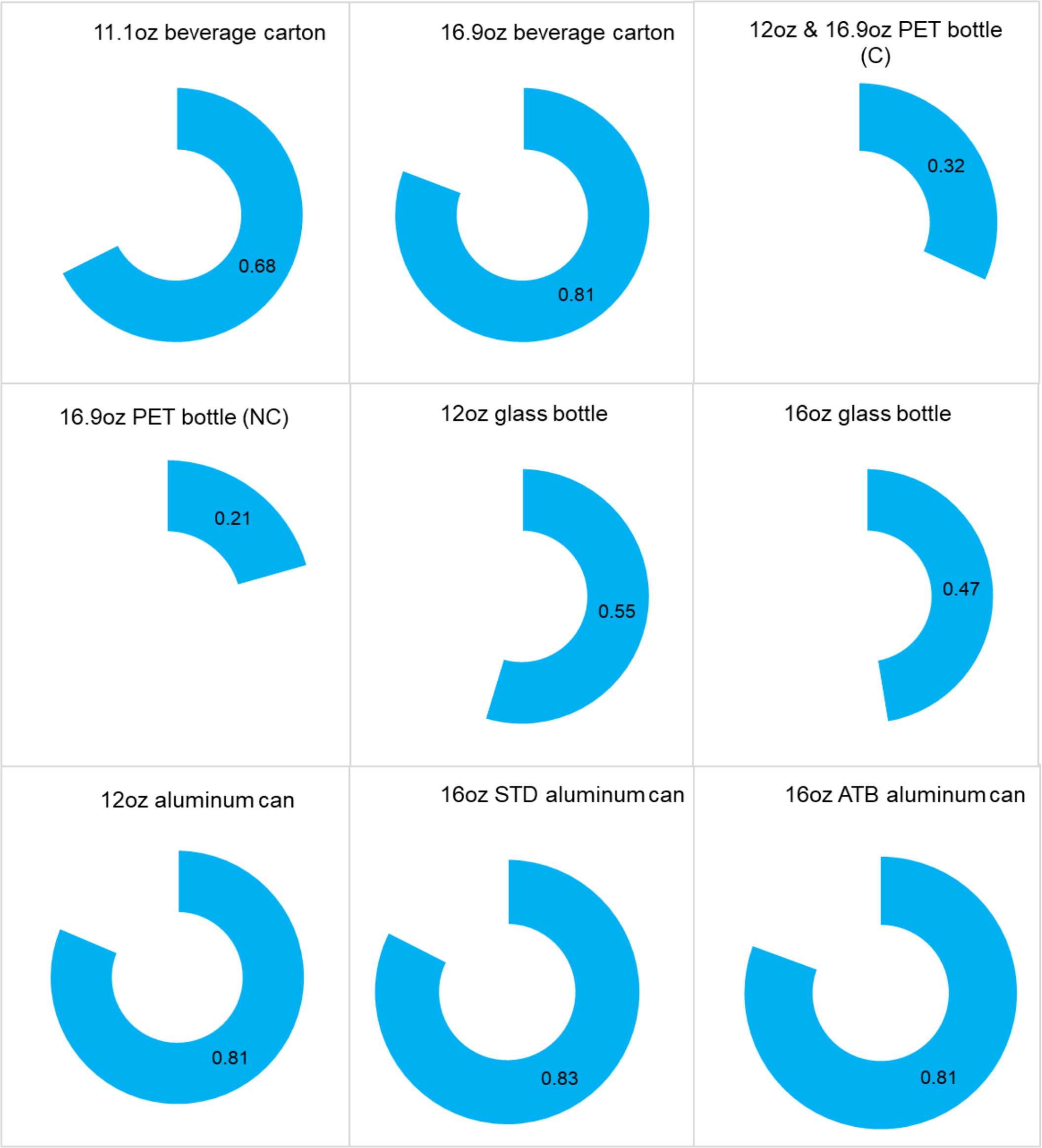

Figure 5-10: **Material Circularity Indicator results for the different packaging options (US)**

5.4. Scenario analyses

5.4.1. Scenario: Recycling methodology

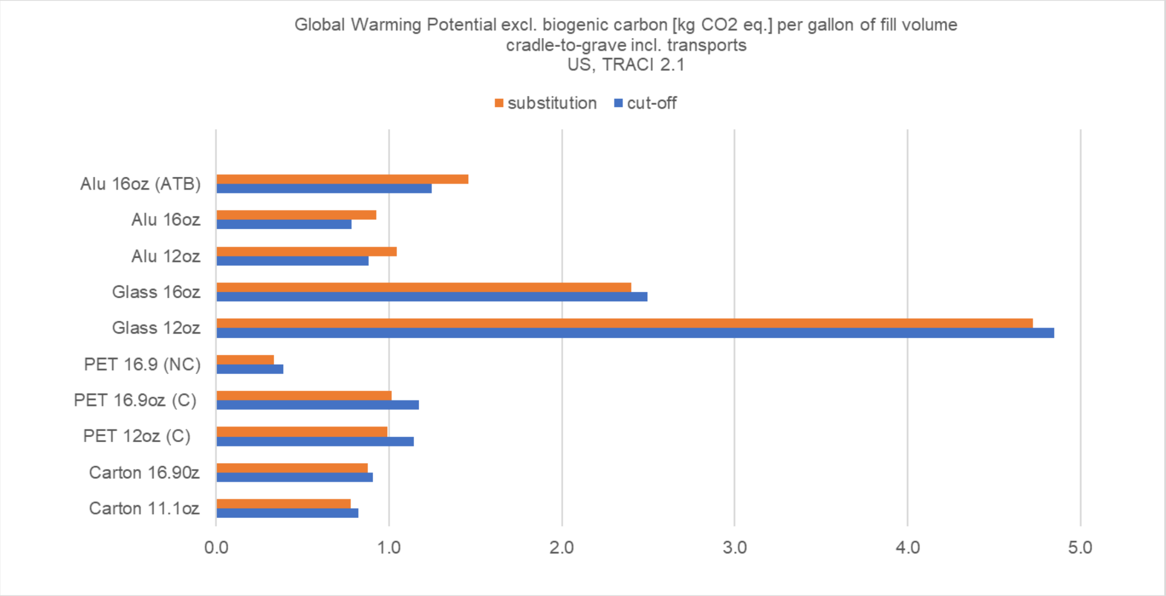

Figure 5-11: **A comparison of the global warming potential results of each product when applying the cut-off approach versus the substitution approach, using the TRACI 2.1 method.**

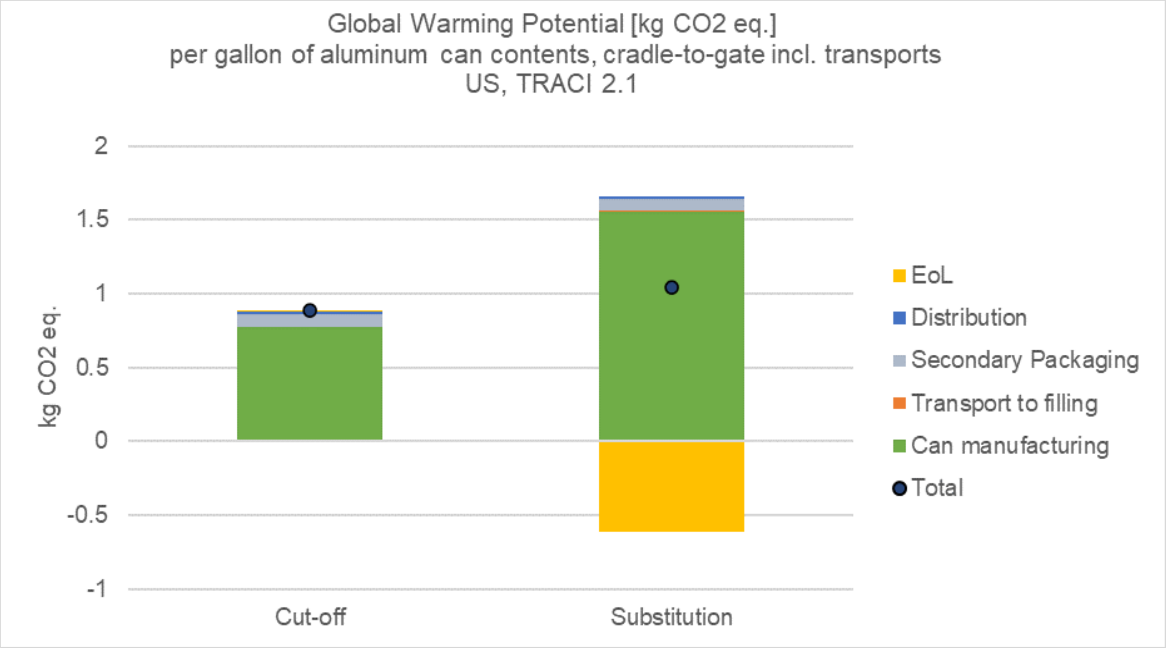

Figure 5-12: **Contribution analysis of the global warming potential for cradle-to-grave processes of aluminum cans using the cut-off approach and substitution approach, using TRACI 2.1 methods.**

As discussed in section 2.4, the baseline results for the US reported in this study use the cut-off approach to account for recycling. This approach only accounts for burdens within the life cycle of the system being assessed – no impacts are assigned to scrap used as input material nor credits assigned for material recycled at end of life. An alternative perspective is the substitution approach, whereby the benefits of recycling material at end of life are rewarded, but the recycled content used for input materials are assigned the same as virgin materials. For both approaches, the inputs and outputs are treated equivalently. If a product receives the same amount of recycled input as it generates at end of life, both methodologies will yield identical results – when this balance is lost, the results may diverge.

This section presents and contrasts the results of each methodological approach to examine how they influence the study outcomes. The GWP of each product using the substitution and cut-off methodologies are summarized in Figure 5-11. The cradle-to-grave results of a 12oz aluminum can are explored in a constitution analysis in Figure 5-12.

The measured GWP of cartons is not significantly impacted by shifting from the cut-off approach to the substitution approach, with a maximum difference of 5% in the results. This represents the relative balance between the burdens of the renewable virgin input materials, and a low recycling rate of 26%.

The cut off approach and substitution approach result in a difference of approximately 15% for PET bottles, with the cut-off approach leading to higher burdens than the substitution approach. This reflects the higher rate of recycling compared to input of recycled materials within the product life cycle. The substitution approach recognizes the higher recycling rate, resulting in lower burdens.

Glass bottles demonstrate the greatest environmental burdens for GWP out of all products analyzed in this study, with <4% difference in the results between the substitution and cut-off approach.

Aluminum cans show the greatest differences in the results for GWP of 11-18%, with the substitution approach yielding higher burdens due to higher recycled content than end of life recycling rate.

5.4.2. **Scenario: Renewable energy in can manufacturing**

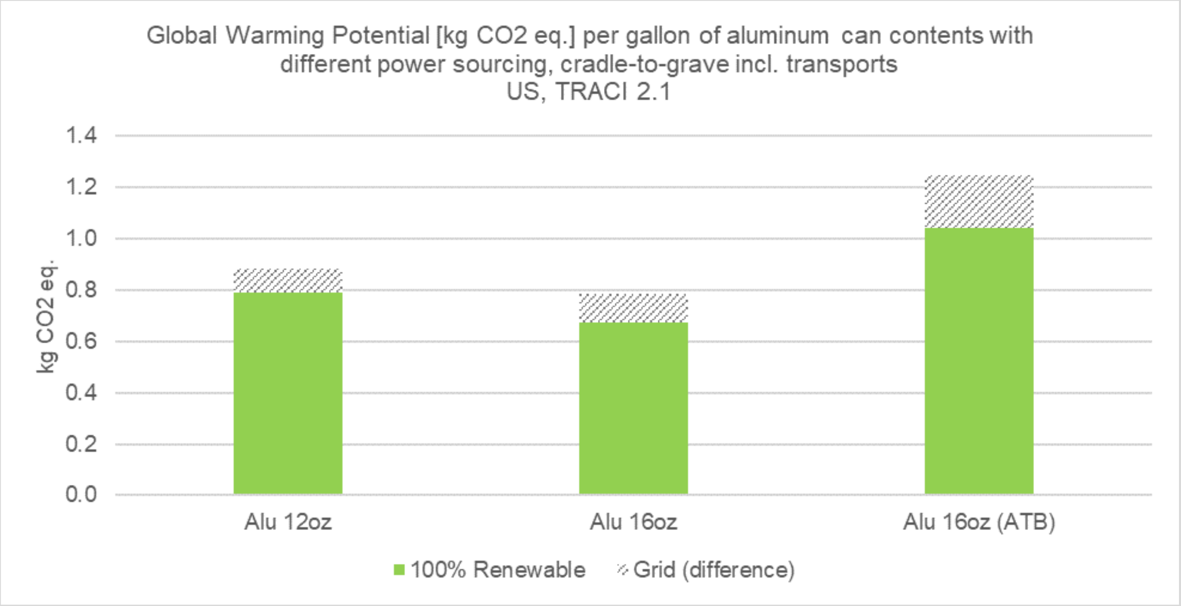

Figure 5-13: The effect of shifting power sources from electricity grid mixes to renewable power on the global warming potential of aluminum cans, per gallon of fill volume, cradle-to-grave incl. transports, using the TRACI 2.1 method.

Ball Corporation has executed two virtual power purchase agreements – one wind and one solar – for 388 megawatts of new renewable energy. These agreements will allow the company to address 100% of the North American electricity load utilized in its corporate, packaging and aerospace operations by the end of 2021. . This scenario is therefore a future projection of what the manufacturing (and total life cycle) impacts will look like, assuming the technological status remains the same, i.e. identical energy and material consumption.

These results show that the cans would benefit from an 11%, 14% and 16% reduction in GWP, for the 12oz, 16oz and the 16oz Alumi-Tek bottle, respectively.

The 16oz Alumi-Tek bottle consumes more energy during can/bottle manufacturing than the 16oz standard can. This means the burdens associated with electricity consumption are more impactful for the 16oz bottle, which explains why a more significant decrease in GWP can be achieved when switching to renewable energy in aluminum bottle manufacturing.

5.5. Sensitivity analysis

5.5.1. Sensitivity to product weight

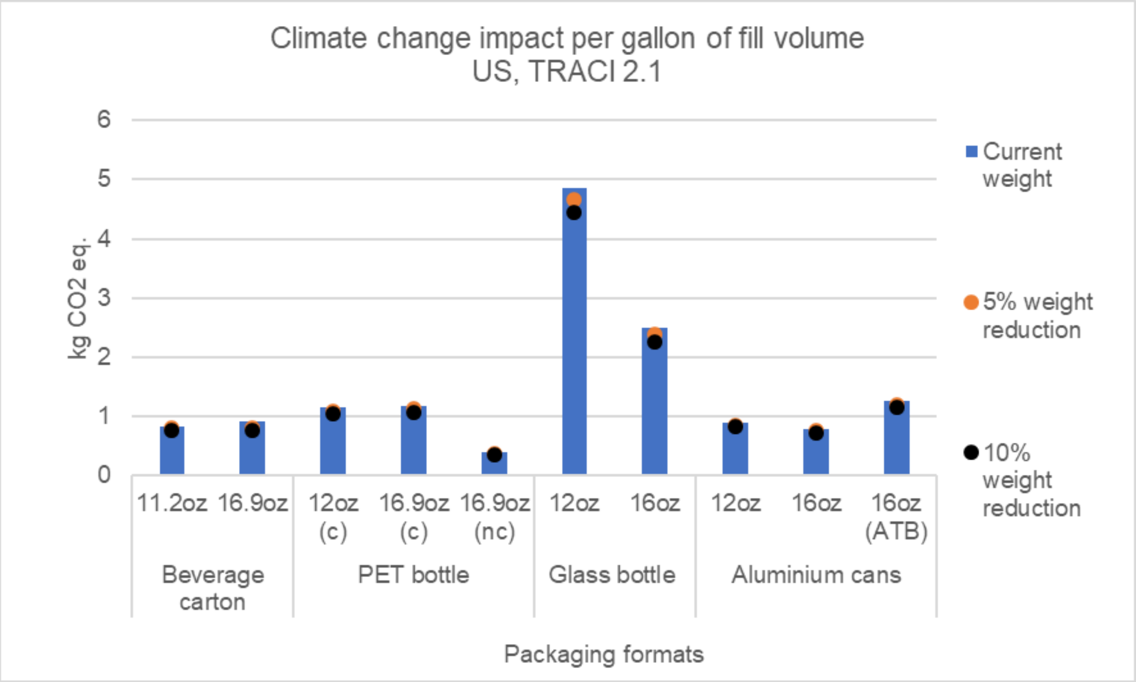

Figure 5-14: The GWP of beverage packaging alternatives at their current weight, with a 5% weight reduction and with a 10% weight reduction, using the cut-off approach and TRACI 2.1 method

Reducing the weight of any packaging format by 5% does not result in significant improvements in the GWP.

Reducing the weight of the 16.9oz beverage carton by 10% decreases the GWP by 5%, indicating a moderate dependence of the environmental performance on the raw materials.

The GWP of the 12oz carbonated and 16.9oz non-carbonated PET bottles decreases by 9% with a 10% reduction in weight.

Glass bottles demonstrate an 8-9 % decrease in GWP when light-weighted by 10%, which reflects the influence of the burdens related to glass bottle manufacturing on the environmental performance of the overall product life cycle.

Aluminum cans showed a 7-8% reduction in GWP when the weight of the packaging types were reduced by 10%.

To varying degrees, all packaging formats reflect the significant influence of the burdens associated with raw material production over other aspects of the product life cycle.

Overall, lightweighting could provide some improvements in the environmental performance of packaging alternatives. Considering the billions of beverage packaging pieces produced each year, even small improvements result in noteworthy benefits for the planet. This analysis further suggests that focusing improvements on the environmental performance of the materials and manufacturing aspects of the life cycle of these specific packaging alternatives (e.g. energy efficiency improvements and renewable energy sources) could significantly reduce their GWPs.

It should be noted, however, that product weight divergence is also possible in the opposite direction. The impact on climate change would be proportionally the same, i.e. 5-10% higher impacts can be expected if the containers increase in weight, for example due to new regulations on tethered caps.

5.5.2. **Sensitivity to recycled content**

The influence of recycled content on the GWP of each packaging alternative is explored through three scenarios : packaging with 0% recycled content, its latest available average recycled content, and with 100% recycled content.

Table 5-1: A summary of the average recycled content of each packaging type considered in this study.

Packaging type	Average recycled content (%)
Beverage cartons	0
PET bottles	6
Glass bottles	35
Aluminum cans	73

The GWP of the beverage carton increases with recycled content because the burdens associated with processing the recycled material are greater than those associated with using virgin material. This is due to the fact that virgin natural material used to manufacture the beverage cartons are assumed to be sustainably sourced (therefore renewable) and sequesters biogenic carbon dioxide as an inherent aspect of the material. These results indicate beverage cartons may deliver a better environmental performance (related to GWP) under a linear economy rather than a more circular system.

The GWP of the glass bottle decreases as recycled content increases. The burdens from manufacturing virgin glass material are significantly greater than re-melting and reusing secondary glass material, in part because virgin glass manufacturing requires greater energy consumption.

PET bottles are predominantly virgin material (6% recycled content), and this study finds the GWP can be decreased when recycled content is. PET is a widely recycled material with a subsequently saturated market, meaning further benefits are provided for the use of secondary material as opposed to virgin material which increases the demand for petrochemically-derived polymers.

Aluminum cans demonstrate the greatest difference in GWP dependent upon the recycled content in the can sheet. Manufacturing virgin aluminum is very energy and resource intensive. However, aluminum is a highly recyclable material that can be recycled infinitely and without losing the intrinsic material properties. The burdens associated with re-melting and reusing aluminum are significantly lower than manufacturing virgin material (e.g. 95% energy savings when recycling aluminium as opposed to virgin aluminium production).

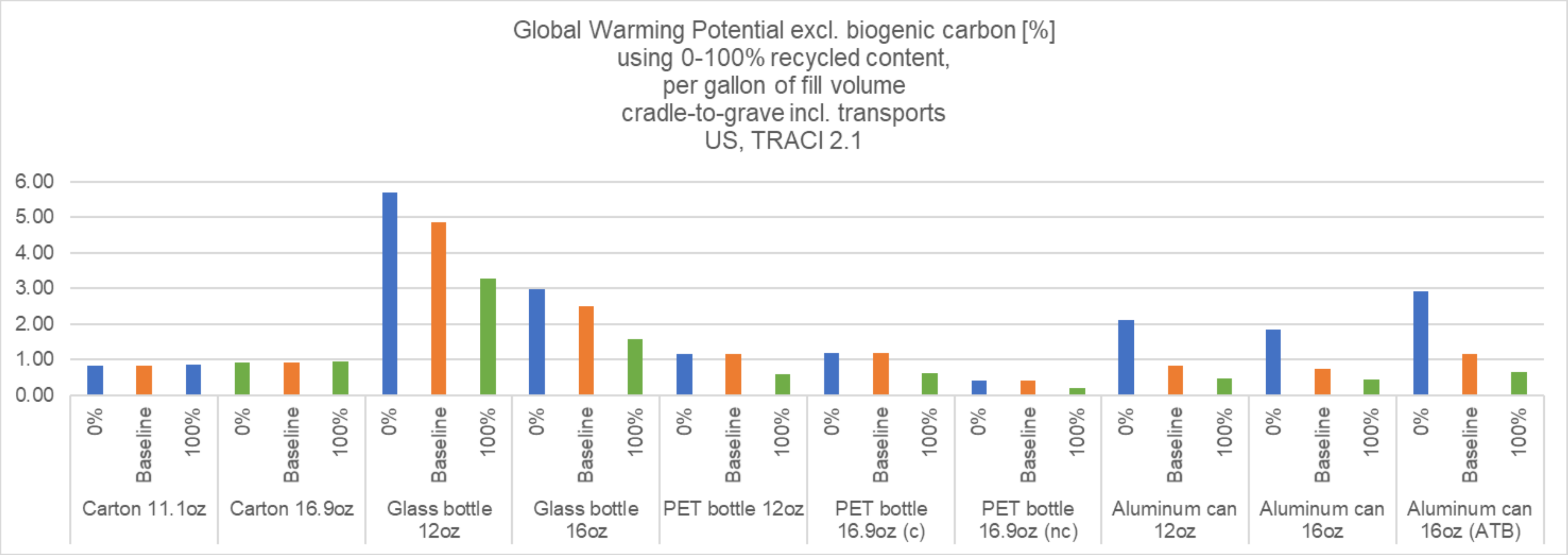

Figure 5-15: **Sensitivity analysis: Global Warming Potential change in relation to recycled content in each of the packaging options. Cradle-to-grave incl. transports, shown perf gallon of fill volume.**

5.5.3. Sensitivity to energy consumption in PET manufacturing

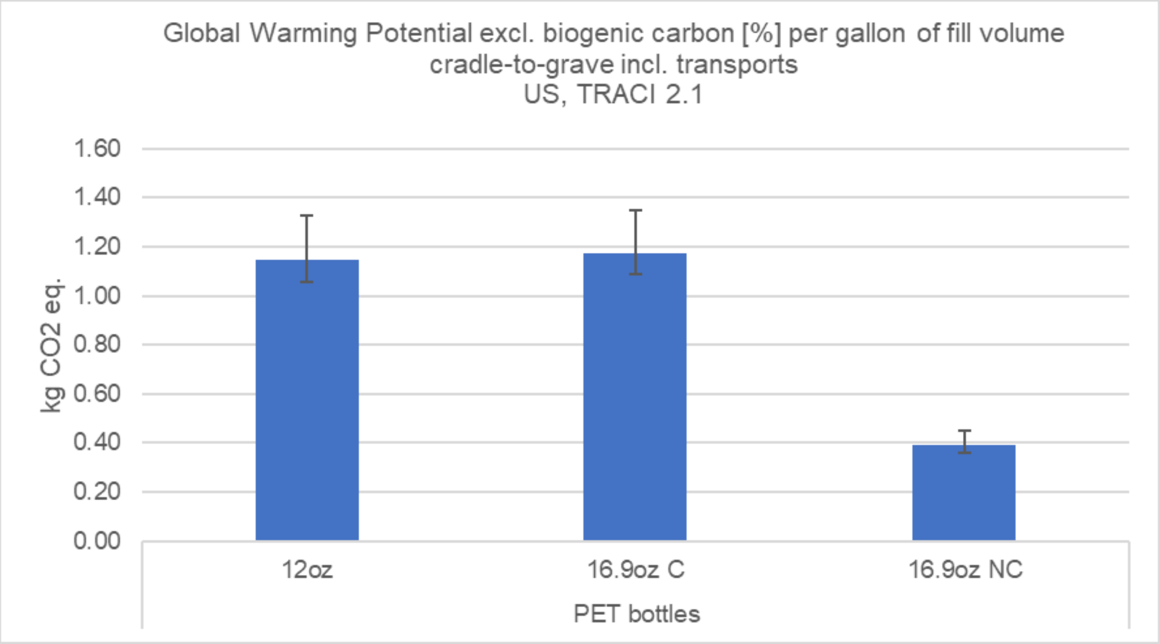

Figure 5-16: The variation in climate change impact for each PET bottle when energy consumption is doubled (upper error bar) and reduced to half the original value (lower error bar).

In terms of data quality, an uncertainty rests within the PET bottle manufacturing process. As described previously, a blow molding process was used originally developed for HDPE bottles. The intended application range of this dataset was for bottles in the range of 0.5 to 4kg sizes, which is significantly larger than the bottle weights in this study (>10x). In the baseline study, we applied the lowest end of this range, i.e. 0.5kg, and the associated energy consumption. The resulting energy consumption is fully in line with the - to the authors' and peer reviewers' knowledge - only ever published LCI dataset specifically developed for stretch blow molding of PET bottles, unfortunately no longer supported by PlasticsEurope[9]. Given the uncertainty and missing primary information on the specific stretch blow molding process for small PET bottles, the authors have explored the potential implications of lowering the energy consumption of this process to half the original (0.5x), and double (2x) the original value.

The results show there is a considerable difference in the climate change impact of each PET bottle if energy consumption is halved or doubled. Energy consumption in manufacturing the bottle contributes about 15% of the baseline climate change impacts for PET bottles, so changing the amount of energy consumed will influence the overall climate change impact of the products by 7-16% (min and max values, respectively).

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[9] To the authors' knowledge PlasticsEurope could not maintain the dataset because PET converters did not provide (sufficient) data.

5.6. Uncertainty analysis

The following section summarizes two aspects of variation explored in the results of this study. The first aspect describes the uncertainty in climate change impact for each packaging format assessed, with respect to data quality and methodology. The second aspect describes the potential variability of climate change impact of each packaging type based on sensitivity analyses performed to assess *potential for change in the future*. Together, the results are intended to show the maximum potential improvements and worst-case outcomes identified for each packaging type. Ultimately, this chapter is designed to allow the reader to understand the reliability of the results and identify the maximum potential improvement in performance for each packaging type by adopting the changes defined in the sensitivity analyses.

Thus, the uncertainty analysis presented in Figure 5-17considered the following scenario and sensitivity analyses:

- Methodology of secondary materials and End of Life treatment of waste (Substitution vs cut-off) (section 5.4.1)
- Manufacturing energy of the PET bottle (section 5.5.3)

In addition to the above uncertainties, further variability was included in Figure 5-18 to account for potential future change:

- Product lightweighting (section 5.5.1)
- Recycled content 0-100% (section 5.5.2)
- Renewable energy for can manufacturing (section 5.4.2)

There is little recorded uncertainty for the beverage cartons (Figure 5-17), and little improvement potential found in the variability analysis (Figure 5-18). This is because the cartons are not significantly affected by methodological differences in the underlying recycling methodology for the study. They respond to improving the amount of recycled content, but are not significantly affected by increasing the recycled content.

The PET bottles show a degree of uncertainty around the baseline impact recorded (Figure 5-17) which is related to uncertainties in the amount of energy consumed during the PET blow-molding manufacturing process (chapter 5.5.3) and differences in the chosen recycling methodology. PET bottles show a significant potential for improvement overall (Figure 5-18), as they show a medium response to improvements in the recycled content.

The single use glass bottles show higher uncertainty related to the recycling methodology used, but also shows great potential for improvement dependent upon the recycled content and product weight.

The aluminum cans demonstrate a higher level of variability, which is derived from differences in the climate change impact found for the baseline recycling methodology and alternative (substitution) recycling methodology. The cans also have a significant potential for improvement based on the recycled content and switching the electricity grid mix supply used for manufacturing from fossil-based to renewable.

The potential improvements identified for each packaging type may be considered more attainable as the current infrastructure for glass refilling systems and recycling are changing rapidly due to new regulations tackling the circular economy.

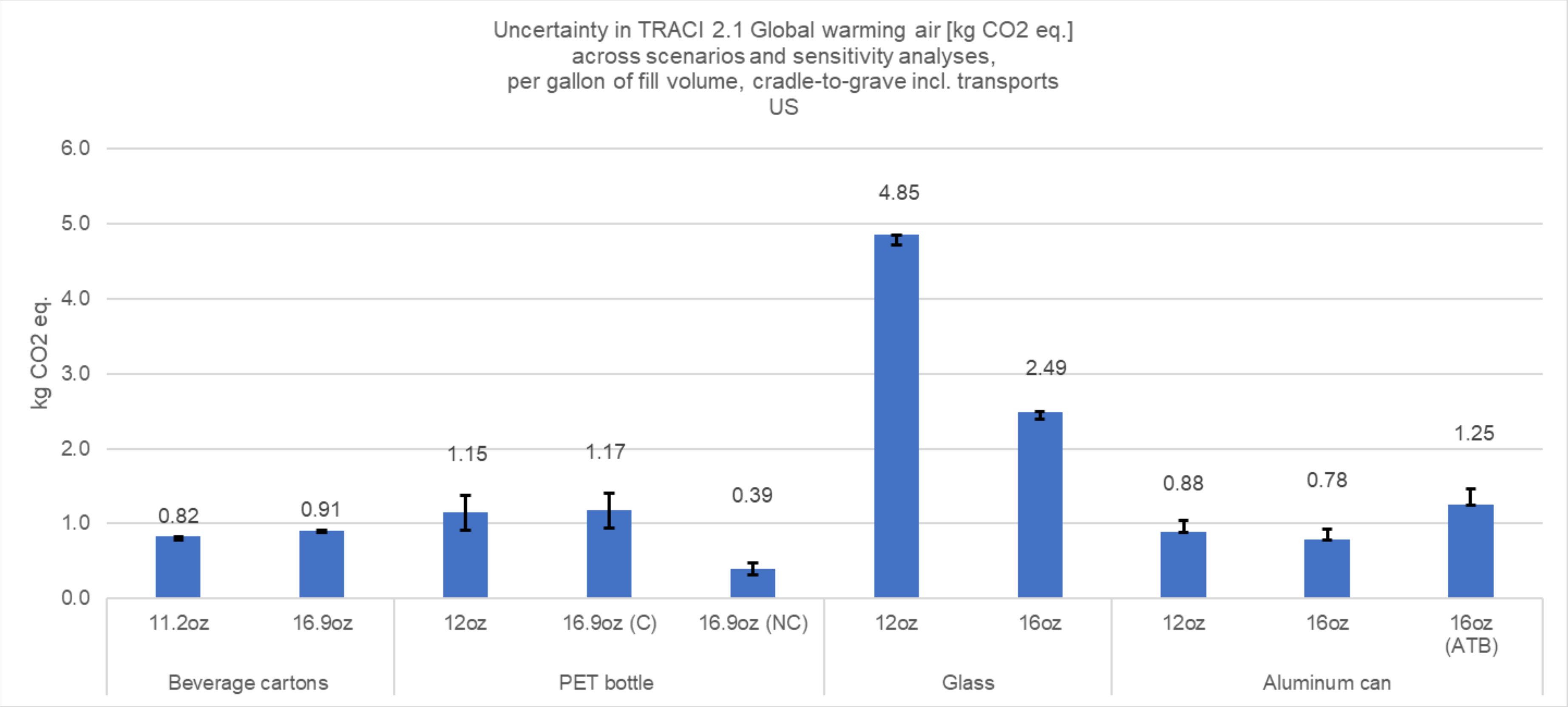

Figure 5-17: Uncertainty analysis of the TRACI 2.1 Global Warming Air [kg CO2 eq.] of products scaled to 1 gallon of fill volume, across various scenarios and sensitivity analysis. Values taken from Table 5-2: baseline – cut-off, min – minimum of values from scenario and sensitivity analyses under the column "Uncertainty", max– maximum of values from scenario and sensitivity analyses under the column "Uncertainty".

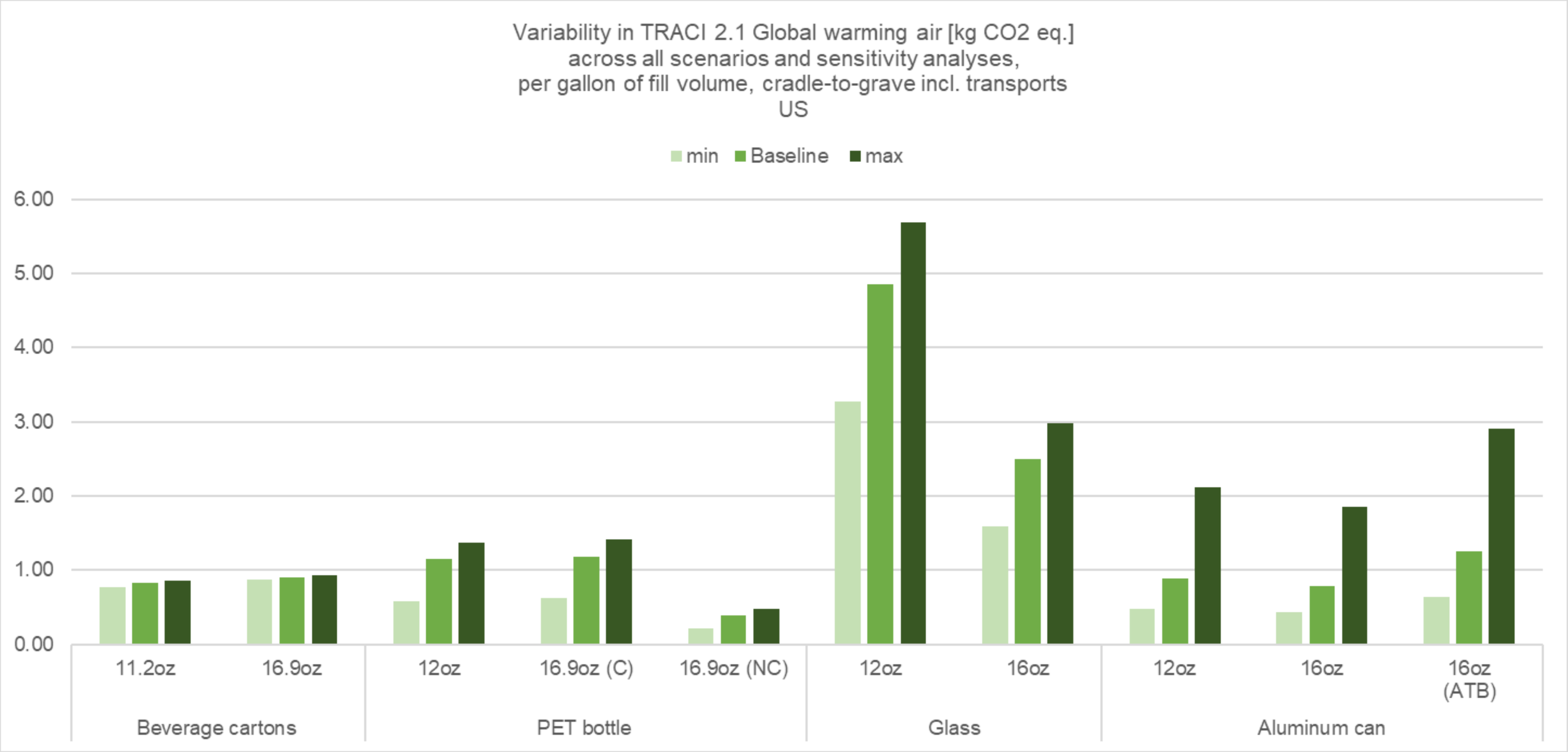

Figure 5-18: **Variability analysis of the TRACI 2.1 Global Warming Air [kg CO2 eq.] of products scaled to 1 gallon of fill volume, cradle-to-grave incl. transports, across all scenarios and sensitivity analysis. Values taken from Table 5-2: baseline – cut-off, min – minimum of values from all scenario and sensitivity analyses, max– maximum of values from all scenario and sensitivity analyses.**

Table 5-2: TRACI 2.1 Global Warming Air [kg CO2 eq.] of products scaled to 1 gallon of fill volume, cradle-to-grave incl. transports. Summary of scenario and sensitivity analyses in US region and calculation of variability by means of minimum and maximum values. Grey cells denote the lack of a corresponding scenario / sensitivity analysis.

