Beverage Packaging in Brazil

A Comparative Life Cycle Assessment

On behalf of
Ball Corporation

Client:	**Ball Corporation**
Title:	**Beverage packaging in Brazil (BR) – A Comparative Life Cycle Assessment**
Report version:	v3.0
Report date:	16/07/2020

On behalf of Sphera and its subsidiaries

Document prepared by

Flora D'Souza fdsouza@sphera.com

16.07.2020 phone +49-711-341817-406

Contributing authors

Rosie Dodd

Maike Horlacher

Iris Matzke

Quality assurance by

Manfred Russ Manfred Russ

Principal Consultant 16.07.2020

Under the supervision of

Dr Sabine Deimling

Principal, Team Lead Food, Agriculture and Renewable Materials

During the course of the project, thinkstep became Sphera Solutions GmbH. Therefore, all references to 'thinkstep' in this report refer to "Sphera Solutions".

Disclaimer (Sphera):

This report has been prepared by Sphera with all reasonable skill and diligence within the terms and conditions of the contract between thinkstep and the client. Sphera is not accountable to the client, or any others, with respect to any matters outside the scope agreed upon for this project.

Regardless of report confidentiality, Sphera does not accept responsibility of whatsoever nature to any third parties to whom this report, or any part thereof, is made known. Any such party relies on the report at its own risk. Interpretations, analyses, or statements of any kind made by a third party and based on this report are beyond Sphera's responsibility. If you have any suggestions, complaints, or any other feedback, please contact us at servicequality@sphera.com.

Disclaimer (Ball):

This Regional Summary is drawn from a comparative Life Cycle Assessment Report ("LCA") conducted by Sphera at Ball Corporation's request. Throughout the production of the LCA, Sphera had full control over the methodology used, the conclusions reached and the contents of LCA. Neither Ball Corporation, nor its employees, officers or directors makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information contained in this Regional Summary, or represents that its use would not infringe privately owned rights The findings and views expressed in this Regional Summary do not necessarily reflect the views of Ball Corporation.

1.1. Abstract

- A comparative Life Cycle Assessment (LCA) was commissioned by Ball Corporation to compare the environmental performance of single-use, small to medium-size aluminum cans and bottles against alternative beverage packaging, in three regions (EU; US and BR). While the full LCA report is available upon request from the commissioner, this regional summary report focuses only on Brazil (BR). The Life Cycle Impact Assessment (LCIA) was complemented by calculations of the Material Circularity Indicator of each packaging option. A critical review was conducted by a panel of three independent experts to ensure conformity to ISO 14040/44 standards. The full report, from which this document is an extract, is available upon request.
- The primary intended application of the study is to provide up-to-date and objective results in various sustainability metrics of specific beverage packaging alternatives: aluminum cans, PET bottles, glass bottles and beverage cartons.
- A specific selection of 2-4 products per packaging material were purchased, measured and weighed. Ball Corporation supplied primary environmental data on can manufacturing, while all other background and foreground data were based on industry averages and association datasets from the GaBi Databases 2019. The full life cycle of the beverage packaging was modelled, excluding among other things the beverages themselves, using the substitution approach. Note that other methodological approaches were chosen in the two other regions not shown in this summary report.
- While in general conservative assumptions have been taken with respect to the aluminum can to avoid unfair bias and misrepresentation, the data quality difference remains a potential limitation of the study.
- It was confirmed that packaging efficiency has a significant impact on the environmental burdens of the packaging, as a container with a larger volume requires relatively less material to provide a given quantity of product. Each packaging option has distinct advantages and disadvantages, with potential for improvement by changing the recycling rate, recycled content, product weight and re-usability.
- No single packaging format is preferred for all impact categories assessed in this study. However, aluminum cans have the strongest overall performance and are the preferred choice from a climate change, freshwater eutrophication, terrestrial acidification and freshwater consumption perspective. The strong performance of aluminum cans can largely be attributed to the lightweight nature of the product compared to other packaging types, the high recycled content and the near perfect recycling rate at end of life in Brazil.
- Material circularity is measured and generally correlates well with findings for global warming potential, although this is not a causal relationship given material circularity does not measure material efficiency.
- The results vary from region to region and show slightly different rankings and conclusions (not explored here). Overall, each packaging material has valid justifications for use from an environmental perspective, as each option exhibits different environmental strengths and weaknesses.

1.2. Goal

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

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

The intended applications of the study are:

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

The reasons for carrying out the study include:

- to identify the environmental hotspots of the aluminum can’s life cycle and related optimization potential;
- to understand the environmental advantages/drawbacks of beverage cans and bottles in the specific context of Brazil;
- to compare the environmental impacts of various beverage packaging alternatives, with the intention of comparative assertions intended to be disclosed to the public (except for confidential primary data);
- to provide comparative environmental impact information to brands and other interested parties that may result in further market share growth of aluminum beverage cans;
- to inform and improve the commissioner’s corporate sustainability strategy.

The study is intended for publication, to beverage manufacturers as the primary audience, but also to provide credible communication material for retailers and other interested parties. This study meets the requirements of the international standards for Life Cycle Assessment (LCA) according to ISO 14040 (ISO, 2006) / ISO 14044 (ISO, 2006).

1.3. Scope of the study

Product systems, function and functional unit

The product systems to be studied are single-use, small to medium-size beverage packaging alternatives for carbonated (c) and non-carbonated drinks (nc). Beverages are not included.

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

The PET bottles, glass bottles and beverage cartons are resealable. The consequences of resealability are not considered in this study because of uncertainties related to the beverage contents and consumption patterns. Representative products have been selected by the commissioner of this study as they are considered to be competing products in Brazil.

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

The functional unit is defined as 1 liter of fill volume of small to medium-size, single-use beverage packaging at point of sale. The reference flow for the product systems is Beverage container (packed), including both the primary and the secondary packaging.

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

<table>
<tr><th colspan="5">Brazil</th></tr>
<tr><th colspan="3">Baseline</th><th colspan="2" rowspan="2">Additional scenarios</th></tr>
<tr><th>Material</th><th>Sizes</th><th>EoL / Treatment of secondary materials</th></tr>
<tr><td rowspan="2">Beverage cartons</td><td>0.20L</td><td rowspan="2">Substitution</td><td colspan="2" rowspan="2">Collection rate 0-100%</td></tr>
<tr><td>1.00L</td></tr>
<tr><td rowspan="3">PET bottle (C)</td><td>0.25L</td><td rowspan="4">Substitution</td><td colspan="2" rowspan="4">Collection rate 0-100%
Manufacturing energy for blow molding</td></tr>
<tr><td>0.6L</td></tr>
<tr><td>0.51L</td></tr>
<tr><td>PET bottle (NC)</td><td>0.90L</td></tr>
<tr><td>Glass bottle (single use)</td><td>0.355L-</td><td rowspan="2">Substitution</td><td>-</td><td rowspan="2">Collection rate 0-100%</td></tr>
<tr><td>Glass bottle (refillable)</td><td>0.60L</td><td>5, 10, 15, 20 refills</td></tr>
<tr><td rowspan="3">Aluminum can</td><td>12oz (0.355L)</td><td rowspan="3">Substitution</td><td colspan="2" rowspan="3">Collection rate 0-100%</td></tr>
<tr><td>16oz (0.473L)</td></tr>
<tr><td>24oz (0.71L)</td></tr>
</table>

System boundaries

The system boundaries are summarized in Table 2, displaying a cradle-to-grave system from production of raw materials up to end-of-life.

