LCA Report

Comparative Life Cycle Assessment of beverage cartons

on the Brazilian market

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INDEX

TABLES AND FIGURES

ACRONYMS

ACE - The Alliance for the Beverage Carton and the Environment

BR - Brazil

CFF - Circular Footprint Formula

CH_4 - Methane

CN - China

CO - Carbon Monoxide

CO_2 - Carbon Dioxide

CTUe - Ecotoxicity impact scores in comparative toxic units

CTUh - Human toxicity impact scores in comparative toxic units

EC - European Commission

EEA - European Environmental Agency

EU - Europe 27+3

FEFCO - European Federation of Corrugated Board Manufacturers

GHG - Green House Gases

GWP - Global Warming Potential

Ifeu - Institut für Energie- und Umweltforschung

IPCC - Intergovernmental Panel on Climate Change

ISO - International Organization for Standardization

LCA - Life Cycle Assessment

LCI - Life Cycle Inventory

LCIA - Life Cycle Impact Assessment

LPB - Liquid Packaging Board

NMVOC - Non-Methane Volatile Organic Compounds

PA - Polyamide

PEFCR - Product Environmental Footprint Category Rules

$PM_{2,5}$ - Particulate Matter with diameter lower than 2,5 µm

SETAC - Society of Environmental Toxicology and Chemistry

UNEP - United Nations Environment Programme

USLCI – United States Life Cycle Inventory Database

About ACV Brasil

ACV Brasil is a consulting company built from the common interests of professionals and researchers in helping the development of the society and the economy, towards more sustainable patterns. We reach this goal through studies that guide changes in production processes, aiming to the rational use of resources and to fairer consumption levels, in compliance with nature's capacity.

The company scope encompasses the life cycle of products and services. The company has partnerships with PRé Consultants, SimaPro® software developer, world's leading LCA software, and with ifu Hamburg GmbH, Umberto® software developer.

Further information can be found on www.acvbrasil.com.br.

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SUMÁRIO EXECUTIVO

A Avaliação do ciclo de vida (ACV) é reconhecida internacionalmente como uma poderosa técnica para avaliar o impacto ambiental potencial de um produto ou serviço. Ela pode também prestar-se ao suporte à tomada de decisão e auxiliar na comparação entre dois ou mais materiais, produtos ou serviços.

A técnica de ACV é baseada no pensamento do ciclo de vida e leva em consideração todos os processos e fluxos ambientais, desde a extração da matéria-prima até a disposição final dos rejeitos.

No Brasil, a ACV tem auxiliado as indústrias na tomada de decisões para melhoria de processos, produtos e serviços, podendo até chegar ao consumidor final por meio das declarações de impacto ambiental de produtos.

Seguindo esta tendência e alinhada com o zelo pela qualidade do meio ambiente e desenvolvimento de produtos mais sustentáveis, a SIG Combibloc promove este estudo de ACV, buscando mensurar potenciais impactos ambientais das embalagens de bebidas no mercado brasileiro, para cada categoria de impacto, consumo ou inventário selecionadas. Dentre os sistemas de produtos considerados nesta análise, encontram-se sete modelos de embalagens diferentes, divididos em três grupos de comparação: **1.** Estruturas SIG MidiBloc para envase de leite e derivados; **2.** Estruturas SIG MidiBloc para envase de sucos; e **3.** Estruturas SIG StandardBloc para envase de leite e derivados.

Os dados utilizados para representar os sistemas de embalagem contam com informações primárias fornecidas pela SIG Combibloc e seus *stakeholders*, enquanto os dados secundários são provenientes de literatura e bancos de dados de Inventário de Ciclo de Vida. As suposições relativas aos critérios de alocação de fim de vida e taxas de reciclagem são testadas nas análises de sensibilidade e de cenários alternativos.

A Avaliação de Impacto do Ciclo de Vida (AICV) abrange as seguintes categorias: Mudanças Climáticas, Depleção da Camada de Ozônio, Acidificação, Eutrofização de Água Doce, Toxicidade Humana, Ecotoxicidade em Água Doce, Formação de Ozônio Fotoquímico, Material Particulado, Recursos Minerais, e Combustíveis Fósseis. Trata-se de uma compilação de métodos de AICV baseada na recomendação da Comissão Europeia no contexto da iniciativa *Environmental Footprint* (EF)[1] e reflete as melhores práticas disponíveis para abordar cada categoria de impacto. Além disso, a Ocupação do Solo e o Consumo de Água são contabilizados no nível de inventário.

[1] A seleção dos métodos de AICV ocorreu por meio de discussões e acordos entre os grupos de trabalho da iniciativa EF e da UNEP Life Cycle Initiative, a evolução dos métodos selecionados está disponível para consulta. Este estudo adotou o método EF 3.0 (v1.2) disponível no SimaPro® com adaptações descritas na seção '*Categories and Life Cycle Impact Assessment Method*'.

Os resultados de qualquer ACV são encontrados com a ajuda de muitos parâmetros, incluindo suposições e limitações. Portanto, os números finais e as conclusões deste estudo devem ser utilizados apenas respeitando o contexto e as limitações apresentadas neste Relatório.

Estruturas SIG MidiBloc para embalagens de leite e derivados

As estruturas SIG MidiBloc para envase de leite e derivados são compostas por **i.** *SIG Terra Alu-free + Forest-based polymers* formada com polímeros de origem renovável (considerando a premissa de balaço de massa), sem barreira de alumínio; **ii.** *SIG Terra Forest-based polymers*, formada com polímeros de origem renovável (considerando a premissa de balaço de massa), com barreira de folha de alumínio; e **iii.** *SIG MidiBloc* convencional, formado com polímeros fósseis e com barreira de folha de alumínio.

A ***SIG Terra Alu-free + Forest-based polymers*** é a melhor alternativa em todas as categorias de impacto ambiental ou de inventário consideradas, exceto para as categorias de Ocupação do Solo e Eutrofização de Água Doce.

A ***SIG Terra Forest-based polymers*** tem impactos ambientais menores do que a ***SIG MidiBloc*** convencional nas categorias de Mudanças Climáticas, Depleção da Camada de Ozônio, Ecotoxicidade em Água Doce e Uso de Recursos Fósseis. No entanto, não há preferência, ou diferença significativa, entre essas alternativas de embalagem considerando as categorias de Formação de Ozônio Fotoquímico, Material Particulado, Toxicidade Humana (efeitos cancerígenos e não cancerígenos), Acidificação, Eutrofização de Água Doce, e Uso de Recursos Minerais e Metais. O inventário de Consumo de Água também é equivalente para ambas as embalagens, enquanto o inventário de Ocupação do Solo é maior para ***SIG Terra Forest-based polymers***.

Estruturas SIG MidiBloc para embalagens de sucos

As estruturas de embalagem de suco SIG MidiBloc são compostas por **i.** *SIG Terra Forest-based polymers*, formada com polímeros de origem renovável (considerando a premissa de balaço de massa), com barreira de folha de alumínio; e **ii.** *SIG MidiBloc* convencional, formado com polímeros fósseis, com barreira de folha de alumínio.

A ***SIG Terra Forest-based polymers*** para envase de suco tem menor impacto ambiental do que a ***SIG MidiBloc*** convencional nas categorias de Mudanças Climáticas, Depleção da Camada de Ozônio, Ecotoxicidade em Água Doce e Uso de Recursos Fósseis. No entanto, não há preferência, ou diferença significativa, entre essas alternativas de embalagem considerando as categorias de Formação de Ozônio Fotoquímico, Material Particulado, Toxicidade Humana (efeitos cancerígenos e não cancerígenos), Acidificação, Eutrofização de Água Doce, e Uso de Recursos Minerais e Metais. O inventário de Consumo de Água também é equivalente para ambos os pacotes, enquanto o inventário de Ocupação do Solo é maior para ***SIG Terra Forest-based polymers***.

ESTRUTURAS SIG STANDARDBLOC PARA EMBALAGENS DE LEITE E DERIVADOS

As estruturas de embalagem SIG StandardBloc para envase de leite e derivados são compostas por **i.** *SIG Terra Forest-based polymers*, formada com polímeros de origem renovável (considerando a premissa de balaço de massa), com barreira de folha de alumínio; e **ii.** *SIG StandardBloc* convencional, formada com polímeros fósseis, com barreira de folha de alumínio.

A ***SIG Terra Forest-based polymers*** tem menor impacto ambiental do que a ***SIG StandardBloc*** convencional nas categorias de Mudanças Climáticas, Depleção da Camada de Ozônio, Ecotoxicidade em Água Doce e Uso de Recursos Fósseis. Já a ***SIG StandardBloc*** convencional tem melhor desempenho ambiental na categoria Eutrofização de Água Doce. Além disso, não há preferência, ou diferença significativa, entre essas alternativas de embalagem considerando as categorias de Formação de Ozônio Fotoquímico, Material Particulado, Toxicidade Humana (efeitos cancerígenos e não cancerígenos), Acidificação, Eutrofização de Água Doce, e Uso de Recursos Minerais e Metais. O inventário de Consumo de Água também é equivalente para ambas as embalagens, enquanto o inventário de Ocupação do Solo é maior para a ***SIG Terra Forest-based polymers***.

ANÁLISES DE SENSIBILIDADE E CENÁRIOS

Uma análise de sensibilidade sobre o método de alocação de fim de vida foi proposta para verificar a robustez das conclusões obtidas. Os resultados indicaram que, apesar da variação dos parâmetros considerados nesses casos, as conclusões do estudo permaneceram consistentes.

Além disso, uma análise de sensibilidade confirmou que a incerteza relacionada à taxa de reciclagem do PolyAl não é significativa para os resultados deste estudo.

Em uma análise de cenário, foi possível concluir que o aumento das taxas de reciclagem de embalagens cartonadas de 39,5% para 50%, 70% ou 100% resultou em benefícios significativos para algumas categorias.

Para a embalagem ***SIG Terra Alu-free + Forest-based polymers***, o aumento da taxa de reciclagem para 50%, provocou uma redução significativa no impacto das Mudanças Climáticas. Com índice de reciclagem de 70%, o inventário de Ocupação do Solo também foi reduzido. Além disso, para uma taxa de reciclagem de 100%, a Formação de Ozônio Fotoquímico, Material Particulado, Toxicidade Humana – efeitos cancerígenos e não cancerígenos e Ecotoxicidade em Água Doce, alcançaram uma redução significativa do impacto.

Para as embalagens ***SIG Terra Forest-based polymers***, ***SIG MidiBloc*** *convencional* e ***SIG StandardBloc*** convencional, o aumento da taxa de reciclagem para 50%, ocasionou uma redução significativa no inventário de Ocupação do Solo. Com uma taxa de reciclagem de 70%, os impactos das Mudanças Climáticas e Ecotoxicidade da Água Doce também foram reduzidos significativamente.

Executive Summary

Life Cycle Assessment (LCA) is internationally known as a powerful technique to evaluate the potential environmental impact of a product or service. It can also support the decision-making process and help with the comparison between two or among several materials, products or services.

The LCA technique is based on Life Cycle Thinking and considers all processes and the environmental flows, from the raw material extraction to the final disposal.

In Brazil, LCA has been helping industries in the decision-making workflow to improve processes, products and services and it could even reach end consumers through the environmental declaration of products.

Leading this trend and aligned with the care for ecosystems quality and the development of more sustainable products, SIG Combibloc promotes this LCA study. It aims to investigate the potential environmental impacts of beverage packaging on the Brazilian market, for each impact, consumption or inventory level category. Among the product systems accounted for in this analysis, lay seven different packaging models, divided into three groups for comparison: **1.** SIG MidiBloc structures for dairy packaging; **2.** SIG MidiBloc structures for juice packaging; and **3.** SIG StandardBloc structures for dairy packaging.

The data used to represent the packaging systems counts on primary information provided by SIG Combibloc and its stakeholders, while the secondary data comes from literature and Life Cycle Inventory databases. The assumptions regarding the end-of-life allocation criteria, and recycling rates are tested in sensitivity and alternative scenario analysis.

The Life Cycle Impact Assessment (LCIA) covers the following categories: Climate Change, Ozone Depletion, Acidification, Eutrophication, Human Toxicity, Ecotoxicity, Photochemical Ozone Formation, Particulate Matter, Mineral Resources, and Fossil Fuels. It is a compilation of LCIA methods based on the European Commission's recommendation in the context of the *Environmental Footprint* (EF)[2] initiative and reflects best available practices for addressing each impact category. Moreover, Land Use and Water Consumption are accounted in the inventory level.

The results of any LCA are found with the help of many parameters, including assumptions and limitations. Therefore, final numbers and conclusions of this study should be only used respecting the context and limitations presented in this Report.

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[2]The selection of the LCIA methods took place through discussions and agreements between the working groups of the EF and the UNEP Life Cycle Initiative , the evolution of the selected methods is available for consultation . This study adopted the EF 3.0 (v1.2) method available in SimaPro® with adaptations described in the Categories and Life Cycle Impact Assessment Method section.

SIG MidiBloc structures for dairy packaging

The dairy packaging SIG MidiBloc structures are comprised by **i.** the SIG Terra Alu-free + Forest-based polymers, formed with mass-balanced polymers, i.e. renewable feedstock, without the aluminium barrier; **ii.** the SIG Terra Forest-based polymers, formed with mass-balanced polymers, with an aluminium foil barrier; and **iii.** the SIG MidiBloc - Conventional, formed with fossil polymers, with an aluminium foil barrier.

The **SIG Terra Alu-free + Forest-based polymers** is the best alternative when considering all environmental impact or inventory level categories, except for the categories of Land Use and Freshwater Eutrophication.

The **SIG Terra Forest-based polymers** has lower environmental impacts than the **SIG MidiBloc - Conventional** in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. However, there is no preference choice between these alternatives considering the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, and Resource Use Minerals and Metals. The Water Consumption inventory is also equivalent for both packages, while the Land Use inventory is higher for the **SIG Terra Forest-based polymers**.

SIG MidiBloc structures for juice packaging

The juice packaging SIG MidiBloc structures are comprised by **i.** the SIG Terra Forest-based polymers, formed with mass-balanced polymers, with an aluminium foil barrier; and **ii.** the SIG MidiBloc - Conventional, formed with fossil polymers, with an aluminium foil barrier.

The **SIG Terra Forest-based polymers** has lower environmental impact than the **SIG MidiBloc - Conventional** in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. However, there is no preference choice between these alternatives considering the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, and Resource Use Minerals and Metals. The Water Consumption inventory is also equivalent for both packages, while the Land Use inventory is higher for the **SIG Terra Forest-based polymers**.

SIG StandardBloc structures for dairy packaging

The dairy packaging SIG StandardBloc structures are comprised by **i.** the SIG Terra Forest-based polymers, formed with mass-balanced polymers, with an aluminium foil barrier; and **ii.** the SIG StandardBloc - Conventional, formed with fossil polymers, with an aluminium foil barrier.

The **SIG Terra Forest-based polymers** has lower environmental impact than the **SIG StandardBloc - Conventional** in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. On the other hand, the **SIG StandardBloc - Conventional** has better environmental performance in the Freshwater Eutrophication category. Furthermore, there is no preference choice between these alternatives considering the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, and Resource Use Minerals and Metals. The Water Consumption inventory is also equivalent for both packages, while the Land Use inventory is higher for the **SIG Terra Forest-based polymers**.

Sensitivity and Scenario Analysis

A sensitivity analysis on the end-of-life allocation method has been proposed in order to verify the robustness of the conclusions. The results indicated that, despite the variation of the parameters considered in these cases, the conclusions of the study remained consistent. Moreover, a sensitivity analysis confirmed that the uncertainty related to the recycling rate of the PolyAl is not significant for the results of this study.

In a scenario analysis, it was possible to conclude that increased beverage carton recycling rates from 39.5% to 50%, 70% or 100%, resulted in significant benefits for a few categories.

For the **SIG Terra Alu-free + Forest-based polymers** package, the increase of the recycling rate to 50% caused a significant reduction in the Climate Change impact. With a 70% recycling rate, the Land Use inventory was also reduced. Furthermore, for a recycling rate of 100%, Photochemical Ozone Formation, Particulate Matter, Human Toxicity – cancer and non-cancer effects, and Freshwater Ecotoxicity, achieved significant impact reduction.

For the **SIG Terra Forest-based polymers** and **conventional** packages, the increase of the recycling rate to 50%, caused a significant reduction in the Land Use inventory. With a 70% recycling rate, the Climate Change and Freshwater Ecotoxicity impacts were also reduced.

1. Goal and Scope

1.1. Goal

According to ISO 14044 **[ISO 14044:2006]**, the goal declaration of a LCA study should include:

i. The intended application,
ii. The reasons for the development of the study,
iii. The target audience and
iv. The intention to use or not to use the results for comparative claims to be publicly disclosed.

These LCA results, for many impact, consumption or inventory level categories, will be applied in the communication of environmental profiles of seven particular sets of packaging. Three made from Liquid Packaging Board (LPB), aluminium barrier and fossil polymers; three further packages made from LPB, aluminium barrier and mass-balanced polymers; and the last package made from LPB and mass-balanced polymers.

The reason for carrying out the study is to deeper know the potential impacts of these product systems evaluated here, aiming to pack dairy and juice, for the year 2023 in Brazil. There is also the intention to use the results for comparative claims, whose target audience is represented by end consumers and SIG Combibloc clients and stakeholders. The LCA results will set up three comparative assessment groups, comprising a total of seven product systems, as described in Figure 1.

Comparison Groups	Description of Structures	Short Name	Previous Name
SIG MidiBloc structures for dairy packaging	'SIG Terra Alu-free + Forest-based polymers' made from LPB and mass-balanced polymers (without aluminium)	MidiBloc Alu-free - Dairy	SIGNature 100
	'SIG Terra Forest-based polymers' for dairy packaging made from LPB, aluminium barrier and mass-balanced polymers	MidiBloc Forest-based - Dairy	CB8 SIGNature Full Barrier
	SIG MidiBloc for dairy packaging made from LPB, aluminium barrier and fossil polymers	MidiBloc - Conventional - Dairy	CB8 Standard
SIG MidiBloc structures for Juice packaging	'SIG Terra Forest-based polymers' for juice packaging made from LPB, aluminium barrier and mass-balanced polymers	MidiBloc Forest-based - Juice	CB8 SIGNature Full Barrier
	SIG MidiBloc for juice packaging made from LPB, aluminium barrier and fossil polymers	MidiBloc - Conventional - Juice	CB8 Standard
SIG StandardBloc structures for dairy packaging	'SIG Terra Forest-based polymers' for dairy packaging made from LPB, aluminium barrier and mass-balanced polymers	StandardBloc Forest-based - Dairy	CB5 SIGNature Full Barrier
	SIG StandardBloc for dairy packaging made from LPB, aluminium barrier and fossil polymers	StandardBloc - Conventional - Dairy	CB5 Standard

Figure 1 Product systems identification

1.2. Scope

The assessment embodies seven product systems, regarding the base scenarios under analysis. The study encompasses the very initial stage of resource acquisition and goes to the production of the packaging and its End-of-Life at the waste scenario of these materials.

1.2.1. Function, Functional Unit and Reference Flow

The product systems function is set to pack beverages, whether with SIG MidiBloc and SIG StandardBloc conventional packaging; SIG MidiBloc Terra Alu-free + Forest-based polymers packaging; or, SIG MidiBloc and SIG StandardBloc Terra Forest-based polymers packaging, complying[3] with physical and chemical characteristics in order to maintain the product function. Then the functional unit refers to this specific purpose, as shown in Figure 2. By default, the reference flows correspond to the number of products necessary to fulfill the functional unit.

BEVERAGE PACKAGING	
FUNCTION	To pack beverages in Brazil, keeping physical and chemical characteristics to maintain the expiration date of the Business as Usual product, in the year of 2023.
FUNCTIONAL UNIT	To pack 1 liter of beverage in Brazil, keeping physical and chemical characteristics to maintain the expiration date of the Business as Usual product, in the year of 2023.
REFERENCE FLOW	1 package (all packages have the same volume capacity of 1 liter each).

Figure 2 Comparison characteristics of the study

1.2.2. Product systems and Boundaries

The packaging products are described in terms of material composition and weight in Table 1. The geography of the raw materials production is informed in Table 2.

[3] For intended application the commissioner ensures that the packages within same comparison group deliver the same function. This means that the packages ensure the required oxygen and light barriers required for beverage preservation.

TABLE 1 BEVERAGE CARTONS STRUCTURE SPECIFICATION

	Unity	MidiBloc Alu-free Dairy	MidiBloc Forest-based Dairy	MidiBloc Forest-based Juice	MidiBloc Conventional Dairy	MidiBloc Conventional Juice	StandardBloc Forest-based Dairy	StandardBloc Conventional Dairy
Beverage type		Dairy	Dairy	Juice	Dairy	Juice	Dairy	Dairy
Volume	mL	1000	1000	1000	1000	1000	1000	1000
Sleeve transformation site		EU	BR	BR	BR	BR	BR	BR
Sleeve mass (sum)	g	29.4	28.6	28.8	28.6	28.8	28.0	28.0
LPB	g	24.40	21.42	21.66	21.42	21.66	20.83	20.83
fossil PE	g				5.35	5.35		5.41
mass-balanced PE	g	4.30	5.35	5.35			5.41	
fossil PE-based adhesive	g		0.42	0.42	0.42	0.42	0.42	0.42
mass-balanced PA	g	0.69						
Aluminium	g		1.36	1.36	1.36	1.36	1.34	1.34
Closure mass	g	2.85	2.75	2.75	2.75	2.75	2.75	2.75
fossil PP	g				1.35	1.35		1.35
mass-balanced PP	g	1.48	1.35	1.35			1.35	
fossil PE	g				1.40	1.40		1.40
mass-balanced PE	g	1.37	1.40	1.40			1.40	
Transport packaging from SIG to retailer (mass per pallet)								
Cartons per pallet	pieces	1020	1020	1020	1020	1020	1080	1080
Cardboard box per pallet	kg	16.4	16.4	16.4	16.4	16.4	10.2	10.2
Strech foil per pallet	kg	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Wood pallet	kg	35	35	35	35	35	35	35
Wood pallet reuse cycles	-	30	30	30	30	30	30	30

TABLE 2 LOCATION OF RAW MATERIALS SUPPLIERS FOR EACH BEVERAGE CARTON STRUCTURE

		MidiBloc Alu-free Dairy	MidiBloc Forest-based Dairy	MidiBloc Forest-based Juice	MidiBloc Conventional Dairy	MidiBloc Conventional Juice	StandardBloc Forest-based Dairy	StandardBloc Conventional Dairy
Sleeve transformation site		EU	BR	BR	BR	BR	BR	BR
Production sites	LPB	EU	BR / EU	BR / EU	BR / EU	BR / EU	BR / EU	BR / EU
	fossil PE	-	-	-	US	US	-	US
	mass-balanced PE	EU	EU	EU	-	-	EU	-
	fossil PE-based adhesive	-	EU	EU	EU	EU	EU	EU
	mass-balanced PA	EU	-	-	-	-	-	-
	Aluminium	-	BR / CN	BR / CN	BR / CN	BR / CN	BR / CN	BR / CN
Closure transformation site		BR	BR	BR	BR	BR	BR	BR
Production sites	fossil PP	-	-	-	BR	BR	-	BR
	mass-balanced PP	EU	EU	EU	-	-	EU	-
	fossil PE	-	-	-	BR	BR	-	BR
	mass-balanced PE	EU	EU	EU	-	-	EU	-
Transport packaging from filler to retailer								
Production sites	Cardboard box	BR	BR	BR	BR	BR	BR	BR
	Stretch foil	BR	BR	BR	BR	BR	BR	BR
	Wood pallet	BR	BR	BR	BR	BR	BR	BR

The boundaries of the analysed product systems are defined as ‘cradle-to-grave’, in other words, it includes the extraction and production of raw materials, converting processes, all transports and the final disposal or recycling of the packaging system.