			Uncertainty				**Future change potential**			
		Baseline	**Scenario**	**Sensitivity analyses**		**Scenario**	**Sensitivity analyses**		
Material	**Sizes**	**Cut-Off**	**Substitution**	**PET mfg energy consumption (15% more)**	**PET mfg energy consumption (15% less)**	**Renewable energy for can mfg**	**Lightweighting (10% less)**	**Recycled content (0%)**	**Recycled content (100%)**
Beverage cartons	11.2oz	0.82	0.78				0.77	0.82	0.85
	16.9oz	0.91	0.88				0.86	0.91	0.93
PET bottle (C)	12oz	1.15	0.99	1.38	0.92		1.04	1.15	0.58
	16.9oz	1.17	1.02	1.41	0.94		1.07	1.17	0.63
PET bottle (NC)	16.9oz	0.39	0.34	0.47	0.31		0.36	0.39	0.21
Glass (single use)	12oz	4.85	4.72				4.45	5.69	3.28
	16oz	2.49	2.40				2.26	2.98	1.58
Aluminum can	12oz	0.88	1.05			0.79	0.82	2.12	0.48
	16oz	0.78	0.93			0.67	0.73	1.85	0.43
	16oz (ATB)	1.25	1.46			1.04	1.15	2.91	0.63

6. Life Cycle Impact Assessment: BR

The overall results have been assessed using four indicators which evaluate the performance of each beverage packaging product, covering: terrestrial acidification, freshwater eutrophication, global warming potential (GWP) and abiotic depletion. The results for all environmental indicators assessed are included in Annex F: Extended LCIA Results.

The LCIA results include contribution analyses, which split the results according to the following life cycle stages: manufacturing, secondary packaging, transport to filling, distribution and end of life. This enables the reader to understand the influence of each life cycle stage on the overall environmental performance of the product.

The 0.6L glass bottle is designed to be refilled, therefore the baseline scenario assumes an ambitious 20 refill cycles. Additional sensitivity analysis explores the sensitivity as it relates to varying number of refills. An additional scenario explores the potential change of results under the theoretical extreme cases of 0-100% collection rates for recycling. While both extremes are unlikely, an exploration of the sensitivity of each packaging alternative within these thresholds was deemed important to assess their potential for change in future scenarios.

While PET bottles, glass bottles and beverage cartons are all using liter fill volumes in Brazil, aluminum cans are typically described in fluid ounces. One fluid ounce equates to 29.6ml.

Aluminum can size in ounces	Can sizes in liters
12oz	0.355L
16oz	0.473L
24oz	0.71L

6.1. Overall results

6.1.1. Terrestrial acidification

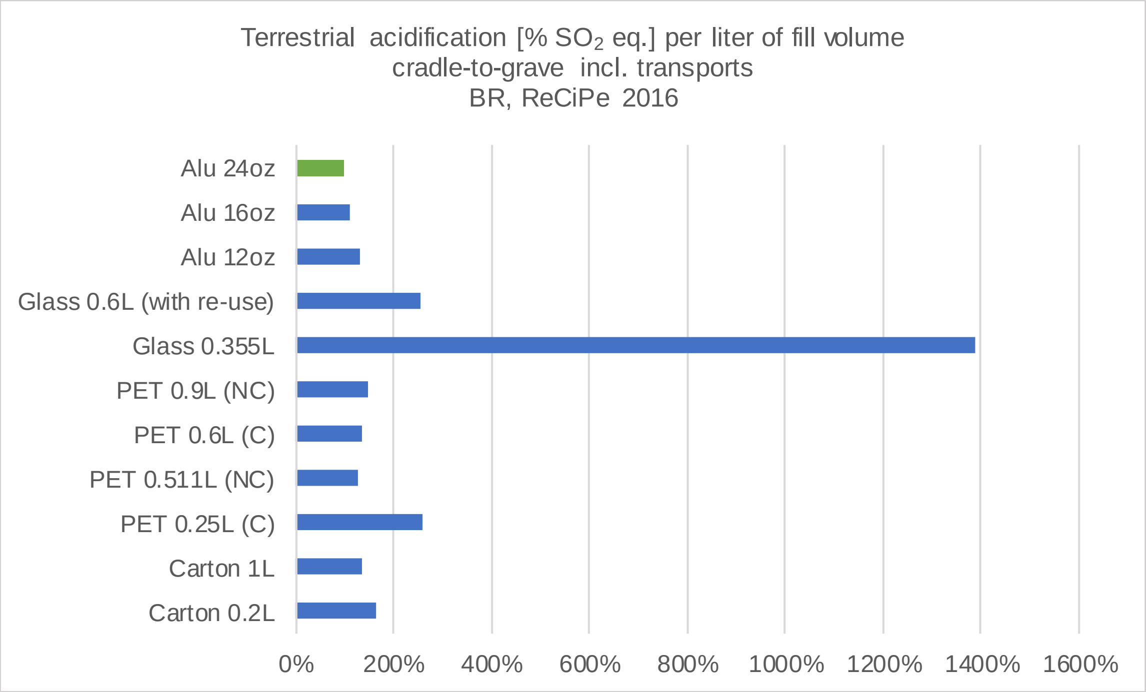

Figure 6-1: **Terrestrial acidification results of each of the compared products scaled to 1 liter of fill volume, using the ReCiPe 2016 method.**

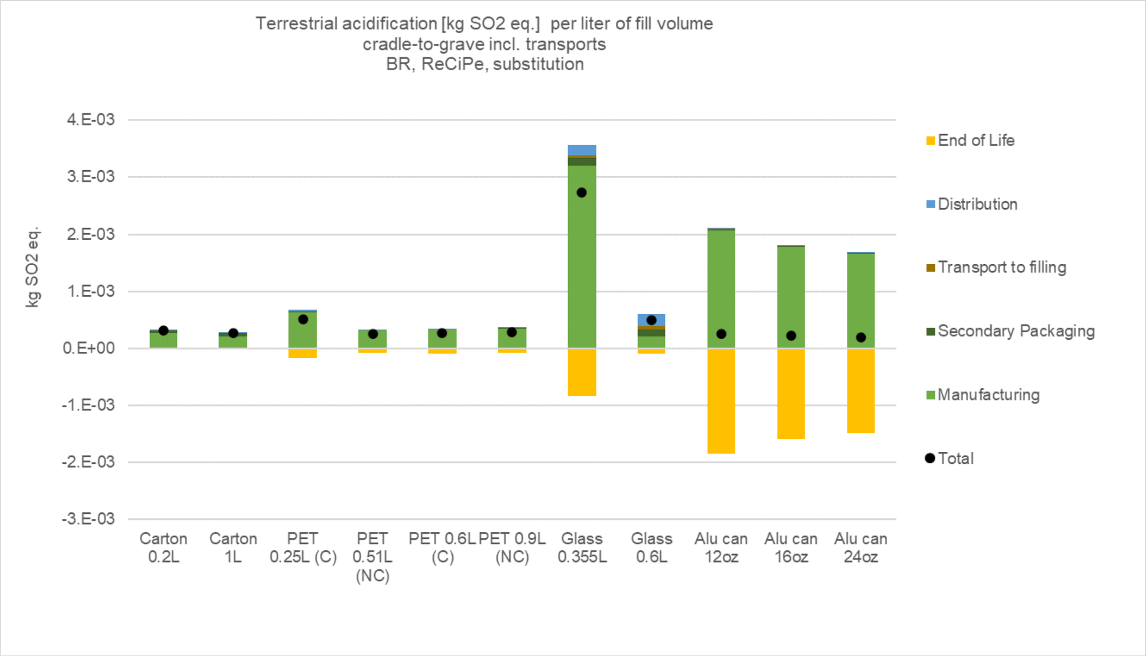

Figure 6-2: **The contribution of different life cycle stages/production processes to the overall terrestrial acidification results scaled to 1 liter of fill volume, using the ReCiPe 2016 method.**

Terrestrial acidification mainly occurs when acid air pollutants such as SO_2, NO_2 are washed out of the atmosphere during rainfall and converted into acids such as H_2SO_4 and HNO_3. These acids can cause ecosystem nutrient imbalances, increase the solubility of metals into soils and corrode calcium carbonate rocks like limestone.

Single-use glass bottles have considerably higher burdens for acidification potential than other options. This partly reflects the high mass compared to other packaging formats and the relatively energy intensive production process for glass manufacture. However, the nature of glass production itself also contributes large amounts of nitrogen monoxide, which are generated during the batch formulation step. Nitrogen monoxide accounts for about 30% of the total acidification for glass bottles but less than 1% for the other packaging options. This also explains why the environmental performance of the re-usable 600ml glass bottle is significantly better – the burdens from raw material production are shared over multiple uses.

Aluminum cans show relatively high burdens related to terrestrial acidification during manufacturing, related to the virgin aluminum production. However, the high recycling rate for beverage cans in Brazil (97%) at end of life results in very significant credits so that aluminum cans are the best performers in this impact category.

Cartons and PET bottles also show very low acidification impacts, only marginally greater than those for aluminum cans.

As with other categories, there are observable improvements in performance as the fill volume of the packaging formats increase, reflecting the improved packaging-to-product ratio of larger pack sizes.

6.1.2. Freshwater eutrophication

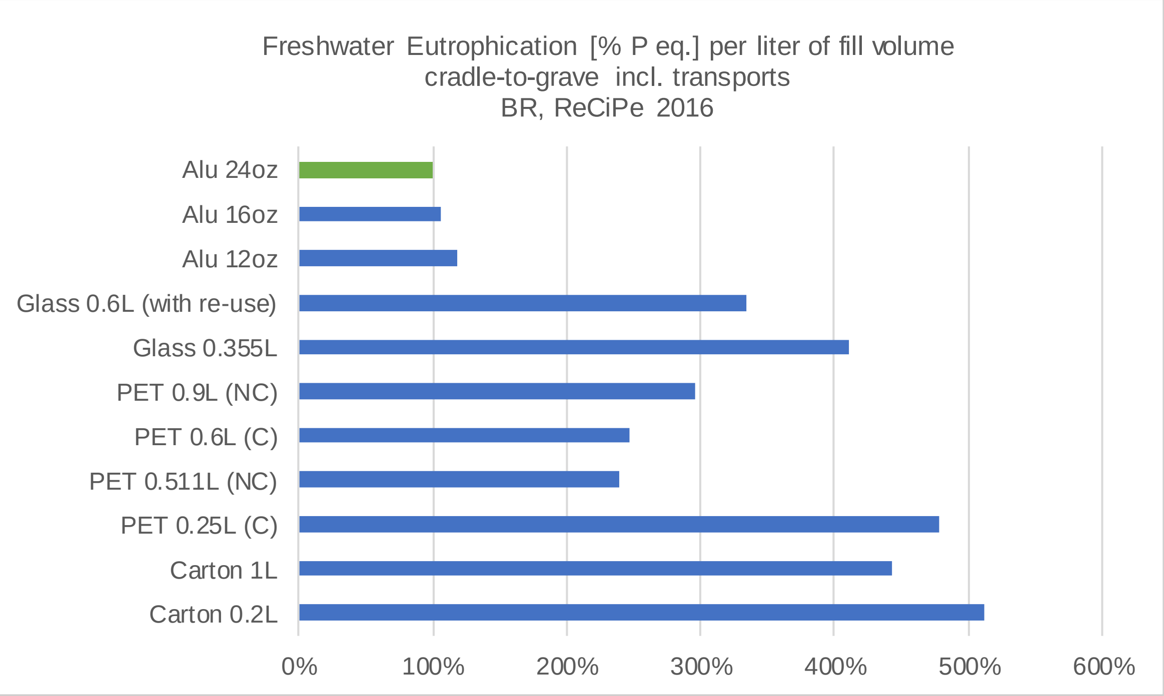

Figure 6-3: Freshwater eutrophication results of each of the compared scenarios scaled to 1 liter of fill volume, using the ReCiPe 2016 method.

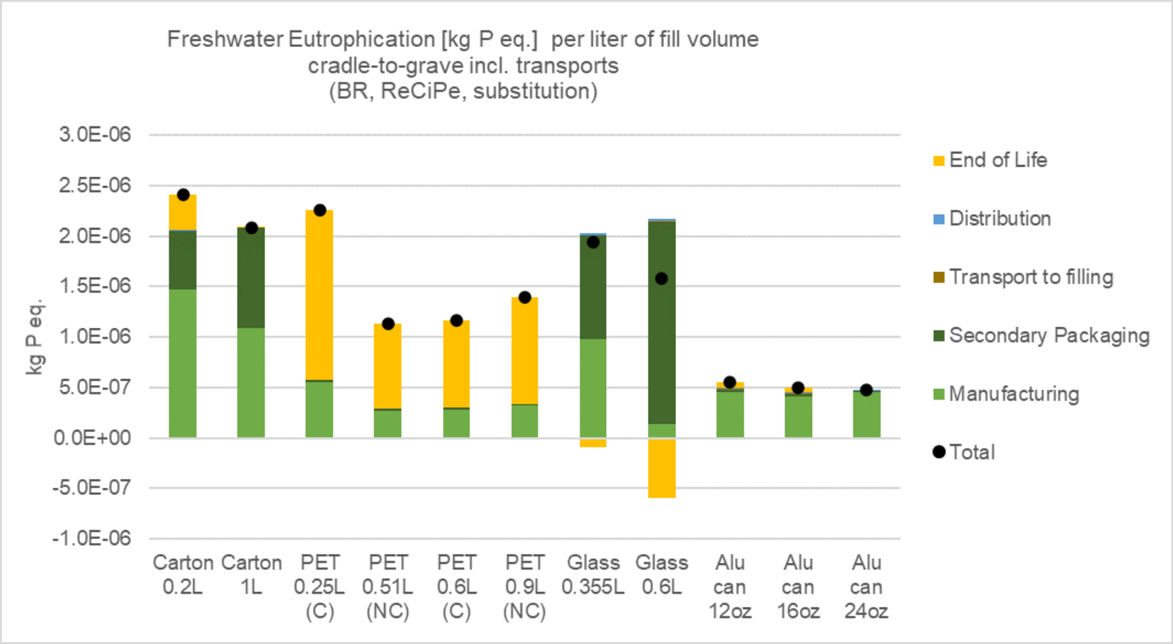

Figure 6-4: **The contribution of different life cycle stages/processes to the overall freshwater eutrophication results, scaled to 1 liter of fill volume, using the ReCiPe 2016 method.**

Freshwater eutrophication is driven by phosphate emissions, as this is usually the limiting nutrient in freshwater ecosystems. These emissions commonly reach fresh water supplies by leaching into ground water or as direct run-off from agriculture (due to fertilizer use) and can unbalance ecosystems causing algal blooms and fish kills.

The overall results show the aluminum cans have a lower contribution to freshwater eutrophication than the other products, which all share a similar environmental performance in this category.

As with acidification, reductions can be observed in burdens as the pack size increases and packaging efficiency improves.

The manufacturing stage is the dominant contributor to the performance of the paperboard cartons and aluminum cans, as well as the 0.355L single-use glass bottle. Water-intensive manufacturing results in high amounts of waste water, which in turn release emissions that lead to freshwater eutrophication. Paper manufacturing especially is associated with high eutrophication, as is shown in the both the manufacturing of the beverage cartons and the relevance of secondary packaging (mostly cardboard). Also relevant is the End of Life washing of glass bottles prior to refill and the washing steps during PET recycling.

6.1.3. Global Warming Potential

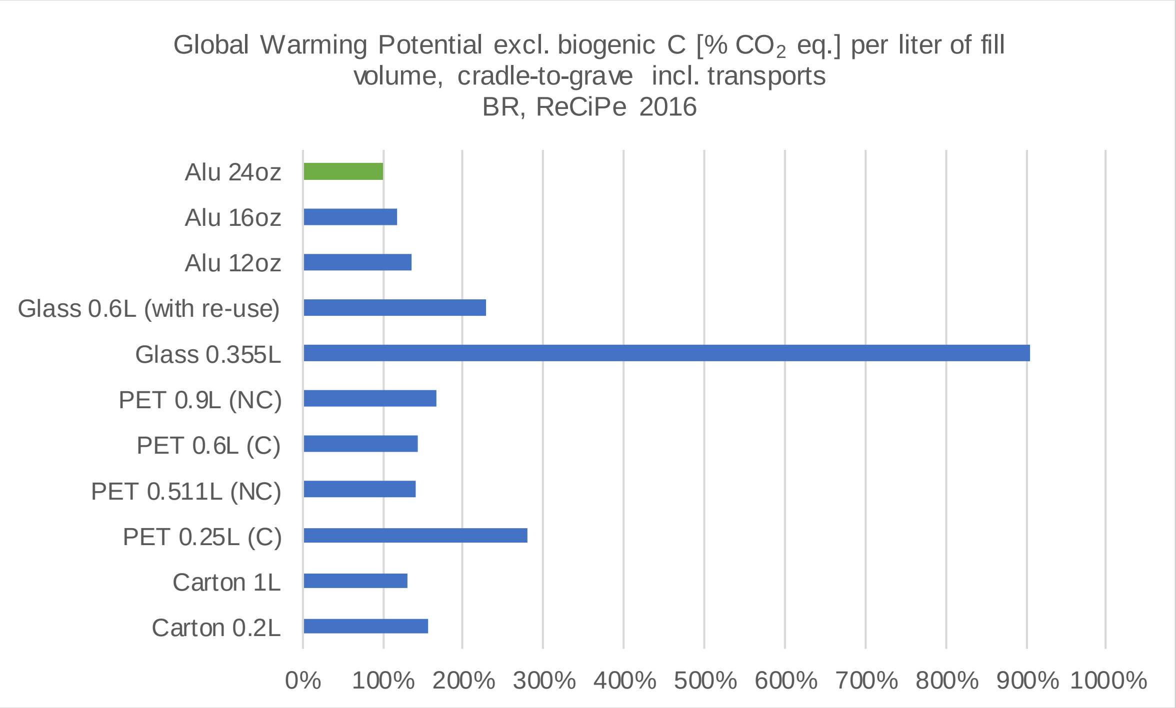

Figure 6-5: **Global warming potential results of each of the compared scaled to 1 liter of fill volume, using the ReCiPe 2016 method.**

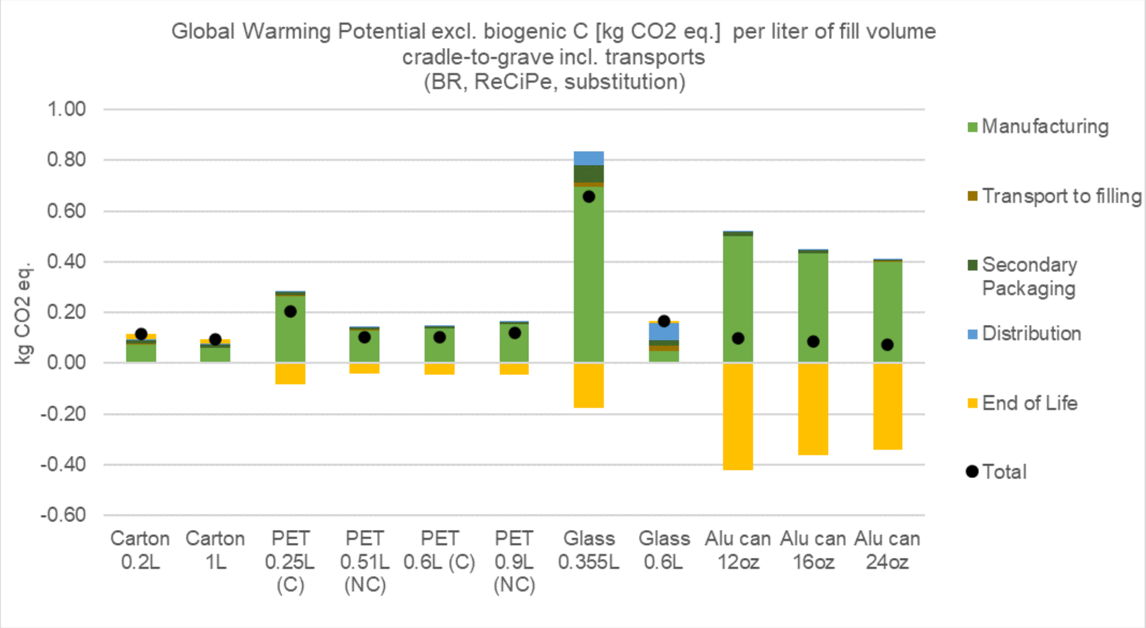

Figure 6-6: **The contribution of different life cycle stages/production processes to the overall global warming potential results, scaled to 1 liter of fill volume, using the ReCiPe 2016 method.**

Global warming potential (GWP) is driven by inorganic and organic emissions to air, primarily carbon dioxide and methane.

The 0.35L single-use glass bottle shows the largest GWP, followed by PET bottles, beverage cartons and aluminum cans with the lowest impact. This is unsurprising given that glass bottle production is energy intensive and the glass container mass is 10x greater than for PET bottles and 20x greater than for aluminum cans and beverage cartons. The 0.6L glass bottle that is refilled 20 times has a much lower GWP, about the same as PET bottles. This underlines the environmental benefits that can be accrued by designing efficient refill systems for beverage packaging (e.g. standardized bottles).

The contribution analysis shows the manufacturing stage is the dominant contributor to GWP for all products. Cartons show the lowest GWP from this life cycle stage because they are predominantly made from paperboard made from virgin fibers, generating by-products (bark, forestry off cuts, wood chips, black liquor, etc.) that serve as renewable fuel for the pulp and papermaking process. Removals and emissions of biogenic carbon dioxide are not shown in these results but will roughly be balanced over the packaging lifetime. Carbon dioxide sequestered during tree growth is re-emitted at end of life, resulting in overall zero net emission of greenhouse gases unless the carbon is converted to methane e.g. on a landfill site. Biogenic carbon converted to methane is included in these results.

The results are all scaled to a functional unit of 1 liter of fill volume, and this impact category once again demonstrates how product-to-packaging ratios influence environmental performance when normalized per liter. Larger bottles require less packaging to contain a given quantity of beverage compared to smaller bottles.

Aluminum cans also have a relatively high impact associated with manufacturing (primarily due to the burdens associated with scrap input), but this is largely offset by the end of life processes due to their very high recycling rate at end of life, thus making aluminum the best performer in this category when summing all life cycle stages.

6.1.4. Abiotic depletion potential

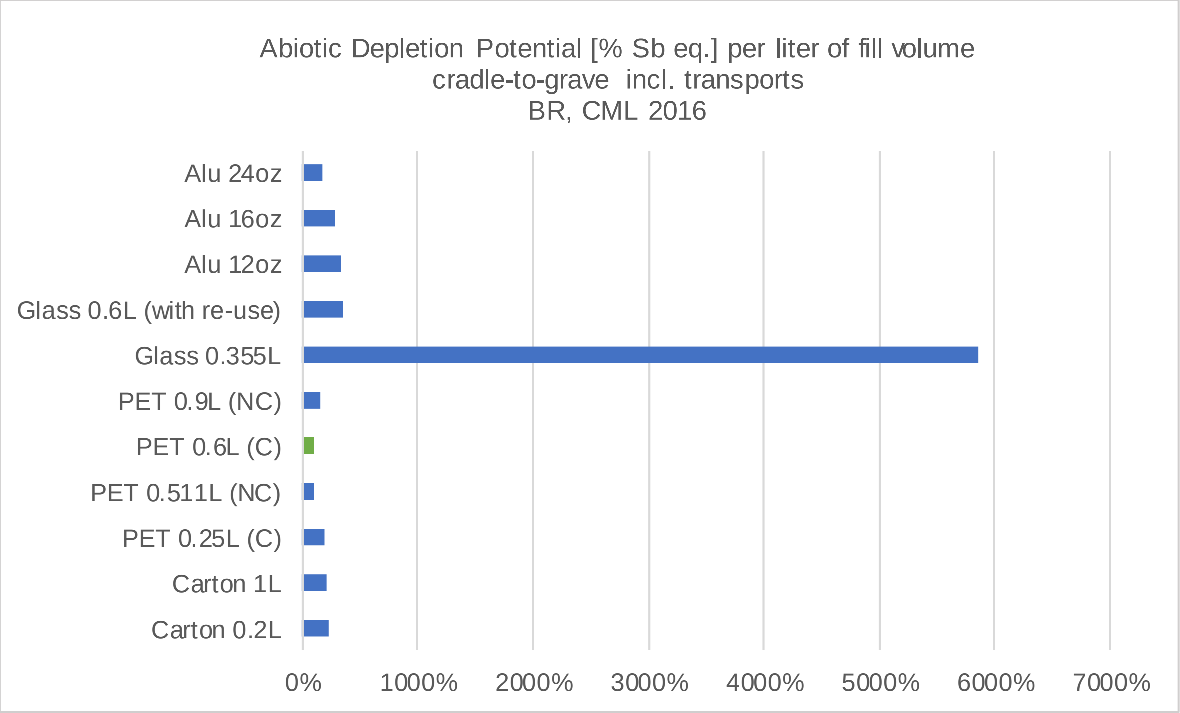

Figure 6-7: Abiotic depletion potential results of each of the compared scenarios scaled to 1 liter of fill volume, using the CML method.

Single-use glass bottles show far greater environmental burdens related to mineral resource depletion than other product types. The main driver for this is the use of sodium chloride, which accounts for over 99% of the total burden due to the synthetic pathway through which soda, one of the main virgin raw materials for glass, is produced. The synthetic pathway in the background of this substance is sodium chloride (brine), and as a mainly mined resource, its abiotic depletion potential is automatically high. As mentioned before, this impact category does not take into account resources that may be in circulation in the economy, but suggests that the removal of resources from the mineral reserves of the Earth's crust affects their scarcity.

The impacts associated with reusable glass bottles are much lower, but still greater than for most other packaging options assessed in this study. Aluminum cans have the next highest burdens while PET bottles and cartons are the least impactful, simply because no mined resources (oil extraction does not count) are part of their value chain.

6.2. Detailed results

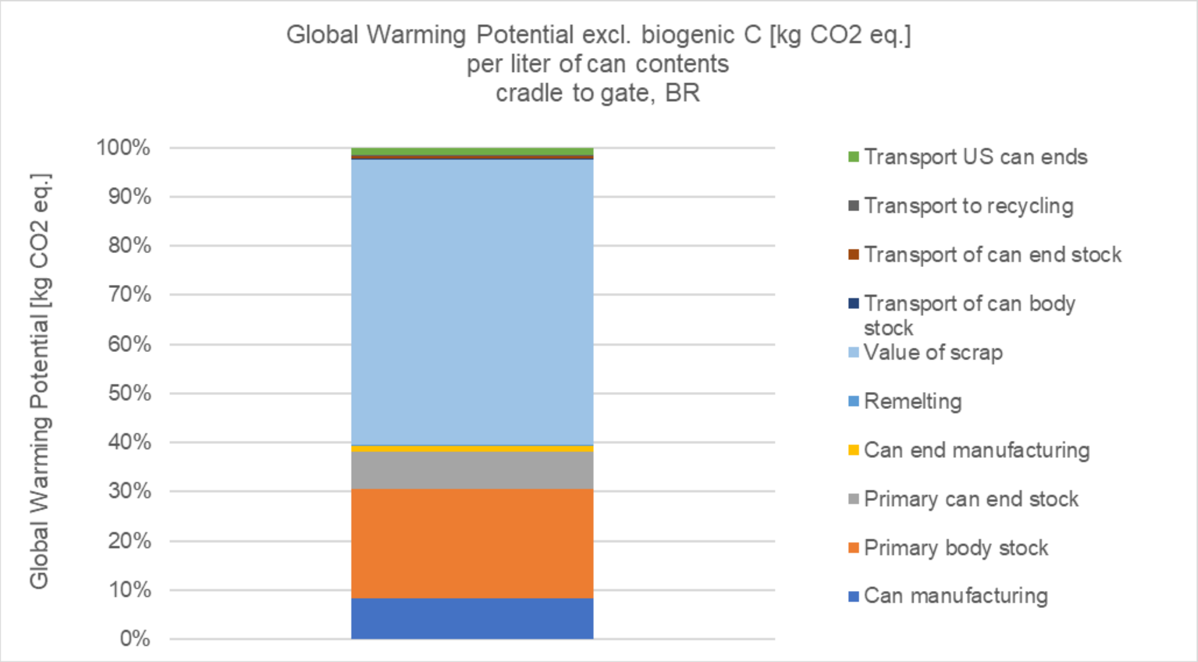

Figure 6-8: Detailed global warming potential contributions in the manufacturing phase of the 12oz aluminum can, shown per liter of fill volume, using the ReCiPe 2016 method.

The contribution analysis for the manufacturing stages of the aluminum can shows the “value of scrap” process accounts for over 50% of the total GWP, considering cradle-to-gate impacts only.

These burdens are assigned because the ISO standard for the substitution method require that inputs and outputs be treated equivalently. Because credits are received for recycling material at end of life (calculated as the burdens of the recycling process minus the burdens of an equivalent amount of virgin production), then equivalent burdens must be applied for scrap consumed during the manufacturing process. The value of scrap is then calculated as the inverse of the credits at the End of Life.

Due to the very high recycling rate in Brazil, the credits received for recycling will more than offset the burdens of the input scrap when the full cradle-to-grave scope is assessed, as can be seen in the previous results.

The GWP related to the remaining manufacturing processes are predominantly derived from the mining, refining, smelting/remelting and rolling of aluminum . The can manufacturing process accounts for a relatively small proportion of the overall burdens of production. Burdens from transport processes are negligible.

6.3. Material Circularity Indicator (MCI) Results

Figure 6-9 shows the results for the material circularity indicator for each of the packaging formats assessed in this study for Brazil.

Three aspects of the product’s life cycle influence the MCI score, as follows:

- Proportion of input material flows that are from reused or recycled sources, or from sustainably sourced biological material (e.g. FSC certified paper)
- Proportion of waste flows that are reused or recycled at end of life
- Product utility measured as the number of reuse cycles compared to the average situation (single-use).

Figure 6-9: Material Circularity Indicator results for the different packaging options (Brazil)

The glass bottle packaging option which is re-used 20 times achieves the highest MCI score of 0.99, indicating this packaging option – according to the MCI methodology – is almost completely circular. By comparison, the single-use glass bottle has an intermediate MCI score of only ~0.5, which demonstrates the benefits of re-using packaging on the circularity score (see next section also). Both glass bottles have an assumed recycled content of around 44% and a recycling rate at end of life of 47%.

The aluminum cans also perform very strongly, despite being single use, with MCI scores above 0.8. These reflect the very high rate of recycled content (78%) and of recycling at end of life (97%), as well as very low recycling yield losses compared to other substrates. The small differences between the MCI scores for different can sizes is mainly due to differences in secondary packaging.

Beverage cartons have an MCI score of around 0.5-0.6. These contain 72% paperboard, which is assumed to be sustainably sourced and therefore considered to be restorative (circular) in nature. However, the end of life recycling rate is only 29% and of this, only the paper fraction is assumed to be recycled. Compared to other packaging formats, the mass of secondary packaging for beverage cartons is relatively high compared to the mass of the primary pack. This gives a positive contribution to the MCI as it is mostly made from cardboard that is also assumed to be sustainably sourced and has a very high recycling rate at end of life. Provided that the carton in the primary packaging is not sourced sustainably, the MCI would sink to 0.33 in case of the 0.2L format, and to 0.45 in case of the 1L format.

PET bottles have the lowest MCI scores among the packaging formats assessed for Brazil, with values of only around 0.3. This is primarily due to the complete lack of recycled or reused materials for making the PET bottles and relatively low recycling rates (59%) compared to e.g. beverage cans.

6.4. Scenario analyses

6.4.1. Scenario: Glass bottle refill cycles

Some glass bottles in Brazil, in particular for the beer market, are refilled. Those bottles are typically produced with thicker walls compared to single use glass to sustain the multiple cycles of transport, washing, refill and use. The baseline scenario for the glass bottles assessed in the overall results describes a 0.6L glass bottle with 20 re-fills, and a 0.35L single-use glass bottle. To fully demonstrate the reduction in environmental burdens by re-using the glass bottles as well as the consequences of not re-filling, the GWP of the 0.6L glass bottle filled only once is compared with re-filling 5 to 20 times, in reference to the single-use bottle in Figure 6-10. To show how altering the use cycles of the product influences each stage of the product life cycle, a contribution analysis is also shown.

By shifting from using a glass bottle once to re-filling it 20 times, the GWP of the product is reduced by 78%. Despite the fact that 0.6L glass bottles have a higher overall mass and with that increased resource demand when compared to the single-use 0.35L glass bottle, by re-filling the 0.6L bottle the manufacturing burdens and end of life burdens drop significantly. Transport provides a more significant contribution to the GWP of the re-filled 0.6L product, but the burdens of this process are not greatly different to the transport process of the single-use 0.355L glass bottle when calculating results for only one life cycle. The decrease in manufacturing impacts is observed because the more times the glass bottle is re-used, the associated burdens are spread across multiple life cycles, reducing the impacts measured for one life cycle assessment. Secondary packaging does not change across the scenarios, because the amount consumed is the same for each case.

The material circularity indicator (MCI) score of the glass bottles is also sensitive to the number of refills. It rises from 0.51 to 0.77 with just 1 refill, to 0.93 with 5 refills and may achieve a maximum MCI score of 0.986 when refilled 20 times, almost double the MCI score of the single-use glass bottle (Figure 6-9)

Overall, this clearly demonstrates the benefits of increasing the number of use cycles of glass bottles, by reducing the consumption of raw materials and manufacturing requirements. The question remains how many use cycles are in fact logistically (and economically) feasible.