Table 2: System boundaries

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

Representativeness

The time reference for primary data collected for the aluminum cans is 2018. The time reference for all other beverage containers is also 2016-2019, as the products were purchased, weighed and measured in 2019 July through September. The intended technology reference is the most current available industry average; even though Ball has provided primary data for can manufacturing, the regional data included averages across various sites. The competing packaging products also aim to represent current industry averages. The geographical reference is the Brazil region.

Multi-output allocation

Liquid packaging board (LPB, used to make composite carton beverage containers like those by Tetra Pak or Elopak) has been mass allocated.

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

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

End of life allocation

End-of-Life (EoL) allocation generally follows the requirements of ISO 14044. In Brazil the substitution approach is adopted for the baseline scenario. A value of scrap burden was calculated for the input amount of scrap metal (i.e. recycled content enters the product system with corresponding burdens), while recovered material at the End of Life was assigned a credit. Although common in many metal-focused studies, a net scrap approach was not used here.

The decision to rely on this method was made together with the commissioner, based on the regional significance and acceptance of the methodology. The substitution approach is most commonly used as it enables the best observation for the impact of variable recycling rates, which is a focal point for this study.

Cut-off Criteria

No cut-off criteria for the foreground system are defined for this study within the primary data collection. 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.

LCIA methodology

As advised by the University of Brasília (Laboratory of Energy and Environment, Department of Mechanical Engineering, Faculty of Engineering), the scientific community in Brazil predominantly uses the ReCiPe methodology.

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 3 and Table 4.

Table 3: ReCiPe impact category descriptions

Impact Category	Description	Unit	Reference
Climate change, default, excl. biogenic carbon	A measure of greenhouse gas emissions, such as CO_2 and methane.	kg CO_2 equivalent	(IPCC, 2013)
Freshwater eutrophication	Phosphorus increase in fresh water	kg P eq.	(Helmes, Huijbregts, Henderson, & Jolliet, 2012) (Azevedo, Henderson, van Zelm, Jolliet, & M.A.J., 2013a) (Azevedo, et al., 2013b) (Azevedo, Development and application of stressor – response relationships of nutrients, 2014)
Terrestrial acidification	Ability of certain substances to build and release H+ ions	kg SO_2 eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)
Photochemical ozone formation – human health	Tropospheric ozone population intake increase (M6M)	kg NOx eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)
Photochemical ozone formation, ecosystems	Tropospheric ozone increase (AOT40)	kg NOx eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)
Stratospheric ozone depletion	Ozone Depletion Potential (ODP) calculating the destructive effects on the stratospheric ozone layer over a time horizon of 100 years.	kg CFC-11 eq.	(Hayashi, Nakagawa, Itsubo, & Inaba, 2006) (De Schryver, et al., 2011)
Ionizing radiation	Absorbed dose increase	kBq Co-60 eq.	(Frischknecht, Braunschweig, Hofstetter, & Suter, 2000) (De Schryver, et al., 2011)
Human Toxicity – cancer	Risk increase of cancer disease incidence	kg 1,4-DCB eq.	(Van Zelm, Huijbregts, & Van de Meent, 2009)
Fossil depletion	Upper heating value	kg oil eq.	

Land use	Occupation and time-integrated transformation	m²×yr annual crop land	(De Baan, Alkemade, & Köllner, 2013) (Elshout, Van Zelm, Karuppiah, Laurenzi, & Huijbregts, 2014) (Köllner & and Scholz, 2007)
Terrestrial ecotoxicity	Hazard-weighted increase in natural soils	kg 1,4-DCB eq.	.
Freshwater ecotoxicity	Hazard-weighted increase in fresh waters	kg 1,4-DCB eq.	.
Marine ecotoxicity	Hazard-weighted increase in marine waters	kg 1,4-DCB eq.	(Van Zelm, Huijbregts, & Van de Meent, 2009)
Fine particulate matter formation	PM2.5 population intake increase	kg PM2.5 eq.	(Van Zelm, Preiss, Van Goethem, Van Dingenen, & Huijbregts, 2016)
Freshwater consumption	Fresh water use	m³	.

Table 4: Other environmental indicators for the BR region

Indicator	Description	Unit	Reference
Blue water consumption	A measure of the net intake and release of fresh water across the life of the product system. This is not an indicator of environmental impact without the addition of information about regional water availability.	Liters of water	(thinkstep, 2014)
Abiotic Depletion Potential	A relative measure derived for the extraction of elements, minerals and fossil fuels.	[kg Sb eq.]	

Material Circularity Indicator

In addition to the impact categories and LCI metrics discussed above, this report also explores the circularity of the products assessed. Circularity is increasingly included in political agendas.

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

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

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

can be considered a suitable measure of product utility, with single use items being the average situation.

The current MCI methodology has been designed with a focus on non-renewable resources and the report does not go into details regarding how to assess renewable resources (e.g. paper, cardboard, biopolymers) – the Ellen MacArthur Foundation is in the process of further developing the methodology to evaluate how to deal with such materials. In this study it is assumed that renewable resource inputs such as fibers used in beverage cartons and secondary packaging are sourced sustainably. This is because some of the biggest producers of the paper and carton products assessed in this study have declared certified sustainable sourcing by the Forest Stewardship Council (FSC). As such, the position was adopted that these inputs are completely restorative and therefore resource scarcity is not considered as a concern.

Software and Databases

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

1.4. Life Cycle Inventory Analysis

Aluminum cans

Primary data were collected using customized data collection templates from Ball Corporation. Primary data covered can body and can end manufacturing for 3 sizes/types. Primary data also extended to the secondary packaging for selected final products that use Ball beverage cans.

PET bottles, glass bottles and beverage cartons

For all other beverage containers secondary data was collected based on sample products selected by Ball for most relevant market shares in Brazil. The final set of specific products is summarized in Table 5. The specified products were purchased, materials identified, measured and weighed to the precision available in-house, by collaborators at the University of Brasília (Laboratory of Energy and Environment, Department of Mechanical Engineering, Faculty of Engineering). For most products, the precision of measurements was at least one decimal place (0.1g), giving a relative error of at most 10% by weight in case of caps (1-2g), but well under 1% relative to the entire primary packaging (bottle plus cap. For carton products produced by Tetra Pak, information on product weight and composition was taken from online resources (Tetra Pak 2019).

