INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

SIGNATURE **portfolio**

Analysis of combibloc **ECO**PLUS & **SIG**NATURE 100 and **SIG**NATURE FULL BARRIER for combiblocSlimline and combiblocMidi on the European market

Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach

Final report

CB-100734

commissioned by SIG Combibloc

Heidelberg, May 2022

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List of abbreviations

ACE	Alliance for Beverage Cartons and the Environment
BC	Beverage carton
BLS	Black Liquor Soap
cb3	combiblocSlimline
cb8	combiblocMidi
ci17	combismileSmall
ci18	combismileBig
cMaxx	combiMaxx
cSwift	combiSwift
CML	Centrum voor Milieukunde (Center of Environmental Science), Leiden University, Netherlands
COD	Chemical Oxygen Demand
EAA	European Aluminium Association
EU27+2	European Union + Switzerland and Norway
EU27+3	European Union + Switzerland, Norway and UK
FB	Full barrier
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (Brussels)
FU	Functional unit
GWP	Global Warming Potential
HBEFA	Handbook emission factors for road transport
ifeu	Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LDPE	Low density polyethylene
LPB	Liquid packaging board

MSWI	Municipal solid waste incineration
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides
pc	packs
PET	Polyethylene terephthalate
PM 2.5	Particulate matter with an aerodynamic diameter of 2.5 µm or smaller
PP	Polypropylene
rPET	recycled PET
RS	Robust structure
UBA	Umweltbundesamt (German Federal Environmental Agency)
VOC	Volatile Organic Compounds

1 Goal and Scope

1.1 Background and Objectives

The combibloc (cb) beverage cartons are aseptic beverage cartons produced by SIG Combibloc which include the variants of packaging systems combibloc standard RS (robust structure), combibloc EcoPlus, combibloc **SIG**NATURE PACK 100 and combibloc **SIG**NATURE PACK FB (full barrier).

In March 2018 ifeu did a life-cycle assessment study for two different **SIG**NATURE PACK combiblocSlimline (cb3) cartons from SIG Combibloc. LCA results were compared with those of a standard combiblocSlimline (cb3) carton as well as those from a combiblocSlimline (cb3) EcoPlus beverage carton. The study covers the European market situation for the EU countries & Switzerland & Norway as well as the German market situation in 2018.

This study is to examine the combiblocSlimline (cb3) **SIG**NATURE PACK and combiblocMidi (cb8) **SIG**NATURE PACK on the European market (EU27+3) in 2021 with additional extensions for the combiblocSlimline (cb3) and combiblocMidi (cb8) formats.

Furthermore, in two separate extensions

(1) combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons regarding the markets Spain, France, Germany, Belgium, Netherlands, Poland and UK
(2) combismileSmall (ci17) and combismileBig (ci18) beverage cartons regarding the markets EU27+3 and Netherlands

are examined.

The beverage cartons combiblocMidi (cb8) **SIG**NATURE PACK 100 and combiblocMidi (cb8) **SIG**NATURE PACK FB contain polymers that originate from renewable European wood sources via a mass balance approach. These replace conventional fossil-based polymers, which usually are contained in most aseptic beverage cartons.

The ifeu (Institute for Energy and Environmental Research, ifeu) was commissioned by SIG Combibloc to conduct the current LCA study with the following goals:

- To provide knowledge about the environmental strengths and weaknesses of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons in the sizes 1000 mL and 500 mL for the packaging at European market conditions and
- To examine two different combibloc **SIG**NATURE PACK cartons per format (combiblocSlimline (cb3) and combiblocMidi (cb8))
- To compare their environmental impact results with those of the respective standard RS variants and in case of the **SIG**NATURE PACK 100 also with the respective EcoPlus carton.

As the results of this study shall be used for internal and external communication, the study is also critically reviewed by an independent expert.

1.2 Organisation of the study

This study was commissioned by SIG Combibloc in 2021. It is being conducted by ifeu.

The members of the project panel are:

- Udo Felten (SIG Combibloc)
- Frank Wellenreuther (ifeu)
- Samuel Mahami (ifeu)
- Saskia Grünwasser (ifeu)
- Sophia Fehrenbach (ifeu)

1.3 Use of the study, target audience and critical review

The comparative results of this study are intended to be used by the commissioner (SIG Combibloc). Further they shall serve for information purposes of SIG Combibloc's customers, e.g. fillers and retail customers. The results are not intended to be considered for other geographical regions than Europe, not even for the same packaging systems. Nor are the results be considered valid for (the same) packaging systems at any other time. Since only variants of packaging systems of SIG Combiblock are compared in the present study and no comparison with third-party products is made, the critical review by an external expert is applied in accordance with specifications in DIN EN ISO 14040, section 7.3.2. The study and/or its results are intended to be disclosed and therefore critically reviewed by Dr. Florian Antony.

1.4 Functional unit

The function examined in this LCA study is the packaging for retail sale. The functional unit for this study is the provision of 1000 L at the point of sale. The packaging of the beverages or liquid food is provided for the required shelf life of the product.

For all packaging systems no packaging type specific differences in shelf life can be observed.

A relevant parameter that makes a difference in the examined beverage cartons is the barrier material. Aluminium is an important barrier material of the beverage cartons, which can be replaced by PA. PA and aluminium do not show exactly the same barrier functions, but in regard to the standards required to ensure the necessary shelf-life, they can be equally suited. Nevertheless, it is assumed that the primary packaging examined is technically equivalent in terms of mechanical protection of the packaged beverage during transport, storage at the point-of-sale and the use phase. CombiblocSlimline (cb3)/combiblocMidi (cb8) standard RS cartons and combiblocSlimline (cb3)/combiblocMidi (cb8) **SIG**NATURE PACK FB cartons contain aluminium as barrier material, while combiblocSlimline (cb3)/combiblocMidi (cb8) EcoPlus contain fossil-based PA and combiblocSlimline (cb3)/combiblocMidi (cb8) **SIG**NATURE PACK 100 contain mass-balanced PA as barrier material.

The reference flow of the product system regarded here refers to the actually filled volume of the containers and includes all packaging systems, i.e. beverage carton and closures as well as the transport packaging (corrugated cardboard trays and shrink foil, pallets), which are necessary for the packaging, filling and delivery of 1000 L.

1.5 System boundaries

The study is designed as a 'cradle-to-grave' LCA without the use phase, 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 of the primary base materials used in the primary packaging systems from the studied systems (incl. closures)
- Converting, recycling and final disposal of primary packaging systems and related transports
- Production, recycling and final disposal of transport packaging (stretch foil, pallets, cardboard trays)
- Production and disposal of process chemicals, as far as not excluded by the cut-off criteria (see below)
- Transports of packaging material from producers to fillers
- Filling processes, which are fully assigned to the packaging system.
- Transport from fillers to potential central warehouses and final distribution to the point of sale
- In all manufacturing and filling processes for the primary and secondary packaging losses are included

Not included are:

- The production and disposal of the infrastructure (machines, transport media, roads, etc.) and their maintenance (spare parts, heating of production halls) as no significant impact is expected. To determine if infrastructure can be excluded the authors apply two criteria by Reinout Heijungs (Heijungs 1992) and Rolf Frischknecht (Frischknecht et al. 2007): Capital goods should be included if the costs of maintenance and depreciation are a substantial part of the product and if environmental hot spots within the supply chain can be identified. Considering relevant information about the supply chain from producers and retailers both criteria are considered to remain unfulfilled. An inclusion of capital goods might also lead to data asymmetries as data on infrastructure is not available for many production data sets
- Production of beverage, and their transport to fillers as no relevant differences between the systems under examination are to be expected.
- Distribution of beverage from the filler to the point-of-sale (distribution of packages is included) as the same amount of beverage is transported for all regarded packaging systems (see transport allocation in **section 1.7.2**).
- Environmental effects from accidents like breakages during transportation, as there is no evidence and no reason to assume differences of the packaging systems.
- Losses of beverage at different points in the supply and consumption chain which might occur for instance in the filling process, during handling and storage, etc. as they are considered to be roughly the same for all examined packaging systems. Significant differences in the amount of lost beverage between the regarded packaging systems might be conceivable only if non-intended uses or product

treatments are considered as for example in regard to different breakability of packages or potentially different amount of residues left in an emptied package due to the design of the package/closure.
Further possible losses are directly related to the handling of the consumer in the use phase, which is not part of this study as handling behaviours are very different and difficult to assess. Therefore these possible beverage loss differences are not quantifiable as almost no data is available regarding these issues. In consequence a sensitivity analysis regarding beverage losses would be highly speculative and is not part of this study. This is indeed not only true for the availability of reliable data, but also uncertainties in inventory modelling methodology of regular and accidental processes and the allocation of potential beverage waste treatment aspects.

- Transport of filled packages from the point of sale to the consumer as no relevant differences between the systems under examination are to be expected and the implementation would be highly speculative as no reliable data is available.
- Use phase of packages at the consumers as no relevant differences between the systems under examination are to be expected (for example in regard to cleaning before disposal) and the implementation would be highly speculative as no reliable data is available.

For recycling and recovery routes the system boundary is set at the point where a secondary product (energy or recycled material) is obtained. The secondary products can replace primary energy generation processes and virgin materials, respectively. This effect is accounted for in the life cycle assessment by attributing credits for secondary products. These credits are calculated based on the environmental loads of the corresponding primary energy generation process or material.

The following simplified flow charts shall illustrate the system boundaries considered for the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons (**Figure 1-1**).