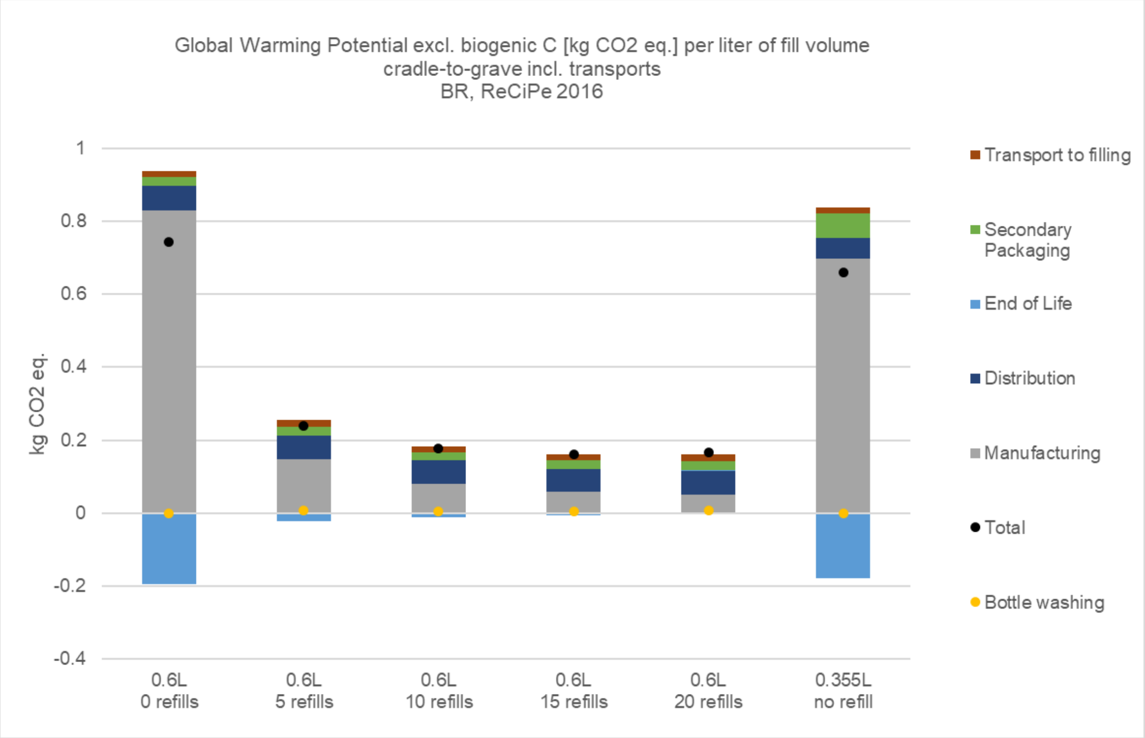

Figure 6-10: **Global warming potential results of the 0.6L glass bottle with 0 uses, 5 uses, 10 uses, 15 uses and 20 uses, and the single-use 0.355L bottle as a reference, scaled to 1 liter of fill volume, cradle-to-grave, using the ReCiPe 2016 method.**

6.4.2. **Sensitivity to collection rates for recycling**

To determine the influence of the end of life of each packaging format on the overall carbon footprint of the packaging, the results of the average collection rate is compared against a 0% collection rate scenario and a 100% collection rate scenario for each packaging format. **Figure** 6-11 shows all products given both extreme cases of collection for recycling rates.

The beverage cartons demonstrate both the best environmental performance under 0% recycling at end of life, and the least variation across the end of life scenarios.

Table 6-1: A summary of the average recycling rate of each packaging type considered in this study.

Packaging type	Average collection for recycling rate (%)
Beverage cartons	21 (paper fraction only)
PET bottles	59
Glass bottles	47
Aluminum cans	97

The GWP of the 0.2L beverage carton increased by 0-1% when the collection for recycling rate was increased from 0% to 100%. For the 1000ml carton it increased by 3-4%. This increase is a consequence of the reliance on external (largely fossil) energy sources in case of recycling, and by contrast, the largely internal and renewable source of energy when using virgin fibres.

Overall, these results suggest no environmental benefits related to GWP would be gained by increasing the circularity of the beverage carton packaging systems. It is important to note, however, that other impact categories, such as eutrophication would see a marked reduction in case of recycling, since the most water- and emission-intensive processes take place during pulping fresh fibres, which are not necessary during recycling.

A significant improvement is observed in the GWP of the PET bottles when the collection for recycling rate at end of life increases from 0% to 100%. Recycling PET reduces the demand for virgin petrochemically-derived plastic polymers, which have high associated environmental burdens. These results indicate environmental benefits may be acquired by increasing the circularity of the PET bottles at the end of life.

The GWP of glass bottles reduced by 50-60% when increasing the collection for recycling rate from 0% to 100%. The benefits of energy recovery from incinerating glass bottles are very small compared to recycling the glass cullet. These results indicate that increasing the material circularity of the glass bottle product systems has significant environmental benefits related to GWP.

Aluminum cans show a significant improvement in GWP when the collection for recycling rate increases from 0% to 100%. The average recycling rate of aluminum cans in Brazil is very high at 97% but closing the gap to a perfect recycling rate still yields some benefits. This indicates that a high material circularity for the aluminum cans product systems has substantial environmental benefits related to GWP and could be pursued to further improve the GWP performance of this packaging type.

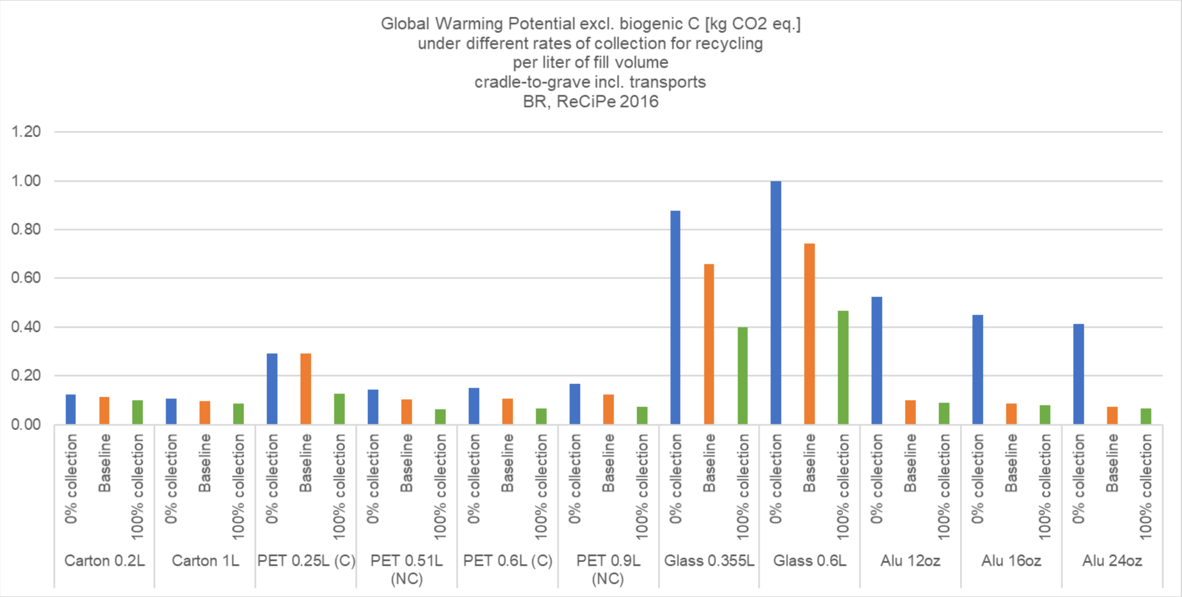

Figure 6-11: **Influence of collection/recycling rates on Global Warming Potential excl. biogenic C [kg CO2 eq.] of products, scaled to 1 liter per fill volume, cradle-to-grave incl. transports.**

6.4.3. Sensitivity to energy consumption

In terms of data quality, the most crucial uncertainty rests within the PET bottle manufacturing process. As described previously, a blow molding process was used originally developed for HDPE bottles. The intended application range of this dataset was for bottles in the range of 0.5 to 4kg sizes, which is significantly (>10x) larger than the bottle weights in this study. In the baseline study, we applied the lowest end of this range, i.e. 0.5kg, and the associated energy consumption. The resulting energy consumption is fully in line with the - to the authors' knowledge - only ever published LCI dataset specifically developed for stretch blow molding of PET bottles, unfortunately no longer supported by PlasticsEurope[10]. Given the uncertainty and missing primary information on the specific stretch blow molding process for small PET bottles, the authors have explored the potential implications of lowering the energy consumption of this process to half the original (0.5x), and double (2x) the original value.

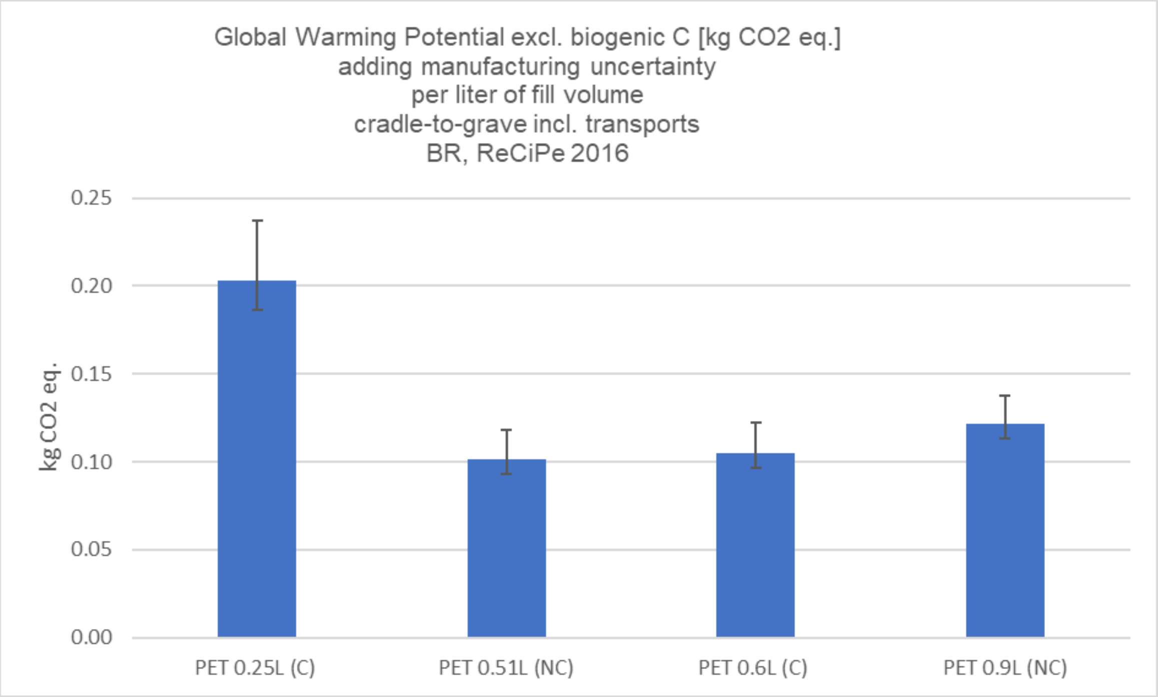

Figure 6-12: **Influence of energy consumption in PET bottle manufacturing on Global Warming Potential excl. biogenic C [kg CO2 eq.], scaled to 1 liter per fill volume, cradle-to-grave incl. transports.**

The results show there is a notable difference in the GWP impact of each PET bottle if the values of energy consumption are doubled or halved.. Energy consumption in manufacturing the bottle contributes about 15% of the baseline climate change impacts for PET bottles, so changing the amount of energy consumed will also influence the overall climate change impact of the products by 7-16% (min and max values, respectively).

6.5. Uncertainty analysis

The following section summarizes two aspects of variability explored in the results of this study. The first aspect describes the uncertainty in climate change impact for each packaging format assessed, with respect to data quality. The second aspect describes the potential variability of climate change impact of each packaging type based on sensitivity analyses performed to assess *potential for change in the future*. Together, the results are intended to show the maximum potential

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[10] To the authors' knowledge PlasticsEurope could not maintain the dataset because PET converters did not provide (sufficient) data.

improvements and worst case outcomes identified for each packaging type. Ultimately, this chapter is designed to allow the reader to understand the reliability of the results and identify the maximum potential improvement in performance for each packaging type by adopting the changes defined in the sensitivity analyses.

Thus, the uncertainty analysis presented in Figure 6-13 considered the following scenario and sensitivity analyses:

- Refill of the glass bottle (section 6.4.1)
- Energy consumption of PET bottle manufacturing (section 6.4.3)

In addition to the above uncertainties, further variability was included in Figure 6-14 to account for potential future change:

- Collection for recycling 0-100% (section 6.4.2)

No uncertainty was calculated for the beverage cartons (Figure 6-13), and no significant improvement potential found in the variability analysis (Figure 6-14). This is because the cartons are not significantly affected by changes to the recycling / collection rate.

For PET bottles, the uncertainty in manufacturing energy added a considerable uncertainty to the results, in both directions. The PET bottles do show a significant potential for improvement overall (Figure 6-14), as they show a strong response to improvements in the collection rate for recycling.

The single use glass bottle was not tested for uncertainty; however, the refillable glass bottle shows substantial uncertainty in GWP dependent on whether or not it is actually refilled, and by how many times. Both glass bottle options show significant potential for improvement based on improvements to the recycling / collection rate.

Although current recycling rates of aluminum cans are already close to 100%, there is still some potential for improvement, demonstrating the high value of this recyclate.

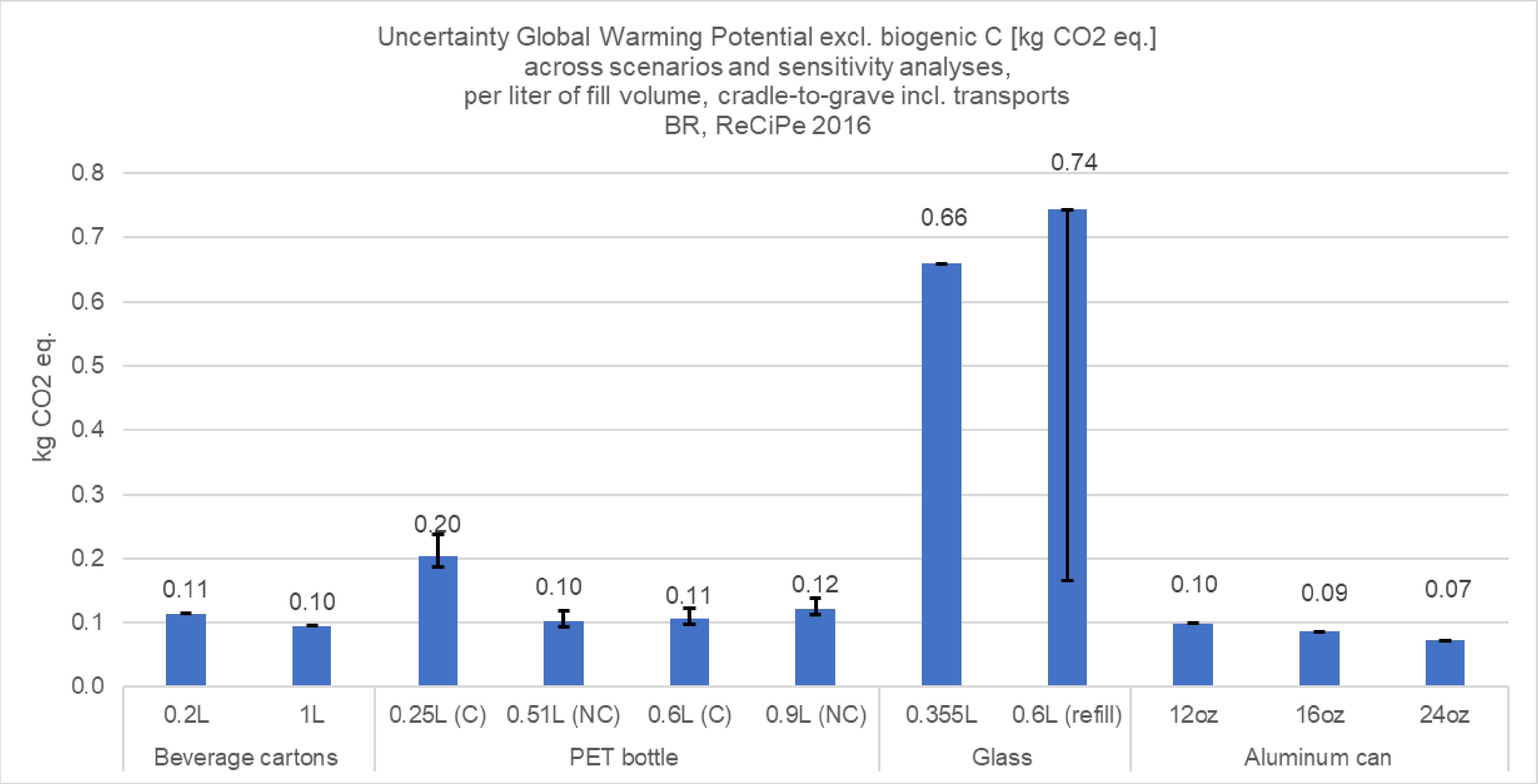

Figure 6-13: **Uncertainty analysis of the Global Warming Potential excl. biogenic C [kg CO2 eq.] of products, scaled to 1 liter per fill volume, cradle-to-grave incl. transports, based on the results of the glass refilling sensitivity analysis and the uncertainty assumed in PET bottle manufacturing. Values taken from Table 6-2: baseline – substitution, min – minimum of values from scenario and sensitivity analyses under the column “Uncertainty”, max– maximum of values from scenario and sensitivity analyses under the column “Uncertainty”.**

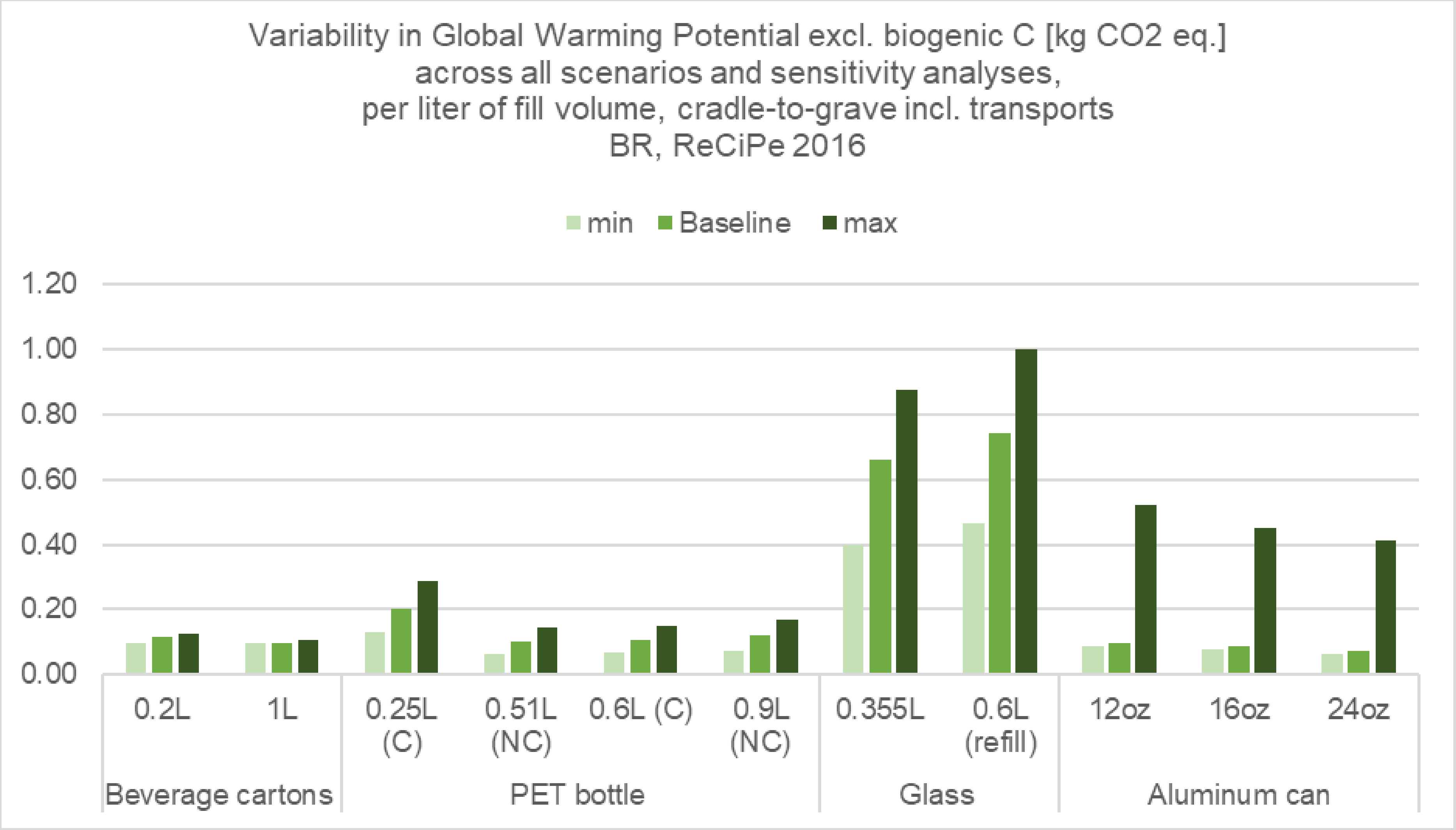

Figure 6-14: **Uncertainty analysis of the Global Warming Potential excl. biogenic C [kg CO2 eq.] of products, scaled to 1 liter per fill volume, cradle-to-grave incl. transports, based on all scenario and sensitivity analyses. Values taken from Table 6-2: baseline – substitution, min – minimum of values from all scenario and sensitivity analyses, max– maximum of values from all scenario and sensitivity analyses.**

Table 6-2: Uncertainty analysis of the Global Warming Potential excl. biogenic C [kg CO2 eq.] of products, scaled to 1 liter per fill volume, cradle-to-grave incl. transports, across all sensitivity analyses.

			Uncertainty			**Future change potential**	
		Baseline	**Sensitivity analyses**			**Sensitivity analysis**	
Material	**Sizes**	**Substitution**	**PET mfg energy consumption (2x baseline)**	**PET mfg energy consumption (0.5x baseline)**	**Glass bottle 20 re-use cycles**	**0% recycling rate**	**100% recycling rate**
Beverage cartons	0.2L	0.11				0.09	0.09
	1L	0.10				0.08	0.09
PET bottle	0.25L (C)	0.20	0.24	0.19		0.29	0.13
	0.51L (NC)	0.10	0.12	0.09		0.14	0.06
	0.6L (C)	0.11	0.12	0.10		0.15	0.07
	0.9L (NC)	0.12	0.14	0.11		0.17	0.07
Glass	0.35L	0.66				0.81	0.37
	0.6L (refill)	0.74			0.17	0.92	0.43
Aluminum can	12.0oz	0.10				0.50	0.08
	16.0oz	0.09				0.43	0.07
	24.0oz	0.07				0.40	0.06

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7. Interpretation

7.1. Identification of Relevant Findings

7.1.1. LCA Results for EU

- The single overall best performer in the selected impact categories in this study is the 0.5L PET bottle for non-carbonated water, due to a very thin-walled bottle design, resulting in a very favorable packaging-to-product ratio.
- As a material option for all non-carbonated beverages, however, beverage cartons perform more consistently well in climate change and acidification.
- The strong performance of beverage cartons is primarily due to the main raw material, paperboard (typically around 70% (w/w) of the carton), which tends to have low manufacturing impacts. If paperboard is produced in an integrated pulp and paper mill, most of the energy used will be derived from biomass such as wood offcuts from forestry, from bark and wood chips and from black liquor produced from the wood during pulp production. Many integrated paperboard mills export excess electricity to the grid, further reducing the production burdens.
- Among the material options for carbonated beverages, PET (C) bottles are a close match with aluminum cans in terms of climate change, and outperform them in other impact categories analyzed in this study. PET bottles fare well due to relatively low virgin material impacts and manufacturing-related impacts. At the same time, this means that unlike for aluminum cans and glass bottles, the use of recycled material does not result in significant improvements for most of the environmental impact categories.
- Aluminum cans are lightweight compared to most other packaging options which helps to reduce impacts. At 69%, the recycling rate at end of life is high while the average level of recycled content is higher than for any other substrate. Interestingly, while prescribed recycled content and recycling rates were directly taken from the PEF Guide and its Annex C, the latest data from European Aluminium reveals a higher recycling rate for beverage cans across Europe of 75%. Taking the higher recycling rate would certainly decrease the impact of aluminum cans further.
- The performance of different packaging types is influenced to some extent by methodological choices. The PEF CFF approach does not favor aluminum cans, 20% of the amount sent to recycling will be treated as cut-off, i.e. without material credit. On the input side, the formula accounts 80% of the recycled content as primary aluminum, thus increasing the impact overall. Importantly, the same approach does not disadvantage beverage cartons in terms of carbon footprint, because the virgin paper has an even better carbon footprint than the recycled one. By contrast, when using the alternative substitution approach, the high end of life recycling rate of aluminum reduces the relative difference to cartons, which have a much lower end of life recycling rate of only 43% (of fiber inputs only). The substitution approach also benefits PET bottles due to the credits accrued at the end of life, but to a lesser degree than aluminum cans.
- Improvement of recycling rates has further potential to reduce the gap between the beverage cartons and aluminum cans. While aluminum cans are fully recyclable (yield of 98%), the potential improvement for cartons is far less. This is because recycling facilities - unlike virgin paper production - need to rely on external energy sources, therefore a higher

recycling rate does not currently improve the performance of cartons in terms of climate change. Even though a 100% collection rate is unfeasible, this finding does demonstrate the environmental benefits of focusing on driving up recycling rates further at end of life – meaning that for aluminum cans, circular economy enhancements and climate protection go hand in hand.

- Cans can accrue a further ~10% improvement once can manufacturing energy provision is fully based on renewable electricity. Certainly, other packaging formats would also benefit from full reliance on renewable energy, most notably PET bottles and to some extent glass, which is, however, primarily reliant on thermal energy. Since the beverage cartons as modeled in this study are already benefiting from the renewable energy supplied by virgin pulp by-products, they are less likely to benefit to a large extent.
- Recycling rate improvements also offer high potential improvement for glass bottles (>20% improvement of the carbon footprint at 100% collection), although relative to the competing packaging alternatives, single-use glass can only improve its carbon footprint up to the level of PET bottles. Reuse at the end of life has an even larger potential. When reused 5 times, glass bottles reach the same reduction in mentioned category as with 100% collection, whereas reusing them 20 times, a glass bottle’s impact can be reduced by ~80% even considering the increased weight required for reusability.
- The environmental performance, especially carbon footprint, of PET bottles can be further improved with higher real recycling rates, although the full potential of improvements would have to include a proportionally higher recycled content as well. Current PEF values estimate recycled content (R2) at 0, and with pure virgin content PET cannot compete with cartons or cans. We have also seen the influence of thin wall designs (bottle for non-carbonated water) on the climate change impact category: reduction in material used goes hand in hand with reduction of environmental impacts.
- Although manufacturing of the primary packaging dominates most impact categories, secondary packaging does become dominant in the impact category eutrophication, where carton in secondary packaging contributes more than half of the total life cycle of aluminum cans and glass bottles due to the amount of waste water produced in the paper and recycling mills.

7.1.2. LCA Results for US

- The single overall best performer in the selected impact categories in this study is the 16.9oz PET bottle for non-carbonated water, due to a very thin-walled bottle design, resulting in favorable packaging-to-product ratio.
- Second and third place for non-carbonated beverage packaging alternates between aluminum cans and beverage cartons. While beverage cartons have the stronger overall performance for acidification and blue water consumption, aluminum performs better on eutrophication. Beverage cartons and standard aluminum cans perform equally well on climate change.
- Among the options for carbonated beverages, aluminum cans are the strongest performers in climate change and eutrophication, while PET bottles show lower impacts in blue water consumption and acidification.
- PET bottles fare well due to relatively low virgin material impacts and manufacturing-related impacts. At the same time, this means that unlike for aluminum cans and glass bottles, the use of recycled material does not result in significant improvements for most of the environmental impact categories.
- Cartons generally show good environmental performance because the main raw material, paperboard (typically around 70% (w/w) of the carton) tends to have low manufacturing impacts. Paperboard is often produced in an integrated pulp and paper mill will have most

of the required energy derived from biomass such as wood offcuts from forestry, bark and wood chips and from black liquor produced from the wood during pulp production. Many integrated paperboard mills export excess electricity to the grid, further reducing the production burdens.

- The strong performance of the aluminum cans can largely be attributed to the lightweight nature of the product compared to other packaging types, the high recycled content (73%) and the decent recycling rate (when compared to other substrates) of 50% at end of life.
- Although already high in recycled content, aluminum cans display the highest potential for improvement via further increases in recycled content. Conversely, the impact of aluminum cans is also most sensitive to drops in recycled content. As indicated previously, the least sensitive to this parameter, are beverage cartons, that show no change with increased or decreased recycled content.
- Glass bottles show the highest impacts among the assessed packaging formats. This is because they are much heavier than the other packaging types and glass production is also relatively resource and energy intensive. Options for looking at reusable glass bottles were not assessed for this region.
- When assessing the results using the substitution recycling methodology instead of the cut off approach fairly minor differences were observed. For most products, the amount of recycled content used as input to packaging manufacture correlates with collection for recycling at end of life. Under these conditions, both substitution and cut-off approaches provide similar results. The substitution approach gives greater burdens than the cut off approach for products that possess more recycled content than is recycled at end of life, and vice versa. Aluminum cans showed the greatest discrepancy in results of 18% between the two methodologies because the proportion of recycled content is higher than the recycling rate. Contrary to aluminum cans, PET bottles benefit from the substitution method since they are predominantly based on virgin granulate (6% recycled content) and have a medium recycling rate (30%), which results in material credits.
- Shifting the electricity grid mix for can manufacturing from fossil-based to renewable energy (as already signed by Ball Corporation) reduces the climate change impacts of the aluminum cans by around 11-16% over the entire life cycle. Similar actions have the power to improve the impact of other packaging designs as well, although to a lesser degree. Beverage cartons are already assumed to rely largely on renewable energy from the pulping by-products, the impact of PET bottles is determined largely by the granulate.
- Lightweighting has a small but relevant potential to improving environmental performance, mostly for PET and glass bottles and slightly less so for aluminum cans. These packaging alternatives are driven more by raw material inputs and less by energy consumption in the foreground (manufacturing) processes.
- Because of the uncertainty in data quality of PET blow molding, an additional manufacturing energy sensitivity analysis was performed for the PET bottle and showed a moderate sensitivity, with 7-15% impact change resulting from halving and doubling energy consumption, respectively.
- Although manufacturing of the primary packaging dominates most impact categories, secondary packaging does become dominant in the impact categories eutrophication and freshwater consumption, where carton in secondary packaging contributes more than half of the total life cycle of some of the beverage cartons and glass bottles, due to water-intensive processes at the paper and recycling mills.

7.1.3. **LCA Results for Brazil**

- No single packaging format is preferred for all impact categories assessed in this study. However, aluminum cans have the strongest overall performance and are the preferred choice from a climate change, freshwater eutrophication, terrestrial acidification and freshwater consumption perspective.

- The strong performance of aluminum cans is, in large part, due to the very high recycling rate in Brazil (97%) and because the impacts associated with recycling aluminum are much lower than those of manufacturing it from virgin materials (95% less energy for secondary vs primary aluminum production). These two factors mean that recycling credits at end of life are very large and greatly reduce the environmental impacts associated with the full life cycle of the product.
- PET bottles have the lowest impact in abiotic depletion potential and compete for second place with cartons in terms of climate change and acidification. PET bottles fare well due to relatively low virgin material impacts and manufacturing-related impacts.
- Cartons generally have a good environmental performance because they are mostly made from paperboard (typically around 70% by weight), which tends to have low manufacturing impacts. If paperboard is produced in an integrated pulp and paper mill most of the energy used will be derived from biomass such as wood offcuts from forestry, from bark and wood chips and from black liquor produced from the wood during pulp production. Many integrated paperboard mills export excess electricity to the grid, further reducing the production burdens.
- The environmental performance of glass bottles diverges strongly depending on whether they are refilled many times or used only once. Bottles that are refilled 20 times generally perform strongly (often similar to cartons) but single-use bottles have much higher impacts and show the highest burdens for climate change and acidification. Glass bottles are much heavier than the other packaging types assessed in this study and glass production is also relatively resource and energy intensive, explaining the high burdens seen for single-use bottles. When refilling bottles, the burdens of manufacturing are shared among multiple use cycles (modelled as being reused 20 times in this study), resulting in greatly reduced burdens for a given functional unit.
- Of the scenarios explored in this study, increasing recycling rates offers the biggest improvement potential in terms of environmental footprint for PET bottles,.
- Aluminum cans show the highest variability in terms of changing recycling rates, followed by glass bottles.
- Although manufacturing of the primary packaging dominates most impact categories, secondary packaging does become dominant in the impact category eutrophication, where carton in secondary packaging contributes more than half of the total life cycle of glass bottles and up to a half of beverage cartons, due to the amount of waste water produced in the paper and recycling mills.

7.1.4. Material Circularity Indicator (MCI)

The MCI scores provide a reliable understanding of the circularity of each packaging option rewarding the use of recycled/reused content and renewable (sustainably sourced) materials and waste treatment through reuse or recycling. However, the indicator does not follow principles of material and energy efficiency and therefore can have very different outcomes from the environmental performance of the packaging formats. The results and following interpretations should always be used in conjunction with the main results of the LCA study. Together, they can help derive the most meaningful positive changes to achieve a circular economy with low environmental impacts.

- Most of the packaging formats assessed are single-use, so their MCI scores are dependent upon the amount of recycled or renewable content, the recycling rate at end of life, and the yield losses during the sorting and recycling processes.

- Aluminum cans consistently achieve very favorable MCI scores (indicating a high degree of circularity) because real recycling rates and levels of recycled content are high in most markets, and because aluminum has extremely low yield losses when recycled.
- Beverage cartons and single use glass bottles both achieve intermediate circularity performance. Beverage cartons have high amounts of renewable content (paperboard) but relatively low collection as well as actual recycling rates at end of life. Glass bottles have moderate levels of both recycled content and end of life recycling rates.
- PET bottles perform poorly in terms of circularity because real recycling rates tend to be rather low when compared to aluminum and glass, the modelled scenarios all use predominantly virgin granulate during production.
- Reusing packaging can have a strong impact on MCI scores. This is underlined by the extremely high MCI score for the refillable glass bottle in Brazil (assuming the bottle is refilled 20 times). This lifts the score for glass bottles from mediocre to outstanding, achieving scores similar or even better than aluminum cans. However, whether or not glass bottles actually achieve refill rates of 20 has to be discussed by the respective fillers.
- Where it is used, secondary packaging made from cardboard also improves the MCI scores reported in this study, as this is a renewable material (assumed to be sustainably sourced) and is recycled at high levels in all three regions assessed. However, this impact highlights the need for exercising caution while applying MCI results, as they will benefit the product with a larger secondary packaging made of cardboard, simply because this results in an overall higher share of renewable materials. MCI results should always be interpreted in conjunction with traditional LCA results.