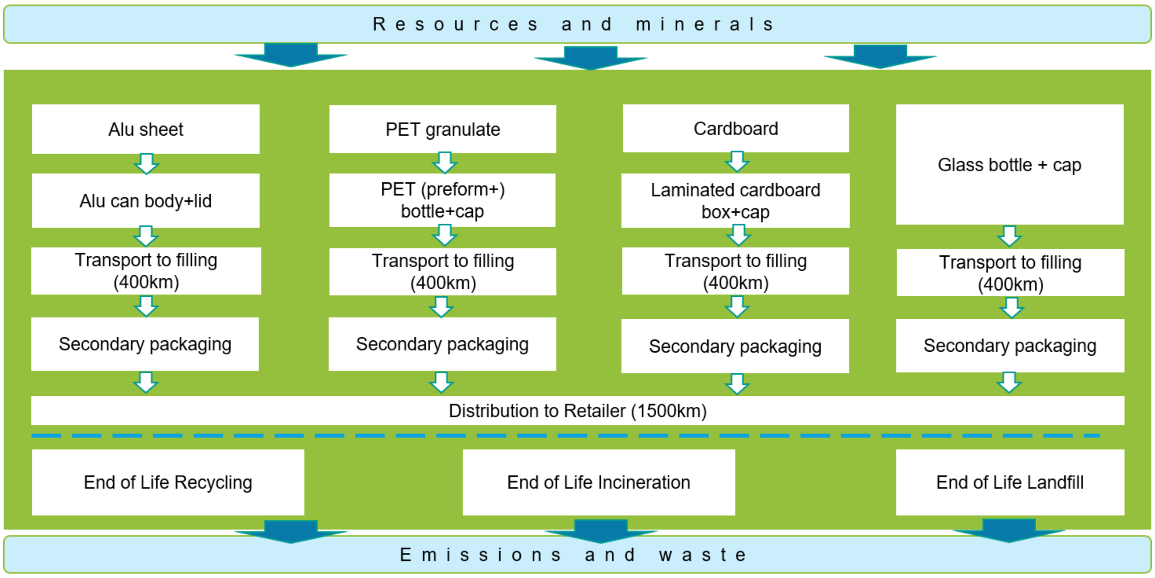


Figure 1: **Overview of system boundaries of the product systems investigated (without displaying details of materials)**

Table 5: Overview product specifications

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

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

** Straw instead of Cap

Table 6: Recycled content of considered packaging alternatives

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

Datasets used in the study

For modelling the aluminum cans, the most relevant datasets included:

- Ingot mix from the International Aluminum Association (IAI) dataset for the region Latin-America (RLA: Aluminium ingot mix IAI 2015) was used (World Aluminium, 2017);
- Aluminum sheet making (BR: Aluminium sheet EAA 2010) and remelting (BR: Remelting & Casting of rolling scrap EAA 2010) are GaBi datasets based on the European Aluminum Association's data (European Aluminium Association, 2013), modified to reflect the boundary conditions in Brazil.

For the PET bottles the most relevant datasets included:

- PET granulate via PTA pathway (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/043fc939-8eff-409b-ac6b-7609312ab447.xml);
- To reflect the manufacturing steps, bottle blow molding originally developed for HDPE bottles (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/3979582f-0678-4dfe-8304-1860a797c0b8.xml) and an injection molding dataset for the closures was applied (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/aaf7c3a1-6ecd-459e-a493-3f376507e29b.xml).

For the glass bottles the most relevant datasets included:

- Production of container glass (100% batch) (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/5f88e494-354b-4e7b-b40a-f734f7304642.xml) and Production of container glass (100% cullet) (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/497a4b72-84bf-4ba0-84ef-cf5ed9fd2a5b.xml) have both been regionalized to Brazilian boundary conditions.
- The closures were modelled as tinplated steel (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6accaea9-92bd-45ee-816e-1037a7f4deb8.xml).

For the beverage cartons the most relevant datasets included:

- The liquid Packaging Board dataset has been proxied with the FEFCO Kraftliner dataset (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ac37d3c-caeb-4216-9f1d-c78c1b8c772b.xml) regionalized to Brazilian boundary conditions.
- The LDPE film has been modelled with virgin granulate (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/1cab96fb-492d-436a-8f14-fd86df4f7843.xml) and plastic film making.
- The aluminum foil has been modelled using the European Aluminum association's film dataset (http://gabi-documentation-2019.gabi-software.com/xml-data/processes/86c4d1c5-19f9-4d43-9bff-0b88b714b93f.xml) combined with ingot mix from the International Aluminum Association (IAI) dataset for Region Latin-America (see details under aluminum cans).

The complete list of used datasets can be found in the full report.

Table 7: Most relevant datasets used to model energy provision for products manufactured in Brazil.

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

Table 8: Most relevant datasets used to model material and product transport in Brazil.

Transport mode	GaBi dataset	Source	Documentation	Reference year
Truck-trailer*	GLO: Truck-trailer, Euro 0 - 6 mix, 34 - 40t gross weight / 27t payload capacity	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/4e47891c-25ca-4263-8ebd-e1b462c0f4b8.xml	2016
Diesel	BR: Diesel mix at refinery ts	ts	http://gabi-documentation-2019.gabi-software.com/xml-data/processes/6ad6b878-05a4-4b8f-9a5d-92f762e80e32.xml	2016

End of Life

For each product three possible end of life waste streams are available; recycling, incineration and landfill. The statistics for each of these recycling streams is sourced from CEMPRE (Cempre, 2018) (annex 3). The recycling yields reflect data from the GaBi databases. The table below summarizes this information. Transport distances to End of Life processing facilities are neglected, as these are expected to be within 100km radius of the disposal site by the end consumer.

The end of life waste streams are split using consistent calculations for all products. Where material or energy is recovered from end of life processes, fixed material credits are applied to compensate the burdens created by the product life cycles.

Table 9: End of Life treatment of packaging alternatives in Brazil.

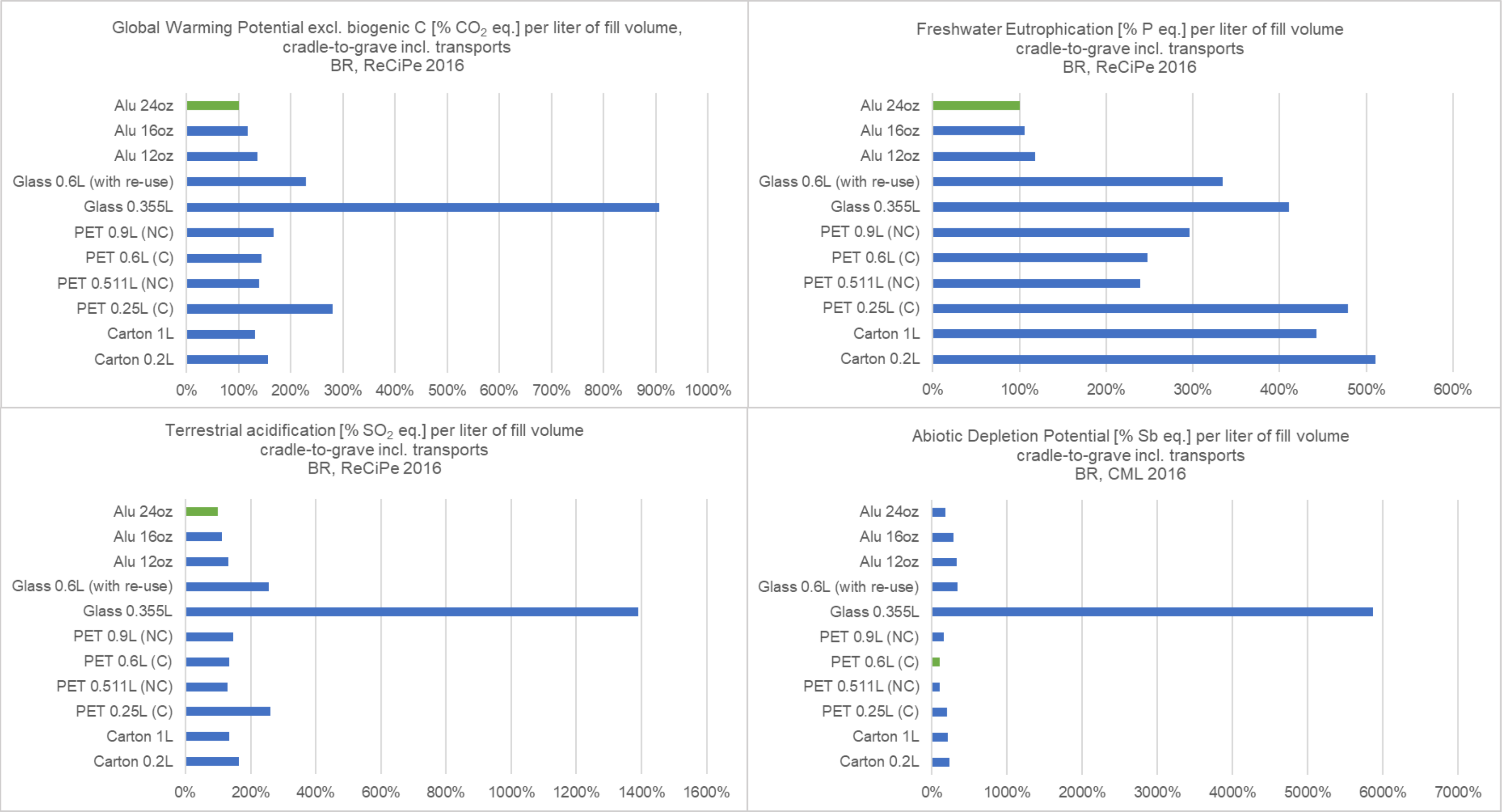
	EoL stream	Collection %	Yield %	Source
Aluminum can	Recycling	97.3	99	CEMPRE
	Incineration	0		
	Landfill	2.2		
PET bottle	Recycling	59	86	
	Incineration	0		
	Landfill	41		
Glass bottle	Recycling	47	97	
	Incineration	0		
	Landfill	53		
	Reuse	0 – 20 reuses		Scenario only
Beverage cartons	Recycling	21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