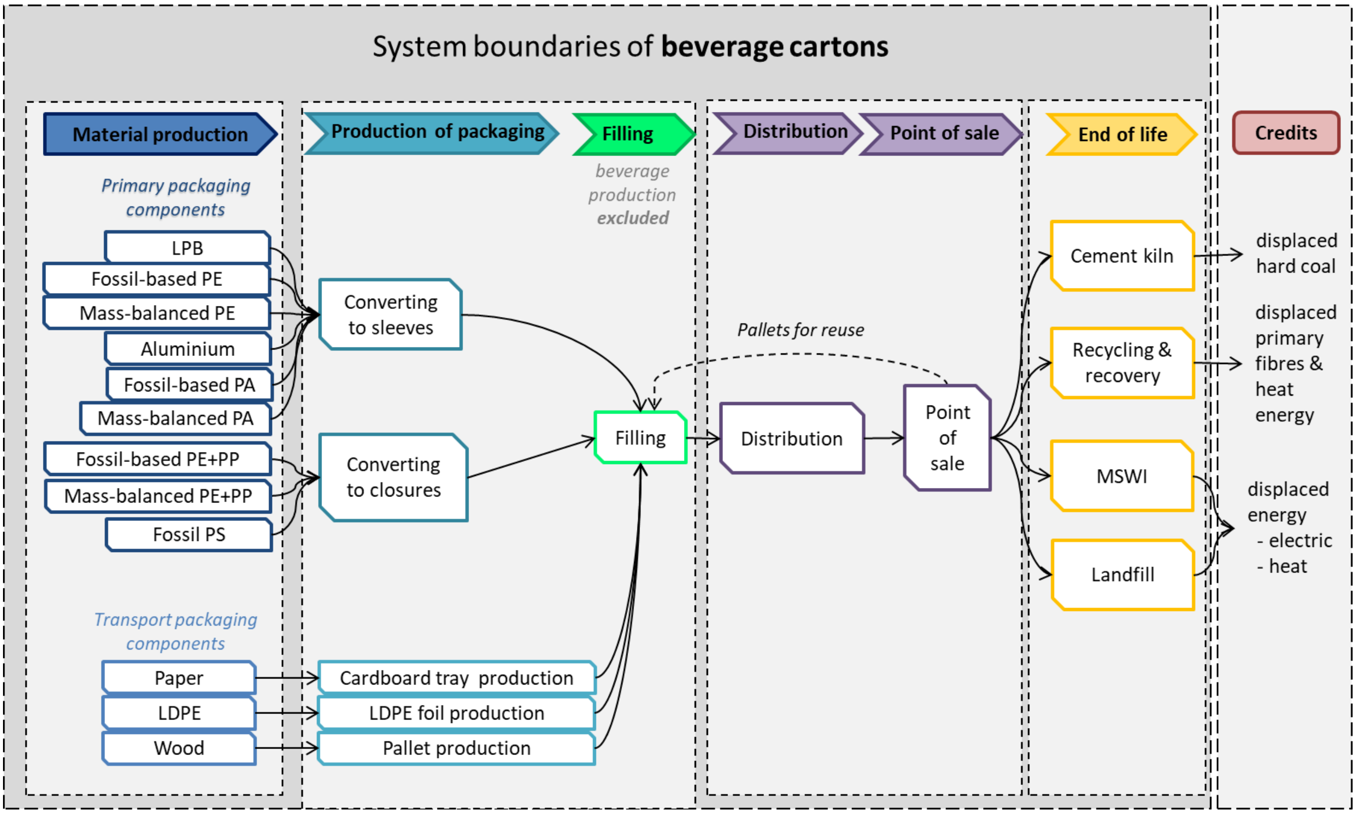

Figure 1-1: System boundaries of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons for all considered formats

Cut-off criteria

In order to ensure the symmetry of the packaging systems to be examined and in order to maintain the study within a feasible scope, a limitation on the detail in system modelling is necessary. So-called cut-off criteria are used for that purpose. According to ISO standard (ISO 14044: 2006), cut-off criteria shall consider mass, energy or environmental significance. Regarding mass-related cut-off, pre-chains from preceding systems with an input material share of less than 1% of the total mass input of a considered process were excluded from the present study. However, total cut-off is not to surpass 5% of input materials as referred to the functional unit. All energy inputs are considered, except the energy related to the material inputs from pre-chains which are cut off according to the mass related rule. Pre-chains with low input material shares, which would be excluded by the mass criterion, are nevertheless included if they are of environmental relevance, e.g. flows that include known toxic substances. The environmental relevance (significant impact on any impact category) of material input flows was determined based on ifeu's expert judgement based on previous studies.

Excluded material flows according to this cut-off rule in this study are:

- Printing ink used for sleeves of beverage carton as part of the converting process: 0.11 g per sleeve for 1 L beverage carton (30.38 g sleeve weight)
- Lubricants used for all industrial processes including machinery: in all cases < 0.1 kg per 1000 kg intermediate good per process (e.g. filling, converting)

The potential effect of these excluded material flows on the results of this study is evaluated as almost nought.

1.6 Data gathering and data quality

The datasets used in this study are described in **section 3** (**Life Cycle Inventory**). All data shall meet the general requirements and characteristics regarding data gathering and data quality as summarised in the following paragraphs.

Time scope

The reference time period for the comparison of packaging systems is 2021, as the packaging specifications listed in **section 2.3** (**Packaging specifications**) refer to 2021. Where no figures are available for these years, the used data shall be as up-to-date as possible. Particularly with regard to data on end-of-life processes of the examined packages, the most current information available is used to correctly represent the recent changes in this area. As some of these data are not yet publicly available, expert judgements are applied in some cases, for example based on confidential exchanges with representatives from the logistics sector and retailers regarding distribution distances.
Most of the applied data refer to the period between 2005 and 2021. Parameters with an essential influence on the result, such as the electricity mix, are continuously updated. Older data have only been deemed acceptable for processes which do not show a high share on the overall impacts.

Geographic scope

In terms of the geographic scope, the LCA study focuses on the production, distribution and disposal of beverage carton packages in Europe (EU27+3), respectively. A certain share of the raw material production as well as converting processes for packaging systems take place in specific European countries. For these, country-specific data is used as well as European averages depending on the availability of datasets. Examples are the liquid packaging board (LPB) production process (country-specific) and the production of plastics (available only as a European average, see **Table 3-1**).

Technical reference

The process technology underlying the datasets used in the study reflects process configurations as well as technical and environmental levels which are typical for process operations in the reference period. The technical reference is intended to represent the average presently applied technology or presently applied technology.

Representativeness

Representativeness is addressed by looking at three indicators: temporal, geographical, and technological correlation. This evaluation aims to reflect how well the used inventory data represent the technology, geography and time scopes of this study. These three indicators meet the (ISO 14044: 2006) standards and is carried out based on several guidelines for data quality assessment (Edelen / Ingwersen 2016; JRC 2010; Weidema et al. 2013; Zampori et al. 2016).

The representativity evaluation regarding the time scope indicates the correlation between the reference year of the used data and the time scope of this study. The qualitative evaluation shows, that the reference year of the used data meet the time scope of this study, is close or close enough to the time scope of this study. It has to be noted, that a lower temporal correlation does not mean the data is not representative. "A more important reflection of correlation would be the technological correlation". (Edelen / Ingwersen 2016)

The geographical representativeness of the used data identifies how well these inventory data represent the geographic scope of this study. The result of the evaluation is, that the used data meet the geographic scope of this study.

The evaluation of the technological correlation shows differences that may be present between used data and the technology scope of this study. The used data covers either average of presently used technology or presently used technology.

The overall representative evaluation shows, that the used data can be regarded as representative for the intended purpose of this study.

Completeness

In general, the data collection and data implementation for the ifeu internal database takes place in four phases: In phase one, to understand the processes like filling, converting or plastics production, they are analysed based on available literature, discussions with the respective stakeholders or the production sites are directly visited. In this phase, the relevant flows of following flow types are identified: reference product, co-products, intermediate inputs, land occupied/transformed, raw inputs, (material, energy and water), waste to treatment (solid and hazardous and liquid), emissions to air (GHGs, Criteria Air Pollutants, Toxics + Other and Water), emissions to water (Nutrients and Toxics + Other), and emissions to soil (Nutrients and Toxics + Other). In phase 2, the respective companies provide data on the identified inputs (e.g. amount of raw materials, energy, or water) and main output products (e.g. emissions to air and water). In phase 3, a completeness check regarding all possible used impact and inventory categories are carried out based on information from phase 1. Based on this, additional relevant data are collected, concerning emissions to air and water, amounts of waste, and transport information. In phase 4, an additional completeness check is carried out, where the LCIA results of the implemented data are cross checked with available LCIA results (e.g. previous data, data from other geographic regions, similar processes).

This procedure applies also for datasets implemented from industries except for the data collection phase.

Missing information on land-use, water use, and toxicity are discussed in **section 1.8** (**Environmental Impact Assessment**) in the respective sections.

Consistency

To ensure consistency only data of the same level of detail were used. While building up the model, crosschecks concerning the plausibility of mass and energy flows were continuously conducted. The methodological framework is consistent throughout the whole model as the same methodological principles are used both in foreground and background system. An exception may be infrastructure which is generally excluded in this study. In case of some aggregated datasets taken from public databases it may be included without being probably documented. If these cases exist at all, then a slight inconsistency in regard to the exclusion of infrastructure may exist.

Reproducibility

All data and information used either are documented in this report or are available from the mathematical model of the processes and process plans designed within the Umberto 5.5 software. The reproducibility is given for internal use since the owners of the technology provided the data and the models are stored and available in a database. It is worth noting that for external audiences, it may be the case that full reproducibility in any degree of detail will not be available for confidentiality reasons. However, experienced experts would easily be able to recalculate and reproduce the product system models.

Sources of data

Process data for base material production and converting were either collected in cooperation with the industry or taken from literature and the ifeu database. Ifeu's internal database includes data either collected in cooperation with industry or is based on literature. The database is continuously updated. Background processes such as energy generation, transportation, MSWI and landfill were taken from the most recent version of it. All data sources are summarised in **Table 3-1** and described in **section 3**.

Precision and uncertainty

For studies to be used in comparative assertions and intended to be disclosed to the public, ISO 14044 asks for an analysis of results for sensitivity and uncertainty. Uncertainties of datasets and chosen parameters are often difficult to determine by mathematically sound statistical methods. Hence, for the calculation of probability distributions of LCA results, statistical methods are usually not applicable or of limited validity. For example, uncertainty measures like variances for elementary flows are not included in industry data sets as "the relevant foreground data is primary data or modelled based on primary information sources of the owner of the technology" (PlasticsEurope 2014a).

However, to address potential uncertainties between the compared product systems, an estimated significance threshold of 10% is chosen as pragmatic approach. This means that differences in the results of the impact category indicators between the comparative systems of ≤ 10% are considered insignificant. Based on the data used for the impact categories considered in this study, the authors' point of view is that the significance threshold of 10% is an appropriate size and guarantees consistency for all impact categories examined.

Modelling and calculation of inventories

For the implementation of the system models the computer tool Umberto® (version 5.5) is used. Umberto® is a standard software for mass flow modelling and LCA. It has been developed by the institute for environmental informatics (ifu) in Hamburg, Germany in collaboration with ifeu, Heidelberg.

