Beverage Packaging Life Cycle Assessment

On behalf of Graphic Packaging International

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List of Acronyms

AP	Acidification Potential
CCNKC	Clay-Coated Natural Kraft Container
CFF	Circular Footprint Formula
CML	Centre of Environmental Science at Leiden
DKL	Double Kraft Liner
EoL	End of Life
EP	Eutrophication Potential
FEFCO	Fédération Européenne des Fabricants de Carton Ondule (European Federation of Corrugated Board Manufacturers)
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
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
LDPE	Low-Density Polyethylene
LHV	Lower Heating Value
NMVOC	Non-Methane Volatile Organic Compound
NOU	Number of Uses
ODP	Ozone Depletion Potential
PCR	Post-Consumer Recycled [content]
PEF	Product Environmental Footprint
POFP	Photochemical Ozone Formation Potential
SFP	Smog Formation Potential
TRACI	Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts

Glossary

Life Cycle

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

Life Cycle Assessment (LCA)

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

Life Cycle Inventory (LCI)

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

Life Cycle Impact Assessment (LCIA)

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

Life Cycle Interpretation

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

Functional Unit

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

Allocation

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

Closed-loop and Open-loop Allocation of Recycled Material

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

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

(ISO 14044:2006, section 4.3.4.3.3)

Foreground System

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

Background System

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

Critical Review

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

Executive Summary

Graphic Packaging International (GPI) seeks to continually improve the environmental performance of its products. For many years, the company has been using life cycle assessment (LCA) to help it to understand the hot spots in the life cycle of its beverage board packaging and to assess the effect of process changes on the overall environmental performance of these products.

This current LCA study compares the environmental performance of two of GPI's beverage can packaging designs to two competing designs in the European and US end markets (Table ES-1):

- GPI's paperboard carton designed to hold 18 beverage cans
- GPI's paperboard KeelClip™ designed to hold 6 beverage cans
- An average manufacturer's shrink-wrap and corrugate tray designed to hold 18 beverage cans
- An average manufacturer's plastic Hi-Cone rings designed to hold 6 beverage cans

The two paperboard designs are produced by GPI at its two paperboard mills (Macon, GA and West Monroe, LA) and converting plants (Perry, GA and Masnières, France). The other two packaging designs are modeled as average production in the US or Europe as GPI does not produce these packages nor are their supply chain details known.

The main audience for the LCA study includes internal to GPI stakeholders as well as GPI's customers and other external stakeholders in both the United States and Europe. GPI is looking to report on the current environmental performance of its products and demonstrate steps the company is making to further reduce its potential environmental impacts. The study has been conducted according to the requirements of ISO 14044 (ISO, 2006) and has undergone independent critical review by a panel of three independent experts.

The functional unit selected for this assessment is:

Packaging for 1,000 beverage cans

These cans can contain either 300 mL or 330 mL (12 fl. oz.) of beverage depending on whether the European or US end market, respectively, is considered. Any differences in packaging due to can size are expected to be minimal as the can sizes are not significantly different and the focus of this study is on secondary packaging and not the cans themselves.

This study considers the full life cycle of the beverage packaging product from cradle to grave. This includes forestry management and logging, paperboard production and conversion into finished beverage packaging, production of plastic resin and corrugate, manufacturing of other packaging designs, distribution packaging, filling, end of life, and transport at all stages in the life cycle. Potential environmental impacts at a warehouse or retailer were excluded, as was transport from a retailer to a consumer home. Furthermore, the beverage cans and the beverage they contain are excluded from the analysis as the focus is on the beverage can packaging (i.e., on secondary packaging).

Table ES-1: Beverage can packaging overview

	Material	Mass by material		Production location	Converting location
		Per package	Per functional unit		
US: Carton	Paperboard	150 g	8.3 kg	Macon, GA West Monroe, LA	Perry, GA
US: KeelClip	Paperboard	26 g	4.3 kg	Macon, GA West Monroe, LA	Perry, GA
US: Wrap+Tray	LDPE film Corrugate	20 g 83 g	1.1 kg 4.6 kg	US	N/A
US: Hi-Cone	LDPE film	3.8 g	0.64 kg	US	N/A
EU: Carton	Paperboard	150 g	8.3 kg	Macon, GA West Monroe, LA	Masnières, France
EU: KeelClip	Paperboard	26 g	4.3 kg	Macon, GA West Monroe, LA	Masnières, France
EU: Wrap+Tray	LDPE film Corrugate	20 g 83 g	1.1 kg 4.6 kg	Europe	N/A
EU: Hi-Cone	LDPE film	3.84 g	0.64 kg	Europe	N/A

Cradle-to-grave life cycle results are presented in Figure ES-1-1 (US) and Figure ES-1-2 (Europe). Climate change characterization factors were taken from the IPCC's 5th Assessment Report; other impact categories are based on the European impact assessment methodology Environmental Footprint v3.0 (EF 3.0) as it is primarily GPI's European customers who are interested in this analysis. Results were also calculated using the US TRACI 2.1 methodology.

The results show that if beverage manufacturers were to switch from the Carton or Wrap+Tray to the KeelClip or Hi-Cone rings, they would be able to reduce the potential environmental impacts of beverage can packaging.

Overall, the Hi-Cone rings have the lowest potential environmental impacts as this design has the lowest material mass. This is generally followed by the KeelClip as it, too, has lower material mass compared to the 18-pack designs. The only impact category in which the KeelClip is comparable to the Hi-Cone rings is energy resource use under the US end market scenario as the Hi-Cone rings is a fossil, plastic-based product whereas the KeelClip is paper-based.

The Carton and Wrap+Tray are generally associated with the highest potential environmental impacts—although which one is higher depends on impact category and end market. In general, the Carton is associated with similar or lower potential impact for the US end market, but higher potential impact for the European market. This is due to the need to transport paper rolls to Europe from GPI's US paperboard mills, combined with the lower potential environmental impacts of average corrugate production in Europe based on current FEFCO data.

Scenario and sensitivity analyses indicate that the conclusion is fairly robust with respect to impact assessment methodology (impact categories from TRACI 2.1 were evaluated). Neither TRACI 2.1 nor EF 3.0, however, address issues such as ocean plastic or material circularity. Therefore, it may be worthwhile for GPI to conduct future studies to gain further understanding of how these packaging designs compare beyond the life cycle impact categories investigated here.

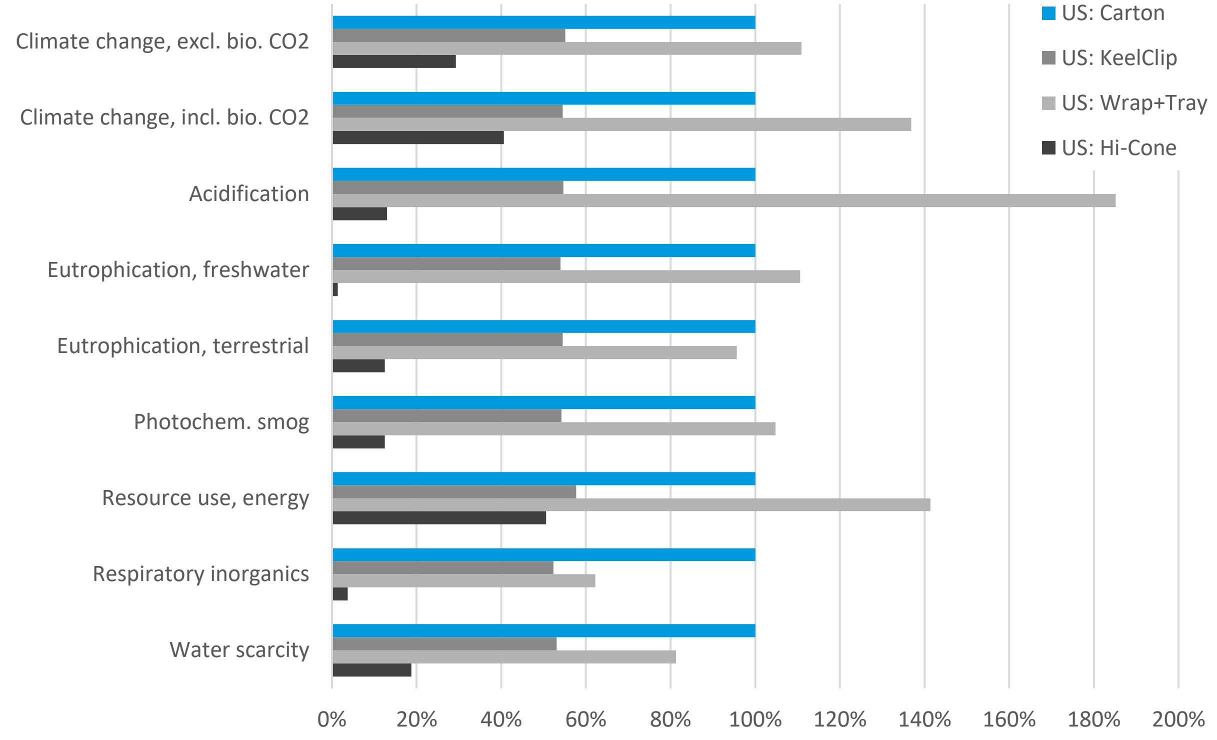

Figure ES-1-1: Cradle-to-grave LCIA results (IPCC AR5 and EF 3.0), normalized to the US Carton scenario (100%)

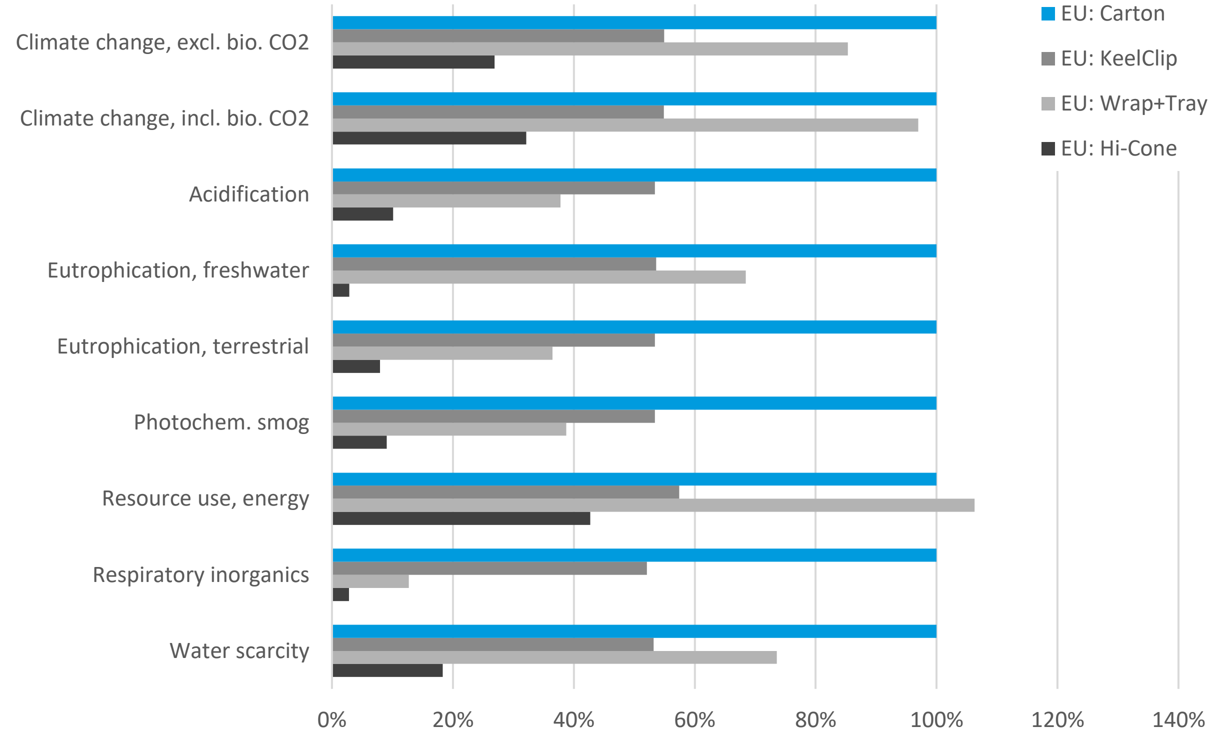

Figure ES-1-2: Cradle-to-grave LCIA results (IPCC AR5 and EF 3.0), normalized to the EU Carton scenario (100%)

1. Goal of the Study

Graphic Packaging International (GPI) seeks to continually improve the environmental performance of its products. For many years, the company has been using life cycle assessment (LCA) to help it to identify the hot spots in the life cycle of its beverage board packaging, to assess the effect of process changes on the overall environmental performance of these products, and to understand how its products compare with those of the competition.

GPI's first LCA study was carried out in 2008-09 and reported results for production of AquaKote™ beverage board products, along with results of alternative beverage packaging designs. This study was subsequently updated in 2012 and 2014 for GPI's production. The current study is the most recent update and extends the earlier studies by looking at the European end market in addition to the US and includes GPI's new KeelClip™ beverage packaging design. For comparison, the competing Hi-Cone plastic rings product and the shrink wrap and tray product have also been assessed.

The main audience for the LCA study includes internal GPI stakeholders as well as GPI's customers and other external stakeholders in both the United States and Europe. GPI is looking to report on the current environmental performance of its products and demonstrate steps the company is making to further reduce its potential environmental impacts.

The study has been conducted according to the requirements of ISO 14044 (ISO, 2006) and has undergone independent critical review by a panel of three independent experts. The critical review statement can be found in Appendix F, and the critical review report is available from GPI upon request.

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

This cradle-to-grave LCA study compares two GPI beverage can packaging designs to two competing designs:

- GPI's paperboard carton designed to hold 18 beverage cans
- GPI's paperboard KeelClip™ designed to hold 6 beverage cans
- An average manufacturer's shrink-wrap and corrugate tray designed to hold 18 x beverage cans
- An average manufacturer's plastic Hi-Cone rings designed to hold 6 beverage cans

The paperboard carton is a standard GPI product. GPI's new KeelClip design is also assessed so that GPI might understand how it compares both to the carton and to competing products—specifically, Hi-Cone plastic rings and a generic shrink film and corrugate tray. These products are not manufactured by GPI and instead are assumed to be produced by an average manufacturer. Figure 2-1 and Figure 2-2 include representative photos of the beverage can packaging designs under consideration.

Two end markets are evaluated in the analysis: United States and Europe. For GPI products, paperboard production takes place in the US and converting in either the US or Europe. Competing product manufacturing is assumed to take place in each region for the respective end market. Additional details are provided in section 3.

Figure 2-1: GPI's carton (left) and KeelClip™ (right) can packaging designs

Figure 2-2: Shrink wrap and tray (left) and Hi-Cone rings (right)

2.2. Product Function and Functional Unit

The function of the product is to provide outer packaging for beverage can multipacks as purchased by a consumer. All packaging designs are assumed to meet specifications, such as requirements for lifting and carrying multiple beverage cans. These requirements are typically defined by the beverage manufacturers (e.g., GPI's customers).

The functional unit selected for this assessment is:

Packaging for 1,000 beverage cans

These cans can contain either 300 mL or 330 mL (12 fl. oz.) of beverage depending on whether the European or US end market, respectively, is considered. Any differences in packaging due to can size are expected to be minimal as the can sizes are not significantly different and the focus of this study is on secondary packaging and not the cans themselves.

The functional unit is consistent with the earlier LCA studies and was selected so that results are scaled to quantities that are familiar from everyday interactions (i.e. reporting in grams and kilograms rather than micrograms and milligrams). This assists with interpreting and understanding the results.

The reference flows for the different packaging options are given in Table 2-1.

Table 2-1: Reference flows for each packaging option

	Carrying capacity	Units required	Weight per unit	Reference flow
Carton	18	55.5	150 g	8.3 kg
KeelClip	6	167	26 g	4.3 kg
Wrap+Tray	18	55.5	103 g	5.7 kg
Hi-Cone	6	167	3.84 g	0.64 kg

2.3. System Boundaries

This study considers the full life cycle of the beverage packaging product from cradle to grave. That is, it considers impacts associated with the extraction of resources from nature (e.g., through mining or forestry) through to the point at which the product is disposed of or recycled at end of life. Table 2-2 shows the major process steps considered within the system boundaries.

Table 2-2: System boundaries

Included	Excluded
✓ Forestry operations or mining operations ✓ Transport of raw materials from suppliers to manufacturing facility ✓ Beverage can packaging production ✓ Distribution packaging (where available) ✓ Transport from converting to filler ✓ Filling (i.e. inserting beverage cans into the packaging) ✓ Transport from filling to retailer ✓ Transport from consumer home to end of life disposal site ✓ End of life (landfill, incineration and recycling)	× Plant capital goods manufacturing and end of life × Infrastructure manufacturing, use, and end of life × Employee commute × Warehousing and retail × Consumer transport from retailer to home × Beverage production, transport, and consumption × Beverage can production, transport, filling, and end of life

Production and maintenance of plant capital goods (e.g., machinery, buildings, etc.) and infrastructure (e.g., power systems, roads, etc.) have been excluded from the study. It is expected that these impacts are negligible compared to the impacts associated with running the equipment or use the infrastructure over its operational lifetime.

The beverage cans and the beverage they contain are excluded from the analysis as the focus is on the beverage can packaging (i.e., on secondary packaging). As such, warehousing and retail operations have also been excluded as these will not be material in the context of other life cycle stages if any refrigeration would be attributed to the can and its contents rather than the packaging.

Transport from retailer to a consumer home has also been excluded from the study. This is in line with most other LCA studies on consumer goods. Impacts from consumer transport vary greatly depending on the mode of transport (on foot, bicycle, public transport, car, etc.). Furthermore, it is common for multiple products to be purchased at a time, which in turn makes it challenging to allocate impacts to a particular product.

2.4. Allocation

2.4.1. Multi-output Allocation

Paperboard mills produce several co-products including paperboard, tall oil[1], and turpentine. Economic allocation was used to assign impacts to these products. Economic allocation (Ardente & Cellura, 2012) was chosen over physical allocation to account for the substantial differences in revenue of these products and reflect the economic driver for running the mill in the first place. An average price provided by GPI was used for all paper grades as the majority of paperboard produced by the mills are not sold externally (and thus do not have individual prices). Additional information on economic allocation can be found in section 3.3.1 and details on the biogenic carbon correction following allocation in section 3.5.

Mass allocation was used among packaging products produced by the converter plants, which produce a wide range of different packaging types and sizes. In this case, mass allocation was chosen over economic allocation due to the similarity among co-products (and for consistency with previous studies).

Allocation of background data (energy and materials) taken from the GaBi 2020 databases is documented online at http://www.gabi-software.com/america/support/gabi/http://documentation.gabi-software.com/.

2.4.2. End of Life Allocation

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

Two main approaches (Figure 2-3) are commonly used in LCA studies to account for end of life recycling and recycled content.

- **Substitution approach (also known as 0:100, closed-loop approximation, recyclability substitution or end of life approach)** – this approach is based on the perspective that material that is recycled into secondary material at end of life will substitute for an equivalent amount of virgin material based on technical substitutability. Hence a credit is given to account for this material substitution, i.e., the system is expanded to include the substituted material, which is subtracted from the overall inventory. However, this also means that burdens equivalent to this credit should be assigned to scrap used as an input to the production process, with the overall result that the impact of recycled granulate is the same as the impact of virgin material. This approach puts emphasis on high-quality end of life recycling to improve the overall environmental performance.
- **Cut-off approach (also known as 100:0 or recycled content approach)** – burdens or benefits associated with material entering the product system for use as secondary content or sent to recycling at EoL are not considered, i.e., they are "cut-off". Therefore, any scrap inputs to the production process are considered to be free of upstream virgin material burdens but, equivalently, no recycling credit is received for scrap available for recycling at end of life. This approach puts emphasis on the use of recycled content but does not reward end of life recycling as much as the substitution approach does.

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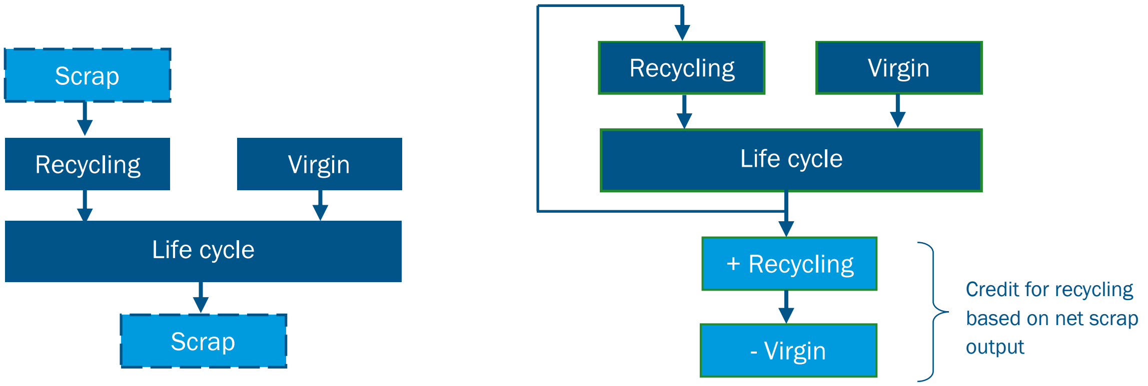
[1] Tall oil or liquid rosin is a by-product of coniferous trees when processed via the Kraft pulping process. Tall oil is often used in adhesives, rubbers, soap and lubricant production, and other applications.

A third approach, the number of uses (NOU) is increasingly being used for paper packaging. Under this approach, an average number of uses is identified for a component or material and potential environmental impacts of that component or material allocated over each use. NOU, however, is most easily applied to product systems that are comprised of 100% virgin content. The paperboard products in this analysis are manufactured from a mix of virgin and recycled content. Properly conducting the NOU calculation would thus require first allocating GPI's mill inputs between virgin paperboard production and re-pulping of recycled content. Once this is done, the inputs attributed to virgin paperboard production can then be allocated to the current use versus subsequent uses.

Furthermore, an environmental burden has to be calculated and assigned to recycled content used by GPI (as under this approach, recycled content does not enter the product system burden-free as it does with the cut-off approach). This burden will depend on whether the recycled content came from paperboard or other paper products. Given the complexity of the NOU calculation, NOU is not considered in this analysis.

The circular footprint formula (CFF) represents a fourth option for allocating environmental burdens between product systems. This approach takes a very mathematical perspective to assigning burdens and is required for product environmental footprint (PEF) studies—which the current analysis is not. Thus, CFF is not evaluated in this study.

Of the two main approaches, the cut-off approach was adopted for this analysis. Accordingly, 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.



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

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

Figure 2-3: Schematic representations of the cut-off and substitution approaches

The system boundary further includes the waste incineration and landfilling processes following the polluter-pays-principle. In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilization rates (flaring vs. power production). No credits for power or heat production are assigned.

The substitution allocation approach is evaluated but included in Appendix E rather than in the main body of this report. Proper calculation of substitution results requires access to life cycle inventories (LCIs) that represent material production from 100% virgin content (for substitution) and from 100% recycled content (for EoL recycling). The latter is available for pulp and paper products, but not the former since all LCI data in GaBi is modeled as containing some amount of recycled content. Inclusion of recycled content in papermaking, furthermore, influences production yield, unit chemical consumption, unit energy consumption, and fuel feedstocks. In short, the needed LCI data are not available to properly calculate substitution results. However, substitution results using best available data are included in Appendix E for continuity with previous GPI reports.

2.5. Cut-off Criteria

No cut-off criteria are defined for this study. 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. 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 Appendix C. The influence of these proxy data on the results of the assessment has been carefully analyzed and is discussed in section 5.

2.6. Selection of LCIA Methodology and Impact Categories

Although GPI has customers in both the US and Europe, it is primarily GPI's European customers who are interested in this analysis. As such, the European methodology Environmental Footprint v3.0 (EF 3.0) is used to assess the potential environmental impacts of the product systems. The impact categories included were originally based on the ILCD recommended methods (Hauschild M, 2011), but several have since been modified and updated by the European Commission as part of the on-going development of the Product Environmental Footprint initiative. EF 3.0 characterization factors are considered to be the most robust and up-to-date available for the European context, are widely used and respected within the LCA community, and are required for Product Environmental Footprint studies.

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-3 and summarized below:

- Climate change, excluding and including biogenic CO_2 [kg CO_2 eq]
- Acidification [mol H^+ eq]
- Eutrophication, freshwater [kg P eq]
- Eutrophication, terrestrial [mol N eq]
- Photochemical ozone formation [kg NMVOC eq]
- Resource use, energy [MJ LHV]
- Respiratory inorganics [disease incidences]
- Water scarcity [m^3 world eq]

The EF 3.0 impact categories for human health, ecotoxicity, ionizing radiation, land use, and resource use of minerals and metals were not included in this analysis. Toxicity was excluded due to high uncertainties in the characterization factors (10 to 100 for ecotoxicity and 100 to 1000 for human toxicity). Resource use of minerals and metals was excluded given the material composition (i.e. primarily paper and plastic) of the packaging designs under consideration. Ionizing radiation was excluded as it is driven by nuclear power use in the background system.