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

1.5. Life Cycle Impact Assessment

The LCIA results include contribution analyses, which split the results according to the following life cycle stages: manufacturing, secondary packaging, transport to filling, distribution and end of life. This enables the reader to understand the influence of each life cycle stage on the overall environmental performance of the product. LCIA results are relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

This summary report contains the details of the global warming potential (GWP) impact category only for brevity. While this is a robust and globally highly relevant impact category, a comparative life cycle assessment should never rely on a single impact category, which is why the full report duly discusses terrestrial acidification potential, freshwater eutrophication potential, and abiotic depletion potential along with GWP. Figure 2 provides an overview of the four selected impact categories: The 100% value is the smallest result in each impact category, and other products are provided in relative terms as percentages.


Global Warming Potential excl. biogenic C [% CO_2 eq.] per liter of fill volume, cradle-to-grave incl. transports BR, ReCiPe 2016

Freshwater Eutrophication [% P eq.] per liter of fill volume cradle-to-grave incl. transports BR, ReCiPe 2016

Terrestrial acidification [% SO_2 eq.] per liter of fill volume cradle-to-grave incl. transports BR, ReCiPe 2016

Abiotic Depletion Potential [% Sb eq.] per liter of fill volume cradle-to-grave incl. transports BR, CML 2016

Figure 2: **Overview of selected impact categories explored in the full report. Results refer to the full life cycle (cradle to grave, scaled to liter of fill volume), in relative terms, showing the product with the lowest impact as 100% (in green).**

Global Warming Potential (GWP) – beverage packaging comparison

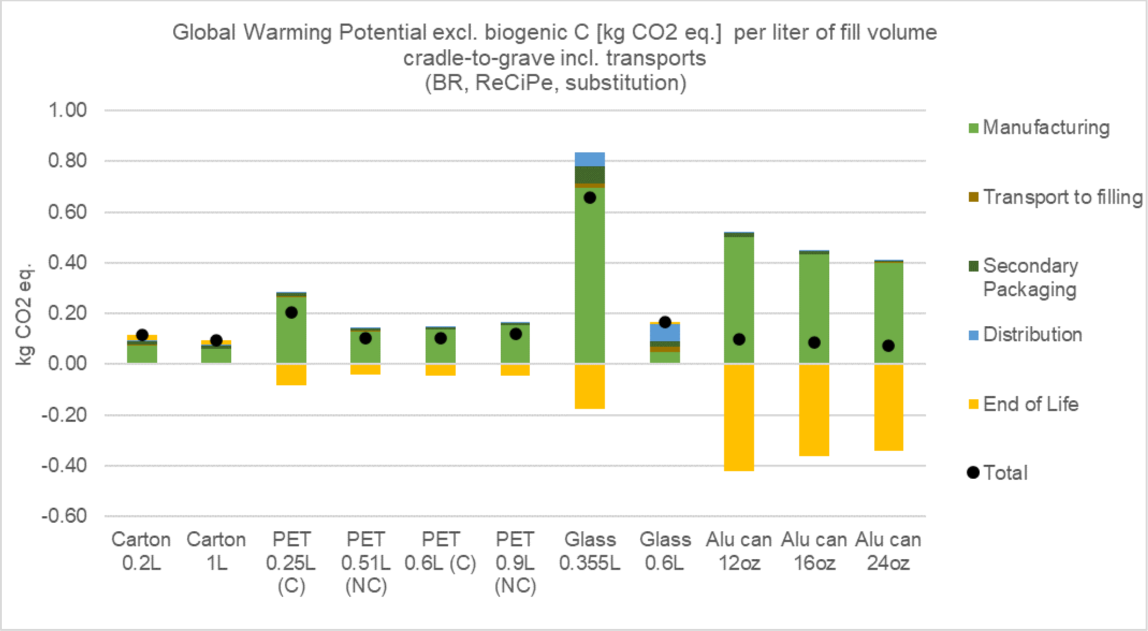


Figure 3: The contribution of different life cycle stages/production processes to the overall global warming potential results, scaled to 1 liter of fill volume, cradle-to-grave including transports, using the ReCiPe 2016 method.

Global warming potential (GWP) is driven is driven by greenhouse gases like CO_2 and CH_4 in the troposphere which trap infrared radiation from and redirect it back towards the Earth's surface. This radically alters the conditions at the Earth's surface and may cause warming or cooling effects which have the potential to alter the Earth's climates. Greenhouse gases are mainly associated with the combustion of fossil fuels which are used in energy generation and manufacturing of fossil-based materials like plastic. The 0.35L single-use glass bottle shows the highest GWP, followed by PET bottles, beverage cartons and aluminum cans with the lowest impact. This is unsurprising given that glass bottle production is energy intensive and the glass container mass is 10x greater than for PET bottles and 20x greater than for aluminum cans and beverage cartons. The 0.6L glass bottle that is refilled 20 times has a much lower GWP than single-use glass bottles, about the same level as PET bottles. This underlines the environmental benefits that can be accrued by designing efficient refill systems for beverage packaging (e.g. standardized bottles).