1.7 Methodological aspects

1.7.1 Mass-balanced renewable material approach applied for the production of polymers in the combiblocSlimline (cb3) and combiblocMidi (cb8) SIGNATURE PACK

Mass balance based polymers are polymers that are produced by using both, fossil and biogenic resources as input materials for the same production process. In practice the input of biogenic materials (in this case tall-oil, a by-product of the paper production processes) to the polymerisation process is done at the same production process where mainly fossil-based ethylene and naphtha is used. This leads to only one final product per production process which is neither 100% fossil-based nor 100% bio-based material. To allocate the specific characteristics of fossil-based or bio-based input materials to the final product the producers declare a certain share of their production as linked to renewable resources. That share, of course is dependent on the share of biogenic input material.

It is important to understand that in reality (in a physical sense) the $(C_2H_4)_n$ and $(C_3H_6)_n$ molecules of the tall oil based polymers are in fact mainly non bio-based, as the share of bio-based ethylene is below 1% of the total production. But as the polymers in the combiblocSlimline (cb3) and combiblocMidi (cb8) **SIG**NATURE PACK are the ones to which the tall-oil input is allocated to, they are modelled as if they would be 100% tall-oil based for the purpose of this study. The allocation of inputs is certified by ISCC PLUS (International Sustainability & Carbon Certification) (ISCC 2019) (please see Appendix A). The properties of the final mass-balanced material (beyond the nature of the molecules) are completely identical to those of a fossil-based material.

The LCA results for the combiblocSlimline (cb3) and combiblocMidi (cb8) **SIG**NATURE PACK will therefore not be directly connected to the physical products examined, but to the products of the production technology concept that lies behind it. In the authors' view the application of the mass balance approach in the production of polymers is an important driver to facilitate an increasing substitution of fossil resources by biogenic resources for the production of polymers. To model the examined products strictly on their physical properties would mean to not acknowledge this function of the mass balance approach.

Jeswani et al. published in 2019 a study investigating the methodology for integrating the biomass balance approach into life cycle assessment with an application in the chemicals sector. This study concludes that "a mass balance approach can be used in life cycle assessment while following the requirements set out in the ISO 14040 and 14044 standards" (Jeswani et al. 2019). Furthermore, this study highlights also that the mass balance approach is an applicable way to evaluate life cycle environmental impacts of bio-based products "without the need for building up the whole value chains separately from the fossil-based routes" (Jeswani et al. 2019).

1.7.2 Allocation

"Allocation refers to partitioning of input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14044: 2006 definition 3.17). This definition comprises the partitioning of flows regarding re-use and recycling, particularly open loop recycling.

In the present study, a distinction is made between process-related and system-related allocation, the former referring to allocation procedures in the context of multi-input and multi-output processes and the latter referring to allocation procedures in the context of open loop recycling.

Both approaches are further explained in the subsequent sections.

Process-related allocation

For *process-related allocations,* a distinction is made between multi-input and multi-output processes.

Multi-input processes

Multi-input processes occur especially in the area of waste treatment. Relevant processes are modelled in such a way that the partial material and energy flows due to waste treatment of the used packaging materials can be apportioned in a causal way. The modelling of packaging materials that have become waste after use and are disposed in a waste incineration plant is a typical example of multi-input allocation. The allocation for e.g. emissions arising from such multi-input processes has been carried out according to physical and/or chemical cause-relationships (e.g. mass, heating value (for example in MSWI), stoichiometry, etc.).

Multi-output processes

For data sets prepared by the authors of this study, the allocation of the outputs from coupled processes is generally carried out via the mass as this is usual practice. If different allocation criteria are used, they are 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.

Transport processes

An allocation between the packaging and contents was carried out for the transportation of the filled packages to the point-of-sale. Only the share in environmental burdens related to transport, which is assigned to the package, has been accounted for in this study. That means the burdens related directly to the beverage is excluded. The allocation between package and filling goods is based on mass criterion. This allocation is applied as the functional unit of the study defines a fixed amount of beverage through all scenarios. Impacts related to transporting the beverage itself would be the same in all scenarios. There they don't need to be included in this comparative study of beverage packaging systems.

System-related allocation

System-related allocation is applied in this study regarding open loop recycling and recovery processes. Recycling refers to material recycling, whereas recovery refers to energy recovery for example in MSWI with energy recovery or cement kilns. System-related allocation is applied to both, recycling and recovery in the end of life of the regarded system and processes regarding the use of recycled materials by the regarded system. System-related allocation is not applied regarding disposal processes like landfills with minor energy recovery possibilities. **Figure 1-2** illustrates the general allocation approach used for uncoupled systems and systems which are coupled through recycling. In **Figure 1-2** (upper graph) in both, 'system A' and 'system B', a virgin material (e.g. polymer) is produced, converted into a product which is used and finally disposed. A virgin material in this case is to be understood as a material without recycled content. A different situation is shown in the lower graph of **Figure 1-2**. Here product A is recovered after use and supplied as a raw material to 'system B' avoiding thus the environmental burdens related to the production ('MP-B') of the virgin materials, e.g. polymer and the disposal of product A ('Dis-A'). In order to do the allocation consistently, besides the virgin material production ('MP-A') already mentioned above and the disposal of product B ('Dis-B'), also the recovery process 'Rec' has to be taken into consideration.

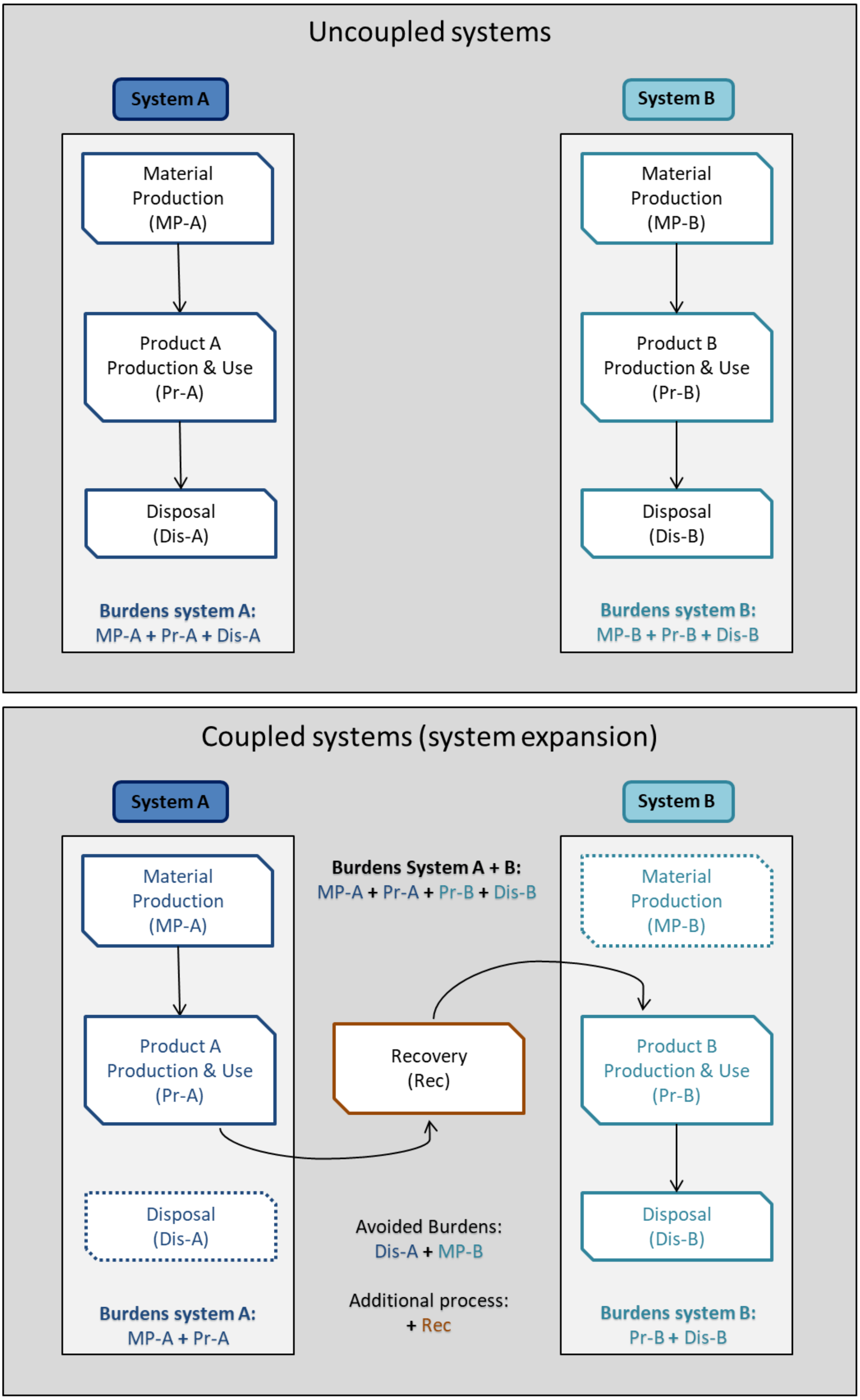

Figure 1-2: Additional system benefit/burden through recycling (schematic flow chart)[1]

If the system boundaries of the LCA are such that only one product system is examined it is necessary to decide how the possible environmental benefits and burdens of the polymer material recovery and recycling and the benefits and burdens of the use of recycled materials shall be allocated (i.e. accounted) to the regarded system. In LCA practice, several allocation methods are found. There is one important premise to be complied with by any allocation method chosen: the mass balance of all inputs and outputs of 'system A' and 'system B' after allocation must be the same as the inputs and outputs calculated for the sum of 'systems A and B' before allocation is performed.

System allocation approaches used in this study

The approach chosen for system-related allocation is illustrated in **Figure 1-3** and **Figure 1-4**. Both graphs show two example product systems, referred to as product 'system A' and 'product system B'. 'System A' shall represent systems under study in this LCA in the case if material is provided for recycling or recovery. 'System B' shall represent systems under study in this LCA in the case recycled materials are used.