For completeness, results for the following TRACI 2.1 (EPA, 2012) impact categories are presented in Appendix D:

- Acidification [kg SO_2 eq]
- Eutrophication [kg N eq]
- Human health particulates [kg PM2.5 eq]
- Resources, fossil [MJ surplus]
- Smog formation [kg O_3 eq]

Climate change and resource use, energy (equivalent to non-renewable primary energy demand) were chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be the most pressing environmental issues of our time. The global warming potential impact category is assessed based on the current IPCC characterization factors taken from the 5th Assessment Report (IPCC, 2013) for a 100 year timeframe (GWP100) as this is currently the most commonly used metric[2].

Global climate change results are considered both with and without photosynthetically bound carbon (also called *biogenic carbon*) as well as the release of that carbon during the use or end of life phase as CO_2.

The impact categories eutrophication, acidification, and photochemical ozone formation 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, VOC, and others.

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 have 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.

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

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

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[2] The climate change methodology used in EF 3.0 is based on the latest IPCC reports but also includes the effects of “climate-carbon feedback” which results in higher global warming potentials but is also associated with greater uncertainty. In this study we have used the more commonly applied emission factors from the same report that exclude climate-carbon feedback effects.

Table 2-3: Impact category descriptions

Impact Category	Description	Characterization factor	Unit	Reference
Climate change	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.	Global warming potential, 100 years (GWP100)	kg CO_2 equivalent	(IPCC, 2013)
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.	Acidification potential (AP)	moles H^+ equivalent	(Seppälä J., 2006; Posch, 2008)
Eutrophication (terrestrial, freshwater)	Eutrophication covers all potential environmental 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.	Eutrophication potential (EP)	Terrestrial: moles N equivalent Freshwater: kg P equivalent	(Seppälä J., 2006; Posch, 2008; Struijs, 2009)
Photochemical Ozone Formation	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.	Photochemical ozone formation potential (POFP)	kg NMVOC equivalent	(Van Zelm R., 2008)

Impact Category	Description	Characterization factor	Unit	Reference
Resource use, energy carriers	A measure of the total amount of non-renewable primary energy extracted from the earth. Resource use is expressed in energy demand from non-renewable resources including both fossil sources (e.g., petroleum, natural gas, etc.) and uranium for nuclear fuel. Efficiencies in energy conversion (e.g., power, heat, steam, etc.) are taken into account.	Energy	MJ	(Guinée, et al., 2002; van Oers, de Koning, Guinée, & Huppes, 2002)
Respiratory inorganics	Particulate matter emissions and secondary aerosols formed in the atmosphere from NOx, NH3 and SO2 emissions contribute to human health impacts in the form of respiratory disease and related effects.	Respiratory inorganics	Disease incidence	(Fantke, 2016)
Water scarcity	An assessment of water scarcity accounting for the net intake and release of fresh water across the life of the product system considering the availability of water in different regions.	Water scarcity	m^3 world equivalent	(Boulay, 2018)

2.7. Interpretation to be Used

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

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

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

2.8. Data Quality Requirements

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

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

Furthermore, this analysis is intended to represent the following supply chains for packaging production:

- Carton: US production and either US or European converting of paperboard by GPI in 2019
- KeelClip: US production and either US or European converting of paperboard by GPI in 2019
- Wrap+Tray: US or European production of packaging by a generic manufacturer in 2019
- Hi-Cone: US or European production of packaging by generic manufacturer in 2019

Once the packaging is produced, it is then shipped to a filling facility in either US or Europe. The filled packages are then distributed, used, and disposed in each respective end market.

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

2.9. Type and Format of the Report

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

2.10. Software and Database

The LCA model was created using the GaBi 9 Software system for life cycle engineering, developed by Sphera Solutions, Inc. The GaBi 2020 LCI database (service pack 40) provides the life cycle inventory data for several of the raw and process materials obtained from the background system.

2.11. Critical Review

The international standard ISO 14044 (ISO, 2006) require a critical review when the study results are intended to support comparative assertions intended to be disclosed to the public. The primary goals of a critical review are to provide an independent evaluation of the LCA study and to provide input to the study authors on how to improve the quality and transparency of the study. The benefits of employing a critical review are to ensure that:

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

If applicable, the critical review panel can also comment on suggested priorities for potential improvements. For this study, the critical review panel consisted of:

- Arpad Horvath, Consultant; Berkeley, CA (Chair)
- Angela Schindler, Consultant; Salem, Germany
- Bill Flanagan, Co-Founder and Director, Aspire Sustainability; Albany, NY

The review was performed according to section 6.3 of ISO 14044 on comparative assertions intended to be disclosed to the public. For the review, an overview of LCA goal and scope, along with assumptions and results, were shown to the panel prior to completing the report draft. Results were then presented in a draft copy of this report that was made available to the panel. The panel provided feedback on the methodology, assumptions, and interpretation. The draft report was subsequently revised, and a final copy submitted to the review panel along with responses to comments.

The critical review statement can be found in Appendix F. The critical review report containing the comments and recommendations of the independent experts as well as the practitioner’s responses is available from GPI upon request. The reviewers were contracted to perform the review as independent experts. Their review comments shall not be construed to represent the positions of their affiliated organizations.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

All primary data were collected using customized data collection templates, which were sent out by email to the respective data providers at GPI. Upon receipt, each questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. If gaps, outliers, or other inconsistencies occurred, Sphera engaged with the data provider to resolve any open issues.

3.2. Product System Overview

Table 3-1 provides an overview of each packaging alternative's raw materials and production location(s). Additionally, packaging mass is depicted in Figure 3-1. Further details on raw materials production, manufacturing, transportation, and other life cycle stages are provided in the following sections.

Table 3-1: Beverage can packaging overview

	Material	Mass by material		Production location	Converting location
		Per package	*Per functional unit*		
US: Carton	Paperboard	150 g	8.3 kg	Macon, GA West Monroe, LA	Perry, GA
US: KeelClip	Paperboard	26 g	4.3 kg	Macon, GA West Monroe, LA	Perry, GA
US: Wrap+Tray	LDPE film Corrugate	20 g 83 g	1.1 kg 4.6 kg	US	N/A
US: Hi-Cone	LDPE film	3.84 g	0.64 kg	US	N/A
EU: Carton	Paperboard	150 g	8.3 kg	Macon, GA West Monroe, LA	Masnières, France
EU: KeelClip	Paperboard	26 g	4.3 kg	Macon, GA West Monroe, LA	Masnières, France
EU: Wrap+Tray	LDPE film Corrugate	20 g 83 g	1.1 kg 4.6 kg	Europe	N/A
EU: Hi-Cone	LDPE film	3.84 g	0.64 kg	Europe	N/A

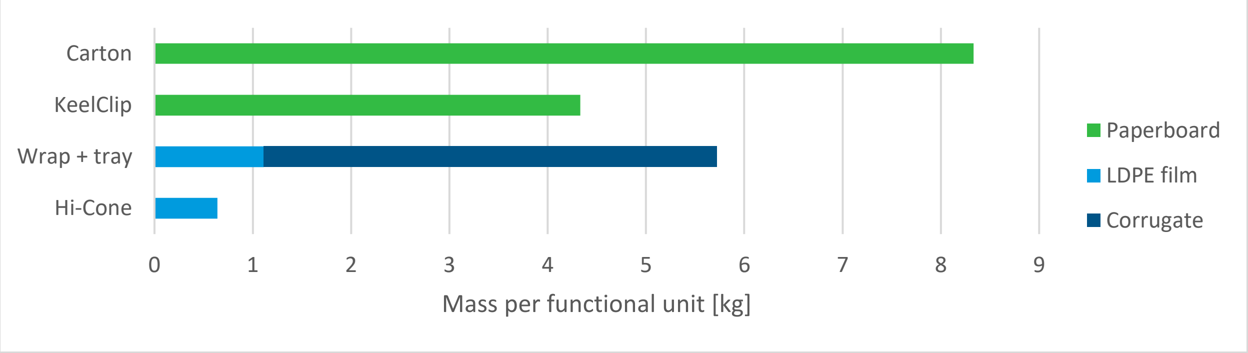

Figure 3-1: Beverage can packaging materials and masses per functional unit

3.3. Packaging Production

3.3.1. Beverage Carton and KeelClip

Beverage carton and KeelClip production details are summarized in Table 3-2. Figure 3-2 presents the top-level flow chart showing the connections between each process in the product life cycle. Each step is discussed in more detail in the following sections.

Table 3-2: Carton and KeelClip details (US units shown in parentheses)

	US: Carton	US: KeelClip	EU: Carton	EU: KeelClip
Basis weight	454 g/m^2 (93 lbs. / 1,000 ft^2)	454 g/m^2 (93 lbs. / 1,000 ft^2)	454 g/m^2 (93 lbs. / 1,000 ft^2)	454 g/m^2 (93 lbs. / 1,000 ft^2)
Finished card area	0.326 m^2 (506 in^2)	0.058 m^2 (90 in^2)	0.326 m^2 (506 in^2)	0.058 m^2 (90 in^2)
Paperboard type	AquaKote™	AquaKote™	AquaKote™ OmniKote™	OmniKote™
Production location	44% Macon 56% West Monroe	44% Macon 56% West Monroe	50% Macon 50% West Monroe	50% Macon 50% West Monroe
Recycled content	11%	11%	11%	10%
Converting location	Perry	Perry	Masnières	Masnières
Distance to converting	48 to 869 km (30 to 540 mi)	48 to 869 km (30 to 540 mi)	7,560 to 8,530 km (4,700 to 5,300 mi)	7,560 to 8,530 km (4,700 to 5,300 mi)
Converting losses	8%	4%	8%	4%
Distribution packaging	Cases, cap sheets, pallets, shrink wrap	Cases, cap sheets, pallets, shrink wrap	Cases, cap sheets, pallets, particleboard, honeycomb	Cases, cap sheets, pallets, particleboard, honeycomb

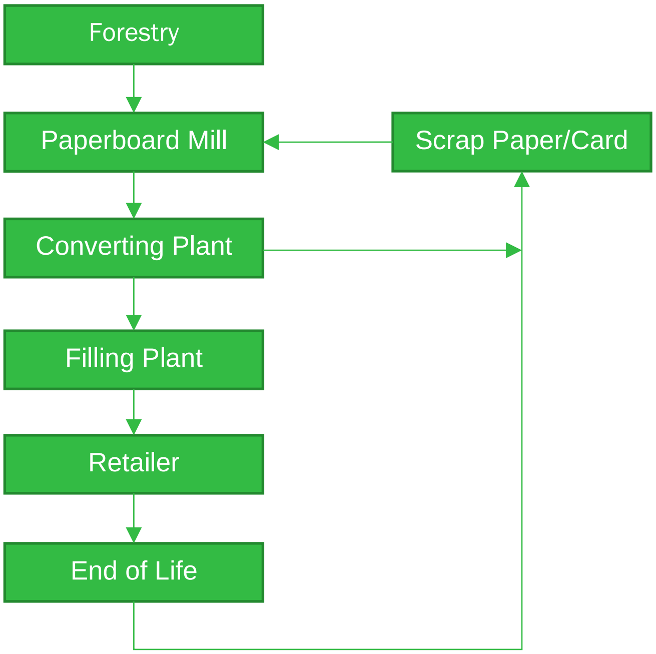

Figure 3-2: Flowchart showing the foreground system (transport processes not shown)

Forestry

Forestry operations are modeled using GaBi datasets for softwood. GPI does not own any of the forests from which it purchases its wood; however, approximately 30% of purchased wood is certified to a forestry standard. The remaining 70% purchased in the South East U.S. and is from smaller landowners who practice responsible forestry management.

Paperboard Mill

GPI produces many different grades at its two paperboard mills in West Monroe, LA and Macon, GA. These range from caliper 14 to 30 with basis weight ranging from 62 to 136 lbs./1,000 ft^2. Production volumes of specific grades vary significantly from year to year within a paperboard mill, as does the proportion of a given grade manufactured in West Monroe compared to Macon. This makes it difficult to distinguish overall changes in environmental performance from differences in each mill.

As such, the impacts of paperboard in this study are modeled based on the mass-based average of all caliper grades produced at each mill, for which there is much less variability. That is, mill inputs and outputs such as energy, colorants, chemicals, water, emissions, etc. that are allocated to paperboard (as opposed to tall oil and turpentine—see section 2.4.1) are not further sub-divided according to paperboard grade or caliper. Instead, an average of inputs and outputs per unit mass of all paperboard produced is calculated and used to model paperboard production. The influence of this assumption on the results is considered to be low as all products have similar composition, regardless of caliper.

The one exception to above is fiber inputs. Inputs of softwood logs and recycled content, which includes double kraft liner (DKL) and clay-coated natural kraft container (CCNKC), were calculated for each paper grade (i.e. AquaKote™ and OmniKote™ / PearlKote™[3]) rather than using an average for all paperboard.

In the paperboard mill, logs from forestry operations and scrap paper, paperboard or corrugate collected for recycling are pulped and converted into paperboard products. This requires energy inputs, process chemicals and functional additives (e.g., clay, wet strength resins, etc.). In recent years GPI has been increasing the proportion of renewable energy used in its paper mills. For example, one of the major changes between 2012 and 2014 is the installation of a new biomass boiler at the Macon paperboard mill.

Paperboard mills produce several co-products including paperboard, tall oil and turpentine. Economic allocation was used to allocate the process inputs and outputs across these products due to the substantial differences in revenue of these products. Paperboard is overwhelmingly dominant, accounting for almost 98% of the total economic value of these co-products. Tall oil accounts for around 1.7% of the total economic value while the remainder is due to the turpentine. Once mill inputs and outputs were allocated, biogenic CO_2 uptake and emissions were corrected so the analysis accurately represents paperboard carbon content (see section 3.5 for more details).

Data on the input and output flows to and from the paperboard mills are provided in Table A-1. Paperboard production at each mill is weighted according to mill output for the AquaKote paper grades for the US scenarios. For the European scenarios, a 50/50 split between the Macon and West Monroe mills was estimated as the paperboard mix is slightly different for Europe compared to the US.

Converting Plant

While paperboard substrate production takes place in the US, converting into finished packaging takes place in local end markets. Data on converting have been sourced from Perry, GA (US) for the US market and Masnières (France) for the European market.

At the converting plant, paperboard sheets from the mill are printed and cut to size to produce the finished beverage packaging. The beverage can packaging is then itself packaged in distribution packaging for shipment to its filling location (e.g., a beverage manufacturer's facility).

Mass allocation was used to assign converting inputs and outputs to GPI's various packaging products. Paperboard scrap from the carton and KeelClip, however, was calculated based on each die design rather than from a generic plant average. Paperboard waste from the converting plants is assumed to be shipped to a paperboard mill for recycling—although not necessarily to GPI's own mills in the US, especially from the European converting facility.

Data on the input and output flows to and from the converting plants are provided in Table A-2.

Upstream and Internal Transport

It is assumed that all transport is by road using trucks with 49,000 lb. maximum payload, class 8 trucks. For fiber transport (supply of logs, chips and scrap paper) the empty return trip is accounted for by reducing the amount to which the truck is loaded. (GaBi datasets assume a default capacity utilization of 85%; this was reduced to 42.5% for inbound fiber transport.) For other transport stages, only the one-way trip is considered as it

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[3] PearlKote is a paperboard grade similar to OmniKote—just produced at a different mill.

is assumed that logistics are optimized so that these do not return empty. All transportation in Table 3-3 is via truck unless noted otherwise.

Table 3-3: Transport distances modeled

Transport stage	Distance, US [mi]		Distance, EU [mi]		Utilization
	Macon	West Monroe	Macon	West Monroe	
Softwood logs to paperboard mill	47	48	47	48	42.5%
Softwood chips to paperboard mill	27	60	27	60	42.5%
CCNKC scrap paper to paperboard mill	30	540	30	540	42.5%
DKL scrap paper to paperboard mill	300	300	300	300	42.5%
Paperboard mill to converting plant	30	540	Truck: 260 Ship: 4,400	Truck: 850 Ship: 4,400	85% 70%

3.3.2. Shrink Wrap and Tray

Shrink wrap and tray production was based solely on secondary data. Packaging component masses were obtained from a previous GPI study (Graphic Packaging International, 2010). That study, in turn, determined shrink wrap and tray masses by purchasing 18-pack and other beverage can pack sizes and weighing the packaging components. GaBi data were used to model plastic film production from granulate and converting corrugate into trays. Distribution packaging was excluded as data for this were not available. While having these data would be ideal in the interest of completeness and consistency, distribution packaging is anticipated to be a minor contributor to potential impact and its exclusion represents a ‘best case’ scenario for the shrink wrap and tray packaging alternative.

Table 3-4: Shrink wrap and tray production data per functional unit

Flow	Unit	Amount	Mode & distance
Inputs			
LDPE shrink wrap	kg	1.1	Truck: 100 mi
Corrugate tray	kg	4.6	Truck: 100 mi
Outputs			
Shrink Wrap+Tray	kg	5.7	

3.3.3. Hi-Cone Plastic Rings

Although Hi-Cone has conducted its own LCA (Hi-Cone, n.d.), it is not available to GPI (nor are GPI’s customers permitted to share the report). To address the lack of primary manufacturing data for Hi-Cone plastic rings, GPI hired an independent consulting firm (Savvy Pack) to model Hi-Cone production and calculate energy and plastic resin consumption. The consultant’s model is an internal, proprietary tool that incorporates production rates, production volume, material recycled, machine energy consumption, and other variables to calculate per unit values. Model results are shown in Table 3-5. Table 3-6 presents distribution packaging per functional unit. Packaging materials and amounts are based on internal expertise and estimations.

Hi-Cone plastic rings are manufactured from low-density polyethylene (LDPE). Plastic pellets from a combination of virgin and post-consumer recycled (PCR) content are compounded with internally recycled resin and the mixture extruded into a sheet. The rings are then die-cut from the sheet and the 'sheet of rings' packaged as a roll around a corrugate core. Each roll is assumed to weigh 11.5 kg and contain 3,000 units.

Die-cut scrap from the manufacturing process is recycled internally. This scrap is assumed to be re-melted and re-granulated before being combined with virgin and PCR plastic granulate. Energy consumption data in Table 3-5 include internal recycling.

According to Hi-Cone's website (Hi-Cone), Hi-Cone products can have up to 50% PCR content. The baseline analysis assumes no recycled content. While using 100% virgin content does not represent a best case for the competing product and from this perspective is not the conservative option, the results will show that even under these conditions, Hi-Cone rings are consistently associated with the lowest potential environmental impacts of all packaging designs. Including PCR content under cut-off allocation assumptions will only serve to further reduce potential environmental impacts and more strongly favor Hi-Cone rings. Thus, the use of PCR content is evaluated in a sensitivity analysis (section 4.3.1) and not in the baseline analysis.

Table 3-5: Hi-Cone production data per functional unit

Flow	Unit	Amount	Mode & distance
Inputs			
LDPE resin, virgin / PCR	kg	0.64	rail: 1,000 mi
LDPE resin, internally recycled	kg	1.2	N/A
Natural gas	MJ	0.235	N/A
Electricity	kWh	1.8	N/A
Outputs			
Hi-Cone rings	kg	0.64	N/A
Internal scrap	kg	1.2	N/A

Table 3-6: Hi-Cone distribution packaging per functional unit

Flow	Unit	Amount	Mode & distance
Inputs			
Hi-Cone rings	kg	0.64	N/A
Wood pallets	kg	0.035	Truck: 100 mi
Paper core	kg	0.012	Truck: 100 mi
Corrugate separator	kg	6.9E-03	Truck: 100 mi
Corrugate cap	kg	9.8E-04	Truck: 100 mi
Steel band	kg	1.7E-04	Truck: 250 mi
Shrink wrap (LDPE)	kg	3.9E-04	Truck: 250 mi
Outputs			
Hi-Cone rings, packaged	kg	0.70	N/A

3.4. Downstream

3.4.1. Transportation

All transportation steps in the downstream portion of the life cycle are modeled apart from consumer transport from the retailer to home[4]. Transportation is via truck. These transportation distances (Table 3-7) are assumed to be the same for all packaging configurations and for the US and Europe scenarios.

Table 3-7: Downstream transportation distances

Transport stage	Distance [miles]
To filling plant	200
Filling plant to retailer	100
Retailer to consumer	Not included
Consumer to end of life	30

3.4.2. Filling Plant

The filling plant, where beverage cans are inserted into the packaging, is the final step before the product is sent to retailers. Information on energy consumption and packaging line speeds at filling plants were estimated based on expected packaging machines power consumption and line speed (Table 3-8). Carton and KeelClip data were provided by GPI as GPI sells not only the packaging, but the machinery systems to insert cans into the cartons or KeelClip. Hi-Cone data were provided by GPI's independent consultant (see section 3.3.3). Wrap+Tray data were obtained from a previous GPI study (Graphic Packaging International, 2010) which, in turn, obtained the values from a Kisters machine specifications (e.g., Innopack Kisters TSP basic tray shrink packer). A brief survey of machine specs today indicates the numbers haven't changed very much over the years. The Wrap+Tray filling machine has the highest power requirements as heat is required for the shrink wrap.

Table 3-8: Filling details

	Machine power consumption	Packs per minute	Electricity per functional unit	Adhesive per functional unit
Carton	30 kW	125 / min	0.22 kWh	0.051 kg
KeelClip	16 kW	350 / min	0.13 kWh	0.33 kg
Wrap+Tray	138 kW	83 / min	1.5 kWh	Not applicable
Hi-Cone	15 kW	333 / min	0.13 kWh	Not applicable

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[4] Estimating consumer transport, especially for groceries, is very uncertain and thus excluded from this analysis. Not only can transport mode (e.g., truck, subway, bus, bike, etc.) vary, so can distance to the store and the number of items consumers purchase per trip.

Packaging required to ship the beverage can packaging to the filling plant is disposed in this life cycle stage. Table 3-9 summarizes end of life fate for distribution packaging. US data were obtained from the US EPA (EPA, 2019) and European data from Eurostat (Eurostat, 2017).

Table 3-9: Distribution packaging waste fate

	Recycling	Landfill	Incineration
United States			
Paper / corrugate	73%	22%	5%
Shrink wrap	13%	70%	17%
Steel banding	73%	22%	5%
Wood / particleboard	17%	66%	17%
Europe			
Paper / corrugate	85%	8%	7%
Shrink wrap	44%	24%	32%
Steel banding	79%	20%	1%
Wood / particleboard	40%	37%	23%

3.4.3. Retailer

No activities were modeled at the retailer. As the focus of this study is the beverage can packaging and not the beverages or the cans, refrigeration is excluded from the analysis.

3.4.4. End of Life

At the end of life, the product is modeled as being disposed to a combination of landfill, incineration, and material recycling. The cut-off allocation approach is applied (see section 2.5) so that scrap from packaging disposal is assumed to leave the system boundary without any burden or credit. End of life assumptions are shown in Table 3-10. US data were obtained from the US EPA (EPA, 2019) and European data from Eurostat (Eurostat, 2017).

Table 3-10: Packaging end of life waste fate

	Recycling	Landfill	Incineration
United States			
Paper / corrugate	73%	22%	5%
Plastic film	13%	70%	17%
Europe			
Paper / corrugate	85%	8%	7%
Plastic film	44%	24%	32%

3.5. Biogenic Carbon

Additional steps were taken to ensure biogenic carbon uptake and emissions are properly balanced in the carton and KeelClip models. These steps were necessary due to the use of economic allocation at the paper mill, along with possible inconsistencies or gaps in background data carbon balances.

Carbon uptake—including the carbon content of recycled paper—and CO_2 and CH_4 emissions are first calculated for cradle-to-gate production of paper at GPI's paperboard mills. A carbon correction was then introduced into the model to match the atmospheric removals of CO_2 to the carbon content of paperboard from the mills of 49.6%. This value is based on the Corrugate Packaging Alliance's estimate for containerboard (NCASI, 2017). Biogenic carbon values of the mills prior to the adjustment, the CO_2 uptake adjustment, and the resulting net carbon uptake are shown in Table 3-11. The process in the model where the adjustment takes place is shown in Figure A-4 and labeled "GLO: Carbon balance correction".

Packaging conversion is then modeled once the paperboard carbon content is adjusted. Any recycled paperboard scrap from conversion is assumed to have the same carbon content value and leave the system, i.e., the carbon content is "handed over" to the subsequent product life cycle and thus modeled as a negative removal.

Table 3-11: Carton and KeelClip biogenic carbon balance (per functional unit)

	US: Carton	US: KeelClip	EU: Carton	EU: KeelClip
Paperboard from mill [kg]	8.89	4.56	8.89	4.56
Biogenic CO_2 uptake [kg CO_2]	32.9	16.9	33.2	17.2
Biogenic CO_2 emissions [kg CO_2]	14.7	7.6	15.0	7.69
Biogenic CH_4 emissions [kg CH_4]	0.00463	0.00237	0.00516	0.00265
Carbon content	49.6%	49.6%	49.6%	49.6%
CO_2 uptake adjustment [kg CO_2]	-1.99	-1.02	-2.01	-1.20
Adjusted net carbon uptake [kg C]	4.42	2.26	4.42	2.27

A similar approach is used to address paper for distribution packaging and the corrugate tray of the Wrap+Tray packaging system. Biogenic carbon content in secondary paper entering the system boundary is modeled as an atmospheric removal and recycled packaging leaving the product system boundary is modeled as having its carbon removals "handed over" to the subsequent product life cycle . That is, additional processes were added to the GaBi model to ensure that secondary paper entered the system with a carbon content of 49.6% (i.e., a net uptake of 1.82 kg CO_2 per kg paper). The same value was used for paper packaging recycled at end of life. Only by assigning a carbon removal to recycled carbon contents will any subsequent emission of biogenic carbon dioxide from the material (e.g., as part of landfill gas) remain carbon-neutral, i.e., removal and emission of CO_2 will cancel each other out.