In general, the study covers the following steps:

- production, converting, distribution, recycling and final disposal of the materials used in the primary packaging elements from the studied systems (including closures)
- primary packaging (or sleeve) formation process and distribution
- production, distribution, recycling and final disposal of transport packaging materials (pallets, shrink plastic film, and cardboard trays)
- filling processes
- materials transports and final distribution from fillers to point of sale

The beverage production is not considered, since its burdens and losses are assumed to be equivalent in systems under comparison. Likewise, the use phase is not accounted for; the burdens of storage and losses at the consuming point are assumed the same for systems under comparison; and, the transport of packages from retailers to the consuming point is not considered, a common practice in LCAs.

An illustration of the systems boundaries is presented in Figure 3.

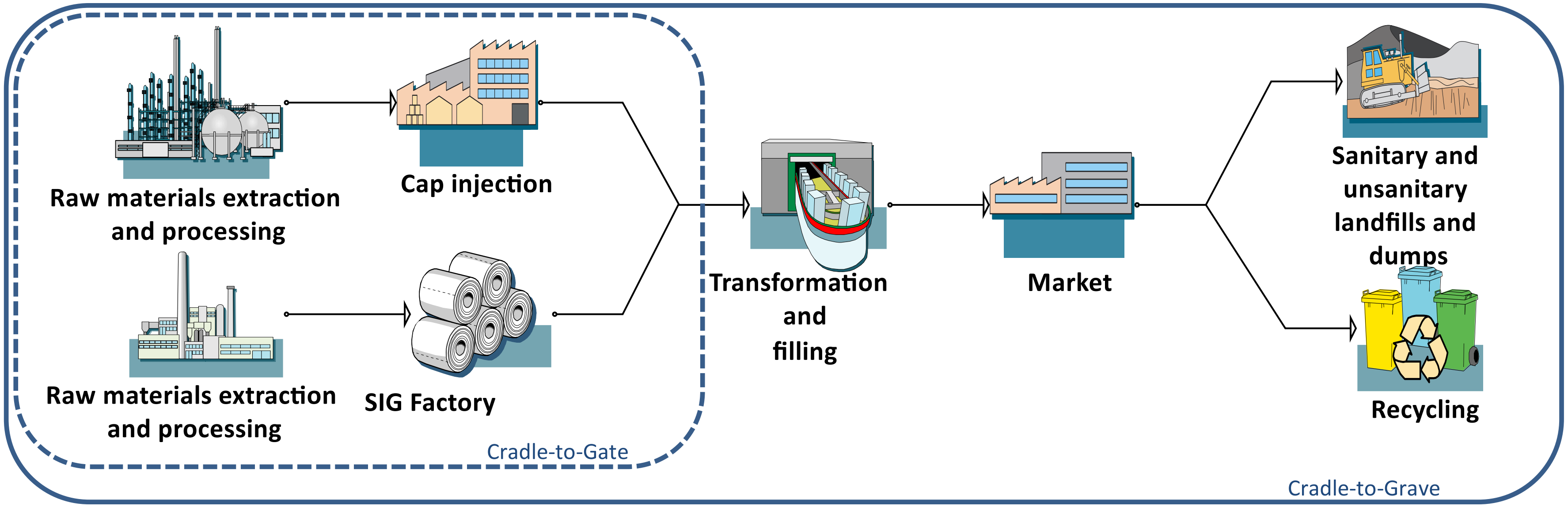


FIGURE 3 FLOW CHART OF SYSTEM PRODUCTS BOUNDARIES

1.2.3. END-OF-LIFE MODELING

Due to the recycling processes of the packaging, the production of virgin materials is offset at some degree. At this lifecycle stage, two life cycles happen to merge: the one under the scope of this Report and another getting to use the post-consumer material. It has to be decided then which system will take the credits and the burdens from the recycling process and at which level, as it can be seen in the example below (Figure 4). For the baseline scenario of this study, the 50/50 approach is adopted. That is, the burdens and credits of the recycling process are 50% allocated to both life cycles.

A sensitivity analysis is carried out with the cut-off (100/0) approach and using Circular Footprint Formula (CFF). In the cut-off approach, all the burdens and credits of the recycling process are allocated to the new post-consumer material. The CFF approach is explained below.

Product Environmental Footprint Category Rules (PEFCR)[4] guidance uses a special equation for those cases (**[EC 2007]**), so-called Circular Footprint Formula. The formula below takes in consideration parameters like allocation factors for burdens and credits, quality of the recycled material, recycling in previous systems and the burdens of it.

$$\boldsymbol{MR = (1 - R_1)E_V + R_1 * \left(A * E_{recycled} + (1 - A)E_V * \frac{Q_{Sin}}{Q_P}\right) + (1 - A)R_2 * (E_{recyclingEOL} - E_V^* \frac{Q_{Sout}}{Q_P})}$$

(Equation 1)

in which:

MR represents the allocated environmental impact of the end-of-life phase

A means allocation factor of burdens and credits between supplier and user of recycled materials (explained ahead).

Q_{Sin} means quality of the ingoing secondary material, i.e. the quality of the recycled material at the point of substitution (defined as 1, meaning no losses due to poor quality. It ranges from 0 to 1).

Q_{Sout} means quality of the outgoing secondary material, i.e. the quality of the recyclable material at the point of substitution, meaning losses due to poor quality. It ranges from 0 to 1).

Q_p means quality of the primary material, i.e. quality of the virgin material (defined as 1, meaning no losses due to poor quality. It ranges from 0 to 1).

[4] Willing to promote a higher level of harmonization among studies, Product Environmental Footprint Category Rules (PEFCR) has been developed in the European Union.

R_1 it is the proportion of material in the input to the production that has been recycled from a previous system.

R_2 it is the proportion of the material in the product that will be recycled (or reused) in a subsequent system.

$E_{recycled}$ means specific emissions and resources consumed (per unit of analysis) arising from the recycling process of the recycled (reused) material, including collection, sorting and transportation process.

$E_{recyclingEoL}$ means specific emissions and resources consumed (per unit of analysis) arising from the recycling process at EoL, including collection, sorting and transportation process.

E_v specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material.

E^*_v means specific emissions and resources consumed (per unit of analysis) arising from the acquisition and pre-processing of virgin material assumed to be substituted by recyclable materials.

Such set up intends to be a fair context for computing end-of-life environmental burdens and credits, as the double counting issue is dispelled. In this manner, the environmental impact arising from the raw material extraction phase can be distributed between the first life cycle and the second product system, started from the generation of a post-consumer recycled item (Figure 4).

Impacts due to the end-of-life stage are thus estimated from the sum of the above equations plus the environmental profile of the remaining waste not diverted from landfills and dumps.

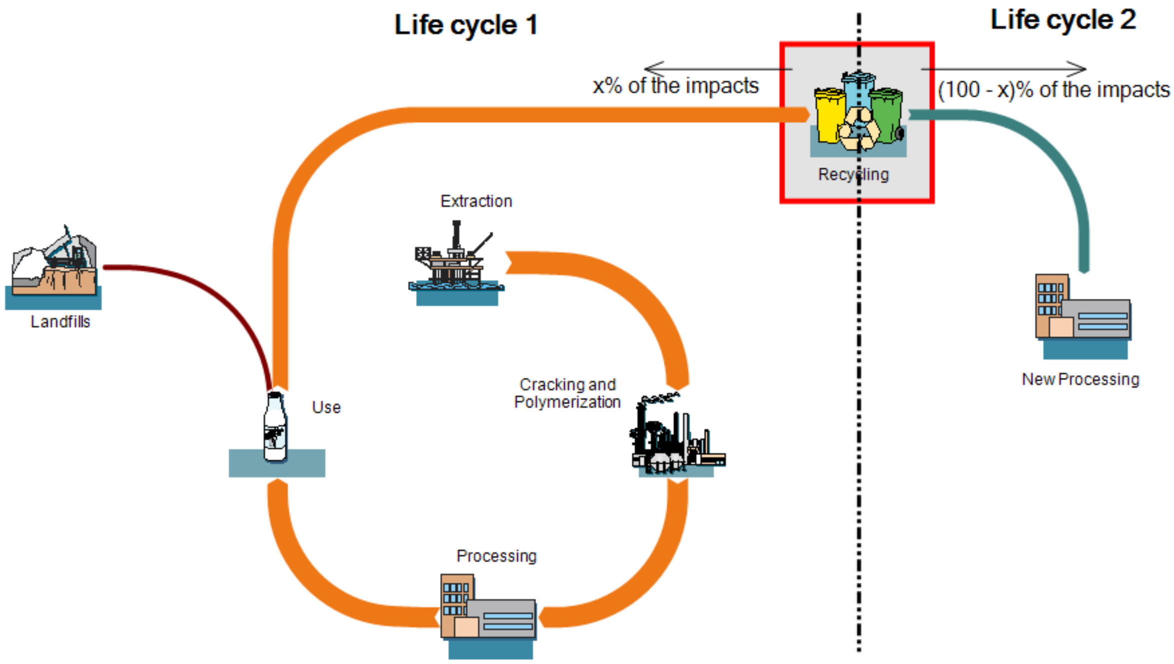


FIGURE 4 EXEMPLIFICATION OF THE DECISION ON HOW TO DEAL WITH BURDEN AND CREDITS OF THE RECYCLING

According to **[EC 2007]**, there is a set of parameters to be used in Circular Footprint Formula, most of them are determined on PEF requirements. The term A, for instance, for plastics is set to 0.5, representing equilibrium between offer and demand of recycled materials. This is similar to define that recycling burdens and credits are equally split between the life cycle using the recycled material and the one originating the waste to be recovered, i.e. equivalent to the 50/50 allocation approach. For LPB and corrugated board, the term A is set to 0.2.

The disposal modeling in sanitary landfills, unsanitary landfills or dumps takes into account the processes and consumptions on this operation, as well as the emissions due to the decomposition of the packaging in a 100 years' timeframe, according to **[Doka 2017]**.

1.2.4. CATEGORIES AND LIFE CYCLE IMPACT ASSESSMENT METHOD

Preliminary cautions are taken regarding the choice of the Life Cycle Impact Assessment (LCIA) method, as this Report is going to be published. According to ISO 14044, when dealing with public comparative assertions, weighting, an optional stage of LCIA, shall not be used. It is common to find weighting proceedings in endpoint models.

Thus, a method compiled by ACV Brasil based on the recommendation of the European Commission in the context of the Environmental Footprint (EF) initiative was used, which includes the following impact categories: Climate Change (kg CO_2 eq), Ozone Depletion (kg CFC-11 eq), Particulate Matter (disease incidence), Photochemical Ozone Formation (kg

NMVOC eq), Acidification (mol H^+ eq), Resource use minerals and metals (kg Sb eq), Eutrophication in freshwater (kg P eq), Resource use Fossil Fuels (MJ), Human Toxicity – carcinogenic effects (CTUh), Human Toxicity – non-carcinogenic effects (CTUh) and Ecotoxicity in freshwater (CTUe). In addition, the impact categories at the level of inventory called Water Consumption (m^3) and Land Use (m^2a) are also considered. Figure 5 describes the impact and inventory level categories considered in the method used in the study.

Water Consumption and Land Use are accounted in the inventory level instead of the related categories originally included in the EF method of impact assessment of Land Use (LANCA method – Soil quality index) and Water Use (AWARE method – m^3 eq). This choice was based on the higher uncertainties associated to these impact assessment methods, which might be inconsistent with the uncertainty related rules defined for this study (see section 1.2.6. Data Quality Requirements). Nevertheless, when interpreting the results of the categories on the inventory level, it is important to take in consideration that no conclusions on environmental performance can be drawn from it.

The approach of the LCIA Method (impact assessment categories) is oriented towards the intermediate point in the environmental mechanism, that is, the impact before producing an effect that affects Human Health or Ecosystem Quality, for example. This intermediate stage of LCIA models is characterized by different Impact Categories.

For each category, there is a defined characterization element, serving as a comparative basis for the other flows. In this way, an emission identified in the Lice Cycle Inventory (LCI) is converted into a contribution to this "environmental impact", multiplying it by an equivalence factor, called the characterization factor, which is exactly the comparison between the chosen element and the potential impact of the flow in question. Take CO_2 as an example, it is used as a basis for comparison for Climate Change, and the other substances that cause this effect are converted into CO_2 equivalents, using this comparative procedure.

Therefore, no grouping of impact categories was carried out. In 2021, the European Commission recommended the adoption of the EF method to measure and communicate the environmental performance of the life cycle of products and organizations [EC, 2021]. The recommendation is addressed to Member States and private and public organizations that measure and/or report the lifecycle environmental performance of their product or organization.

Considering the global relevance of the EF initiative and the harmonization of LCA studies, it is understood that, at the present time, the adoption of the EF method reflects the best practices available to address each impact category. In addition, the EF method is in line with the recommendations of the Life Cycle Initiative and The International EPD® System environmental labeling program.

FIGURE 5 EXPLANATORY TABLE OF THE CONSIDERED IMPACT AND INVENTORY-LEVEL CATEGORIES

LCIA METHOD (emissions-related categories)	
CLIMATE CHANGE (kg CO_2 eq)	Climate Change is related to the impact of emissions, called greenhouse gas (GHG) emissions, on the radiative forcing of the atmosphere. The characterization factors (in kg of carbon dioxide equivalent/kg of emission) are expressed as the global warming potential for a time horizon of 100 years from **[IPCC, 2013]**, which represents a robust well-documented model and achieves high degree of consensus among the scientific community.
OZONE DEPLETION (kg CFC-11 eq)	It represents the impact on the Earth's atmosphere, which leads to the decomposition of naturally present ozone molecules, disturbing the molecular balance in the stratosphere. The consequence of this imbalance is that a greater amount of UV-B radiation reaches the Earth's surface, causing damage to natural resources and human health. Characterization factors are applied in this category based on **[WMO 2014]**, a robust, up-to-date method widely accepted by the scientific community. The factors define ozone depletion potentials (ODP) of different gases (kg CFC-11 equivalent/kg emission).
ACIDIFICATION (mol H^+ eq)	Acidification affects aquatic and terrestrial ecosystems, altering the acid-base balance through the entry of acidifying substances. The indicator in this category is named in terms of accumulated exceedance, AE), highlighting the overload of chemical elements in the sensitive areas of terrestrial and freshwater ecosystems, to which such acidifying substances are deposited. The Acidification Potential (expressed as mol equivalent of H^+/kg of emission) is applied as the characterization factor, based on **[Posch et al., 2008]** and **[Seppälä et al., 2006]**. The method is well documented and includes the most important substances for acidification, such as ammonia (NH_3), nitrogen dioxide (NO_2) and sulfur oxides (SOx).
EUTROPHICATION (FRESHWATER) (kg P eq)	Eutrophication includes impacts due to excessive levels of macronutrients in ecosystems. Compounds containing nitrogen and phosphorus are among the most eutrophic. Eutrophication must be differentiated according to the intermediate medium in which it occurs. The Eutrophication Potential for freshwater (expressed as kg phosphorus equivalent/kg emission) is applied as the characterization factor, based on **[Struijs *et al.*, 2009]**.

FIGURE 5 EXPLANATORY TABLE OF THE CONSIDERED IMPACT AND INVENTORY-LEVEL CATEGORIES

LCIA METHOD (emissions-related categories)	
HUMAN TOXICITY (CTUh)	Human toxicity includes impacts of emissions to air, water and soil that threaten human health. Toxicity depends on the environmental fate of the substances, the exposure of humans to the substance, and the effects caused by these substances on humans. For this category, toxicity is further divided into toxic effects that cause cancer and toxic effects that do not cause cancer. This category includes impacts of toxic agents, based on data obtained from laboratory studies. Characterization factors are from the USEtox 2.1 model adapted by **[Saouter *et al.*, 2018]**, expressed as CTUh (human toxicity impact scores in comparative toxic units) that provide the estimated increase in morbidity in the global human population per unit mass of a chemical substance emitted.
ECOTOXICITY (CTUe)	Ecotoxicity includes impacts generated by emissions to air, water and soil that threaten the health of species. Toxicity depends on the environmental fate of the substances, the exposure of species to the substances, and the effects caused by those substances on the species. Characterization factors are also taken from USEtox 2.1 adapted by **[Saouter *et al.*, 2018]** and expressed in comparative toxic units (CTUe), providing an estimate of the potentially affected fraction of species integrated over time and the volume per unit mass of an emitted chemical.
PHOTOCHEMICAL OZONE FORMATION (kg NMVOC eq)	Photochemical ozone formation is the photochemical creation of reactive substances (mainly ozone) that affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides and volatile organic compounds in the presence of sunlight. Photochemical ozone creation potentials for substances emitted to air are calculated based on **[Van Zelm *et al.*, 2008]**and expressed in kg equivalent of Volatile Organic Compounds|Non-Methane (NMVOC).
PARTICULATE MATERIAL (disease incidence)	This category covers the effects of primary and secondary fine particles, for which a correlation with respiratory diseases has already been demonstrated by epidemiological studies. The indicator defined as incidence of diseases/kg of emitted $PM_{2.5}$ aims to assess the damage to human health resulting from outdoor and indoor emissions of particulate matter in urban and rural areas. The characterization factors are applied from **[Fantke *et al.*, 2016]**.

FIGURE 5 EXPLANATORY TABLE OF THE CONSIDERED IMPACT AND INVENTORY-LEVEL CATEGORIES

LCIA METHOD (consumption-related categories)	
MINERAL RESOURCES (kg Sb eq)	This impact category indicator is related to the extraction of minerals that enter the ecosystem. The resource depletion factor is determined for each mineral extraction (kg of antimony equivalents/kg of extraction) based on its reserves and extraction rate. It is obtained based on CML 2002 **[Van Oers et al., 2002]**, a well-documented and robust method, relatively complete for mineral depletion.
FOSSIL FUELS (MJ)	This impact category indicator is related to the consumption of fossil fuels entering the ecosystem. The resource consumption factor is determined for each fuel extraction in MJ. It is obtained based on CML 2002 **[Van Oers et al., 2002]**, a well-documented and robust method, relatively complete for fossil fuel consumption.
CATEGORIES ON INVENTORY LEVEL	
LAND USE (m^2a)	The Land Use inventory category reflects the demand for the use of available areas for exploration and development of economic activities. Inventory indicators, expressed in m^2a, are available in the SimaPro® method library.
WATER CONSUMPTION (m^3)	The Water Consumption inventory category reflects the difference between the amount of water withdrawn and the amount of water returned to the environment and its losses (evaporation and incorporation into the product). The return is considered only when carried out in the same environmental compartment as the catchment. Factors at the inventory level, just expressing total water consumption, are taken from ReCiPe **[Huijbregts *et al.*, 2017]**, represented in m^3.

The Total Climate Change category is divided into the following subcategories according to the type of emission or removal of Climate Forcing substances:

- Climate Change – Fossil: Emissions of substances of fossil origin;
- Climate Change – Biogenic: Emissions of biogenic carbon-based substances, i.e. regeneration of carbon from renewable materials;
- Climate Change – Land Use and Land Use Change: Biogenic carbon emissions associated with land transformation, i.e. carbon content in soil and vegetation;
- Climate Change – Uptake: Removal of atmospheric carbon dioxide into renewable materials.

1.2.5. MAIN ASSUMPTIONS

Aiming at the transparency of the evaluations being discussed, the following assumptions are highlighted:

i. For situations in which Brazilian data is not available and bearing in mind the low level of national inventories, data from other geography or technology shall be used;

ii. For any data gap in the product systems, sector-specific inventories are investigated depending on the relevance of the data to the results, when data is not available ecoinvent v3.8 (cut-off approach) may be used;

iii. The biogenic carbon uptake and release on renewable materials' life cycles, such as paper-based products and mass-balanced polymers, are accounted for. For renewable materials, the carbon content of the product has been considered to calculate the biogenic carbon uptake over its cradle-to-gate stage. For paper-based products, emissions related to waste degradability in landfills (over 100 years) are implemented according to the models selected from the ecoinvent 3.8 database, which assume 48% of biogenic carbon content and 32.44% of waste degradability in landfill (in 100 years). It means 32.44% of all biogenic carbon stored in paper will be released as CO_2, CH_4 or CO in landfills.

iv. The biogenic carbon uptake of avoided materials, i.e. credits for recycling processes, are accounted for.

v. Land use change (dLUC), which implies carbon emissions / removals due to land transformation, was considered in this study through inventories from the ecoinvent database used as background for modeling the product systems;

vi. The assessment is performed only on the product systems described; other aspects, like management or infrastructure of companies, are not assessed;

vii. Long-term characterization factors are not present in the foreground level of the model, due to their high related uncertainty.

1.2.6. DATA QUALITY REQUIREMENTS

Several estimations done along the life cycle modeling have a given uncertainty level. It is thus possible to evaluate how significant changes on this choice values alter the final results.

To analyze the data quality, a simplified approach of the Matrix Pedigree (Appendix A) will be used. The technique used here involves a qualitative evaluation of data quality indicators **[Pedersen Weidema & Wesnaes 1996]**. Each foreground process is qualified according to 5 indicators: reliability, completeness, temporal correlation, geographical correlation and further technological correlation.

These properties are then rated in 5 quality levels, having scores from 1 to 5, so a set of 5 scores is assigned to individual input and output flows (except the reference flow). Besides, there are three bands for the data quality level, i.e., low, medium and high data quality levels. The final data quality level associated with a certain flow is given by the sum of the score set, as shown in Table 3.

TABLE 3. DATA QUALITY QUALIFICATION BANDS

Data Quality level	Sum score
Low	From 19 to 25
Medium	From 12 to 18
High	From 5 to 11

A summary of this Data Quality classification is presented in Appendix A – Pedigree matrix. The quality of the data used for modeling is also checked, to some extent, by Sensitivity Analyses made in this study, once they seek to help in spotting sharp changes in the results after parameters have been changed.

Using the Pedigree Matrix and Sensitivity Analyses, the developers of this Report intend to minimize the effects derived from asymmetric data. This assessment shall be interpreted and reflected in the conclusions.

The criteria applied for this Report for uncertainty analysis is that a difference higher than 10% would allow stating that one product has a better environmental performance than another in a specific category.

1.2.7. ALLOCATION

For data sets prepared by the authors of this study, the allocation of the outputs from single or coupled processes is generally carried out via the mass. If different allocation criteria are used, they will be documented in the description of the data in case they are of special importance for the individual data sets. For literature data, the source is generally referred to.

For system-related allocation, i.e. in the context of open loop recycling, the 50/50 approach is applied as described in the section ‘End-Of-Life Modeling’.

The ecoinvent database model cut-off is used for the background processes. These datasets are already allocated, in most cases according to the revenue of the co-products in multi-output processes, and following the cut-off approach for system-related allocation.

1.2.8. Critical review

An accompanying review by external experts has been conducted through various stages of this study, i.e. Goal and Scope Definition, Results presentation, and LCA report. The external reviewers of this study are:

- Frank Wellenreuther (ifeu)
- Saskia Grünwasser (ifeu)

According to the ISO standards on LCA, the external communication of the results requires that an external review is conducted. Therefore, this type of review should be carried out prior to the external communication of results.

The Critical Review Statement is presented in Appendix C.

2. LIFE CYCLE INVENTORY

2.1. DATA COLLECTION

The quality of an LCA study is directly related to the quality of data collected, which should be assessed by considering the following aspects: reliability, representativeness and temporal, geographical and technological correlation. The data collected in this study sought to address key requirements of data quality. It used primary data from SIG Combibloc and its suppliers, as well as, from recyclers. Secondary data were put together from ecoinvent v3.8 and from available literature, for mass-balanced polymers, for instance. All background processes also come from ecoinvent v3.8.

The inventory library ecoinvent v3.8 is internationally recognized by the quantity and quality of its data. When using an international database to represent Brazilian processes, however, discrepancies can be found in certain areas. However, it is believed that the consistency and accuracy of this database make this option acceptable. Additionally, although this library has European roots, it contains information representing many regions of the world. For example, it is included in the database the Brazilian electricity grid. Thus, whenever possible, background and foreground datasets had their electricity mixes adapted to Brazil.