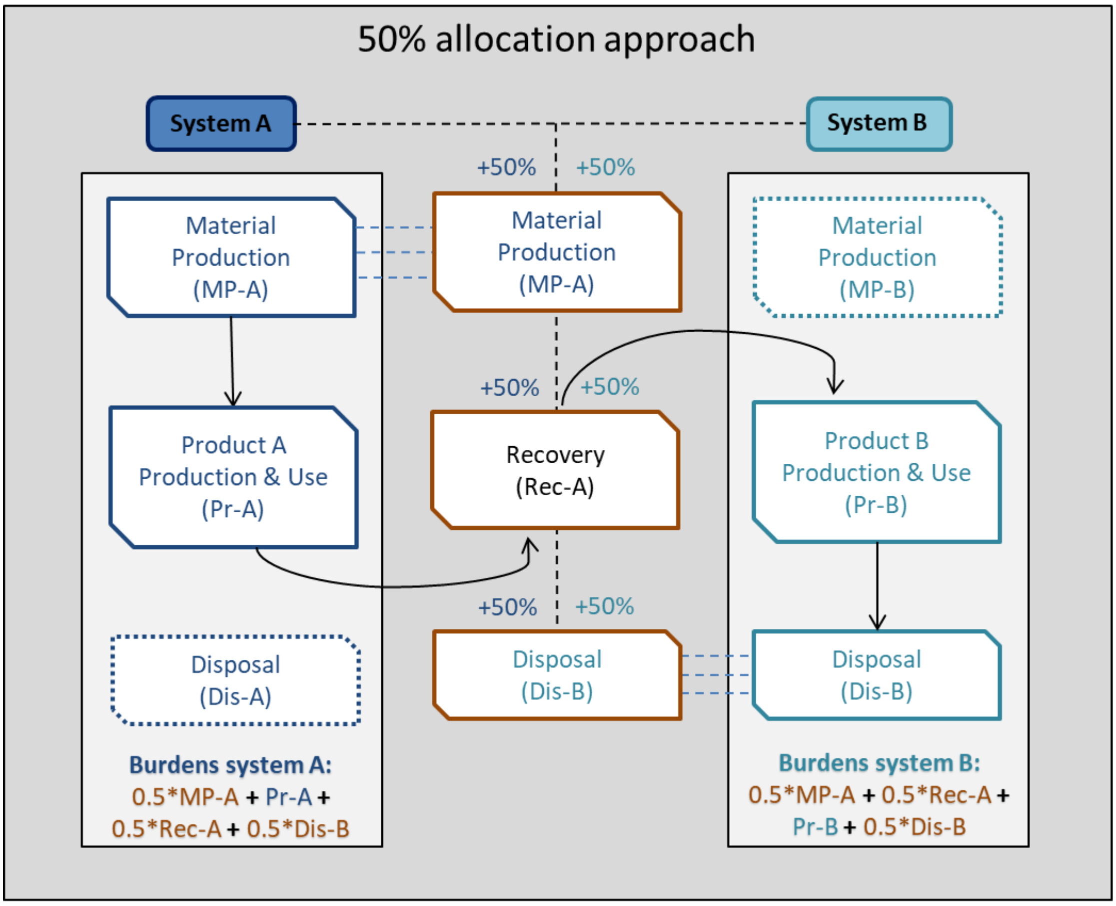

Figure 1-3: Scenario I: Principles of 50% allocation (schematic flow chart)[2]

Scenario I: allocation with the 50% method (Figure 1-3)

[2] shaded boxes are avoided processes

In this method, benefits and burdens of ‘MP-A’, ‘Rec-A’ and ‘Dis-B’ are equally shared between ‘system A’ and ‘system B’ (50% method). Thus, ‘system A’, from its viewpoint, receives a 50% credit for avoided primary material production and is assigned with 50% of the burden or benefit from waste treatment (Dis-B). If recycled material is used in the regarded system, the perspective of ‘system B’ applies. Also in this case benefits and burdens of ‘MP-A’, ‘Rec-A’ and ‘Dis-B’ are equally shared between ‘system A’ and ‘system B’.

Example 1 (‘system A’), virgin beverage carton, which is recycled or thermally recovered after its use: All burdens from recycling and recovery processes are shared between the regarded beverage carton system and the following system (use of secondary material or energy production). Also the benefits from replacing virgin materials or grid energy are shared between the regarded system and the following systems.

Example 2 (‘system B’), PET bottle containing recycled PET (rPET): All burdens from recycling of the used rPET are shared between the regarded rPET bottle system and the preceding system. Also the benefits from replacing virgin materials are shared between the regarded system and the preceding system.

The 50% method has often been discussed in the context of open loop recycling, see the following references (Fava et al. 1991; Frischknecht 1998; Kim et al. 1997; Klöpffer 1996). According to Klöpffer (2007), this rule is furthermore commonly accepted as a “fair” split between two coupled systems.

The approach of sharing the burdens and benefit from both, providing material for recycling and recovery, as well as using recycled material, follows the goal of encouraging the increase in recyclability as well as the use of recycled material. These goals are also in line with those of several packaging waste directives and laws as for example the European Packaging and Packaging Waste Directive (EU 2018) or the German packaging law (Verpackungsgesetz - VerpackG 2021).

The 50% method has been used in numerous LCAs carried out by ifeu and also is the standard approach applied in the packaging LCAs commissioned by the German Environment Agency (UBA). Additional background information on this allocation approach can be found in (UBA 2000, 2016).

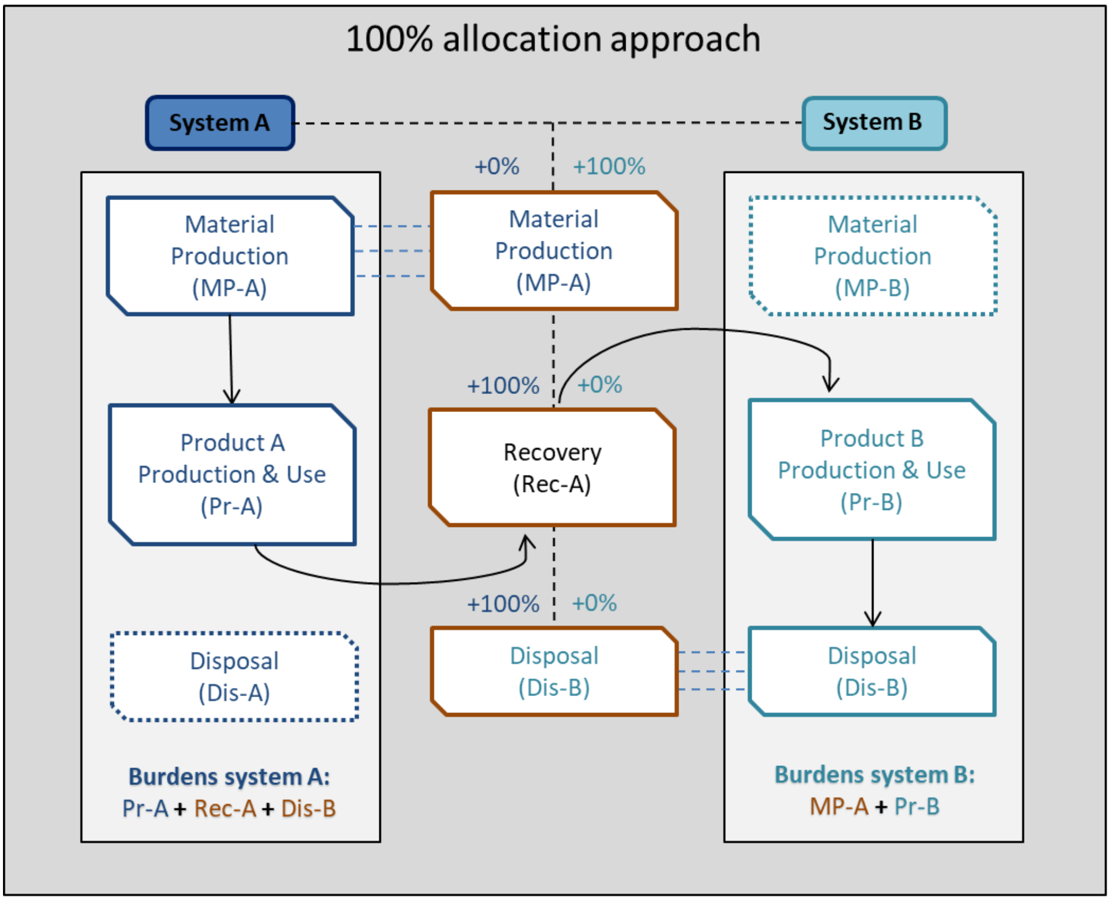

Figure 1-4: Scenario II: Principles of 100% allocation (schematic flow chart) [3]

Scenario II: Allocation with the 100% method (Figure 1-4)

In this method, the principal rule is applied that 'system A' gets all benefits for displacing the virgin material and the involved production process 'MP-B'. At the same time, all burdens for producing the secondary raw material via 'Rec-A' are assigned to 'system A'. The same is valid for energy recovery. All benefits and burdens for displacing energy production are allocated to 'system A'. In addition, also the burdens that are generated by waste treatment of 'product B' in 'Dis-B' is charged to 'system A', whereas the waste treatment of 'product A' is avoided and thus charged neither to 'system A' nor to 'system B'.

If recycled material is used in the regarded system, the perspective of 'system B' applies. The burdens associated with the production process 'MP-A' are then allocated to 'System B' (otherwise the mass balance rule would be violated). However, 'system B' is not charged with burdens related to 'Rec' as the burdens are already accounted for in 'system A'. At the same time, 'Dis-B' is not charged to 'system B' (again a requirement of the mass balance rule), as it is already assigned to 'system A'.

[3] shaded boxes are avoided processes

Example 1 (‘system A’), virgin beverage carton which is recycled or thermally recovered after its use: All burdens from recycling and recovery processes are allocated to the regarded beverage carton system. Also the benefits from replacing virgin materials or grid energy are fully allocated to the regarded system.

Example 2 (‘system B’), PET bottle containing recycled PET (rPET): All burdens from recycling of the used rPET are allocated to the preceding system. Also the benefits from replacing virgin materials are allocated to the preceding system.

The application of the allocation 100% is considered as a conservative approach from the view of the beverage carton. It means that a comparatively unfavourable case for the beverage cartons is chosen. The plastic and glass bottles benefit more from accounting of 100 % material credits due to the much higher burdens of their avoided primary material production, compared to the production of LPB. The allocation factor of 100 % is expected to lead to higher benefits for plastic and glass bottles.

Following the ISO standard’s recommendation on subjective choices, the 50% and 100% allocation methods are applied equally in this study. Conclusions in terms of comparing results between packaging systems are only drawn if they apply to both allocation methods.

General notes regarding Figure 1-2 to Figure 1-4

The diagrams are intended to support a general understanding of the allocation process and for that reason they are strongly simplified. The diagrams serve

- To illustrate the difference between the 50% allocation method and the 100% allocation method
- To show which processes are allocated:
    - Primary material production
    - Recycling and recovery processes
    - Waste treatment of final residues

However, within the study the actual situation is modelled based on certain key parameters, for example the actual recycling flow and the actual recycling efficiency as well as the actual substituted material including different substitution factors.

The allocation of final waste treatment is consistent with UBA LCA methodology (UBA 2000, 2016) and additionally this approach – beyond the UBA methodology – is also in accordance with (ISO 14044: 2006).