7.2. Assumptions and Limitations

- In general, conservative assumptions have been taken with respect to the aluminum can to avoid any misrepresentation of results and unfair treatment of the competitive products. Specifically, the following conservative assumptions have been taken to avoid providing an unfair advantage to aluminum cans:
    - Cooling of the beverage product has been neglected from this study, as this may or may not be required for some products; it also was expected to favor aluminum cans (ICF International , 2016).
    - Exclusion of shelf-life and the protective properties of the packaging. Aluminum’s intrinsic properties allow for a very long shelf life without additives or protective layers.
    - Recycling of beverage cartons has been assumed to recover the full amount of fibers (paperboard) in the product, while the collection scenario assumed full recovery of aluminum foil as well. Current technologies, as German recycling facilities discussed, are generally limited in their capacity to recover laminated substances, and average industrial practice is either the incineration or partial recovery of the fibers, after collection for recycling.
    - Sustainably sourced fibers have been assumed for all carton and paper products, improving the MCI of beverage cartons in regions, where sustainable sourcing may be difficult to achieve for the majority of producers.
    - In the US and Brazil, many recycling rates reported by trade associations or government agencies are only collection rates. But not all material collected will be recycled – either because materials gets sorted incorrectly, are contaminated, or because at any given time the economics of recycling one substrate may simply not

    work. While aluminum cans are easily sorted and recycled (mono-material, sorting through eddy currents in place, accepted in all collection schemes, highest economic value of all beverage packaging substrates) and real recycling rates have been considered in this study, other substrates benefit from treating collection rates as real recycling rates.
  - For the Brazilian aluminum cans, a sheet making proxy was required so the European Aluminium (EA) dataset from 2010 was adapted to Brazilian background data. According to the EA report (European Aluminum, 2018), the recently published 2016 datasets improved on climate change by about 25%. Because of the uncertainty of the technological status of Brazilian aluminum manufacturing, the conservative approach was taken, and the older dataset was used, even though Brazil is known for its advanced energy saving measures due to high electricity prices.
  - In general, while the use of primary industry data increases accuracy of results, it tends to also drive the impacts up due to the simple logic that more data means more impacts captured. Therefore it is expected that aluminum can manufacturing might have been slightly overestimated compared to other substrates.
- The most relevant proxy data is:
  - The Brazilian sheet making dataset. an older dataset with higher manufacturing energy was applied (conservative assumption).
  - The carton conversion (liquid packaging board, laminated with aluminum and polyethylene film for beverage cartons) dataset is an association (ACE) dataset from 2009. The validity has been checked via communication with various producers, and an update has been made to correct the water balance. However, this dataset being a secondary dataset used for products that are shown as high-performing products throughout this study, brings attention to the potential limitations of data quality.
  - Glass datasets in the EU are based on association data from FEVE and can generally be considered technologically representative. While adapting it to the US and Brazil, recycled content, type of soda and energy provision have been applied to represent regional specifications. Since glass manufacturing has a very long-standing history, it is relatively unlikely that significant differences exist across these regions. Further research on the technological representativeness for these regions, however, was not within the scope of the study. Considering the comparative nature of the study, this would be an important limitation. However, we have seen in case of the European findings that glass can be best optimized by reuse, and while technological differences may account for 10-15% difference, it is highly unlikely that the order of results would be changed, given more representative data[11].
  - In case of PET bottles, the granulate manufacturing and the bottle manufacturing are the most relevant components of the total impact. While a Brazilian granulate mix has been generated by a simple adaptation of energy carriers and the use of the applicable monomer, a technological representativeness is probably quite good simply because of the industry average technologies have reached a level of

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[11] It should be noted that as the number of glass bottle refills increases to 10–20 refills, transport distances may become overwhelmingly relevant to the results.

    maturity and efficiency that is probably globally widespread in an industry where raw materials are expensive.
  - PET bottle blow molding is lacking in commercial LCI databases. The best available proxy is the blow molding dataset original developed for HDPE bottles of larger size ranges (0.5 to 4kg). Since this dataset was taken, a number of sensitivity assessments were run to check its influence on the results.
- The most relevant limitation of the study is the data quality difference between the subjects of the comparison, specifically, the primary data-based aluminum cans and the secondary data-based alternative packaging products. It can, however, be said that using conservative assumptions, a range of scenarios and sensitivity analyses and personal communication with manufacturers (of beverage cartons), results have been corroborated and uncertainties underlined so as to avoid any false conclusions.

7.3. Results of Sensitivity, Scenario, and Uncertainty Analysis

7.3.1. Sensitivity Analysis

Sensitivity analyses were performed to test the influence on the results of changes in parameter values that are based on assumptions or are otherwise uncertain. These analyses showed that results based on the substitution approach are sensitive to recycling / collection rates at end of life, with up to 30% reduction of the baseline aluminum cans achieved in terms of the GWP, where 100% of aluminum cans are collected. This is expected as the end of life treatment of several of the products has a major potential in offsetting some of the manufacturing-related impacts, by recycling. It is also important to note that beverage cartons are largely unaffected by the collection rates, as the value of recycled paper versus primary fibers is not significantly different, in terms of their climate change burdens. In contrast, metals such as aluminum, generally show much lower impacts for recycling compared to virgin production, so increasing recycling rates yields larger benefits and provide high-value recyclates that can – in case of cans – be directly channeled into production of new cans, as valuable input scrap.

The system is therefore highly sensitive to end of life collection for recycling. Additionally, the system is relatively sensitive to the amount of recycled content applied, when the cut-off method is applied, whereby scrap enters the system burden-free (original manufacturing is discounted, only the environmental burdens of recycling & processing are included). Also part of the end of life treatment, refills for glass bottles were tested over the range of zero to 20 refills to demonstrate the impact of bottle refilling on environmental performance and MCI score. The system was also shown to be highly sensitive to these changes, reducing the glass bottle impact by 74% and making it theoretically competitive with the aluminum can and carton options that otherwise performed far better. It should be noted that such systems have been installed for PET bottles, too, and these are expected to decrease the impacts to a similar degree as seen for glass. Since these systems are still not prevalent in most markets (most notably successful in Germany), these were not analyzed in detail in this study.

The observed range of PET bottle weight optimization (±10%) resulted in changes in impact of ~9% due to the dominant impact of the virgin granulate input. The sensitivity to the manufacturing energy of PET bottles was slightly less, but the perceived uncertainty larger. In the assessed range of 0.5x to 2x energy consumption relative to the baseline, the reduction of the impact in the category GWP was about -7 and +15%, respectively.

7.3.2. Scenario Analysis

Scenario analyses were performed to compare results between different sets of assumptions or modelling choices.

The choice of recycling methodology (CFF, cut-off or substitution approach) was assessed in this way. The substitution method would generally be recommended for the packaging materials used in this study, based on the guidance provided in the GHG Protocol Product Life Cycle Accounting and Reporting Standard (WRI, 2011). This can be recommended for cases where:

- The market for recycled material is not saturated (demand exceeds supply) such that creating more recycled material is likely to increase the amount of recycled content in products. This is the case for metals, paper and carton.
- The time period of the product’s use stage is short and/or well known. Which is the case for most packaging applications.

The results show that for these packaging formats, the choice of methodology does not have a big impact on the results for most materials. For aluminum the difference can be more significant as absolute values may vary by up to 17% from the baseline. However, the rank order changes only slightly, as aluminum cans impact tended to decrease when switching from PEF CFF to substitution (EU), and from substitution to cut-off (US).

A scenario analysis was also conducted to examine the influence on the results of the choice of grid mix used for the aluminum can manufacturing process in both the EU and the US. This showed that switching from a mainly fossil mix to a renewable mix enabled a reduction in climate change impact of up to 16% in the US, and about 10% in the EU. The slightly lower reduction in the EU is due in part to an already higher renewable mix currently in use, but more importantly to the higher portion and therefore relevance of the virgin raw material (aluminum ingot) than in the US. This reduction via renewable energy sourcing is sufficient for the aluminum cans to outperform beverage cartons in terms of climate change impact in the US.

7.3.3. Uncertainty Analysis

Uncertainty analysis was performed by assessing the range of changes observed across all sensitivity analyses. Changes across various parameters and their ranges (as in a Monte Carlo assessment) were not assessed. The analysis showed that:

- While the system is highly sensitive to collection rates, they are not, strictly speaking, uncertain parameters, but rather parameters subject to change. Even so, a general increase in collection can be said to benefit all materials, with very little to no potential improvement for the beverage cartons.
- Glass bottle impacts are highly sensitive to refill cycles. The tested 20 refills scenario makes the glass bottle competitive with the other two strongest performers: beverage cartons and aluminum cans. Glass bottles may be designed to withstand washing & refills up to 20 times, but there are no reliable statistical figures of actual refill rates available at the time of writing this report. There is much speculation about where actual refill rates lie, and good intentions to improve the situation, but individualized bottles and complex logistics remain tremendous barriers to overcome.
- Product weight is a sensitive parameter, although most so for the PET bottles and glass bottles (~ 9% impact change with 10% weight decrease) and to a slightly smaller degree in case of aluminum cans (7-8%) and beverage cartons (5-7%). This sensitivity has all the more relevance for PET bottles because considerable variations exist on the market with some non-carbonated water bottles demonstrating extremely thin walls whereas other products in the non-carbonated segment are packaged in considerably thicker bottles.

All other sensitivity and scenario assessments left the rankings of the compared system largely unchanged.

7.4. 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 GaBi 2019 database were used with the GaBi 9.2 Software SP39. The LCI datasets from the GaBi 2019 Databases are widely distributed and 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.

In Annex B: Data quality evaluation, several aspects of data quality have been quantified separately for each region. On average, regional data for each of the packaging materials achieved a score of good (3) to very good (4). European data has the highest scores, followed by the US and then Brazil, where arguably fewer geographically representative datasets exist. In terms of the packaging alternatives compared, PET bottles have slightly lower scores in all regions, which is why more sensitivity analyses have been performed. Aluminum data has the highest scores in each region, relying largely on primary foreground data and recently updated background data (except for Brazilian sheet making).

7.4.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data (material types and weights in the packaging options) are measured data or calculated based on primary information sources of the owner of the technology or based on measurements of purchased product samples, precision is considered to be high. Primary data for manufacturing (foreground) was available for aluminum (can and can end and tab manufacturing). Data sourced for competitor products are less precise than the primary data provided for Ball products. For this reason, the competitor products assessed here carry a generally larger uncertainty margin than do the aluminum cans. Seasonal variations and variations across different manufacturing were balanced out by using yearly averages. Foreground data on manufacturing processes of beverage cartons, glass bottles and PET bottles are based on association and/GaBi data, as documented in chapter 3, therefore the precision of these datasets can be considered medium to medium high. All background data are sourced from GaBi 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 GaBi databases with the documented completeness.

7.4.2. 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 GaBi databases. Can manufacturing data, however, represents a higher level of precision that do manufacturing processes of other materials, therefore the consistency is known to be sub-optimal. There is no consistency for data across regions, therefore comparisons are not made between Europe, US and Brazil. See Chapter 2: Scope of the Study for further details.

- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling 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 modelling approaches. The only exception are primary data from Ball Corporation, which, however, can be replaced by can manufacturing averages from association data (e.g. AA 2012 http://gabi-documentation-2020.gabi-software.com/xml-data/processes/03146d40-8dd6-4a76-809c-cd23d70f9b8e.xml).

7.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2018-2019. All secondary data come from the GaBi 2019 databases and are representative of the years 2013-2017. As the study intended to compare the product systems for the reference year 2018, temporal representativeness is considered to be good.
- ✓ **Geographical:** All primary data were collected specific to the countries or regions under study. Where country-specific or region-specific background data were unavailable, regional adaptations were created for main raw materials by changing the energy provision to local mixes. Proxy data from other regions were used for auxiliaries and processes with no known technological differentiation (End of Life). Geographical representativeness is considered to be good to very good.
- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. This includes the PET bottle blow-molding manufacturing stage and certain elements of aluminum can manufacturing. Technological representativeness is considered to be good to very good.

7.5. Model Completeness and Consistency

7.5.1. Completeness

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

7.5.2. 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 predominantly using LCI data from the GaBi 2019 databases. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

7.6. Conclusions, Limitations, and Recommendations

7.6.1. Conclusions

- Packaging efficiency has a significant impact on the environmental burdens of the packaging. A packaging container with a larger volume requires relatively less material to provide a given quantity of product. This is an important factor to consider when making comparisons across different packaging formats and sizes. It is important to note here, that the study focused on small-to-medium sized products, not all beverage packaging types and formats.

- Among non-carbonated beverages, the best performers in Europe and the US tend to be PET bottles for water, where thin wall designs result in much reduced impacts. In Europe, where non-carbonated PET bottles also include a juice bottle, beverage cartons in fact perform more consistently well. In Brazil, the high recycling rate of aluminum cans make them the best performer in all but one impact category.
- Among carbonated beverages, aluminum cans and PET bottles compete for best performance. In Europe, PET bottles tend to have somewhat more consistently high performance, whereas in the US aluminum cans have a lower GWP and acidification, while PET performs better in the other impact categories. In Brazil, aluminum cans are the best performers across all but one impact categories.
- PET bottles perform well in most impact categories due to being relatively lightweight, with little secondary packaging, and relatively low manufacturing energy demand. A combination of low recycling rates at end of life and lack of recycled content, leave a marked potential for future improvement for this packaging option. Returnable bottles would predictably have a significant potential to improve the impact of these packaging systems as well.
- Aluminum cans show low impacts partly because they are lightweight, so less material is needed to manufacture them, but mainly because of the high average levels of recycled content used during manufacturing and the high recycling rates at end of life. Design for a circular economy coupled to a greening of energy supply for manufacturing enables this packaging format to reach its potential for future improvement.
- Hotspot analysis of the aluminum can reveals that the most significant contribution to environmental impacts are derived from the can body stock during the manufacturing phase. Given the high yield of aluminum recycling, the easiest way to reduce this impact is by increasing collection rates (for example via deposit return schemes) and closing the loop, as is exemplified quite well by the Brazilian case. While can manufacturing energy is not negligible, most energy consumption occurs further upstream in aluminum production, and to a lesser degree in sheet rolling, and thus energy efficiency measures and provision of renewable energy in those parts of the supply chain have more improvement potential. Certainly, further lightweighting can further reduce the overall impact of cans, too.
- Cartons have an intrinsic advantage, being made from paperboard and produced from virgin natural and renewable fibers. These are typically sourced from integrated mills that are mostly fueled by biomass and so are far less reliant on fossil fuels for manufacturing than are the competing products in this study. It is important that the paperboard used in cartons be sourced from sustainably managed forests (e.g. FSC or PEFC certified), if the fiber used is sourced as a result of deforestation, the burdens would be much higher, although a quantification of lost forest cover due to paper production is difficult to assess and include into Life Cycle Inventories.
- The regional variation in rankings has mostly to do with differences in recycled content and recycling rates, but is also impacted by the choice of methodology: in the EU, the PEF CFF method generates markedly higher results for aluminum cans with medium recycled content and high recycling rates, whereas with high recycled content and medium recycling rates the US applies a slightly more favorable method (cut-off) for aluminum cans. By contrast, in Brazil both recycling and recycled content are at their highest among all regions. In addition, the methodology applied (substitution) favors products with higher recycling than recycled content ratios.

- Single-use glass bottles consistently show the highest environmental burdens across all impact categories and in all regions, due to their high mass and relatively energy intensive manufacturing process.
- The glass bottles that are inherently designed for re-use, and are extensively reused outperform single-use bottles. Reuse is the single most important future improvement potential for this packaging format. Importantly, however, it has yet to be demonstrated by reliable data how many times glass bottles can in fact be re-filled, and how efficient the infrastructure is in terms of logistics and economies of scale.
- Cartons have less potential to improve through increasing recycling rates as the paper recycling process is much less beneficial compared to the virgin process than is the case for aluminum. For some impact categories, recycling paper may be more impactful than virgin production, as recyclers do not have access to the large quantities of biomass fuel that is available to integrated pulp and paper mills. Certainly, renewable energy can be purchased also by recyclers and integrated virgin and recycled paper mills also exist sharing the benefits of renewable energy carrier by-products.
- Although this study is a strictly attributional LCA, a broader picture helps focus the conclusions and their applications to pragmatic decisions. When considering what materials should be used for beverage packaging it is also important to consider the bigger picture and ask what would happen if there were large shifts in materials choice (strictly speaking, only to be addressed in consequential LCAs). For cartons, there is clearly a potential limitation in the amount of sustainably managed forest available. This would need to be increased in parallel with the increased demand for cartons if deforestation is to be avoided. Similarly, aluminum is a high-value material that has applications in other sectors (e.g. automotive and construction) and increasing the demand for aluminum cans may have some knock-on effects for other aluminum products, although currently the can market is a small fraction of the total aluminum demand when compared to other sectors.
- This report examines potential routes for improving the environmental performance for each packaging type and highlights how these options vary depending on the packaging format. It is worth noting that environmental performance is one among many factors that determine packaging choice including technical performance (for example, cartons are not suitable for storing carbonated drinks) and other functionalities (such as the ability to close the container after opening), price, branding and consumer acceptance. To satisfy all these needs it is likely that a range of packaging formats will continue to be needed in the future. It is therefore encouraging that all packaging types assessed are shown to have the potential to further reduce their environmental footprints.
- With respect to circularity, it can be said that for a given material option (e.g. aluminum cans) the MCI often correlates quite well with findings on GWP, i.e. the higher the MCI, the lower the GWP. However, this is a correlation only and not a causal relationship because MCI scores do not measure material efficiency during production processes. Therefore, when comparing the MCI performance of different packaging materials it should be noted that this correlation does not necessarily mean the packaging material with the highest MCI score has the best environmental performance overall. Aluminum cans tend to outperform other packaging materials, as a result of the highly developed infrastructure for collection, highly efficient material recycling technology, very high levels of recycled content, and extremely low yield losses during recycling, closing the loop rather well. Beverage cartons perform quite well primarily due to their renewable main raw material, paperboard. A near-perfect MCI can be achieved by refillable glass bottles, if in fact refilled many times. Attention must be paid when comparing MCI scores because material efficiency during production processes is not considered by this indicator. Therefore, it is strongly recommended that any statement or decision based on the MCI should be supported by environmental indicators as well.

7.6.2. Limitations

- A key limitation of the study is the data quality difference between the subjects of the comparison, specifically, the primary data-based aluminum cans and the secondary data-based alternative packaging products. It can, however, be said that using conservative assumptions, a range of scenarios and sensitivity analyses and personal communication with manufacturers (of beverage cartons), results have been corroborated and uncertainties underlined to avoid any false conclusions.
- The results and conclusions described in this report are valid only within the specified scope of the study, i.e. focusing on aluminum cans, cartons, glass and PET bottles for the specific pack sizes and scenarios assessed. Conclusions may differ when assessing packaging for alternative products, different pack sizes or for other geographies.
- Similarly, supply chain models for each packaging type have been developed based on typical transport distances and supplier locations. Results may differ when modeling packaging from specific suppliers to specific locations or from suppliers that are external to the assessed region (e.g. US packaging suppliers serving the Brazilian market).
- As stated in ISO 14044, it should be noted that LCA shall not be the sole basis for making comparative assertions. Other social, economic and environmental aspects should also be considered. One such aspect is shown by the socio-economic concept of circularity, measured by the MCI, which has gained enormous social and political traction. EU legislation is actively working towards a more circular society and this report demonstrates both the potential merits of combining it with environmental indicators and the limitations when applied alone.

7.6.3. Recommendations

- The study findings indicate the paramount importance of enhancing circular systems for high-value / high-impact materials such as aluminum, glass or (to a lesser degree) PET by
  - Increasing recycled content as far as technologically feasible,
  - Increasing collection rates at the end of life,
  - Maximizing refill cycles of bottles designed for reuse,
  - Supporting the logistics of closing the loop, i.e. providing the scrap input in the quality and quantity that is required by the input side.
- Although it is not the intention of the study to compare across regions, one can take the learnings from one region and apply it to another. The Brazilian modus operandi as such cannot be recommended due to its heavy reliance on enormous economic differences in the society, resulting in the poorest classes effectively acting as the collection system for high-value aluminum cans and other substrates. However, the system does demonstrate the environmental benefits of achieving near-perfect recycling rates and an almost completely closed loop. Given more efficient infrastructure and the right incentives (e.g. deposit return schemes), higher recycling rates are achievable without relying on the economic gap in societies.
- Sourcing renewable energy for manufacturing sites is another action that can be recommended to improve the overall environmental profile as well as further energy saving measures.
- In terms of improving the study results, or providing results with further-reaching conclusions, it is recommended to focus on specific beverage product types (e.g. beer, water or juices) whereby additional aspects can be included:
  - Cooling needs, if required,
  - Protective function of materials to increase shelf life,
  - Product losses,

  - Consumer patterns etc.,
  - Impact ratio product to packaging,
  - Total impact of product with packaging.
- Each packaging option has valid justifications for use from an environmental perspective, as each option exhibits different environmental strengths and weaknesses. Maintaining diversity in the consumption of materials by using a range of packaging options is arguably fundamental to sustainable resilience, because each packaging option exerts different burdens on the planet. Although our industrial processes are far from balanced with nature, favoring the use of single packaging options could have more severe environmental impacts than are currently seen across the range of packaging alternatives:
  - Carton may look like the optimal choice for some of the regions / cases. An increase in production will, however, likely lead to further deforestation. If, on the other hand, primary fibers are substituted with recycled fibers, the environmental impacts are partly (e.g. carbon footprint) expected to rise given current prevalent technologies. Certainly, this can be improved, if paper factories invest in modernization and renewable energy sourcing.
  - In case of PET bottles, the well-known impact of products “lost” in inefficient waste management systems has contributed to the accumulation of plastics in the ocean. Therefore, more efficient collection systems (be it deposit return schemes or other initiatives) and infrastructure for recycling and preserving the quality of recycled materials are of paramount importance.

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Annex A: Critical Review Report

Title of the Document:	Beverage Packaging: A Comparative Life Cycle Assessment Critical Review Report
Written by the Critical Review team:	Prof. Dr. Pere Fullana i Palmer, chairperson UNESCO Chair in Life Cycle and Climate Change ESCI-UPF Dr. Ivo Mersiowsky, panelist Quiridium GbR Angela Schindler, panelist Umweltberatung und Ingenieurdienstleistung
LCA Practitioner's team (Sphera Solutions GmbH):	Flora D'Souza (Senior Consultant, Project management) Pete Shonfield & Manfred Russ (Quality Assurance) Dr. Sabine Deimling (Internal supervision)
LCA Commissioner's team (Ball Corporation):	Björn Kulmann (Global Sustainability Director)
Place and date	Barcelona, 2020-07-17

ABSTRACT

OBJECTIVE. The LCA study with the title “Beverage Packaging: A Comparative Life Cycle Assessment” has been conducted by the consulting company Sphera Solutions GmbH, the commissioner being Ball Corporation. The LCA study has been submitted to critical review in order to ensure that the presented comparative assertion is in line with the ISO 14040 and ISO 14044 standards.

HISTORY. The review started in June 2019 at an early stage of the LCA study, being the first round mainly reviewing the "goal and scope definition" draft. A second round was held in September 2019, in order to complete the G&S phase. The draft final LCA report was delivered in mid-January 2020, starting the third review round, ending in early March 2020. A second version of the full report was sent back to the panel early April 2020 and the fourth review round was performed, and a draft review statement delivered for check. In May 2020, a number of new comments by the commissioner were received, adding to new comments by the panel. A second draft of the review statement was produced. Early June 2020, after another thorough revision, the practitioner found a sensitive issue, which affected a significant part of the report. This motivated a new calculation, report editing, and critical review during June 2020. The regional reports were delivered in early July 2020, and their review and the regional review statements, and the overall study review statement were delivered during July 2020. The complexity of the process shows somehow the deepness of the study and review, and how intense all participants delivered their tasks, as the comparative assertion was seen as influential in the market.

METHODOLOGY. The review was performed by a review panel according to ISO 14044 clause 6.3., following a procedure in iterative steps during the development of the LCA study, finding consensus at each of those steps. In order to perform the review, and due to the usually expected long list of issues, an ad hoc Excel tool prepared by the panel chair was used for the full report review in round three and onwards, in which all review comments were classified by study chapter, reviewer, ISO clause and importance to final results. Those comments were responded in the same tool by the practitioner and a dialogue was established until consensus was reached. This discussion is kept confidential. The most critical comments have been collected within this critical review report, to be included in the LCA study.

STATEMENT. The review comments have been correctly responded by the practitioner, whether modifying the report accordingly or convincing the review team that there was no need to do so. Therefore, following ISO 14044 clause 6.1, the critical review panel wants to state that, within their knowledge:

- “the methods used to carry out the LCA are consistent with the above International Standards;
- 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.”

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1. Reviewing procedure

The critical review panel, composed of three independent external experts, was selected by the practitioner of the study. All members of the panel declare to be independent from the Commissioner and the Practitioner of the LCA study and “not involved in defining the scope or conducting the LCA study” [ISO 2014], and have been accepted by the panel chairperson. Being independent does not mean that the panel members haven’t previously worked together with the commissioner or the practitioner in other projects. The members of the panel are dedicated LCA experts and have extended knowledge in the field of ISO standards for LCA, LCA methodology, critical reviews, and the relevant scientific disciplines involved. Further interested parties were not included in the review process, apart from the Commissioner and the Practitioner.

The critical review (CR) covered one document (Beverage Packaging: A Comparative Life Cycle Assessment). The review was performed in accordance with the ISO 14044 Section 6.3 requirements to the critical review, which applies to an LCA study that supports comparative assertions to be disclosed to the public.

The main objective of this CR was to ensure that the LCA study is in line with the ISO 14040 and ISO 14044 standards.

The methodology followed has been based on the few points within the ISO standards, together with good practice from past experience, literature and the ILCD Handbook. The standards state that: “The critical review process shall ensure that

- the methods used to carry out the LCA are consistent with this International standard,
- 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.”

Only virtual panel meetings took place and were organized by the practitioner via internet, and bilateral phone calls and emailing were used to communicate with the panel chair. All actors always attended. Additional virtual meetings were held among the panelists. An ad hoc Excel tool was provided by the panel chair, in order to facilitate the description and classification of review comments by the reviewers and the consequent responses by the Practitioner and/or the Commissioner.

The review started in June 2019 at an early stage of the LCA study, being the first round mainly reviewing the "goal and scope definition" draft. A second round was held in September 2019, in order to complete the G&S phase. Full LCA report was planned for mid-November. However, it was finally delayed until mid-January 2020, starting the third review round. The following review meeting was held in early March 2020. A second version of the full report was sent back to the panel early April 2020 and the fourth review round was performed, and a draft review statement delivered for check. In May 2020, a number of new comments by the commissioner were received, and the practitioner had to adapt the report once more. In addition, new comments arrived from the panel. A second draft of the review statement was produced. Early June 2020, after another thorough revision, the practitioner found a sensitive issue which may change the results of one of the packaging competing options, which affected quite a lot to the report. This motivated a new calculation, report editing and critical review during June 2020. The regional reports were delivered in early July 2020; their review, the regional review statements, and the overall study review statement were delivered during July 2020. The complexity of the process shows somehow the deepness of the study and review, and how intense all participants delivered their tasks, as the comparative assertion was seen as influential in the market.

This report has been drafted by the panel chair and reviewed by the rest of the panel, the Commissioner and the Practitioner. It was decided that the working documents, with all the review comments and responses, would be kept internally, while this summary document would be added to the LCA report. It will be up to the Practitioner and the Commissioner to disclose any further information to any stakeholder.

2. Documents used by the review team

About the project:

- 2019-06: Goal & Scope_ts_15-05-2019.pdf
- 2019-07: 2019-07-01 Goal and Scope Meeting Minutes.docx
- 2019-10: First results 27-09-2019 - post-presentation.pptx
- 2019-10: 2019-09-27 Results Preview Meeting Minutes.docx
- 2020-01: Ball Comparative LCA report Ready for Review_cleaned.docx
- 2020-04: Ball Comparative LCA report - Final version 2.0.docx
- 2020-06: Ball Comparative LCA report - Revision 3.0 with tracked changes
- 2020-07: US/EU/BR Regional report for review - excerpt of Ball Comparative LCA report

About the methodology:

- ISO 14040:2006 - Environmental Management. Life Cycle Assessment. Principles and Framework
- ISO 14044:2006 - Environmental Management. Life Cycle Assessment. Requirements and Guidelines
- International Reference Life Cycle Data System Handbook (ILCD handbook). General guide for Life Cycle Assessment – Detailed guidance.

3. Summary of important review comments

Three types of comments were sent by the review panel:

- General: refers to LCA practice or reporting practice in general and it affects significantly the study, and must be considered;
- Technical: refers to LCA practice specifically and it affects significantly the study, and must be considered;
- Editorial: typographic error or improvable language

More than 150 comments were addressed in the first rounds. All in all, more than 400 comments were made, being 133 of them general and 127 technical issues, and editorial the rest. **All those comments were discussed. Some of them led to improvements of the LCA study and others were finally not applied, as they were consensually found not appropriate.**

Only those most relevant comments are presented below. All the relevant comments (not editorials), together with the responses by the practitioner, are presented in the confidential Annex 2.

3.1 Comments globally related

General comments

- The division of initially reviewing the Goal and Scope, and afterwards reviewing the whole LCA is a better practice than only reviewing the study when it is finished. Having at least two rounds of both enhanced the process and, for instance, the final document was fairly more readable than the first version.

- The Commissioner has been extremely active in the review process introducing a long list of comments at each review stage. The review panel thinks that these issues raised by the Commissioner should have been resolved with the Practitioner, prior to sending any new version of the document to be reviewed.

- The study provides dedicated information for three different global regions. The inventory data, the methodological approach for secondary material, as well as the impact assessment methods have been adapted to regional standards and practices, thus facilitating a more differentiated approach than other, often quite generic, studies. The ramifications of packaging material choices are examined diligently. It serves to express the manifold aspects even to be considered when looking on a small variation of materials and packaging types out of the broad range in the packaging industry.

- The study falls somewhat short on its original goal of providing the necessarily multifaceted understanding of environmental advantages and drawbacks of beverage cans and bottles. By reducing the choice of beverage packaging options essentially to a material-driven selection, relevant specifics of packaging solutions in relation to logistics and consumption patterns remain unexamined. Key improvement options appear to exist in the end-of-life management, namely deposit and reuse systems. While currently not globally widespread, these improvement potentials would have deserved deeper analysis to render decision support. This limitation has been taken into consideration by clarifying the goal and scope definition.

- The study with more than 240 pages shows a detailed analysis of an important segment of packaging systems. Still, it does reflect only a part of available systems. The challenge will be to communicate the results and conclusions to the intended audience. In case only parts of the large report are extracted, it is essential to also have these documents externally reviewed and thoroughly be checked to avoid any distortion by simplification of complex matrices.

3.2 Comments related to the Summary and the Goal and Scope Definition

Summary

- Within the summary, you may include aspects such as: an explanation about the consequences of not considering the beverage; an explanation about the consequences of not considering a Deposit Return System (DRS), and consumer behavior; an explanation on why recycling is good for aluminum and bad for paper; reasoning about why considering the MCI and how to interpret it.

- Try to avoid overall preferences on alternatives, especially for those having lower quality data.

As it normally happens, G&S Definition is the most conflicting phase when reviewing. All parts have to come to a common understanding and all methodological aspects must be agreed on. Issues raised and resolved in the final iteration include:

- Change the goal of the study to refer to a comparison of single-use packaging, including the refillable glass packaging only as a sensitivity analysis. Modify the FU accordingly, as well.
- While regional on a high (national) level, the results are hardly market-specific enough to support recommendations on a product level (i.e. a packaging for a specific application on a specific consumer market).
- Judging by the sizes, most products considered here seem to be for immediate consumption (rather than storage), except the 1L glass bottle. You might wish to specify whether this is for retail (supermarket), convenience (gas stations), or hotel/restaurants (minibar).
- Influence of DRS in this comparison is completely missing. In addition, the study fails to take into consideration logistics and consumers patterns.
- Reasons for inclusion and limitations of the Material Circularity Index (MCI) are not clear.
- Reasoning for selecting Climate Change as a lead indicator were not clear.
- Clarify that an attributional methodology is followed and that, therefore, consequential information should be taken with caution.
- Reasoning for the different selection of impact categories in the three studied regions.
- Define consistently the actual applied products and reference flows
- Include at each exclusion from the system a sentence stating whether it benefits cans or their competitors and why
- Include details on mass and price of the different co-products.
- Consider excluding ADP of the 3.0 PEF list of impact categories and substitute by ADP elements (CML 2001 – 2016)
- Including MCI does not make the goal more holistic. The study focus on recycling; a holistic view should include ways to refuse, reduce, reuse and recycle.
- The study should not be interpreted as to solve “the plastic pollution”. So far, it was a material/product discussion, but plastics pollution is predominantly a waste management issue, which should not be construed as a weakness of the material. Also, the term plastic pollution may reinforce the notion that a material competition is at the heart of study, which will considerably lower its acceptability on the market.

3.3. Comments related to the Life Cycle Inventory Analysis.

Discussion on Inventory was fairly straightforward and well structured. The practitioner was asked to and revised the following:

- Improve measuring of packaging parts weight to decrease uncertainty
- Clarification on how iron is modelled

- Explain how the transport distances are chosen
- Clarification on how blow molding is modelled
- Clarification on how carton recycling is modelled
- Clarification on why quality of recycled paper is considered equal to virgin one
- Check primary sources of statistical waste collection data for EU. DRS may influence a lot.
- What would happen if wind power was used by other options as for Alu?
- What would happen if reusable PET bottles were used?

3.4. Comments related to the Life Cycle Impact Assessment.

LCIA results are not easy to follow, as different methodologies are applied to the different regions studied. Specifically, the practitioner was asked to and revised the following:

- Better explain climate change impact category
- Specify when the impact was coming from secondary packaging
- Explain which is the problem on considering scarcity impact categories
- Clarify how using more material makes the MCI better

3.5. Comments related to the Life Cycle Interpretation.

Interpretation is always a good chapter for discussion. This chapter was very well structured and complete. Specifically, the practitioner was asked to and revised the following:

- Give a better explanation of allocation approaches
- Clarify aluminum recycling figures
- Explain why to avoid comparisons among regions
- Remove rather improbable scenarios from analysis
- Change description of data quality, as those data for Aluminum are better than those for the rest of alternatives
- Check what would happen if average data was used for Alu instead of Ball data
- Include EU renewable energy targets for EU region modelling
- Clearly describe pros and cons of the MCI
- Increase quantification of data quality assessment
- Include conclusions on circularity
- Include a longer description on the macro consequences on having refill systems, not only for glass, and the need of having a DRS.

3.6. Issues without consensus.

No unsolved issues remained after the last conference call of the review process.

4. Conclusions and statement

The review panel wants to express their gratitude to both the practitioner and the commissioner for their continuous help and fine work to make the review smooth and sound.

The review team wishes to thank the practitioner's team for the fruitful discussions at all times and their open-minded attitude in relation to this panel's comments. It is of general understanding that the review process has brought much new learning to all of us.

The review panel also wants to state that their task was to check the documents provided by the practitioner (not the models developed or the data used) with the limitations of their accumulated experience and the given time constrains. Any judgement of external studies, data and information are beyond the scope of the review process.

This review has been prepared by the review panel with all reasonable skill and diligence, being the result of their opinion on the reviewed study, and by no means a certificate of its quality.

The panel is not accountable by any others with respect to any matters related to their opinions. Reactions of any kind made by a third party and based on this review are beyond the panel responsibility

The review comments described in this document and all the rest (those more relevant are included in confidential Annex 2) have been correctly responded to by the Practitioner, whether modifying the report accordingly or convincing the review team that there was no need to do so.

Having gone through several reviewing rounds, which have led to final consensus among all parties, and following the critical review panel wants to state that, within their knowledge:

- the methods used to carry out the LCA are consistent with this International Standard,
- 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."

Therefore, it is the critical review panel opinion that the quality of the chosen methodology and its application in the analysis are adequate for the purposes of the study and in accordance with the ISO 14040 and ISO 14044 standards. This does not imply an endorsement of the conclusions, recommendations, or comparative assertions made in the study.

In addition, we state that the readability of the report is very high and transparent, and we believe that it will now more easily fulfill its communication requirements, as shorter regional reports have been prepared. The discussion of the results covers the relevant aspects in accordance with the goal of the study, and the conclusions are well founded on the outcome of the study and in accordance with the defined goal.

Finally, we want to congratulate Sphera Solutions GmbH for their fine work.

Barcelona, 2020-07-17

Angela Schindler

Angela Schindler Dr. Ivo Mersiowsky Prof. Dr. Pere Fullana i Palmer (chair)

Annex A.1 Short CVs of the critical review panel members

Prof. Dr.-Ing Pere Fullana i Palmer

Dr. Fullana, studied chemical engineering (Final Project Award 1988) at Institut Químic de Sarrià (IQS, URL, Barcelona) and Industrial Engineering at UAB. He continued with a PhD Degree in Industrial Engineering at Universitat Ramon Llull. He is the Director of the UNESCO Chair in Life Cycle and Climate Change at ESCI-UPF, in Barcelona, a research group that has been awarded with the Environmental Award 2008 by the Government of Catalonia.

From the very beginning, he was the Spanish delegate for drafting the ISO on LCA, eco-design and eco-labelling and also for drafting the CEN regulation on LCA for packaging and ecolabels in construction materials. He has been a member of the International Life Cycle Board of the UNEP-SETAC Life Cycle Initiative and has been involved in writing the Product standard of the Green House Gases Protocol by the World Business Council for Sustainable Development. He is a former Chair of the LCA Steering Committee of SETAC Europe. He has received a number of honours, including the Award for the Most Significant Contribution to the International Life Cycle Management Conference (LCM 2009). He represented the Research and Independent NGOs (Academia) and stated their conclusions in the Closing Plenary of COP25 on Climate Change.