3.6. Background Data

Documentation for all GaBi datasets can be found online at http://www.gabi-software.com/support/gabi/gabi-database-2020-lci-documentation/ (Sphera, 2020). The tables in this section indicate what the dataset is intended to represent, (e.g., electricity generated in Europe) which dataset was used, and whether the dataset is a geographical ("geo.") proxy.

3.6.1. Fuels and Energy

National/regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2020 databases. The most relevant LCI datasets used in modeling the product systems are presented in Table 3-12. Electricity consumption was modeled using regional grid mixes that account for imports from neighboring countries/regions.

Overall, the datasets used are considered appropriate given this study's goal and scope (see section 2.8). Electricity grid mixes and fuels represent the regions considered in the analysis. Although dataset reference years do not align with the study's intent to represent production in 2019, these datasets were chosen because they are the best available options. Potential environmental impacts from fuel production and combustion are not expected to significantly change over three years. While electricity grid mixes can and do change, it often takes a few years for the US EPA or the International Energy Agency to publish updated mixes.

Table 3-12: Key energy datasets used in inventory analysis

Energy	Location	Dataset	Data Provider	Ref. Year	Proxy?
Electricity	Europe	EU-28: Electricity grid mix	Sphera	2016	No
Electricity	U.S.	US: Electricity grid mix	Sphera	2016	No
Electricity, GPI	France	FR: Electricity grid mix	Sphera	2016	No
Electricity, GPI	Louisiana	US: Electricity grid mix – SRMV	Sphera	2016	No
Electricity, GPI	Georgia	US: Electricity grid mix – SRSO	Sphera	2016	No
Gasoline	U.S.	US: Gasoline mix (regular) at refinery	Sphera	2016	No
Light fuel oil	U.S.	US: Light fuel oil at refinery	Sphera	2016	No
LPG	U.S.	US: Liquefied Petroleum Gas (LPG) (70% propane; 30% butane)	Sphera	2016	No
Natural gas	U.S.	US: Natural gas mix	Sphera	2016	No
Tech. heat, LPG	France	EU-28: Thermal energy from LPG	Sphera	2016	No
Tech. heat, LPG	U.S.	US: Thermal energy from LPG	Sphera	2016	No
Technical heat, Natural gas	U.S.	US: Thermal energy from natural gas	Sphera	2016	No
Technical heat, Natural gas	Europe	EU-28: Thermal energy from natural gas	Sphera	2016	No

3.6.2. Raw Materials and Processes

Data for upstream and downstream raw materials and unit processes were obtained from the GaBi 2020 database. The most relevant LCI datasets used in modeling the product systems are presented in Table 3-13 and Table 3-14; additional datasets for materials and processes are in Appendix C.

For the Carton and KeelClip, only softwood logs are shown as these, along with recycled paper, constitute the raw materials from which paperboard is manufactured. Other raw materials, including chemicals and colorants, used at a papermill are in Table C-1. LCIA results for the logs are included in Table C-2.

US and European average data were chosen for the LDPE shrink wrap and corrugate tray. The intent of this study is to represent this competing product as produced the appropriate region by an average manufacturer who uses an average amount of recycled and virgin content and not specifically as produced by GPI as GPI does not make this type of packaging. Consequently, average datasets were used rather than data representing GPI's specific supply chain and facilities. LCIA results for these average datasets are included in Table C-3. Average cradle-to-gate corrugate results are compared to those for paperboard production and converting at GPI's facilities in section A.2.

Regional average data were used to model Hi-Cone production as supply chain-specific data were not available. Datasets for virgin and PCR resin are included in Table 3-13, although the PCR datasets are only used in the sensitivity analysis. Since Hi-Cone has published its own LCA (which is not available to GPI), the expectation is that GPI's customers will compare GPI's results from this report to Hi-Cone's results from its report in addition to reviewing comparative results within this document.

Table 3-13: Key material datasets used in inventory analysis

Material / Process	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
GPI Paperboard					
Virgin softwood	U.S.	US: Log softwood mix	Sphera	2019	No
Wrap+Tray					
Shrink wrap	U.S.	US: Polyethylene film (LDPE/PE-LD)	Sphera	2019	No
Shrink wrap	Europe	EU-28: Polyethylene Film (PE-LD) without additives	Sphera	2019	No
Corrugate tray	U.S.	US: Average Corrugated Product (Cradle-to-Gate, 2014)	CPA	2014	No
Corrugate tray	Europe	EU-28: Corrugated board 2015, average composition, for use in avoided burden EoL	FEFCO	2015	No
Hi-Cone					
Virgin LDPE resin	U.S.	US: Polyethylene Low Density Granulate (LDPE/PE-LD)	Sphera	2019	No
Virgin LDPE resin	Europe	EU-28: Polyethylene Low Density Granulate (LDPE/PE-LD)	Sphera	2019	No
PCR LDPE resin	U.S.	US: Polyethylene low density granulate (LDPE/PE-LD) secondary	Sphera	2019	No
PCR LDPE resin	Europe	EU-28: Plastic granulate secondary (simplified, non specific)	Sphera	2019	No

Table 3-14: Distribution packaging datasets used in inventory analysis

Material / Process	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
Corrugate boxes and rolls	U.S. / Europe	US: Average Corrugated Product (Cradle-to-Gate, 2014)	CPA	2014	Geo.
Corrugate boxes and rolls	France	EU-28: Corrugated board 2015, average composition, for use in avoided burden EoL	FEFCO	2015	No
Shrink wrap	U.S. / Europe	US: Polyethylene film (LDPE/PE-LD)	Sphera	2019	Geo.
Shrink wrap	France	EU-28: Polyethylene Film (PE-LD) without additives	Sphera	2019	No
Particleboard	France	EU-28: Particle board	Sphera	2019	No
Pallets	U.S. / Europe	RNA: Softwood lumber	CORRIM	2011	Geo.
Kraft paper core	U.S. / Europe	EU-28: Kraft paper (EN15804 A1-A3)	Sphera	2019	Geo.
Steel banding	U.S. / Europe	GLO: Steel hot rolled coil	worldsteel	2017	No

3.6.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials to production facilities. The most relevant LCI datasets used in modeling the product systems are presented in Table 3-15. In general, default capacity values were used except for inbound fiber transportation, for which empty backhauls were assumed (see section 3.3.1).

US or global datasets were used as GPI's packaging products originate in the US. Although some transportation is anticipated to take place in Europe (e.g. from converting to filling and from the consumer home to the disposal site), any differences between US and European truck data are not anticipated to significantly affect the results.

Table 3-15: Transportation and road fuel datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
Heavy fuel oil	U.S.	US: Heavy fuel oil at refinery (0.3wt.% S)	Sphera	2016	No
Ship	U.S.	GLO: Container ship, 5,000 to 200,000 dwt payload capacity, ocean going	Sphera	2019	No
Diesel	U.S. / Europe	US: Diesel mix at filling station	Sphera	2016	Geo.
Rail	U.S. / Europe	GLO: Rail transport cargo - Diesel, average train, gross tonne weight 1,000t / 726t payload capacity	Sphera	2019	No
Truck	U.S. / Europe	US: Truck - TL/dry van (EPA SmartWay)	Sphera	2019	Geo.
Truck	U.S.	US: Truck - Flatbed, platform, etc. / 49,000 lb payload - 8b	Sphera	2019	No

3.6.4. End of Life

End of life datasets are presented in Table 3-16. These datasets were used to model both beverage can packaging disposal as well as distribution packaging disposal.

The cut-off allocation approach was applied as the base case; consequently, no background data were needed to represent material recycling as the recycling process is part of the subsequent, scrap-consuming product system. However, the carbon content in paper for recycling was modeled as “handed over” to the next product system (see section 3.5) to preserve carbon neutrality for any CO_2 emissions from PCR contents. A factor of 1.82 kg CO_2 per kg paper was used based on a carbon content of 49.6%.

Carbon corrections were also applied to paper incineration to ensure biogenic carbon releases align with paper carbon content. The US paper incineration dataset required additional emissions of 0.449 kg CO_2 / kg paper while the EU paper incineration dataset required additional emissions of 0.437 kg CO_2 / kg paper.

Table 3-16: End of life datasets, key materials and water

Mode / fuels	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
Wastewater treatment	U.S.	US: Municipal wastewater treatment (mix)	Sphera	2019	No
Paperboard and corrugate tray					
Incineration, paper	U.S.	US: Paper waste (water 0%) in waste incineration plant	Sphera	2019	No
Incineration, paper	Europe	EU-28: Paper and board (water 0%) in waste incineration plant	Sphera	2019	No
Landfill, paper	U.S.	US: Paper waste on landfill, post-consumer (according to the WARM model)	Sphera	2019	No
Landfill, paper	Europe	EU-28: Paper waste on landfill	Sphera	2019	No
Shrink wrap and Hi-Cone rings					
Incineration, LDPE	U.S.	US: Polyethylene (PE) in waste incineration plant	Sphera	2019	No
Incineration, LDPE	Europe	EU-28: Polyethylene (PE) in waste incineration plant	Sphera	2019	No
Landfill, LDPE	U.S. / Europe	US: Glass/inert on landfill	Sphera	2019	Geo.

Table 3-17: End of life datasets, distribution packaging materials

Mode / fuels	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
Incineration, corrugate	U.S.	US: Paper waste (water 0%) in waste incineration plant	Sphera	2019	No
Incineration, corrugate	Europe	EU-28: Paper and board (water 0%) in waste incineration plant	Sphera	2019	No
Landfill, corrugate	U.S.	US: Paper waste on landfill, post-consumer (according to the WARM model)	Sphera	2019	No
Landfill, corrugate	Europe	EU-28: Paper waste on landfill	Sphera	2019	No
Incineration, shrink wrap	U.S.	US: Polyethylene (PE) in waste incineration plant	Sphera	2019	No
Incineration, shrink wrap	Europe	EU-28: Polyethylene (PE) in waste incineration plant	Sphera	2019	No
Landfill, shrink wrap	U.S. / Europe	US: Glass/inert on landfill	Sphera	2019	Geo.
Incineration, particleboard	U.S. / Europe	US: Wood product (OSB, particle board) waste in waste incineration plant	Sphera	2019	Geo.
Landfill, particleboard	U.S. / Europe	US: Wood products (OSB, particle board) on landfill, post-consumer (according to the WARM model)	Sphera	2019	Geo.
Incineration, wood	U.S. / Europe	US: Untreated wood in waste incineration plant	Sphera	2019	Geo.
Landfill, wood	U.S. / Europe	US: Untreated wood on landfill, post-consumer (according to the WARM model)	Sphera	2019	Geo.
Incineration, steel	U.S. / Europe	US: Ferro metals in waste incineration plant	Sphera	2019	Geo.
Landfill, steel	U.S. / Europe	US: Glass/inert on landfill	Sphera	2019	Geo.

3.7. 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”. A complete inventory typically comprises hundreds of flows. In the interest of clarity and space, a selection of flows based on their relevance to the subsequent impact assessment is provided in Appendix B. The aim of the appendix is to provide a transparent link between the inventory and impact assessment results.

4. LCIA Results

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

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

4.1. Overall Results

Table 4-1 provides an overview of cradle-to-grave results for all packaging designs. Global warming potential both with and without the removal and release of biogenic carbon dioxide is considered, along with impact categories from EF 3.0. Figure 4-1 and Figure 4-2 show results normalized to the Carton scenario.

In general, potential environmental impacts are primarily driven by mass (see Figure 3-1). The Carton and Wrap+Tray, which weigh more than the other two packaging alternatives, typically have the higher potential environmental impacts. The KeelClip provides an alternative solution to the Carton if GPI wishes to reduce potential environmental impacts. The Hi-Cone rings, as the lightest-weight packaging design by far, is shown to have the lowest potential environmental impacts overall.

Table 4-1: Cradle-to-grave results per functional unit

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
IPCC AR5								
Climate change, excl. bio. CO_2	1.10E+01	6.05E+00	1.22E+01	3.21E+00	1.03E+01	5.67E+00	8.79E+00	2.77E+00
Climate change, incl. bio. CO_2	7.78E+00	4.24E+00	1.06E+01	3.16E+00	8.48E+00	4.65E+00	8.22E+00	2.72E+00
EF 3.0								
Acidification [mol H^+ eq]	3.91E-02	2.14E-02	7.24E-02	5.08E-03	5.13E-02	2.74E-02	1.94E-02	5.20E-03
Eutrophication, fresh [kg P eq]	2.03E-04	1.10E-04	2.24E-04	2.83E-06	1.73E-04	9.25E-05	1.18E-04	4.90E-06
Eutrophication, terr. [mol N eq]	1.38E-01	7.50E-02	1.32E-01	1.72E-02	1.78E-01	9.52E-02	6.50E-02	1.42E-02
Photo. ozone form. [kg NMVOC eq]	3.68E-02	2.00E-02	3.86E-02	4.59E-03	4.90E-02	2.62E-02	1.90E-02	4.44E-03
Resource, energy [MJ]	1.42E+02	8.17E+01	2.00E+02	7.16E+01	1.48E+02	8.48E+01	1.57E+02	6.31E+01
Resp. [disease incidences]	1.33E-06	6.98E-07	8.31E-07	4.92E-08	1.63E-06	8.51E-07	2.07E-07	4.60E-08
Water [m^3 world eq.]	2.72E+00	1.44E+00	2.21E+00	5.09E-01	2.73E+00	1.45E+00	2.01E+00	5.02E-01

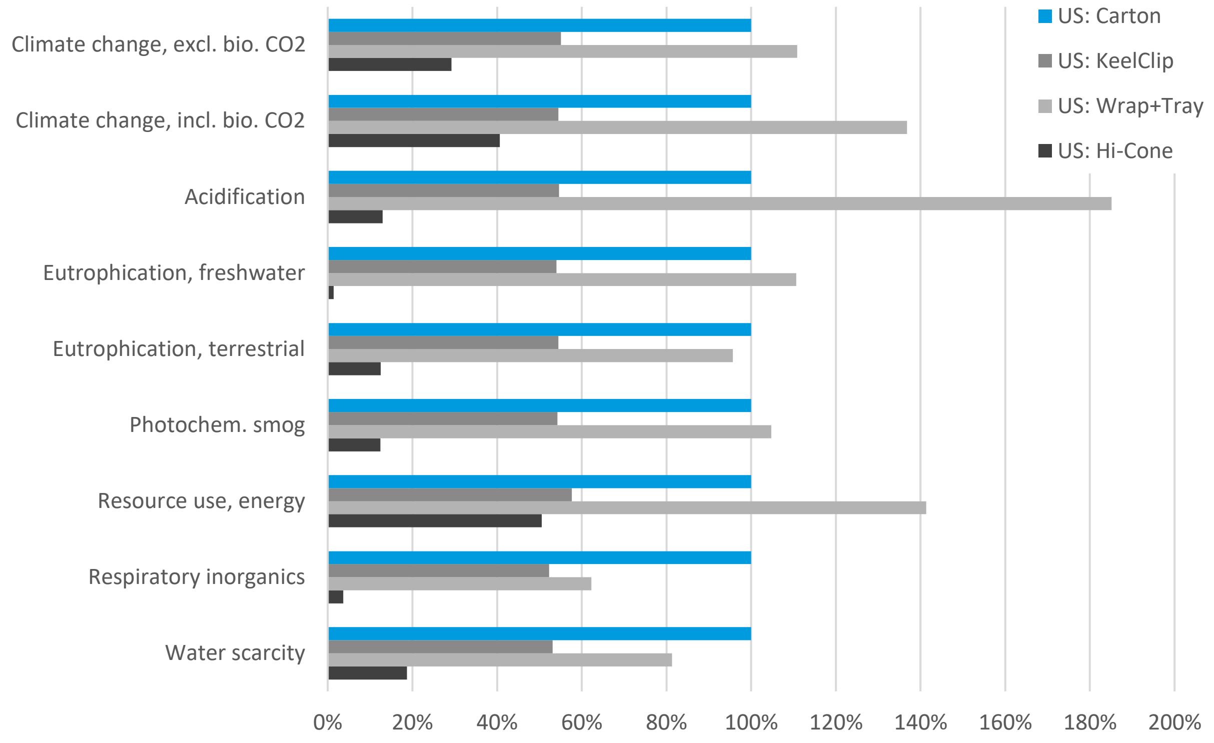

Figure 4-1: Cradle-to-grave LCIA results (IPCC AR5 and EF 3.0), normalized to the US Carton scenario (100%)

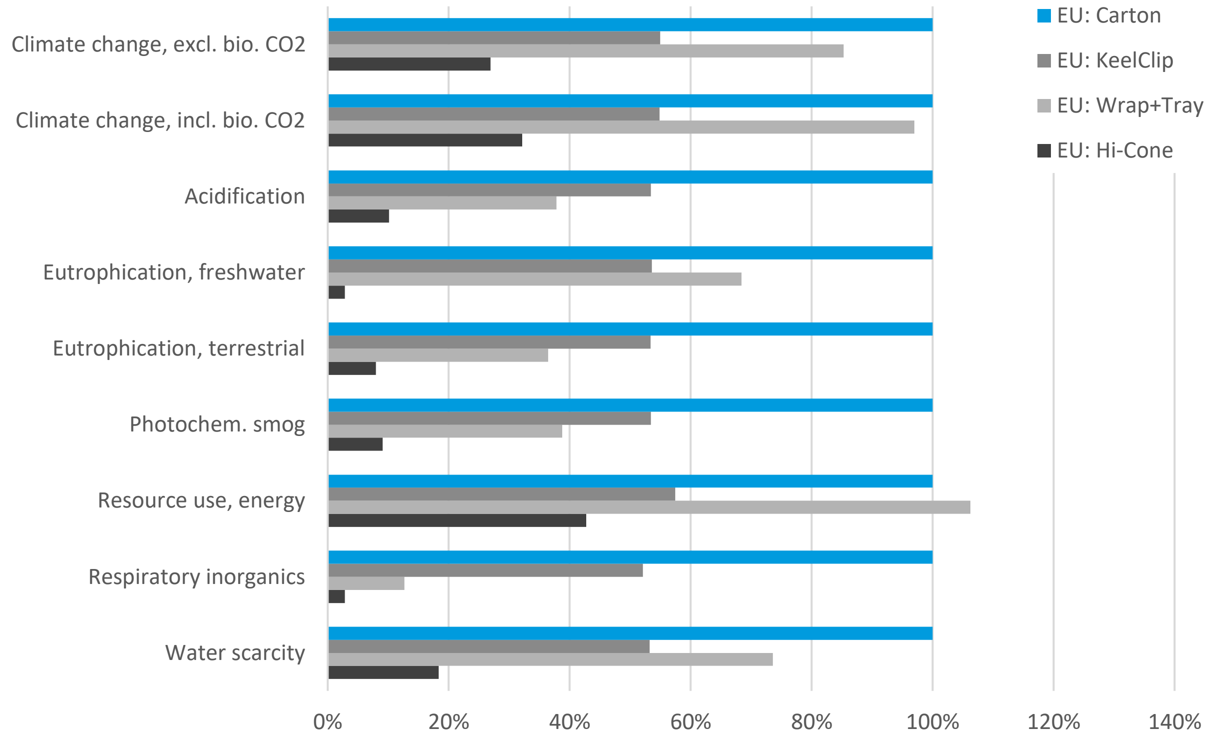

Figure 4-2: Cradle-to-grave LCIA results (IPCC AR5 and EF 3.0), normalized to the EU Carton scenario (100%)

4.2. Detailed Results

In this section, each environmental indicator is assessed separately. Results are broken down into the following categories:

- Wood – wood and fiber production. Includes biogenic carbon content of recycled paper for use at GPI's paper mills.
- Papermill – GPI's facilities that produce paper rolls from virgin and recycled fiber.
- Converting – GPI's facilities that convert paper rolls into the finished paperboard packaging. Includes distribution packaging for the beverage can packages.
- Production – raw materials and production of non-GPI packaging alternatives.
- Packaging – distribution packaging raw materials and converting for non-GPI packaging alternatives.
- Filling – filling of the packages with beverage cans. Includes disposal of distribution packaging.
- Transport – all transportation stages, including transport of raw materials (e.g., logs, paper for recycling, plastic resin, distribution packaging materials, etc.) to the manufacturing facility, transport of paper rolls to the converting facility, and downstream transportation to the filling facility, retailer, and end of life.
- End of life – disposal or recycling of packaging waste.

4.2.1. Climate Change, Excluding Biogenic CO_2

Climate change results are shown in Figure 4-3 and tabulated results in Table 4-2. Raw materials and packaging production are the primary contributors to climate change results.

- Impact drivers
  - The climate change for packaging produced by GPI is primarily driven by paperboard mill activities, in particular fossil CO_2 emissions.
  - For non-GPI packaging, potential impact is primarily from raw materials production and beverage packaging production.
  - Filling accounts for a modest contribution.
  - Transportation is a modest contribution for the Wrap+Tray and Hi-Cone rings, but represents a larger fraction of potential impact for GPI packaging, particularly when the paperboard is shipped to Europe.
  - End of life varies by packaging design and is influenced by incineration of plastic waste and methane emissions from landfill.
- Impact comparisons
  - Both the Carton and the Wrap+Tray are associated with highest cradle-to-grave results.
  - The Carton as produced for the European market has a lower potential impact than the carton as produced for the US market. Although the former includes transportation of the paperboard roll to Europe, GPI's converting facility in France uses less natural gas per functional unit and purchases electricity from a power grid that contains a lot of nuclear power.
  - The Hi-Cone, as the lightest weight packaging option, is associated with the lowest climate change.

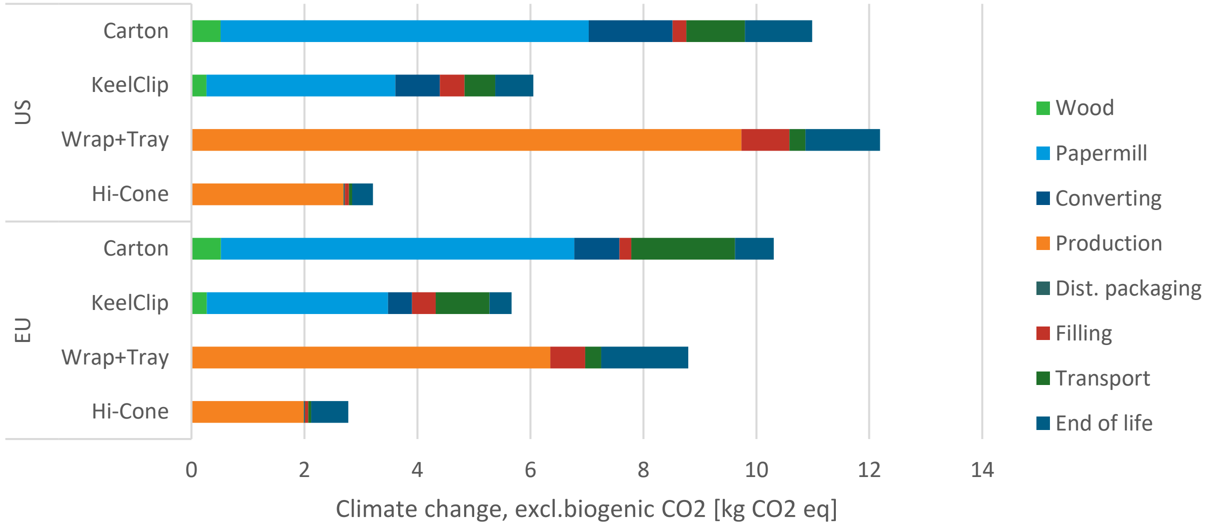

Figure 4-3: Climate change results per functional unit, excluding biogenic CO₂

Table 4-2: Climate change results per functional unit, excluding biogenic CO₂ [kg CO₂ eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	5.17E-01	2.65E-01	-	-	5.21E-01	2.72E-01	-	-
Papermill	6.52E+00	3.34E+00	-	-	6.26E+00	3.21E+00	-	-
Converting	1.48E+00	7.89E-01	-	-	8.01E-01	4.27E-01	-	-
Production	-	-	9.73E+00	2.69E+00	-	-	6.36E+00	1.99E+00
Packaging	-	-	0.00E+00	2.35E-02	-	-	0.00E+00	2.35E-02
Filling	2.42E-01	4.36E-01	8.52E-01	7.42E-02	2.10E-01	4.17E-01	6.16E-01	5.28E-02
Transport	1.04E+00	5.44E-01	2.81E-01	5.30E-02	1.83E+00	9.51E-01	2.81E-01	5.30E-02
End of life	1.19E+00	6.78E-01	1.32E+00	3.71E-01	6.88E-01	3.92E-01	1.54E+00	6.54E-01
Total	**1.10E+01**	**6.05E+00**	**1.22E+01**	**3.21E+00**	**1.03E+01**	**5.67E+00**	**8.79E+00**	**2.77E+00**

4.2.2. Climate Change, Including Biogenic CO₂

Climate change results including biogenic CO₂ (Figure 4-4) are fairly similar to those excluding biogenic CO₂ for the Hi-Cone rings as this design is 100% plastic (although its distribution packaging includes bio-based materials). The other three packaging designs, however, use paperboard or corrugate. The carbon uptake during biomass growth for these materials is reflected in the “Wood” category for GPI products and in the “Production” category for the Wrap+Tray. This carbon is then either fully or partially released back into the atmosphere when the packaging is incinerated or landfilled at end of life, or handed over to the next product life cycle when the packaging is recycled, thus leading to a higher end of life impact compared to climate change excluding biogenic CO₂ (section 4.2.1).