For simplification some aspects are not explicitly documented in the mentioned graphs, among them the following:

- Material losses occur in both ‘systems A and B’, but are not shown in the graphs. These losses are of course taken into account in the calculations, their disposal is included within the respective systems.
- Hence, not all material flows from system A are passed on to ‘system B’, as the simplified material flow graphs may imply. Consequently only the effectively recycled and recovered material’s life cycle steps are allocated between ‘systems A and B’.

- The graphs do not show the individual process steps relevant for the waste material flow out of 'packaging system A', which is sorted as residual waste, including the respective final waste treatment.
- For simplification, a substitution factor of 1 underlies the graphs. However, in the real calculations smaller values are used where appropriate. For example if a material's properties after recycling are different from those of the primary material it replaces, this translates to a loss in material quality. A substitution factor < 1 accounts for such effects.

Application of allocation rules

The allocation factors have been applied on a mass basis (i.e. the environmental burdens of the recycling process are charged with the total burdens multiplied by the allocation factor) and where appropriate have been combined with substitution factors. The substitution factor indicates what amount of the secondary material substitutes for a certain amount of primary material. For example, a substitution factor of 0.8 means that 1 kg of recycled (secondary) material replaces 0.8 kg of primary material and receives a corresponding credit. With this, a substitution factor < 1 also accounts for so-called 'down-cycling' effects, which describe a recycling process in which waste materials are converted into new materials of lesser quality.

The substitution factors used in the current LCA study to calculate the credits for recycled materials provided for consecutive (down-stream) uses are based on author assessment and expert judgments from German waste sorting operator "Der Grüne Punkt – Duales System Deutschland GmbH" from the year 2003 (DSD 2003). The substitution factors apply to the secondary materials after the recycling processes with their production losses (see **section 3.8** (**Recovery and recycling**)).

- Paper fibres
    - from LPB (carton-based primary packaging): 0.9
    - in cardboard trays (secondary packaging): 0.9
- LDPE from foils: 0.94
- HDPE: 0.8

1.7.3 Biogenic carbon

Renewable materials like paper fibres or mass-balanced plastics originate from renewable biomass that absorbs carbon from the air. The growth of biomass reduces the amount of CO_2 in the atmosphere. In this study, the binding of CO_2 by plants is referred as CO_2 uptake and the (re-)emission of CO_2 at the material's end of life is referred as CO_2 regenerative (reg.).

Application and allocation

At the impact assessment level, it must be decided how to model and calculate the uptake and emissions of biogenic CO_2. In the present study, the non-fossil CO_2 has been included at two points in the model, its uptake during the plant growth phase attributed with negative Global Warming Potential (GWP) values and the corresponding re-emissions at end of life with positive ones. In this study biogenic CO_2 is treated in the same way as other resources and emissions and is therefore subject to the same allocation rules as other resources and emissions.

According to packaging waste directives and laws as for example the European Packaging and Packaging Waste Directive (EU 2018) or the German packaging law (Verpackungsgesetz - VerpackG 2021) the following practices in packaging production shall be promoted:

- Use of recycled content in packaging systems
- Recyclability of packaging systems
- Use of renewable resources in packaging systems

In the view of the authors it is important that the environmental benefits of all of these practices are made visible in the results of LCA.

The first two practices are considered by the choice of the allocation factor 50% for system-related allocation as one of the two allocation approaches equally applied in this study. As described in **section 1.7.1** the application of the allocation 50% shows benefits for the use of recycled content in packaging systems as well as their recycling. In order to not restrain the recyclability of packaging systems and in order to also promote the use of renewable resources a convention in this study is made, that implies that the CO_2 uptake is not considered in credited materials or energy.

The application of the CO_2 uptake in credits would reduce the CO_2 uptake of regarded packaging systems containing regenerative materials by the amount of CO_2 which has been absorbed from the atmosphere by the substituted processes. The selection of substituted processes is based on the current market situation within the addressed geographic scope. Regarding energy credits from the incineration of renewable materials, the substituted processes are the production of electrical and thermal energy. These to a high extent fossil-based processes do absorb negligibly small amounts of biogenic CO_2. Therefore almost no CO_2 uptake would be attributed to the substituted processes. The benefit of the CO_2 uptake of the regarded packaging systems containing regenerative materials would not be reduced.

On the other hand, if packaging systems containing renewable materials are materially recycled, and if the substituted processes for the material credits are the production of other primary renewable materials, the absorption of CO_2 from the atmosphere would be substituted. Therefore the benefits of the CO_2 uptake of regarded packaging systems would be reduced by the CO_2 uptake of the substituted processes.

Using the example of mainly renewable materials like LPB, the application of the CO_2 uptake in credits would deter from recycling efforts of packaging containing renewable materials as incineration instead of recycling would lead to lower LCA results for 'Climate Change'.

The authors of this study acknowledge that with the application of this convention only the producers of products containing primary renewable materials benefit. This is considered appropriate as these producers are responsible for sourcing renewable materials in the first place. Producers of products which merely contain renewable materials sourced from recycling processes would not be benefited. As no packaging systems which contain recycled renewable materials are analysed in this study, this approach of not considering CO_2 uptake in credits is seen suitable within this study. This convention does also comply with ISO 14040/14044 as the mass balance of all inputs and outputs regarding biogenic CO_2 of 'system A' (combiblocSlimline (cb3) **SIG**NATURE PACK 100) and 'system B' (subsequent system) together stays the same.

The carbon balance is shown exemplarily for the combiblocSlimline (cb3) **SIG**NATURE PACK 100, 1000 mL on the European market in the following **Table 1-1**.

Table 1-1: Carbon balance for combiblocSlimline (cb3) **SIG**NATURE PACK 100 Europe (per 1000 litres packed)

Biogenic carbon balance	CO_2 uptake	Carbon in CO_2 uptake	Carbon in biog. CO_2 and CH_4 emissions		Carbon sequestration in landfills	Carbon emissions and sequestration
Product systems	cb3 SIGNATURE 100 cSwift LP TC 1000 mL	cb3 SIGNATURE 100 cSwift LP TC 1000 mL	cb3 SIGNATURE 100 cSwift LP TC 1000 mL	Subsequent system	cb3 SIGNATURE 100 cSwift LP TC 1000 mL	cb3 SIGNATURE 100 cSwift LP TC 1000 mL + Subsequent system
Allocation factor 50	**65.27 kg CO_2**	**17.80 kg C**	6.84 kg C	5.83 kg C	5.13 kg C	**17.80 kg C**
Allocation factor 100	**65.27 kg CO_2**	**17.80 kg C**	12.67 kg C	0.00 kg C	5.13 kg C	**17.80 kg C**

The difference between the emissions of combiblocSlimline (cb3) **SIG**NATURE PACK 100, 1000 mL and those of the following system when applying an allocation factor of 50% can be explained by the emissions from landfills as these are not affected by system allocation.

As described in **section 1.7.1** system-related allocation is applied in this study for energy recovery processes like MSWI with energy recovery and incineration in cement kilns. Therefore system-related allocation applies for the emissions of biogenic CO_2 from energy recovery of renewable materials. In case of allocation 50%, half of the biogenic CO_2 emissions are attributed to the examined system and half of the biogenic CO_2 emissions are attributed to the following system, for example the MSWI plants with energy recovery.

Together with the full CO_2 uptake for the regarded system and the non-consideration of the CO_2 uptake in credits the mass balance of all biogenic carbon is the same after and before allocation following ISO 14040 and 14044. Regarding the LCA results for 'Climate Change', packaging systems containing renewable materials benefit if the system-related allocation 50% is applied for recovery processes. When applying the allocation 50% approach the benefit regarding the LCA results for 'Climate Change' of packaging systems containing renewable materials can promote the increase of use of renewable materials in packaging system.

In case of applying allocation 100% for recovery processes all of the CO_2 reg. emissions are attributed to the regarded system. Therefore in this case the extra benefit for 'Climate Change' results, packaging systems with primary renewable materials receive by only getting allocated 50% of the biogenic CO_2 emissions, is gone.

As these decisions and conventions applied in this study are partly based on political reasons, it is especially important to consider the results of the 100% allocation approach equally alongside those of the 50% allocation approach. All conclusions in this study will always be based on the outcomes of both assessments, the 50% allocation and 100% allocation approach.

1.8 Environmental Impact Assessment

The environmental impact assessment phase is intended to increase the understanding and evaluating of the potential environmental impacts for a product system throughout the whole life cycle (ISO 14040: 2006; ISO 14044: 2006).

To assess the environmental performance of the examined packaging systems, a set of environmental impact categories is used. Related information as well as references of applied models is provided below. In the present study, midpoint categories are applied. Midpoint indicators represent potential primary environmental impacts and are located between emission and potential harmful effect. This means that the potential damage caused by the substances is not taken into account.

The selection of the impact categories is based both on the current practice in LCA and the applicability of as less as uncertain characterisation models also with regard to the completeness and availability of the inventory data. This choice is similar to that of the UBA approach (UBA 2016), which is fully consistent with the requirements of (ISO 14040: 2006; ISO 14044: 2006). However, it is nearly impossible to carry out an assessment in such a high level of detail, that all environmental issues are covered. A broad examination of as many environmental issues as possible is highly dependent on the quality of the available inventory datasets and of the scientific acceptance of the certain assessment methods. ISO 14044: 2006 recommends that: “the impact categories, category indicators and characterisation models should be internationally accepted, i.e. based on an international agreement or approved by a competent international body”. As there are almost no truly international (i.e. global) agreements or bodies beyond ISO or IPCC that endorse specific environmental impact categories, in LCA practice categories, indicators and characterisation models which are widely used are considered to fulfil this recommendation. All the impact categories, category indicators and characterisation models used in this study are widely used internationally and are endorsed by internationally accepted bodies like EPA, IPCC, CML or UBA.

The LCA framework in this study addresses potential environmental impacts calculated based on generic spatial independent inventory data with global supply chains. Therefore, the characterisation models and associated factors are intended to support Life Cycle Impact Assessment on a global level for each impact category.

The description of the different impact categories and their indicators is based on the terminology by (ISO 14044: 2006). It has to be noted; that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. All the applied methodologies for impact assessment can be considered to be internationally accepted.

The selected impact categories and additional inventory categories to be assessed and presented in this study are listed and briefly addressed below.

1.8.1 Impact categories related to emissions

Climate Change

Climate Change addresses the impact of anthropogenic emissions on the radiative forcing of the atmosphere. Greenhouse gas emissions enhance the radiative forcing, resulting in an increase of the earth’s temperature. The characterisation factors applied here are based on the category indicator Global Warming Potential (GWP) for a 100-year time horizon (Stocker et al. 2013).