He has participated in more than 150 LCA studies and published numerous scientific articles. Dr. Fullana is an experienced LCA Critical Reviewer with more than 20 participations, including the review of the ILCD Handbook chapter on Critical Review.

Dr. Ivo Mersiowsky

Dr. Mersiowsky studied environmental and construction engineering at the Technical University of Hamburg-Harburg, Germany, where he also was awarded a PhD degree for research into the environmental behaviour of PVC products. His career steps include: LCA practitioner and in-house consultant Life Cycle & Sustainability at Solvay; senior consultant Product Sustainability at Five Winds International; business line manager Sustainability Management at DEKRA; founder and managing partner at Quiridium, a consultancy specialising on sustainability and leadership development.

Among other assignments, he worked as PlasticsEurope’s Eco-profile programme manager for seven more than ten years, as project manager for the International Zinc Association IZA’s Zince for Life programme, and as a critical reviewer for numerous corporate LCA projects and IBU EPDs. Nowadays, he focuses on integrating life cycle and sustainability aspects in product innovation and business management .

Angela Schindler

Angela Schindler holds a degree in chemical engineering from the Georg-Simon-Ohm university in Nuremberg, Germany. She is working since many years as expert for life cycle assessment focusing on energy and material flow analysis, critical reviews according to ISO 14040/44 and environmental labelling. She is expert and trainer for the application of the life cycle software GaBi. She has generated a large number of LCA studies for the industry sectors construction, aluminum, logistics, plastics, food, electronics. Angela Schindler was panel member for the PEFCR review for thermal insulation of the European Commission’s Product Environmental Footprint pilot study. She is accredited verifier for environmental product declarations (EPDs) of the program owner IBU, Berlin, environdec, Stockholm and Bau EPD GmbH, Vienna.

Previously she has worked at thinkstep, as Senior Consultant for life cycle assessments and conducting quality assurance projects. She has been working as engineer for environmental matters in the R&D department for floor coverings made from rubber (nora systems GmbH) and as process responsible in a pilot plan for thin film solar cells (Würth Solar GmbH & Co KG).

Annex B: Data quality evaluation

Table B-0-1: Data quality indicators for the EU region. 4 – very good, 3 – good, 2 – fair, 1 - poor

Data quality	Technical	Temporal	Geographical	Completeness	Precision
Processes					
Electricity	4	4	4	4	4
Thermal energy	4	4	4	4	4
Transports	4	4	3	2	3
Manufacturing of	3.5	3	4	3.75	3.5
Beverage cartons	4	3	4	4	4
PET bottles	3	2	4	3	3
Glass bottles	3	3	4	4	3
Aluminum cans	4	4	4	4	4
Materials					
Raw materials of	3.75	3.25	4	3.75	4
Beverage cartons	3	3	4	4	4
PET bottles	4	3	4	3	4
Glass bottles	4	3	4	4	4
Aluminum cans	4	4	4	4	4
Operating materials	4	4	4	4	4
End of life stage					
Recycling	3	3	4	4	3
Incineration	4	4	4	4	4
Landfilling	4	4	4	4	4
Overall per packaging alternative					
Beverage cartons	3.8	3.7	3.9	3.8	3.8
PET bottles	3.8	3.6	3.9	3.6	3.7
Glass bottles	3.8	3.7	3.9	3.8	3.7
Aluminum cans	3.9	3.9	3.9	3.8	3.8

Table B-0-2: Data quality indicators for the US region. 4 – very good, 3 – good, 2 – fair, 1 – poor.

Data quality	Technical	Temporal	Geographical	Completeness	Precision
Processes					
Electricity	4	4	4	4	4
Thermal energy	4	4	4	4	4
Transports	4	4	3	2	3
Manufacturing of	3.5	3	3.25	3.75	3.5
Beverage cartons	4	3	3	4	4
PET bottles	3	2	3	3	3
Glass bottles	3	3	3	4	3
Aluminum cans	4	4	4	4	4
Materials					
Raw materials of	3.5	3.5	3.5	3.75	3.75
Beverage cartons	3	3	3	4	4
PET bottles	4	4	4	3	4
Glass bottles	3	3	3	4	3
Aluminum cans	4	4	4	4	4
Operating materials	4	4	3	4	4
End of life stage					
Recycling	3	3	3	4	3
Incineration	4	4	4	4	4
Landfilling	4	4	4	4	4
Overall per packaging alternative					
Beverage cartons	3.8	3.7	3.4	3.8	3.8
PET bottles	3.8	3.7	3.6	3.6	3.7
Glass bottles	3.7	3.7	3.4	3.8	3.6
Aluminum cans	3.9	3.9	3.7	3.8	3.8

Table B-0-3: Data quality indicators for the BR region. 4 – very good, 3 – good, 2 – fair, 1 – poor.

Data quality	Technical	Temporal	Geographical	Completeness	Precision
Processes					
Electricity	4	4	4	4	4
Thermal energy	4	4	4	4	4
Transports	4	4	3	2	3
Manufacturing of	3.5	3	3.25	3.75	3.5
Beverage cartons	4	3	3	4	4
PET bottles	3	2	3	3	3
Glass bottles	3	3	3	4	3
Aluminum cans	4	4	4	4	4
Materials					
Raw materials of	3.25	3.25	2.5	3.75	3.25
Beverage cartons	3	3	3	4	4
PET bottles	4	4	3	3	3
Glass bottles	3	3	2	4	3
Aluminum cans	3	3	2	4	3
Operating materials	4	4	2	4	4
End of life stage					
Recycling	3	3	3	4	3
Incineration	4	4	3	4	3
Landfilling	4	4	3	4	3
Overall per packaging alternative					
Beverage cartons	3.8	3.7	3.1	3.8	3.6
PET bottles	3.8	3.7	3.1	3.6	3.3
Glass bottles	3.7	3.7	3.0	3.8	3.3
Aluminum cans	3.8	3.8	3.1	3.8	3.4

Annex C: Life Cycle Inventory

EU

Table C-0-4: Summary of the life cycle inventory results in terms of energy (MJ, net calorific value) for all packaging options in the EU, per liter of product.

		Beverage cartons		PET (C)		PET (NC)		Glass bottle			Aluminum cans		
	Unit	0.33L	0.50L	0.38L	0.5L	0.30L	0.5L	0.25L	0.33L	1L	0.25L	0.33L	0.50L
Resources	MJ	**2.9E+00**	**2.8E+00**	**6.1E+00**	**4.0E+00**	**5.7E+00**	**2.6E+00**	**1.2E+01**	**9.3E+00**	**8.2E+00**	**5.2E+00**	**5.1E+00**	**3.7E+00**
Energy resources	**MJ**	**2.9E+00**	**2.8E+00**	**6.1E+00**	**4.0E+00**	**5.7E+00**	**2.6E+00**	**1.2E+01**	**9.3E+00**	**8.2E+00**	**5.2E+00**	**5.1E+00**	**3.7E+00**
Non renewable energy resources	**MJ**	**2.3E+00**	**2.1E+00**	**5.7E+00**	**3.7E+00**	**5.3E+00**	**2.5E+00**	**1.1E+01**	**8.6E+00**	**7.6E+00**	**3.9E+00**	**3.8E+00**	**2.8E+00**
Crude oil (resource)	MJ	1.3E+00	1.1E+00	2.5E+00	2.8E+00	1.8E+00	1.2E+00	1.8E+00	1.5E+00	1.3E+00	6.3E-01	7.6E-01	5.4E-01
Hard coal (resource)	MJ	1.6E-01	1.4E-01	2.9E-01	2.0E-01	2.9E-01	1.3E-01	8.4E-01	6.5E-01	5.6E-01	9.3E-01	8.3E-01	6.5E-01
Lignite (resource)	MJ	5.0E-02	5.0E-02	1.5E-01	1.0E-01	1.5E-01	6.5E-02	3.0E-01	2.4E-01	2.1E-01	1.5E-01	1.4E-01	1.1E-01
Natural gas (resource)	MJ	7.1E-01	7.1E-01	2.1E+00	1.4E+00	2.0E+00	9.2E-01	6.9E+00	5.7E+00	5.1E+00	1.6E+00	1.5E+00	1.1E+00
Peat (resource)	MJ	1.3E-03	2.5E-03	1.9E-03	1.2E-03	1.8E-03	8.2E-04	6.7E-03	2.8E-03	2.5E-03	4.1E-03	4.4E-03	2.0E-03
Uranium (resource)	MJ	1.1E-01	1.0E-01	3.8E-01	2.5E-01	3.7E-01	1.6E-01	6.8E-01	5.6E-01	5.0E-01	5.7E-01	5.3E-01	4.1E-01
Renewable energy resources	**MJ**	**6.4E-01**	**7.3E-01**	**4.0E-01**	**2.6E-01**	**3.9E-01**	**1.7E-01**	**1.1E+00**	**6.6E-01**	**5.9E-01**	**1.4E+00**	**1.3E+00**	**8.9E-01**
Biomass (MJ)	MJ	2.5E-11	4.6E-11	2.0E-22	1.2E-22	1.7E-22	8.2E-23	3.9E-07	1.5E-07	6.9E-08	3.6E-11	4.4E-11	8.9E-12
Primary energy from geothermics	MJ	8.6E-04	7.5E-04	3.7E-03	2.5E-03	3.6E-03	1.6E-03	6.7E-03	5.5E-03	4.9E-03	3.3E-03	3.1E-03	2.4E-03
Primary energy from hydro power	MJ	1.9E-01	1.7E-01	8.3E-02	5.5E-02	8.1E-02	3.6E-02	1.2E-01	1.0E-01	9.0E-02	8.5E-01	7.6E-01	6.1E-01
Primary energy from solar energy	MJ	4.3E-01	5.5E-01	2.0E-01	1.3E-01	1.9E-01	8.5E-02	7.6E-01	3.8E-01	3.4E-01	4.1E-01	4.5E-01	2.0E-01
Primary energy from waves	MJ	2.1E-14	1.9E-14	1.2E-13	7.9E-14	1.2E-13	5.2E-14	2.3E-13	1.9E-13	1.7E-13	9.9E-14	9.2E-14	7.1E-14
Primary energy from wind power	MJ	2.1E-02	1.9E-02	1.1E-01	7.5E-02	1.1E-01	4.9E-02	2.1E-01	1.7E-01	1.5E-01	1.1E-01	9.7E-02	7.5E-02
Material resources	**MJ**	**1.3E-04**	**1.9E-04**	**7.0E-05**	**4.7E-05**	**6.9E-05**	**3.0E-05**	**3.5E-04**	**1.7E-04**	**1.5E-04**	**1.7E-04**	**1.9E-04**	**7.6E-05**
Deposited goods	**MJ**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**
Emissions to air	**MJ**	**5.4E-01**	**5.0E-01**	**1.4E+00**	**8.9E-01**	**1.3E+00**	**5.9E-01**	**1.8E+00**	**1.4E+00**	**1.3E+00**	**1.2E+00**	**1.1E+00**	**8.4E-01**
Emissions to fresh water	**MJ**	**1.2E-01**	**1.1E-01**	**1.8E-01**	**1.2E-01**	**1.8E-01**	**7.9E-02**	**3.2E-01**	**2.6E-01**	**2.3E-01**	**4.9E-01**	**4.5E-01**	**3.5E-01**
Emissions to sea water	**MJ**	**1.3E-02**	**1.3E-02**	**4.9E-02**	**3.3E-02**	**4.9E-02**	**2.1E-02**	**1.7E-01**	**1.4E-01**	**1.2E-01**	**2.7E-02**	**2.6E-02**	**1.7E-02**

Table C-0-5: Summary of the life cycle inventory in terms of mass (kg) for all packaging options in Europe, per liter of product content.

		Beverage cartons		PET (C)		PET (NC)		Glass bottle			Aluminum cans		
	Unit	0.33L	0.50L	0.38L	0.5L	0.30L	0.5L	0.25L	0.33L	1L	0.25L	0.33L	0.50L
Resources	**kg**	**3.8E+02**	**3.3E+02**	**2.4E+02**	**1.6E+02**	**2.4E+02**	**1.1E+02**	**4.1E+02**	**3.4E+02**	**3.0E+02**	**2.2E+03**	**2.0E+03**	**1.6E+03**
Energy resources	**kg**	**5.7E-02**	**5.2E-02**	**1.4E-01**	**8.9E-02**	**1.3E-01**	**5.9E-02**	**2.6E-01**	**2.1E-01**	**1.9E-01**	**9.9E-02**	**9.7E-02**	**7.1E-02**
Non renewable energy resources	kg	5.7E-02	5.2E-02	1.4E-01	8.9E-02	1.3E-01	5.9E-02	2.6E-01	2.1E-01	1.9E-01	9.9E-02	9.7E-02	7.1E-02
Crude oil (resource)	kg	3.0E-02	2.6E-02	6.5E-02	4.2E-02	5.9E-02	2.8E-02	4.2E-02	3.5E-02	3.1E-02	1.5E-02	1.8E-02	1.3E-02
Hard coal (resource)	kg	6.0E-03	5.4E-03	1.1E-02	7.5E-03	1.1E-02	4.9E-03	3.2E-02	2.5E-02	2.1E-02	3.5E-02	3.2E-02	2.5E-02
Lignite (resource)	kg	4.2E-03	4.2E-03	1.3E-02	8.4E-03	1.2E-02	5.5E-03	2.5E-02	2.0E-02	1.8E-02	1.3E-02	1.2E-02	9.0E-03
Natural gas (resource)	kg	1.6E-02	1.6E-02	4.8E-02	3.2E-02	4.6E-02	2.1E-02	1.6E-01	1.3E-01	1.1E-01	3.5E-02	3.5E-02	2.5E-02
Peat (resource)	kg	1.5E-04	3.0E-04	2.2E-04	1.5E-04	2.2E-04	9.7E-05	8.0E-04	3.3E-04	3.0E-04	4.9E-04	5.3E-04	2.3E-04
Uranium (resource)	kg	2.1E-07	1.8E-07	6.9E-07	4.6E-07	6.7E-07	3.0E-07	1.2E-06	1.0E-06	9.1E-07	1.1E-06	9.7E-07	7.6E-07
Renewable energy resources	kg	1.7E-12	3.1E-12	1.4E-23	8.1E-24	1.2E-23	5.6E-24	2.7E-08	1.0E-08	4.7E-09	2.4E-12	3.0E-12	6.0E-13
Biomass (MJ)	kg	1.7E-12	3.1E-12	1.4E-23	8.1E-24	1.2E-23	5.6E-24	2.7E-08	1.0E-08	4.7E-09	2.4E-12	3.0E-12	6.0E-13
Material resources	**kg**	**3.8E+02**	**3.3E+02**	**2.4E+02**	**1.6E+02**	**2.4E+02**	**1.1E+02**	**4.1E+02**	**3.4E+02**	**3.0E+02**	**2.2E+03**	**2.0E+03**	**1.6E+03**
Non renewable elements	**kg**	**1.8E-04**	**1.9E-04**	**3.7E-04**	**2.4E-04**	**3.6E-04**	**1.6E-04**	**3.7E-03**	**1.3E-03**	**4.9E-04**	**1.4E-03**	**1.3E-03**	**1.0E-03**
Non renewable resources	**kg**	**1.4E-01**	**1.3E-01**	**3.5E-01**	**2.3E-01**	**3.4E-01**	**1.5E-01**	**1.5E+00**	**1.3E+00**	**1.1E+00**	**5.4E-01**	**5.0E-01**	**3.8E-01**
Renewable resources	**kg**	**3.8E+02**	**3.3E+02**	**2.4E+02**	**1.6E+02**	**2.4E+02**	**1.1E+02**	**4.1E+02**	**3.4E+02**	**3.0E+02**	**2.2E+03**	**2.0E+03**	**1.6E+03**
Water	kg	3.8E+02	3.3E+02	2.4E+02	1.6E+02	2.4E+02	1.0E+02	4.1E+02	3.4E+02	3.0E+02	2.2E+03	2.0E+03	1.6E+03
Air	kg	5.7E-01	5.0E-01	1.8E+00	1.2E+00	1.7E+00	7.8E-01	1.2E+00	9.7E-01	8.7E-01	1.5E+00	1.4E+00	1.1E+00
Carbon dioxide	kg	4.1E-02	7.0E-02	1.1E-02	7.1E-03	1.0E-02	4.6E-03	1.0E-01	2.3E-02	2.0E-02	6.2E-02	7.2E-02	2.2E-02
Forest, primary	kg	-5.2E-10	-5.6E-10	-1.9E-09	-1.3E-09	-1.9E-09	-8.2E-10	-7.5E-09	4.1E-09	1.1E-08	-6.2E-10	-6.1E-10	-3.6E-10
Nitrogen	kg	6.6E-12	6.8E-12	1.7E-12	1.1E-12	1.6E-12	7.2E-13	4.6E-12	3.9E-12	5.0E-12	3.1E-12	3.4E-12	1.4E-12
Oxygen	kg	2.4E-05	2.4E-05	2.2E-05	1.5E-05	2.1E-05	9.5E-06	5.7E-06	1.8E-05	2.2E-05	8.7E-04	7.2E-04	5.4E-04
Renewable fuels	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.1E-10	6.4E-10	0.0E+00	0.0E+00	0.0E+00
Soft wood, dry matter	kg	1.1E-12	2.0E-12	9.0E-24	5.2E-24	7.6E-24	3.6E-24	1.4E-12	-9.2E-13	-8.2E-13	1.6E-12	2.0E-12	3.9E-13
Deposited goods	**kg**	**1.1E-01**	**1.1E-01**	**2.7E-01**	**1.8E-01**	**2.6E-01**	**1.2E-01**	**8.7E-01**	**7.3E-01**	**6.5E-01**	**4.4E-01**	**4.1E-01**	**3.1E-01**
Stockpile goods	kg	1.1E-01	1.1E-01	2.7E-01	1.8E-01	2.6E-01	1.2E-01	8.7E-01	7.3E-01	6.5E-01	4.4E-01	4.1E-01	3.1E-01
Hazardous waste (deposited)	kg	1.4E-08	2.1E-08	8.0E-09	5.2E-09	7.5E-09	3.5E-09	1.1E-07	7.2E-08	6.1E-08	3.1E-08	3.3E-08	1.7E-08
Overburden (deposited)	kg	8.0E-02	7.7E-02	2.3E-01	1.6E-01	2.3E-01	1.0E-01	6.1E-01	5.0E-01	4.5E-01	3.6E-01	3.4E-01	2.6E-01
Slag (deposited)	kg	6.1E-13	5.5E-13	3.5E-12	2.3E-12	3.5E-12	1.5E-12	6.8E-12	5.6E-12	5.0E-12	2.7E-12	2.5E-12	1.9E-12
Spoil (deposited)	kg	2.1E-03	1.9E-03	3.0E-03	2.0E-03	2.9E-03	1.3E-03	5.3E-03	4.3E-03	3.8E-03	9.6E-03	8.7E-03	6.8E-03
Tailings (deposited)	kg	4.7E-04	4.4E-04	7.8E-04	5.1E-04	7.6E-04	3.3E-04	-2.5E-03	-8.4E-04	-2.7E-04	4.0E-03	3.6E-03	2.9E-03
Waste (deposited)	kg	3.0E-02	2.8E-02	2.9E-02	1.9E-02	2.7E-02	1.3E-02	2.7E-01	2.2E-01	2.0E-01	6.0E-02	5.7E-02	4.3E-02
Emissions to air	**kg**	**2.9E+00**	**3.7E+00**	**4.2E+00**	**2.8E+00**	**4.0E+00**	**1.8E+00**	**8.9E+00**	**5.2E+00**	**4.6E+00**	**6.6E+00**	**6.6E+00**	**4.0E+00**
Heavy metals to air	**kg**	**1.6E-07**	**1.4E-07**	**8.1E-07**	**5.5E-07**	**7.9E-07**	**3.6E-07**	**-6.4E-07**	**-1.5E-07**	**1.1E-08**	**9.6E-07**	**8.3E-07**	**6.1E-07**
Inorganic emissions to air	**kg**	**2.4E+00**	**3.2E+00**	**2.7E+00**	**1.8E+00**	**2.6E+00**	**1.2E+00**	**7.7E+00**	**4.3E+00**	**3.8E+00**	**5.6E+00**	**5.6E+00**	**3.2E+00**
Organic emissions to air (group VOC)	**kg**	**7.1E-04**	**7.5E-04**	**8.3E-04**	**5.4E-04**	**7.8E-04**	**3.6E-04**	**1.7E-03**	**1.2E-03**	**1.1E-03**	**1.1E-03**	**1.1E-03**	**7.5E-04**
Group NMVOC to air	kg	8.0E-05	7.1E-05	1.8E-04	1.1E-04	1.6E-04	7.7E-05	1.6E-04	1.2E-04	1.1E-04	3.9E-04	3.7E-04	3.0E-04
Group PAH to air	kg	2.4E-07	2.0E-07	3.5E-09	2.2E-09	3.2E-09	1.5E-09	-1.5E-07	-6.5E-08	-3.5E-08	1.4E-06	1.2E-06	1.0E-06
Halogenated organic emissions to air	kg	2.2E-07	1.9E-07	1.9E-08	1.2E-08	1.7E-08	8.1E-09	-1.3E-08	-1.6E-08	-1.4E-08	1.2E-06	1.0E-06	8.4E-07
Hydrocarbons (unspecified)	kg	5.2E-07	4.3E-07	9.5E-07	5.9E-07	8.9E-07	3.9E-07	6.4E-07	6.0E-07	5.7E-07	7.8E-07	7.3E-07	5.6E-07
Methane	kg	2.7E-04	2.4E-04	6.4E-04	4.2E-04	6.0E-04	2.8E-04	1.3E-03	1.1E-03	9.4E-04	5.2E-04	5.0E-04	3.7E-04
Methane (biotic)	kg	3.5E-04	4.3E-04	9.2E-06	6.1E-06	9.1E-06	4.0E-06	2.2E-04	2.7E-05	2.3E-05	1.9E-04	2.2E-04	8.2E-05
VOC (unspecified)	kg	1.3E-05	1.3E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.0E-14	1.1E-13	-5.0E-17	-4.3E-17	-3.2E-17
Other emissions to air	**kg**	**5.2E-01**	**4.6E-01**	**1.5E+00**	**1.0E+00**	**1.5E+00**	**6.7E-01**	**1.2E+00**	**9.3E-01**	**8.3E-01**	**1.1E+00**	**1.0E+00**	**7.7E-01**
Particles to air	**kg**	**2.7E-05**	**2.5E-05**	**4.4E-05**	**3.0E-05**	**4.3E-05**	**1.9E-05**	**1.8E-04**	**1.4E-04**	**1.3E-04**	**1.4E-04**	**1.3E-04**	**9.7E-05**
Aluminium oxide (dust)	kg	6.3E-12	5.4E-12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.0E-16	2.7E-16	2.2E-16
Dust (> PM10)	kg	4.2E-06	4.0E-06	1.6E-05	1.1E-05	1.6E-05	7.2E-06	3.6E-05	2.8E-05	2.4E-05	4.4E-05	3.9E-05	2.9E-05
Dust (PM10)	kg	2.8E-08	3.9E-08	6.5E-08	4.4E-08	6.5E-08	2.8E-08	4.4E-06	1.6E-06	6.8E-07	1.2E-07	1.1E-07	6.4E-08
Dust (PM2.5 - PM10)	kg	1.0E-05	9.1E-06	1.3E-05	9.0E-06	1.3E-05	5.9E-06	9.5E-05	8.1E-05	7.1E-05	5.0E-05	4.5E-05	3.4E-05
Dust (PM2.5)	kg	1.2E-05	1.2E-05	1.4E-05	9.5E-06	1.4E-05	6.2E-06	4.0E-05	3.1E-05	2.7E-05	4.9E-05	4.4E-05	3.3E-05

Dust (unspecified)	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.0E-09	3.1E-09	0.0E+00	0.0E+00	0.0E+00
Metals (unspecified)	kg	1.6E-11	1.4E-11	9.0E-11	6.0E-11	8.9E-11	3.9E-11	3.6E-06	3.1E-06	2.7E-06	7.9E-11	7.3E-11	5.6E-11
Silicon dioxide (silica)	kg	1.3E-11	1.2E-11	7.3E-11	4.8E-11	7.2E-11	3.1E-11	1.4E-10	1.2E-10	1.0E-10	6.3E-11	5.8E-11	4.5E-11
Silicon dust	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-3.5E-17	-3.0E-17	-2.3E-17
Pesticides to air	**kg**	**1.7E-09**	**2.6E-09**	**9.8E-10**	**6.5E-10**	**9.6E-10**	**4.2E-10**	**4.7E-09**	**1.8E-09**	**1.6E-09**	**2.7E-09**	**3.0E-09**	**1.1E-09**
Radioactive emissions to air	**kg**	**-3.6E-14**	**-4.4E-14**	**-2.0E-13**	**-1.3E-13**	**-2.0E-13**	**-8.7E-14**	**-8.2E-13**	**2.0E-13**	**7.6E-13**	**-6.0E-14**	**-5.9E-14**	**-3.3E-14**
Emissions to fresh water	**kg**	**3.8E+02**	**3.3E+02**	**2.5E+02**	**1.7E+02**	**2.4E+02**	**1.1E+02**	**4.2E+02**	**3.5E+02**	**3.1E+02**	**2.2E+03**	**2.0E+03**	**1.6E+03**
Analytical measures to fresh water	kg	4.3E-06	3.9E-05	9.3E-05	6.2E-05	9.0E-05	4.0E-05	2.4E-04	1.1E-04	1.0E-04	1.9E-04	1.9E-04	1.0E-04
Adsorbable organic halogen compounds (AOX)	kg	2.7E-06	2.3E-06	4.7E-06	2.9E-06	4.2E-06	2.0E-06	3.4E-06	2.8E-06	2.5E-06	4.1E-07	7.9E-07	4.4E-07
Biological oxygen demand (BOD)	kg	7.9E-06	1.1E-05	1.9E-06	1.3E-06	1.8E-06	8.5E-07	1.1E-05	1.6E-06	1.4E-06	8.9E-06	1.0E-05	3.9E-06
Chemical oxygen demand (COD)	kg	-7.2E-06	2.5E-05	8.5E-05	5.6E-05	8.2E-05	3.7E-05	2.2E-04	1.1E-04	9.6E-05	1.8E-04	1.8E-04	9.9E-05
Nitrogenous Matter (unspecified, as N)	kg	7.8E-09	7.2E-09	1.1E-08	7.5E-09	1.1E-08	4.9E-09	2.7E-07	1.1E-07	6.2E-08	3.0E-08	2.8E-08	2.2E-08
Solids (dissolved)	kg	1.3E-07	1.0E-07	2.9E-07	1.9E-07	2.8E-07	1.3E-07	-1.2E-06	-4.3E-07	-1.6E-07	7.6E-07	6.9E-07	5.6E-07
Total dissolved organic bound carbon (TOC)	kg	5.2E-11	4.8E-11	5.8E-11	3.8E-11	5.7E-11	2.5E-11	1.0E-10	8.6E-11	7.7E-11	8.5E-11	7.8E-11	6.1E-11
Total organic bound carbon (TOC)	kg	7.5E-07	8.4E-07	1.5E-06	9.6E-07	1.4E-06	6.4E-07	1.5E-06	9.4E-07	8.6E-07	7.2E-07	8.5E-07	4.2E-07
Heavy metals to fresh water	**kg**	**9.7E-06**	**9.4E-06**	**2.7E-05**	**1.8E-05**	**2.7E-05**	**1.2E-05**	**5.5E-05**	**4.3E-05**	**3.8E-05**	**2.8E-05**	**2.7E-05**	**2.0E-05**
Inorganic emissions to fresh water	**kg**	**3.2E-03**	**2.7E-03**	**8.6E-03**	**5.6E-03**	**8.0E-03**	**3.7E-03**	**3.6E-02**	**3.1E-02**	**2.8E-02**	**3.3E-03**	**3.5E-03**	**2.6E-03**
Organic emissions to fresh water	**kg**	**7.1E-05**	**1.0E-04**	**4.1E-05**	**2.7E-05**	**3.9E-05**	**1.8E-05**	**2.5E-04**	**1.4E-04**	**1.2E-04**	**1.4E-04**	**1.5E-04**	**7.9E-05**
Halogenated organic emissions to fresh water	kg	**1.9E-10**	**1.9E-10**	**-5.5E-13**	**-3.6E-13**	**-5.5E-13**	**-2.3E-13**	**-2.9E-12**	**-2.1E-12**	**-1.6E-12**	**3.1E-14**	**1.3E-14**	**6.5E-14**
Hydrocarbons to fresh water	**kg**	**1.1E-05**	**9.6E-06**	**7.2E-06**	**4.6E-06**	**6.6E-06**	**3.0E-06**	**2.6E-05**	**2.2E-05**	**2.0E-05**	**5.2E-05**	**4.7E-05**	**3.8E-05**
Other emissions to fresh water	**kg**	**3.8E+02**	**3.2E+02**	**2.4E+02**	**1.6E+02**	**2.3E+02**	**1.0E+02**	**4.0E+02**	**3.3E+02**	**2.9E+02**	**2.2E+03**	**2.0E+03**	**1.6E+03**
Pesticides to fresh water	**kg**	**3.9E-09**	**6.4E-09**	**9.6E-10**	**6.4E-10**	**9.4E-10**	**4.2E-10**	**8.7E-09**	**1.7E-09**	**1.5E-09**	**5.3E-09**	**6.2E-09**	**1.8E-09**
Particles to fresh water	**kg**	**6.8E-04**	**9.8E-04**	**6.2E-04**	**4.1E-04**	**5.9E-04**	**2.7E-04**	**4.8E-03**	**3.3E-03**	**2.9E-03**	**1.1E-03**	**1.2E-03**	**5.0E-04**
Radioactive emissions to fresh water	**kg**	**3.5E+00**	**3.0E+00**	**1.1E+01**	**7.4E+00**	**1.1E+01**	**4.9E+00**	**2.0E+01**	**1.7E+01**	**1.5E+01**	**1.7E+01**	**1.6E+01**	**1.2E+01**
Emissions to sea water	**kg**	**8.8E-01**	**7.7E-01**	**1.2E+00**	**8.3E-01**	**1.2E+00**	**5.4E-01**	**3.0E+00**	**2.4E+00**	**2.1E+00**	**4.7E+00**	**4.3E+00**	**3.4E+00**
Analytical measures to sea water	**kg**	**1.1E-06**	**9.4E-07**	**2.5E-06**	**1.6E-06**	**2.3E-06**	**1.0E-06**	**2.8E-06**	**2.2E-06**	**1.9E-06**	**7.2E-07**	**8.1E-07**	**5.7E-07**
Heavy metals to sea water	**kg**	**9.5E-08**	**7.8E-08**	**2.0E-07**	**1.3E-07**	**1.8E-07**	**8.5E-08**	**1.5E-07**	**1.2E-07**	**1.1E-07**	**4.9E-08**	**5.7E-08**	**4.0E-08**
Hydrocarbons to sea water	**kg**	**5.8E-07**	**4.8E-07**	**1.3E-06**	**7.9E-07**	**1.2E-06**	**5.3E-07**	**9.2E-07**	**7.5E-07**	**6.8E-07**	**3.0E-07**	**3.5E-07**	**2.5E-07**
Cooling water to sea	**kg**	**8.8E-01**	**7.7E-01**	**1.2E+00**	**8.3E-01**	**1.2E+00**	**5.4E-01**	**2.8E+00**	**2.3E+00**	**2.0E+00**	**4.7E+00**	**4.3E+00**	**3.4E+00**
Processed water to sea	**kg**	**2.4E-03**	**2.0E-03**	**9.4E-04**	**6.3E-04**	**7.2E-04**	**4.6E-04**	**1.7E-01**	**9.6E-02**	**6.8E-02**	**1.0E-02**	**9.3E-03**	**7.4E-03**
Particles to sea water	**kg**	**1.2E-05**	**1.1E-05**	**2.8E-05**	**1.8E-05**	**2.6E-05**	**1.2E-05**	**7.0E-05**	**5.8E-05**	**5.1E-05**	**1.5E-05**	**1.6E-05**	**1.1E-05**
Solids (suspended)	kg	1.2E-05	1.1E-05	2.8E-05	1.8E-05	2.6E-05	1.2E-05	7.0E-05	5.8E-05	5.1E-05	1.5E-05	1.6E-05	1.1E-05
Emissions to agricultural soil	**kg**	**6.4E-08**	**8.6E-08**	**1.8E-08**	**1.1E-08**	**1.7E-08**	**7.5E-09**	**2.2E-07**	**1.4E-07**	**1.2E-07**	**4.5E-08**	**5.4E-08**	**1.4E-08**
Heavy metals to agricultural soil	kg	4.6E-08	6.9E-08	1.7E-08	1.1E-08	1.7E-08	7.4E-09	2.2E-07	1.4E-07	1.2E-07	**4.5E-08**	**5.4E-08**	**1.4E-08**
Inorganic emissions to agricultural soil	kg	1.7E-08	1.7E-08	2.4E-10	1.7E-10	2.4E-10	1.1E-10	7.3E-10	6.0E-10	5.3E-10	**1.5E-10**	**1.4E-10**	**1.1E-10**
Other emissions to agricultural soil	**kg**	**2.6E-18**	**4.9E-18**	**1.7E-29**	**9.4E-30**	**1.4E-29**	**6.7E-30**	**3.5E-18**	**-2.2E-18**	**-2.0E-18**	**3.8E-18**	**4.7E-18**	**9.4E-19**
Pesticides to agricultural soil	**kg**	**2.6E-18**	**4.9E-18**	**1.7E-29**	**9.4E-30**	**1.4E-29**	**6.7E-30**	**3.5E-18**	**-2.2E-18**	**-2.0E-18**	**3.8E-18**	**4.7E-18**	**9.4E-19**
Emissions to industrial soil	**kg**	**5.0E-05**	**5.0E-05**	**5.2E-05**	**3.2E-05**	**4.6E-05**	**2.2E-05**	**5.3E-05**	**3.5E-05**	**3.1E-05**	**1.8E-05**	**2.3E-05**	**1.2E-05**
Heavy metals to industrial soil	**kg**	**8.7E-09**	**7.7E-09**	**1.7E-08**	**1.1E-08**	**1.5E-08**	**7.2E-09**	**3.3E-08**	**1.3E-08**	**6.6E-09**	**4.3E-09**	**5.1E-09**	**3.3E-09**
Inorganic emissions to industrial soil	**kg**	**5.0E-05**	**4.9E-05**	**5.2E-05**	**3.2E-05**	**4.6E-05**	**2.2E-05**	**5.3E-05**	**3.5E-05**	**3.1E-05**	**1.8E-05**	**2.3E-05**	**1.2E-05**
Organic emissions to industrial soil	**kg**	**3.6E-11**	**3.1E-11**	**5.2E-11**	**3.4E-11**	**5.1E-11**	**2.2E-11**	**1.2E-10**	**9.1E-11**	**7.9E-11**	**2.1E-10**	**1.9E-10**	**1.5E-10**
Hydrocarbons (unspecified)	**kg**	**8.3E-15**	**7.6E-15**	**4.9E-14**	**3.2E-14**	**4.8E-14**	**2.1E-14**	**9.4E-14**	**7.8E-14**	**6.9E-14**	**3.7E-14**	**3.4E-14**	**2.6E-14**
Other emissions to industrial soil	**kg**	**1.2E-18**	**2.3E-18**	**9.6E-30**	**5.5E-30**	**8.0E-30**	**3.9E-30**	**2.7E-10**	**1.0E-10**	**4.7E-11**	**1.8E-18**	**2.2E-18**	**4.4E-19**
Pesticides to industrial soil	**kg**	**1.2E-18**	**2.3E-18**	**9.6E-30**	**5.5E-30**	**8.0E-30**	**3.9E-30**	**1.6E-18**	**-1.0E-18**	**-9.2E-19**	**1.8E-18**	**2.2E-18**	**4.4E-19**

US

Table C-0-6: **Summary of the life cycle inventory results in terms of energy (MJ, net calorific value) for all packaging options in the US, per gallon of product.**

		Beverage cartons		PET (C)		PET (NC)	Glass bottle		Aluminum cans		
	Unit	11.1oz	16.9oz	12oz	16.9oz	16.9oz	12oz	16oz	12oz	16oz STD	16oz ATB
Resources	**MJ**	**2.2E+01**	**2.5E+01**	**2.5E+01**	**2.6E+01**	**8.7E+00**	**8.3E+01**	**3.9E+01**	**1.5E+01**	**1.4E+01**	**2.2E+01**
Energy resources	**MJ**	**2.2E+01**	**2.5E+01**	**2.5E+01**	**2.6E+01**	**8.7E+00**	**8.3E+01**	**3.9E+01**	**1.5E+01**	**1.4E+01**	**2.2E+01**
Non renewable energy resources	**MJ**	**1.4E+01**	**1.3E+01**	**2.4E+01**	**2.5E+01**	**8.4E+00**	**6.8E+01**	**3.5E+01**	**1.2E+01**	**1.0E+01**	**1.7E+01**
Crude oil (resource)	MJ	3.2E+00	3.1E+00	8.0E+00	8.4E+00	3.0E+00	9.8E+00	4.6E+00	2.0E+00	1.8E+00	2.8E+00
Hard coal (resource)	MJ	2.1E+00	1.9E+00	2.0E+00	2.0E+00	6.8E-01	5.6E+00	3.3E+00	1.7E+00	1.5E+00	2.4E+00
Lignite (resource)	MJ	1.7E-01	2.7E-01	1.6E-01	1.7E-01	5.0E-02	1.1E+00	4.6E-01	1.6E+00	1.4E+00	2.3E+00
Natural gas (resource)	MJ	7.5E+00	7.4E+00	1.3E+01	1.3E+01	4.3E+00	4.8E+01	2.5E+01	5.5E+00	4.9E+00	7.9E+00
Peat (resource)	MJ	2.3E-02	4.4E-02	3.9E-03	4.4E-03	2.1E-05	8.4E-02	1.6E-02	8.2E-03	9.3E-03	9.9E-03
Uranium (resource)	MJ	6.2E-01	6.6E-01	1.1E+00	1.1E+00	3.9E-01	3.5E+00	1.8E+00	8.2E-01	7.2E-01	1.2E+00
Renewable energy resources	MJ	**7.9E+00**	**1.1E+01**	**1.3E+00**	**1.4E+00**	**2.5E-01**	**1.5E+01**	**3.7E+00**	**3.8E+00**	**3.6E+00**	**5.1E+00**
Biomass (MJ)	MJ	3.5E-10	7.0E-10	6.2E-11	7.1E-11	1.8E-21	5.7E-06	8.4E-06	-3.0E-07	-2.6E-07	-4.3E-07
Primary energy from geothermics	**MJ**	**1.8E-02**	**1.9E-02**	**4.0E-02**	**4.1E-02**	**1.4E-02**	**9.6E-02**	**5.0E-02**	**2.6E-02**	**2.2E-02**	**3.6E-02**
Primary energy from hydro power	**MJ**	**3.5E-01**	**3.0E-01**	**1.9E-01**	**1.9E-01**	**6.6E-02**	**5.9E-01**	**3.1E-01**	**2.1E+00**	**1.8E+00**	**3.1E+00**
Primary energy from solar energy	**MJ**	**7.4E+00**	**1.1E+01**	**8.4E-01**	**9.2E-01**	**9.3E-02**	**1.3E+01**	**2.9E+00**	**1.4E+00**	**1.6E+00**	**1.8E+00**
Primary energy from waves	**MJ**	**5.9E-14**	**8.1E-14**	**8.3E-14**	**8.5E-14**	**2.8E-14**	**5.6E-13**	**2.8E-13**	**7.2E-14**	**6.5E-14**	**1.1E-13**
Primary energy from wind power	**MJ**	**1.3E-01**	**1.5E-01**	**2.4E-01**	**2.4E-01**	**8.2E-02**	**8.7E-01**	**4.4E-01**	**1.7E-01**	**1.5E-01**	**2.5E-01**

Table C-0-7: Summary of the life cycle inventory in terms of mass (kg) for all packaging options in the US, per gallon of product contents.