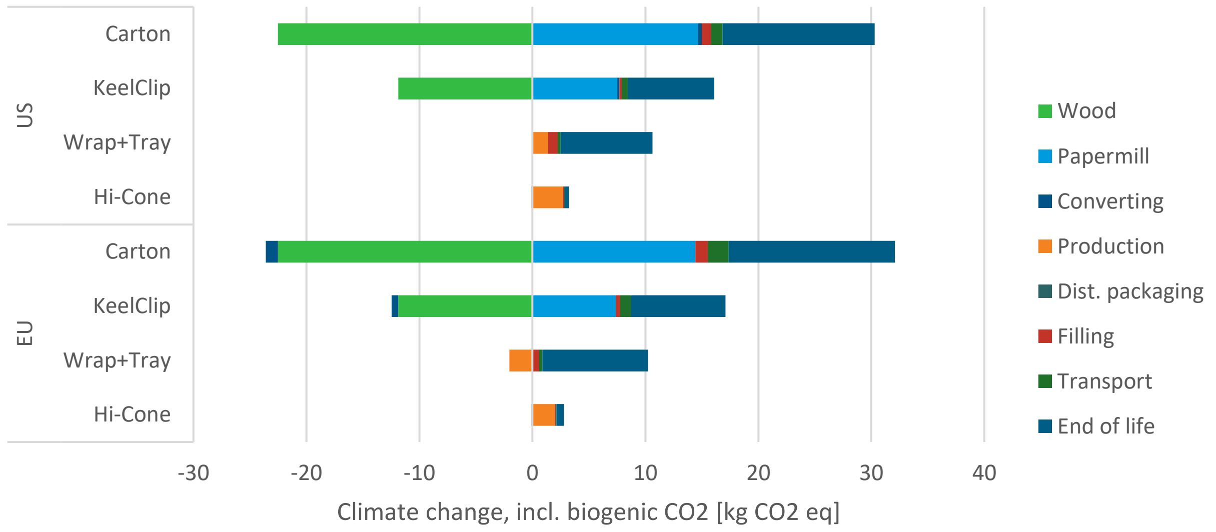

Figure 4-4: Climate change results per functional unit, including biogenic CO_2

Table 4-3: Climate change results per functional unit, including biogenic CO_2 [kg CO_2 eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	-2.25E+01	-1.19E+01	-	-	-2.25E+01	-1.19E+01	-	-
Papermill	1.47E+01	7.52E+00	-	-	1.44E+01	7.40E+00	-	-
Converting	3.49E-01	1.86E-01	-	-	-1.08E+00	-5.75E-01	-	-
Production	-	-	1.38E+00	2.69E+00	-	-	-2.02E+00	1.99E+00
Packaging	-	-	0.00E+00	-7.00E-02	-	-	0.00E+00	-7.00E-02
Filling	8.08E-01	2.19E-01	8.51E-01	1.13E-01	1.12E+00	3.81E-01	6.13E-01	1.00E-01
Transport	1.03E+00	5.42E-01	2.79E-01	5.30E-02	1.83E+00	9.48E-01	2.79E-01	5.30E-02
End of life	1.34E+01	7.65E+00	8.13E+00	3.70E-01	1.47E+01	8.38E+00	9.35E+00	6.54E-01
Total	**7.78E+00**	**4.24E+00**	**1.06E+01**	**3.16E+00**	**8.48E+00**	**4.65E+00**	**8.22E+00**	**2.72E+00**

4.2.3. Acidification

Acidification results are shown in Figure 4-5 and tabulated results in Table 4-4. Raw materials and packaging production, along with transportation, are the primary contributors to acidification results.

- Impact drivers
    - Nitrogen oxides and sulfur dioxide emissions from the paperboard mill are key drivers for the Carton and KeelClip. Converting has a modest contribution and its potential impact is primarily from corrugate used for distribution packaging (and modeled with a US corrugate average dataset—see Table 3-14.)
    - Transportation via container ship of paper rolls to Europe for converting also accounts for a significant contribution to acidification for the European Carton and KeelClip scenarios.
    - Results for the Wrap+Tray differ between the US and European scenarios due to differences between the European and US corrugate datasets used in the model (in particular, amount of recycled content—see Table C-3 and accompanying text). For the US end market, corrugate

production is the primary contributor to acidification, whereas for the European end market, both corrugate and polyethylene production contribute.

- Impact comparisons
    - As with climate change, Hi-Cone is associated with the lowest potential impact due to having the lowest material use.
    - The Wrap+Tray is associated with the highest acidification results of the US scenarios due to emissions associated with US average data for corrugate production.
    - The Carton and KeelClip have the highest potential impact among the European scenarios due to transportation to Europe as the Wrap+Tray and Hi-Cone are assumed to be manufactured in Europe for the European market.

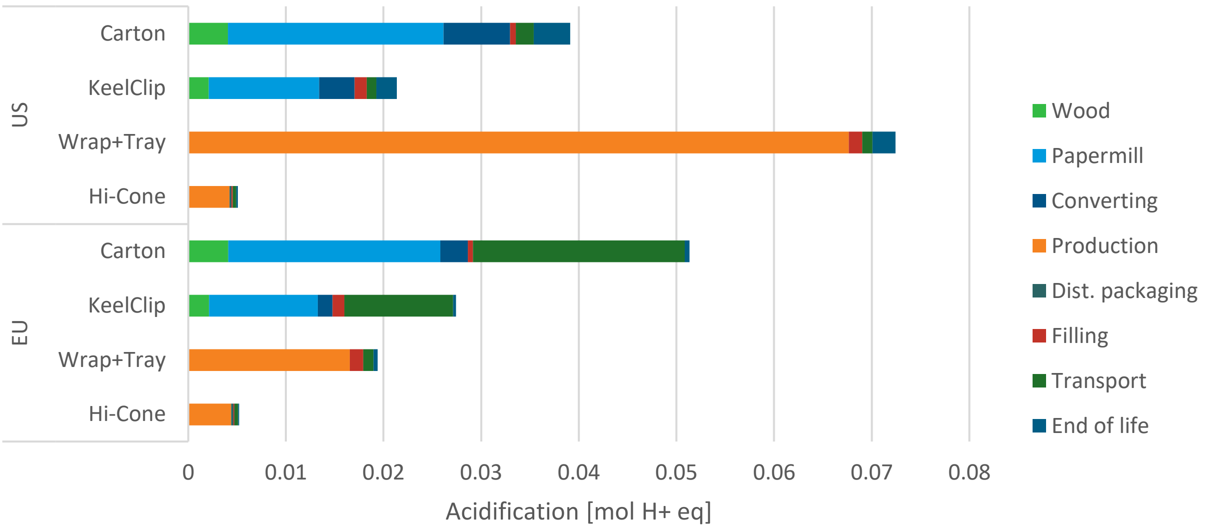

Figure 4-5: Acidification results per functional unit

Table 4-4: Acidification results per functional unit [mol H$^+$ eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	4.08E-03	2.09E-03	-	-	4.11E-03	2.15E-03	-	-
Papermill	2.21E-02	1.13E-02	-	-	2.17E-02	1.11E-02	-	-
Converting	6.83E-03	3.64E-03	-	-	2.83E-03	1.50E-03	-	-
Production	-	-	6.76E-02	4.22E-03	-	-	1.66E-02	4.40E-03
Packaging	-	-	0.00E+00	2.09E-04	-	-	0.00E+00	2.09E-04
Filling	5.92E-04	1.25E-03	1.40E-03	1.32E-04	5.00E-04	1.20E-03	1.37E-03	1.22E-04
Transport	1.85E-03	9.67E-04	1.04E-03	3.69E-04	2.17E-02	1.11E-02	1.04E-03	3.69E-04
End of life	3.72E-03	2.12E-03	2.34E-03	1.54E-04	4.86E-04	2.76E-04	4.44E-04	9.83E-05
Total	**3.91E-02**	**2.14E-02**	**7.24E-02**	**5.08E-03**	**5.13E-02**	**2.74E-02**	**1.94E-02**	**5.20E-03**

4.2.4. Eutrophication, Freshwater

Eutrophication results are shown in Figure 4-6 and tabulated results in Table 4-5. Raw materials and packaging production are the primary contributors to eutrophication, freshwater results.

- Impact drivers
    - Phosphate emissions to water from oxidized starch production and phosphorous emissions from municipal wastewater treatment are the key drivers for the Carton and KeelClip at the paperboard mill. Converting has a modest contribution and its potential impact is primarily from phosphate and phosphorous emissions arising from corrugate used for distribution packaging.
    - Results for the Wrap+Tray differ between the US and European scenarios due to differences between the European and US corrugate datasets used in the model (see Table C-3).
- Impact comparisons
    - Hi-Cone is again associated with the lowest potential impact due to being made of a commodity plastic and having the lowest material mass.
    - The Wrap+Tray and Carton are both associated with high eutrophication when considered for the US end market. The Wrap+Tray's eutrophication result falls below that of the Carton when considered for the European end market due to regional differences for corrugate production.

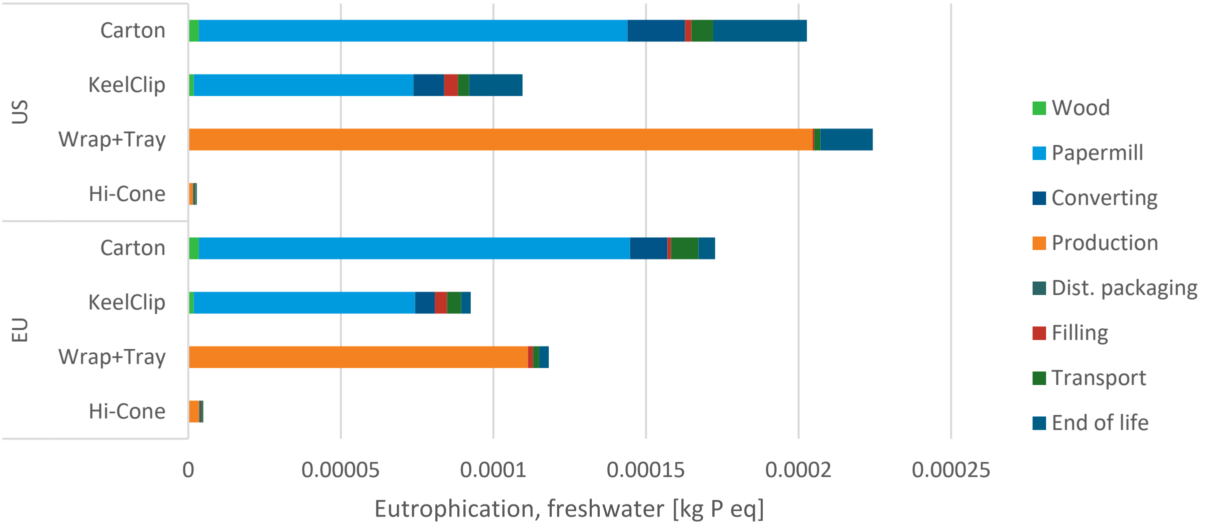

Figure 4-6: Eutrophication, freshwater results per functional unit

Table 4-5: Eutrophication, freshwater results per functional unit [kg P eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	3.42E-06	1.75E-06	-	-	3.45E-06	1.80E-06	-	-
Papermill	1.40E-04	7.20E-05	-	-	1.41E-04	7.25E-05	-	-
Converting	1.89E-05	1.00E-05	-	-	1.22E-05	6.50E-06	-	-
Production	-	-	2.05E-04	1.54E-06	-	-	1.11E-04	3.60E-06
Packaging	-	-	0.00E+00	7.29E-07	-	-	0.00E+00	7.29E-07
Filling	2.16E-06	4.49E-06	4.72E-07	1.22E-07	1.19E-06	3.98E-06	1.66E-06	1.68E-07
Transport	7.11E-06	3.72E-06	2.03E-06	3.74E-07	8.98E-06	4.68E-06	2.03E-06	3.74E-07
End of life	3.07E-05	1.75E-05	1.72E-05	6.48E-08	5.45E-06	3.10E-06	3.08E-06	2.76E-08
Total	**2.03E-04**	**1.10E-04**	**2.24E-04**	**2.83E-06**	**1.73E-04**	**9.25E-05**	**1.18E-04**	**4.90E-06**

4.2.5. Eutrophication, Terrestrial

Eutrophication, terrestrial results are shown in Figure 4-7 and tabulated results in Table 4-6. Raw materials, packaging production, and transportation are the primary contributors to eutrophication, terrestrial results.

- Impact drivers
    - Nitrogen oxides from the paperboard mill and ammonia emissions from mill chemicals and US landfill are key contributors to the Carton and KeelClip eutrophication, terrestrial results.
    - Transportation via container ship of paper rolls to Europe for converting also accounts for a significant contribution to eutrophication for the European Carton and KeelClip scenarios.
    - Results for the Wrap+Tray differ between the US and European scenarios due to differences between the European and US corrugate datasets used in the model (see Table C-3). For the US end market, corrugate production is the primary contributor to eutrophication, whereas for the European end market, both corrugate and polyethylene production contribute.
- Impact comparisons
    - Hi-Cone is again associated with the lowest potential impact due to being made from a commodity plastic and having the lowest material mass.
    - The Wrap+Tray and the Carton are both associated with the highest eutrophication of the US scenarios.
    - The Carton and KeelClip have the highest potential impact among the European scenarios due to transportation to Europe (whereas the Wrap+Tray and Hi-Cone are assumed to be manufactured in Europe for the European market).

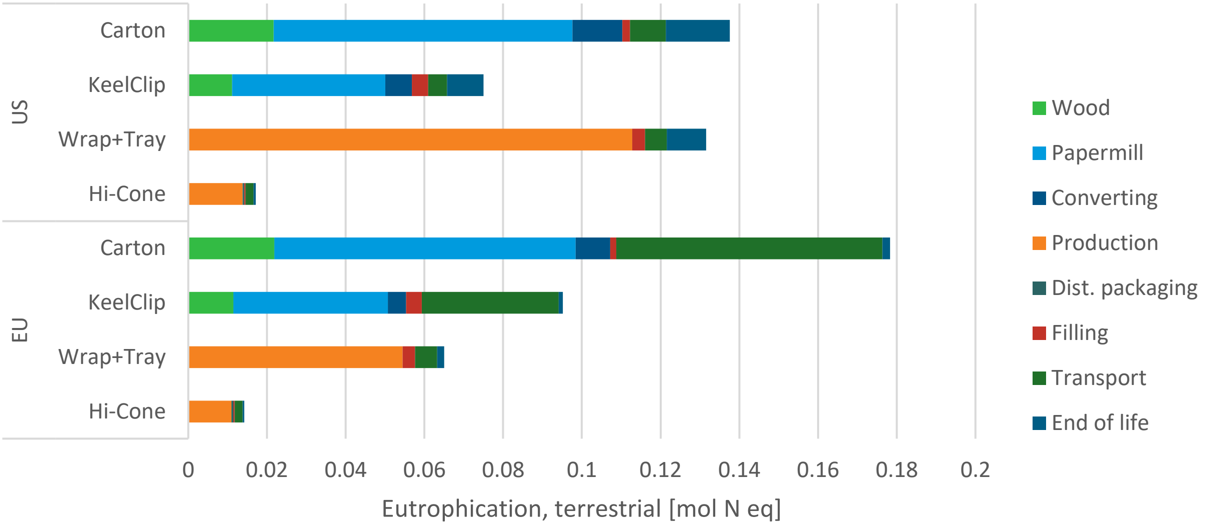

Figure 4-7: Eutrophication, terrestrial results per functional unit

Table 4-6: Eutrophication, terrestrial results per functional unit [mol N eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	2.17E-02	1.11E-02	-	-	2.19E-02	1.14E-02	-	-
Papermill	7.59E-02	3.89E-02	-	-	7.65E-02	3.92E-02	-	-
Converting	1.27E-02	6.76E-03	-	-	8.79E-03	4.68E-03	-	-
Production	-	-	1.13E-01	1.38E-02	-	-	5.45E-02	1.10E-02
Packaging	-	-	0.00E+00	4.43E-04	-	-	0.00E+00	4.43E-04
Filling	1.97E-03	4.19E-03	3.21E-03	3.33E-04	1.57E-03	3.98E-03	3.19E-03	3.03E-04
Transport	9.10E-03	4.76E-03	5.56E-03	2.05E-03	6.76E-02	3.47E-02	5.56E-03	2.05E-03
End of life	1.62E-02	9.23E-03	9.99E-03	5.49E-04	1.95E-03	1.11E-03	1.80E-03	4.02E-04
Total	**1.38E-01**	**7.50E-02**	**1.32E-01**	**1.72E-02**	**1.78E-01**	**9.52E-02**	**6.50E-02**	**1.42E-02**

4.2.6. Photochemical Ozone Formation

Photochemical ozone formation results are shown in Figure 4-8 and tabulated results in Table 4-7. Raw materials and packaging production, along with transportation, are the primary contributors to POF.

- Impact drivers
  - Nitrogen oxides and VOC emissions from the paperboard mill are key drivers for the Carton and KeelClip. Converting has a modest contribution and its potential impact is primarily from corrugate used for distribution packaging and electricity generation.
  - Transportation via container ship of paper rolls to Europe for converting also accounts for a significant contribution to POF for the European Carton and KeelClip scenarios.
  - Results for the Wrap+Tray differ between the US and European scenarios due to differences between the European and US corrugate datasets used in the model (see Table C-3).
- Impact comparisons
  - Hi-Cone is associated with the lowest potential impact due to being made from a commodity plastic and having the lowest material mass.
  - The Wrap+Tray and Carton are both associated with high POF when considered for the US end market. The Wrap+Tray's POF falls below that of the Carton when considered for the European end market due to regional differences for corrugate production.
  - The Carton and KeelClip have the highest potential impact among the European scenarios due to transportation to Europe as the Wrap+Tray and Hi-Cone are assumed to be manufactured in Europe for the European market.

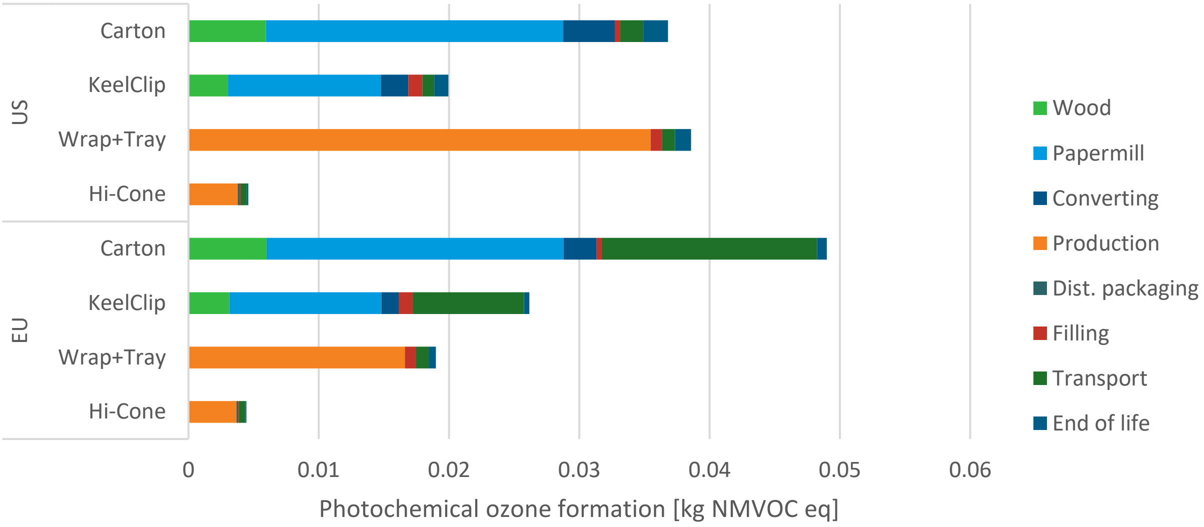

Figure 4-8: Photochemical ozone formation results per functional unit

Table 4-7: Photochemical ozone formation results per functional unit [kg NMVOC eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	5.96E-03	3.05E-03	-	-	6.00E-03	3.14E-03	-	-
Papermill	2.28E-02	1.17E-02	-	-	2.28E-02	1.17E-02	-	-
Converting	3.97E-03	2.11E-03	-	-	2.53E-03	1.35E-03	-	-
Production	-	-	3.55E-02	3.79E-03	-	-	1.66E-02	3.68E-03
Packaging	-	-	0.00E+00	1.38E-04	-	-	0.00E+00	1.38E-04
Filling	3.97E-04	1.08E-03	8.56E-04	8.02E-05	3.88E-04	1.07E-03	8.33E-04	7.45E-05
Transport	1.78E-03	9.29E-04	1.01E-03	4.85E-04	1.65E-02	8.50E-03	1.01E-03	4.85E-04
End of life	1.89E-03	1.08E-03	1.22E-03	9.76E-05	7.46E-04	4.25E-04	5.30E-04	6.50E-05
Total	**3.68E-02**	**2.00E-02**	**3.86E-02**	**4.59E-03**	**4.90E-02**	**2.62E-02**	**1.90E-02**	**4.44E-03**

4.2.7. Resource Use, Energy

Fossil energy resource use results are shown in Figure 4-9 and tabulated results in Table 4-8. Raw materials and packaging production are the primary contributors to resource use, followed by transportation and converting.

- Impact drivers
    - Natural gas and electricity consumption are key contributors to energy resource use for the Carton and KeelClip—both at the papermill and at converting.
    - Both corrugate and shrink film production contribute to the potential impact for Wrap+Tray production. Although this packaging design is mostly corrugate by mass, the corrugate uses renewable resources, which are not counted in this metric, whereas the shrink film is made from fossil resources.
    - Likewise, the Hi-Cone is made from plastic that is produced from fossil resources.

- Impact comparisons
    - Between its fossil resource use for both corrugate and shrink wrap production, the Wrap+Tray has the highest potential impact for the US end market, and its potential impact is on par with that for the Carton in the European end market.
    - The Hi-Cone has the lowest potential impact for the European end market. For the US end market, Hi-Cone and KeelClip have approximately the same potential impact—in part because Hi-Cone rings are a fossil-based product, whereas the KeelClip is bio-based.

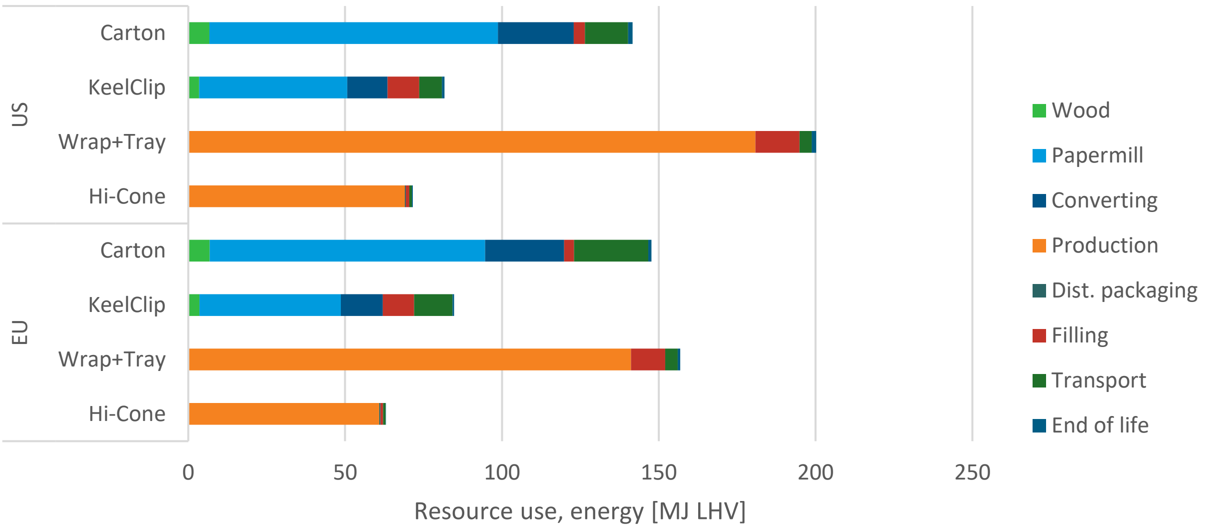

Figure 4-9: Resource use, energy results per functional unit

Table 4-8: Resource use, energy results per functional unit [MJ LHV]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	6.76E+00	3.47E+00	-	-	6.81E+00	3.56E+00	-	-
Papermill	9.20E+01	4.72E+01	-	-	8.79E+01	4.51E+01	-	-
Converting	2.41E+01	1.28E+01	-	-	2.51E+01	1.34E+01	-	-
Production	-	-	1.81E+02	6.90E+01	-	-	1.41E+02	6.09E+01
Packaging	-	-	0.00E+00	3.41E-01	-	-	0.00E+00	3.41E-01
Filling	3.57E+00	1.02E+01	1.40E+01	1.16E+00	3.22E+00	9.97E+00	1.09E+01	9.00E-01
Transport	1.37E+01	7.19E+00	3.94E+00	7.28E-01	2.36E+01	1.23E+01	3.94E+00	7.28E-01
End of life	1.42E+00	8.09E-01	1.41E+00	3.52E-01	9.72E-01	5.53E-01	8.54E-01	1.77E-01
Total	**1.42E+02**	**8.17E+01**	**2.00E+02**	**7.16E+01**	**1.48E+02**	**8.48E+01**	**1.57E+02**	**6.31E+01**

4.2.8. Respiratory Inorganics

Respiratory inorganics results are shown in Figure 4-10 and tabulated results in Table 4-9. Raw materials and packaging production are the primary contributors to respiratory inorganics, followed by transportation and converting.