In reference to the functional unit (FU), the category indicator results, GWP results, are expressed as kg CO_2-e/FU.

Ozone Depletion

This impact category addresses the anthropogenic impact on the earth’s atmosphere, which leads to the decomposition of naturally present ozone molecules, thus disturbing the molecular equilibrium in the stratosphere. The underlying chemical reactions are very slow processes and the actual impact, often referred to in a simplified way as the ‘ozone hole’, takes place only with considerable delay of several years after emission. The consequence of this disequilibrium is that an increased amount of UV-B radiation reaches the earth’s surface, where it can cause damage to certain natural resources or human health. In this study, the Ozone Depletion compiled by the World Meteorological Organisation (WMO 2011) is used as category indicator.

In reference to the functional unit, the unit for Ozone Depletion is kg R-11-e/FU.

Summer Smog

Summer Smog (Photo-oxidant formation) is the photochemical creation of reactive substances (mainly ozone), which 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.

In this study, ‘Maximum Incremental Reactivity‘ (MIR) developed in the US by William P. L. Carter is applied as category indicator for the impact category Summer Smog. MIRs expressed as [kg O_3-e/emission i] are used in several reactivity-based VOC (Volatile Organic Compounds) regulations by the California Air Resources Board (Air Resources Board 2000). The approach of William P. L. Carter includes characterisation factors for individual VOC, unspecified VOC and Nitrogen oxides (NOx). The ‘Nitrogen-Maximum Incremental Reactivity‘ (NMIR) for NOx is introduced for the first time in 2008 (Carter 2008). The MIRs and NMIRs are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NOx inputs. The factors applied in this study were published by Carter (2010). According to Carter (2008), “MIR values may also be appropriate to quantify relative ozone impacts of VOCs for life cycle assessment analyses as well, particularly if the objective is to assess the maximum adverse impacts of the emissions of the compounds involved.” The results reflect the potential where VOC or NOx reductions are the most effective for reducing ozone.

The MIR concept seems to be the most appropriate characterisation model for LCIA based on generic spatial independent global inventory data and combines following needs:

- Provision of characterisation factors for more than 1100 individual VOC, VOC mixtures, nitrogen oxides and nitrogen dioxides
- Consistent modelling of potential impacts for VOC and NOx

- Considering of the maximum formation potential by inclusion of most supporting background concentrations of the gas mixture and climatic conditions. This is in accordance with the precautionary principle.

To provide as wide as possible knowledge of the environmental strengths and weaknesses of SIGs carton systems, the 'Summer Smog' results are displayed without NMIRs as additional information. These results show the potential impacts of VOCs on photo-oxidant formation. This additional information is not used for the final conclusions and recommendations of the study. Only the complete Summer Smog results incl. NMIR are considered.

The unit for Summer Smog is kg O_3-e/FU.

Acidification

Acidification affects aquatic and terrestrial ecosystems by changing the acid-basic-equilibrium through the input of acidifying substances. The acidification potential expressed as SO_2-equivalents according to (Heijungs 1992) is applied here as category indicator.

The characterisation model by (Heijungs 1992) is chosen as the LCA framework addresses potential environmental impacts calculated based on generic spatial independent global inventory data. The method is based on the potential capacity of the pollutant to form hydrogen ions. The results of this indicator, therefore, represent the maximum acidification potential per substance without an undervaluation of potential impacts.

The method by (Heijungs 1992) is, in contrast to methods using European dispersion models, applicable for emissions outside Europe. Even though this study focusses on the European market on the product level, many processes especially the sourcing of resources (f.e. oil and coal) take place outside Europe and therefore need a global scope. The authors of the method using accumulated exceedance note that "the current situation does not allow one to use these advanced characterisation methods, such as the AE method, outside of Europe due to a lack of suitable atmospheric dispersion models and/or measures of ecosystem sensitivity" (Posch et al. 2008).

The unit for the Acidification potential is kg SO_2-e/FU.

Eutrophication

Eutrophication means the excessive supply of nutrients and can apply to both surface waters and soils. As these two different media are affected in very different ways, a distinction is made between water-eutrophication and soil-eutrophication:

1. ***Terrestrial Eutrophication*** (i.e., eutrophication of soils by atmospheric emissions)
2. ***Aquatic Eutrophication*** (i.e., eutrophication of water bodies by effluent releases)

Nitrogen- and phosphorus-containing compounds are among the most eutrophying elements. The eutrophication of surface waters also causes oxygen-depletion. A measure of the possible perturbation of the oxygen levels is given by the Chemical Oxygen Demand (COD). In order to quantify the magnitude of this undesired supply of nutrients and oxygen depletion substances, the eutrophication potential according to (Guinée 2002; Heijungs 1992) was chosen as an impact indicator.

The unit for both types of Eutrophication is kg PO_4-e/FU.

Particulate Matter

The category covers effects of fine particulates with an aerodynamic diameter of less than 2.5 µm (PM 2.5) emitted directly (primary particles) or formed from precursors as NOx and SO_2 (secondary particles). Epidemiological studies have shown a correlation between the exposure to particulate matter and the mortality from respiratory diseases as well as a weakening of the immune system. Following an approach of (de Leeuw 2002), the category indicator aerosol formation potential (AFP) is applied. Within the characterisation model, secondary fine particulates are quantified and aggregated with primary fine particulates as PM2.5 equivalents[4]. This approach addresses the potential impacts on human health and nature independent of the population density.

The characterisation models suggested by Goedkoop et al. (2013) and (JRC 2011) calculate intake fractions based on population densities. This means that emissions transported to rural areas are weighted lower than transported to urban areas. These approaches contradict the idea that all humans independent of their residence should be protected against potential impacts. Therefore, not the intake potential, but the formation potential is applied for the impact category particulate matter.

In reference to the functional unit, the unit for Particulate Matter is kg PM 2.5-e/FU.

[4] In previous LCA studies commissioned by SIG and conducted by ifeu the contribution to the 'fine Particulate Matter Potential' was calculated by summing the products of the amounts of the individual harmful substances and the respective PM10 equivalent. According to Detzel et al. (2016) the characterisation factors of de Leeuw (2002) shall now be related to PM2.5 equivalent. This recommendation is based on the respective guidelines of WHO (2021) WHO: It states that the fraction PM2.5 is mainly responsible for toxic effects.

Table 1-2: Examples of elementary flows and their classification to emission related impact categories

Impact category	Elementary flows								Unit
Climate Change	CO_2*	CH_4**	N_2O	$C_2F_2H_4$	CF_4	CCl_4	C_2F_6	R22	kg CO_2-e
Ozone Depletion	CFC-11	N_2O	HBFC-123B2	Halon-1211	Methyl Bromide	Methyl Chloride	CCl_4		kg R-11-e
Summer Smog	CH_4	NMVOC	Benzene	Formaldehyde	Ethyl acetate	VOC	TOC	NOx	kg O_3-e
Acidification	NO_x	NH_3	SO_2	TRS***	HCl	H_2S	HF		kg SO_2-e
Terrestrial Eutrophication	NO_x	NH_3	SO_x						kg PO_4-e
Aquatic Eutrophication	COD	N	NH^{4+}	NO^{3-}	NO^{2-}	P			kg PO_4-e
Particulate Matter	PM 2.5	SO_2	NO_X	NH_3	NMVOC				kg PM 2.5-e

* included: CO_2 fossil and biogenic
** included: CH_4 fossil and biogenic
*** total reduced sulfur

Human and Eco Toxicity (excl. Particulate Matter)

LCA results on toxicity are often unreliable, mainly due to incomplete inventories, and also due to incomplete impact assessment methods and uncertainties in the characterisation factors. None of the available methods is clearly better than the others, although there is a slight preference for the consensus model USEtox. Based on comparisons among the different methods, the USEtox authors employ following residual errors (RE) related to the square geometric standard deviation (GSD^2):

Table 1-3: Model uncertainty estimates for USEtox characterisation factors (reference: (Rosenbaum et al. 2008))

Characterisation factor	GSD^2
Human health, emission to rural air	77
Human health, emission to freshwater	215
Human health, emission to agricultural soil	2.189
Freshwater ecotoxicity, emission to rural air	176
Freshwater ecotoxicity, emission to freshwater	18
Freshwater ecotoxicity, emission to agricultural soil	103

To capture the 95% confidence interval, the mean value of each substance would have to be divided and multiplied by the GSD^2. (Sala et al. 2018) also concludes that the results for the impact categories human and eco toxicity are “not sufficiently robust to be included in external communications” before the robustness of the impact category was improved. Therefore, no assessment of human and eco toxicity is included in this study.

1.8.2 Impact categories related to the use/consumption of resources

Abiotic resource depletion

The consumption of resources is deemed adverse for human society. In all considerations regarding sustainable, environmentally-compatible commerce, the conservation of resources plays a key role. The safeguard subject of this category is the reduction of depletion and dissemination of abiotic resources (fossil fuels and minerals) that can be extracted from the lithosphere.

For this study the approach of (Guinée 2002) based on parameters on ultimate reserves and extraction rates by (Guinée 2002; Heijungs 1992) are applied. This model considers the scarcity of materials as a function of the natural reserve of the resource in connection with the annual extraction rate. The natural reserve of raw materials is based on ultimate reserves, i.e. on concentrations of elements and fossil carbon in the Earth's crust. The quotients of extraction and ultimate reserve of a resource are related to the corresponding quotient of the reference antimony to express the Abiotic Resource Depletion (ADP) as antimony equivalents (Sb-e/kg resource). With the approach of (Guinée 2002) both, the fossil and mineral/metal resources are addressed together in one impact category.

The characterisation factors for Abiotic Resource Depletion elements (minerals and metals) are taken from (CML 2016). The annual extraction rate of the elements is based on USGS (U.S. Geological Survey) with the reference year 2011. Mineral and metals that consist of more than one element like barium sulphate, characterisation factors have been recalculated based on the factors from (CML 2016).

The method by CML (2016) separates Abiotic Resource Depletion into two single impact categories. Nevertheless, the authors of this study are not going along with this change as the assessment of abiotic resources is only complete when all abiotic resources are included. Therefore, the approach of (Guinée 2002) without separating Abiotic Resource Depletion in two categories is applied. The characterisation factors for the fossil Abiotic Resource Depletion have been updated to the same reference year as for element resources (2011) based on the calculation method described in (Guinée 2002). The quotients of extraction and ultimate reserve of the fossil resources are related to the corresponding quotient of the reference antimony. This calculation results in the following characterisation factor: 0.000093 kg Sb-e/MJ fossil fuel.