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

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

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

Global Warming Potential – aluminum can hotspot analysis

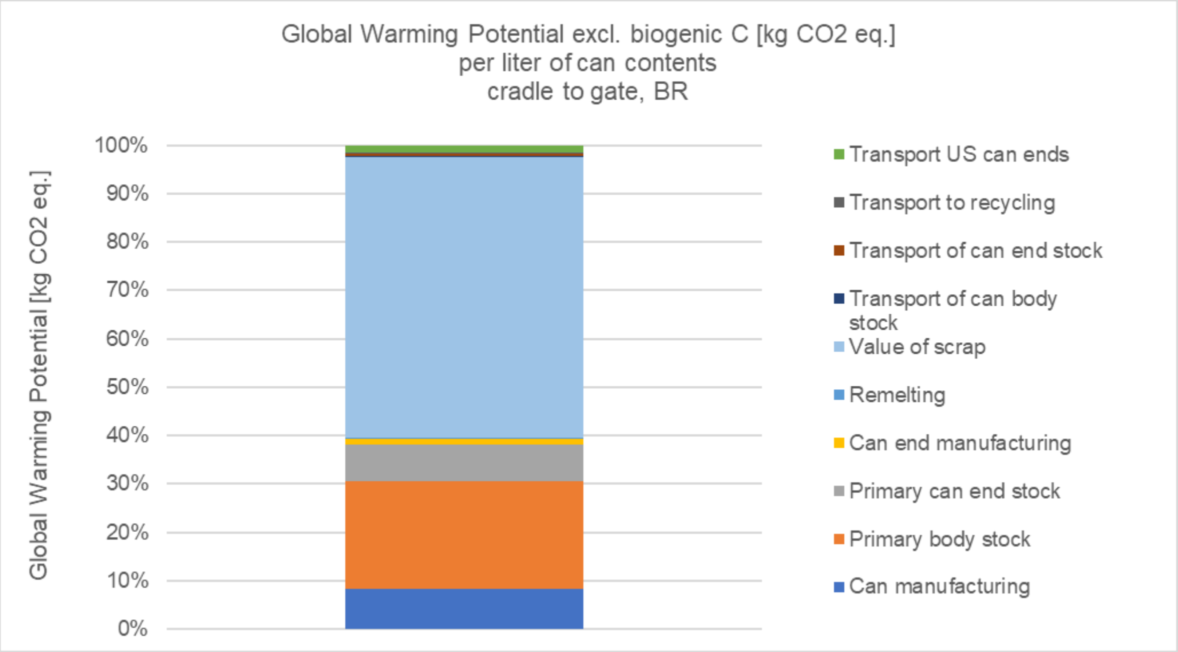


Figure 4: Detailed global warming potential contributions in the manufacturing phase of the 12oz aluminum can, shown per liter of fill volume, using the ReCiPe 2016 method.

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

These burdens are assigned because the ISO standard for the substitution method require that inputs and outputs be treated equivalently. Because credits are received for recycling material at end of life (calculated as the burdens of the recycling process minus the burdens of an equivalent amount of virgin production), then equivalent burdens must be applied for scrap consumed during the manufacturing process. The value of scrap[1] is then calculated as the inverse of the credits at the End of Life.

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

The GWP related to the remaining manufacturing processes are predominantly derived from the mining, refining, smelting/remelting and rolling of aluminum. The can manufacturing process

---

[1] Value of scrap refers to the estimated environmental burdens associated with the provision of secondary material prior to recycling (i.e. scrap). Calculated as the environmental impact of primary material minus the impact of recycling.

accounts for a relatively small proportion of the overall burdens of production. Burdens from transport processes are negligible.

1.6. Uncertainty and variability: sensitivity and scenario analyses

In order to account for potential variability within the foreseeable future as well as for uncertainties in a few parameter values and methodological choices, scenarios and sensitivity analyses are provided in section 0.

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

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

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

- Refill of the glass bottle (0-20 refills)
- PET bottle manufacturing (2x and 0.5x baseline energy consumption for blow molding)

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

- Collection for recycling (0-100%)

No uncertainty was calculated for the beverage cartons (Figure 5), and no significant improvement potential found in the variability analysis (Figure 6). This is because the cartons are not significantly affected by changes to the collection /recycling rate.

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

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

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

Table 10: Summary of scenario and sensitivity analyses in the BR region for ReCiPe Global Warming Potential excl. biogenic C [kg CO2 eq.] impact of products scaled to 1 liter of fill volume, cradle-to-grave incl. transports, and calculation of uncertainty by means of minimum and maximum values. Grey cells denote the lack of a corresponding scenario / sensitivity analysis.

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

.

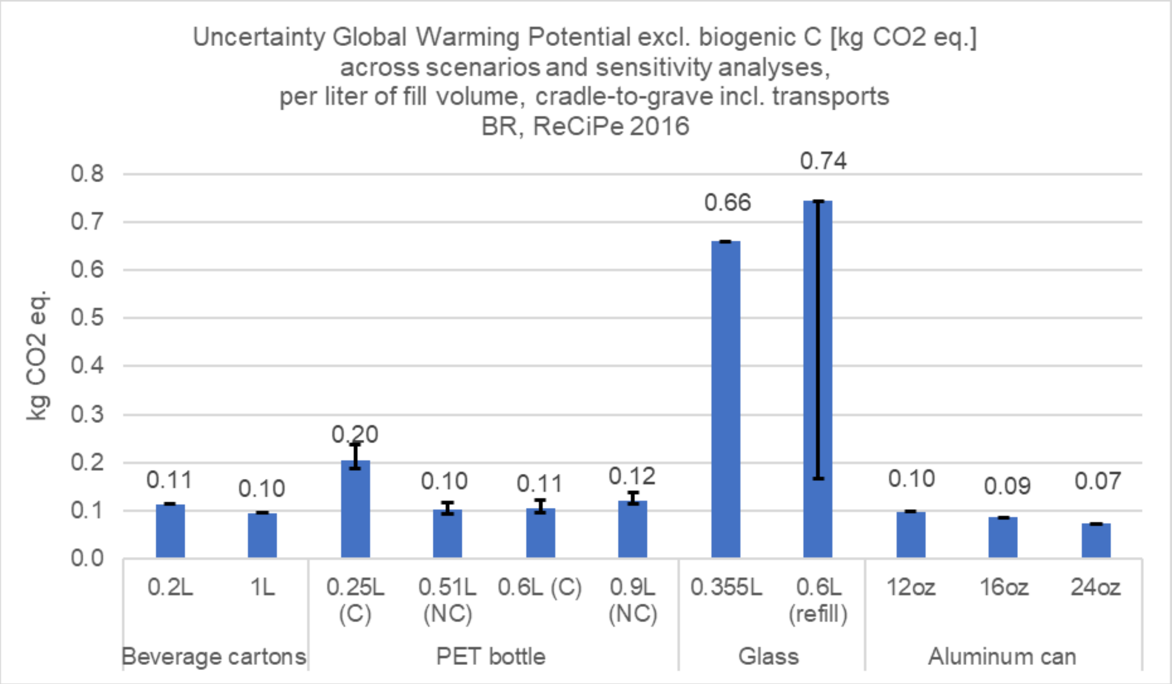


Figure 5: **Uncertainty analysis of the Global Warming Potential excl. biogenic C [kg CO2 eq.] of products, scaled to 1 liter per fill volume, cradle-to-grave incl. transports, based on all scenario and sensitivity analyses. Values taken from Table 10: baseline – substitution, min – minimum of values from all scenario and sensitivity analyses, max– maximum of values from all scenario and sensitivity analyses.**