- Impact drivers
    - Dust emissions from the paperboard mills is the key driver for Carton and KeelClip.

  - Transportation via container ship of paper rolls to Europe for converting also accounts for a significant contribution to respiratory inorganics for the European Carton and KeelClip scenarios.
  - Results for the Wrap+Tray differ between the US and European scenarios due to differences between the European and US corrugate datasets used in the model (see Table C-3).
- Impact comparisons
  - Hi-Cone is associated with the lowest potential impact due to being made from a commodity plastic and having the lowest material mass.
  - The Carton has the highest potential impact for both the US and European end markets.

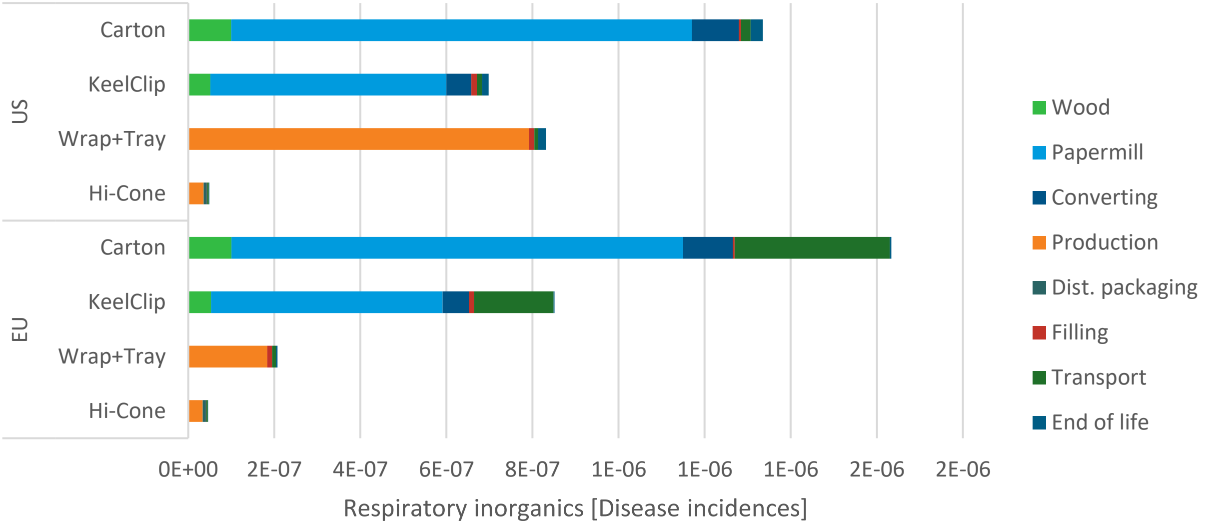

Figure 4-10: Respiratory inorganics results per functional unit

Table 4-9: Respiratory inorganics results per functional unit [disease incidences]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	9.98E-08	5.12E-08	-	-	1.01E-07	5.25E-08	-	-
Papermill	1.07E-06	5.49E-07	-	-	1.05E-06	5.38E-07	-	-
Converting	1.09E-07	5.79E-08	-	-	1.15E-07	6.13E-08	-	-
Production	-	-	7.92E-07	3.60E-08	-	-	1.84E-07	3.36E-08
Packaging	-	-	0.00E+00	7.03E-09	-	-	0.00E+00	7.03E-09
Filling	5.23E-09	1.25E-08	1.25E-08	1.16E-09	4.44E-09	1.21E-08	1.15E-08	1.01E-09
Transport	2.28E-08	1.20E-08	8.92E-09	3.65E-09	3.60E-07	1.85E-07	8.92E-09	3.65E-09
End of life	2.75E-08	1.57E-08	1.78E-08	1.38E-09	3.71E-09	2.11E-09	3.36E-09	7.31E-10
Total	**1.33E-06**	**6.98E-07**	**8.31E-07**	**4.92E-08**	**1.63E-06**	**8.51E-07**	**2.07E-07**	**4.60E-08**

4.2.9. Water Scarcity

Water scarcity results are shown in Figure 4-11 and tabulated results in Table 4-10. Raw materials and packaging production are the primary contributors.

- Impact drivers
    - Water consumption at paperboard mills is the key driver for the Carton and KeelClip scenarios.
    - Both shrink wrap production and corrugate production contribute to the potential impact for the Wrap+Tray in both the US and European end markets.
- Impact comparisons
    - Hi-Cone is associated with the lowest potential impact.
    - The Carton has the highest potential impact for both the US and European end markets.

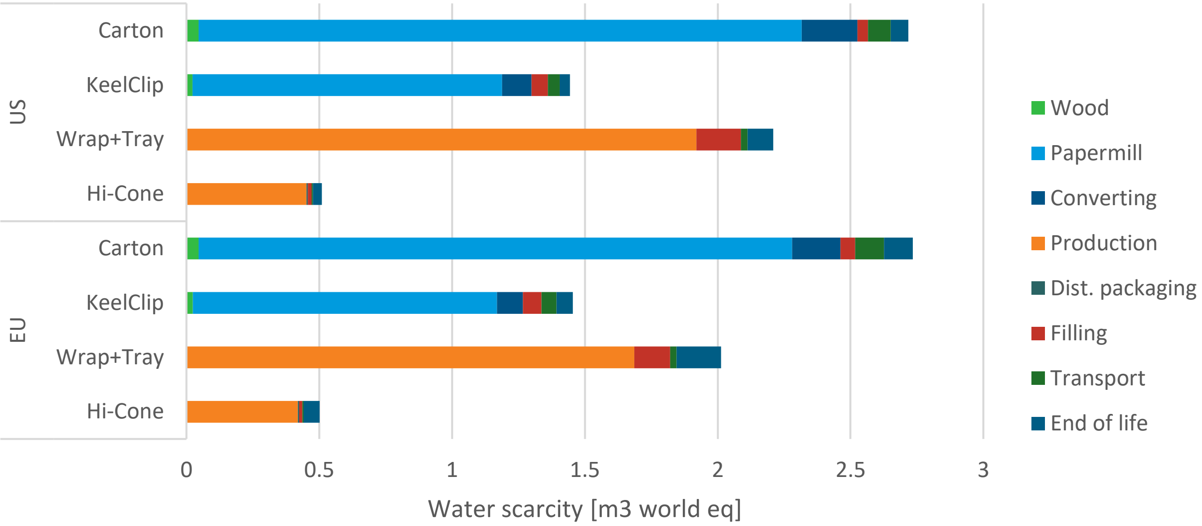

Figure 4-11: Water scarcity results per functional unit

Table 4-10: Water scarcity results per functional unit [m^3 world eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	4.58E-02	2.35E-02	-	-	4.61E-02	2.41E-02	-	-
Papermill	2.27E+00	1.16E+00	-	-	2.23E+00	1.15E+00	-	-
Converting	2.09E-01	1.11E-01	-	-	1.83E-01	9.74E-02	-	-
Production	-	-	1.92E+00	4.52E-01	-	-	1.69E+00	4.20E-01
Packaging	-	-	0.00E+00	4.73E-03	-	-	0.00E+00	4.73E-03
Filling	3.96E-02	6.14E-02	1.67E-01	1.47E-02	5.48E-02	6.93E-02	1.35E-01	1.24E-02
Transport	8.56E-02	4.48E-02	2.46E-02	4.55E-03	1.09E-01	5.68E-02	2.46E-02	4.55E-03
End of life	6.66E-02	3.79E-02	9.66E-02	3.36E-02	1.08E-01	6.17E-02	1.67E-01	6.01E-02
Total	**2.72E+00**	**1.44E+00**	**2.21E+00**	**5.09E-01**	**2.73E+00**	**1.45E+00**	**2.01E+00**	**5.02E-01**

4.3. Additional Analyses

4.3.1. Sensitivity Analysis: Hi-Cone Post-Consumer Recycled Content

According to Hi-Cone's website (Hi-Cone), Hi-Cone products can have up to 50% post-consumer recycled (PCR) content. The baseline analysis assumes no recycled content. Although modeling Hi-Cone production from 100% virgin content does not represent a best-case of the packaging product, the results indicate that the Hi-Cone rings are consistently associated with the lowest potential environmental impacts even under these conditions. Therefore, the use of PCR content is only considered in a sensitivity analysis.

Results of this sensitivity analysis are shown for global warming potential, including biogenic CO_2 (Figure 4-12) and for energy resource use (Figure 4-13). The cut-off allocation approach is used to handle recycled content, consistent with the primary analysis in this report. The charts indicate that a 50% increase in PCR content leads to around a 20% decrease in life-cycle climate change and a 35% decrease in life-cycle energy resource use. Potential environmental impacts of the other scenarios remain the same.

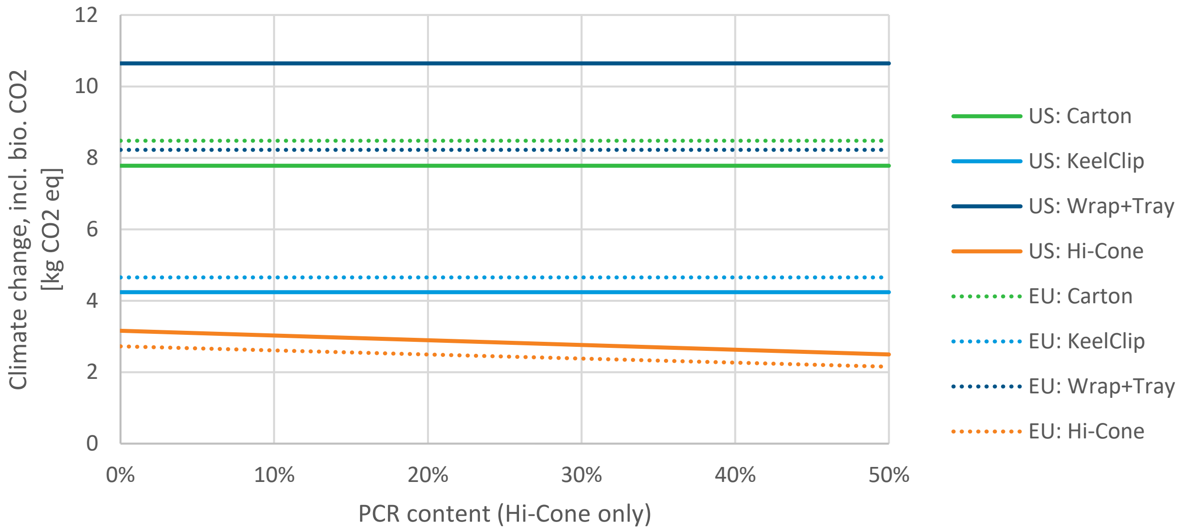

Figure 4-12: Climate change, including biogenic CO_2 sensitivity analysis for Hi-Cone PCR

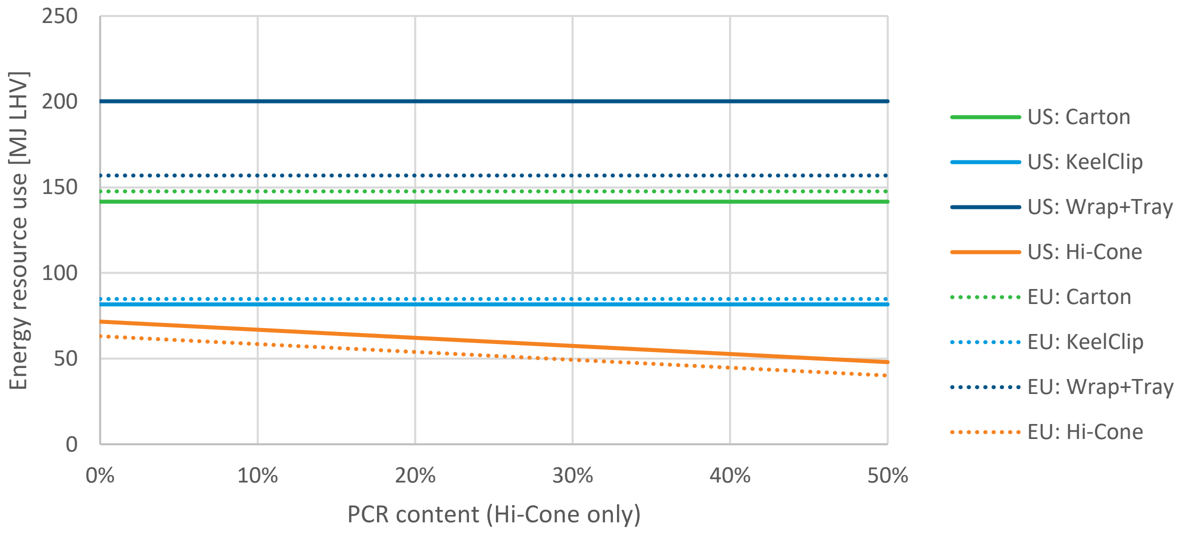

Figure 4-13: Energy resource use sensitivity analysis for Hi-Cone PCR

4.3.2. Sensitivity Analysis: Paperboard Mill

The primary analysis considers averages of AquaKote and OmniKote paper grades produced at both GPI mills. The US analysis uses a production weighted average, whereas the European analysis estimates that the Masnières converting facility receives around 50% of paperboard from each mill. To help GPI better understand which mill is driving potential environmental impacts, the percentage of paper from each mill is varied in this sensitivity analysis.

Analysis results are shown in Figure 4-14 and Figure 4-15 for climate change and energy resource use, respectively. The x-axis in both figures represents the percentage of paper from GPI's West Monroe mill (with the remainder coming from GPI's Macon mill). The square and round points represent baseline scenarios for Europe and the US, respectively. The results indicate that the West Monroe mill has the higher potential impact for climate change and energy resource use compared to the Macon mill. This is due to a combination of West Monroe using more raw materials, including logs, process chemicals, and colorants, more electricity, and more natural gas per unit of paperboard manufactured (even accounting for differences in grid mix). For exact values see Table A-1.

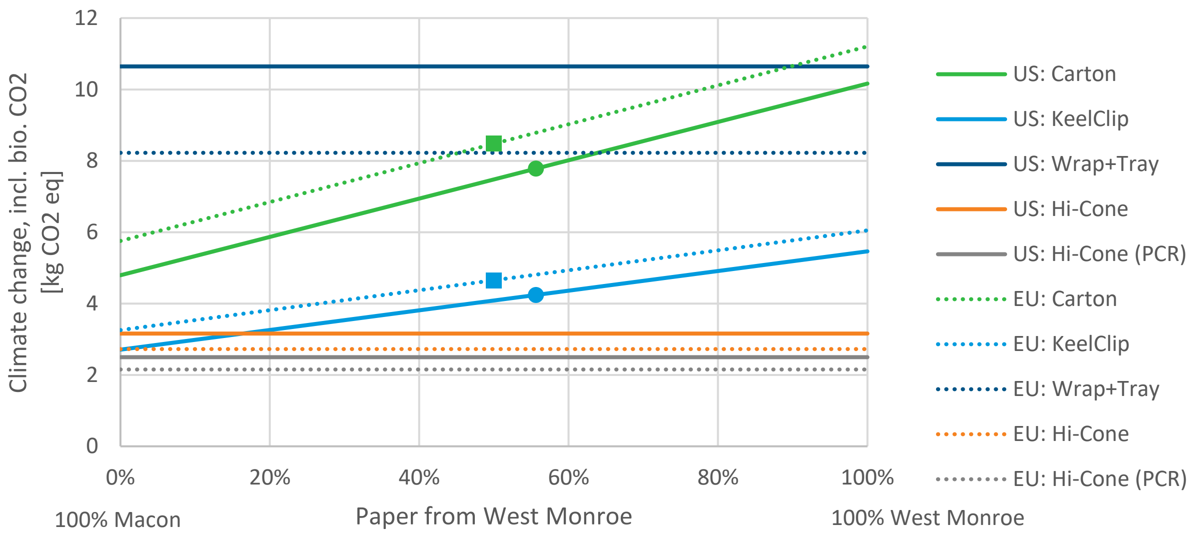

Figure 4-14: Climate change, including biogenic CO_2 sensitivity analysis for GPI papermill

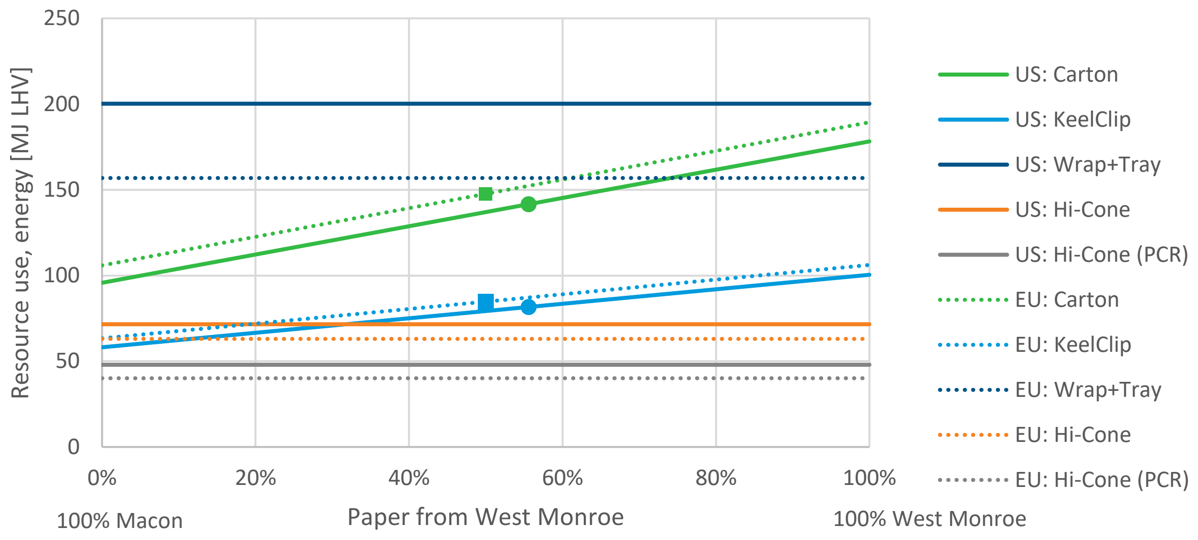

Figure 4-15: Energy resource use sensitivity analysis for GPI papermill

4.3.3. Scenario Analysis: Assessment Methodology

Although GPI has customers in both the US and Europe, it is primarily GPI's European customers who are interested in this analysis. As such, the European methodology Environmental Footprint v3.0 (EF 3.0) was used for the main body of this analysis. To assess the implications of the LCIA methodology, results are calculated for the following TRACI 2.1 impact categories:

- Acidification [kg SO_2 eq]
- Eutrophication [kg N eq]
- Human health particulates [kg PM2.5 eq]
- Resources, fossil [MJ surplus]
- Smog formation [kg O_3 eq]

These results are shown in Table 4-11, along with Figure 4-16 and Figure 4-17. Overall, conclusions are fairly similar to those for EF 3.0 (see Figure 4-1 and Figure 4-2). Hi-Cone rings are typically associated with the lowest potential environmental impacts and either the Carton or the Wrap+Tray with the highest potential environmental impacts. The one exception is eutrophication, for which the Carton and KeelClip have higher eutrophication results under the TRACI 2.1 methodology as TRACI 2.1 considers chemical species beyond those included in EF 3.0, along with biological oxygen demand (BOD) and chemical oxygen demand (COD). COD, for example, represents about half of eutrophication impact. Additional TRACI 2.1 results are included in Appendix D.

Table 4-11: Cradle-to-grave TRACI 2.1 results per functional unit

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Acidification [kg SO_2 eq]	3.70E-02	2.02E-02	6.24E-02	4.62E-03	4.64E-02	2.48E-02	1.74E-02	4.78E-03
Eutrophication [kg N eq]	1.08E-02	5.70E-03	5.06E-03	3.40E-04	1.09E-02	5.72E-03	3.76E-03	3.76E-04
Particulates [kg PM 2.5 eq]	5.95E-03	3.12E-03	4.78E-03	2.81E-04	7.33E-03	3.83E-03	1.09E-03	2.69E-04
Resources, fossil [MJ]	1.85E+01	1.07E+01	2.30E+01	8.56E+00	1.84E+01	1.06E+01	1.95E+01	7.26E+00
Smog formation [kg O_3 eq]	7.38E-01	4.00E-01	6.98E-01	9.69E-02	1.05E+00	5.58E-01	3.50E-01	8.07E-02

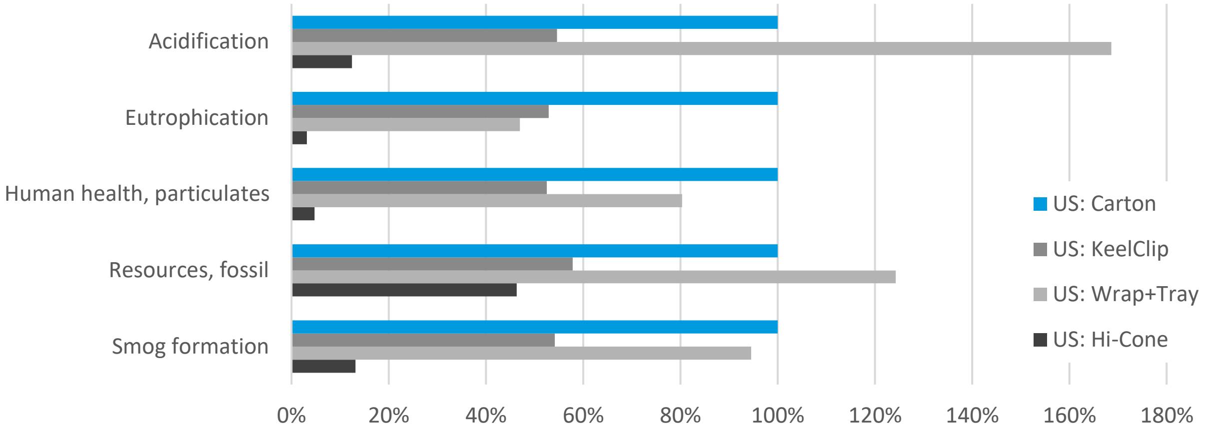

Figure 4-16: Cradle-to-grave TRACI 2.1 results, normalized to the US Carton scenario (100%)

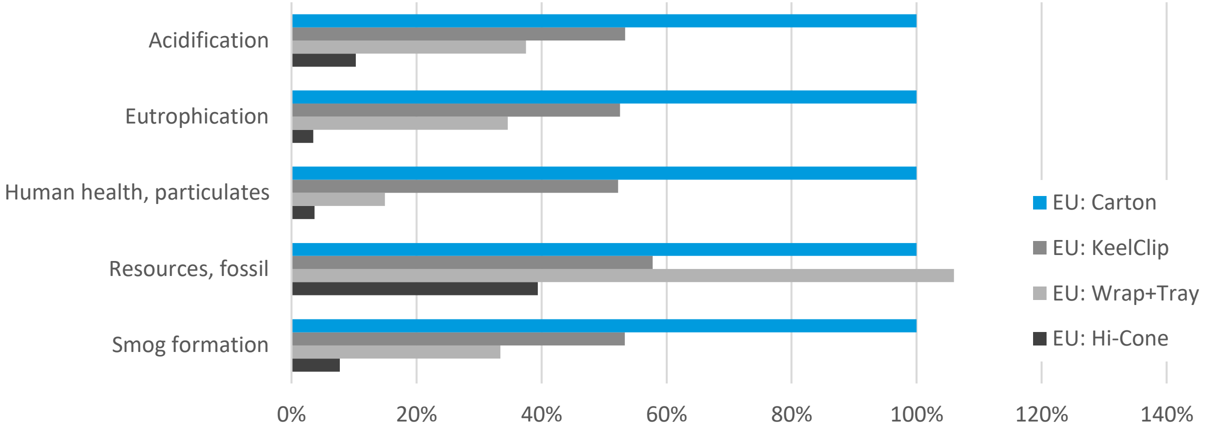

Figure 4-17: Cradle-to-grave TRACI 2.1 results, normalized to the EU Carton scenario (100%)

4.3.4. Uncertainty Analysis

There is inherent uncertainty in any LCA study. This uncertainty can arise from model imprecision, input uncertainty, and data variability, among other sources. For example, in this particular analysis, there can be uncertainty and variability in the data provided by GPI (e.g., from the models used to calculate facility emissions to air and water), in the background data (e.g., the use of average LCI data to represent GPI's specific supply chain), and in characterization factors. Because of this—mostly unknown—uncertainty, it is often impossible to state whether one product system is 'better' than another when their LCIA results are within a few percentage points of each other. Some impact categories such as toxicity require differences of 2 to 3 orders of magnitude in order for one product system to be considered as having lower potential environmental impacts.