Nevertheless, the Abiotic Resource Depletion of mineral and metal resources (Abiotic Resource Depletion elements) is presented as additional information at the end of each set of results.

In reference to the functional unit, the unit for Abiotic Resource Depletion is kg Sb-e/FU.

Table 1-4: Examples of elementary flows and their classification to resource related impact category

Impact category	Elementary flow examples							Unit
ADP	Crude oil	Natural gas	Hard coal	Soft coal	Al	Ab	Fe	kg Sb-e

1.8.3 Additional categories at the inventory level

Inventory level categories differ from impact categories to the extent that no characterisation step using characterisation factors is used for assessment. The results of the categories at inventory level are presented and discussed in **section 4** (**Results and discussion**) but are not intended to be used for comparison between systems and drawing of recommendations.

Primary Energy

The Total Primary Energy and the Non-renewable Primary Energy serve primarily as a source of information regarding the energy intensity of a system.

Total Primary Energy (Cumulative Energy Demand, total)

The Total Primary Energy is a parameter to quantify the primary energy consumption of a system. It is calculated by adding the energy content of all used fossil fuels, nuclear and renewable energy (including biomass). This category is described in (VDI 1997) and has not been changed considerably since then. It is a measure for the overall energy efficiency of a system, regardless the type of energy resource which is used.

The unit for Total Primary Energy is MJ/FU.

Non-renewable Primary Energy (Cumulative Energy Demand, non-renewable)

The category Non-renewable Primary Energy considers the primary energy consumption based on non-renewable, i.e. fossil and nuclear energy sources.

The unit for Non-renewable Primary Energy is MJ/FU.

Table 1-5: Examples of elementary flows and their classification to inventory level categories

Categories at inventory level		Elementary flow examples					Unit
Total Primary Energy	Non-renewable primary energy	hard coal	brown coal	crude oil	natural gas	uranium ore	MJ
	Renewable primary energy	hydro energy	solar energy	hydro energy	biomass	wind energy	

Use of nature

Land use could have large impacts on the natural environment, such as decrease in biodiversity due to direct loss of natural area or indirect impacts like area fragmentation, and impacts on the life support function of the biosphere, such as raw materials providing or climate regulation. It can be especially relevant when examining products based on agriculture or forestry compared to products with other base and/or main materials.

The currently available methodology by (Beck et al. 2010; Chaudhary / Brooks 2018; Fehrenbach et al. 2015) on land use especially on different forest management types and ecoregions are only well applicable in geographical context of Europe, but with regard to the supply chains under study, global resource chains are relevant. Therefore no assessment of the use of nature is included in this study.

Water scarcity footprint

Due to the growing water demand, increased water scarcity in many areas and degradation of water quality, water as a scarce natural resource has become increasingly central to the global debate on sustainable development.

Due to the lack of mandatory information, for example regarding the region of water use in the applied data sets, water scarcity footprint cannot be examined on an LCIA level within this study. Some of the qualitative aspects are considered in this report in the impact category "Aquatic Eutrophication".

2 Packaging systems and scenarios

2.1 Selection of packaging systems

The focus of this study lies on the beverage cartons combibloc **SIG**NATURE PACK developed by SIG Combibloc, for which this study aims to provide knowledge of its strengths and weaknesses regarding environmental aspects. In this context, they are also compared with other SIG beverage cartons selected by SIG for this study.

The packaging systems examined in this study are summarised in the following table:

Table 2-1: List of combinations of beverage cartons which are compared to each other in Europe

<table>
<tr><th>Classification and volume of beverage carton system</th><th>Beverage carton systems overview</th><th>Compared beverage carton systems overview</th></tr>
<tr><td rowspan="4">combiblocSlimline (cb3) 1000</td><td>EcoPlus with
• Fossil-based PE
• Fossil-based PA foil as barrier material
cSwift LP closure made of
• Fossil-based PP & PE</td><td>Standard RS with
• Fossil-based PE
• Aluminium foil as barrier material
cSwift closure made of
• Fossil-based PP & PE
cMaxx closure made of
• Fossil-based PP & PE & PS</td></tr>
<tr><td rowspan="2">SIGNATURE PACK 100 with
• Mass-balanced PE
• Mass-balanced PA as barrier material
cSwift LP closure made of
• Mass-balanced PP & PE</td><td>Standard RS with
• Fossil-based PE
• Aluminium foil as barrier material
cSwift closure made of
• Fossil-based PP & PE
cMaxx closure made of
• Fossil-based PP & PE & PS</td></tr>
<tr><td>EcoPlus with
• Fossil-based PE
• Fossil-based PA foil as barrier material
cSwift LP closure made of
• Fossil-based PP & PE</td></tr>
<tr><td>SIGNATURE PACK FB with</td><td>Standard RS with</td></tr>
</table>

	• Mass-balanced PE • Aluminium foil as barrier material **cSwift closure** made of • Mass-balanced PP & PE **cMaxx closure** made of • Mass-balanced PP & PE and fossil PS	• Fossil PE • Aluminium foil as barrier material **cSwift closure** made of • Fossil-based PP & PE **cMaxx closure** made of • Fossil-based PP & PE & PS
CombiblocMidi (cb8) 1000	**EcoPlus** with • Fossil-based PE • Fossil-based PA foil as barrier material **cSwift LP closure** made of • Fossil-based PP & PE	**Standard RS** with • Fossil-based PE • Aluminium foil as barrier material **cSwift closure** made of • Fossil-based PP & PE **cMaxx closure** made of • Fossil-based PP & PE & PS
	SIGNATURE PACK 100 with • Mass-balanced PE • Mass-balanced PA as barrier material **cSwift LP closure** made of • Mass-balanced PP & PE	**Standard RS** with • Fossil-based PE • Aluminium foil as barrier material **cSwift closure** made of • Fossil-based PP & PE **cMaxx closure** made of • Fossil-based PP & PE & PS
		EcoPlus with • Fossil-based PE • Fossil-based PA foil as barrier material **cSwift LP closure** made of • Fossil-based PP & PE
	SIGNATURE PACK FB with • Mass-balanced PE • Aluminium foil as barrier material **cSwift closure** made of • Mass-balanced PP & PE **cMaxx closure** made of • Mass-balanced PP & PE and fossil PS	**Standard RS** with • Fossil-based PE • Aluminium foil as barrier material **cSwift closure** made of • Fossil-based PP & PE **cMaxx closure** made of • Fossil-based PP & PE & PS
combiblocMidi (cb8) 500	**EcoPlus** with • Fossil-based PE • Fossil-based PA foil as barrier material **cSwift LP closure** made of • Fossil-based PP & PE	**Standard RS** with • Fossil-based PE • Aluminium foil as barrier material **cSwift closure** made of • Fossil-based PP & PE

In 2024, the Directive (EU) 2019/904 Single-use plastic articles on tethered caps will come into force: from then on, closures and lids may be placed on the market only if the closures and lids remain attached to the one-way beverage packaging during the period of intended use of the articles with a volume of up to three litres. The aim is to recycle the caps together with the containers and to avoid littering of the environment by discarded caps.

Currently, there are no tethered caps (TC) on the market, but they have been developed for each type of closure. Therefore, 2 variants are available for each type of closure (standard and TC (new). Only 1 scenario (the heavier closure) was calculated in each case to ensure the validity of both variants.

Table 2-2Fehler! Verweisquelle konnte nicht gefunden werden. shows matching closures of the examined beverage cartons. The coloured values of closures were chosen for the examination.

The maximum difference of the closure weights can be found regarding the cMaxx closure (0.4 g). The chosen values are the heaviest ones of each type of closure to take a conservative approach, as the heavier closures cause higher burdens. Since the regulation of the TC as described applies in 2024, and the new TC are heavier (except the cSwift LP, which was therefore based on the heavier standard weight), the results of the closures can also be considered valid in the future, when the regulation of the TC comes into force.

Table 2-2: Selection of closures for SIG cartons and closures selected for the study (marked)

	cSwift		cSwift LP		cMaxx	
	TC (new)	standard	TC (new)	standard	TC (new)	standard
Weight of closure (g)	**2.75**	2.74	2.81	**2.85**	**3.00**	2.60

2.2 Description of packaging systems

All the packaging systems examined in this study are beverage cartons with refastenable closures.

The sleeve of the standard RS (robust structure) carton is a standard carton consisting of about 76% LPB, 19% PE and 5% aluminium foil. Closures consist of about 42%-52% PP, 41%-48% PE and the cMaxx closure also consists of about 17% PS.

The EcoPlus carton differs from the Standard RS in the barrier material: The barrier material aluminium is replaced by PA in the EcoPlus carton. Furthermore, the **SIG**NATURE PACK FB carton differs from the **SIG**NATURE PACK 100 in the barrier material: In this case also, the barrier material aluminium is replaced by PA in the **SIG**NATURE PACK 100.

In all **SIG**NATURE cartons considered, all fossil-based plastic components (PE, PP) in the sleeves and closures are replaced by mass-balanced plastic components (mass-balanced PE, mass-balanced PP).

The following abbreviations, which are included in the packaging names are applied in this study:

- standard RS (robust structure, structure with aluminium foil barrier)
- cSwift (combiSwift, closure)
- cMaxx (combiMaxx, closure)
- **SIG**NATURE PACK FB (full barrier, containing aluminium)
- **SIG**NATURE PACK 100 (100% mass-balanced PE, PP, PA)

Table 2-3: Overview of beverage cartons and their short names used in the figures of the results

combiblocSlimline (cb3) 1000 mL		combiblocMidi (cb8) 1000 mL, 500 mL	
beverage carton	**short name**	**beverage carton**	**short name**
combiblocSlimline (cb3) standard RS	cb3 standard RS	combiblocMidi (cb8) standard RS	cb8 standard RS
combiblocSlimline (cb3) EcoPlus	cb3 EcoPlus	combiblocMidi (cb8) EcoPlus	cb8 EcoPlus
combiblocSlimline (cb3) **SIG**NATURE PACK 100	cb3 **SIG**NATURE PACK 100	combiblocMidi (cb8) **SIG**NATURE PACK 100	cb8 **SIG**NATURE PACK 100
combiblocSlimline (cb3) **SIG**NATURE PACK FB	cb3 **SIG**NATURE PACK FB	combiblocMidi (cb8) **SIG**NATURE PACK FB	cb8 **SIG**NATURE PACK FB

The cartons examined differ in their materials, but are essentially identical in their shape and functionality. The requirements for the filling machines are also the same, so that no different filling machines are needed for the different packaging systems.