For the final disposal scenario, ecoinvent v3.8 were used to represent Brazilian reality. Beyond sanitary landfills, these datasets also model emissions from dumps and unsanitary landfills (**[Doka 2017]**), which are part of the Brazilian solid waste disposal scenario.

When applicable, units of measurement and mass balances were verified. Further details and relevant information can also be retrieved in Table 4. The detailed LCA model description has been restricted to the LCA practitioners, the commissioner and external reviewers of the study.

2.2. DATA SOURCES

A summary of the data sources can be found in Table 4.

The data quality qualification, as proposed in Table 3, is presented in Appendix A – Pedigree Matrix.

TABLE 4 LIST OF MAIN DATA SOURCES

Life cycle stage	Data source	Representative period	Geographic Scope
Materials production			
Aluminium (primary) foil production and transformation	International Aluminium Institute, as implemented in ecoinvent 3.8 database	2015	Brazil and China
Aluminiun foil formation	ecoinvent 3.8	2008	Brazil and China
Liquid Packaging Board (Brazilian supplier)	From producer (confidential)	2021	Brazil
Liquid Packaging Board (European supplier)	Average production process of the main European LPB producers (ACE), as implemented in ecoinvent 3.9.1.	2018	Finland/Sweden
Fossil LDPE (for package layers)	U.S. Life Cycle Inventory Database	2011	U.S.
Fossil PE-based adhesive	Plastics Europe as implemented in ecoinvent 3.8: HDPE production dataset with adaptations to represent PE-based adhesive raw-materials	2016	Europe
Fossil based HDPE (closure)	Plastics Europe, as implemented in ecoinvent 3.8, with adaptations of the electricity grid to Brazil.	2016	Brazil
Mass-balanced PE	Based on information provided by SIG Combibloc, ecoinvent 3.8 and literature	2016	Europe
Mass-balanced PP	Based on information provided by SIG Combibloc, ecoinvent 3.8 and literature	2016	Europe
Mass-balanced PA	From producer (confidential), ecoinvent 3.8 and literature	2015	Europe
Corrugated Board Box production	FEFCO, as implemente in ecoinvent 3.8	2015	Brazil
Production			
Sleeve transformation (MidiBloc Alu-free - Dairy)	ACE	2019	Europe
Sleeve transformation (all other 6 packages)	SIG Combibloc	2021	Brazil
Cap injection	ecoinvent 3.8	2010	Brazil
Filling			
Package filling	SIG Combibloc	2021	Brazil
Recovery			
Corrugated board box and beverage cartons (LPB) recycling	From one beverage carton recycling plant in Brazil, confidential	2021	Brazil
Beverage cartons (PolyAl) recycling	ecoinvent 3.8 database	1993	Brazil
Background data			
Landfills and dumps	ecoinvent 3.8 database	1994-2006	Brazil
Electricity production	ecoinvent 3.8 database	2015	Brazil
Electricity production	ecoinvent 3.8 database	2018	Germany
Lorry transport	ecoinvent 3.8 database	2020	Brazil
Lorry transport	ecoinvent 3.8 database	2017	Europe
Oceanic transport	ecoinvent 3.8 database	2017	Global

2.2.1. Liquid Packaging Board Production

The LPB is supplied by a Brazilian producer and by a European producer (Table 2). The local supplier provided their own life cycle inventory (confidential), which is modelled consistently with assumptions regarding background data and biogenic carbon used in the present study. To represent the European producer, the last available inventory from The Alliance for Beverage Cartons and the Environment (ACE) implemented in the ecoinvent 3.9.1 database was selected. The carbon content of the LPBs has been used to calculate the biogenic carbon dioxide balance of the datasets – ACE's LPB has 41.65% biogenic carbon content according to the ecoinvent 3.9.1 dataset documentation.

2.2.2. Corrugated Board Box

Data from the European Federation of Corrugated Board Manufacturers (FEFCO) for the base year of 2015[5], as implemented in the ecoinvent 3.8 database, is used as a proxy to represent the Brazilian corrugated board box production due to lack of local data. The recycled content of the corrugated box is of 71% and its biogenic carbon content is of 45% (ecoinvent 3.8). This information have been used to calculate the biogenic carbon dioxide balance of the dataset.

2.2.3. Mass-balanced Polymers

The production process of mass-balanced polymers are modelled considering tall oil pitch as the feedstock. Tall oil is derived from wood and is obtained as a by-product of pulp and paper production. In this approach, the carbon content of the mass-balanced polymers is assumed to be from biogenic origin. The carbon content considered for PE and PP is 85.7% and for PA is 63.7%.

Crude tall oil production is modelled considering the ecoinvent 3.8 dataset "Tall oil, crude {RER}| containerboard production, linerboard, kraftliner | Cut-off, U", which represents the data from FEFCO for the base year of 2015. The containerboard production dataset applies an allocation factor of 1.73% to the crude tall oil co-product, as implemented in the ecoinvent 3.8 database "cut-off" model. The refinement of crude tall oil to tall oil pitch is modelled considering the ecoinvent 3.8 dataset "Pitch {GLO}| tall oil refinery operation | Cut-off, U", which represents data from Cashman et al. (2015). The applied allocation factor to tall oil pitch is 3.18% (ecoinvent 3.8 database).

[5] The most recent ecoinvent database version 3.9.1 brings an updated corrugated board box data from FEFCO for the year 2018. For comparison, the Global Warming Potential of 2018's data is 0.983 kg CO_2 eq./kg (IPCC 2021 method) and 0.927 kg CO_2 eq./kg (IPCC 2013 method) for 2015's data. The small difference in the results indicate that the use of the older data would not cause damage to data quality.

The production of mass-balanced PE and PP is modelled by replacing the fossil feedstock (i.e. ethylene or propylene) input on the polymerization process by hydrotreated tall oil pitch. The hydrotreatment process data is retrieved from Nikander (2008).

The production of mass-balanced PA is modelled by replacing the input of fossil naphtha by tall oil pitch according to their energy content. The data for PA production is provided by the producer, and the amount of naphtha input is calculated based on the crude oil flow.

2.2.4. ALUMINIUM FOIL

Primary aluminium production datasets are retrieved from the ecoinvent 3.8 database, which uses the inventory compiled by the International Aluminium Institute (IAI) for various regions of the world. In ecoinvent 3.8, the IAI datasets are representative for the year of 2015. However, the IAI has already published inventories for the year of 2019, which are not implemented in the ecoinvent database yet.

In order to assess the differences between both versions of the IAI datasets, flows with high contribution to the Climate Change impact of primary aluminium production have been selected. For the IAI South America region (representing the Brazilian aluminium production), from 2015 to 2019 the electricity consumed in the electrolysis process has decreased 1.5% and the consumption of alumina has increased by 2.2%. For the IAI China region, from 2015 to 2019 the electricity consumed in the electrolysis process has increased by 0.8%.

Moreover, the datasets compiled by IAI for the Chinese region are mostly incomplete, and the dataset published in ecoinvent is built with data from different regions of the world.

2.2.5. RECYCLING

The considered recycling rates represent the last available statistics for Brazil, representing the year 2021 (**[CEMPRE, 2022]**). In the baseline scenario, 35.9% of post-consumer beverage cartons and 85% of corrugated boxes are recycled.

To represent the LPB and corrugated board box recycling processes, primary data has been collected from a paper recycling plant located in Curitiba, Brazil. For PolyAl recycling, ecoinvent 3.8 data has been used as a proxy.

2.2.6. TRANSPORTATION DISTANCES AND MODES

Table 5 presents the distribution distances and modes assumed for the raw materials and products.

TABLE 5 DISTRIBUTION MODELS FOR RAW MATERIALS AND PRODUCTS

Distance in km and transport modes							
Production site	**Destination**	Road (BR)	Road (EU)	Road (Rest of World)	Sea	Rail	Source
LPB							
EU	**BR**	150	150		11100		Calculated
EU	**EU**		300		800	400	Calculated
BR	**BR**	215					Calculated
Mass-balanced polymers							
EU	**BR**	150	150		10100		Calculated
EU	**EU**		150				Assumption
PE-based adhesive							
EU	**BR**	150	150		10100		Calculated
Aluminium							
CN	**BR**	150		150	20192		Calculated
BR	**BR**	500					Calculated
Fossil PE and PP							
US	**BR**	150		150	10134		Calculated
BR	**BR**	150					Assumption
Sleeve							
EU	**BR**	150	150		10100		Calculated
Cardboard box, stretch film, and wood pallet							
BR	**BR**	150					Assumption
Sleeve distribution from SIG to filler							
BR	**BR**	997					Primary data from SIG Combibloc
Distribution from filler to retailer							
BR	**BR**	300					Assumption

Notes: Calculated distances are based on the production and destination sites. 150 km by road has been assumed for local distribution.

3. RESULTS[6]

The information in this section should be used only within the context of this study and its boundaries and assumptions, considering the statements on Limitations and Assumptions. This section presents the results of the Life Cycle Impact Assessment (LCIA), for the selected impact categories described in section 1.2.4. Categories and life cycle impact assessment method and Inventory Assessment, for the inventory level categories of Land Use and Water Consumption.

It should be emphasized that there is no significance in drawing comparative conclusions between products based on individual stages of the life cycle. Furthermore, the impacts described by the LCA are estimates of potential impacts rather than direct measurements of actual impacts. Moreover, although the results at the inventory level (Land Use and Water Consumption) are presented together with the impact assessment categories, they are not intended to drive conclusions regarding the environmental performance of the products.

The sections below are split in Base Scenario and Sensitivity Analyses. A Contribution Analysis, auxiliary material for the comprehension of this Report, is delivered in Appendix B – Contribution Analysis.

The calculations were performed in the SimaPro® 9.4.0.2 software.

3.1. BASE SCENARIO

3.1.1. SIG MIDIBLOC FOR DAIRY PACKAGING

Below, in Figure 6, the results of the Life Cycle Assessment of the SIG MidiBloc model products used for packing dairy beverages are presented for the impact categories and the categories at the resource consumption or inventory level. The absolute values of the results are presented in Tables 6 and 7. The percentages in Table 8 represent the difference of the net results for all three packaging groups of comparison in the three End-of-Life allocation approaches assessed in this report (in the Base Scenario and Sensitivity Analysis): '50/50' (base scenario), '100/0', and 'CFF' (Circular Footprint Formula).

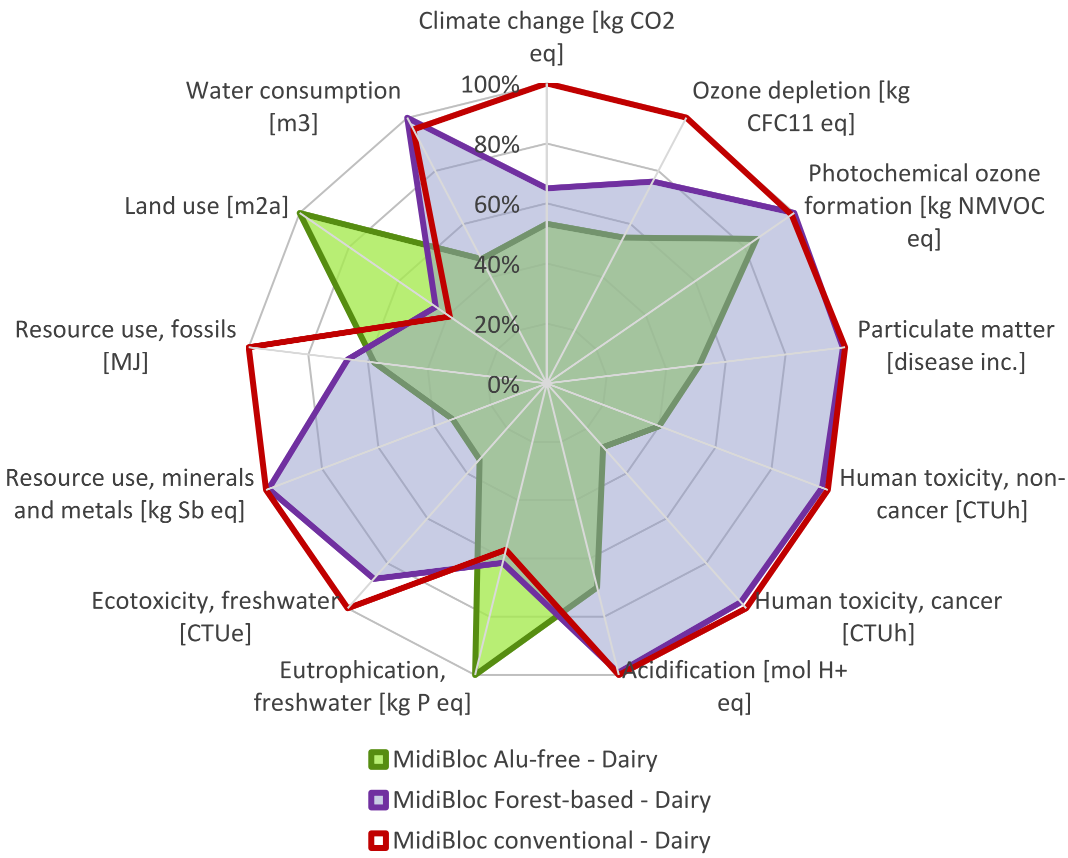
For the categories of **Climate Change**, **Ozone Depletion**, **Freshwater Ecotoxicity**, and **Resource Use Fossils**, it is possible to resolve that the packages produced with mass-balanced polymers, MidiBloc Alu-free - Dairy and MidiBloc Forest-based, stand for better options in comparison with the MidiBloc - Conventional, i.e. at least 10% difference in the results. The use of mass-balanced instead of fossil polymers is the main reason for the differences in the

[6] The criteria applied for this Report was that a difference higher than 10% would allow stating that one product has a better environmental performance than other in a specific category.

results. As can be noticed in Appendix B – Contribution Analysis, the uptake of carbon dioxide on the mass-balanced polymers contributes to the lower Climate Change impact. For the aforementioned categories, the MidiBloc Alu-free - Dairy stands for the best option among the three packaging alternatives by avoiding the production of the aluminum barrier, i.e. the MidiBloc Alu-free - Dairy sleeve is formed with only a mass-balanced plastic barrier instead of the aluminium foil.

MidiBloc Alu-free - Dairy also stands for the best packaging alternative for the categories of **Photochemical Ozone Formation**, **Particulate Matter**, **Human Toxicity (cancer and non-cancer effects)**, **Acidification**, **Resource Use Fossils**, and **Water Consumption**. This advantage is also explained by avoiding the use of an alumininum barrier.

On the other hand, the MidiBloc Alu-free - Dairy packaging exceeds the MidiBloc Forest-based and the MidiBloc - Conventional packages in the results for **Freshwater Eutrophication** and **Land Use**, owing to the different shares of LPB suppliers.



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 6 RESULTS OF THE LIFE CYCLE ASSESSMENT OF THE SIG MIDIBLOC MODEL PRODUCTS USED FOR PACKING DAIRY BEVERAGE

Table 6 Cradle-To-Grave Results for Each Package in the Baseline Scenario

Cradle-to-Grave results applying the 50/50 allocation (baseline)		MidiBloc Alu-free Dairy	MidiBloc Forest-based Dairy	MidiBloc Conventional Dairy	MidiBloc Forest-based Juice	MidiBloc Conventional Juice	StandardBloc Forest-based Dairy	StandardBloc Conventional Dairy
Climate change - Total [kg CO2 eq]	Net results	0.0576	0.0705	0.108	0.070	0.108	0.0659	0.104
	CO2 Uptake	-0.104	-0.133	-0.106	-0.140	-0.113	-0.130	-0.103
	CO2 EoL emissions	0.0921	0.113	0.112	0.119	0.119	0.112	0.111
	Burdens	0.0540	0.0763	0.0880	0.0759	0.0876	0.0697	0.0814
	Credits	0.0156	0.0143	0.0143	0.0144	0.0144	0.0142	0.0142
Ozone depletion [kg CFC11 eq]	Net results	5.11E-09	7.06E-09	9.29E-09	7.26E-09	9.49E-09	6.50E-09	8.76E-09
	Burdens	5.40E-09	7.38E-09	9.61E-09	7.58E-09	9.81E-09	6.81E-09	9.07E-09
	Credits	-2.91E-10	-3.15E-10	-3.15E-10	-3.16E-10	-3.16E-10	-3.14E-10	-3.14E-10
Photochemical ozone formation [kg NMVOC eq]	Net results	0.000255	0.000300	0.000297	0.000291	0.000288	0.000270	0.000267
	Burdens	0.000274	0.000321	0.000318	0.000312	0.000309	0.000291	0.000288
	Credits	-1.99E-05	-2.10E-05	-2.10E-05	-2.11E-05	-2.11E-05	-2.09E-05	-2.09E-05
Particulate matter [disease inc.]	Net results	2.71E-09	5.25E-09	5.29E-09	5.24E-09	5.28E-09	4.74E-09	4.78E-09
	Burdens	3.27E-09	5.80E-09	5.84E-09	5.80E-09	5.84E-09	5.29E-09	5.33E-09
	Credits	-5.59E-10	-5.56E-10	-5.56E-10	-5.58E-10	-5.58E-10	-5.52E-10	-5.52E-10
Human toxicity, non-cancer [CTUh]	Net results	5.48E-10	1.34E-09	1.37E-09	1.38E-09	1.40E-09	1.30E-09	1.33E-09
	Burdens	5.78E-10	1.37E-09	1.40E-09	1.41E-09	1.44E-09	1.33E-09	1.36E-09
	Credits	-3.05E-11	-3.30E-11	-3.30E-11	-3.31E-11	-3.31E-11	-3.28E-11	-3.28E-11
Human toxicity, cancer [CTUh]	Net results	1.38E-11	4.77E-11	4.90E-11	4.77E-11	4.91E-11	4.55E-11	4.68E-11
	Burdens	1.58E-11	4.96E-11	5.10E-11	4.97E-11	5.10E-11	4.74E-11	4.88E-11
	Credits	-1.93E-12	-1.96E-12	-1.96E-12	-1.97E-12	-1.97E-12	-1.95E-12	-1.95E-12
Acidification [mol H+ eq]	Net results	0.000325	0.000461	0.000465	0.000451	0.000455	0.000419	0.000423
	Burdens	0.000345	0.000483	0.000487	0.000473	0.000477	0.000441	0.000444
	Credits	-2.00E-05	-2.16E-05	-2.16E-05	-2.17E-05	-2.17E-05	-2.15E-05	-2.15E-05
Eutrophication, freshwater [kg P eq]	Net results	7.31E-06	4.50E-06	4.17E-06	3.78E-06	3.46E-06	3.35E-06	3.02E-06
	Burdens	7.45E-06	4.64E-06	4.31E-06	3.93E-06	3.60E-06	3.49E-06	3.16E-06
	Credits	-1.43E-07	-1.42E-07	-1.42E-07	-1.43E-07	-1.43E-07	-1.41E-07	-1.41E-07
Ecotoxicity, freshwater [CTUe]	Net results	0.782	2.01	2.32	2.02	2.32	1.90	2.21
	Burdens	0.842	2.08	2.38	2.08	2.39	1.96	2.27
	Credits	-0.0599	-0.0657	-0.0657	-0.0659	-0.0659	-0.0653	-0.0653
Resource use, minerals and metals [kg Sb eq]	Net results	4.06E-08	1.20E-07	1.21E-07	1.39E-07	1.40E-07	1.33E-07	1.34E-07
	Burdens	4.80E-08	1.28E-07	1.29E-07	1.47E-07	1.48E-07	1.41E-07	1.42E-07
	Credits	-7.45E-09	-7.57E-09	-7.57E-09	-7.59E-09	-7.59E-09	-7.51E-09	-7.51E-09
Resource use, fossils [MJ]	Net results	0.856	0.989	1.48	0.971	1.46	0.885	1.38
	Burdens	0.880	1.02	1.51	1.00	1.49	0.911	1.41
	Credits	-0.0234	-0.0263	-0.0263	-0.0264	-0.0264	-0.0262	-0.0262
Land use [m2a]	Net results	0.104	0.0467	0.0408	0.0313	0.0254	0.0227	0.0168
	Burdens	0.144	0.0855	0.0796	0.0702	0.0643	0.0612	0.0553
	Credits	-0.0405	-0.0388	-0.0388	-0.0389	-0.0389	-0.0384	-0.0384
Water consumption [m3]	Net results	0.000942	0.00201	0.00192	0.00209	0.00200	0.00197	0.00189
	Burdens	0.00114	0.00220	0.00212	0.00229	0.00220	0.00217	0.00208
	Credits	-0.000196	-0.000195	-0.000195	-0.000196	-0.000196	-0.000193	-0.000193
Climate change - Fossil [kg CO2 eq]	Net results	0.0507	0.0725	0.0842	0.0722	0.0839	0.0661	0.0778
	Burdens	0.0530	0.0752	0.0869	0.0750	0.0866	0.0688	0.0805
	Credits	-0.00233	-0.00275	-0.00275	-0.00276	-0.00276	-0.00274	-0.00274
Climate change - Biogenic [kg CO2 eq]	Net results	0.0799	0.101	0.101	0.108	0.107	0.100	0.100
	Burdens	0.0921	0.113	0.112	0.119	0.119	0.112	0.111
	Credits	-0.0122	-0.0117	-0.0117	-0.0118	-0.0118	-0.0116	-0.0116
Climate change - Land use and LU change [kg CO2 eq]	Net results	0.000988	0.00108	0.00108	0.000907	0.000909	0.000874	0.000875
	Burdens	0.00101	0.00110	0.00110	0.000933	0.000934	0.000899	0.000901
	Credits	-1.93E-05	-2.53E-05	-2.53E-05	-2.53E-05	-2.53E-05	-2.53E-05	-2.53E-05
Climate change - CO2 uptake [kg CO2 eq]	Net results	-0.0740	-0.104	-0.0775	-0.111	-0.0838	-0.101	-0.0742
	CO_2 uptake disregarding credits for recycling	-0.104	-0.133	-0.106	-0.140	-0.113	-0.130	-0.103
	Credits	0.0301	0.0289	0.0289	0.0290	0.0290	0.0286	0.0286

Note: CO2 uptake - Uptake of atmospheric CO2 during the plant growth phase; CO2 EoL emissions - Biogenic (regenerative) CO2 emissions from landfilling of biobased materials; burdens - overall environmental loads; credits - Credits for material recycling; Net results - subtraction of credits from overall environmental loads.

TABLE 7 CRADLE-TO-GATE RESULTS FOR EACH PACKAGE IN THE BASELINE SCENARIO

Impact category	MidiBloc Alu-free Dairy	MidiBloc Forest-based Dairy	MidiBloc Conventional Dairy	MidiBloc Forest-based Juice	MidiBloc Conventional Juice	StandardBloc Forest-based Dairy	StandardBloc Conventional Dairy
Climate change - Total (without CO_2 uptake) [kg CO2 eq]	0.0532	0.101	0.112	0.107	0.118	0.104	0.115
Ozone depletion [kg CFC11 eq]	3.06E-09	5.03E-09	7.26E-09	5.23E-09	7.46E-09	5.13E-09	7.40E-09
Photochemical ozone formation [kg NMVOC eq]	0.000173	0.000220	0.000217	0.000211	0.000208	0.000208	0.000205
Particulate matter [disease inc.]	1.18E-09	3.71E-09	3.75E-09	3.70E-09	3.74E-09	3.64E-09	3.68E-09
Human toxicity, non-cancer [CTUh]	2.17E-10	1.02E-09	1.05E-09	1.05E-09	1.08E-09	1.03E-09	1.06E-09
Human toxicity, cancer [CTUh]	7.71E-12	4.15E-11	4.28E-11	4.15E-11	4.29E-11	4.08E-11	4.22E-11
Acidification [mol H+ eq]	0.000209	0.000346	0.000350	0.000336	0.000340	0.000330	0.000334
Eutrophication, freshwater [kg P eq]	5.46E-06	2.65E-06	2.32E-06	1.94E-06	1.61E-06	1.90E-06	1.57E-06
Ecotoxicity, freshwater [CTUe]	0.293	0.994	1.30	1.00	1.30	0.979	1.29
Resource use, minerals and metals [kg Sb eq]	4.26E-08	1.22E-07	1.23E-07	1.41E-07	1.43E-07	1.36E-07	1.37E-07
Resource use, fossils [MJ]	0.484	0.618	1.11	0.600	1.09	0.593	1.09
Land use [m2a]	0.116	0.0570	0.0511	0.0417	0.0358	0.0404	0.0345
Water consumption [m3]	0.000466	0.00150	0.00142	0.00158	0.00150	0.00155	0.00146
Climate change - Fossil [kg CO2 eq]	0.0239	0.0459	0.0575	0.0456	0.0573	0.0449	0.0566
Climate change - Biogenic [kg CO2 eq]	0.0290	0.0551	0.0544	0.0609	0.0602	0.0586	0.0579
Climate change - Land use and LU change [kg CO2 eq]	0.000289	0.000386	0.000387	0.000214	0.000215	0.000221	0.000222

Note: For cradle-to-gate results, the uptake of CO_2 from the atmosphere into renewable materials is not considered, because the eventual regeneration of biogenic CO_2 to the environment in the End-of-Life stage is not accounted.