Given the availability and quality of data used for this analysis, any uncertainty or potential variation in results is not anticipated to affect conclusions or alter which packaging system has the lowest potential environmental impacts. Foreground data provided by GPI is, to the author's knowledge, accurate and comparable to previous years. Data for other packaging systems are believed to be representative of the systems. Finally, background data choices represent the best available choices. Background data, furthermore, were sourced from a single database and expected to be internally consistent.

5. Interpretation

5.1. Identification of Relevant Findings

5.1.1. Impact Drivers

- Paperboard packaging production, in particular at the mill but also at the converting facility, is a key driver of the Carton and KeelClip impact, regardless of the end market of the packaging product.
- Likewise, production of raw materials and processing into packaging components are the key contributors to the Wrap+Tray and Hi-Cone packaging alternatives.
- Potential environmental impact of the Wrap+Tray packaging design varies significantly between US and European end market scenarios due to differences in average corrugate production between the two regions. In particular, average US corrugate is assumed to contain 52% recycled content, whereas average European corrugate is assumed to contain 94% recycled content (see Table C-3 and accompanying text).
- Transportation of paperboard packaging to Europe via container ship was shown to be a key contributor to acidification, eutrophication (terrestrial), POF, and respiratory inorganics; otherwise, transportation was at most a modest contributor.
- Filling the packaging with beverage cans and disposal of distribution packaging typically accounted for a modest fraction of potential impact.
- End of life, including landfill and incineration of the beverage can packaging, also represented a modest contribution for most impact categories.

5.1.2. Impact Comparisons

- Hi-Cone rings are shown to have the lowest potential impact for all impact categories considered due to this product being the lightest-weight packaging design (see Figure 3-1).
- The KeelClip design typically has the second lowest potential impact for all impact categories under US end market assumptions. When the European end market is considered, the KeelClip is either the second or third lowest due to a combination of container ship emissions from transporting paper rolls to GPI's converting facility in France and lower potential impact of European corrugate production compared to production in the US.
- The Carton and Wrap+Tray packaging scenarios are generally associated with the highest potential environmental impacts. Under US end market assumptions, the Wrap+Tray has the highest environmental burden for climate change (including biogenic CO_2), acidification, and energy resource use. It is also comparable to the Carton's environmental burden for climate change (excluding biogenic CO_2), eutrophication, and POF. The Wrap+Tray is lower only for respiratory inorganics and water scarcity.
- Under European end market assumptions, the Carton has the highest environmental burden for climate change (excluding biogenic CO_2), acidification, eutrophication, POF, respiratory inorganics, and water scarcity. It is about the same for climate change (including biogenic CO_2) and energy resource use. As with the KeelClip packaging, this is due to a combination of container ship emissions from transporting paper rolls to GPI's converting facility in France and lower potential impact of European corrugate production compared to production in the US.

5.2. Assumptions and Limitations

The analysis assumes that each beverage can packaging design meets beverage customer specifications, such as requirements for lifting and carrying multiple beverage cans or for wet strength—that is, the ability of a carton to remain intact even after exposure to moisture or condensation. From this perspective, the designs are thus assumed to be functionally equivalent. These requirements are typically defined by the beverage manufacturers (e.g., GPI's customers) and vary between manufacturers as well as between regions. No explicit requirements were considered in this analysis.

The functional unit is centered around beverage cans. These cans differ slightly in size for the US versus the European markets—330-mL versus 300-mL. Differences in beverage can packaging (i.e., secondary packaging), however, are expected to be negligible as the can dimensions are not significantly different and the beverage cans themselves are outside the system boundary.

Primary data were used for the design and modeling of the Carton and KeelClip as GPI is the supplier of these two packaging products. Average data were used for the Wrap+Tray and Hi-Cone rings—both for the design and for the LCA model—because specific data for these competing products (e.g., manufacturing energy consumption, facility locations, supply chain details, etc.) were not available. Furthermore, this is in line with a goal of the analysis—that is, to compare GPI-specific packaging to competing packaging produced by an average manufacturer.

Data for Hi-Cone production and distribution packaging were calculated by an independent consultant hired by GPI. Wrap+Tray data were based on a previous GPI report in which packaging component masses were measured. No distribution packaging information was available for the Wrap+Tray so this was excluded from the analysis.

The specific caliper of AquaKote or OmniKote paperboard used for GPI's beverage packaging products was not modeled. Instead, these production impacts were assessed based on the average impact of all AquaKote or OmniKote caliper grades. The influence of this assumption on the results is considered to be low as all AquaKote or OmniKote products have similar composition, regardless of caliper.

The background data are generally of high quality. As much as possible, datasets chosen were representative of the geography, timescales and technology of the modeled product system. However, where precise matches could not be made, proxy data were used. In most cases, the main difference was that the geographical representativeness was not exact; data on the correct materials or processes were used but based on production or operation in another region (usually the European Union or Germany). It is expected that the technology used will not differ but there will be some variation due to the use of different regional energy mixes in these background datasets. It is worth reiterating that region-specific data were applied to all electricity and thermal energy sources used by foreground processes in the life cycle model.

5.3. Results of Additional Analyses

Additional analyses were carried out to test the effect of methodological choices made during modeling on the results. The first analysis addressed the amount of PCR content in the Hi-Cone rings. Results indicate that increasing PCR content decreases the potential impact of the Hi-Cone packaging. As the Hi-Cone scenario already has the lowest potential impact in all impact categories, this did not affect conclusions. However, it does underscore potential challenges if one desires to create an alternative packaging design with lower environmental burden.

A second analysis evaluated changes to the ratio of paperboard from GPI's Macon mill versus GPI's West Monroe mill. The analysis indicates that West Monroe is associated with higher potential environmental impacts—at least for climate change and energy resource use. Sourcing packaging from only the Macon mill has the potential to reduce climate change impacts to the point at which they are comparable to those of the Hi-Cone rings.

The European methodology EF 3.0 was chosen for this report as it is GPI's European customers who are primarily interested in analysis outcomes. However, TRACI 2.1 LCIA results were also calculated, both to test the robustness of conclusions as well as to support GPI in addressing US customer requests. Except for eutrophication, the US methodology did not change study conclusions. Eutrophication potential under TRACI 2.1 considers emissions to water and air beyond those in EF 3.0, which leads to the paperboard products having highest potential impact.

Lastly, the effect of uncertainty on analysis results was considered. Given the quality of both foreground and background data (assessed more thoroughly in the following section) as well as the degree to which packaging system results differ, uncertainty in the results—while not quantifiable comprehensively—is not anticipated to significantly affect conclusions.

5.4. Data Quality Assessment

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

To cover these requirements and to ensure reliable results, first-hand industry data (where available) in combination with consistent background LCA information from the GaBi 2020 database were used. The LCI datasets from the GaBi 2020 database are widely distributed and used with the GaBi 9 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science. Overall, the foreground and background data used in this analysis are considered appropriate given study goal and scope.

5.4.1. Precision and Completeness

- ✓ **Precision:** As the majority of the relevant foreground data for the paperboard packaging designs are measured data or calculated based on primary information sources of the owner of the technology, precision is considered to be high. Seasonal variations were balanced out by using yearly averages. Data for the Wrap+Tray and Hi-Cone rings are based on industry-average numbers. 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. Except for Wrap+Tray distribution packaging for which data were not available, no data were knowingly omitted. This is considered acceptable as it benefits the competing packaging system. Completeness of foreground unit process data is considered to be high. All background data are sourced from GaBi databases with the documented completeness.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while all background data were sourced from the GaBi databases. Secondary data were used for the Wrap+Tray and Hi-Cone; consequently, fewer details were available compared to primary data from GPI.

Additional details may increase the potential environmental impact of these alternatives, but are unlikely to significantly alter study conclusions.

- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modeling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modeling approaches.

5.4.3. Representativeness

- ✓ **Temporal:** All primary data were collected for the year 2019. All secondary data come from the GaBi 2020 databases and are representative of the years 2011-2019. As the study intended to compare the product systems for the reference year 2019, temporal representativeness is considered to be high.
- ✓ **Geographical:** All primary and secondary data were collected specific to the countries or regions under study. Where country-specific or region-specific data were unavailable, proxy data were used. Geographical representativeness is considered to be high as proxy data were limited to chemicals, distribution packaging, and other minor components of the analysis.
- ✓ **Technological:** All primary and secondary data were modeled to be specific to the technologies or technology mixes under study. Average LCI data were chosen to model the Wrap+Tray and Hi-Cone packaging systems as specific facility locations and manufacturing details (e.g., the amount of recycled content in corrugate board) are unknown. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.5. Model Completeness and Consistency

5.5.1. Completeness

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

5.5.2. Consistency

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

5.6. Conclusions, Limitations, and Recommendations

5.6.1. Conclusions

This study evaluates four beverage can packaging designs in two end markets (the US and Europe) to further GPI's understanding of how its products compare to those of the competition. The results indicate that raw material production and package manufacturing drive impact, as does transporting paper rolls to Europe for the European market. They also show that if beverage manufacturers were to switch from the Carton or Wrap+Tray to the KeelClip or Hi-Cone rings, they would be able to reduce potential impact of beverage can packaging.

Overall, the Hi-Cone rings have the lowest potential environmental impacts as this design has the lowest material mass. This is generally followed by the KeelClip as it, too, has lower material mass compared to the 18-pack designs. The only impact category in which the KeelClip out-performs the Hi-Cone rings is energy resource use under the US end market as the Hi-Cone rings is a fossil plastic-based product, whereas the KeelClip is paper-based.

The Carton and Wrap+Tray are generally associated with the highest potential environmental impacts—although which one is higher depends on impact category and end market. In general, the Carton is associated with similar or lower potential impact for the US end market, but higher potential impact for the European market. This is due to the need to transport paper rolls to Europe from GPI's US paperboard mills, combined with the lower potential impact of average corrugate production in Europe.

The European methodology Environmental Footprint v3.0 was used as it is primarily GPI's European customers who are interested in this analysis. However, results were calculated using the US TRACI 2.1 methodology. Except for eutrophication potential, the different methodology did not conclusions—thus showing the robustness of results and independence of the methodology applied.

5.6.2. Limitations

The Carton and KeelClip packaging designs are specific to production by GPI, whereas the Wrap+Tray and Hi-Cone designs are intended to represent industry averages. Changes to the packaging designs, manufacturing processes, supply chain, etc. could influence study results.

Only the relevant impact categories (as outlined in section 2.6) are considered. Impact categories not considered include abiotic depletion potential of elements (i.e. mineral resources), land use, and toxicity as these were deemed not relevant to packaging. Consequently, issues such as heavy metal emissions to air from bunker oil combustion in container ships are not captured as heavy metals do not contribute to impact categories considered.

Furthermore, the characterization factors developed for the impact categories considered assume emissions from land-based sources in Europe or the US. Most emissions from container ships do not happen near land, and the ships typically switch to cleaner fuels once they approach coastlines due to internal conventions. Thus, it is possible that emissions of nitrogen oxides, sulfur oxides, and particulate matter would have different characterization factors when released over the open ocean rather than over land.

Life cycle assessment, furthermore, does not address the issue of ocean plastic. Increasingly, plastic from packaging and other sources is finding its way into the oceans rather than to a recycling, landfill, or incineration facility. Specifically, plastic beverage can holders like Hi-Cone have frequently been found to pose a hazard to wildlife due to entanglement or ingestion. However, since there is no consensus method on assessing oceanic littering regarding its impacts on wildlife, the ecosystem, and humans at present, the potential environmental impacts could not be included in this study.

Additionally, this analysis does not address material circularity. Given that paperboard can be and is recycled in both the US and Europe, an evaluation in a separate study could be worthwhile—especially given differences in recycling rate between paperboard and plastic films.

5.6.3. Recommendations

Although distribution packaging is a minor contributor to potential impact, adding distribution packaging for the Wrap+Tray scenario would be ideal in interest of completeness and consistency. Furthermore, a 50/50 split is assumed for paperboard rolls shipped from the US mills to Europe. GPI may wish to revisit this assumption in the future to more accurately represent its European production.

The results indicate that paperboard mills represent the majority of potential environmental impact. If GPI desires to reduce the impact of their products, this would require reducing energy consumption as most of the LCIA results are, in turn, driven by emissions at the mill (e.g., combustion emissions and dust). Emissions from transporting paper products to Europe also account for a significant contribution to select impact categories. If GPI could avoid this transportation step—for example, by working with a partner in Europe—environmental footprint reductions may be feasible.

Finally, a future step may be to evaluate the packaging designs using the Material Circularity Indicator, as provided by the Ellen MacArthur Foundation, to better understand how the packaging designs perform under this methodology.

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Appendix A. Confidential Data

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Appendix B. Life Cycle Inventory Results

Key input and output flows are presented in Table B-1 and Table B-2, respectively. The full LCI is typically comprised of hundreds of flows so only the ones relevant to impact assessment results presented in section 4 are presented.

Table B-1 shows input flows for renewable and non-renewable energy, water, and biogenic carbon dioxide. Energy and water flows affect energy resource use and water scarcity impact categories, respectively. Biogenic carbon dioxide contributes to global warming potential, although its characterization factor is -1 kg CO_2 eq. / kg as it represents the uptake of carbon dioxide from the atmosphere due to biomass growth.

Output flows are presented in Table B-2. Water flows represent water returned to a river either following wastewater treatment, after passing through a turbine to generate hydro power, or another such process. Net water consumption is the difference between input water flows in Table B-1 and output water flows in Table B-2. Emission flows represent the release of substances to air, water, and soil. As mentioned above, only the ones relevant to impact categories listed in section 2.6 are shown.

Table B-1: Key LCI input flows

Input flow	Units	US: Carton	US: KeelClip	US: Wrap+Tray	US: Hi-Cone	EU: Carton	EU: KeelClip	EU: Wrap+Tray	EU: Hi-Cone
Energy									
Crude oil	MJ	3.27E+01	2.39E+01	4.05E+01	1.41E+01	4.23E+01	2.89E+01	6.82E+01	3.17E+01
Anthracite & bituminous	MJ	1.17E+01	6.43E+00	3.98E+01	8.57E+00	6.34E+00	3.56E+00	7.25E+00	3.62E+00
Lignite	MJ	6.82E-01	4.17E-01	8.84E-01	6.46E-01	1.18E+00	6.95E-01	5.79E+00	2.93E+00
Natural gas	MJ	9.28E+01	4.92E+01	1.13E+02	4.39E+01	8.43E+01	4.47E+01	6.44E+01	1.78E+01
Uranium	MJ	5.61E+00	3.14E+00	7.77E+00	5.38E+00	1.61E+01	8.74E+00	1.10E+01	7.06E+00
Geothermal	MJ	6.80E-02	4.02E-02	2.38E-01	1.89E-01	6.39E-02	3.76E-02	1.18E-01	8.28E-02
Hydro power	MJ	6.24E-01	3.70E-01	1.18E+00	9.22E-01	1.67E+00	9.33E-01	2.34E+00	1.55E+00
Solar	MJ	3.27E+02	1.75E+02	5.17E+00	1.72E+00	3.35E+02	1.81E+02	3.39E+01	4.60E+00
Wind power	MJ	6.80E-01	4.15E-01	1.67E+00	1.34E+00	1.58E+00	8.97E-01	3.29E+00	2.35E+00
Water									
Ground water	L	1.27E+02	6.59E+01	3.04E+01	8.12E+00	1.20E+02	6.22E+01	4.87E+01	8.55E+00
Lake water	L	1.49E+02	8.75E+01	2.92E+02	2.33E+02	2.75E+02	1.55E+02	4.24E+02	2.75E+02
River water	L	9.45E+02	5.84E+02	1.16E+03	8.94E+02	5.65E+03	3.11E+03	7.19E+03	4.61E+03
Resources									
Carbon dioxide, biogenic	kg	2.00E+01	1.06E+01	8.18E+00	1.72E-01	1.89E+01	9.98E+00	2.87E+00	3.29E-01

Table B-2: Key LCI output flows

Output flow	Units	US: Carton	US: KeelClip	US: Wrap+Tray	US: Hi-Cone	EU: Carton	EU: KeelClip	EU: Wrap+Tray	EU: Hi-Cone
Water									
Cooling water to river	L	7.98E+01	4.62E+01	9.44E+01	6.84E+01	9.49E+01	5.42E+01	1.19E+02	6.69E+01
Processed water to river	L	2.54E+02	1.34E+02	1.28E+02	3.24E+00	2.46E+02	1.29E+02	4.82E+01	5.00E+00
Turbined water to river	L	8.37E+02	5.30E+02	1.35E+03	1.05E+03	5.64E+03	3.10E+03	7.42E+03	4.81E+03
Emissions to air									
Ammonia	kg	1.55E-03	8.56E-04	1.17E-03	4.29E-05	5.11E-04	2.68E-04	2.88E-04	4.99E-05
Carbon dioxide, biogenic	kg	1.67E+01	8.77E+00	6.55E+00	1.17E-01	1.70E+01	8.94E+00	2.28E+00	2.78E-01
Carbon dioxide, fossil	kg	8.91E+00	4.90E+00	9.99E+00	2.89E+00	8.81E+00	4.84E+00	7.85E+00	2.56E+00
Carbon monoxide	kg	2.34E-02	1.25E-02	1.05E-02	1.58E-03	2.44E-02	1.31E-02	8.84E-03	1.59E-03
Methane	kg	2.30E-02	1.25E-02	3.15E-02	1.03E-02	2.09E-02	1.13E-02	1.71E-02	6.24E-03
Methane, biogenic	kg	4.74E-02	2.66E-02	3.99E-02	2.21E-04	2.88E-02	1.61E-02	1.32E-02	4.48E-04
Nitrogen dioxide	kg	2.55E-04	1.36E-04	1.33E-04	2.35E-05	3.80E-04	2.01E-04	1.75E-04	2.19E-05
Nitrogen monoxide	kg	1.09E-03	5.87E-04	7.79E-04	8.89E-05	1.29E-03	6.88E-04	1.31E-03	8.25E-05
Nitrogen oxides	kg	2.55E-02	1.39E-02	2.60E-02	3.74E-03	3.79E-02	2.03E-02	1.22E-02	3.04E-03
Nitrous oxide	kg	2.35E-04	1.28E-04	4.96E-04	4.33E-05	2.28E-04	1.24E-04	2.21E-04	4.77E-05
Non-methane VOCs	kg	1.85E-03	1.03E-03	3.20E-03	2.71E-04	2.25E-03	1.24E-03	3.51E-03	7.22E-04
Sulfur dioxide	kg	1.08E-02	5.92E-03	3.73E-02	1.58E-03	1.52E-02	8.13E-03	6.04E-03	2.06E-03
Sulfur oxides	kg	2.20E-05	1.17E-05	1.81E-06	3.63E-06	6.24E-05	3.32E-05	1.81E-06	3.63E-06
VOC (unspecified)	kg	1.67E-02	8.55E-03	0.00E+00	2.35E-05	1.61E-02	8.25E-03	0.00E+00	2.35E-05
Emissions to fresh water									
Ammonia	kg	1.55E-03	8.56E-04	1.17E-03	4.29E-05	5.11E-04	2.68E-04	2.88E-04	4.99E-05
Biological oxygen demand	kg	1.05E-02	5.41E-03	5.74E-03	3.10E-05	1.05E-02	5.42E-03	1.09E-03	2.15E-05
Chemical oxygen demand	kg	1.01E-01	5.27E-02	5.01E-03	1.67E-03	1.06E-01	5.50E-02	1.14E-02	1.46E-03
Nitrate	kg	1.26E-03	6.63E-04	4.71E-04	1.10E-04	1.38E-03	7.29E-04	1.67E-03	2.02E-04
Nitrogen organic bound	kg	1.19E-03	6.19E-04	2.42E-04	2.01E-05	1.18E-03	6.16E-04	7.43E-04	4.66E-05
Phosphate	kg	2.69E-04	1.40E-04	1.10E-04	4.80E-06	2.62E-04	1.37E-04	1.77E-04	1.06E-05
Phosphorus	kg	1.10E-04	6.08E-05	1.80E-04	1.21E-06	8.29E-05	4.56E-05	5.91E-05	1.35E-06

Output flow	Units	US: Carton	US: KeelClip	US: Wrap+Tray	US: Hi-Cone	EU: Carton	EU: KeelClip	EU: Wrap+Tray	EU: Hi-Cone
Emissions to sea water									
Ammonia	kg	1.55E-03	8.56E-04	1.17E-03	4.29E-05	5.11E-04	2.68E-04	2.88E-04	4.99E-05
Ammonium / ammonia	kg	1.22E-08	6.44E-09	1.94E-08	5.57E-09	1.11E-08	5.89E-09	7.42E-09	3.20E-09
Biological oxygen demand	kg	1.05E-02	5.41E-03	5.74E-03	3.10E-05	1.05E-02	5.42E-03	1.09E-03	2.15E-05
Chemical oxygen demand	kg	1.01E-01	5.27E-02	5.01E-03	1.67E-03	1.06E-01	5.50E-02	1.14E-02	1.46E-03
Phosphate	kg	2.69E-04	1.40E-04	1.10E-04	4.80E-06	2.62E-04	1.37E-04	1.77E-04	1.06E-05
Phosphorus	kg	1.10E-04	6.08E-05	1.80E-04	1.21E-06	8.29E-05	4.56E-05	5.91E-05	1.35E-06

Appendix C. Additional Background Data

Additional background datasets used to model chemicals and colorants in GPI papermills and converting plants are provided in Table C-1. Key datasets are in section 3.6.