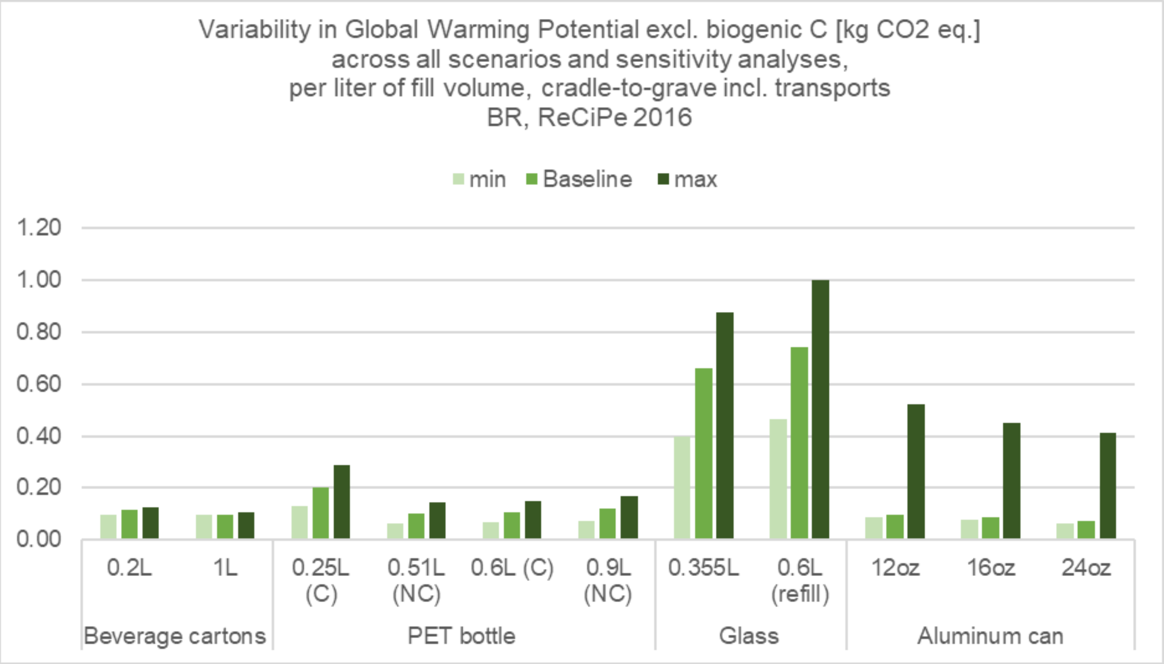


Figure 6: Variability analysis of the Global Warming Potential excl. biogenic C [kg CO2 eq.] of products, scaled to 1 liter per fill volume, cradle-to-grave incl. transports, based on all scenario and sensitivity analyses. Values taken from Table 10: baseline – substitution, min – minimum of values from all scenario and sensitivity analyses, max– maximum of values from all scenario and sensitivity analyses.

1.7. Material Circularity Indicator

Figure 7: Material Circularity Indicator results for the different packaging options (BR)

A score of 1 indicates a completely circular product, and a score of 0.1 indicates a completely linear product. This means that conversely to all previous environmental impact charts, a higher MCI value indicates a better material circularity performance.

The glass bottle packaging option which is re-used 20 times achieves the highest MCI score of 0.99, indicating this packaging option – according to the MCI methodology – is almost completely circular. By contrast, the single-use glass bottle has an intermediate MCI score of only ~0.5, which demonstrates the benefits of re-using packaging on the circularity score. Already with a single refill, the MCI rises from 0.51 to 0.77, and further to 0.93 with 5 refills. Both glass bottles have an assumed recycled content of around 44% and a recycling rate at end of life of 47%.

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

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

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

1.8. Interpretation

Assumptions and Limitations

Data quality differences between the subjects of the comparison, specifically, the primary data-based aluminum cans and the secondary data-based alternative packaging products pose the most critical limitation to the study.

Consequently, conservative assumptions have generally been taken with respect to the aluminum can to avoid any misrepresentation of results and unfair treatment of the competitive products.

Product ranking/performance

- No single packaging format is preferred for all impact categories assessed in this study. However, aluminum cans have the strongest overall performance and are the preferred choice from a climate change, freshwater eutrophication, terrestrial acidification and freshwater consumption perspective.
- The strong performance of aluminum cans is, in large part, due to the very high recycling rate in Brazil (97%) and because the impacts associated with recycling aluminum are much lower than those of manufacturing it from virgin materials (95% less energy for secondary vs primary aluminum production). These two factors mean that recycling credits at end of life are very large and greatly reduce the environmental impacts associated with the full life cycle of the product.
- PET bottles have the lowest impact in abiotic depletion potential and compete for second place with cartons in terms of climate change and acidification. PET bottles fare well due to relatively low virgin material impacts and manufacturing-related impacts.
- Cartons generally have a good environmental performance because they are mostly made from paperboard (typically around 70% by weight), which tends to have low manufacturing impacts. If paperboard is produced in an integrated pulp and paper mill most of the energy used will be derived from biomass such as wood offcuts from forestry, from bark and wood chips and from black liquor produced from the wood during pulp production. Many integrated paperboard mills export excess electricity to the grid, further reducing the production burdens.

- The environmental performance of glass bottles diverges strongly depending on whether they are refilled many times or used only once. Bottles that are refilled 20 times generally perform strongly (often similar to cartons) but single-use bottles have much higher impacts and show the highest burdens for climate change and acidification. Glass bottles are much heavier than the other packaging types assessed in this study and glass production is also relatively resource and energy intensive, explaining the high burdens seen for single-use bottles. When refilling bottles, the burdens of manufacturing are shared among multiple use cycles (modelled as being reused 20 times in this study), resulting in greatly reduced burdens for a given functional unit.
- Of the scenarios explored in this study, increasing recycling rates offers the biggest improvement potential in terms of environmental footprint for PET bottles.
- Aluminum cans show the highest variability in terms of changing recycling rates, followed by glass bottles.
- Although manufacturing of the primary packaging dominates most impact categories, secondary packaging does become dominant in the impact category eutrophication, where carton in secondary packaging contributes more than half of the total life cycle of glass bottles and up to a half of beverage cartons, due to the amount of waste water produced in the paper and recycling mills.

Conclusions and recommendations

- Packaging efficiency has a significant impact on the environmental burdens of the packaging. A packaging container with a larger volume requires relatively less material to provide a given quantity of product. This is an important factor to consider when making comparisons across different packaging formats and sizes. It is important to note here, that the study focused on small-to-medium sized products, not all beverage packaging types and formats.
- Aluminum cans are the best performers in terms of GWP, terrestrial acidification and freshwater eutrophication. Aluminum cans show low impacts partly because they are lightweight, so less material is needed to manufacture them, but mainly because of the high average levels of recycled content used during manufacturing and the near perfect recycling rates at end of life. Design for a circular economy coupled to a greening of energy supply for manufacturing enables this packaging format to reach its potential for further improvement in the future.
- Hotspot analysis of the aluminum can reveals that the most significant contribution to environmental impacts are derived from the can body stock (and value of scrap, denoting the theoretical impact of aluminum scrap) during the manufacturing phase. Given the high yield of aluminum recycling, the easiest way to reduce this impact is by closing the loop, as it is done in Brazil with a close to 98% collection rate. While can manufacturing energy is not negligible, most energy consumption occurs further upstream in aluminum production, and to a lesser degree in sheet rolling, and thus energy efficiency measures and provision of renewable energy in those parts of the supply chain have more improvement potential. Certainly, further lightweighting can further reduce the overall impact of cans, too.
- PET bottles perform well in several impact categories due to being relatively lightweight, with little secondary packaging, and relatively low manufacturing energy demand. A combination of low recycling rates at end of life and lack of recycled content, leave a marked potential for future improvement for this packaging option. Returnable bottles would predictably have a significant potential to improve the impact of these packaging systems as well.
- Cartons have less potential to improve through increasing recycling rates as the paper recycling process is much less beneficial compared to the virgin process than is the case

for aluminum. For some impact categories, recycling paper may be more impactful than virgin production, as recyclers do not have access to the large quantities of biomass fuel that is available to integrated pulp and paper mills. Certainly, renewable energy can be purchased also by recyclers and integrated virgin and recycled paper mills also exist sharing the benefits of renewable energy carrier by-products.