TABLE 8 COMPARISON OF THE NET RESULTS BETWEEN EQUIVALENT PACKAGING FORMATS

	The net results of														
	MidiBloc Alu-free Dairy			**MidiBloc Alu-free Dairy**			**MidiBloc Forest-based Dairy**			**MidiBloc Forest-based Juice**			**StandardBloc Forest-based Dairy**		
	are lower (green)/higher (red) than those of														
	MidiBloc Conventional Dairy			**MidiBloc Forest-based Dairy**			**MidiBloc Conventional Dairy**			**MidiBloc Conventional Juice**			**StandardBloc Conventional Dairy**		
Impact category\Allocation Model	**50/50 (baseline)**	**100/0**	**CFF**	**50/50 (baseline)**	**100/0**	**CFF**	**50/50 (baseline)**	**100/0**	**CFF**	**50/50 (baseline)**	**100/0**	**CFF**	**50/50 (baseline)**	**100/0**	**CFF**
Climate change - Total [kg CO2 eq]	-47%	-59%	-41%	-18%	-28%	-15%	-35%	-43%	-31%	-35%	-43%	-32%	-37%	-45%	-33%
Ozone depletion [kg CFC11 eq]	-45%	-44%	-46%	-28%	-27%	-28%	-24%	-23%	-24%	-23%	-23%	-24%	-26%	-25%	-26%
Photochemical ozone formation [kg NMVOC eq]	-14%	-14%	-15%	-15%	-15%	-16%	1%	1%	1%	1%	1%	1%	1%	1%	1%
Particulate matter [disease inc.]	-49%	-45%	-52%	-48%	-44%	-51%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%
Human toxicity, non-cancer [CTUh]	-60%	-59%	-60%	-59%	-58%	-60%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%	-2%
Human toxicity, cancer [CTUh]	-72%	-69%	-73%	-71%	-69%	-72%	-3%	-3%	-3%	-3%	-3%	-3%	-3%	-3%	-3%
Acidification [mol H+ eq]	-30%	-29%	-31%	-29%	-29%	-30%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%
Eutrophication, freshwater [kg P eq]	75%	73%	76%	63%	61%	63%	8%	8%	8%	9%	9%	10%	11%	11%	11%
Ecotoxicity, freshwater [CTUe]	-66%	-65%	-67%	-61%	-60%	-62%	-13%	-13%	-13%	-13%	-13%	-13%	-14%	-14%	-14%
Resource use, minerals and metals [kg Sb eq]	-67%	-63%	-69%	-66%	-63%	-69%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%	-1%
Resource use, fossils [MJ]	-42%	-42%	-42%	-13%	-13%	-14%	-33%	-33%	-33%	-34%	-33%	-34%	-36%	-36%	-36%
Land use [m2a]	154%	82%	346%	123%	70%	236%	14%	7%	33%	23%	9%	248%	35%	11%	100%
Water consumption [m3]	-51%	-48%	-53%	-53%	-50%	-55%	5%	4%	5%	4%	4%	4%	5%	5%	5%

Notes:

1. The different End-of-Life allocation models are described in section 1.2.3. End-of-life modelling; the 50/50 allocation approach is chosen as the base scenario for this study.
2. The colours green and red are used to illustrate more (green) and less (red) favorable net results.
3. Differences lower than 10% are considered insignificant according to the Uncertainty rules applied in this report.

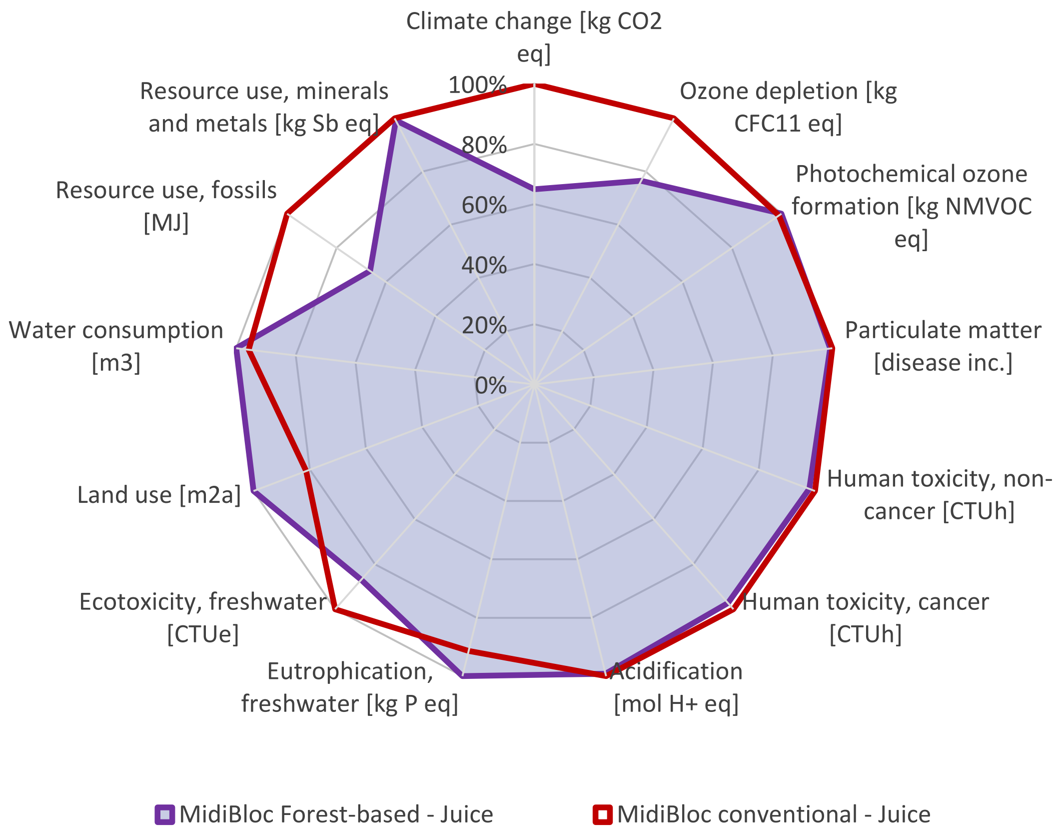
3.1.2. SIG MidiBloc for juice packaging

Below, in Figure 7, the results of the Life Cycle Assessment of the SIG MidiBloc model products used for packing juice beverages are presented for the impact categories and the categories at the resource consumption or inventory level. The absolute values of the results are presented in Tables 6 and 7. The percentages in Table 8 represent the difference of the net results for all three packaging groups of comparison in the three End-of-Life allocation approaches assessed in this report (in the Base Scenario and Sensitivity Analysis): ‘50/50’ (base scenario), ‘100/0’, and ‘CFF’ (Circular Footprint Formula).

For the categories of **Climate Change**, **Ozone Depletion**, **Freshwater Ecotoxicity**, and **Resource Use Fossils**, it is possible to resolve that the package produced with mass-balanced polymers, the MidiBloc Forest-based, stands for the best option in comparison with the MidiBloc - Conventional, i.e. at least 10% difference in the results. The use of mass-balanced instead of fossil polymers is the main reason for the differences in the results. As can be noticed in Appendix B – Contribution Analysis, the uptake of carbon dioxide on the mass-balanced polymers chain contributes to the lower Climate Change impact.

On the other hand, the MidiBloc Forest-based package exceeds the MidiBloc - Conventional package in the results for **Land Use**, owing to the production chain of the mass-balanced polymers.

The categories of **Photochemical Ozone Formation**, **Particulate Matter**, **Human Toxicity (cancer and non-cancer effects)**, **Acidification**, **Eutrophication**, **Resource Use Minerals and Metals**, and **Water Consumption** present very similar results for both system products under comparison. This means that the impacts are driven by either the aluminum barrier or the LPB production, which are the same for both products.



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 7 RESULTS OF THE LIFE CYCLE ASSESSMENT OF THE SIG MIDIBLOC MODEL PRODUCTS USED FOR PACKING JUICE BEVERAGES

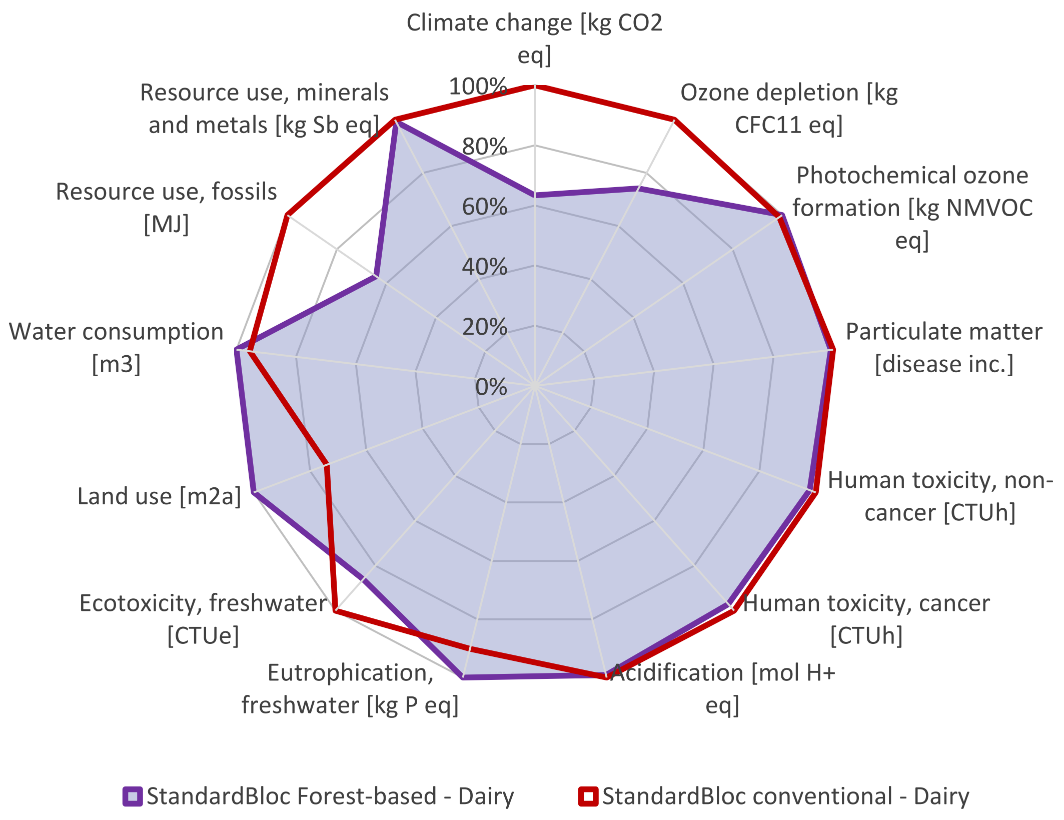
3.1.3. SIG STANDARDBLOC FOR DAIRY PACKAGING

Below, in Figure 8, the results of the Life Cycle Assessment of the SIG StandardBloc beverage packaging model are presented for the impact categories and the categories at the resource consumption or inventory level. The absolute values of the results are presented in Tables 6 and 7. The percentages in Table 8 represent the difference of the net results for all three packaging groups of comparison in the three End-of-Life allocation approaches assessed in this report (in the Base Scenario and Sensitivity Analysis): '50/50' (base scenario), '100/0', and 'CFF' (Circular Footprint Formula).

For the categories of **Climate Change**, **Ozone Depletion**, **Freshwater Ecotoxicity**, and **Resource Use Fossils**, it is possible to resolve that the package produced with mass-balanced polymers, the StandardBloc Forest-based - Dairy, stands for the best option in comparison with the StandardBloc - Conventional, i.e. at least 10% difference in the results. The use of mass-balanced instead of fossil polymers is the main reason for the differences in the results. As can be noticed in Appendix B – Contribution Analysis, the uptake of carbon dioxide on the mass-balanced polymers chain contributes to the lower Climate Change impact.

On the other hand, the StandardBloc Forest-based - Dairy package exceeds the StandardBloc - Conventional - Dairy package in the results for **Eutrophication** and **Land Use**, owing to the production chain of the mass-balanced polymers.

The categories of **Photochemical Ozone Formation**, **Particulate Matter**, **Human Toxicity (cancer and non-cancer effects)**, **Acidification**, **Resource Use Minerals and Metals**, and **Water Consumption** present very similar results for both system products under comparison. This means that the impacts are driven by either the aluminum barrier or the LPB production, which are the same for both products.



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

Figure 8 Results of the Life Cycle Assessment of the SIG StandardBloc beverage packaging model

3.2. Sensitivity Analysis

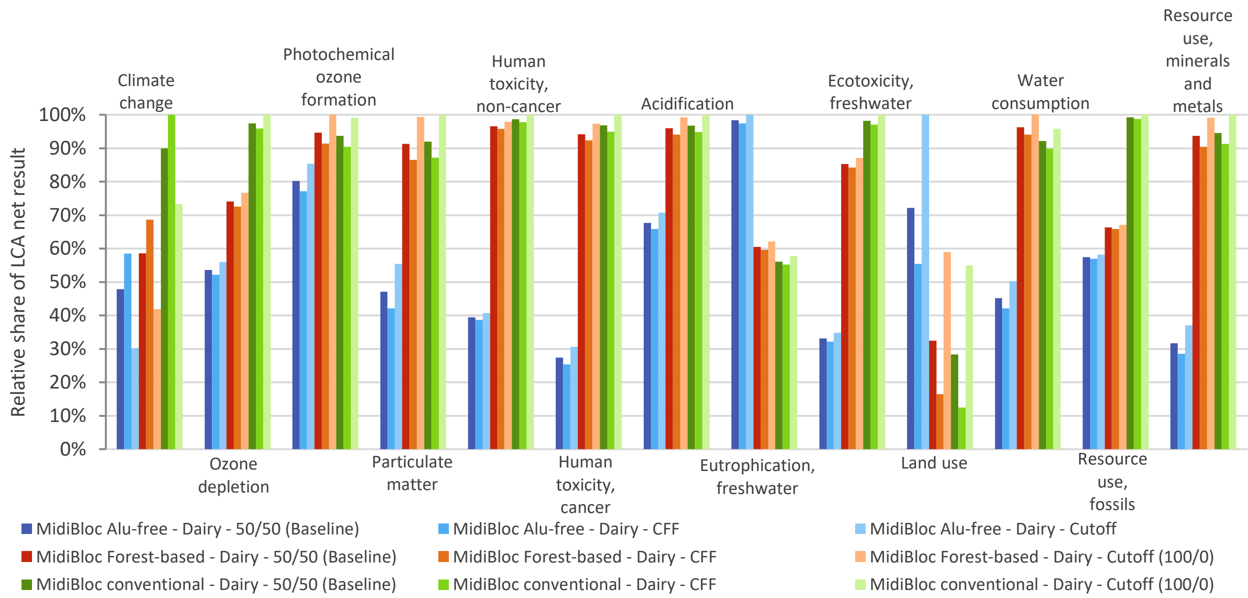
3.2.1. Cut-Off and Circular Footprint Formula Allocation Approach

As previously explained in the End-of-Life modeling, the 50/50 approach was chosen to define the allocation factors for the burdens and credits of recycled products. In this approach, 50% of the burdens and credits of recycling processes are allocated to the SIG packaging systems under study. When applying the CFF approach, the allocation factors of the same burdens and credits are material-specific. In this study, the only difference between 50/50 and CFF is for the LPB and corrugated box, which have 80% of their recycling processes burdens and credits allocated to the SIG packaging systems (***A*** = 0.2 in Equation 1, from the 1.2.3 End-of-life modeling section). For PolyAl material recovery, the allocation factors are assumed to be the same for 50/50 and CFF approaches. In another alternative, the cut-off approach (or 100/0 approach), the burdens and credits of recycling are 100% allocated to the recycled product itself; for instance, in the recycling of Poly-Aluminium, all burdens of the process and credits for avoiding fibre-cement roofing panels are allocated to the recycled roofing panel, thus it is not accounted in the SIG packaging life-cycle.

The results considering the cut-off and CFF allocation are presented in Figures 9, 10 and 11. The absolute values are presented in Tables 9 and 10. Although these choices resulted in different absolute values, the comparisons between the packaging alternatives remained the same. The percentages in Table 8 represent the difference of the net results for all three packaging groups of comparison in the three End-of-Life allocation approaches assessed in this report (in the Base Scenario and Sensitivity Analysis): ‘50/50’ (base scenario), ‘100/0’, and ‘CFF’ (Circular Footprint Formula).

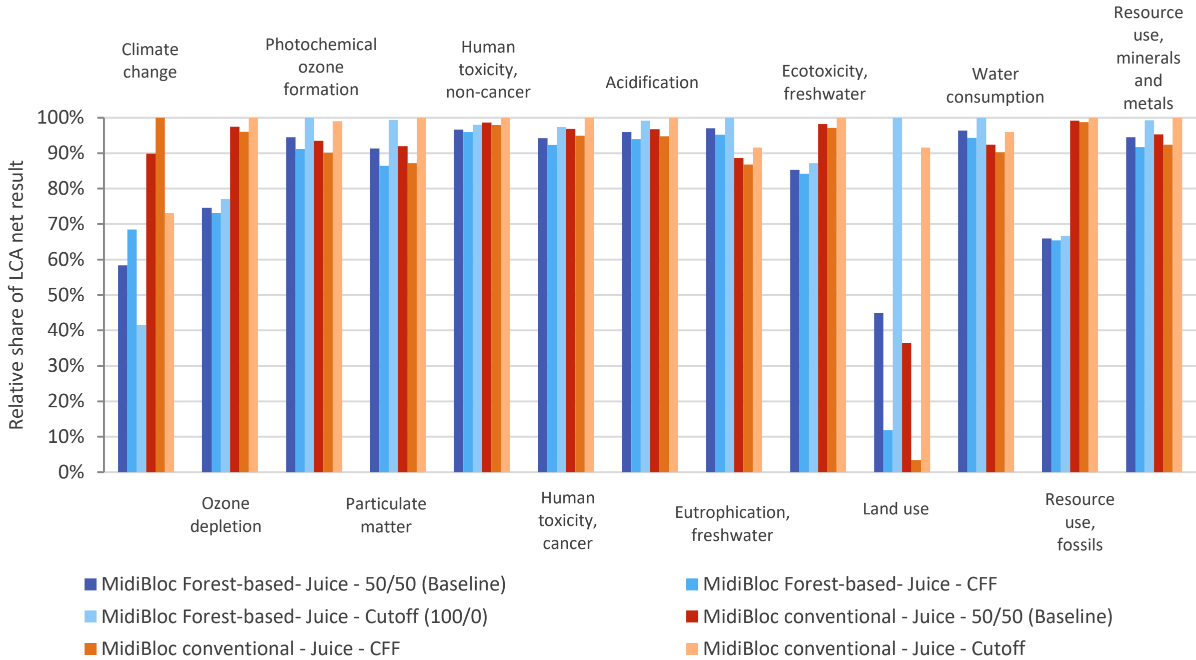
For all packaging systems, the **Climate Change** impact category presented significant variations (>10%) among the different allocation methods. The CFF approach led to higher Climate Change results compared to the baseline (50/50) scenario. As presented in Appendix B – Contribution Analysis, the recycling stage of the LPB and corrugated board results in virtual Climate Change emissions – instead of negative Climate Change credits – due to the avoided carbon sequestration of the avoided virgin products (sulphate pulp). This means that the higher the share of recycling credits allocated to the packaging system under study, the higher its Climate Change net result. Therefore, the CFF approach leads to the highest Climate Change results and the Cut-off (100/0) approach to the lowest.

For all the other impact assessment or inventory level categories, the opposite trend is observed. The LPB and corrugated box recycling credits result in lower net results. The CFF allocation approach incorporates a higher share of the credits and, thus, presents the lowest scores. The Cut-off (100/0) approach leads to the highest scores because it does not absorb any of the recycling credits.