Table C-1: Other material and process datasets used in inventory analysis

Material / Process	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
Water	U.S.	US: Water deionized	Sphera	2019	No
Tap water	U.S.	US: Tap water from groundwater	Sphera	2019	No
Tap water	France	EU-28: Tap water from groundwater	Sphera	2019	No
Chemicals					
Alum	U.S.	US: Aluminium sulphate (estimation)	Sphera	2019	No
Calcium hydroxide	U.S.	US: Calcium hydroxide (Ca(OH)2; dry; slaked lime)	Sphera	2019	No
Cationic starch	U.S.	US: Dried starch (corn wet mill) (economic allocation)	Sphera	2019	No
Defoamer	U.S.	US: Wax / Paraffins at refinery	Sphera	2016	No
	U.S.	US: Propylene glycol (via PO-hydrogenation)	Sphera	2019	No
Dispersing agent	U.S.	GLO: Soaping agent (phosphonic acid and foam stabilizers)	Sphera	2019	Yes
	U.S.	US: Sodium hydroxide (from chlorine-alkali electrolysis, diaphragm)	Sphera	2019	No
	U.S.	DE: Polyacrylate dispersion (solid content)	Sphera	2019	Yes
	U.S.	US: Triple superphosphate (TSP)	Sphera	2019	Yes
Dry strength (acrylamide)	U.S.	US: Acrylonitrile (AN) by product ammonium sulfate, hydrogen cyanide	Sphera	2019	No
	U.S.	US: Sulphuric acid aq. mix (96%)	Sphera	2019	No
	U.S.	US: Ammonia (NH3) without CO2 recovery (carbon dioxide emissions to air)	Sphera	2019	No
Fertilizer	U.S.	US: Phosphate concentrate (raw phosphate 31.9%)	Sphera	2019	No
	U.S.	US: Ammonium nitrate (AN, solution)	Sphera	2019	No
Flocculant	U.S.	DE: Polyacrylamide (cationic), powder	Sphera	2019	Yes
Oxidized starch	U.S.	US: Starch (from winter wheat)	Sphera	2019	No
Rosin	U.S.	EU-28: Colophony (rosin)	Sphera	2019	Yes
Soda ash	U.S.	US: Soda (Na2CO3)	Sphera	2019	No
Sodium hydrosulfide	U.S.	EU-28: Hydrogen sulphide	Sphera	2019	Yes

Material / Process	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
	U.S.	US: Sodium hydroxide (from chlorine-alkali electrolysis, diaphragm)	Sphera	2019	Yes
Sodium hydroxide	U.S.	US: Sodium hydroxide (caustic soda) mix (100%)	Sphera	2019	No
Sodium hypochlorite	U.S.	US: Sodium hypochlorite solution	Sphera	2019	No
Sulfuric acid	U.S.	US: Sulphuric acid aq. mix (96%)	Sphera	2019	No
Water treatment polymer	U.S.	US: Wax / Paraffins at refinery	Sphera	2016	Yes
	U.S.	US: Maleic anhydride (MSA) (via oxidation of xylol)	Sphera	2019	Yes
	U.S.	DE: Acrylamide (enzymatic hydration) (50% solution)	Sphera	2019	Yes
	U.S.	US: Citric acid (from starch)	Sphera	2019	Yes
Wet strength (polyamide epichlorohydrin)	U.S.	US: Polyamide 6 Granulate (PA 6)	Sphera	2019	Yes
	U.S.	US: Glycerine (from Epichlorohydrine)	Sphera	2019	Yes
Colorants					
AK clay	U.S.	US: Kaolin (mining and processing)	Sphera	2019	No
Alco-gum	U.S.	GLO: Soaping agent (acrylic polymer)	Sphera	2019	Yes
Ammonia water	U.S.	US: Ammonia water (weight share 25% NH3)	Sphera	2019	No
BR clay	U.S.	US: Kaolin (mining and processing)	Sphera	2019	No
Dyes	U.S.	DE: Dyes	Sphera	2019	Yes
Glyoxal	U.S.	US: Ethylene glycol (from ethene and oxygen via EO)	Sphera	2019	No
Polyco 2160	U.S.	EU-28: Polyvinyl acetate (PVAC) (estimation)	Sphera	2019	Yes
Polyco 3960	U.S.	EU-28: Polyvinyl acetate (PVAC) (estimation)	Sphera	2019	Yes
	U.S.	US: Acrylic acid (Propene)	Sphera	2019	No
SA latex	U.S.	EU-28: Styrene acrylate	Sphera	2019	No
Sterocoll	U.S.	US: Dried starch (corn wet mill) (economic allocation)	Sphera	2019	Yes
	U.S.	DE: Methyl acrylate from acrylic acid by esterification	Sphera	2019	Yes
Titanium dioxide	U.S.	US: Titanium dioxide pigment (sulphate process)	Sphera	2019	No
TR clay	U.S.	US: Kaolin (mining and processing)	Sphera	2019	No
Converting					
Cold glue	U.S., France	DE: Polyvinyl acetate (PVAC) (estimation)	Sphera	2019	Yes
Extender	U.S., France	US: Dimethylamine	Sphera	2019	Yes
	U.S., France	US: Ethylene oxide (EO) via air	Sphera	2019	Yes
	U.S., France	US: Isopropanol	Sphera	2019	Yes

Material / Process	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
	U.S., France	US: Propylene glycol (via PO-hydrogenation)	Sphera	2019	Yes
	U.S., France	DE: Urea (stamicarbon process)	Sphera	2019	Yes
Hot melt glue	U.S., France	DE: Polyvinyl acetate (PVAC) (estimation)	Sphera	2019	Yes
	U.S., France	US: Wax / Paraffins at refinery	Sphera	2016	Yes
	U.S., France	EU-28: Colophony (rosin)	Sphera	2019	Yes
Imaje ink	U.S., France	DE: Dyes	Sphera	2019	Yes
	U.S., France	US: Ethanol (96%) (hydrogenation with nitric acid)	Sphera	2019	Yes
	U.S., France	US: Isopropanol	Sphera	2019	Yes
	U.S., France	US: Methanol from natural gas (combined reforming)	Sphera	2019	Yes
Ink	U.S., France	DE: Styrene acrylonitrile (SAN)	Sphera	2019	Yes
	U.S., France	GLO: Soaping agent (acrylic polymer)	Sphera	2019	Yes
	U.S., France	US: Urea (stamicarbon process)	Sphera	2019	Yes
	U.S., France	US: Ammonia water (weight share 25% NH3)	Sphera	2019	Yes
	U.S., France	US: Isopropanol	Sphera	2019	Yes
	U.S., France	US: Glycerine (from Epichlorohydrine)	Sphera	2019	Yes
	U.S., France	US: Ethylene glycol (from ethene and oxygen via EO)	Sphera	2019	Yes
	U.S., France	DE: Dyes	Sphera	2019	Yes
Isopropanol	U.S., France	US: Isopropanol	Sphera	2019	Yes
Make-up fluid	U.S., France	US: Ethanol (96%) (hydrogenation with nitric acid)	Sphera	2019	Yes
	U.S., France	US: Methyl isobutyl ketone (MIBK)	Sphera	2019	Yes
Non-skid flexo Gloss	U.S., France	US: Ammonia water (weight share 25% NH3)	Sphera	2019	Yes
	U.S., France	US: Isopropanol	Sphera	2019	Yes
	U.S., France	US: Polyethylene film (LDPE/PE-LD)	Sphera	2019	Yes
	U.S., France	DE: Styrene acrylonitrile (SAN)	Sphera	2019	Yes
pH adjuster	U.S., France	US: Dimethylamine	Sphera	2019	Yes
	U.S., France	US: Ethylene oxide (EO) via air	Sphera	2019	Yes

Additional information on the US softwood log mix, used to model logs for GPI's mills, is provided in Table C-2. This dataset is used internally at Sphera and was developed to model US lumber and adapt European FEFCO data to US conditions. It was chosen over CORRIM's softwood lumber dataset as lumber includes kiln drying, which is not needed for logs sent to a paperboard mill.

The softwood dataset assumes a mix of 50% pine and 50% spruce. The forestry and harvesting of the pine and spruce, in turn, are modeled. Logs are assumed to be 100% moisture upon arrival at GPI's mills.

Table C-2: US softwood LCIA results (per kg)

	US: Log softwood mix	US: Pine log free forest track	US: Spruce log free forest track
IPCC AR5			
Climate change, excl. bio. CO_2	8.58E-01	1.36E+00	2.12E+00
Climate change, incl. bio. CO_2	-7.20E-01	2.48E-01	2.12E+00
EF 3.0			
Acidification [mol H^+ eq]	2.09E-03	1.36E-02	6.09E-03
Eutrophication, freshwater [kg P eq]	2.34E-05	4.39E-05	2.83E-06
Eutrophication, terrestrial [mol N eq]	8.64E-03	2.03E-02	1.29E-02
Ionizing radiation [kBq U235 eq]	5.11E-04	4.67E-04	5.44E-04
Land use [Pt]	4.88E+01	2.25E+00	4.50E-01
Ozone depletion [kg CFC11 eq]	1.45E-11	5.14E-08	4.64E-15
Photochem. ozone form. [kg NMVOC eq]	2.20E-03	6.53E-03	5.71E-03
Resource use, energy [MJ LHV]	1.16E+01	1.76E+01	7.72E+01
Resp. [disease incidences]	2.65E-08	1.62E-07	5.40E-08
Water [m^3 world eq.]	2.50E-01	2.81E-01	4.71E-01
TRACI 2.1			
Acidification [kg SO_2 eq]	1.89E-03	1.14E-02	5.24E-03
Eutrophication [kg N eq]	6.82E-04	8.86E-04	2.72E-04
Particulates [kg PM 2.5 eq]	1.31E-04	9.43E-04	3.23E-04
Ozone depletion [kg CFC11 eq]	1.93E-11	6.84E-08	6.19E-15
Resources [MJ surplus]	1.43E+00	1.69E+00	1.04E+01
Smog formation [kg O_3 eq]	4.58E-02	1.15E-01	7.97E-02

Table C-3 presents LCIA results for 1 kg of corrugate and 1 kg LDPE film as represented by average U.S. and European datasets. These datasets are listed in Table 3-13 and are used to model the Wrap+Tray packaging scenario, as well as distribution packaging for the Carton, KeelClip, and Hi-Cone scenarios. The European average corrugate is based on FEFCO data (FEFCO, 2015) and represents product with 94% recycled content; the US average dataset is based on NCASI's study (NCASI, 2017) and represents product with 52% recycled content.

Table C-3: European versus US average for corrugate and LDPE film (per kg)

	US: Corrugate	EU: Corrugate	US: LDPE film	EU: LDPE film
IPCC AR5				
Climate change, excl. bio. CO_2	1.36E+00	8.58E-01	3.04E+00	2.12E+00
Climate change, incl. bio. CO_2	2.48E-01	-7.20E-01	3.04E+00	2.12E+00
EF 3.0				
Acidification [mol H^+ eq]	1.36E-02	2.09E-03	4.52E-03	6.09E-03
Eutrophication, freshwater [kg P eq]	4.39E-05	2.34E-05	1.71E-06	2.83E-06
Eutrophication, terrestrial [mol N eq]	2.03E-02	8.64E-03	1.71E-02	1.29E-02
Ionizing radiation [kBq U235 eq]	1.90E-02	4.99E-02	9.42E-02	1.76E-01
Land use [Pt]	2.25E+00	4.88E+01	1.37E+00	4.50E-01
Ozone depletion [kg CFC11 eq]	5.14E-08	1.45E-11	2.85E-15	4.64E-15
Photochem. ozone form. [kg NMVOC eq]	6.53E-03	2.20E-03	4.72E-03	5.71E-03
Resource use, energy [MJ LHV]	1.76E+01	1.16E+01	8.81E+01	7.72E+01
Resp. [disease incidences]	1.62E-07	2.65E-08	3.75E-08	5.40E-08
Water [m^3 world eq.]	2.81E-01	2.50E-01	4.64E-01	4.71E-01
TRACI 2.1				
Acidification [kg SO_2 eq]	1.14E-02	1.89E-03	4.10E-03	5.24E-03
Eutrophication [kg N eq]	8.86E-04	6.82E-04	2.82E-04	2.72E-04
Particulates [kg PM 2.5 eq]	9.43E-04	1.31E-04	2.11E-04	3.23E-04
Ozone depletion [kg CFC11 eq]	6.84E-08	1.93E-11	3.80E-15	6.19E-15
Resources [MJ surplus]	1.69E+00	1.43E+00	1.19E+01	1.04E+01
Smog formation [kg O_3 eq]	1.15E-01	4.58E-02	9.91E-02	7.97E-02

Appendix D. Other LCIA Results

Life cycle impact assessment results for TRACI 2.1 impact categories are included in this section. A summary of these results is presented as a scenario analysis in section 4.3.2. The following tables include the breakdown by life cycle stage.

Table D-1: Acidification (TRACI 2.1) results per functional unit [kg SO_2 eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	3.80E-03	1.95E-03	-	-	3.83E-03	2.00E-03	-	-
Papermill	2.05E-02	1.05E-02	-	-	2.04E-02	1.04E-02	-	-
Converting	5.84E-03	3.11E-03	-	-	2.52E-03	1.34E-03	-	-
Production	-	-	5.74E-02	3.84E-03	-	-	1.46E-02	4.06E-03
Packaging	-	-	0.00E+00	1.79E-04	-	-	0.00E+00	1.79E-04
Filling	5.94E-04	1.14E-03	1.28E-03	1.23E-04	4.67E-04	1.08E-03	1.33E-03	1.19E-04
Transport	1.68E-03	8.77E-04	9.66E-04	3.46E-04	1.87E-02	9.60E-03	9.66E-04	3.46E-04
End of life	4.61E-03	2.62E-03	2.79E-03	1.25E-04	5.93E-04	3.38E-04	4.68E-04	7.81E-05
Total	**3.70E-02**	**2.02E-02**	**6.24E-02**	**4.62E-03**	**4.64E-02**	**2.48E-02**	**1.74E-02**	**4.78E-03**

Table D-2: Eutrophication (TRACI 2.1) results per functional unit [kg N eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	3.11E-04	1.59E-04	-	-	3.13E-04	1.64E-04	-	-
Papermill	8.86E-03	4.54E-03	-	-	9.07E-03	4.65E-03	-	-
Converting	4.72E-04	2.52E-04	-	-	3.99E-04	2.13E-04	-	-
Production	-	-	4.41E-03	2.73E-04	-	-	3.45E-03	3.12E-04
Packaging	-	-	0.00E+00	1.81E-05	-	-	0.00E+00	1.81E-05
Filling	7.47E-05	1.58E-04	9.70E-05	1.03E-05	5.13E-05	1.46E-04	1.24E-04	1.13E-05
Transport	2.69E-04	1.41E-04	1.08E-04	3.05E-05	9.27E-04	4.78E-04	1.08E-04	3.05E-05
End of life	7.84E-04	4.46E-04	4.49E-04	7.51E-06	1.21E-04	6.90E-05	7.62E-05	4.96E-06
Total	**1.08E-02**	**5.70E-03**	**5.06E-03**	**3.40E-04**	**1.09E-02**	**5.72E-03**	**3.76E-03**	**3.76E-04**

Table D-3: Human health particulate (TRACI 2.1) results per functional unit [kg PM2.5 eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	4.32E-04	2.21E-04	-	-	4.35E-04	2.27E-04	-	-
Papermill	4.70E-03	2.41E-03	-	-	4.61E-03	2.36E-03	-	-
Converting	5.86E-04	3.12E-04	-	-	5.22E-04	2.78E-04	-	-
Production	-	-	4.59E-03	2.17E-04	-	-	9.68E-04	2.10E-04
Packaging	-	-	0.00E+00	3.33E-05	-	-	0.00E+00	3.33E-05
Filling	2.84E-05	6.80E-05	8.47E-05	7.54E-06	2.55E-05	6.64E-05	7.50E-05	6.47E-06
Transport	9.47E-05	4.96E-05	3.44E-05	1.54E-05	1.72E-03	8.83E-04	3.44E-05	1.54E-05
End of life	1.02E-04	5.83E-05	6.99E-05	7.27E-06	2.03E-05	1.16E-05	1.76E-05	3.53E-06
Total	**5.95E-03**	**3.12E-03**	**4.78E-03**	**2.81E-04**	**7.33E-03**	**3.83E-03**	**1.09E-03**	**2.69E-04**

Table D-4: Resources, fossil (TRACI 2.1) results per functional unit [MJ surplus]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	9.02E-01	4.62E-01	-	-	9.08E-01	4.75E-01	-	-
Papermill	1.27E+01	6.51E+00	-	-	1.21E+01	6.20E+00	-	-
Converting	2.41E+00	1.28E+00	-	-	1.65E+00	8.77E-01	-	-
Production	-	-	2.14E+01	8.31E+00	-	-	1.84E+01	7.06E+00
Packaging	-	-	0.00E+00	3.44E-02	-	-	0.00E+00	3.44E-02
Filling	3.36E-01	1.30E+00	8.75E-01	7.39E-02	2.88E-01	1.27E+00	4.62E-01	3.94E-02
Transport	1.96E+00	1.03E+00	5.60E-01	1.03E-01	3.37E+00	1.75E+00	5.60E-01	1.03E-01
End of life	1.80E-01	1.02E-01	1.78E-01	4.37E-02	1.17E-01	6.67E-02	1.02E-01	2.07E-02
Total	**1.85E+01**	**1.07E+01**	**2.30E+01**	**8.56E+00**	**1.84E+01**	**1.06E+01**	**1.95E+01**	**7.26E+00**

Table D-5: Smog formation (TRACI 2.1) results per functional unit [kg O_3 eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	1.28E-01	6.56E-02	-	-	1.29E-01	6.74E-02	-	-
Papermill	4.72E-01	2.42E-01	-	-	4.74E-01	2.43E-01	-	-
Converting	7.35E-02	3.91E-02	-	-	4.99E-02	2.66E-02	-	-
Production	-	-	6.43E-01	7.98E-02	-	-	3.02E-01	6.44E-02
Packaging	-	-	0.00E+00	2.59E-03	-	-	0.00E+00	2.59E-03
Filling	7.39E-03	2.20E-02	1.82E-02	1.65E-03	7.84E-03	2.23E-02	1.77E-02	1.56E-03
Transport	3.66E-02	1.92E-02	2.19E-02	1.09E-02	3.75E-01	1.93E-01	2.19E-02	1.09E-02
End of life	2.12E-02	1.20E-02	1.53E-02	2.00E-03	1.09E-02	6.22E-03	8.38E-03	1.30E-03
Total	**7.38E-01**	**4.00E-01**	**6.98E-01**	**9.69E-02**	**1.05E+00**	**5.58E-01**	**3.50E-01**	**8.07E-02**

EF 3.0 results for ionizing radiation and land use are also included in this appendix. Ionizing radiation is added because GPI's converting facility in France, where nuclear power represents a significant fraction of grid mix, is used to represent paperboard converting in Europe (although GPI has converting facilities elsewhere in Europe). Land use is added to address the forestry and mining required by paper and plastic, respectively.

Ionizing radiation results are shown in Figure D-1 and Table D-6. Converting dominates the Carton and KeelClip results for Europe due to France's grid mix, which uses a lot of nuclear power. Nuclear power in Europe's average grid mix also influences Wrap+Tray and Hi-Cone production and filling, which are modeled with European average datasets.

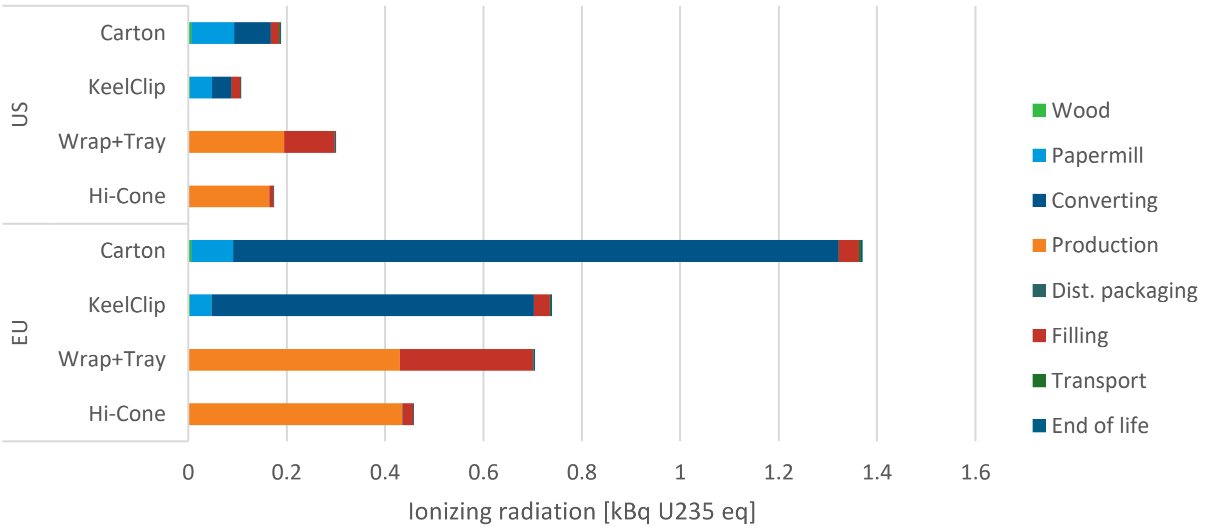

Figure D-1: Ionizing radiation (EF 3.0) results per functional unit

Table D-6: Ionizing radiation (EF 3.0) results per functional unit [kBq U235 eq]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	6.74E-03	3.46E-03	-	-	6.79E-03	3.55E-03	-	-
Papermill	8.69E-02	4.46E-02	-	-	8.50E-02	4.36E-02	-	-
Converting	7.43E-02	3.96E-02	-	-	1.23E+00	6.55E-01	-	-
Production	-	-	1.95E-01	1.64E-01	-	-	4.30E-01	4.35E-01
Packaging	-	-	0.00E+00	8.36E-04	-	-	0.00E+00	8.36E-04
Filling	1.66E-02	1.84E-02	1.03E-01	8.40E-03	4.12E-02	3.27E-02	2.71E-01	2.21E-02
Transport	2.29E-03	1.20E-03	8.13E-04	1.50E-04	4.00E-03	2.07E-03	8.13E-04	1.50E-04
End of life	1.54E-03	8.77E-04	1.54E-03	3.85E-04	3.38E-03	1.92E-03	3.30E-03	8.03E-04
Total	**1.88E-01**	**1.08E-01**	**3.00E-01**	**1.74E-01**	**1.37E+00**	**7.39E-01**	**7.05E-01**	**4.58E-01**

Land use results are shown in Figure D-2 and Table D-7. These results for the Carton and KeelClip are driven by softwood log and other biomass production. The Wrap+Tray packaging design for the European end market has a much lower impact since the corrugate is assumed to be produced mostly from recycled content. The Wrap+Tray for the US end market has an even lower impact—possibly because the average LCI dataset does not fully account for land use.

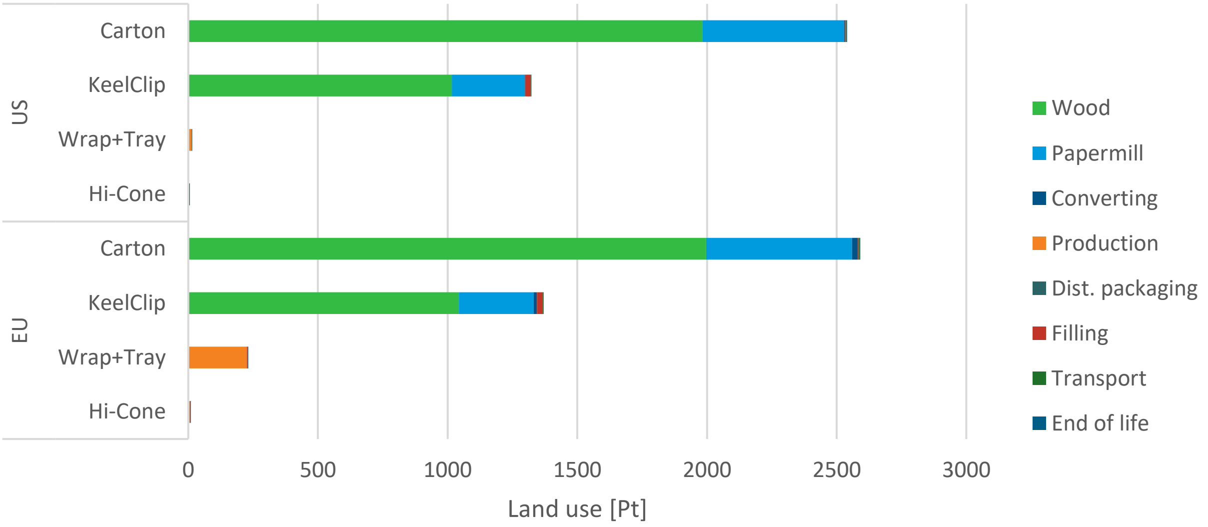

Figure D-2: Land use (EF 3.0) results per functional unit

Table D-7: Land use (EF 3.0) results per functional unit [Pt]

	US				EU			
	Carton	KeelClip	Wrap+Tray	Hi-Cone	Carton	KeelClip	Wrap+Tray	Hi-Cone
Wood	1.98E+03	1.02E+03	-	-	2.00E+03	1.04E+03	-	-
Papermill	5.46E+02	2.80E+02	-	-	5.62E+02	2.88E+02	-	-
Converting	4.54E+00	2.42E+00	-	-	2.26E+01	1.20E+01	-	-
Production	-	-	1.19E+01	2.17E+00	-	-	2.26E+02	5.61E+00
Packaging	-	-	0.00E+00	2.20E+00	-	-	0.00E+00	2.20E+00
Filling	3.55E+00	2.19E+01	1.28E+00	1.07E-01	3.87E+00	2.21E+01	3.47E+00	2.84E-01
Transport	3.33E+00	1.74E+00	9.51E-01	1.76E-01	4.17E+00	2.17E+00	9.51E-01	1.76E-01
End of life	1.71E-01	9.75E-02	1.72E-01	4.34E-02	1.20E-01	6.84E-02	1.27E-01	3.40E-02
Total	**2.54E+03**	**1.32E+03**	**1.43E+01**	**4.69E+00**	**2.59E+03**	**1.37E+03**	**2.30E+02**	**8.30E+00**

Appendix E. Previous Years

Over the past decade, GPI has conducted numerous LCAs of its own products as well as competing products. Additional results are provided in this appendix for continuity with previous analyses.

E.1. Revision of Previous Results

Table E-1 and Table E-2 provide results generated by entering previous years' data into the current model. All results represent a functional unit (i.e., 1,000 12-oz. beverage cans).