- The glass bottles that are designed for reuse, and are extensively reused outperform single-use bottles. Reuse is the single most important future improvement potential for this packaging format. Importantly, however, it has yet to be demonstrated by reliable data how many times glass bottles can in fact be re-filled, and how efficient the infrastructure is in terms of logistics and economies of scale.
- With respect to circularity, it can be said that for a given material option (e.g. aluminum cans) the MCI often correlates quite well with findings on GWP, i.e. the higher the MCI, the lower the GWP. Aluminum cans tend to outperform other packaging materials, as a result of the highly developed infrastructure for collection, highly efficient material recycling technology, very high levels of recycled content, and extremely low yield losses during recycling, closing the loop rather well. However, the correlation between MCI and GWP is not a causal relationship because MCI scores do not measure material efficiency during production processes. Therefore, when comparing the MCI performance of different packaging materials it should be noted that this correlation does not necessarily mean the packaging material with the highest MCI score has the best environmental performance overall.
- The study findings indicate the paramount importance of enhancing circular systems for high-value / high-impact materials such as aluminum, glass or (to a lesser degree) PET by
    - Increasing recycled content as far as technologically feasible,
    - Increasing collection rates at the end of life,
    - Maximizing refill cycles of bottles designed for reuse,
    - Supporting the logistics of closing the loop, i.e. providing the scrap input in the quality and quantity that is required by the input side.
- The Brazilian modus operandi as such cannot be recommended due to its reliance on enormous economic differences in society, resulting in the poorest classes effectively acting as the collection system for high-value substrates. However, the system does demonstrate the environmental benefits of achieving near-perfect recycling rates and an almost completely closed loop. Given more efficient infrastructure and the right incentives (e.g. deposit return schemes), higher recycling rates are achievable without relying on the economic gap in societies.

1.9. References

Azevedo, L. (2014). *Development and application of stressor – response relationships of nutrients.* Radboud University Nijmegen.

Azevedo, L., Henderson, A., van Zelm, R., Jolliet, O., & M.A.J., H. (2013a). Assessing the Importance of Spatial Variability versus Model Choices in Life Cycle Impact Assessment: The Case of Freshwater Eutrophication in Europe. *Environmental Science & Technology, 47 (23)*, 13565-13570.

Azevedo, L., van Zelm, R., Elshout, P., Hendriks, A., Leuven, R., Struijs, J., . . . Huijbregts, M. (2013b). Species richness–phosphorus relationships for lakes and streams worldwide. *Global Ecology and Biogeography, 22 (12):*, 1304-1314.

Bare, J. (2012). *Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) - Software Name and Version Number: TRACI version 2.1 - User's Manual.* Washington, D.C.: U.S. EPA.

Bos, U., Horn, R., Beck, T., Lindner, J., & Fischer, M. (2016). *LANCA® -Characterisation Factors for Life Cycle Impact Assessment, Version 2.0.* Stuttgart: Fraunhofer Verlag.

BSI. (2012). *PAS 2050-1:2012: Assessment of life cycle greenhouse gas emissions from horticultural products.* London: British Standards Institute.

BSI. (2012). *PAS 2050-1:2012: Assessment of life cycle greenhouse gas emissions from horticultural products.* London: British Standards Institute.

Cempre. (2018). *Articles and Publications: Aseptic Carton.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/9/embalagens-longa-vida

Cempre. (2018). *Articles and Publications: Aseptic Cartons.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/9/embalagens-longa-vida

Cempre. (2018). *Articles and Publications: End of Life Statistics Corrugated Paper.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/3/papel-ondulado

Cempre. (2018). *Articles and Publications: Glass.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/6/vidro

Cempre. (2018). *Articles and Publications: Paper Labels.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/2/papel-de-escritorio

Cempre. (2018). *Articles and Publications: PET.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: (CEMPRE) http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/8/pet

Cempre. (2018). *Articles and Publications: PET.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/8/pet

Cempre. (2018). *Articles and Publications: Plastics.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/4/plasticos

Cempre. (n.d.). *Articles and Publications: Steel Caps.* Retrieved 04/ 2020, from Compromisso Empresarial Para Reciclagem: http://cempre.org.br/artigo-publicacao/ficha-tecnica/id/1/latas-de-aco

De Baan, L., Alkemade, R., & Köllner, T. (2013). Land use impacts on biodiversity in LCA: A global approach. *national Journal of Life Cycle Assessment, 18 (6)*, 1216-1230.

De Schryver, A., Van Zelm, R., Humbert, S., Pfister, S., McKone, T., & Huijbregts, M. (2011). Value choices in life cycle impact assessment of stressors causing human health damage. *Journal of Industrial Ecology, 15 (5)*, 796-815.

Dr.-Ing. Joachim Harder, O. C. (2018, 05). *recovery*. Retrieved from https://www.recovery-worldwide.com/en/artikel/glass-recycling-current-market-trends_3248774.html

Drielsmaa, J., Russell-Vacari, A., Drnek, T., Brady, T., Weihed, P., Mistry, M., & Perez Simbor, L. (2016). Mineral resources in life cycle impact assessment—defining the path forward. *International Journal of Life Cycle Assessment*, 85-105.

Elshout, P., Van Zelm, R., Karuppiah, R., Laurenzi, I., & Huijbregts, M. (2014). A spatially explicit data-driven approach to assess the effect of agricultural land occupation on species groups. *The International Journal of Life Cycle Assessment, 19 (4)*, 758-769.

EPA. (2012). *Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) – User's Manual.* Washington, D.C.: U.S. EPA.

EPA. (2015). *Advancing Sustainable Materials Management: Facts and Figures Report.* Retrieved 04/ 2020, from United States Environmental Protection Agency: https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/advancing-sustainable-materials-management

EPA. (2018). *Advancing Sustainable Materials Management: 2015 Tables and Figures.* Retrieved 04/ 2020, from United States Environmental Protection Agency: https://www.epa.gov/sites/production/files/2018-07/documents/smm_2015_tables_and_figures_07252018_fnl_508_0.pdf

European Aluminium Association. (2013). *Environmental Profile Report for the European Aluminium Industry .* European Aluminium Association.

European Aluminum. (2018). *Environmental Profile Report. Life-Cycle inventory data for aluminium.* European Aluminum.

European Comission. (2018). *Default paramters CFF.* Retrieved 04/ 2020, from https://ec.europa.eu/environment/eussd/smgp/pdf/CFF_Default_Parameters_March2018.xlsx

European Comission. (2020). *Results and deliverables of the Environmental Footprint pilot phase*. Retrieved 04/ 2020, from https://ec.europa.eu/environment/eussd/smgp/PEFCR_OEFSR_en.htm

European Commission, J. R.-I. (2011). International Reference Life Cycle Data System (ILCD) Handbook- Recommendations for Life Cycle Impact Assessment in the European context. Luxemburg: European Commission.

Fantke, P., Evans, J., Hodas, N., Apte, J., Jantunen, M., Jolliet, O., & McKone, T. (2016). Health impacts of fine particulate matter. *Global Guidance for Life Cycle Impact Assessment Indicators: Volume 1. UNEP/SETAC Life Cycle Initiative*, pp. 76-99.