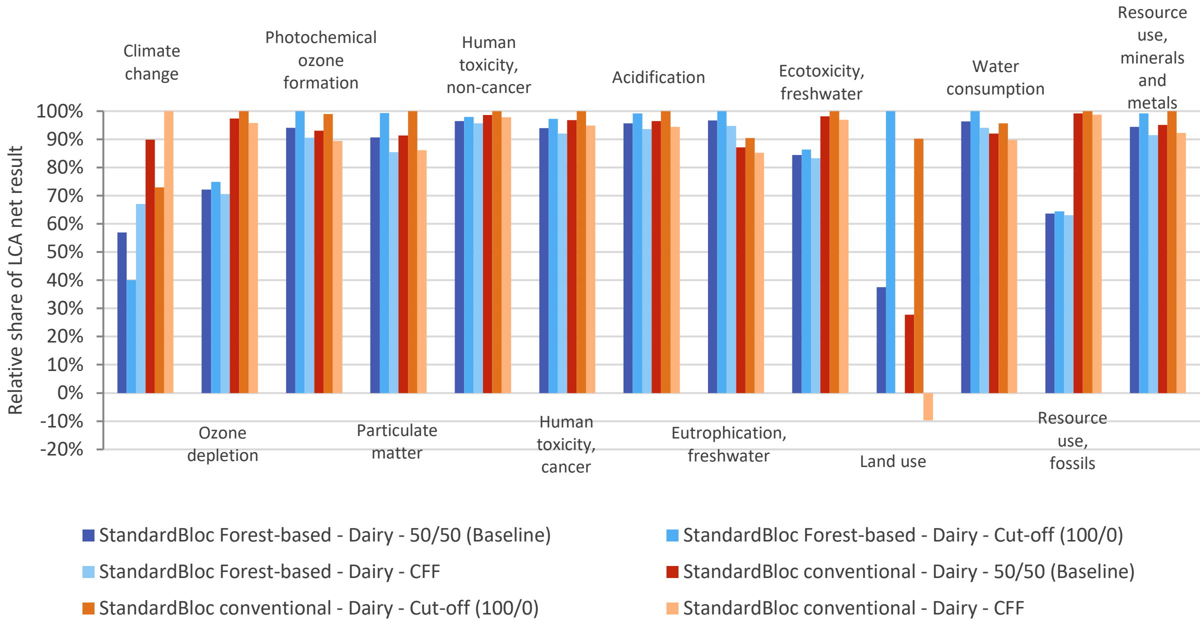
Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 9 RESULTS CONSIDERING THE CUT-OFF AND CFF ALLOCATION FOR THE SIG MIDIBLOC USED FOR DAIRY PACKAGING



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 10 RESULTS CONSIDERING THE CUT-OFF AND CFF ALLOCATION FOR THE SIG MIDIBLOC USED FOR JUICE PACKAGING



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 11 RESULTS CONSIDERING THE CUT-OFF AND CFF ALLOCATION FOR THE SIG STANDARDBLOC PACKAGING MODEL

Table 9 Cradle-To-Grave Results for Each Package in the CFF Allocation Scenario

Cradle-to-Grave results applying the CFF allocation		MidiBloc Alu-free Dairy	MidiBloc Forest-based Dairy	MidiBloc Conventional Dairy	MidiBloc Forest-based Juice	MidiBloc Conventional Juice	StandardBloc Forest-based Dairy	StandardBloc Conventional Dairy
Climate change [kg CO2 eq]	Net results	0.0704	0.0826	0.120	0.082	0.120	0.0777	0.116
	CO2 Uptake	-0.104	-0.133	-0.106	-0.139	-0.112	-0.130	-0.103
	CO2 EoL emissions	0.0947	0.116	0.115	0.122	0.121	0.114	0.114
	Burdens	0.0546	0.0770	0.0886	0.0765	0.0882	0.0703	0.0821
	Credits	0.0250	0.0229	0.0229	0.0230	0.0230	0.0227	0.0227
Ozone depletion [kg CFC11 eq]	Net results	4.97E-09	6.92E-09	9.15E-09	7.12E-09	9.34E-09	6.35E-09	8.61E-09
	Burdens	5.44E-09	7.42E-09	9.65E-09	7.62E-09	9.85E-09	6.85E-09	9.12E-09
	Credits	-4.66E-10	-5.05E-10	-5.05E-10	-5.06E-10	-5.06E-10	-5.02E-10	-5.02E-10
Photochemical ozone formation [kg NMVOC eq]	Net results	0.000245	0.000290	0.000287	0.000281	0.000278	0.000260	0.000257
	Burdens	0.000277	0.000324	0.000321	0.000315	0.000312	0.000293	0.000290
	Credits	-3.18E-05	-3.37E-05	-3.37E-05	-3.38E-05	-3.38E-05	-3.35E-05	-3.35E-05
Particulate matter [disease inc.]	Net results	2.42E-09	4.97E-09	5.01E-09	4.96E-09	5.00E-09	4.47E-09	4.50E-09
	Burdens	3.31E-09	5.86E-09	5.90E-09	5.86E-09	5.89E-09	5.35E-09	5.39E-09
	Credits	-8.94E-10	-8.90E-10	-8.90E-10	-8.93E-10	-8.93E-10	-8.83E-10	-8.83E-10
Human toxicity, non-cancer [CTUh]	Net results	5.37E-10	1.33E-09	1.36E-09	1.36E-09	1.39E-09	1.29E-09	1.32E-09
	Burdens	5.86E-10	1.38E-09	1.41E-09	1.42E-09	1.45E-09	1.34E-09	1.37E-09
	Credits	-4.87E-11	-5.28E-11	-5.28E-11	-5.29E-11	-5.29E-11	-5.25E-11	-5.25E-11
Human toxicity, cancer [CTUh]	Net results	1.29E-11	4.67E-11	4.81E-11	4.68E-11	4.81E-11	4.45E-11	4.59E-11
	Burdens	1.59E-11	4.99E-11	5.12E-11	4.99E-11	5.13E-11	4.76E-11	4.90E-11
	Credits	-3.09E-12	-3.14E-12	-3.14E-12	-3.15E-12	-3.15E-12	-3.11E-12	-3.11E-12
Acidification [mol H+ eq]	Net results	0.000316	0.000452	0.000456	0.000442	0.000446	0.000410	0.000414
	Burdens	0.000348	0.000486	0.000490	0.000476	0.000480	0.000444	0.000448
	Credits	-3.21E-05	-3.46E-05	-3.46E-05	-3.47E-05	-3.47E-05	-3.44E-05	-3.44E-05
Eutrophication, freshwater [kg P eq]	Net results	7.23E-06	4.43E-06	4.10E-06	3.71E-06	3.39E-06	3.28E-06	2.95E-06
	Burdens	7.46E-06	4.65E-06	4.33E-06	3.94E-06	3.62E-06	3.51E-06	3.18E-06
	Credits	-2.29E-07	-2.28E-07	-2.28E-07	-2.29E-07	-2.29E-07	-2.26E-07	-2.26E-07
Ecotoxicity, freshwater [CTUe]	Net results	0.759	1.99	2.29	1.99	2.29	1.87	2.18
	Burdens	0.855	2.09	2.40	2.10	2.40	1.98	2.28
	Credits	-0.0958	-0.105	-0.105	-0.105	-0.105	-0.105	-0.105
Resource use, minerals and metals [kg Sb eq]	Net results	3.65E-08	1.16E-07	1.17E-07	1.35E-07	1.36E-07	1.29E-07	1.30E-07
	Burdens	4.84E-08	1.28E-07	1.29E-07	1.47E-07	1.48E-07	1.41E-07	1.42E-07
	Credits	-1.19E-08	-1.21E-08	-1.21E-08	-1.21E-08	-1.21E-08	-1.20E-08	-1.20E-08
Resource use, fossils [MJ]	Net results	0.849	0.982	1.47	0.964	1.46	0.878	1.37
	Burdens	0.887	1.02	1.51	1.01	1.50	0.920	1.41
	Credits	-0.0374	-0.0421	-0.0421	-0.0422	-0.0422	-0.0419	-0.0419
Land use [m2a]	Net results	0.0799	0.0238	0.0179	0.00822	0.00237	7.59E-06	-0.00590
	Burdens	0.145	0.0858	0.0800	0.0705	0.0647	0.0615	0.0556
	Credits	-0.0648	-0.0621	-0.0621	-0.0623	-0.0623	-0.0615	-0.0615
Water consumption [m3]	Net results	0.000878	0.00196	0.00188	0.00204	0.00196	0.00193	0.00184
	Burdens	0.00119	0.00227	0.00219	0.00236	0.00227	0.00224	0.00215
	Credits	-0.000313	-0.000312	-0.000312	-0.000313	-0.000313	-0.000309	-0.000309
Climate change - Fossil [kg CO2 eq]	Net results	0.0498	0.0714	0.0831	0.0711	0.0828	0.0650	0.0767
	Burdens	0.0535	0.0758	0.0875	0.0755	0.0872	0.0694	0.0811
	Credits	-0.00372	-0.00440	-0.00440	-0.00441	-0.00441	-0.00438	-0.00438
Climate change - Biogenic [kg CO2 eq]	Net results	0.0752	0.0968	0.0961	0.103	0.102	0.0958	0.0951
	Burdens	0.0947	0.116	0.115	0.122	0.121	0.114	0.114
	Credits	-0.0195	-0.0188	-0.0188	-0.0189	-0.0189	-0.0186	-0.0186
Climate change - Land use and LU change [kg CO2 eq]	Net results	0.00103	0.00112	0.00112	0.000953	0.000954	0.000919	0.000921
	Burdens	0.00107	0.00116	0.00116	0.000994	0.000995	0.000960	0.000961
	Credits	-3.09E-05	-4.05E-05	-4.05E-05	-4.05E-05	-4.05E-05	-4.05E-05	-4.05E-05
Climate change - CO2 uptake [kg CO2 eq]	Net results	-0.0556	-0.0868	-0.0599	-0.0930	-0.0661	-0.0840	-0.0570
	CO2 uptake disregarding credits for recycling	-0.104	-0.133	-0.106	-0.139	-0.112	-0.130	-0.103
	Credits	0.0482	0.0462	0.0462	0.0463	0.0463	0.0457	0.0457

Note: CO2 uptake - Uptake of atmospheric CO2 during the plant growth phase; CO2 EoL emissions - Biogenic (regenerative) CO2 emissions from landfilling of biobased materials; burdens - overall environmental loads; credits - Credits for material recycling; Net results - subtraction of credits from overall environmental loads.

TABLE 10 CRADLE-TO-GRAVE RESULTS FOR EACH PACKAGE IN THE CUT-OFF ALLOCATION SCENARIO

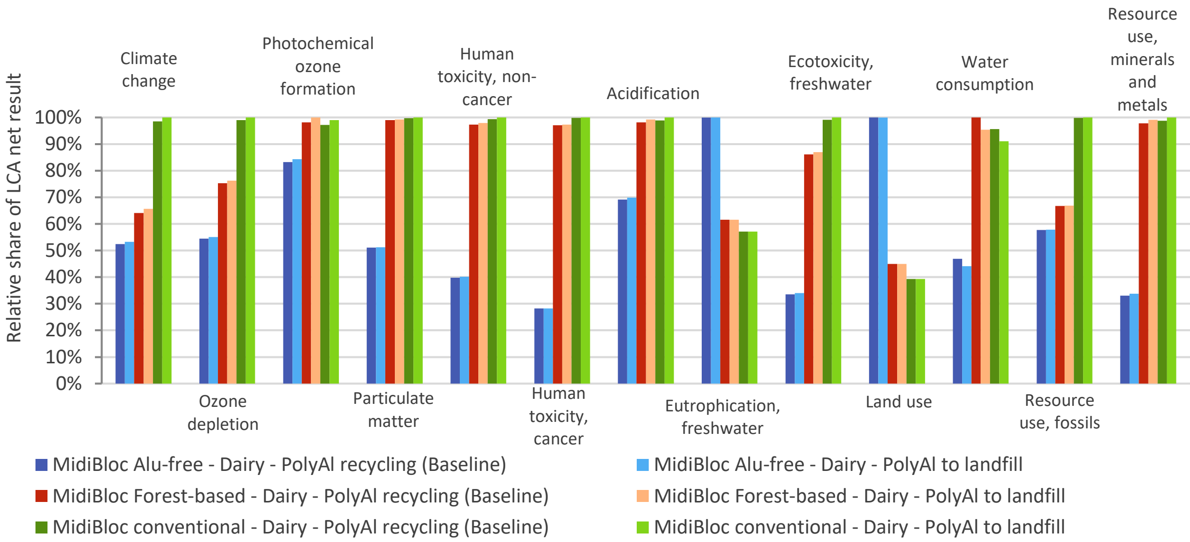
Cradle-to-Grave results applying the 100/0 allocation		MidiBloc Alu-free Dairy	MidiBloc Forest-based Dairy	MidiBloc Conventional Dairy	MidiBloc Forest-based Juice	MidiBloc Conventional Juice	StandardBloc Forest-based Dairy	StandardBloc Conventional Dairy
Climate change [kg CO2 eq]	Net results	0.0363	0.0504	0.0882	0.0498	0.0876	0.0464	0.0845
	CO2 Uptake	-0.105	-0.134	-0.107	-0.140	-0.113	-0.130	-0.103
	CO2 EoL emissions	0.0878	0.109	0.108	0.115	0.114	0.108	0.107
	Burdens	0.0532	0.0753	0.0870	0.0749	0.0865	0.0687	0.0804
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ozone depletion [kg CFC11 eq]	Net results	5.34E-09	7.31E-09	9.53E-09	7.50E-09	9.73E-09	6.74E-09	9.00E-09
	Burdens	5.34E-09	7.31E-09	9.53E-09	7.50E-09	9.73E-09	6.74E-09	9.00E-09
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Photochemical ozone formation [kg NMVOC eq]	Net results	0.000271	0.000317	0.000314	0.000308	0.000305	0.000287	0.000284
	Burdens	0.000271	0.000317	0.000314	0.000308	0.000305	0.000287	0.000284
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Particulate matter [disease inc.]	Net results	3.18E-09	5.71E-09	5.74E-09	5.70E-09	5.74E-09	5.19E-09	5.23E-09
	Burdens	3.18E-09	5.71E-09	5.74E-09	5.70E-09	5.74E-09	5.19E-09	5.23E-09
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Human toxicity, non-cancer [CTUh]	Net results	5.65E-10	1.36E-09	1.39E-09	1.39E-09	1.42E-09	1.32E-09	1.35E-09
	Burdens	5.65E-10	1.36E-09	1.39E-09	1.39E-09	1.42E-09	1.32E-09	1.35E-09
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Human toxicity, cancer [CTUh]	Net results	1.55E-11	4.93E-11	5.06E-11	4.93E-11	5.07E-11	4.70E-11	4.84E-11
	Burdens	1.55E-11	4.93E-11	5.06E-11	4.93E-11	5.07E-11	4.70E-11	4.84E-11
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Acidification [mol H+ eq]	Net results	0.000340	0.000477	0.000480	0.000467	0.000470	0.000434	0.000438
	Burdens	0.000340	0.000477	0.000480	0.000467	0.000470	0.000434	0.000438
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Eutrophication, freshwater [kg P eq]	Net results	7.43E-06	4.61E-06	4.28E-06	3.90E-06	3.57E-06	3.46E-06	3.13E-06
	Burdens	7.43E-06	4.61E-06	4.28E-06	3.90E-06	3.57E-06	3.46E-06	3.13E-06
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ecotoxicity, freshwater [CTUe]	Net results	0.822	2.06	2.36	2.06	2.36	1.94	2.25
	Burdens	0.822	2.06	2.36	2.06	2.36	1.94	2.25
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Resource use, minerals and metals [kg Sb eq]	Net results	4.74E-08	1.27E-07	1.28E-07	1.46E-07	1.47E-07	1.40E-07	1.41E-07
	Burdens	4.74E-08	1.27E-07	1.28E-07	1.46E-07	1.47E-07	1.40E-07	1.41E-07
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Resource use, fossils [MJ]	Net results	0.868	1.00	1.49	0.983	1.47	0.896	1.39
	Burdens	0.868	1.00	1.49	0.98	1.47	0.896	1.39
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Land use [m2a]	Net results	0.144	0.0849	0.0791	0.0696	0.0638	0.0606	0.0547
	Burdens	0.144	0.0849	0.0791	0.0696	0.0638	0.0606	0.0547
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Water consumption [m3]	Net results	0.00105	0.00209	0.00200	0.00217	0.00208	0.00205	0.00196
	Burdens	0.00105	0.00209	0.00200	0.00217	0.00208	0.00205	0.00196
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Climate change - Fossil [kg CO2 eq]	Net results	0.0523	0.0743	0.0860	0.0741	0.0857	0.0679	0.0796
	Burdens	0.0523	0.0743	0.0860	0.0741	0.0857	0.0679	0.0796
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Climate change - Biogenic [kg CO2 eq]	Net results	0.0878	0.1088	0.108	0.115	0.114	0.108	0.107
	Burdens	0.0878	0.109	0.108	0.115	0.114	0.108	0.107
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Climate change - Land use and LU change [kg CO2 eq]	Net results	0.000911	0.00100	0.00100	0.000831	0.000832	0.000799	0.000800
	Burdens	0.000911	0.00100	0.00100	0.000831	0.000832	0.000799	0.000800
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Climate change - CO2 uptake [kg CO2 eq]	Net results	-0.105	-0.134	-0.107	-0.140	-0.113	-0.130	-0.103
	CO2 uptake disregarding credits for recycling	-0.105	-0.134	-0.107	-0.140	-0.113	-0.130	-0.103
	Credits	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Note: CO2 uptake - Uptake of atmospheric CO2 during the plant growth phase; CO2 EoL emissions - Biogenic (regenerative) CO2 emissions from landfilling of biobased materials; burdens - overall environmental loads; credits - Credits for material recycling; Net results - subtraction of credits from overall environmental loads.

3.2.2. POLYAL RECYCLING RATE

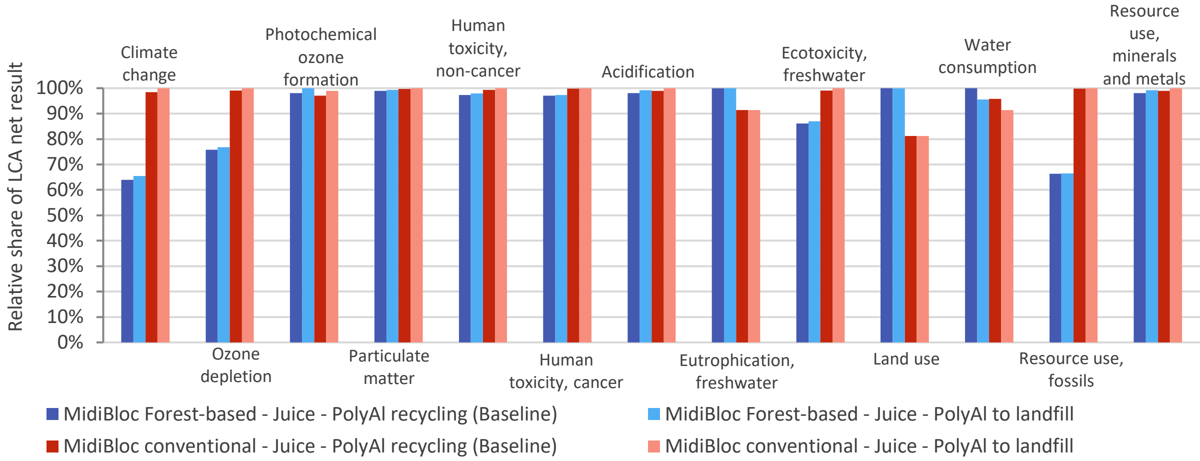
In the baseline scenario, all the Polyaluminium from beverage cartons diverted to recycling is assumed to be recovered and recycled after the separation from the LPB material. The recycling process for PolyAl is assumed to be the fabrication of roofing slabs via a thermoforming process. Despite this being a common practice reported by the Brazilian beverage carton sector and recyclers, the authors and reviewers of this work opt to conduct a sensitivity analysis on the PolyAl recovery rate to analyse the uncertainty related to this modelling assumption. Therefore, this section assesses a scenario in which all PolyAl – including the one from cartons sent to recycling – is treated in a final disposal scenario (sanitary and unsanitary landfills, and dumps). The results of this sensitivity analysis is compared with the baseline scenario (39.5% recycling rate) in Figure 12, 13 and 14.

The results reveal that changing the PolyAl recycling rate from 39.5% (all beverage cartons collected for recycling) to 0% does not cause significant variations in the absolute results and the conclusions driven by the packaging comparison groups.



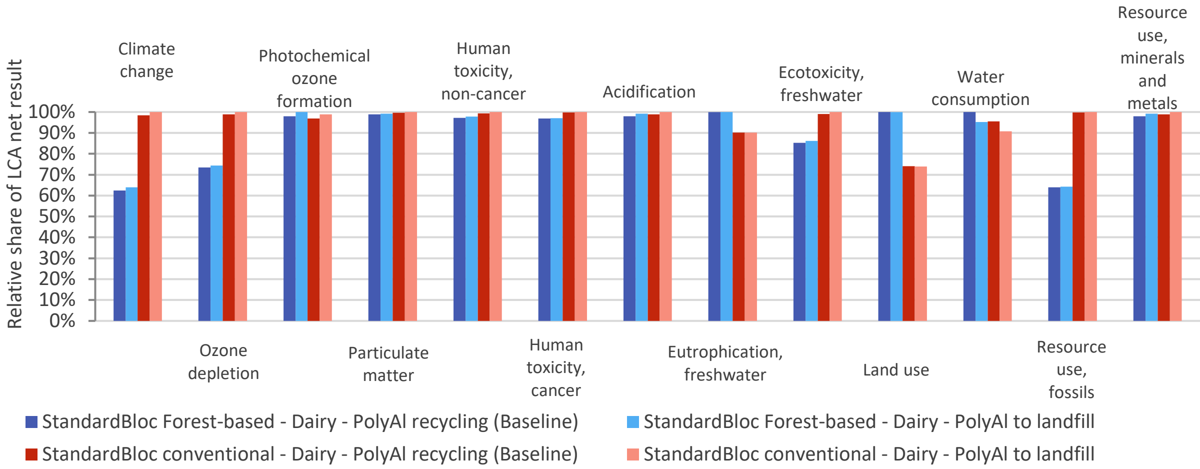
Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 12 POLYAL RECYCLING RATE SENSITIVITY FOR THE SIG MIDIBLOC USED FOR DAIRY PACKAGING



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 13 POLYAL RECYCLING RATE SENSITIVITY FOR THE SIG MIDIBLOC USED FOR JUICE PACKAGING



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 14 POLYAL RECYCLING RATE SENSITIVITY FOR THE SIG STANDARDBLOC PACKAGING MODEL

3.3. SCENARIO ANALYSIS

3.3.1. RECYCLING RATE OF BEVERAGE CARTONS

Three scenarios of increased national recycling rates of beverage cartons have been assessed. The baseline recycling rate of 35.9% was increased to 50%, 70% and 100% (Figures 15, 16 and 17).

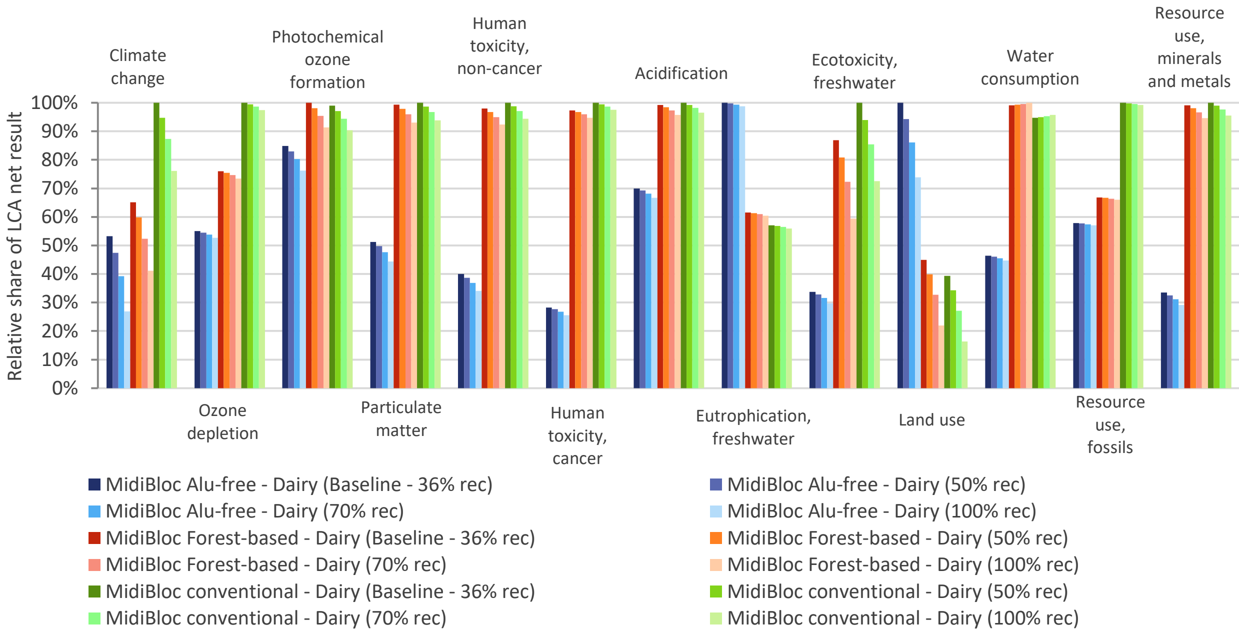
For the **MidiBloc Alu-free - Dairy** package, higher recycling rates lead to significant benefits (more than 10%) for Climate Change, Photochemical Ozone Formation, Particulate Matter, Human Toxicity – cancer and non-cancer effects, Freshwater Ecotoxicity, and Land Use. For Climate Change, significant impact reduction happens from a 50% recycling rate; for the Land Use inventory category, the benefit is observed for a 70% recycling rate; for Photochemical Ozone Formation, Particulate Matter, Human Toxicity – cancer and non-cancer effects, and Freshwater Ecotoxicity, significant impact reduction is only achieved for a 100% recycling rate.

For the **SIGNature Forest-based** (with aluminium barrier) **and Standard** packages, significant benefits are observed for Climate Change, Freshwater Ecotoxicity, and Land Use. For Climate Change and Freshwater Ecotoxicity, a significant impact reduction is observed from the 70% recycling rate; for the Land Use inventory category, the 50% recycling rate would be sufficient for a significant score reduction.

Despite not leading to significant variations in the results, the inventory level category of Water Consumption shows increased scores for higher recycling rates. This is explained by the relatively high amount of water consumed in the thermoforming dataset used to represent the PolyAl recycling process.