Table E-1: 18-pack carton results based on 2012 data

	Total	Wood	Papermill	Converting	Filling	Transport	End of life
IPCC AR5							
Climate change, excl. bio. CO_2	**1.14E+01**	5.78E-01	6.76E+00	1.30E+00	1.87E-01	6.80E-01	1.92E+00
Climate change, incl. bio. CO_2	**6.97E+00**	-1.22E+01	4.78E+00	5.90E-01	7.73E-01	6.76E-01	1.24E+01
EF 3.0							
Acidification [mol H^+ eq]	**4.87E-02**	4.56E-03	3.05E-02	6.16E-03	3.96E-04	1.27E-03	5.77E-03
Eutrophication, freshwater [kg P eq]	**1.52E-04**	3.83E-06	7.43E-05	1.78E-05	9.59E-07	4.65E-06	5.03E-05
Eutrophication, terrestrial [mol N eq]	**1.60E-01**	2.43E-02	9.25E-02	1.12E-02	1.15E-03	6.28E-03	2.50E-02
Land use [Pt]	**2.40E+03**	2.22E+03	1.75E+02	2.92E+00	3.52E+00	2.17E+00	2.26E-01
Ozone depletion [kg CFC11 eq]	**2.00E-08**	2.31E-16	7.49E-14	2.00E-08	1.96E-13	5.42E-17	3.05E-16
Photochem. ozone Form. [kg NMVOC eq]	**4.20E-02**	6.67E-03	2.75E-02	3.54E-03	2.86E-04	1.22E-03	2.80E-03
Resource use, energy [MJ LHV]	**1.54E+02**	7.57E+00	1.10E+02	2.21E+01	3.39E+00	8.98E+00	1.89E+00
Resp. [disease incidences]	**1.52E-06**	1.12E-07	1.27E-06	7.10E-08	3.70E-09	1.58E-08	4.31E-08
Water [m^3 world eq.]	**3.40E+00**	5.12E-02	3.07E+00	1.79E-01	3.09E-02	5.59E-02	1.70E-02
TRACI 2.1							
Acidification [kg SO_2 eq]	**4.62E-02**	4.26E-03	2.79E-02	5.27E-03	3.70E-04	1.15E-03	7.26E-03
Eutrophication [kg N eq]	**8.61E-03**	3.48E-04	6.34E-03	4.30E-04	4.20E-05	1.79E-04	1.27E-03
Particulates [kg PM 2.5 eq]	**6.86E-03**	4.83E-04	5.72E-03	4.13E-04	2.20E-05	6.51E-05	1.58E-04
Ozone depletion [kg CFC11 eq]	**2.66E-08**	3.08E-16	9.99E-14	2.66E-08	2.62E-13	7.23E-17	4.07E-16
Resources [MJ surplus]	**1.82E+01**	1.01E+00	1.29E+01	2.45E+00	3.14E-01	1.28E+00	2.46E-01
Smog formation [kg O_3 eq]	**8.48E-01**	1.43E-01	5.82E-01	6.45E-02	5.82E-03	2.52E-02	2.77E-02

Table E-2: 18-pack carton results based on 2014 data

	Total	Wood	Papermill	Converting	Filling	Transport	End of life
IPCC AR5							
Climate change, excl. bio. CO_2	**1.01E+01**	5.37E-01	5.53E+00	1.26E+00	1.88E-01	6.79E-01	1.92E+00
Climate change, incl. bio. CO_2	**5.50E+00**	-9.85E+00	9.82E-01	5.61E-01	7.75E-01	6.76E-01	1.24E+01
EF 3.0							
Acidification [mol H^+ eq]	**4.87E-02**	4.23E-03	3.09E-02	6.10E-03	3.96E-04	1.27E-03	5.77E-03
Eutrophication, freshwater [kg P eq]	**1.42E-04**	3.55E-06	6.52E-05	1.77E-05	9.60E-07	4.64E-06	5.03E-05
Eutrophication, terrestrial [mol N eq]	**1.47E-01**	2.26E-02	8.12E-02	1.09E-02	1.15E-03	6.29E-03	2.50E-02
Land use [Pt]	**2.44E+03**	2.06E+03	3.74E+02	2.42E+00	3.52E+00	2.17E+00	2.26E-01
Ozone depletion [kg CFC11 eq]	**2.00E-08**	2.15E-16	9.79E-14	2.00E-08	1.96E-13	5.42E-17	3.05E-16
Photochem. ozone Form. [kg NMVOC eq]	**3.95E-02**	6.19E-03	2.56E-02	3.47E-03	2.86E-04	1.22E-03	2.80E-03
Resource use, energy [MJ LHV]	**1.37E+02**	7.02E+00	9.48E+01	2.12E+01	3.40E+00	8.97E+00	1.89E+00
Resp. [disease incidences]	**1.56E-06**	1.04E-07	1.33E-06	7.05E-08	3.71E-09	1.58E-08	4.31E-08
Water [m^3 world eq.]	**3.00E+00**	4.75E-02	2.67E+00	1.76E-01	3.10E-02	5.59E-02	1.70E-02
TRACI 2.1							
Acidification [kg SO_2 eq]	**4.56E-02**	3.95E-03	2.77E-02	5.21E-03	3.71E-04	1.15E-03	7.26E-03
Eutrophication [kg N eq]	**7.91E-03**	3.23E-04	5.67E-03	4.24E-04	4.20E-05	1.79E-04	1.27E-03
Particulates [kg PM 2.5 eq]	**7.08E-03**	4.49E-04	5.98E-03	4.10E-04	2.20E-05	6.51E-05	1.58E-04
Ozone depletion [kg CFC11 eq]	**2.66E-08**	2.86E-16	1.30E-13	2.66E-08	2.62E-13	7.23E-17	4.07E-16
Resources [MJ surplus]	**1.73E+01**	9.37E-01	1.22E+01	2.33E+00	3.14E-01	1.28E+00	2.46E-01
Smog formation [kg O_3 eq]	**7.74E-01**	1.33E-01	5.19E-01	6.30E-02	5.82E-03	2.53E-02	2.77E-02

A comparison of climate change is shown in Figure E-1 and comparisons of other impact categories in Figure E-2. Note that climate change including biogenic CO_2 may not be fully comparable to previous years due to differences primary data and model set-up. The higher eutrophication emissions from 2019 can be partly attributed to COD emissions (chemical oxygen demand), which were not provided by Macon in previous years.

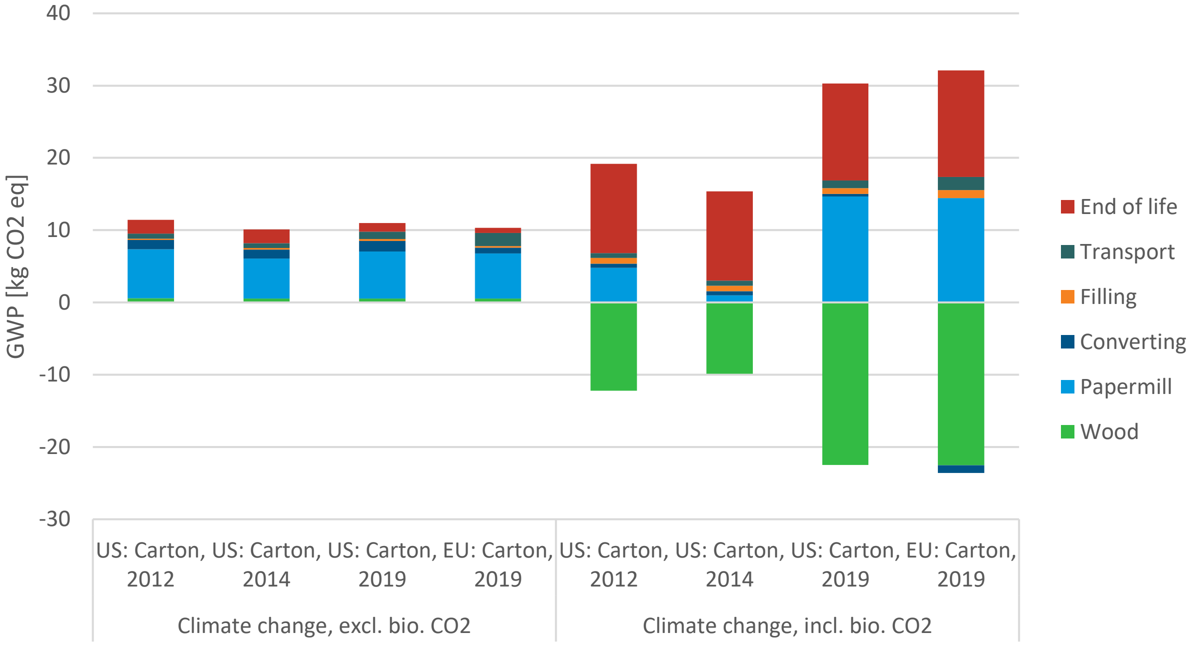

Figure E-1: 18-pack carton climate change comparison to previous years

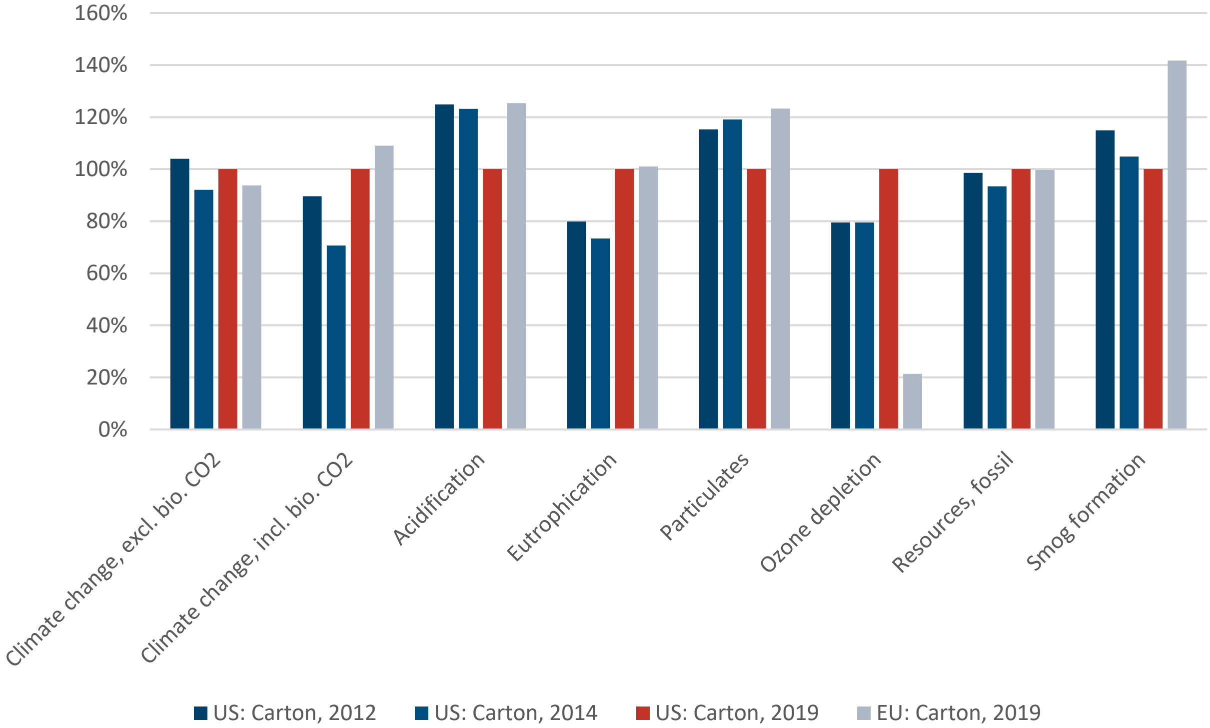

Figure E-2: 18-pack carton comparison to previous years

E.2. Scenario Analysis: End of Life Allocation

The cut-off allocation approach was adopted for the main analysis. This scenario analysis evaluates use of substitution as an alternative approach to allocation. Substitution adopts the ‘net scrap’ approach in which the net amount of scrap entering or leaving the system boundary is first calculated. If more scrap leaves the system boundary than is used by the system (i.e., the system has a net scrap production), the scrap leaving the system is modeled as being recycled and credit based on the virgin material. However, if more scrap is used by the system than is recovered (i.e., the system has a net scrap consumption), then the system is allocated the burden of the virgin material production minus the burden associated with recycling the scrap. Furthermore, credit is given for energy recovered from incineration and landfill gas.

This scenario analysis is included in an appendix rather than the main report body as the data to properly calculate substitution results are not available (see explanation in section 2.4.2). Specifically, the dataset “EU-28: Kraft paper (EN15804 A1-A3)” (see Table E-3), which is intended to represent paper manufactured from 100% virgin content, actually incorporates around 35% recycled content. Older versions of this dataset were used in GPI’s previous studies so substitution results are calculated here for continuity.

Table E-3: End of life datasets

Mode / fuels	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
GPI Paperboard					
Recovery, paperboard	U.S. / Europe	EU-28: Testliner (2015) - for use in avoided burden EoL scenario cases	FEFCO	2015	Geo
Credit, paperboard	U.S. / Europe	EU-28: Kraft paper (EN15804 A1-A3)	Sphera	2019	Geo
Wrap+Tray					
Recovery, shrink wrap	U.S.	US: Polyethylene low density granulate (LDPE/PE-LD) secondary	Sphera	2019	No
Recovery, shrink wrap	Europe	EU-28: Plastic granulate secondary (simplified, non specific)	Sphera	2019	No
Credit, shrink wrap	U.S.	US: Polyethylene Low Density Granulate (LDPE/PE-LD)	Sphera	2019	No
Credit, shrink wrap	Europe	EU-28: Polyethylene Low Density Granulate (LDPE/PE-LD)	Sphera	2019	No
Recovery, corrugate	U.S. / Europe	EU-28: Testliner (2015) - for use in avoided burden EoL scenario cases	FEFCO	2015	Geo
Credit, corrugate	U.S. / Europe	EU-28: Kraft paper (EN15804 A1-A3)	Sphera	2019	Geo
Hi-Cone					
Recovery, plastic rings	U.S.	US: Polyethylene low density granulate (LDPE/PE-LD) secondary	Sphera	2019	No
Recovery, plastic rings	Europe	EU-28: Plastic granulate secondary (simplified, non specific)	Sphera	2019	No
Credit, plastic rings	U.S.	US: Polyethylene Low Density Granulate (LDPE/PE-LD)	Sphera	2019	No
Credit, plastic rings	Europe	EU-28: Polyethylene Low Density Granulate (LDPE/PE-LD)	Sphera	2019	No

Mode / fuels	Geographic Reference	Dataset	Data Provider	Ref. Year	Proxy?
Other					
Recovery + credit, steel banding	U.S. / Europe	GLO: Value of scrap	worldsteel	2017	No
Credit, electricity	U.S.	US: Electricity grid mix	Sphera	2016	No
Credit, electricity	Europe	EU-28: Electricity grid mix	Sphera	2016	No
Credit, steam	U.S.	US: Process steam from natural gas 90%	Sphera	2016	No
Credit, steam	Europe	EU-28: Process steam from natural gas 90%	Sphera	2016	No

Table E-3 lists the datasets used to model material recycling and credits. For example, a dataset for testliner is used to model recycling of paperboard and corrugate, and a dataset for kraft paper to model the credit that represents the burden of virgin material production that is handed over to the subsequent product system. Likewise, datasets for the secondary production of LDPE are used to model the recovery of plastic film—both from the Hi-Cone and Wrap+Tray scenarios—and datasets for LDPE granulate to represent the burden of primary material production being handed over. A comparison of the two allocation approaches is shown in Figure E-3 for climate change, including biogenic CO_2 and in Figure E-4 for energy resource use. Hi-Cone results both with and without post-consumer recycled content are included.

For most packaging design scenarios, calculating climate change results using substitution reduces potential environmental impacts. The Carton, KeelClip, and Wrap+Tray impacts are lower in part due to energy recovery at the incineration and landfill facilities. Under both allocation approaches, the biogenic carbon content of recycled paperboard is ‘handed over’ to a subsequent product life cycle. For the cut-off approach, this handover is modeled as a negative removal of carbon from the atmosphere (see section 3.5); for substitution, virgin material credit is given—and with it, negative carbon removal as well.

The Hi-Cone scenario’s potential environmental impacts are reduced under the substitution allocation approach due to credits for material recycling and energy recovery from incineration. When PCR content is considered for packaging production, the analysis yields the same result as without PCR content. This is because there is a net amount of scrap entering the product system when the Hi-Cone rings are assumed to use 50% PCR. This scrap is allocated the burden of virgin material production; consequently, using PCR content versus virgin content does not affect results under the substitution allocation approach. The higher incineration rate and energy recovery in Europe compared to the US—and corresponding credits—further reduces potential environmental impacts and thus leads to substitution results below those for cut-off—at least for the European end market.

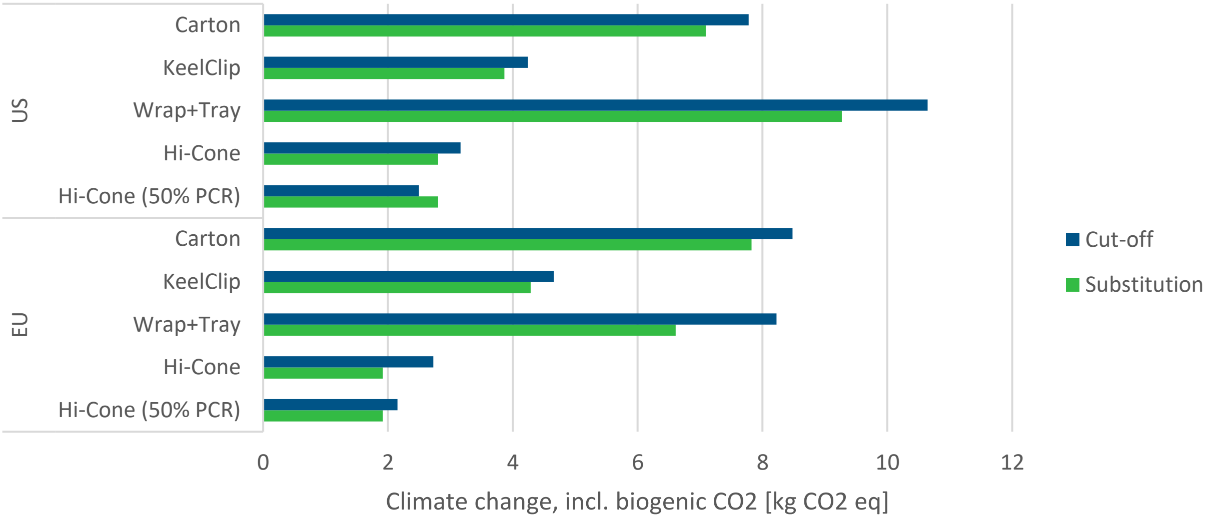

Figure E-3: Effect of allocation approach on climate change results, including biogenic CO_2

Using substitution is shown to slightly increase energy resource use for the Carton and KeelClip (Figure E-4) due to the differences in fossil energy consumption between recycled paper versus virgin paper. Virgin paper production consumes less fossil energy than recycled paper production as virgin papermills are able to use other parts of the logs and wood chips (e.g. lignin, bark, etc.) that are not available to recycled papermills.

Although the Wrap+Tray contains corrugate, the recycling of which increases fossil energy resource use, this increase is offset by credits from recycling plastic and energy recovery at landfill and incineration facilities. Fossil energy resource use is notably decreased for the European Wrap+Tray scenario due to the net amount of paper scrap entering the product system. This paper scrap is allocated the burden of virgin paper production minus the burden of recycled paper production, which has the net effect of reducing fossil energy consumption.

Eutrophication results are shown in Figure E-5 as these tend to be fairly representative of acidification and POF as well—that is, potential environmental impact decreases with the substitution approach due to credits from energy recovery.

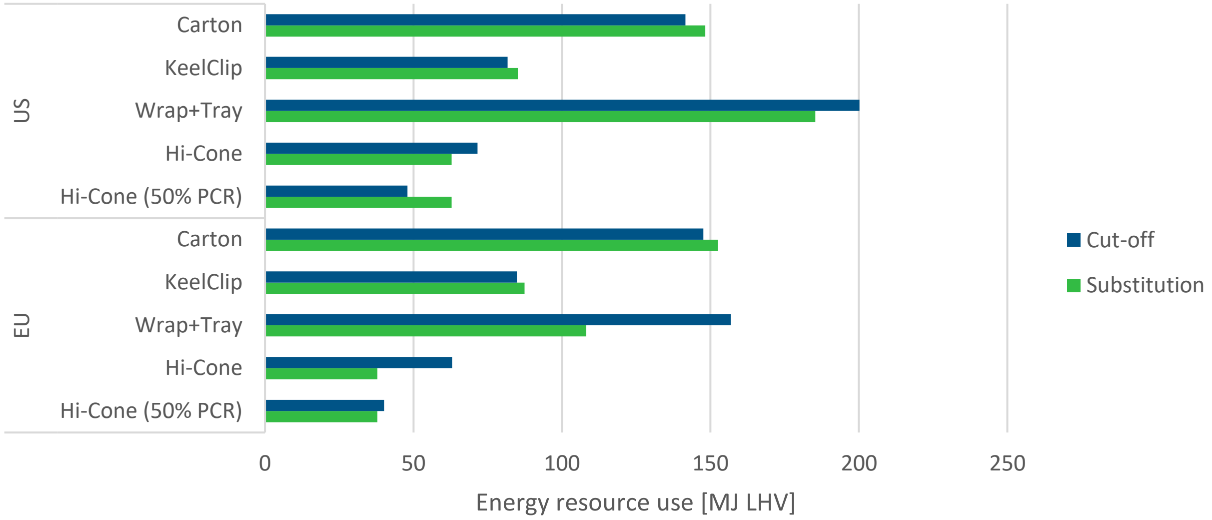

Figure E-4: Effect of allocation approach on energy resource use

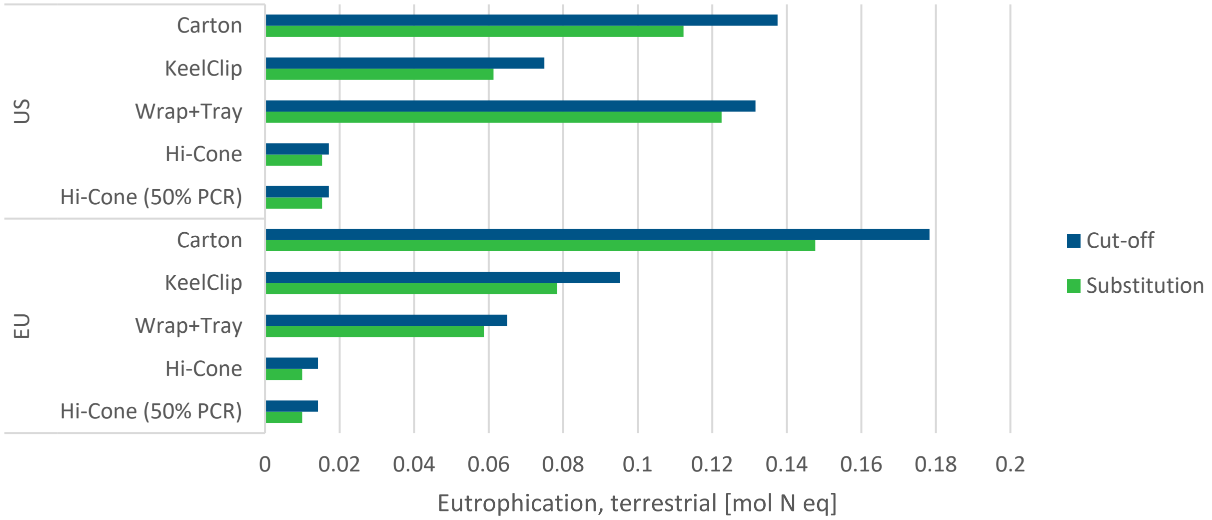

Figure E-5: Effect of allocation approach on eutrophication, terrestrial

Appendix F. Critical Review Statement

Review of the Report “Beverage Packaging Life Cycle Assessment”

Study commissioned by:	Graphic Packaging International
Report written by:	Trisha Montalbo, Sphera Solutions, Inc., Boston, MA
Critical Review Panel:	Arpad Horvath, Consultant; Berkeley, CA (Chair) Angela Schindler, Consultant; Salem, Germany Bill Flanagan, Co-Founder and Director, Aspire Sustainability; Albany, NY
Valid as of:	August 25, 2020

Scope of the Critical Review

The review proceeded on two versions of the report “Beverage Packaging Life Cycle Assessment.” This review statement applies to the last version, 1.0, dated August 25, 2020.

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

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

Critical Review Process

The review was conducted by exchanging comments and responses between the Critical Review Panel and the LCA practitioner using an Excel spreadsheet based on Annex A of ISO/TS 14071:2014. There were two formal rounds of comments. A copy of the review spreadsheet containing all comments and responses is available from the study commissioner upon request.

General Evaluation

The study’s scope was set appropriately to support the goal of establishing an LCA of various options of beverage packaging. High level of technical knowledge and methodological proficiency was exhibited by the report author. Primary data were collected from the study commissioner. The rest of the data were sourced from the GaBi data sets. Considerable effort was extended to ensure representativeness of the data and develop a study with defensible results. The report was written with careful attention to detail.

Conclusions

Based on the revised study report, it can be concluded that the methods used to carry out the LCA are consistent with the international standard ISO 14044, they are scientifically and technically valid, the data used are appropriate and reasonable in relation to the goal of the study, and the interpretations reflect the limitations identified and the goal of the study. The report is sufficiently transparent and consistent and conforms to the reporting requirements of ISO 14044, sections 5.1 and 5.2.

This review statement only applies to the report and version named in the title, but not to any other report versions, derivative reports, excerpts, press releases, and similar documents.

August 25, 2020

A Horvath Angela Schindler William P. Flanagan

Arpad Horvath Angela Schindler Bill Flanagan