FEVE. (2018). *Raise The Glass.* The European Container Glass Federation.

Frischknecht, R., Braunschweig, A., Hofstetter, P., & Suter, P. (2000). Modelling human health effects of radioactive releases in Life Cycle Impact Assessment. *Environmental Impact Assessment Review, 20 (2)*, 159-189.

GPI. (2014, 09). *Achieving 50% Recycled Content for Glass Containers.* Retrieved from http://gpi.org/sites/default/files/GPI%20Recycled%20Content%20Report%2C%20September%202014.pdf

Graedel, T., & Reck, B. (2015). Six Years of Criticality Assessments - What Have We Learned So Far? *Journal of Industrial Ecology*. doi:10.1111/jiec.12305

Guinée, J. B., Gorrée, M., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., . . . Huijbregts, M. (2002). *Handbook on life cycle assessment. Operational guide to the ISO standards.* Dordrecht: Kluwer.

Hayashi, K., Nakagawa, A., Itsubo, N., & Inaba, A. (2006). Expanded Damage Function of Stratospheric Ozone Depletion to Cover Major Endpoints Regarding Life Cycle Impact Assessment. *The International Journal of Life Cycle Assessment, 11 (3)*, 150-161.

Helmes, R., Huijbregts, M., Henderson, A., & Jolliet, O. (2012). Spatially explicit fate factors of phosphorous emissions to fresh water at the global scale. *International Journal of Life Cycle Assessment, 17 (5)*, 646-654.

ICF International . (2016). *Analysis of the Energy and Greenhouse Gas Emission Implications of Distributing and Refrigerating Beverages.* https://www.aluminum.org/sites/default/files/AluminumCanUse_Report_Clean%20Final_07-22-2016.pdf: Aluminum Association.

Ifeu. (2011). *LCI dataset for converting of beverage carton packaging material.* Heidelberg: Institute for Energy- and Environmental Research.

Ifeu. (2011). *LCI dataset for Liquid Packaging Board (LPB) production.* Heidelberg: Institute for Energy- and Environmental Research.

Ifeu. (2017). *Comparative Life Cycle Assessment of TetraPak® carton packages and alternative packaging systems for liquid food on the Nordic market.* Heidelberg: Institute for Energy- and Environmental Research.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4 - Agriculture, Forestry and Other Land Use.* Geneva, Switzerland: IPCC.

IPCC. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4 - Agriculture, Forestry, and Other Land Use.* Geneva, Switzerland: IPCC.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis.* Geneva, Switzerland: IPCC.

IPCC. (2013). *Climate Change 2013: The Physical Science Basis.* Genf, Schweiz: IPCC.

ISO. (2006). *ISO 14040: Environmental management – Life cycle assessment – Principles and framework.* Geneva: International Organization for Standardization.

ISO. (2006). *ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines.* Geneva: International Organization for Standardization.

JRC. (2010). *ILCD Handbook: General guide for Life Cycle Assessment – Detailed guidance. EUR 24708 EN* (1st ed.). Luxembourg: Joint Research Centre.

Köllner, T., & and Scholz, R. (2007). Assessment of land use impacts on the natural environment. Part 1: An analytical framework for pure land occupation and land use change. *International Journal of Life Cycle Assessment 12*, 16-23.

Nassar, N., Barr, R., Browning, M., Diao, Z., Friedlander, E., Harper, E., . . . Graedel, T. (2012). Criticality of the Geological Copper Family. *Environmental Science & Technology*, 1071-1078.

National Association of PET Container Resources (NAPCOR) and The Association of Plastic Recyclers (APR) . (2018). *Report on Postconsumer PET Container Recycling Activity in 2017 .* National Association of PET Container Resources (NAPCOR).

Pfister, S., Koehler, A., & Hellweg, S. (2009). Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environ. Sci. Technol., 43(11)*, 4098–4104.

Pfister, S., Koehler, A., & Hellweg, S. (2009). Assessing the Environmental Impacts of Freshwater Consumption in LCA. *Environ. Sci. Technol., 43(11)*, 4098–4104.

Rosenbaum, R. K., Bachmann, T. M., Swirsky Gold, L., Huijbregts, M., Jolliet, O., Juraske, R., . . . Hauschild, M. Z. (2008). USEtox—the UNEP-SETAC toxicity model: recommended characterisation factors for human toxicity and freshwater ecotoxicity in life cycle impact assessment. *Int J Life Cycle Assess, 13(7)*, 532–546.

Struijs, J., van Wijnen, H., van Dijk, A., & Huijbregts, M. (2009). *ReCiPe 2008.A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition.*

Tetrapak. (2018). *FSC Certification, Labelling and Verification.* Retrieved from Tetrapak: https://www.tetrapak.com/sustainability/cases-and-articles/fsc-certification

thinkstep. (2014). *GaBi LCA Database Documentation*. Retrieved from thinkstep AG: http://database-documentation.gabi-software.com

UNEP. (2016). UNEP-SETAC Life Cycle Initiative . Available Water Remaining (AWARE). *Global Guidance for Life Cycle Impact Assessment Indicators. Volume 1.*

van Oers, L., de Koning, A., Guinée, J. B., & Huppes, G. (2002). *Abiotic resource depletion in LCA.* The Hague: Ministry of Transport, Public Works and Water Management.

Van Zelm, R., Huijbregts, M., & Van de Meent, D. (2009). USES-LCA 2.0: a global nested multi-media fate, exposure and effects model. *The International Journal of LCA, 14 (30)*, 282-284.

Van Zelm, R., Huijbregts, M., Den Hollander, H., Van Jaarsveld, H., Sauter, F., Struijs, J., . . . Van de Meent, D. (2008). European characterization factors for human health damage of PM10 and ozonein life cycle impact assessment. *Atmospheric Environment 42*, pp. 441-453.

Van Zelm, R., Preiss, P., Van Goethem, T., Van Dingenen, R., & Huijbregts, M. (2016). Regionalized life cycle impact assessment of air pollution on the global scale: damage to human health and vegetation. *Atmospheric Environment 134*, 129-137.

WMO. (2009). *cientific Assessment of Ozone Depletion: 2014,Global Ozone Research and Monitoring ProjectReport No. 55.* Geneva, Switzerland.

WMO. (2014). *Scientific Assessment of Ozone Depletion: 2014 ,Global Ozone Research and Monitoring ProjectReport No. 55.* Geneva, Switzerland.

World Aluminium. (2017). *LIFE CYCLE INVENTORY DATA AND ENVIRONMENTAL METRICS FOR THE PRIMARY ALUMINIUM INDUSTRY.* World Aluminium.

WRI. (2011). *GHG Protocol Product Life Cycle Accounting and Reporting Standard.* Washington D.C.: World Resource Institute.

1.10. Critical Review report summary

A critical review was conducted by a panel of three independent experts:

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

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

The review panel also wants to state that their task was to check the documents provided by the practitioner (not the models developed or the data used) with the limitations of their accumulated experience and the given time constraints.

This review has been prepared by the review panel with all reasonable skill and diligence, being the result of their opinion on the reviewed study, and by no means a certificate of its quality. The panel is not accountable by any others with respect to any matters related to their opinions. Reactions of any kind made by a third party and based on this review are beyond the panel responsibility.

The unabridged Critical Review Statement can be found in the full report available upon request from the study commissioner. Having gone through several reviewing rounds which have led to final consensus among all parties, and following ISO 14044 clause 6.1, the critical review panel wants to state that, within their knowledge:

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