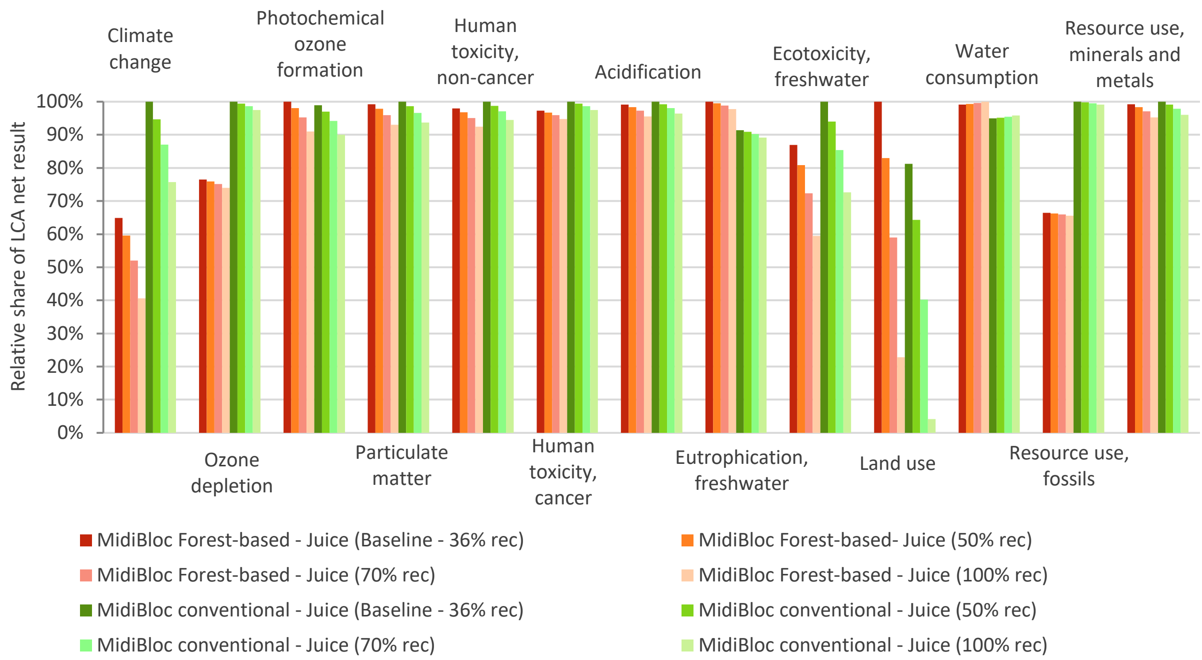
The Land Use inventory level category is very sensitive to varying recycling rates due to the credits obtained from the avoided product (sulphate pulp) in the LPB and corrugated board recycling processes. The dataset that represents the avoided sulphate pulp production has a higher Land Use inventory amount than the datasets which represent the primary LPB and corrugated box productions. For this reason, the Land Use inventory category happens to be negative in the 100% recycling scenario for the StandardBloc - Conventional - Dairy package (Figure 17).

The conclusions regarding the comparison of beverage carton models remained the same.



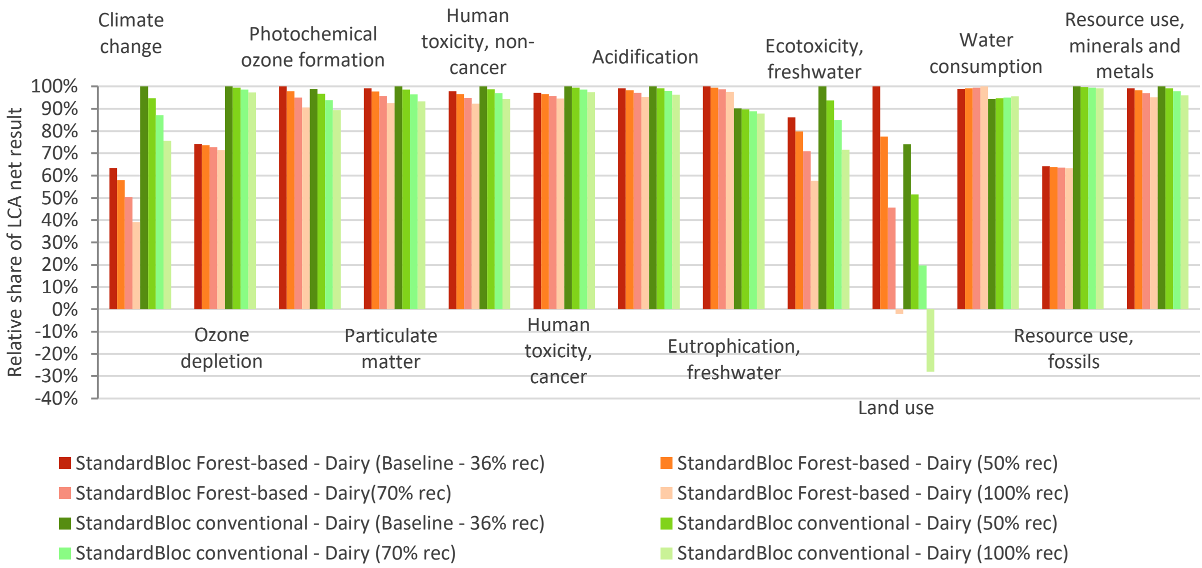
Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 15 RECYCLING RATE SCENARIO RESULTS FOR SIG MIDIBLOC FOR DAIRY PACKAGING



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 16 RECYCLING RATE SCENARIO RESULTS FOR SIG MIDIBLOC FOR JUICE PACKAGING



Note: The inventory level categories (Land Use and Water Consumption) are not intended to drive conclusions regarding the environmental performance of the products.

FIGURE 17 RECYCLING RATE SCENARIO RESULTS FOR SIG STANDARDBLOC FOR DAIRY PACKAGING

4. INTERPRETATION

For the **dairy packaging MidiBloc structures**, the results reveal that, in the Base Scenario, the packages produced with mass-balanced polymers (MidiBloc Alu-free - Dairy and MidiBloc Forest-based - Dairy) have lower impacts than the MidiBloc - Conventional package in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. These categories are sensitive to the substitution of fossil polymers for mass-balanced polymers with tall oil-pitch feedstock. MidiBloc Alu-free - Dairy has the lowest results among the aforementioned categories and also stands for the best packaging alternative for the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Resource Use Minerals and Metals, and Water Consumption.

Appendix B – Contribution Analysis indicates that aluminum foil production is the major contributor to the categories of Climate Change, Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, and Freshwater Ecotoxicity. MidiBloc Alu-free - Dairy structure avoids the use of the aluminium foil barrier by using a mass-balanced PA polymer barrier instead. This is the main reason for its advantage over the other two MidiBloc dairy packaging alternatives.

On the other hand, the MidiBloc Alu-free - Dairy packaging exceeds the MidiBloc Forest-based and the MidiBloc - Conventional packages in the results for Freshwater Eutrophication – 57% to 62% impact increase – and Land Use – 39% to 45% inventory increase – owing to the different shares of LPB suppliers.

For the **juice packaging MidiBloc structures**, for the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils, it is possible to resolve that the package produced with mass-balanced polymers, the MidiBloc Forest-based, stands for the best option in comparison with the MidiBloc - Conventional. On the other hand, the MidiBloc Forest-based package exceeds the MidiBloc - Conventional package in the results of Land Use inventory, owing to the production chain of the mass-balanced polymers. The categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, Resource Use Minerals and Metals, and Water Consumption present very similar results for both system products under comparison – this means that the impacts are driven by either the aluminum barrier or the LPB production, which are the same for both products.

Similarly, for the **StandardBloc structures**, the StandardBloc Forest-based is better than the StandardBloc - Conventional for the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. On the other hand, the StandardBloc Forest-based package exceeds the StandardBloc - Conventional package in the results for

Freshwater Eutrophication and Land Use inventory, owing to the production chain of the mass-balanced polymers. The categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Resource Use Minerals and Metals, and Water Consumption present very similar results for both system products under comparison – this means that the impacts are driven by either the aluminum barrier or the LPB production, which are the same for both products.

Although the sensitivity of the allocation method of the burdens and credits of recycled materials inputs and end-of-life product recovery resulted in different absolute values, the comparisons between the packaging alternatives remained the same.

A sensitivity analysis confirmed that the assumption that PolyAl is also recovered and recycled once a beverage carton package reaches a recycling scheme is not significant for this LCA results and is within the uncertainty interval considered in this study.

In a scenario analysis, it was possible to conclude that increased MidiBloc Alu-free - Dairy package recycling rates resulted in significant benefits for Climate Change, Photochemical Ozone Formation, Particulate Matter, Human Toxicity – cancer and non-cancer effects, Freshwater Ecotoxicity, and Land Use scores. Meanwhile, for the Forest-based (with aluminium barrier) and conventional packages, significant benefits are observed for Climate Change, Freshwater Ecotoxicity, and Land Use.

4.1. Limitations

Previously, assumptions, limitations and other choices were made explicit. It is vital to highlight such considerations from a critical point of view, as addressed below:

- Part of the materials and processes used to represent the life cycle stages of the analysed product systems are based on European data of the ecoinvent database. The most representative processes were sought; nevertheless, differences between the processes and technology used in different regions have to be considered;
- In the overall picture, some LCI datasets refer to European conditions, indicating that this study may not be fully representative for Brazilian practices. However, a database in such level of quality, transparency and robustness is still not available for the country or for other more similar regions;
- LCA is a decision-making support tool and shall be used as an additional technique;

- Consequential evaluations, or even a consequential approach of the life cycle, were not employed in the Report as a standard procedure. Therefore, any results and conclusions must be used only for the current production levels;
- Differently from other methodologies in the regulatory field, LCA shows potential environmental impacts and provides results for a more likely scenario.

CONCLUSIONS

When communicating the results of this study, it should be taken into consideration that they are obtained following many constraints, such as the established assumptions, the chosen data, the employed processes and the limitations of the study (see section 4.1 Limitations) among other aspects. When addressing the conclusions of this report it is important to consider that the categories of Land Use and Water Consumption are calculated on the inventory level, and do not perform environmental impact assessment as the other categories from the LCIA method. Therefore, the results for Land Use and Water Consumption should not be used to assert the environmental performance of the products.

For the **dairy packaging MidiBloc** structures, the **MidiBloc Alu-free - Dairy** is the best alternative when considering all environmental impact or inventory level categories, except for the categories of Land Use and Freshwater Eutrophication.

The **MidiBloc Forest-based for dairy packaging** has lower environmental impacts than the **MidiBloc - Conventional** in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. However, there is no preference choice between these alternatives considering the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, and Resource Use Minerals and Metals. The Water Consumption inventory is also equivalent for both packages, while the Land Use inventory is higher for the **MidiBloc Forest-based**.

For the **juice packaging MidiBloc** structures, the **MidiBloc Forest-based** has lower environmental impact than the **MidiBloc - Conventional** in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. However, there is no preference choice between these alternatives considering the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, and Resource Use Minerals and Metals. The Water Consumption inventory is also equivalent for both packages, while the Land Use inventory is higher for the **MidiBloc Forest-based**.

Similarly, for the **StandardBloc dairy packaging** structures, the **StandardBloc Forest-based - Dairy** has lower environmental impact than the **StandardBloc - Conventional - Dairy** in the categories of Climate Change, Ozone Depletion, Freshwater Ecotoxicity, and Resource Use Fossils. On the other hand, the **StandardBloc - Conventional - Dairy** has better environmental performance in the Freshwater Eutrophication category. Furthermore, there is no preference choice between StandardBloc alternatives considering the categories of Photochemical Ozone Formation, Particulate Matter, Human Toxicity (cancer and non-cancer effects), Acidification, Freshwater Eutrophication, and Resource Use Minerals and Metals. The

Water Consumption inventory is also equivalent for both packages, while the Land Use inventory is higher for the **StandardBloc Forest-based - Dairy**.

A sensitivity analysis on the end-of-life allocation method has been proposed in order to verify the robustness of the conclusions. The results indicated that, despite the variation of the parameters considered in these cases, the conclusions of the study remained consistent. Moreover, a sensitivity analysis confirmed that the uncertainty related to the recycling rate of the PolyAl is not significant for the results of this study.

In a scenario analysis, it was possible to conclude that increased beverage carton recycling rates from 39.5% to 50%, 70% or 100%, resulted in significant benefits for a few categories.

For the **MidiBloc Alu-free - Dairy** package, the increase of the recycling rate to 50%, caused a significant reduction in the Climate Change impact. With a 70% recycling rate, the Land Use inventory was also reduced. Furthermore, for a recycling rate of 100%, Photochemical Ozone Formation, Particulate Matter, Human Toxicity – cancer and non-cancer effects, and Freshwater Ecotoxicity, achieved significant impact reduction.

For the **Forest-based** (with aluminium barrier) **and conventional** packages, the increase of the recycling rate to 50%, caused a significant reduction in the Land Use inventory. With a 70% recycling rate, the Climate Change and Freshwater Ecotoxicity impacts were also reduced.

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APPENDIX A – PEDIGREE MATRIX

TABLE 11. INDICATORS AND DATA QUALITY LEVELS OF THE PEDIGREE MATRIX **[PEDERSEN WEIDEMA & WESNAES 1996]**.

Indicator score	**1**	**2**	**3**	**4**	**5**
Reliability	Verified data based on measurements	Verified data partly based on assumptions or non-verified data based on measurements	Non-verified data partly based on qualified estimates	Qualified estimate (e.g. by industrial expert)	Non-qualified estimate
Completeness	Representative data from all sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from >50% of the sites relevant for the market considered, over an adequate period to even out normal fluctuations	Representative data from only some sites (<<50%) relevant for the market considered or >50% of sites but from shorter periods	Representative data from only one site relevant for the market considered or some sites but from shorter periods	Representativeness unknown or data from a small number of sites and from shorter periods
Temporal correlation	Less than 3 years of difference to the time period of the dataset	Less than 6 years of difference to the time period of the dataset	Less than 10 years of difference to the time period of the dataset	Less than 15 years of difference to the time period of the dataset	Age of data unknown or more than 15 years of difference to the time period of the dataset
Geographical correlation	Data from area under study	Average data from larger area in which the area under study is included	Data from area with similar production conditions	Data from area with slightly similar production conditions	Data from unknown or distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia)
Further technological correlation	Data from enterprises, processes and materials under study	Data from processes and materials under study (i.e. identical technology) but from different enterprises	Data from processes and materials under study but from different technology	Data on related processes or materials	Data on related processes on laboratory scale or from different technology

TABLE 12 DATA QUALITY ASSESSMENT RESULTS

Life cycle stage	Reliability	Completeness	Temporal correlation	Geographical correlation	Further technological correlation	Total	Classification
Aluminium foil production and transformation	1	2	3	2	1	9	High
Liquid Packaging Board production in Brazil	2	1	1	2	1	7	High
Liquid Packaging Board production in Europe	2	1	2	2	1	8	High
Fossil based polymers production (package layers)	1	1	4	1	1	8	High
Fossil based polymers production (closure)	1	1	4	5	2	13	Medium
Mass-balanced polymers	2	3	2	3	2	12	Medium
Sleeve transformation	1	1	1	1	1	5	High
Cap injection	1	2	4	5	1	13	Medium
Corrugated Board Box production	1	2	3	5	1	12	Medium
Package filling	1	1	1	1	1	5	High
Disposal scenario	2	3	3	5	2	15	Medium
Recycling	1	1	1	1	1	5	High

Appendix B – Contribution Analysis

MidiBloc - Conventional for dairy packaging

The MidiBloc - Conventional for dairy packaging life cycle is revealed in the Contribution Analysis shown in Figure 18 and Figure 19. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The aluminium foil production is the major contributor for most categories: Climate Change (25%), Photochemical Ozone Formation (29%), Particulate Matter (45%), Human Toxicity Non Cancer (47%), Human Toxicity Cancer (68%), Acidification (37%), Freshwater Ecotoxicity (28%) impact categories.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (18%), Photochemical Ozone Formation (21%), Particulate Matter (12%), Human Toxicity Non Cancer (20%), Human Toxicity Cancer (11%), Acidification (19%), Eutrophication (37%), and Resource Use Minerals and Metals (96%) impact categories, as well as in the inventory level categories of Land Use (61%, excluding recycling burdens and credits) and Water Consumption (30%).

Likewise, the Corrugated Board Box used for transport from filler to retailer presents significant contribution in most categories. It has even more prominence in the category of Particulate Matter (21%).

The fossil PE package layers results standout for the Ozone Depletion (38%) and Resource Use Fossils (33%) categories.

The filling step is a relevant contributor of the Eutrophication (19%) and Water Consumption (18%) categories. The sleeve formation process is also significant for Water Consumption (16%).

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 19. Biogenic carbon is sequestered in the production of LPB and corrugated box used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the 'CO_2 uptake' subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), aluminium foil and corrugated board productions are the most representative elements.

The net result of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 25% of the total impact is caused by the aluminium production and 34% corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 6% and 12% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-24% of the total impact).

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

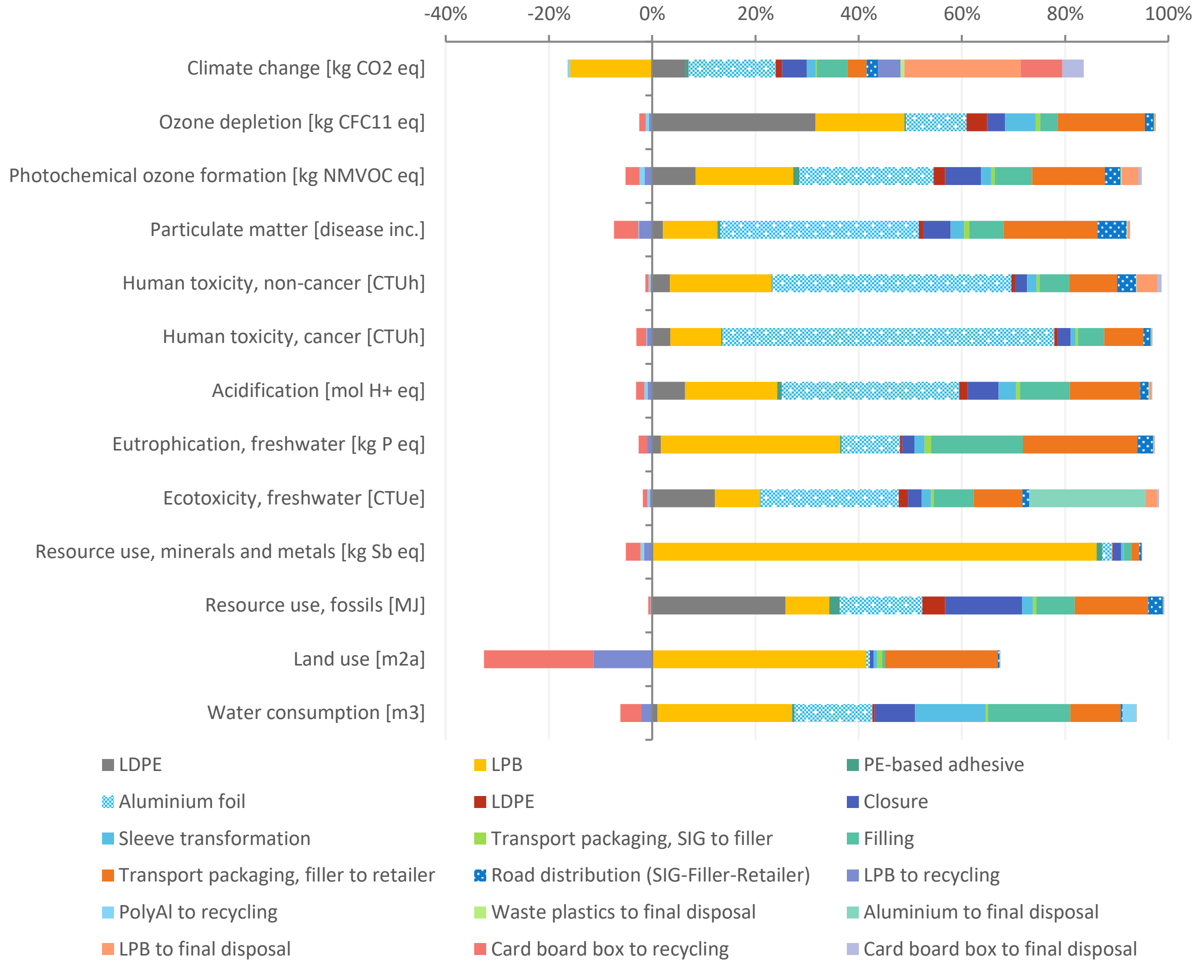

FIGURE 18 MIDIBLOC - CONVENTIONAL FOR DAIRY PACKAGING LIFE CYCLE CONTRIBUTION ANALYSIS

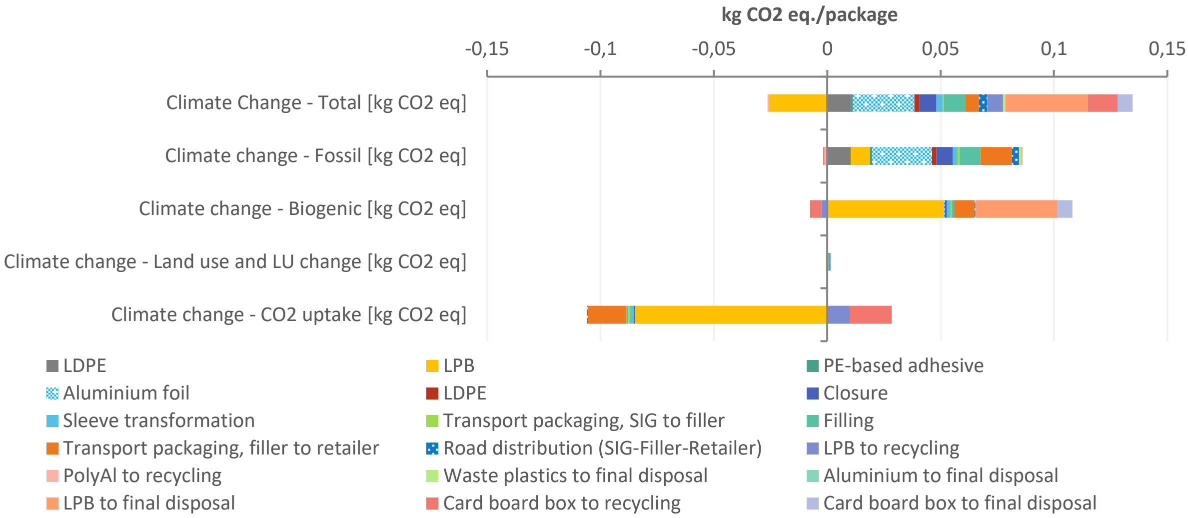

FIGURE 19 CONTRIBUTION ANALYSIS AND BREAKDOWN OF CLIMATE CHANGE CATEGORY FOR MIDIBLOC - CONVENTIONAL FOR DAIRY PACKAGING

MidiBloc Forest-based for dairy packaging

The MidiBloc Forest-based for dairy packaging life cycle is revealed in the Contribution Analysis shown in Figure 20 and Figure 21. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The aluminium foil production is the major contributor for most categories: Climate Change (38%), Photochemical Ozone Formation (29%), Particulate Matter (46%), Human Toxicity Non Cancer (48%), Human Toxicity Cancer (70%), Acidification (37%), Freshwater Ecotoxicity (32%), and Resource Use Fossils (24%) impact categories.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (24%), Photochemical Ozone Formation (21%), Particulate Matter (12%), Human Toxicity Non Cancer (21%), Human Toxicity Cancer (11%), Acidification (19%), Eutrophication (34%), and Resource Use Minerals and Metals (97%) impact categories, as well as in the inventory level categories of Land Use (57%, excluding burdens and credits for recycling) and Water Consumption (28%).

Likewise, the Corrugated Board Box used for transport from filler to retailer presents significant contribution in most categories. It has even more prominence in the category of Particulate Matter (21%).