		Beverage cartons		PET (C)		PET (NC)	Glass bottle		Aluminum cans		
	Unit	11.1oz	16.9oz	12oz	16.9oz	16.9oz	12oz	16oz	12oz	16oz STD	16oz ATB
Resources	**kg**	**4.9E+02**	**4.7E+02**	**2.7E+02**	**2.7E+02**	**9.0E+01**	**1.3E+03**	**6.3E+02**	**2.5E+03**	**2.1E+03**	**3.6E+03**
Energy resources	**kg**	**3.6E-01**	**3.6E-01**	**6.3E-01**	**6.5E-01**	**2.2E-01**	**1.7E+00**	**8.7E-01**	**3.8E-01**	**3.4E-01**	**5.5E-01**
Non renewable energy resources	kg	3.6E-01	3.6E-01	6.3E-01	6.5E-01	2.2E-01	1.7E+00	8.7E-01	3.8E-01	3.4E-01	5.5E-01
Crude oil (resource)	kg	9.8E-02	9.3E-02	2.5E-01	2.7E-01	9.4E-02	2.9E-01	1.4E-01	5.5E-02	4.9E-02	7.9E-02
Hard coal (resource)	kg	8.0E-02	7.4E-02	7.5E-02	7.7E-02	2.6E-02	2.1E-01	1.3E-01	6.6E-02	5.7E-02	9.1E-02
Lignite (resource)	kg	1.4E-02	2.2E-02	1.4E-02	1.4E-02	4.2E-03	9.2E-02	3.9E-02	1.4E-01	1.2E-01	2.0E-01
Natural gas (resource)	kg	1.7E-01	1.7E-01	2.9E-01	2.9E-01	9.8E-02	1.1E+00	5.7E-01	1.2E-01	1.1E-01	1.8E-01
Peat (resource)	kg	2.7E-03	5.3E-03	4.6E-04	5.3E-04	2.5E-06	1.0E-02	1.9E-03	9.8E-04	1.1E-03	1.2E-03
Uranium (resource)	kg	1.1E-06	1.2E-06	2.1E-06	2.1E-06	7.1E-07	6.4E-06	3.3E-06	1.5E-06	1.3E-06	2.1E-06
Renewable energy resources	kg	2.4E-11	4.8E-11	4.2E-12	4.8E-12	1.3E-22	3.9E-07	5.7E-07	-2.1E-08	-1.8E-08	-2.9E-08
Biomass (MJ)	kg	2.4E-11	4.8E-11	4.2E-12	4.8E-12	1.3E-22	3.9E-07	5.7E-07	-2.1E-08	-1.8E-08	-2.9E-08
Material resources	**kg**	**4.9E+02**	**4.7E+02**	**2.7E+02**	**2.7E+02**	**9.0E+01**	**1.3E+03**	**6.3E+02**	**2.5E+03**	**2.1E+03**	**3.6E+03**
Non renewable elements	**kg**	**1.5E-03**	**1.7E-03**	**4.3E-03**	**4.4E-03**	**1.5E-03**	**3.4E-02**	**3.9E-02**	**4.3E-03**	**3.9E-03**	**5.8E-03**
Non renewable resources	**kg**	**1.1E+00**	**1.2E+00**	**1.3E+00**	**1.3E+00**	**4.4E-01**	**9.6E+00**	**5.2E+00**	**2.4E+00**	**2.1E+00**	**3.4E+00**
Renewable resources	**kg**	**4.9E+02**	**4.7E+02**	**2.7E+02**	**2.7E+02**	**8.9E+01**	**1.3E+03**	**6.2E+02**	**2.5E+03**	**2.1E+03**	**3.6E+03**
Water	kg	4.8E+02	4.7E+02	2.6E+02	2.7E+02	8.7E+01	1.3E+03	6.2E+02	2.5E+03	2.1E+03	3.5E+03
Air	kg	3.4E+00	3.1E+00	6.7E+00	6.8E+00	2.3E+00	1.1E+01	5.8E+00	8.2E+00	7.1E+00	1.2E+01
Carbon dioxide	kg	7.7E-01	1.2E+00	9.3E-02	1.0E-01	5.5E-03	1.7E+00	3.3E-01	1.8E-01	2.0E-01	2.2E-01
Forest, primary	kg	-5.8E-09	-5.9E-09	-9.7E-09	-1.0E-08	-3.3E-09	-4.1E-08	-2.1E-08	-3.6E-09	-3.3E-09	-5.3E-09
Nitrogen	kg	3.7E-11	4.9E-11	3.9E-12	4.4E-12	3.2E-13	8.2E-11	1.2E-11	1.2E-11	1.2E-11	1.6E-11
Oxygen	kg	1.0E-03	9.7E-04	1.4E-03	1.4E-03	4.8E-04	6.6E-03	3.2E-03	1.9E-03	1.7E-03	2.8E-03
Soft wood, dry matter	kg	1.5E-11	3.1E-11	2.8E-12	3.1E-12	8.1E-23	7.0E-11	7.6E-12	5.7E-12	6.5E-12	6.8E-12
Wood, hard, standing	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.0E-07	1.7E-07	2.9E-07
Wood, primary forest, standing	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.1E-13	1.8E-13	3.0E-13
Wood, soft, standing	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.2E-09	1.1E-09	1.8E-09
Wood, soft, US PNW, standing/m3	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.1E-12	2.7E-12	4.5E-12
Wood, soft, US SE, standing/m3	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.7E-07	6.6E-07	1.1E-06
Wood, unspecified, standing/kg	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.0E-08	7.7E-08	1.3E-07
Deposited goods	**kg**	**7.8E-01**	**8.3E-01**	**7.8E-01**	**8.0E-01**	**2.7E-01**	**5.2E+00**	**2.7E+00**	**2.0E+00**	**1.7E+00**	**2.8E+00**
Stockpile goods	kg	7.8E-01	8.3E-01	7.8E-01	8.0E-01	2.7E-01	5.2E+00	2.7E+00	2.0E+00	1.7E+00	2.8E+00
Hazardous waste (deposited)	kg	1.2E-07	2.1E-07	2.9E-08	3.1E-08	4.5E-09	4.9E-07	2.0E-07	3.5E-05	3.0E-05	5.0E-05
Overburden (deposited)	kg	5.6E-01	6.3E-01	5.2E-01	5.3E-01	1.7E-01	2.8E+00	1.4E+00	1.7E+00	1.5E+00	2.5E+00
Slag (deposited)	kg	1.8E-12	2.5E-12	2.6E-12	2.6E-12	8.5E-13	1.7E-11	8.5E-12	2.2E-12	2.0E-12	3.5E-12
Spoil (deposited)	kg	3.2E-02	2.9E-02	5.0E-02	5.1E-02	1.7E-02	1.7E-01	9.1E-02	3.7E-02	3.3E-02	5.3E-02
Tailings (deposited)	kg	2.1E-02	1.9E-02	6.2E-02	6.5E-02	2.3E-02	1.4E-01	7.5E-02	1.7E-02	1.6E-02	2.1E-02
Waste (deposited)	kg	1.7E-01	1.5E-01	1.5E-01	1.5E-01	5.3E-02	2.0E+00	1.2E+00	2.0E-01	1.7E-01	2.8E-01
Emissions to air	**kg**	**2.1E+01**	**3.4E+01**	**1.7E+01**	**1.7E+01**	**4.9E+00**	**8.1E+01**	**2.6E+01**	**2.5E+01**	**2.3E+01**	**3.4E+01**
Heavy metals to air	**kg**	**5.5E-07**	**6.1E-07**	**6.3E-07**	**6.4E-07**	**2.1E-07**	**2.0E-06**	**1.1E-06**	**1.9E-06**	**1.7E-06**	**2.4E-06**
Inorganic emissions to air	**kg**	**1.9E+01**	**3.1E+01**	**1.1E+01**	**1.2E+01**	**3.0E+00**	**7.1E+01**	**2.0E+01**	**1.8E+01**	**1.7E+01**	**2.5E+01**
Organic emissions to air (group VOC)	**kg**	**4.3E-03**	**4.6E-03**	**4.0E-03**	**4.2E-03**	**1.4E-03**	**1.4E-02**	**6.7E-03**	**3.3E-03**	**3.1E-03**	**4.2E-03**
Group NMVOC to air	**kg**	**4.6E-04**	**4.8E-04**	**3.7E-04**	**3.9E-04**	**1.3E-04**	**1.0E-03**	**4.6E-04**	**1.3E-03**	**1.3E-03**	**1.4E-03**
Halogenated organic emissions to air	**kg**	**2.1E-06**	**2.0E-06**	**1.7E-06**	**1.7E-06**	**6.0E-07**	**6.6E-07**	**1.7E-07**	**3.7E-06**	**3.2E-06**	**5.3E-06**
Hydrocarbons (unspecified)	kg	9.2E-05	8.0E-05	2.7E-04	2.9E-04	1.0E-04	2.5E-04	1.2E-04	3.9E-05	3.5E-05	5.3E-05
Methane	kg	2.1E-03	2.0E-03	3.3E-03	3.4E-03	1.1E-03	1.1E-02	5.8E-03	1.8E-03	1.6E-03	2.6E-03
Methane (biotic)	kg	1.6E-03	1.9E-03	6.7E-05	7.5E-05	2.9E-06	1.3E-03	3.6E-04	1.3E-04	1.5E-04	1.6E-04
VOC (unspecified)	kg	4.3E-05	4.1E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.4E-06	1.2E-06	1.9E-06
Other emissions to air	**kg**	**2.9E+00**	**2.6E+00**	**5.3E+00**	**5.5E+00**	**1.9E+00**	**1.0E+01**	**5.1E+00**	**6.9E+00**	**5.9E+00**	**9.8E+00**
Particles to air	**kg**	**2.3E-04**	**2.3E-04**	**9.1E-05**	**9.4E-05**	**3.0E-05**	**1.6E-03**	**9.1E-04**	**4.2E-04**	**3.6E-04**	**5.9E-04**
Aluminium oxide (dust)	kg	2.4E-11	1.9E-11	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	9.3E-13	8.0E-13	1.3E-12
Dust (> PM10)	kg	5.8E-05	5.9E-05	3.3E-05	3.4E-05	1.1E-05	3.8E-04	2.2E-04	5.9E-05	5.1E-05	7.7E-05

Dust (PM10)	kg	3.7E-05	2.9E-05	1.2E-06	1.3E-06	4.2E-07	1.7E-05	2.1E-05	4.7E-06	4.0E-06	6.6E-06
Dust (PM2.5 - PM10)	kg	5.6E-05	5.5E-05	2.4E-05	2.4E-05	8.0E-06	3.5E-04	2.0E-04	2.5E-04	2.1E-04	3.5E-04
Dust (PM2.5)	kg	7.5E-05	8.6E-05	3.3E-05	3.4E-05	1.0E-05	8.4E-04	4.6E-04	1.1E-04	9.5E-05	1.5E-04
Ethyl cellulose	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	6.5E-18	5.6E-18	9.3E-18
Metals (unspecified)	kg	5.3E-11	6.9E-11	8.2E-11	8.4E-11	2.7E-11	1.6E-05	9.1E-06	6.5E-11	5.9E-11	1.0E-10
Silicon dioxide (silica)	kg	3.8E-11	5.1E-11	5.2E-11	5.3E-11	1.7E-11	3.5E-10	1.7E-10	4.7E-11	4.2E-11	7.4E-11
Silicon dust	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	2.7E-13	2.3E-13	3.9E-13
Tar	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.9E-19	1.6E-19	2.7E-19
Pesticides to air	**kg**	**7.7E-09**	**1.4E-08**	**2.3E-09**	**2.4E-09**	**4.2E-10**	**2.7E-08**	**6.6E-09**	**3.1E-09**	**3.3E-09**	**4.0E-09**
Radioactive emissions to air	**kg**	**-5.3E-13**	**-5.5E-13**	**-9.9E-13**	**-1.0E-12**	**-3.4E-13**	**-4.4E-12**	**-2.3E-12**	**-3.2E-13**	**-3.0E-13**	**-4.7E-13**
Emissions to fresh water	**kg**	**4.8E+02**	**4.5E+02**	**2.7E+02**	**2.8E+02**	**9.1E+01**	**1.3E+03**	**6.4E+02**	**2.5E+03**	**2.1E+03**	**3.5E+03**
Analytical measures to fresh water	**kg**	**1.7E-03**	**2.1E-03**	**6.1E-04**	**6.3E-04**	**1.8E-04**	**3.0E-03**	**9.4E-04**	**5.0E-04**	**4.9E-04**	**6.8E-04**
Adsorbable organic halogen compounds (AOX)	kg	3.7E-05	2.7E-05	7.0E-05	7.4E-05	2.6E-05	3.7E-05	1.9E-05	1.3E-06	1.3E-06	1.7E-06
Biological oxygen demand (BOD)	kg	5.3E-05	1.1E-04	2.1E-05	2.3E-05	4.1E-06	2.2E-04	4.3E-05	2.9E-05	3.1E-05	4.0E-05
Chemical oxygen demand (COD)	kg	1.6E-03	2.0E-03	5.1E-04	5.3E-04	1.5E-04	2.7E-03	8.7E-04	4.6E-04	4.5E-04	6.3E-04
Nitrogenous Matter (unspecified, as N)	kg	6.0E-08	5.5E-08	7.2E-08	7.4E-08	2.5E-08	1.1E-06	1.3E-06	7.5E-08	6.6E-08	1.1E-07
Solids (dissolved)	kg	-1.7E-07	-1.1E-07	-5.2E-07	-5.3E-07	-1.8E-07	-9.0E-06	-1.1E-05	1.2E-06	1.0E-06	1.8E-06
Total dissolved organic bound carbon (TOC)	kg	1.5E-10	1.5E-10	1.0E-11	1.1E-11	2.9E-12	1.9E-10	9.6E-11	2.5E-10	2.2E-10	3.6E-10
Total organic bound carbon (TOC)	kg	6.2E-06	8.9E-06	7.4E-06	7.8E-06	2.5E-06	2.5E-05	8.9E-06	3.6E-06	3.4E-06	5.0E-06
Heavy metals to fresh water	**kg**	**2.3E-04**	**3.7E-04**	**2.8E-04**	**2.9E-04**	**8.9E-05**	**1.2E-03**	**4.2E-04**	**3.0E-03**	**2.5E-03**	**4.2E-03**
Heavy metals to water (unspecified)	**kg**	**-9.0E-14**	**-7.7E-14**	**-1.3E-13**	**-1.4E-13**	**-4.6E-14**	**-4.7E-13**	**-2.4E-13**	**8.3E-09**	**7.1E-09**	**1.2E-08**
Inorganic emissions to fresh water	**kg**	**1.8E-02**	**1.7E-02**	**4.1E-02**	**4.3E-02**	**1.5E-02**	**5.7E-02**	**2.8E-02**	**9.3E-03**	**8.4E-03**	**1.3E-02**
Organic emissions to fresh water	**kg**	**9.9E-04**	**1.6E-03**	**8.2E-04**	**8.7E-04**	**2.6E-04**	**3.5E-03**	**9.9E-04**	**4.7E-04**	**4.8E-04**	**6.2E-04**
Halogenated organic emissions to fresh water	**kg**	**-2.5E-12**	**-2.5E-12**	**-4.2E-12**	**-4.3E-12**	**-1.4E-12**	**-1.8E-11**	**-9.1E-12**	**-1.3E-12**	**-1.2E-12**	**-1.9E-12**
Hydrocarbons to fresh water	**kg**	**3.7E-04**	**3.1E-04**	**6.3E-04**	**6.6E-04**	**2.4E-04**	**6.1E-04**	**3.1E-04**	**1.5E-04**	**1.3E-04**	**2.1E-04**
Other emissions to fresh water	**kg**	**4.6E+02**	**4.4E+02**	**2.4E+02**	**2.5E+02**	**8.2E+01**	**1.2E+03**	**5.9E+02**	**2.5E+03**	**2.1E+03**	**3.5E+03**
Pesticides to fresh water	**kg**	**1.8E-08**	**3.3E-08**	**3.8E-09**	**4.2E-09**	**4.1E-10**	**6.0E-08**	**1.2E-08**	**6.4E-09**	**7.1E-09**	**8.0E-09**
Cooling water to river	**kg**	**2.8E+00**	**3.5E+00**	**1.7E-01**	**1.8E-01**	**1.6E-02**	**3.0E+00**	**7.9E-01**	**1.6E+00**	**1.5E+00**	**2.3E+00**

Brazil

Table C-0-8: Summary of the life cycle inventory results in terms of energy (MJ, net calorific value) for all packaging options, per liter of product contents.

		Beverage cartons		PET (C)		PET (NC)		Glass bottle		Aluminum cans		
	Unit	0.2L	1L	0.25L	0.6L	0.51L	0.9L	0.355L	0.6L	12oz	16oz	24oz
Resources	**MJ**	**2.4E+00**	**1.9E+00**	**4.9E+00**	**2.5E+00**	**2.5E+00**	**3.1E+00**	**1.0E+01**	**1.1E+01**	**2.0E+00**	**1.8E+00**	**1.5E+00**
Energy resources	**MJ**	**2.4E+00**	**1.9E+00**	**4.9E+00**	**2.5E+00**	**2.5E+00**	**3.1E+00**	**1.0E+01**	**1.1E+01**	**2.0E+00**	**1.8E+00**	**1.5E+00**
Non renewable energy resources	**MJ**	**1.7E+00**	**1.4E+00**	**4.3E+00**	**2.2E+00**	**2.1E+00**	**2.7E+00**	**9.1E+00**	**9.4E+00**	**1.7E+00**	**1.5E+00**	**1.2E+00**
Crude oil (resource)	MJ	5.1E-01	4.0E-01	1.6E+00	8.1E-01	7.8E-01	9.2E-01	1.7E+00	1.7E+00	5.0E-01	4.8E-01	4.7E-01
Hard coal (resource)	MJ	9.2E-02	7.2E-02	1.7E-01	8.8E-02	8.6E-02	1.0E-01	8.9E-01	9.5E-01	9.6E-02	7.7E-02	5.4E-02
Lignite (resource)	MJ	1.7E-02	1.7E-02	3.6E-02	1.9E-02	1.8E-02	2.1E-02	6.3E-02	7.3E-02	3.1E-02	3.0E-02	2.6E-02
Natural gas (resource)	MJ	1.1E+00	8.3E-01	2.4E+00	1.2E+00	1.2E+00	1.6E+00	6.3E+00	6.6E+00	9.9E-01	8.3E-01	6.2E-01
Peat (resource)	MJ	2.8E-03	4.2E-03	2.4E-05	1.2E-05	1.2E-05	1.5E-05	3.7E-03	7.9E-03	2.5E-05	2.3E-05	2.1E-05
Uranium (resource)	MJ	3.8E-02	3.1E-02	1.1E-01	5.5E-02	5.3E-02	6.1E-02	1.2E-01	1.0E-01	6.1E-02	5.4E-02	4.5E-02
Renewable energy resources	**MJ**	**6.9E-01**	**5.9E-01**	**6.7E-01**	**3.5E-01**	**3.3E-01**	**3.8E-01**	**1.1E+00**	**1.3E+00**	**3.3E-01**	**3.0E-01**	**3.2E-01**
Biomass (MJ)	MJ	2.5E-11	3.4E-11	9.6E-22	5.0E-22	4.8E-22	5.5E-22	-2.4E-06	-1.4E-06	-2.1E-10	-1.9E-10	-1.8E-10
Primary energy from geothermics	**MJ**	**7.8E-04**	**5.5E-04**	**2.3E-03**	**1.2E-03**	**1.2E-03**	**1.3E-03**	**1.7E-03**	**4.9E-04**	**1.1E-03**	**8.3E-04**	**5.3E-04**
Primary energy from hydro power	**MJ**	**2.0E-01**	**1.6E-01**	**4.6E-01**	**2.4E-01**	**2.3E-01**	**2.6E-01**	**5.9E-01**	**6.8E-01**	**1.8E-01**	**1.6E-01**	**1.9E-01**
Primary energy from solar energy	**MJ**	**4.8E-01**	**4.2E-01**	**1.4E-01**	**7.4E-02**	**7.1E-02**	**8.2E-02**	**3.9E-01**	**5.1E-01**	**1.1E-01**	**9.9E-02**	**9.6E-02**
Primary energy from waves	**MJ**	**4.8E-15**	**4.8E-15**	**5.8E-15**	**3.0E-15**	**2.9E-15**	**3.4E-15**	**1.6E-14**	**1.8E-14**	**1.3E-14**	**1.2E-14**	**8.2E-15**
Primary energy from wind power	**MJ**	**1.6E-02**	**1.4E-02**	**6.5E-02**	**3.4E-02**	**3.2E-02**	**3.7E-02**	**8.5E-02**	**9.0E-02**	**4.1E-02**	**3.8E-02**	**3.7E-02**

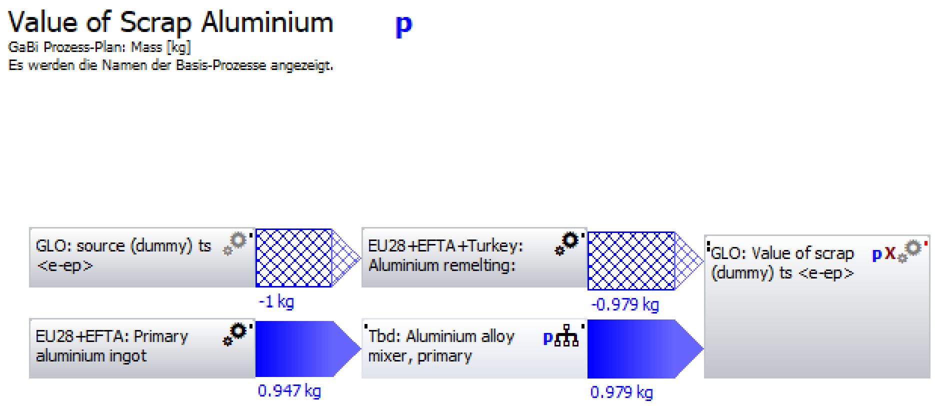
Table D-0-9: Summary of the life cycle inventory results in terms of mass (kg) for all packaging options, per liter of product contents.

		Beverage cartons		PET (C)		PET (NC)		Glass bottle		Aluminum cans		
	Unit	0.2L	1L	0.25L	0.6L	0.51L	0.9L	0.355L	0.6L	12oz	16oz	24oz
Resources	**kg**	**8.7E+01**	**7.2E+01**	**1.6E+02**	**8.4E+01**	**8.1E+01**	**9.3E+01**	**2.3E+02**	**2.6E+02**	**7.3E+01**	**6.6E+01**	**7.0E+01**
Energy resources	**kg**	**4.3E-02**	**3.4E-02**	**1.0E-01**	**5.3E-02**	**5.2E-02**	**6.5E-02**	**2.3E-01**	**2.3E-01**	**4.2E-02**	**3.7E-02**	**3.1E-02**
Non renewable energy resources	kg	4.3E-02	3.4E-02	1.0E-01	5.3E-02	5.2E-02	6.5E-02	2.3E-01	2.3E-01	4.2E-02	3.7E-02	3.1E-02
Crude oil (resource)	kg	1.4E-02	1.1E-02	3.9E-02	2.0E-02	2.0E-02	2.4E-02	4.4E-02	4.1E-02	1.3E-02	1.3E-02	1.3E-02
Hard coal (resource)	kg	3.5E-03	2.7E-03	6.5E-03	3.4E-03	3.3E-03	3.8E-03	3.4E-02	3.6E-02	3.7E-03	2.9E-03	2.1E-03
Lignite (resource)	kg	1.4E-03	1.4E-03	3.0E-03	1.6E-03	1.5E-03	1.7E-03	5.3E-03	6.1E-03	2.6E-03	2.6E-03	2.2E-03
Natural gas (resource)	kg	2.4E-02	1.9E-02	5.4E-02	2.8E-02	2.7E-02	3.6E-02	1.4E-01	1.5E-01	2.2E-02	1.9E-02	1.4E-02
Peat (resource)	kg	3.3E-04	5.0E-04	2.9E-06	1.5E-06	1.4E-06	1.7E-06	4.5E-04	9.4E-04	3.0E-06	2.7E-06	2.5E-06
Uranium (resource)	kg	7.0E-08	5.7E-08	1.9E-07	1.0E-07	9.8E-08	1.1E-07	2.2E-07	1.8E-07	1.1E-07	9.9E-08	8.2E-08
Renewable energy resources	kg	1.7E-12	2.3E-12	6.6E-23	3.4E-23	3.3E-23	3.8E-23	-1.6E-07	-9.6E-08	-1.5E-11	-1.3E-11	-1.2E-11
Biomass (MJ)	kg	1.7E-12	2.3E-12	6.6E-23	3.4E-23	3.3E-23	3.8E-23	-1.6E-07	-9.6E-08	-1.5E-11	-1.3E-11	-1.2E-11
Material resources	**kg**	**8.7E+01**	**7.2E+01**	**1.6E+02**	**8.4E+01**	**8.1E+01**	**9.3E+01**	**2.3E+02**	**2.6E+02**	**7.3E+01**	**6.6E+01**	**7.0E+01**
Non renewable elements	**kg**	**4.6E-04**	**3.7E-04**	**4.9E-04**	**2.5E-04**	**2.5E-04**	**3.7E-04**	**4.9E-03**	**3.4E-03**	**1.2E-04**	**7.4E-05**	**4.4E-05**
Non renewable resources	**kg**	**1.3E-01**	**1.1E-01**	**2.2E-01**	**1.2E-01**	**1.1E-01**	**1.4E-01**	**1.3E+00**	**1.5E+00**	**1.1E-01**	**9.6E-02**	**7.3E-02**
Renewable resources	**kg**	**8.6E+01**	**7.1E+01**	**1.6E+02**	**8.4E+01**	**8.1E+01**	**9.3E+01**	**2.3E+02**	**2.6E+02**	**7.3E+01**	**6.6E+01**	**7.0E+01**
Water	kg	8.6E+01	7.1E+01	1.6E+02	8.3E+01	8.0E+01	9.2E+01	2.3E+02	2.6E+02	7.2E+01	6.6E+01	6.9E+01
Air	kg	3.8E-01	3.0E-01	1.3E+00	6.9E-01	6.7E-01	7.7E-01	9.2E-01	7.9E-01	7.4E-01	6.8E-01	6.5E-01
Carbon dioxide	kg	4.7E-02	4.0E-02	1.4E-02	7.0E-03	6.7E-03	7.8E-03	3.6E-02	4.6E-02	9.3E-03	8.8E-03	8.8E-03
Forest, primary	kg	-8.2E-10	-6.6E-10	-1.9E-09	-9.7E-10	-9.4E-10	-1.2E-09	-5.2E-09	-5.4E-09	-8.3E-10	-7.0E-10	-5.2E-10
Nitrogen	kg	5.7E-12	5.1E-12	3.6E-14	1.9E-14	1.9E-14	1.8E-14	1.4E-12	2.8E-12	-1.0E-11	-8.8E-12	-8.3E-12

Oxygen	kg	1.4E-04	1.1E-04	6.8E-04	3.5E-04	3.4E-04	3.7E-04	7.0E-04	7.2E-04	1.4E-04	1.0E-04	6.5E-05
Soft wood, dry matter	kg	1.1E-12	1.5E-12	4.3E-23	2.2E-23	2.1E-23	2.5E-23	1.2E-12	2.5E-12	-9.5E-12	-8.3E-12	-7.8E-12
Deposited goods	**kg**	**9.2E-02**	**7.7E-02**	**1.3E-01**	**6.7E-02**	**6.5E-02**	**8.0E-02**	**7.5E-01**	**8.6E-01**	**6.1E-02**	**5.5E-02**	**4.5E-02**
Stockpile goods	kg	9.2E-02	7.7E-02	1.3E-01	6.7E-02	6.5E-02	8.0E-02	7.5E-01	8.6E-01	6.1E-02	5.5E-02	4.5E-02
Hazardous waste (deposited)	kg	1.3E-08	1.4E-08	1.6E-09	8.1E-10	7.9E-10	1.0E-09	2.1E-08	2.4E-08	1.4E-09	1.2E-09	1.1E-09
Overburden (deposited)	kg	4.4E-02	4.0E-02	7.4E-02	3.8E-02	3.7E-02	4.3E-02	3.7E-01	4.4E-01	5.4E-02	5.1E-02	4.1E-02
Slag (deposited)	kg	1.5E-13	1.5E-13	1.8E-13	9.4E-14	9.1E-14	1.1E-13	5.4E-13	5.7E-13	3.8E-13	3.7E-13	2.4E-13
Spoil (deposited)	kg	4.8E-03	3.6E-03	7.6E-03	3.9E-03	3.9E-03	5.5E-03	1.5E-02	1.4E-02	2.7E-03	2.3E-03	2.1E-03
Tailings (deposited)	kg	2.3E-03	1.7E-03	2.6E-03	1.3E-03	1.3E-03	2.4E-03	4.3E-03	2.1E-03	1.6E-03	1.3E-03	1.9E-03
Waste (deposited)	kg	4.0E-02	3.1E-02	4.5E-02	2.3E-02	2.2E-02	2.9E-02	3.5E-01	4.1E-01	2.5E-03	7.4E-04	-7.9E-04
Emissions to air	**kg**	**1.2E+01**	**1.0E+01**	**7.8E+00**	**4.0E+00**	**3.8E+00**	**4.4E+00**	**1.3E+01**	**1.6E+01**	**3.4E+00**	**3.2E+00**	**3.4E+00**
Heavy metals to air	**kg**	**2.7E-07**	**2.1E-07**	**6.6E-07**	**3.4E-07**	**3.3E-07**	**3.7E-07**	**7.7E-07**	**8.5E-07**	**3.1E-07**	**2.6E-07**	**2.5E-07**
Inorganic emissions to air	**kg**	**1.1E+01**	**9.9E+00**	**6.8E+00**	**3.5E+00**	**3.4E+00**	**3.9E+00**	**1.2E+01**	**1.6E+01**	**3.0E+00**	**2.8E+00**	**3.0E+00**
Organic emissions to air (group VOC)	**kg**	**8.2E-04**	**6.6E-04**	**7.0E-04**	**3.6E-04**	**3.5E-04**	**4.6E-04**	**1.7E-03**	**1.8E-03**	**4.8E-04**	**3.9E-04**	**2.9E-04**
Group NMVOC to air	**kg**	**7.3E-05**	**6.0E-05**	**1.0E-04**	**5.2E-05**	**5.0E-05**	**6.6E-05**	**1.7E-04**	**1.8E-04**	**2.1E-04**	**1.7E-04**	**1.2E-04**
Group PAH to air	**kg**	**8.1E-08**	**6.3E-08**	**1.7E-08**	**8.6E-09**	**8.4E-09**	**1.1E-08**	**4.4E-08**	**3.3E-08**	**-4.1E-08**	**-4.5E-08**	**-4.1E-08**
Halogenated organic emissions to air	**kg**	**5.9E-07**	**4.6E-07**	**5.1E-07**	**2.6E-07**	**2.5E-07**	**3.3E-07**	**2.5E-07**	**1.1E-07**	**-5.5E-08**	**-7.4E-08**	**-8.7E-08**
Hydrocarbons (unspecified)	kg	8.8E-06	6.2E-06	8.8E-06	4.5E-06	4.7E-06	9.1E-06	1.4E-05	4.1E-06	5.8E-06	4.9E-06	7.5E-06
Methane	kg	2.6E-04	2.0E-04	5.8E-04	3.0E-04	2.9E-04	3.8E-04	1.4E-03	1.5E-03	2.5E-04	2.1E-04	1.6E-04
Methane (biotic)	kg	4.7E-04	3.8E-04	8.2E-06	4.3E-06	4.1E-06	4.6E-06	6.8E-05	1.6E-04	7.7E-06	4.4E-06	4.4E-06
VOC (unspecified)	kg	1.2E-05	8.7E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-1.1E-18	2.4E-19	1.2E-18
Other emissions to air	kg	3.0E-01	2.4E-01	9.7E-01	5.0E-01	4.8E-01	5.7E-01	7.4E-01	6.4E-01	4.2E-01	3.8E-01	3.1E-01
Ammonium chloride	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Clean gas	kg	7.3E-04	5.6E-04	2.8E-04	1.5E-04	1.4E-04	1.9E-04	2.1E-03	2.4E-03	6.3E-04	6.5E-04	2.5E-04
Exhaust	kg	2.4E-01	1.9E-01	7.9E-01	4.1E-01	3.9E-01	4.5E-01	6.5E-01	6.1E-01	3.7E-01	3.3E-01	2.7E-01
Isocyanic acid	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Other emissions to air	**kg**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**	**0.0E+00**
Particles to air	**kg**	**4.2E-05**	**3.4E-05**	**3.1E-05**	**1.6E-05**	**1.5E-05**	**1.8E-05**	**2.2E-04**	**2.6E-04**	**2.6E-05**	**1.9E-05**	**1.5E-05**
Aluminium oxide (dust)	kg	5.5E-12	4.2E-12	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.0E-19	-2.1E-20	-1.1E-19
Dust (> PM10)	kg	6.0E-06	4.9E-06	5.3E-06	2.7E-06	2.7E-06	3.2E-06	4.4E-05	5.0E-05	4.5E-06	3.5E-06	2.6E-06
Dust (PM10)	kg	1.1E-05	8.5E-06	2.6E-07	1.3E-07	1.3E-07	1.6E-07	2.5E-06	1.9E-06	-7.5E-06	-8.0E-06	-7.7E-06
Dust (PM2.5 - PM10)	kg	1.2E-05	9.3E-06	1.1E-05	5.7E-06	5.5E-06	6.2E-06	5.5E-05	6.4E-05	9.6E-06	8.3E-06	8.0E-06
Dust (PM2.5)	kg	1.3E-05	1.1E-05	1.5E-05	7.5E-06	7.2E-06	8.8E-06	1.2E-04	1.4E-04	2.0E-05	1.5E-05	1.2E-05
Ethyl cellulose	kg									0.0E+00	0.0E+00	0.0E+00
Metals (unspecified)	kg	5.2E-12	4.8E-12	1.2E-11	6.3E-12	6.1E-12	7.0E-12	2.9E-06	3.5E-06	1.3E-11	1.3E-11	1.0E-11
Silicon dioxide (silica)	kg	3.2E-12	3.1E-12	3.7E-12	1.9E-12	1.9E-12	2.2E-12	1.1E-11	1.2E-11	7.8E-12	7.6E-12	5.0E-12
Silicon dust	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	-7.9E-19	1.7E-19	8.5E-19
Tar	kg	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Pesticides to air	**kg**	**1.1E-09**	**1.5E-09**	**8.7E-10**	**4.5E-10**	**4.3E-10**	**4.9E-10**	**2.3E-09**	**3.8E-09**	**5.6E-10**	**5.4E-10**	**5.4E-10**
Radioactive emissions to air	**kg**	**-7.3E-14**	**-5.9E-14**	**-2.0E-13**	**-1.0E-13**	**-1.0E-13**	**-1.3E-13**	**-5.7E-13**	**-6.1E-13**	**-9.0E-14**	**-7.5E-14**	**-5.7E-14**
Emissions to fresh water	**kg**	**7.6E+01**	**6.2E+01**	**1.6E+02**	**8.1E+01**	**7.7E+01**	**8.9E+01**	**2.2E+02**	**2.4E+02**	**7.0E+01**	**6.4E+01**	**6.7E+01**
Analytical measures to fresh water	kg	2.5E-04	2.2E-04	2.3E-04	1.2E-04	1.1E-04	1.3E-04	3.5E-04	4.0E-04	1.2E-04	1.2E-04	1.2E-04
Adsorbable organic halogen compounds (AOX)	kg	7.7E-06	5.7E-06	2.2E-05	1.1E-05	1.1E-05	1.4E-05	8.1E-06	7.3E-07	2.2E-06	1.8E-06	9.9E-07
Biological oxygen demand (BOD)	kg	3.7E-06	5.1E-06	2.4E-06	1.3E-06	1.2E-06	1.5E-06	5.9E-06	1.0E-05	2.4E-06	2.3E-06	2.8E-06
Chemical oxygen demand (COD)	kg	2.4E-04	2.1E-04	2.1E-04	1.1E-04	1.0E-04	1.2E-04	3.2E-04	3.9E-04	1.2E-04	1.1E-04	1.2E-04
Nitrogenous Matter (unspecified, as N)	kg	7.6E-09	5.9E-09	1.1E-08	5.4E-09	5.3E-09	7.4E-09	1.4E-07	9.1E-08	4.5E-09	3.6E-09	2.6E-09
Solids (dissolved)	kg	-5.3E-08	-4.1E-08	-1.9E-07	-9.6E-08	-9.5E-08	-1.3E-07	6.2E-06	3.3E-06	-3.5E-08	-2.0E-08	-2.2E-08
Total dissolved organic bound carbon (TOC)	kg	3.9E-11	3.0E-11	5.6E-12	2.9E-12	2.8E-12	3.2E-12	1.1E-11	1.3E-11	4.0E-12	3.9E-12	3.6E-12
Total organic bound carbon (TOC)	kg	6.2E-07	5.9E-07	1.1E-06	5.9E-07	5.7E-07	7.3E-07	1.3E-06	1.4E-06	3.7E-07	3.8E-07	3.6E-07
Heavy metals to fresh water	**kg**	**1.7E-05**	**1.4E-05**	**7.5E-05**	**3.9E-05**	**3.7E-05**	**4.3E-05**	**9.7E-05**	**1.0E-04**	**4.2E-05**	**4.0E-05**	**4.0E-05**
Inorganic emissions to fresh water	**kg**	**2.9E-03**	**2.3E-03**	**1.1E-02**	**5.5E-03**	**5.3E-03**	**6.1E-03**	**6.9E-02**	**8.1E-02**	**3.6E-03**	**3.5E-03**	**2.7E-03**
Organic emissions to fresh water	**kg**	**1.5E-04**	**1.4E-04**	**7.9E-05**	**4.1E-05**	**4.0E-05**	**5.5E-05**	**1.8E-04**	**2.2E-04**	**4.2E-05**	**3.8E-05**	**4.5E-05**
Halogenated organic emissions to fresh water	**kg**	**-3.7E-13**	**-3.0E-13**	**-8.7E-13**	**-4.5E-13**	**-4.4E-13**	**-5.8E-13**	**-2.4E-12**	**-2.6E-12**	**-3.6E-13**	**-3.0E-13**	**-2.3E-13**
Hydrocarbons to fresh water	**kg**	**3.4E-05**	**2.5E-05**	**2.6E-05**	**1.3E-05**	**1.4E-05**	**2.4E-05**	**4.3E-05**	**2.2E-05**	**5.6E-06**	**2.9E-06**	**8.9E-06**
Other emissions to fresh water	**kg**	**7.5E+01**	**6.1E+01**	**1.5E+02**	**7.9E+01**	**7.6E+01**	**8.7E+01**	**2.2E+02**	**2.4E+02**	**6.8E+01**	**6.2E+01**	**6.6E+01**

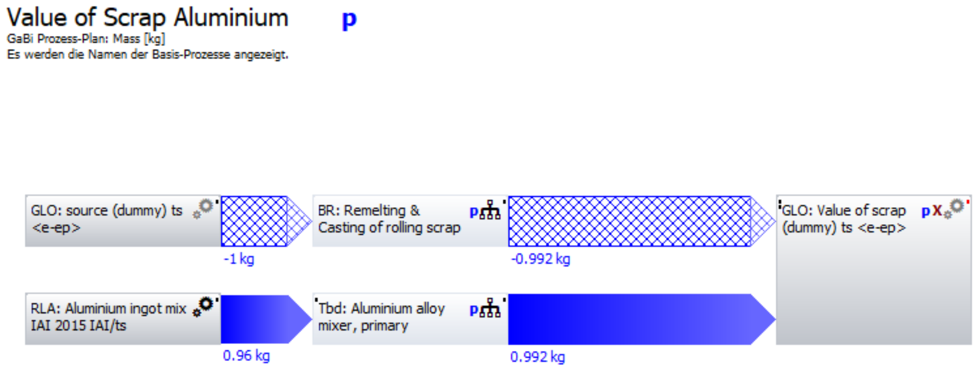
Pesticides to fresh water	**kg**	**2.3E-09**	**3.4E-09**	**2.4E-10**	**1.2E-10**	**1.2E-10**	**1.4E-10**	**3.2E-09**	**6.6E-09**	**2.2E-10**	**2.2E-10**	**1.8E-10**
Cooling water to river	kg	4.9E-01	4.1E-01	1.4E-02	7.0E-03	6.8E-03	8.4E-03	2.3E-01	3.0E-01	1.9E-02	1.9E-02	9.5E-03

Annex D: Additional GaBi Screenshots



Value of Scrap Aluminium p
GaBi Prozess-Plan: Mass [kg]
Es werden die Namen der Basis-Prozesse angezeigt.

Figure D-0-1: **Screenshot of modelling the value of scrap in GaBi, in EU.**



Value of Scrap Aluminium p
GaBi Prozess-Plan: Mass [kg]
Es werden die Namen der Basis-Prozesse angezeigt.

Figure D-0-2: **Screenshot of modelling the value of scrap in GaBi, in Brazil.**

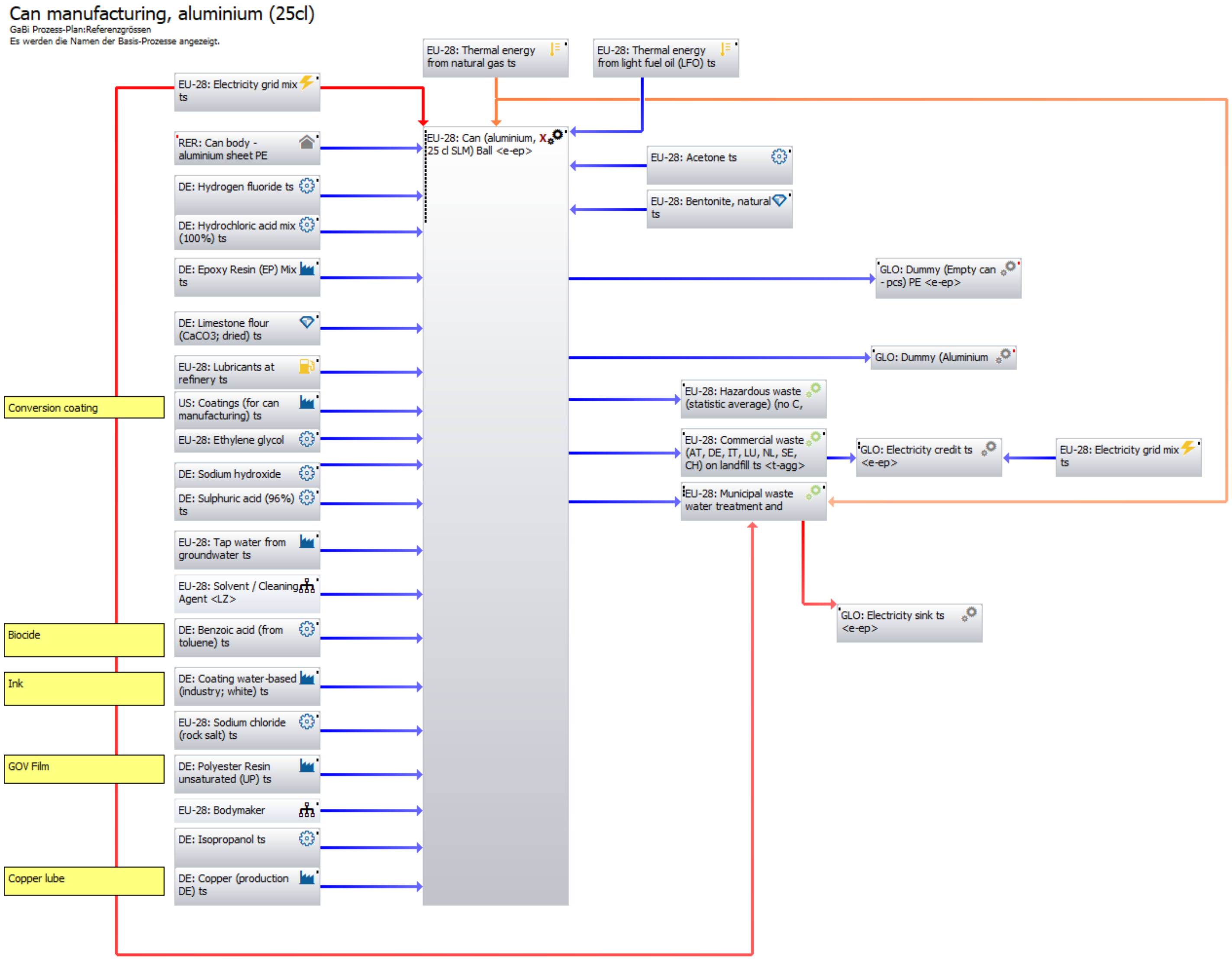


Figure D-0-3: **Can manufacturing in the EU (example: 25cl aluminum can)**

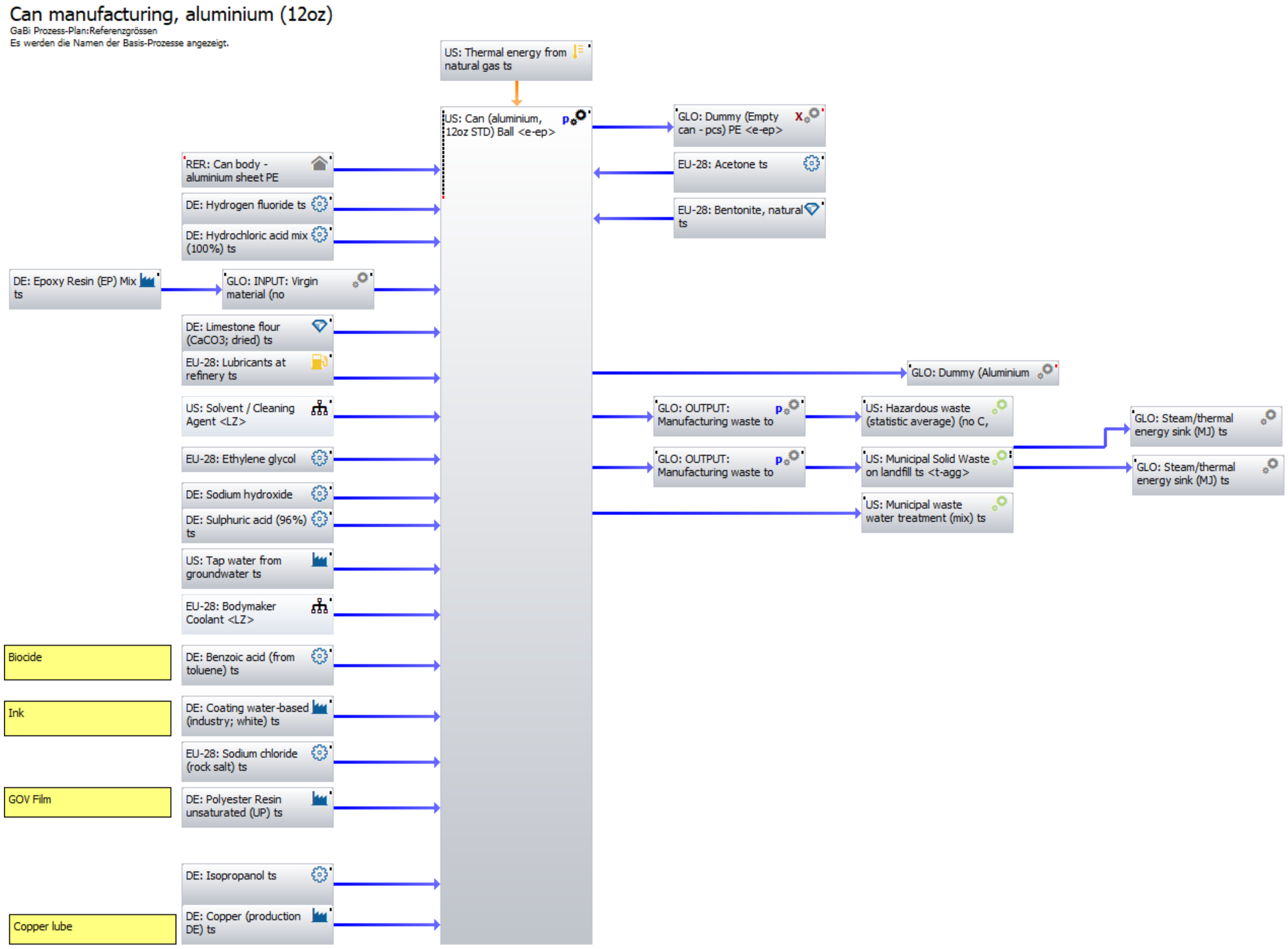


Figure D-0-4: **Can manufacturing in the US (example: 12oz aluminum can). Note that electricity is connected at a level higher (not shown here).**

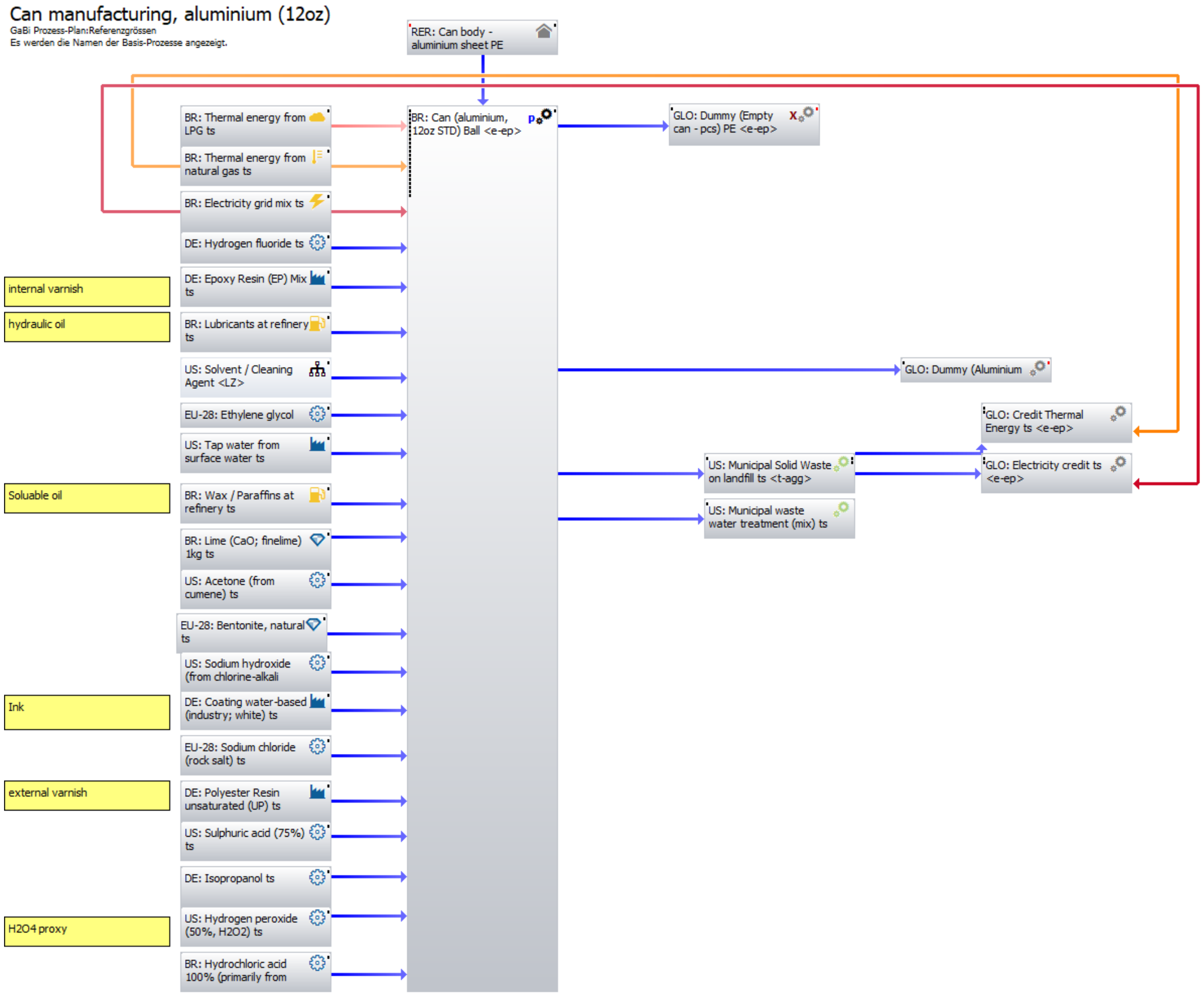


Figure D-0-5: Can manufacturing in Brazil (example: 12oz aluminum can).

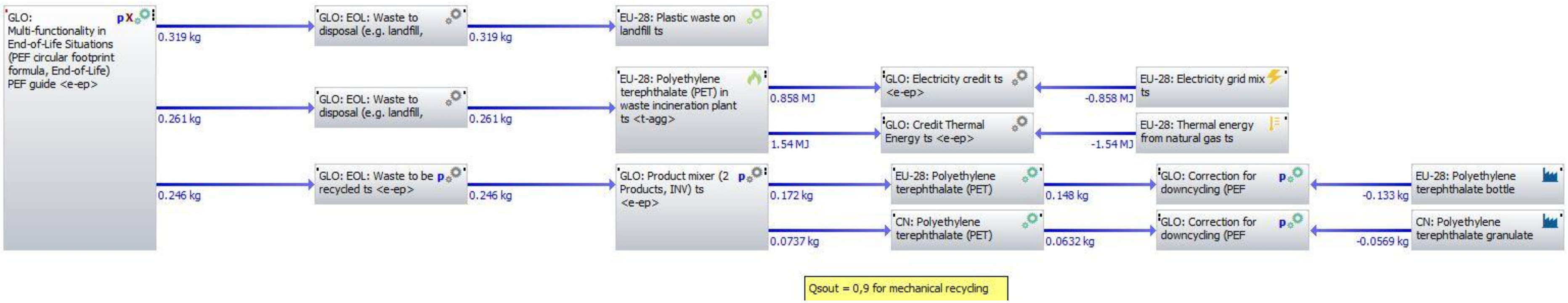


Figure D-0-6: GaBi screenshot: PET Multifunctionality in End-of-Life Situations, EU, PEF CFF.

Annex E: LCIA Results (per piece)

The full range of life cycle impact assessment (LCIA) environmental impact categories assessed for each region are summarized here. Each region applied a different combination of methodologies for environmental impact assessment, which are summarized in the tables below.

EU

Table E-0-10: Life cycle impact assessment results for product options manufactured in Europe, per single packaging piece.

	Carton 0.33L	Carton 0.5L	PET 0.3L (NC)	PET 0.38L (C)	PET 0.5L (C)	PET 0.5L (NC)	Glass 0.25L	Glass 0.33L	Glass 1L	Alu 0.25L	Alu 0.33L	Alu 0.50L
EF 3.0 (Environmental Footprint 3.0)												
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	1.6E-04	2.3E-04	1.8E-04	2.4E-04	2.1E-04	1.4E-04	1.1E-03	1.3E-03	3.4E-03	3.2E-04	3.9E-04	4.4E-04
EF 3.0 Cancer human health effects [CTUh]	1.9E-11	2.9E-11	6.1E-11	7.9E-11	6.9E-11	4.5E-11	1.1E-10	1.2E-10	3.3E-10	2.4E-11	3.0E-11	3.2E-11
EF 3.0 Cancer human health effects (Metal) [CTUh]	7.9E-12	1.1E-11	2.7E-11	3.5E-11	3.2E-11	2.1E-11	9.9E-12	1.1E-11	2.9E-11	6.5E-12	8.5E-12	1.0E-11
EF 3.0 Cancer human health effects (Organic) [CTUh]	1.1E-11	1.8E-11	3.4E-11	4.3E-11	3.8E-11	2.4E-11	1.0E-10	1.1E-10	3.0E-10	1.7E-11	2.1E-11	2.2E-11
EF 3.0 Climate Change [kg CO2 eq.]	4.4E-02	6.6E-02	7.9E-02	1.1E-01	9.2E-02	6.1E-02	1.8E-01	1.9E-01	5.0E-01	7.3E-02	9.2E-02	1.0E-01
EF 3.0 Climate Change (biogenic) [kg CO2 eq.]	3.9E-03	7.3E-03	9.2E-05	1.2E-04	1.0E-04	6.8E-05	1.9E-03	3.1E-04	7.9E-04	1.6E-03	2.4E-03	1.4E-03
EF 3.0 Climate Change (fossil) [kg CO2 eq.]	4.0E-02	5.9E-02	7.9E-02	1.1E-01	9.2E-02	6.1E-02	1.7E-01	1.9E-01	5.0E-01	7.1E-02	9.0E-02	9.9E-02
EF 3.0 Climate Change (land use change) [kg CO2 eq.]	9.9E-05	2.1E-04	6.4E-05	8.5E-05	7.3E-05	4.8E-05	5.0E-04	4.7E-04	1.2E-03	1.2E-04	1.7E-04	1.2E-04
EF 3.0 Ecotoxicity freshwater [CTUe]	3.4E-01	4.4E-01	8.0E-01	1.1E+00	9.3E-01	6.2E-01	2.4E+00	2.7E+00	7.4E+00	3.2E-01	4.4E-01	5.0E-01
EF 3.0 Ecotoxicity freshwater (Inorganic) [CTUe]	3.0E-01	3.8E-01	7.2E-01	9.8E-01	8.4E-01	5.6E-01	1.9E+00	2.1E+00	5.8E+00	2.2E-01	3.1E-01	3.4E-01
EF 3.0 Ecotoxicity freshwater (Metals) [CTUe]	3.2E-02	4.4E-02	7.4E-02	9.6E-02	8.4E-02	5.5E-02	5.3E-01	5.9E-01	1.6E+00	9.4E-02	1.2E-01	1.4E-01
EF 3.0 Ecotoxicity freshwater (Organic) [CTUe]	8.5E-03	1.1E-02	9.8E-03	1.4E-02	1.1E-02	7.7E-03	1.1E-02	1.2E-02	3.2E-02	1.3E-02	1.7E-02	1.9E-02
EF 3.0 Eutrophication freshwater [kg P eq.]	5.1E-07	9.5E-07	2.2E-07	2.9E-07	2.5E-07	1.7E-07	4.7E-07	2.4E-07	6.5E-07	2.9E-07	4.3E-07	2.8E-07

	Carton 0.33L	Carton 0.5L	PET 0.3L (NC)	PET 0.38L (C)	PET 0.5L (C)	PET 0.5L (NC)	Glass 0.25L	Glass 0.33L	Glass 1L	Alu 0.25L	Alu 0.33L	Alu 0.50L
EF 3.0 Eutrophication marine [kg N eq.]	4.3E-05	7.0E-05	4.3E-05	5.7E-05	5.0E-05	3.3E-05	3.5E-04	3.8E-04	1.0E-03	6.3E-05	8.0E-05	8.4E-05
EF 3.0 Eutrophication terrestrial [Mole of N eq.]	4.6E-04	7.3E-04	4.7E-04	6.2E-04	5.4E-04	3.6E-04	3.9E-03	4.3E-03	1.2E-02	6.8E-04	8.5E-04	9.1E-04
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	4.2E-03	5.9E-03	7.1E-03	9.2E-03	8.0E-03	5.2E-03	1.1E-02	1.2E-02	3.2E-02	9.8E-03	1.2E-02	1.4E-02
EF 3.0 Land Use [Pt]	-5.4E-01	-3.5E-01	1.0E-01	1.3E-01	1.1E-01	7.2E-02	9.4E-01	3.8E-01	1.0E+00	5.4E-01	8.3E-01	4.0E-01
EF 3.0 Non-cancer human health effects [CTUh]	4.1E-10	6.2E-10	2.3E-09	2.9E-09	2.6E-09	1.7E-09	1.1E-09	1.2E-09	3.3E-09	6.2E-10	7.8E-10	9.3E-10
EF 3.0 Non-cancer human health effects (Inorganic) [CTUh]	8.0E-11	1.2E-10	1.9E-10	2.5E-10	2.2E-10	1.4E-10	5.3E-10	5.6E-10	1.5E-09	1.2E-10	1.6E-10	1.7E-10
EF 3.0 Non-cancer human health effects (Metals) [CTUh]	3.3E-10	4.9E-10	2.1E-09	2.6E-09	2.4E-09	1.6E-09	5.8E-10	6.5E-10	1.8E-09	4.9E-10	6.0E-10	7.4E-10
EF 3.0 Non-cancer human health effects (Organic) [CTUh]	6.2E-12	8.5E-12	1.2E-11	1.6E-11	1.3E-11	8.9E-12	1.8E-11	1.9E-11	5.1E-11	1.3E-11	1.6E-11	1.9E-11
EF 3.0 Ozone depletion [kg CFC-11 eq.]	6.1E-11	8.8E-11	3.3E-16	4.2E-16	3.7E-16	2.4E-16	1.6E-13	4.6E-13	2.2E-12	7.5E-13	9.4E-13	1.0E-12
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	1.3E-04	1.9E-04	1.5E-04	2.0E-04	1.7E-04	1.1E-04	7.1E-04	7.7E-04	2.1E-03	2.6E-04	3.2E-04	3.6E-04
EF 3.0 Resource use, energy carriers [MJ]	7.6E-01	1.0E+00	1.6E+00	2.2E+00	1.9E+00	1.2E+00	2.6E+00	2.8E+00	7.6E+00	9.6E-01	1.3E+00	1.4E+00
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	5.6E-09	1.0E-08	7.7E-09	1.0E-08	8.9E-09	5.8E-09	1.6E-08	1.5E-08	3.9E-08	2.0E-07	2.3E-07	2.9E-07
EF 3.0 Respiratory inorganics [Disease incidences]	1.6E-09	2.4E-09	1.8E-09	2.3E-09	2.1E-09	1.4E-09	6.6E-09	7.0E-09	1.9E-08	4.4E-09	5.2E-09	6.0E-09
EF 3.0 Water scarcity [m³ world equiv.]	9.7E-03	1.5E-02	1.7E-02	2.2E-02	1.9E-02	1.3E-02	1.5E-02	1.4E-02	3.8E-02	9.9E-03	1.3E-02	1.3E-02
Water												
Blue water consumption [kg]	3.6E-01	5.8E-01	4.6E-01	6.0E-01	5.3E-01	3.5E-01	5.1E-01	4.5E-01	1.2E+00	7.2E-01	9.0E-01	9.8E-01

USA

Table E-0-11: Life cycle impact assessment results for product options manufactured in the USA, per single packaging piece.

	Carton 11.1oz	Carton 16.90z	PET 12oz (C)	PET 16.9oz (C)	PET 16.9oz (NC)	Glass 12oz	Glass 16oz	Alu 12oz	Alu 16oz	Alu 16oz (ATB)
TRACI 2.1										
TRACI 2.1, Acidification [kg SO2 eq.]	2.2E-04	3.6E-04	1.9E-04	2.8E-04	9.2E-05	1.8E-03	1.3E-03	3.5E-04	4.0E-04	6.5E-04
TRACI 2.1, Ecotoxicity (recommended) [CTUe]	5.6E-03	9.9E-03	1.0E-02	1.5E-02	5.2E-03	2.1E-02	1.2E-02	4.1E-03	5.0E-03	7.4E-03
TRACI 2.1, Eutrophication [kg N eq.]	3.2E-05	6.9E-05	1.6E-05	2.4E-05	6.9E-06	1.4E-04	7.5E-05	1.6E-05	2.0E-05	2.9E-05
TRACI 2.1, Global Warming Air, excl. biogenic carbon [kg CO2 eq.]	7.2E-02	1.2E-01	1.1E-01	1.6E-01	5.2E-02	4.5E-01	3.1E-01	8.3E-02	9.8E-02	1.6E-01
TRACI 2.1, Global Warming Air, incl. biogenic carbon [kg CO2 eq.]	3.2E-02	1.3E-02	1.0E-01	1.5E-01	5.2E-02	3.3E-01	2.8E-01	7.0E-02	7.9E-02	1.4E-01
TRACI 2.1, Human Health Particulate Air [kg PM2.5 eq.]	2.0E-05	3.1E-05	1.2E-05	1.7E-05	5.6E-06	1.6E-04	1.2E-04	4.9E-05	5.7E-05	9.2E-05
TRACI 2.1, Human toxicity, cancer (recommended) [CTUh]	3.1E-11	4.9E-11	4.7E-11	6.9E-11	2.4E-11	1.3E-10	7.5E-11	4.6E-11	5.4E-11	8.8E-11
TRACI 2.1, Human toxicity, non-canc. (recommended) [CTUh]	3.1E-09	5.5E-09	3.5E-09	5.1E-09	1.7E-09	1.3E-08	7.3E-09	5.1E-09	6.0E-09	9.2E-09
TRACI 2.1, Ozone Depletion Air [kg CFC 11 eq.]	3.8E-11	4.5E-11	6.4E-14	1.0E-13	-5.5E-15	1.5E-12	3.3E-13	2.4E-12	2.8E-12	4.2E-12
TRACI 2.1, Resources, Fossil fuels [MJ surplus energy]	1.4E-01	2.1E-01	2.8E-01	4.1E-01	1.4E-01	8.1E-01	5.5E-01	1.0E-01	1.2E-01	2.0E-01
TRACI 2.1, Smog Air [kg O3 eq.]	3.7E-03	6.8E-03	3.4E-03	5.0E-03	1.6E-03	3.1E-02	2.1E-02	4.2E-03	5.0E-03	7.6E-03
Water										
Blue water consumption [kg]	5.1E-01	1.0E+00	6.3E-01	8.9E-01	2.8E-01	1.7E+00	7.9E-01	1.1E+00	1.3E+00	2.1E+00

Table E-0-12: Life cycle impact assessment results for product options manufactured in Brazil, per single packaging piece.