The closure produced with mass balanced polymers has a net Climate Change credit due to the carbon sequestration over its life cycle. It has a significant contribution only to Ozone Depletion (10%). The mass balanced PE package layers present similar results, with significant contribution only to Ozone Depletion (13%) and Photochemical Ozone Formation (13%).

The filling step is a relevant contributor of the Water Consumption category (17%). It is also significant for Climate Change (14%), Acidification (10%), Eutrophication (17%), and Resource Use Fossil (11%).

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 21. Biogenic carbon is sequestered in the production of LPB, mass-balanced polymers, and corrugated box used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the 'CO_2 uptake' subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its

degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), aluminium foil and corrugated board productions are the most representative elements.

The net results of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 38% of the total impact is caused by the aluminium production and 51% corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 10% and 18% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-36% of the total impact). Similarly, the mass-balanced polymers contribution (including carton layers and closure) is -25% of the total impact.

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

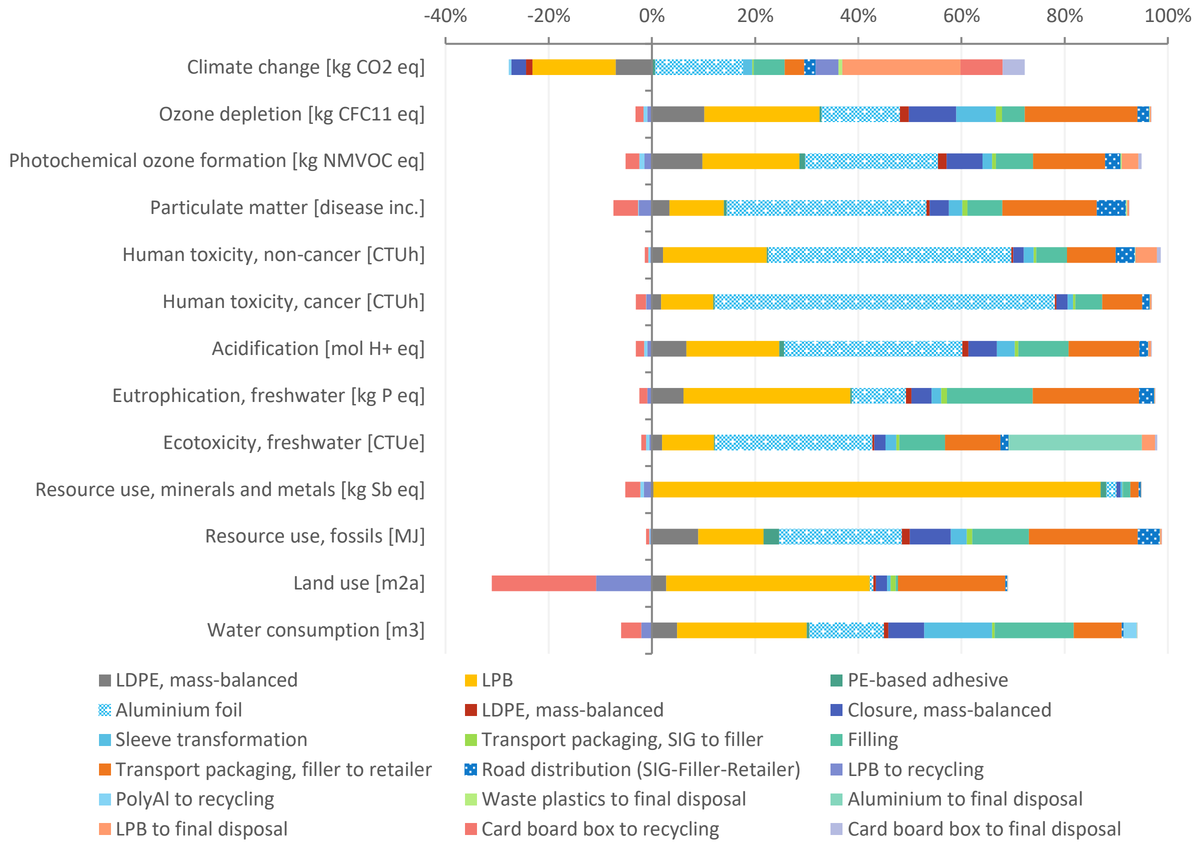

FIGURE 20 MIDIBLOC FOREST-BASED FOR DAIRY PACKAGING LIFE CYCLE CONTRIBUTION ANALYSIS

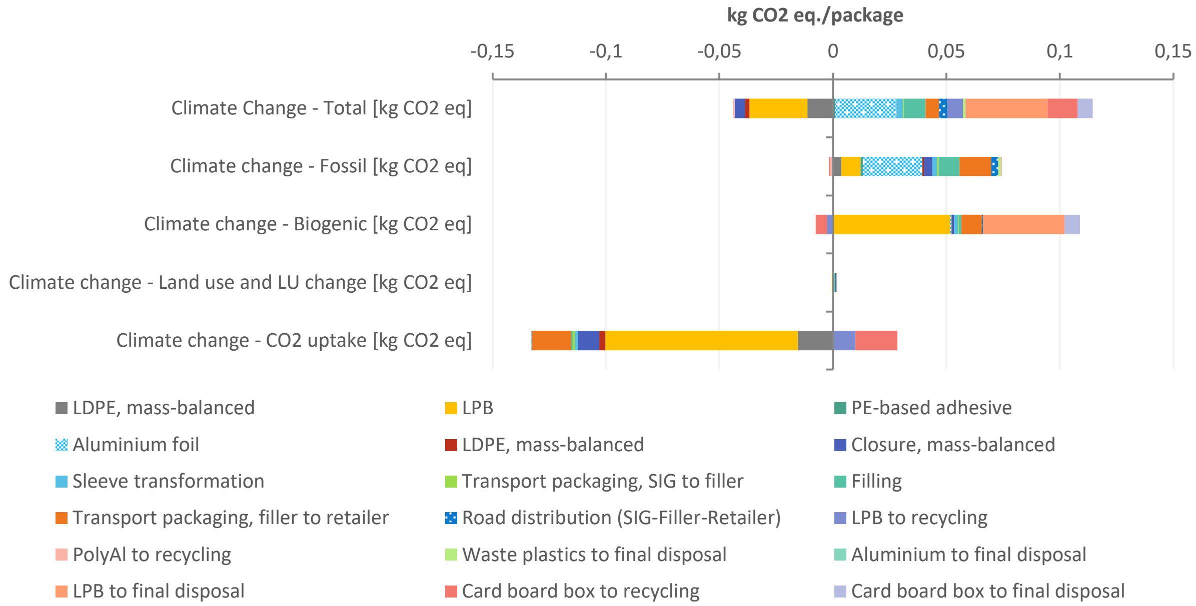

FIGURE 21 CONTRIBUTION ANALYSIS AND BREAKDOWN OF CLIMATE CHANGE CATEGORY FOR MIDIBLOC FOREST-BASED FOR DAIRY PACKAGING

MidiBloc Alu-free for dairy packaging

The MidiBloc Alu-free - Dairy packaging life cycle is revealed in the Contribution Analysis shown in Figure 22 and Figure 23. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (18%), Photochemical Ozone Formation (39%), Particulate Matter (26%), Human Toxicity Non Cancer (26%), Human Toxicity Cancer (36%), Acidification (40%), Eutrophication (60%), Freshwater Ecotoxicity (25%), and Resource Use Minerals and metals (97%) impact categories, as well as in the inventory level categories of Land Use (76%, excluding burdens and credits for recycling) and Water Consumption (27%).

Likewise, the Corrugated Board Box used for transport from filler to retailer presents significant contribution in most categories. It has even more prominence in the categories of Ozone Depletion (32%), Particulate Matter (42%), and Freshwater Ecotoxicity (29%).

The closure produced with mass balanced polymers has a net Climate Change credit due to the carbon sequestration over its life cycle. It has a significant contribution only to Ozone Depletion (14%), Resource Use Fossil (12%), and Water Consumption (10%) categories. The mass balanced PE package layers present a very similar result. The mass balanced polyamide package layer is not significant for all categories (<10%).

The filling step is the main contributor of the Water Consumption category (37%). It is also significant for Climate Change (17%), Particulate Matter (15%), Human Toxicity Non Cancer (15%), Human Toxicity Cancer (19%), Acidification (15%), Eutrophication (11%), Freshwater Ecotoxicity (24%), and Resource Use Fossil (13%).

The transport of the sleeve from Europe to the SIG plant in Brazil is responsible for 25% of the Photochemical Ozone Formation, and 28% of the Acidification results.

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 23. Biogenic carbon is sequestered in the production of LPB, mass-balanced polymers, and corrugated box used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the ‘CO_2 uptake’ subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its

degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), corrugated board productions, LPB production process and the filling step are the most representative elements.

The net results of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 72% of the total impact corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 14% and 23% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-37% of the total impact). Similarly, the mass-balanced polymers contribution (including carton layers and closure) is -23% of the total impact.

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

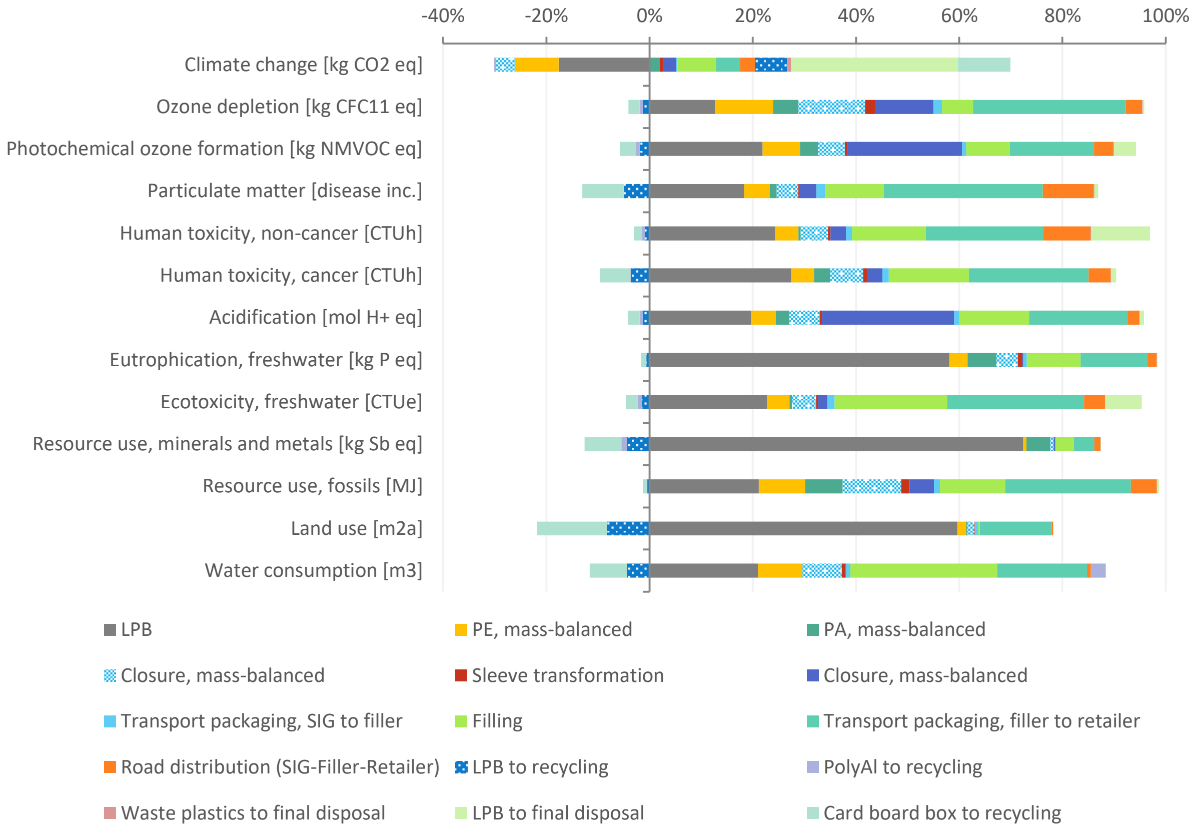

FIGURE 22 MIDIBLOC ALU-FREE - DAIRY PACKAGING LIFE CYCLE CONTRIBUTION ANALYSIS

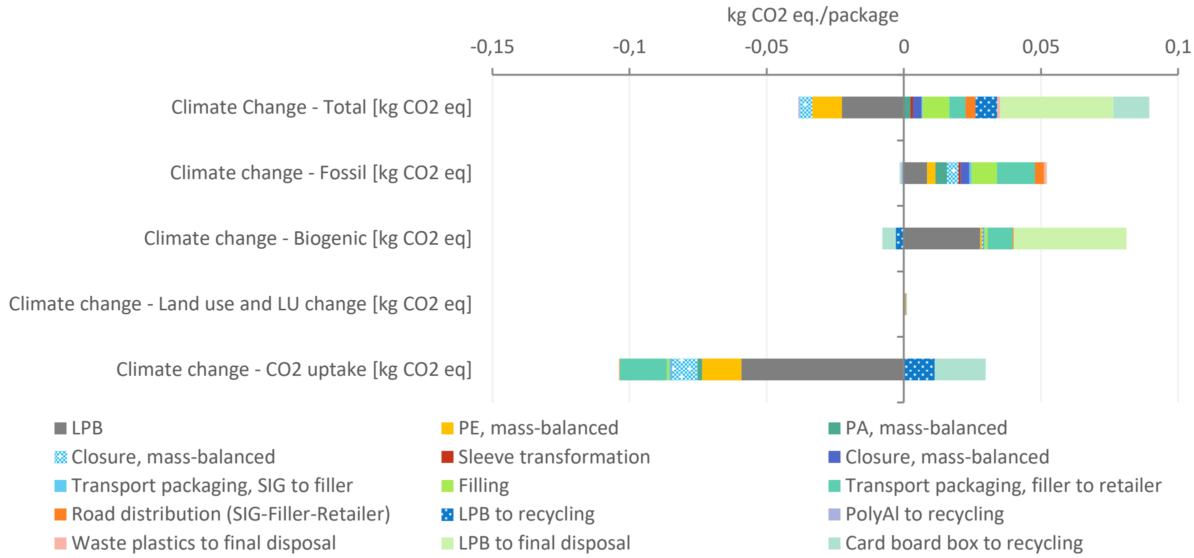

FIGURE 23 CONTRIBUTION ANALYSIS AND BREAKDOWN OF CLIMATE CHANGE CATEGORY FOR MIDIBLOC ALU-FREE - DAIRY PACKAGING

MidiBloc - Conventional for juice packaging

The MidiBloc - Conventional for juice packaging life cycle is revealed in the Contribution Analysis shown in Figure 24 and Figure 25. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The aluminium foil production is the major contributor for most categories: Climate Change (25%), Photochemical Ozone Formation (29%), Particulate Matter (45%), Human Toxicity Non Cancer (47%), Human Toxicity Cancer (68%), Acidification (37%), and Freshwater Ecotoxicity (28%) impact categories.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (18%), Photochemical Ozone Formation (21%), Particulate Matter (12%), Human Toxicity Non Cancer (20%), Human Toxicity Cancer (11%), Acidification (19%), Eutrophication (37%), and Resource Use Minerals and Metals (96%) impact categories, as well as in the inventory level categories of Land Use (41%, excluding burdens and credits for recycling) and Water Consumption (30%).

Likewise, the Corrugated Board Box used for transport from filler to retailer presents significant contribution in most categories. It has even more prominence in the category of Particulate Matter (21%).

The fossil PE package layers results standout for the Ozone Depletion (38%) and Resource Use Fossils (33%) categories.

The filling step is a relevant contributor of the Acidification (10%), Eutrophication (19%) and Water Consumption (18%) categories. The sleeve formation process is also significant for Water Consumption (16%).

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 25. Biogenic carbon is sequestered in the production of LPB and corrugated box used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the 'CO_2 uptake' subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), aluminium foil and corrugated board productions are the most representative elements.

The net result of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 26% of the total impact is caused by the aluminium production and 34% corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 7% and 13% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-25% of the total impact).

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

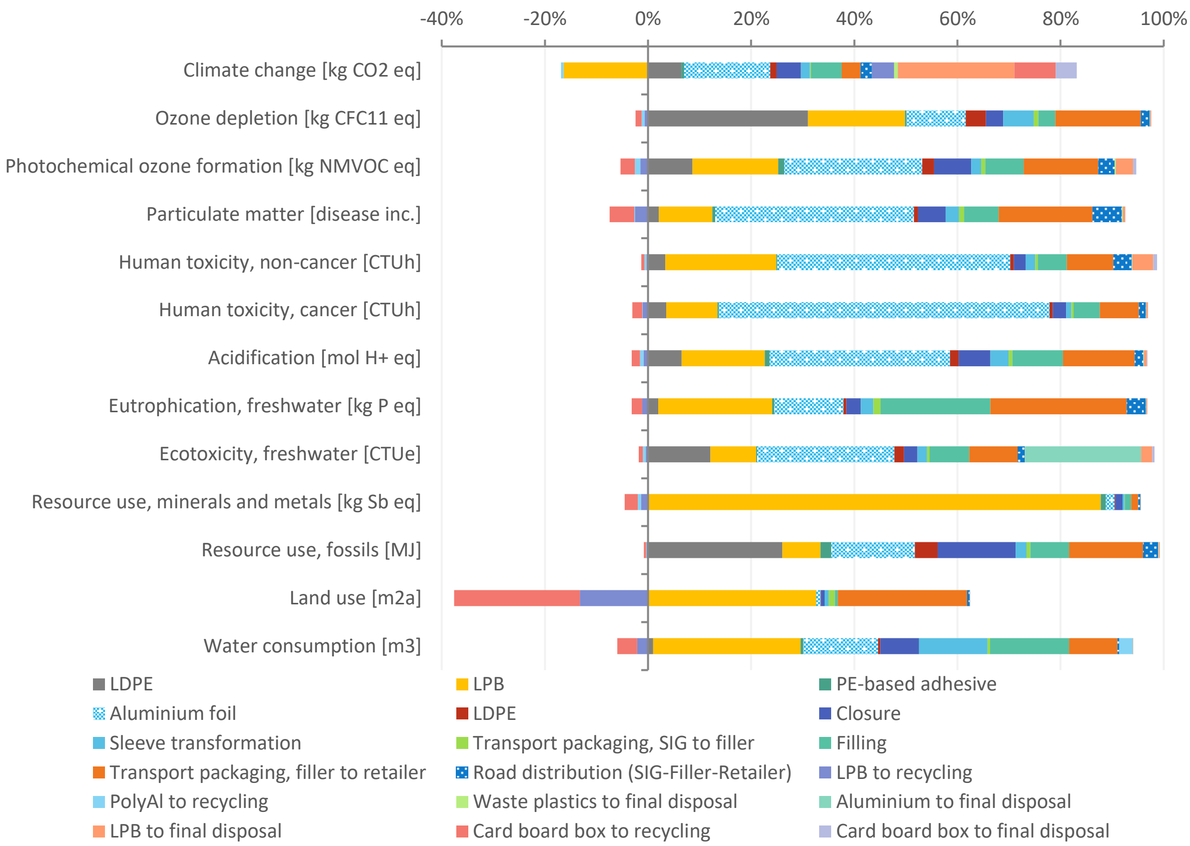

FIGURE 24 MIDIBLOC - CONVENTIONAL FOR JUICE PACKAGING LIFE CYCLE CONTRIBUTION ANALYSIS

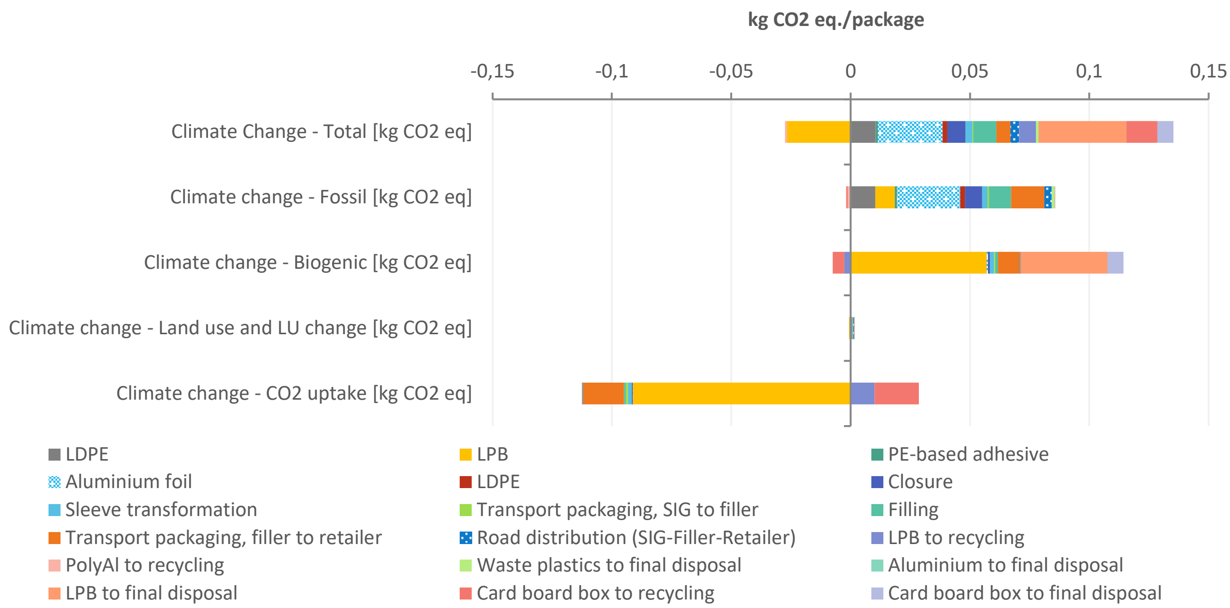

FIGURE 25 CONTRIBUTION ANALYSIS AND BREAKDOWN OF CLIMATE CHANGE CATEGORY FOR MIDIBLOC - CONVENTIONAL FOR JUICE PACKAGING

MidiBloc Forest-based for juice packaging

The MidiBloc Forest-based for juice packaging life cycle is revealed in the Contribution Analysis shown in Figure 26 and Figure 27. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The aluminium foil production is the major contributor for most categories: Climate Change (38%), Photochemical Ozone Formation (29%), Particulate Matter (46%), Human Toxicity Non Cancer (48%), Human Toxicity Cancer (70%), Acidification (37%), Freshwater Ecotoxicity (32%), and Resource Use Fossils (24%) impact categories.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (24%), Photochemical Ozone Formation (21%), Particulate Matter (12%), Human Toxicity Non Cancer (21%), Human Toxicity Cancer (11%), Acidification (19%), Eutrophication (34%), and Resource Use Minerals and Metals (97%) impact categories, as well as in the inventory level categories of Land Use (37%, excluding burdens and credits for recycling) and Water Consumption (28%).

Likewise, the Corrugated Board Box used for transport from filler to retailer presents significant contribution in most categories. It has even more prominence in the category of Particulate Matter (23%).

The closure produced with mass balanced polymers has a net Climate Change credit due to the carbon sequestration over its life cycle. It has a significant contribution only to Ozone Depletion (10%). The mass balanced PE package layers present a very similar result.

The filling step is a relevant contributor of the Water Consumption category (47%). It is also significant for Climate Change (14%), Acidification (10%), Eutrophication (17%), and Resource Use Fossil (11%).

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 27. Biogenic carbon is sequestered in the production of LPB, mass-balanced polymers, and corrugated box used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the 'CO_2 uptake' subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), aluminium foil and corrugated board productions are the most representative elements.

The net result of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 39% of the total impact is caused by the aluminium production and 52% corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 10% and 19% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-38% of the total impact). Similarly, the mass-balanced polymers contribution (including carton layers and closure) is -25% of the total impact.