	Carton 0.2L	Carton 1L	PET 0.25L (C)	PET 0.511L (NC)	PET 0.6L (C)	PET 0.9L (NC)	Glass 0.355L	Glass 0.6L (with re-use)	Alu 12oz	Alu 16oz	Alu 24oz
ReCiPe 2016 v1.1 (H)											
ReCiPe 2016 v1.1 Midpoint (H) - Climate change, default, excl biogenic carbon [kg CO2 eq.]	2.3E-02	9.5E-02	5.1E-02	5.2E-02	6.3E-02	1.1E-01	2.3E-01	1.0E-01	3.5E-02	4.1E-02	5.2E-02
ReCiPe 2016 v1.1 Midpoint (H) - Climate change, incl biogenic carbon [kg CO2 eq.]	2.4E-02	1.0E-01	5.1E-02	5.2E-02	6.3E-02	1.1E-01	2.3E-01	9.9E-02	3.5E-02	4.0E-02	5.1E-02
ReCiPe 2016 v1.1 Midpoint (H) - Fine Particulate Matter Formation [kg PM2.5 eq.]	2.0E-05	8.3E-05	4.1E-05	4.2E-05	5.1E-05	8.4E-05	3.2E-04	1.0E-04	3.4E-05	3.8E-05	4.9E-05
ReCiPe 2016 v1.1 Midpoint (H) - Fossil depletion [kg oil eq.]	8.1E-03	3.2E-02	2.5E-02	2.6E-02	3.1E-02	5.7E-02	7.7E-02	3.0E-02	1.4E-02	1.7E-02	2.0E-02
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater Consumption [m3]	9.2E-04	3.9E-03	1.1E-03	1.1E-03	1.4E-03	2.3E-03	2.2E-03	1.3E-03	5.8E-04	7.1E-04	1.2E-03
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater ecotoxicity [kg 1,4 DB eq.]	5.3E-06	2.2E-05	1.7E-05	1.7E-05	2.1E-05	3.6E-05	3.1E-05	3.2E-05	8.1E-06	1.0E-05	1.4E-05
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater Eutrophication [kg P eq.]	4.8E-07	2.1E-06	5.6E-07	5.8E-07	7.0E-07	1.3E-06	6.9E-07	9.5E-07	2.0E-07	2.4E-07	3.3E-07
ReCiPe 2016 v1.1 Midpoint (H) - Human toxicity, cancer [kg 1,4-DB eq.]	1.1E-05	4.2E-05	4.7E-05	4.8E-05	5.9E-05	9.5E-05	6.5E-05	6.2E-05	2.9E-05	3.6E-05	5.2E-05
ReCiPe 2016 v1.1 Midpoint (H) - Human toxicity, non-cancer [kg 1,4-DB eq.]	1.6E-03	6.8E-03	6.0E-03	6.1E-03	7.5E-03	1.2E-02	9.9E-03	1.1E-02	2.6E-03	3.3E-03	4.4E-03
ReCiPe 2016 v1.1 Midpoint (H) - Ionizing Radiation [Bq C-60 eq. to air]	4.6E-05	2.0E-04	1.3E-04	1.4E-04	1.7E-04	2.8E-04	2.4E-04	1.2E-04	1.1E-04	1.3E-04	1.6E-04
ReCiPe 2016 v1.1 Midpoint (H) - Land use [Annual crop eq.·y]	4.1E-03	1.8E-02	9.3E-04	9.4E-04	1.2E-03	1.9E-03	4.7E-03	7.9E-03	9.8E-04	1.2E-03	1.8E-03
ReCiPe 2016 v1.1 Midpoint (H) - Marine ecotoxicity [kg 1,4-DB eq.]	1.7E-05	6.9E-05	6.3E-05	6.4E-05	7.9E-05	1.3E-04	9.8E-05	8.0E-05	2.8E-05	3.4E-05	4.9E-05
ReCiPe 2016 v1.1 Midpoint (H) - Marine Eutrophication [kg N eq.]	1.2E-06	5.6E-06	1.1E-06	1.1E-06	1.4E-06	2.3E-06	6.6E-06	4.1E-06	9.8E-07	1.2E-06	2.0E-06
ReCiPe 2016 v1.1 Midpoint (H) - Metal depletion [kg Cu eq.]	5.8E-05	2.6E-04	4.5E-05	4.7E-05	5.6E-05	1.1E-04	8.8E-03	1.0E-03	6.0E-05	5.1E-05	3.3E-05
ReCiPe 2016 v1.1 Midpoint (H) - Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	5.9E-05	2.5E-04	1.2E-04	1.2E-04	1.5E-04	2.5E-04	1.1E-03	5.4E-04	1.6E-04	1.8E-04	2.1E-04
ReCiPe 2016 v1.1 Midpoint (H) - Photochemical Ozone Formation, Human Health [kg NOx eq.]	5.8E-05	2.5E-04	1.2E-04	1.2E-04	1.4E-04	2.4E-04	1.1E-03	5.4E-04	1.5E-04	1.7E-04	2.1E-04
ReCiPe 2016 v1.1 Midpoint (H) - Stratospheric Ozone Depletion [kg CFC-11 eq.]	6.3E-09	2.9E-08	1.1E-08	1.1E-08	1.4E-08	2.3E-08	3.3E-08	3.6E-08	9.1E-09	1.2E-08	1.8E-08
ReCiPe 2016 v1.1 Midpoint (H) - Terrestrial Acidification [kg SO2 eq.]	6.4E-05	2.6E-04	1.3E-04	1.3E-04	1.6E-04	2.6E-04	9.7E-04	3.0E-04	9.1E-05	1.0E-04	1.4E-04
ReCiPe 2016 v1.1 Midpoint (H) - Terrestrial ecotoxicity [kg 1,4-DB eq.]	1.1E-02	4.5E-02	3.1E-02	3.2E-02	3.9E-02	6.3E-02	5.7E-02	2.0E-02	1.8E-02	2.1E-02	3.0E-02

	Carton 0.2L	Carton 1L	PET 0.25L (C)	PET 0.511L (NC)	PET 0.6L (C)	PET 0.9L (NC)	Glass 0.355L	Glass 0.6L (with re-use)	Alu 12oz	Alu 16oz	Alu 24oz
Others											
Blue water consumption [kg]	9.2E-01	3.9E+00	1.1E+00	1.1E+00	1.4E+00	2.3E+00	2.2E+00	1.3E+00	5.8E-01	7.1E-01	1.2E+00

Annex F: Extended LCIA Results (per Functional Unit)

EU

Table F-0-13: Life cycle impact assessment results for product types manufactured in Europe per liter fill volume, using the EF 3.0 method. Note: results from the water scarcity footprint are to be interpreted with care as the underlying association data in the study does not allow for a reliable water scarcity assessment. Resource use, mineral and metals should also be read with caution (see main text) and instead the CML method for ADP is recommended by the authors.

	Carton 0.33L	Carton 0.5L	PET 0.3L (NC)	PET 0.38L (C)	PET 0.5L (C)	PET 0.5L (NC)	Glass 0.25L	Glass 0.33L	Glass 1L	Alu 0.25L	Alu 0.33L	Alu 0.50L
EF 3.0												
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	4.7E-04	4.6E-04	6.1E-04	6.4E-04	4.3E-04	2.8E-04	4.6E-03	3.8E-03	3.4E-03	1.3E-03	1.2E-03	8.8E-04
EF 3.0 Cancer human health effects [CTUh]	5.9E-11	5.8E-11	2.0E-10	2.1E-10	1.4E-10	9.0E-11	4.6E-10	3.7E-10	3.3E-10	9.5E-11	9.1E-11	6.4E-11
EF 3.0 Climate Change [kg CO2 eq.]	1.3E-01	1.3E-01	2.6E-01	2.8E-01	1.8E-01	1.2E-01	7.1E-01	5.7E-01	5.0E-01	2.9E-01	2.8E-01	2.0E-01
EF 3.0 Ecotoxicity freshwater [CTUe]	1.0E+00	8.7E-01	2.7E+00	2.9E+00	1.9E+00	1.2E+00	9.8E+00	8.3E+00	7.4E+00	1.3E+00	1.3E+00	9.9E-01
EF 3.0 Eutrophication freshwater [kg P eq.]	1.6E-06	1.9E-06	7.3E-07	7.7E-07	5.0E-07	3.3E-07	1.9E-06	7.3E-07	6.5E-07	1.2E-06	1.3E-06	5.6E-07
EF 3.0 Eutrophication marine [kg N eq.]	1.3E-04	1.4E-04	1.4E-04	1.5E-04	9.9E-05	6.5E-05	1.4E-03	1.2E-03	1.0E-03	2.5E-04	2.4E-04	1.7E-04
EF 3.0 Eutrophication terrestrial [Mole of N eq.]	1.4E-03	1.5E-03	1.6E-03	1.6E-03	1.1E-03	7.2E-04	1.6E-02	1.3E-02	1.2E-02	2.7E-03	2.6E-03	1.8E-03
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	1.3E-02	1.2E-02	2.4E-02	2.4E-02	1.6E-02	1.0E-02	4.4E-02	3.6E-02	3.2E-02	3.9E-02	3.6E-02	2.8E-02
EF 3.0 Land Use [Pt]	-1.6E+00	-7.0E-01	3.3E-01	3.4E-01	2.2E-01	1.4E-01	3.8E+00	1.2E+00	1.0E+00	2.2E+00	2.5E+00	8.0E-01
EF 3.0 Non-cancer human health effects [CTUh]	1.2E-09	1.2E-09	7.6E-09	7.6E-09	5.3E-09	3.4E-09	4.5E-09	3.7E-09	3.3E-09	2.5E-09	2.4E-09	1.9E-09
EF 3.0 Ozone depletion [kg CFC-11 eq.]	1.8E-10	1.8E-10	1.1E-15	1.1E-15	7.4E-16	4.8E-16	6.2E-13	1.4E-12	2.2E-12	3.0E-12	2.9E-12	2.1E-12
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	3.8E-04	3.8E-04	4.9E-04	5.2E-04	3.4E-04	2.3E-04	2.9E-03	2.3E-03	2.1E-03	1.0E-03	9.7E-04	7.3E-04
EF 3.0 Resource use, energy carriers [MJ]	2.3E+00	2.1E+00	5.3E+00	5.7E+00	3.7E+00	2.5E+00	1.1E+01	8.6E+00	7.6E+00	3.9E+00	3.8E+00	2.8E+00

	Carton 0.33L	Carton 0.5L	PET 0.3L (NC)	PET 0.38L (C)	PET 0.5L (C)	PET 0.5L (NC)	Glass 0.25L	Glass 0.33L	Glass 1L	Alu 0.25L	Alu 0.33L	Alu 0.50L
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	1.7E-08	2.0E-08	2.6E-08	2.7E-08	1.8E-08	1.2E-08	6.6E-08	4.4E-08	3.9E-08	7.9E-07	7.1E-07	5.7E-07
EF 3.0 Respiratory inorganics [Disease incidences]	4.8E-09	4.7E-09	5.9E-09	6.2E-09	4.1E-09	2.7E-09	2.6E-08	2.1E-08	1.9E-08	1.7E-08	1.6E-08	1.2E-08
EF 3.0 Water scarcity [m³ world equiv.]	2.9E-02	3.1E-02	5.5E-02	5.8E-02	3.8E-02	2.5E-02	5.8E-02	4.2E-02	3.8E-02	4.0E-02	3.9E-02	2.6E-02
Others												
Blue water consumption [kg]	1.1E+00	1.2E+00	1.5E+00	1.6E+00	1.1E+00	6.9E-01	2.0E+00	1.4E+00	1.2E+00	2.9E+00	2.7E+00	2.0E+00
CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	3.5E-08	4.3E-08	4.3E-08	4.5E-08	3.0E-08	2.0E-08	9.8E-07	8.1E-07	7.2E-07	8.7E-07	7.9E-07	6.2E-07

Table F-0-14: Heat map comparison of the environmental performance of the packaging options for each impact category.

	Carton 0.33L	Carton 0.5L	PET 0.3L (NC)	PET 0.38L (C)	PET 0.5L (C)	PET 0.5L (NC)	Glass 0.25L	Glass 1L	Alu 0.25L	Alu 0.33L	Alu 0.50L
EF 3.0											
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	168%	164%	217%	228%	152%	100%	1619%	1197%	448%	416%	312%
EF 3.0 Cancer human health effects [CTUh]	100%	100%	349%	355%	238%	154%	783%	556%	162%	156%	109%
EF 3.0 Climate Change [kg CO2 eq.]	111%	109%	218%	229%	151%	100%	585%	415%	241%	230%	166%
EF 3.0 Ecotoxicity freshwater [CTUe]	118%	100%	305%	328%	213%	142%	1120%	846%	148%	153%	114%
EF 3.0 Eutrophication freshwater [kg P eq.]	464%	570%	217%	230%	151%	100%	556%	194%	349%	391%	167%
EF 3.0 Eutrophication marine [kg N eq.]	200%	213%	219%	229%	152%	100%	2149%	1572%	386%	368%	257%
EF 3.0 Eutrophication terrestrial [Mole of N eq.]	193%	203%	219%	229%	152%	100%	2201%	1619%	378%	359%	254%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	122%	113%	226%	231%	153%	100%	417%	304%	374%	343%	269%
EF 3.0 Land Use [Pt]	100%	43%	-20%	-21%	-14%	-9%	-229%	-62%	-133%	-153%	-49%
EF 3.0 Non-cancer human health effects [CTUh]	101%	100%	609%	616%	425%	276%	363%	269%	201%	190%	150%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	38430950%	36833481%	230%	232%	154%	100%	130091%	451323%	627346%	597013%	432470%
EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	168%	170%	217%	228%	151%	100%	1259%	915%	455%	430%	322%
EF 3.0 Resource use, energy carriers [MJ]	111%	100%	256%	273%	178%	118%	506%	368%	185%	183%	134%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	146%	172%	220%	229%	152%	100%	564%	332%	6783%	6083%	4897%
EF 3.0 Respiratory inorganics [Disease incidences]	178%	174%	218%	226%	152%	100%	964%	693%	642%	584%	442%
EF 3.0 Water scarcity [m³ world equiv.]	116%	121%	217%	227%	152%	100%	230%	149%	157%	156%	102%
Others											
Blue water consumption [kg]	160%	169%	220%	228%	152%	100%	296%	179%	418%	394%	283%
CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	175%	218%	213%	227%	150%	100%	4901%	3607%	4365%	3942%	3129%

USA

Table F-0-15: Life cycle impact assessment results for product types manufactured in the USA per gallon fill volume, using the TRACI 2.1 method.

	Carton 11.1oz	Carton 16.90z	PET 12oz (C)	PET 16.9oz (C)	PET 16.9oz (NC)	Glass 12oz	Glass 16oz	Alu 12oz	Alu 16oz	Alu 16oz (ATB)
TRACI 2.1										
TRACI 2.1, Acidification [kg SO2 eq.]	2.5E-03	2.7E-03	2.1E-03	2.1E-03	7.0E-04	1.9E-02	1.0E-02	3.7E-03	3.2E-03	5.2E-03
TRACI 2.1, Ecotoxicity (recommended) [CTUe]	6.4E-02	7.5E-02	1.1E-01	1.2E-01	4.0E-02	2.2E-01	9.6E-02	4.4E-02	4.0E-02	5.9E-02
TRACI 2.1, Eutrophication [kg N eq.]	3.7E-04	5.2E-04	1.8E-04	1.8E-04	5.2E-05	1.5E-03	6.0E-04	1.7E-04	1.6E-04	2.3E-04
TRACI 2.1, Global Warming Air, excl. biogenic carbon [kg CO2 eq.]	8.2E-01	9.1E-01	1.1E+00	1.2E+00	3.9E-01	4.8E+00	2.5E+00	8.8E-01	7.8E-01	1.2E+00
TRACI 2.1, Global Warming Air, incl. biogenic carbon [kg CO2 eq.]	3.7E-01	9.6E-02	1.1E+00	1.1E+00	3.9E-01	3.5E+00	2.3E+00	7.5E-01	6.3E-01	1.1E+00
TRACI 2.1, Human Health Particulate Air [kg PM2.5 eq.]	2.3E-04	2.3E-04	1.3E-04	1.3E-04	4.3E-05	1.7E-03	9.5E-04	5.2E-04	4.5E-04	7.4E-04
TRACI 2.1, Human toxicity, cancer (recommended) [CTUh]	3.5E-10	3.7E-10	5.1E-10	5.3E-10	1.8E-10	1.4E-09	6.0E-10	4.9E-10	4.3E-10	7.0E-10
TRACI 2.1, Human toxicity, non-canc. (recommended) [CTUh]	3.6E-08	4.2E-08	3.7E-08	3.9E-08	1.3E-08	1.4E-07	5.9E-08	5.4E-08	4.8E-08	7.3E-08
TRACI 2.1, Ozone Depletion Air [kg CFC 11 eq.]	4.4E-10	3.4E-10	6.8E-13	7.9E-13	-4.2E-14	1.6E-11	2.6E-12	2.6E-11	2.2E-11	3.3E-11
TRACI 2.1, Resources, Fossil fuels [MJ surplus energy]	1.6E+00	1.6E+00	3.0E+00	3.1E+00	1.1E+00	8.6E+00	4.4E+00	1.1E+00	1.0E+00	1.6E+00
TRACI 2.1, Smog Air [kg O3 eq.]	4.3E-02	5.2E-02	3.7E-02	3.8E-02	1.2E-02	3.3E-01	1.7E-01	4.4E-02	4.0E-02	6.1E-02
AWARE, OECD+BRIC average for unspecified water [m^3 world equiv.]	1.8E-01	2.2E-01	2.2E-01	2.2E-01	7.2E-02	5.2E-01	1.9E-01	4.1E-01	3.6E-01	5.7E-01
Water										
Blue water consumption [kg]	5.9E+00	7.7E+00	6.7E+00	6.8E+00	2.2E+00	1.8E+01	6.3E+00	1.2E+01	1.1E+01	1.7E+01

Table F-0-16: Heat map comparison of the environmental performance of the packaging options for each impact category.

	Carton 11.1oz	Carton 16.90z	PET 12oz (C)	PET 16.9oz (C)	PET 16.9oz (NC)	Glass 12oz	Glass 16oz	Alu 12oz	Alu 16oz	Alu 16oz (ATB)
TRACI 2.1										
TRACI 2.1, Acidification [kg SO2 eq.]	356%	394%	296%	305%	100%	2748%	1477%	529%	463%	745%
TRACI 2.1, Ecotoxicity (recommended) [CTUe]	163%	190%	279%	292%	100%	556%	243%	110%	102%	149%
TRACI 2.1, Eutrophication [kg N eq.]	714%	1002%	336%	352%	100%	2795%	1142%	324%	313%	442%
TRACI 2.1, Global Warming Air, excl. biogenic carbon [kg CO2 eq.]	210%	232%	293%	300%	100%	1237%	636%	225%	200%	319%
TRACI 2.1, Global Warming Air, incl. biogenic carbon [kg CO2 eq.]	388%	100%	1128%	1149%	409%	3689%	2375%	781%	657%	1135%
TRACI 2.1, Human Health Particulate Air [kg PM2.5 eq.]	529%	546%	298%	307%	100%	4016%	2234%	1231%	1063%	1726%
TRACI 2.1, Human toxicity, cancer (recommended) [CTUh]	195%	207%	279%	291%	100%	750%	331%	272%	240%	389%
TRACI 2.1, Human toxicity, non-canc. (recommended) [CTUh]	276%	319%	284%	298%	100%	1079%	450%	416%	368%	564%
TRACI 2.1, Ozone Depletion Air [kg CFC 11 eq.]	-1047012%	-822517%	-1639%	-1890%	100%	-38694%	-6311%	-61818%	-52931%	-79722%
TRACI 2.1, Resources, Fossil fuels [MJ surplus energy]	159%	156%	299%	309%	105%	865%	441%	111%	100%	159%
TRACI 2.1, Smog Air [kg O3 eq.]	354%	423%	300%	310%	100%	2663%	1392%	364%	328%	500%
AWARE, OECD+BRIC average for unspecified water [m³ world equiv.]	252%	314%	307%	310%	100%	731%	266%	570%	499%	803%
Water										
Blue water consumption [kg]	275%	356%	310%	314%	100%	827%	292%	561%	494%	793%

Brazil

Table F-0-17: Life cycle impact assessment results for product types manufactured in Brazil per liter fill volume, using the ReCiPe 2016 method.

	Carton 0.2L	Carton 1L	PET 0.25L (C)	PET 0.511L (NC)	PET 0.6L (C)	PET 0.9L (NC)	Glass 0.355L	Glass 0.6L (with re-use)	Alu 12oz	Alu 16oz	Alu 24oz
ReCiPe											
ReCiPe 2016 v1.1 Midpoint (H) - Climate change, default, excl biogenic carbon [kg CO2 eq.]	1.1E-01	9.5E-02	2.0E-01	1.0E-01	1.1E-01	1.2E-01	6.6E-01	1.7E-01	9.9E-02	8.6E-02	7.3E-02
ReCiPe 2016 v1.1 Midpoint (H) - Climate change, incl biogenic carbon [kg CO2 eq.]	1.2E-01	1.0E-01	2.0E-01	1.0E-01	1.1E-01	1.2E-01	6.6E-01	1.6E-01	9.8E-02	8.5E-02	7.2E-02
ReCiPe 2016 v1.1 Midpoint (H) - Fine Particulate Matter Formation [kg PM2.5 eq.]	1.0E-04	8.3E-05	1.6E-04	8.2E-05	8.5E-05	9.4E-05	9.0E-04	1.7E-04	9.6E-05	8.0E-05	7.0E-05
ReCiPe 2016 v1.1 Midpoint (H) - Fossil depletion [kg oil eq.]	4.1E-02	3.2E-02	1.0E-01	5.1E-02	5.2E-02	6.4E-02	2.2E-01	5.0E-02	4.0E-02	3.5E-02	2.9E-02
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater Consumption [m3]	4.6E-03	3.9E-03	4.4E-03	2.2E-03	2.3E-03	2.5E-03	6.3E-03	2.2E-03	1.6E-03	1.5E-03	1.7E-03
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater ecotoxicity [kg 1,4 DB eq.]	2.7E-05	2.2E-05	6.8E-05	3.4E-05	3.5E-05	4.0E-05	8.7E-05	5.4E-05	2.3E-05	2.2E-05	2.0E-05
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater Eutrophication [kg P eq.]	2.4E-06	2.1E-06	2.3E-06	1.1E-06	1.2E-06	1.4E-06	1.9E-06	1.6E-06	5.6E-07	5.0E-07	4.7E-07
ReCiPe 2016 v1.1 Midpoint (H) - Human toxicity, cancer [kg 1,4-DB eq.]	5.3E-05	4.2E-05	1.9E-04	9.3E-05	9.8E-05	1.1E-04	1.8E-04	1.0E-04	8.0E-05	7.5E-05	7.3E-05
ReCiPe 2016 v1.1 Midpoint (H) - Human toxicity, non-cancer [kg 1,4-DB eq.]	8.1E-03	6.8E-03	2.4E-02	1.2E-02	1.3E-02	1.4E-02	2.8E-02	1.9E-02	7.3E-03	7.0E-03	6.3E-03
ReCiPe 2016 v1.1 Midpoint (H) - Ionizing Radiation [Bq C-60 eq. to air]	2.3E-04	2.0E-04	5.3E-04	2.7E-04	2.8E-04	3.1E-04	6.6E-04	2.0E-04	3.2E-04	2.8E-04	2.2E-04
ReCiPe 2016 v1.1 Midpoint (H) - Land use [Annual crop eq.·y]	2.1E-02	1.8E-02	3.7E-03	1.8E-03	1.9E-03	2.1E-03	1.3E-02	1.3E-02	2.8E-03	2.6E-03	2.6E-03
ReCiPe 2016 v1.1 Midpoint (H) - Marine ecotoxicity [kg 1,4-DB eq.]	8.4E-05	6.9E-05	2.5E-04	1.3E-04	1.3E-04	1.4E-04	2.8E-04	1.3E-04	7.8E-05	7.2E-05	6.9E-05
ReCiPe 2016 v1.1 Midpoint (H) - Marine Eutrophication [kg N eq.]	5.8E-06	5.6E-06	4.4E-06	2.2E-06	2.3E-06	2.5E-06	1.9E-05	6.8E-06	2.8E-06	2.6E-06	2.8E-06
ReCiPe 2016 v1.1 Midpoint (H) - Metal depletion [kg Cu eq.]	2.9E-04	2.6E-04	1.8E-04	9.1E-05	9.3E-05	1.2E-04	2.5E-02	1.7E-03	1.7E-04	1.1E-04	4.6E-05
ReCiPe 2016 v1.1 Midpoint (H) - Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	3.0E-04	2.5E-04	4.7E-04	2.3E-04	2.4E-04	2.8E-04	3.2E-03	9.0E-04	4.6E-04	3.7E-04	3.0E-04
ReCiPe 2016 v1.1 Midpoint (H) - Photochemical Ozone Formation, Human Health [kg NOx eq.]	2.9E-04	2.5E-04	4.7E-04	2.3E-04	2.4E-04	2.7E-04	3.2E-03	8.9E-04	4.3E-04	3.6E-04	2.9E-04
ReCiPe 2016 v1.1 Midpoint (H) - Stratospheric Ozone Depletion [kg CFC-11 eq.]	3.1E-08	2.9E-08	4.5E-08	2.2E-08	2.3E-08	2.6E-08	9.2E-08	5.9E-08	2.6E-08	2.5E-08	2.6E-08
ReCiPe 2016 v1.1 Midpoint (H) - Terrestrial Acidification [kg SO2 eq.]	3.2E-04	2.6E-04	5.1E-04	2.5E-04	2.6E-04	2.9E-04	2.7E-03	5.1E-04	2.6E-04	2.2E-04	2.0E-04
ReCiPe 2016 v1.1 Midpoint (H) - Terrestrial ecotoxicity [kg 1,4-DB eq.]	5.5E-02	4.5E-02	1.3E-01	6.2E-02	6.5E-02	7.0E-02	1.6E-01	3.3E-02	5.0E-02	4.5E-02	4.3E-02

	Carton 0.2L	Carton 1L	PET 0.25L (C)	PET 0.511L (NC)	PET 0.6L (C)	PET 0.9L (NC)	Glass 0.355L	Glass 0.6L (with re-use)	Alu 12oz	Alu 16oz	Alu 24oz
Others											
Blue water consumption [kg]	4.6E+00	3.9E+00	4.4E+00	2.2E+00	2.3E+00	2.5E+00	6.3E+00	2.2E+00	1.6E+00	1.5E+00	1.7E+00
CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	6.4E-08	5.6E-08	5.3E-08	2.7E-08	2.7E-08	4.2E-08	1.6E-06	9.4E-08	9.0E-08	7.8E-08	4.9E-08

Table F-0-18: Heat map comparison of the environmental performance of the packaging options for each impact category.

	Carton 0.2L	Carton 1L	PET 0.25L (C)	PET 0.511L (NC)	PET 0.6L (C)	PET 0.9L (NC)	Glass 0.355L	Glass 0.6L (with re-use)	Alu 12oz	Alu 16oz	Alu 24oz
ReCiPe											
ReCiPe 2016 v1.1 Midpoint (H) - Climate change, default, excl biogenic carbon [kg CO2 eq.]	157%	131%	280%	140%	145%	167%	906%	229%	136%	118%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Climate change, incl biogenic carbon [kg CO2 eq.]	168%	138%	282%	141%	146%	169%	910%	227%	136%	118%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Fine Particulate Matter Formation [kg PM2.5 eq.]	146%	120%	236%	117%	122%	135%	1288%	238%	137%	115%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Fossil depletion [kg oil eq.]	142%	113%	353%	177%	182%	222%	758%	174%	139%	122%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater Consumption [m3]	305%	256%	292%	144%	151%	166%	417%	145%	108%	100%	111%
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater ecotoxicity [kg 1,4 DB eq.]	131%	109%	335%	167%	174%	197%	426%	263%	112%	107%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Freshwater Eutrophication [kg P eq.]	511%	443%	479%	240%	247%	297%	411%	334%	118%	106%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Human toxicity, cancer [kg 1,4-DB eq.]	125%	100%	447%	221%	231%	249%	433%	245%	191%	179%	173%
ReCiPe 2016 v1.1 Midpoint (H) - Human toxicity, non-cancer [kg 1,4-DB eq.]	130%	109%	386%	192%	200%	218%	444%	305%	117%	111%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Ionizing Radiation [Bq C-60 eq. to air]	115%	100%	269%	136%	140%	156%	337%	100%	160%	141%	112%
ReCiPe 2016 v1.1 Midpoint (H) - Land use [Annual crop eq.·y]	1114%	1001%	202%	100%	104%	116%	726%	712%	150%	140%	140%
ReCiPe 2016 v1.1 Midpoint (H) - Marine ecotoxicity [kg 1,4-DB eq.]	123%	100%	369%	183%	191%	209%	403%	193%	113%	105%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Marine Eutrophication [kg N eq.]	267%	257%	203%	100%	105%	115%	857%	310%	127%	119%	126%
ReCiPe 2016 v1.1 Midpoint (H) - Metal depletion [kg Cu eq.]	627%	553%	389%	196%	201%	258%	53573%	3712%	361%	233%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Photochemical Ozone Formation, Ecosystems [kg NOx eq.]	126%	107%	201%	100%	104%	117%	1346%	382%	194%	159%	129%
ReCiPe 2016 v1.1 Midpoint (H) - Photochemical Ozone Formation, Human Health [kg NOx eq.]	126%	106%	201%	100%	104%	117%	1361%	386%	187%	154%	125%
ReCiPe 2016 v1.1 Midpoint (H) - Stratospheric Ozone Depletion [kg CFC-11 eq.]	141%	129%	201%	100%	104%	117%	412%	267%	115%	113%	115%
ReCiPe 2016 v1.1 Midpoint (H) - Terrestrial Acidification [kg SO2 eq.]	164%	134%	260%	129%	135%	148%	1391%	257%	131%	111%	100%
ReCiPe 2016 v1.1 Midpoint (H) - Terrestrial ecotoxicity [kg 1,4-DB eq.]	165%	135%	380%	187%	196%	212%	484%	100%	152%	136%	129%

	Carton 0.2L	Carton 1L	PET 0.25L (C)	PET 0.511L (NC)	PET 0.6L (C)	PET 0.9L (NC)	Glass 0.355L	Glass 0.6L (with re-use)	Alu 12oz	Alu 16oz	Alu 24oz
Others											
Blue water consumption [kg]	305%	256%	292%	144%	151%	166%	417%	145%	108%	100%	111%
CML2001 - Jan. 2016, Abiotic Depletion (ADP elements) [kg Sb eq.]	232%	206%	195%	100%	100%	152%	5865%	345%	328%	284%	178%

Annex G: MCI input/outputs

Packaging inputs and outputs

Material Circularity Indicator, MCI' = 1-LFI'*F(X)

Linear Flow Index, LFI' = $(V'+W')/(2M+(W_F-W_C)/2+(W'_F-W'_C)/2)$
where:

M = Mass of product

W_F = Mass of waste from recycling feedstock in final product

W_C = Mass of waste from recycling at EoL

W'_F = Mass of waste from recycling of feedstock not in final product

W'_C = Mass of waste from recycling manufacturing waste

Factor, F(X) = 0.9/X
where:

Utility, $X = L/L_{AV}*U/U_{AV}$

L = Product lifetime

L_{AV} = Industry average lifetime

U = Products intensity

U_{AV} = Industry average intensity

Mass of virgin feedstock, V' = M'*(1-FR-FU)
where:

M' = Mass of raw materials

F_R = Fraction of feedstock from recycled sources, M_R/M'

F_U = Fraction of feedstock from reused sources, M_U/M'

M_R = Mass of feedstock from recycled sources

M_U = Mass of feedstock from reused sources

M = Mass of product

Total mass of non-recovered waste, W' = $W+W'_O+(W'_F+W'_c)/2$
where:

W = Mass of waste

W'_F = Mass of waste from recycling of feedstock not in final product

W'_C = Mass of waste from recycling manufacturing waste

$W'o$ = Mass of non-recovered waste from manufacturing

W_O = Mass of non-recovered waste at EoL

Annex H: Tertiary Packaging

As stated in section 2.3, tertiary packaging has not been included in this study. To justify this decision a scenario has been calculated for the European 330ml beverage carton. The 330ml beverage carton has been taken into consideration as the sample in this study is a Tetra Prisma Aseptic Square carton and its packaging specifications have been calculated in the report by ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH, 2017. The tertiary packaging specifications that are considered in this scenario analysis are given in Table H-0-19.

Deviations in indicator results are given in percenteage in Table H-0-20. They do not exceed 1% difference except for the land use and respiratory inorganics indicators. As they have not been selected as relevant indicators in this study, tertiary packaging stays un-reported.

Table H-0-19 Tertiary packaging specifications for TPA Square 330ml applied in scenario analysis

Packaging Components	Unit	Amount/type
Pallet mass	kg	25
type of pallet	-	EURO, wood
number of use cycles	-	25
stretch foil mass per pallet	kg	0,17
type of stretch foil	-	LDPE
Beverage cartons per pallet	pc	1824

Table H-0-20 Deviations in results for a scenario calculation including tertiary packaging

Environmental indicators	Scenario excluding tertiary packaging	Scenario including tertiary packaging
EF 3.0 Acidification terrestrial and freshwater [Mole of H+ eq.]	100%	101%
EF 3.0 Cancer human health effects [CTUh]	100%	100%
EF 3.0 Climate Change [kg CO2 eq.]	100%	101%
EF 3.0 Ecotoxicity freshwater [CTUe]	100%	101%
EF 3.0 Eutrophication freshwater [kg P eq.]	100%	100%
EF 3.0 Eutrophication marine [kg N eq.]	100%	101%
EF 3.0 Eutrophication terrestrial [Mole of N eq.]	100%	101%
EF 3.0 Ionising radiation - human health [kBq U235 eq.]	100%	99,5 %
EF 3.0 Land Use [Pt]	100%	83,4 %
EF 3.0 Non-cancer human health effects [CTUh]	100%	101%
EF 3.0 Ozone depletion [kg CFC-11 eq.]	100%	100%

EF 3.0 Photochemical ozone formation - human health [kg NMVOC eq.]	100%	101%
EF 3.0 Resource use, energy carriers [MJ]	100%	101%
EF 3.0 Resource use, mineral and metals [kg Sb eq.]	100%	100%
EF 3.0 Respiratory inorganics [Disease incidences]	100%	105%
EF 3.0 Water scarcity [m^3 world equiv.]	100%	101%

Annex I: Documentation of AA 2016 data (to be released)

Remelting and DC casting of can sheet rolling ingot

Aluminum scrap, often categorized as used beverage container (UBC) scrap, non-UBC post-consumer scrap (e.g. building demolition scrap and automotive shredder scrap), post-industrial scrap (e.g. can stamping scrap), and rolling mill internal “run-around” scrap, is the majority of metal source for can sheet production in North America. Scrap is pretreated to remove non-aluminum alloy materials and contaminates. This is often done through shredding and sorting. The scrap is then fed into decoating or delacquering furnace. This unit heats the metal and coatings results in the vaporization of moisture and oxidation of the coatings. The decoating process results in the transfer of the hot metal to the melting furnace where the metal is turned into molten form. Primary aluminum is added to sweeten and adjust the composition. In addition, alloying elements are added as per the final specifications of the ingot to be produced. The molten metal is then transferred to cast house for casting. The casting process is similar to the process described in section on Primary Ingot Casting. Most of the decoating units and melting furnaces are natural gas fired furnaces.

Aluminum can sheet rolling

Can sheet rolling is to convert ingots into can stock and lid stock coil. In Hot mill rolling, aluminum ingots (approximately 18 to 26 inches thick and weighing approximately 15 to 30 metric tons) are preheated to about 1000°F and fed through a hot reversing mill. In the reversing mill, the coil passes back and forth between rollers and the thickness is reduced from the initial thickness to between 1 to 2 inches with a corresponding increase in length. Following the reverse mills, the slabs are fed to a continuous hot mill where the thickness is further reduced to less that ¼ inch in thickness. The metal, called re-roll or hot coil, is rolled into coil and ready to be transferred to the cold mill. Prior to the cold mill, the coils may be annealed to give the metal the workability for down-stream processing. Some plants have moved towards self annealing which requires no additional energy investment as the industry has improved their energy management. The coils are then passed through multiple sets of continuous rollers to reduce the gauge to approximately 0.012 inches required by the can makers. The coils are slit to the width and cut to the length required by can manufacturers. The coils are packaged to prevent damage to the metal in shipping.

UBC scrap remelting and casting

Scrap is pretreated to remove non-aluminum alloy materials and contaminates. This is often done through shredding and sorting. The scrap is then fed into decoating and delacquering furnace. This unit heats the metal and remove moisture and oxidize coatings and paints. The decoating process results in the transfer of the hot metal to the melting furnace. Molten metal is then casted into ingots. The casting process is similar to the process described in section on Primary Ingot Casting (Cast House). Most of the decoating units and melting furnaces are natural gas fired furnaces.