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

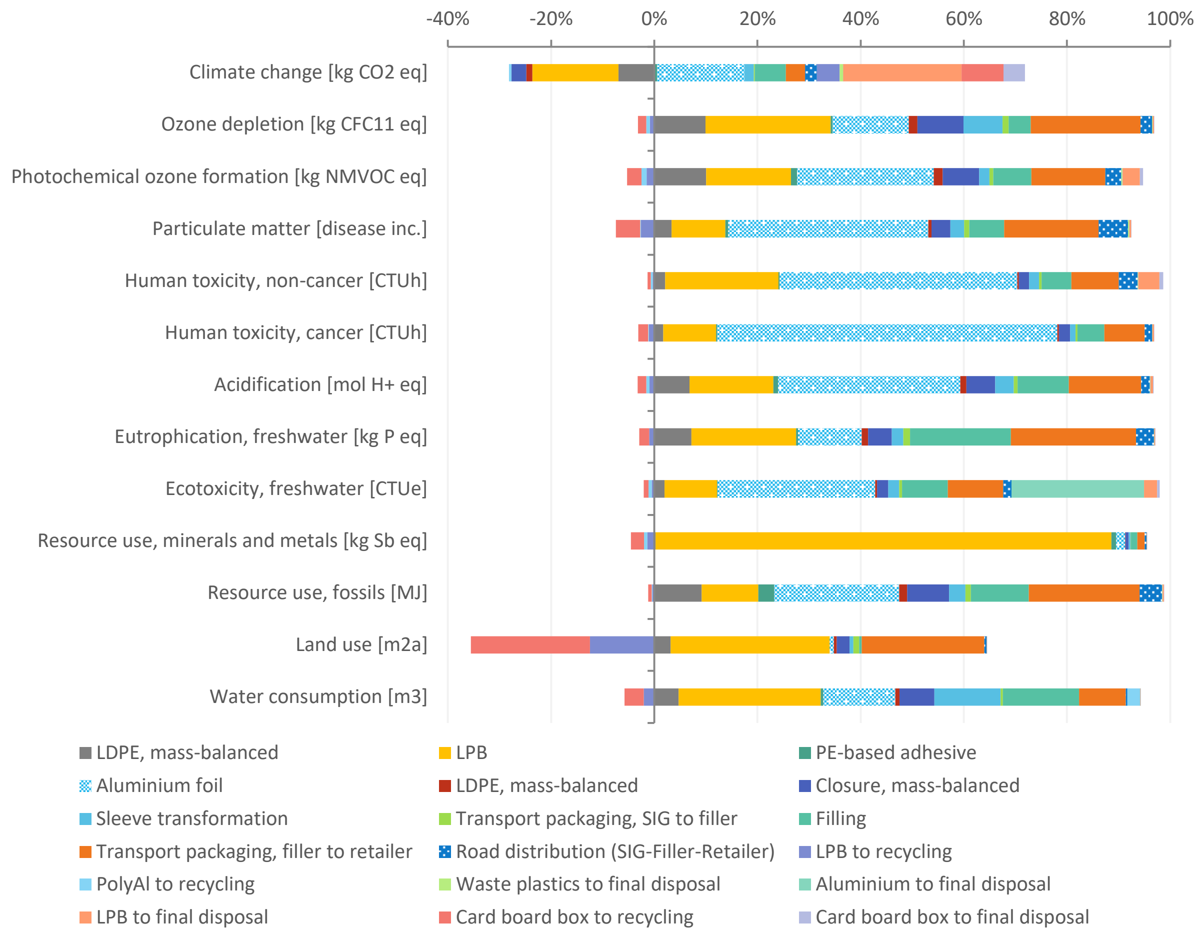

Figure 26 MidiBloc Forest-based for juice packaging life cycle Contribution Analysis

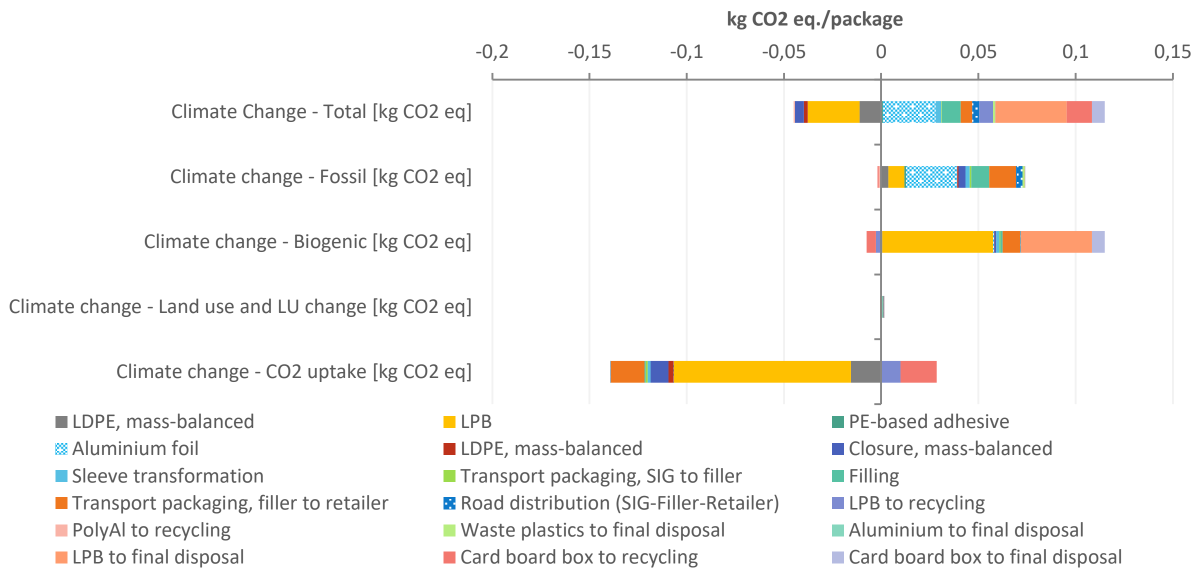

Figure 27 Contribution analysis and breakdown of Climate Change category for MidiBloc Forest-based for juice packaging

StandardBloc - Conventional - Dairy

The StandardBloc - Conventional - Dairy packaging life cycle is revealed in the Contribution Analysis shown in Figure 28 and Figure 29. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The aluminium foil production is the major contributor for most categories: Climate Change (26%), Photochemical Ozone Formation (31%), Particulate Matter (49%), Human Toxicity Non Cancer (49%), Human Toxicity Cancer (70%), Acidification (38%), and Freshwater Ecotoxicity (29%) impact categories.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (20%), Photochemical Ozone Formation (23%), Particulate Matter (14%), Human Toxicity Non Cancer (21%), Human Toxicity Cancer (11%), Acidification (20%), Eutrophication (41%), and Resource Use Minerals and Metals (96%) impact categories, as well as in the inventory level categories of Land Use (46%, excluding burdens and credits for recycling) and Water Consumption (31%).

The Corrugated Board Box used for transport from filler to retailer presents significant contribution in categories of Ozone Depletion (11%), Photochemical Ozone Formation (10%), Particulate Matter (14%), Eutrophication (10%) and Resource Uso Fossils (10%).

The fossil PE package layers results standout for the Ozone Depletion (41%) and Resource Use Fossils (35%) categories.

The filling step is a relevant contributor of the Acidification (11%), Eutrophication (21%) and Water Consumption (19%) categories. The sleeve formation process is also significant for Water Consumption (16%).

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 29. Biogenic carbon is sequestered in the production of LPB and corrugated box used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the 'CO_2 uptake' subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), aluminium foil and corrugated board productions are the most representative elements.

The net result of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 26% of the total impact is caused by the aluminium production and 34% corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 7% and 13% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-25% of the total impact).

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

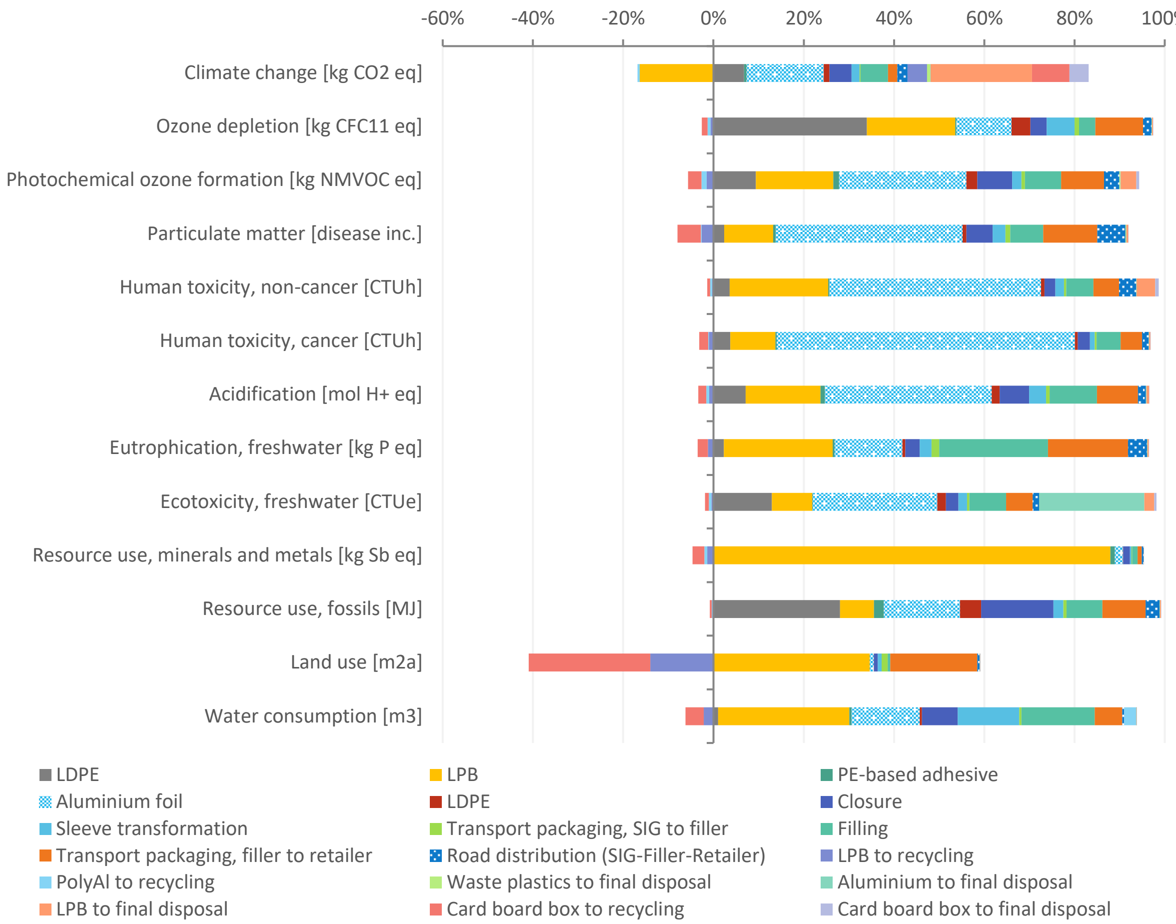

Figure 28 StandardBloc - Conventional - Dairy packaging life cycle Contribution Analysis

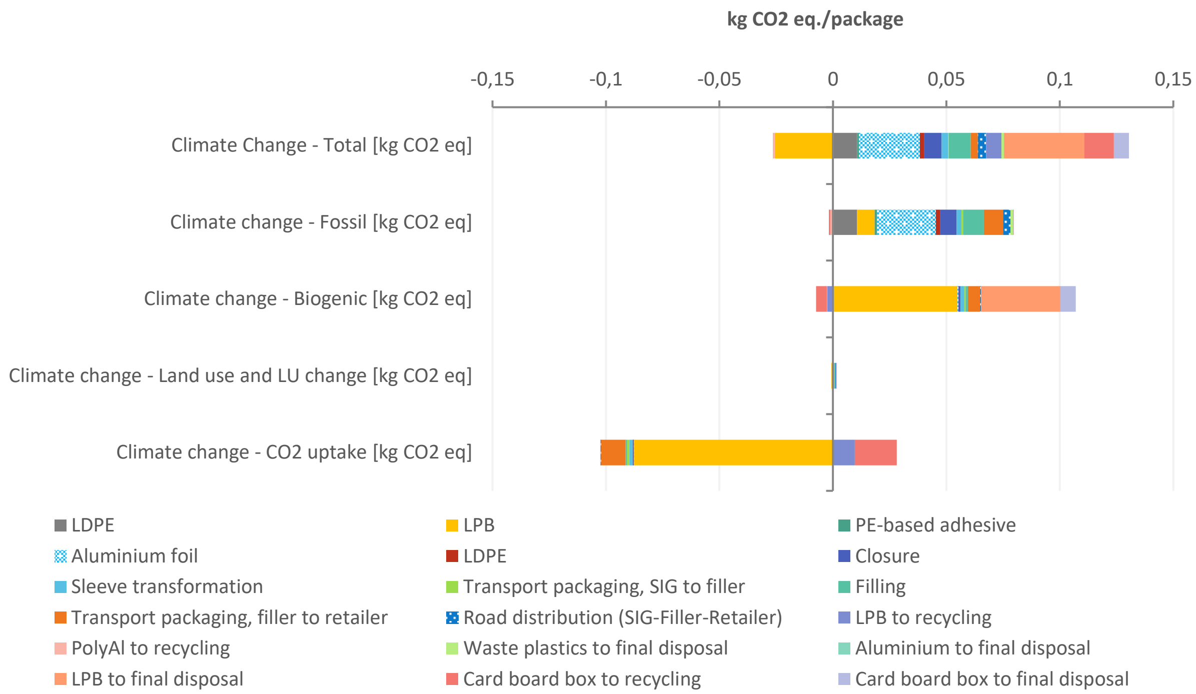

Figure 29 Contribution analysis and breakdown of climate change category for StandardBloc - Conventional - Dairy packaging

StandardBloc Forest-based - Dairy

The StandardBloc Forest-based - Dairy packaging life cycle is revealed in the Contribution Analysis shown in Figure 30 and Figure 31. In those elements, it becomes visible that environmental impacts arising from this product are concentrated on the package materials, although filling and distribution phases are significant for a few categories as well.

The aluminium foil production is the major contributor for most categories: Climate Change (41%), Photochemical Ozone Formation (30%), Particulate Matter (49%), Human Toxicity Non Cancer (50%), Human Toxicity Cancer (72%), Acidification (39%), Freshwater Ecotoxicity (33%), and Resource Use Fossils (26%) impact categories.

The Liquid Packaging Board life cycle plays a significant role in the Climate Change, Ozone Depletion (26%), Photochemical Ozone Formation (22%), Particulate Matter (14%), Human Toxicity Non Cancer (22%), Human Toxicity Cancer (11%), Acidification (20%), Eutrophication (37%), and Resource Use Minerals and Metals (97%) impact categories, as well as in the inventory level categories of Land Use (42%, excluding burdens and credits for recycling) and Water Consumption (30%).

The Corrugated Board Box used for transport from filler to retailer presents significant contribution in categories of Ozone Depletion (15%), Photochemical Ozone Formation (10%), Particulate Matter (14%), Eutrophication (14%), Resource Uso Fossils (15%), and Land Use (15%, excluding recycling burdens and credits).

The closure produced with mass balanced polymers has a net Climate Change credit due to the carbon sequestration over its life cycle. It has a significant contribution only to Ozone Depletion (11%). The mass balanced PE package layers present a very similar result.

The filling step is a relevant contributor of the Water Consumption category (18%). It is also significant for Climate Change (15%), Acidification (11%), Eutrophication (19%), Freshwater Ecotoxicity (10%) and Resource Use Fossil (12%).

The Climate Change burdens, emissions and recycling net contributions over the SIG packaging life cycle are further detailed in Figure 31. Biogenic carbon is sequestered in the production of LPB, mass-balanced polymers, and corrugated boxes used for transport packaging (represented in the Climate Change – CO_2 uptake subcategory). The recycling processes of LPB and corrugated box in the End-of-Life phase generate credits – avoided production of sulphate pulp – which happens to result in net positive emission in the 'CO_2 uptake' subcategory, because of the avoided sequestration of CO_2 associated to the avoided production of sulphate pulp.

The carbon uptake in the renewable materials that compose the packaging is released in the disposal scenario (sanitary landfills, unsanitary landfills and dumps) depending on its

degradability (Climate Change – Biogenic subcategory). Part of the carbon uptake in the LBP production is also released in the same production chain as biogenic carbon emissions.

Regarding fossil CO_2 emissions (burdens), aluminium foil and corrugated board productions are the most representative elements.

The net result of the Climate Change category (total) is composed by the sum of all Climate Change subcategories (Fossil, Biogenic, Land Use and Land Use Change, and CO_2 uptake). 41% of the total impact is caused by the aluminium production and 54% corresponds to the LPB decomposition in the disposal scenario. The recycling stage of the LPB and CBB results in net Climate Change burdens – 10% and 20% of total impact, respectively – due to the avoided carbon sequestration of the avoided virgin products. The LPB production results in a net carbon sequestration (-39% of the total impact). Similarly, the mass-balanced polymers contribution (including carton layers and closure) is -27% of the total impact.

For the remaining impact and inventory level categories, negative contributions are related to the credits obtained from the avoided products in the recycling steps.

FIGURE 30 STANDARDBLOC FOREST-BASED - DAIRY PACKAGING LIFE CYCLE CONTRIBUTION ANALYSIS

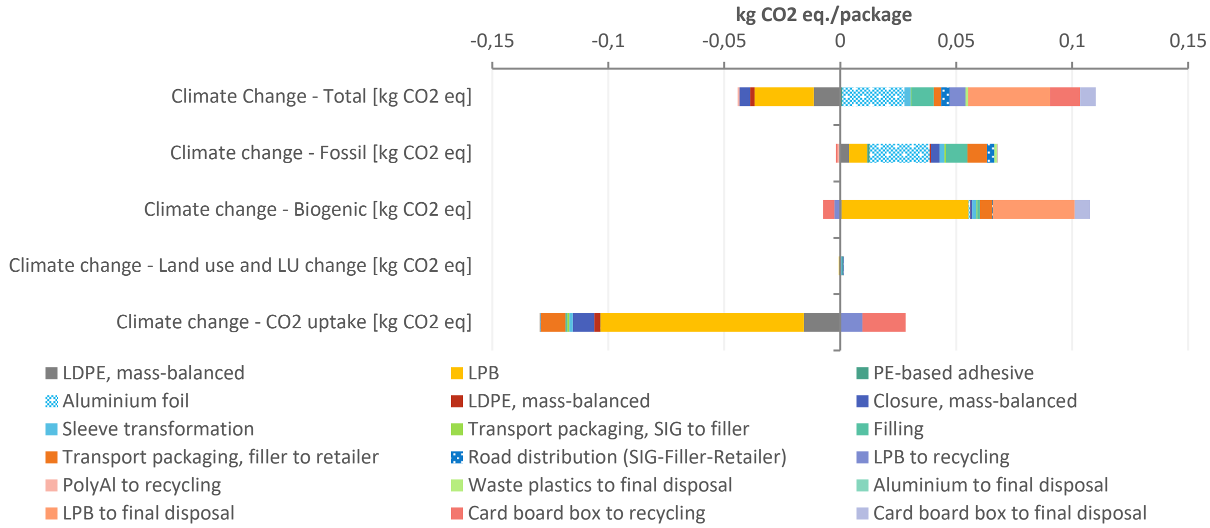

FIGURE 31 CONTRIBUTION ANALYSIS AND BREAKDOWN OF CLIMATE CHANGE CATEGORY FOR STANDARDBLOC FOREST-BASED - DAIRY PACKAGING

APPENDIX C – CRITICAL REVIEW STATEMENT

INSTITUT FÜR ENERGIE-
UND UMWELTFORSCHUNG
HEIDELBERG

Critical Review Statement

Comparative Life Cycle Assessment of beverage cartons on the Brazilian market

Heidelberg, November 2023

Table of contents

1 Background

1.1 Partial carbon footprint study for review

Comparative Life Cycle Assessment of beverage cartons on the Brazilian market

Date: 16.11.2023

Version: 1.0

1.2 Authors of the LCA report

The study has been carried out at ACV Brasil by Fábio Valebona and Tiago Rocha

1.3 Commissioner

The study was commissioned by SIG Combibloc

1.4 Critical review

The study was critically review by Frank Wellenreuther and Saskia Grünwasser at ifeu Heidelberg (Institute for energy and environmental research)

2 Nature of the critical review

The task of the review is to check the reliability, transparency, relevance and representativeness of the used methods and data in this Life Cycle Assessment (LCA) study.

According to IS 14044 the critical review process included checks if:

- the methods used to carry out the LCA are consistent with the standard's requirements,
- 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.

The present Critical Review statement is delivered to SIG Combibloc. The critical reviewers cannot be held responsible for the use of its work by any third party. The conclusions of the critical reviewers cover the full report from the study "Comparative Life Cycle Assessment of beverage cartons on the Brazilian market" provided to the reviewers on November 17th 2023 and no other report, extract or publication, which may eventually be undertaken. The critical review conclusions are given with regard to the current state of the art and the information which has been received. The conclusions expressed are specific to the context and content of the present study only and shall not be generalised any further.

3 Critical review process

The critical review process began at an online meeting where ACV already presented first results. In the following three draft reports were shared with the reviewers who then provided comments to each draft, which were considered for subsequent versions of the report.

The timeline of the critical review process was:

- 12.04.2023 Kick-off meeting between commissioner, practitioner & reviewer
- 09.05.2023 Provision of first draft version of LCA report to the reviewers
- 12.05.2023 Provision of first set of reviewers' comments to ACV
- 14.06.2023 Provision of second draft version of LCA report to the reviewers
- 20.06.2023 Provision of second set of reviewers' comments to ACV
- 22.06.2023 Online meeting to discuss draft report and reviewers' comments
- 03.07.2023 Provision of third draft version of LCA report to the reviewers
- 30.07.2023 Provision of third set of comments and draft CR statement to ACV
- 15.08.2023 Provision of LCA report to the reviewers
- 25.09.2023 Provision of CR statement to ACV and SIG Combibloc
- 25.09.2023 Additional comments from SIG Combibloc
- 10.11.2023 Provision of updated version of LCA report
- 13.11.2023 Provision of final comments to ACV
- 17.11.2023 Provision of updated final version of LCA report
- 27.11.2023 Provision of final CR statement to ACV and SIG Combibloc

4 Critical review results

The LCA report is well written and describes the study in a consistent and transparent way. The various products are well described in the report. The different LCA datasets for the materials were reviewed and found relevant and satisfactory with a transparent reference. In some cases data with an early reference date has been used. The use and relevance of these data has been explained and justified.

The LCA model system and its boundaries were reviewed and found relevant and well described in the report. The allocations made in the study, including allocations for end of life, are relevant. A sensitivity analysis of the system allocation performed also exemplifies the effect of the different allocation strategies. In the impact assessment part of the study, the following impact categories were considered: Climate Change, Ozone Depletion, Particulate Matter, Photochemical Ozone Formation, Acidification, Resource Use minerals and metals, Eutrophication in Freshwater, Resource Use Fossil Fuels, Human Toxicity - carcinogenic effects, Human Toxicity – non-carcinogenic effects and Ecotoxicity in freshwater. The choice of impact categories was based on the recommendation of the European Commission for the assessment of environmental footprints and are considered to be relevant for this study. The categories Water Consumption and Land Use were only included on an inventory level. This decision is explained in the report, referring to high uncertainties associated to these categories. This is considered a reasonable decision by the reviewers.

After discussions and requests in the review process satisfactory changes were made to all issues addressed by the critical reviewers. The review process also includes minor editorial changes. The comments and corrections are documented directly in the different versions of the draft reports. The information in the review process is thus traceable throughout the entire review process.

5 Review Statement

The undersigned reviewers confirm that the reviewed study “Comparative Life Cycle Assessment of beverage cartons on the Brazilian market” has been conducted according to and in compliance with the ISO standards 14040 and 14044 and has relevant data sources. The interpretations reflect the limitations identified and the goal of the study, and the study report is transparent and consistent.

Frank Wellenreuther

ifeu

Heidelberg, Germany

Saskia Grünwasser

ifeu

Heidelberg, Germany