As the SIG packaging combifitMidi (cf8) is identical to the combiblocMidi (cb8) with regard to all packaging specifications (including secondary and tertiary packaging), the results of the combiblocMidi (cb8) 1000 mL also apply to the combifitMidi (cf8) 1000 mL and, correspondingly, the results of the combiblocMidi (cb8) 500 mL also apply to the combifitMidi (cf8) 500 mL.

2.3 Packaging specifications

The packaging systems examined in the LCA study are specified in **Table 2-4** to **Table 2-6**.

Table 2-4: Packaging specifications of the beverage cartons in EU: combiblocSlimline (cb3) 1000 mL

combiblocSlimline (cb3) 1000

Specification	Unit	Packaging system					
		cb3 standard RS		cb3 EcoPlus	cb3 SIGNATURE PACK 100	cb3 SIGNATURE PACK FB	
closure	-	cSwift	cMaxx	cSwift LP	cSwift LP	cSwift	cMaxx
volume	mL	1000		1000	1000	1000	
geographic scope	-	EU		EU	EU	EU	
chilled	-						
ambient							
primary packaging (sum)[1]	**g**	**29.05**	**29.30**	**30.50**	**30.50**	**29.05**	**29.30**
primary packaging (per FU)	**g/FU**	**29050**	**29300**	**30500**	**30500**	**29050**	**29300**
composite material (sleeve)	g	26.30		27.65	27.65	26.30	
- liquid packaging board	g	20.00		22.90	22.90	20.00	
- fossil PE	g	4.90		4.24	-	-	
- mass-balanced PE	g	-		-	4.24	4.90	
- aluminium foil	g	1.40		-	-	1.40	
- fossil PA	g	-		0.51	-	-	
- mass-balanced PA	g	-		-	0.51	-	
closure	g	2.75	3.00	2.85	2.85	2.75	3.00
- fossil PP	g	1.47	1.25	1.48	-	-	
- mass-balanced PP	g	-	-	-	1.48	1.47	1.25
- fossil PE	g	1.28	1.23	1.37	-	-	
- mass-balanced PE	g	-	-	-	1.37	1.28	1.23
- fossil PS	g	-	0.52	-	-	-	0.52
secondary packaging (sum)[2]	**g**	134		134	134	134	
- tray/box (corr.cardboard)	g	134		134	134	134	
tertiary packaging (sum)[3]	**g**	**20350**		**20350**	**20350**	**20350**	
- pallet	g	20000		20000	20000	20000	
- type of pallet	-	EURO		EURO	EURO	EURO	
number of use cycles	-	25		25	25	25	
- stretch foil (per pallet)	g	350		350	350	350	
pallet configuration							
cartons per tray	pc	12		12	12	12	
trays / packs per layer	pc	12		12	12	12	
layers per pallet	pc	5		5	5	5	
cartons per pallet	pc	720		720	720	720	

[1] per primary packaging unit; [2] per secondary packaging unit; [3] per tertiary packaging unit (pallet)

Table 2-5: Packaging specifications of the beverage cartons in EU: combiblocMidi (cb8) 1000 mL

combiblocMidi (cb8) 1000

Specification	Unit	Packaging system					
		cb8 standard RS		cb8 EcoPlus	cb8 SIGNATURE PACK 100	cb8 SIGNATURE PACK FB	
closure	-	cSwift	cMaxx	cSwift LP	cSwift LP	cSwift	cMaxx
volume	mL	1000		1000	1000	1000	
geographic scope	-	EU		EU	EU	EU	
chilled / ambient							
primary packaging (sum)[1]	**g**	**29.45**	**29.70**	**32.24**	**32.24**	**29.45**	**29.70**
primary packaging (per FU)	**g/FU**	**29450**	**29700**	**32240**	**32240**	**29450**	**29700**
composite material (sleeve)	g	26.70		29.39	29.39	26.70	
- liquid packaging board	g	20.30		24.40	24.40	20.30	
- fossil PE	g	5.00		4.30	-	-	
- mass-balanced PE	g	-		-	4.30	5.00	
- aluminium foil	g	1.40		-	-	1.4	
- fossil PA	g	-		0.69	-	-	
- mass-balanced PA	g	-		-	0.69	-	
closure	g	2.75	3.00	2.85	2.85	2.75	3.00
- fossil PP	g	1.47	1.25	1.48	-	-	
- mass-balanced PP	g	-	-	-	1.48	1.47	1.25
- fossil PE	g	1.28	1.23	1.37	-	-	
- mass-balanced PE	g	-	-	-	1.37	1.28	1.23
- fossil PS	g	-	0.52	-	-	-	0.52
secondary packaging (sum)[2]	**g**	204		204	204	204	
- tray/box (corr.cardboard)	g	204		204	204	204	
tertiary packaging (sum)[3]	g	**20350**		**20350**	**20350**	**20350**	
- pallet	g	20000		20000	20000	20000	
- type of pallet	-	EURO		EURO	EURO	EURO	
number of use cycles	-	25		25	25	25	
- stretch foil (per pallet)	g	350		350	350	350	
pallet configuration							
cartons per tray	pc	12		12	12	12	
trays / packs per layer	pc	13		13	13	13	
layers per pallet	pc	5		5	5	5	
cartons per pallet	pc	780		780	780	780	

[1] per primary packaging unit; [2] per secondary packaging unit; [3] per tertiary packaging unit (pallet)

Table 2-6: Packaging specifications of the beverage cartons in EU: combiblocMidi (cb8) 500 mL

combiblocMidi (cb8) 500

Specification	Unit	Packaging system	
		cb8 standard RS	cb8 EcoPlus
closure	-	cSwift	cSwift LP
volume	mL	500	500
geographic scope	-	EU	EU
chilled			
ambient			
primary packaging (sum)[1]	**g**	**20.25**	**23.05**
primary packaging (per FU)	**g/FU**	**40500**	**46100**
composite material (sleeve)	g	17.50	20.20
- liquid packaging board	g	13.30	16.7
- fossil PE	g	3.30	3.00
- mass-balanced PE	g	-	-
- aluminium foil	g	0.9	-
- fossil PA	g	-	0.5
- mass-balanced PA	g	-	-
closure	g	2.75	2.85
- fossil PP	g	1.47	1.48
- mass-balanced PP	g	-	-
- fossil PE	g	1.28	1.37
- mass-balanced PE	g	-	-
- fossil PS	g	-	-
secondary packaging (sum)[2]	**g**	60	60
- tray/box (corr.cardboard)	g	60	60
tertiary packaging (sum)[3]	**g**	**20350**	**20350**
- pallet	g	20000	20000
- type of pallet	-	EURO	EURO
number of use cycles	-	25	25
- stretch foil (per pallet)	g	350	350
pallet configuration			
cartons per tray	pc	12	12
trays / packs per layer	pc	13	13
layers per pallet	pc	8	8
cartons per pallet	pc	1248	1248

[1] per primary packaging unit; [2] per secondary packaging unit; [3] per tertiary packaging unit (pallet)

In general terms, packaging systems can be defined based on the primary, secondary and tertiary packaging elements they are made up of. The composition of each of these individual packaging systems and their components' masses depend strongly on the function they are designed to fulfil, i.e. on requirements of the filler and retailer as well as the distribution of the packaged product to the point-of-sale. The main function of the examined primary packaging is the packaging and protection of beverages and liquid food. The packaging protects the filled products' freshness, flavours and nutritional qualities during transportation, whilst on sale and at home. All examined packaging systems are considered to achieve this.

Table 2-4 shows the packaging specifications of the four combiblocSlimline (cb3) beverage cartons for 1000 mL. For two packaging systems, there are two different variants of closures (combiblocSlimline (cb3) standard RS and combiblocSlimline (cb3) **SIG**NATURE PACK FB).

Table 2-5 shows the packaging specifications of the four combiblocMidi (cb8) packaging systems for 1000 mL. For two packaging systems, there are two different variants of closures (combiblocMidi (cb8) standard RS and combiblocMidi (cb8) **SIG**NATURE PACK FB).

Table 2-6 shows the packaging specifications of the two combiblocMidi (cb8) packaging systems for 500 mL.

It is conspicuous that the sleeve weight of the combiblocMidi (cb8) packaging systems changes according to the packaging size, but the different closure variants show the same mass, independent of the volumes of the packaging (500 mL, 1000 mL).

The polymers LDPE, PP and HDPE of the beverage cartons are linked to renewable resources via the mass-balance approach while the polymer PS is based entirely on fossil resources.

These polymers linked to renewable resources are produced by using both, fossil and biogenic resources as input materials for the same production process. In practice the input of biogenic materials (in this case tall-oil, a by-product of paper production processes) to the polymerisation process is done at the same production process where mainly fossil-based ethylene and naphtha is used. This leads to only one final product per production process which is neither 100% fossil-based nor 100% bio-based material. To allocate the specific characteristics of fossil-based or bio-based input materials to the final product the producers declare a certain share of their production as linked to renewable resources. That share, of course is dependent on the share of biogenic input material.

It is important to understand that in reality (in a physical sense) the $(C_2H_4)_n$ and $(C_3H_6)_n$ molecules of the tall oil based polymers are in fact mainly non bio-based, as the share of bio-based ethylene is below 1% of the total production. But as the polymers in the **SIG**NATURE PACK are the ones to which the tall-oil input is allocated to, they are modelled as if they would be 100% tall-oil based for the purpose of this study. The allocation of inputs is certified by ISCC PLUS (International Sustainability & Carbon Certification) (ISCC 2019).

2.4 End-of-life

To model the end-of-life of the examined beverage cartons one needs to know their fate after their use by the consumers. It is aimed to apply the recycling rate and disposal split for the beverage cartons of the EU market. These data has been collected from different waste management reports and statistics. For beverage cartons the specific recycling rate is publicly available for the market examined. The assumption of sorting losses is 10%, therefore, with a recycling rate of 51%, the collection rate is 57%. The recycling rate represents the actual amount of material undergoing a material recycling process after sorting took place. The collection rate represents the amount of material before sorting.

The remaining part of the post-consumer packaging waste is modelled and calculated according to the average rates for landfilling and incineration (MSWI) in Europe. The disposal split (100%) is divided into landfilling, 44.7% and incineration, 55.3%.

The applied recycling rate and the disposal split for Europe are listed in **Table 2-7**.

Table 2-7: End-of-life split of beverage cartons examined

Europe		Source
Recycling rate		
Beverage cartons	51.0 %	(EXTR:ACT 2020), data for 2019
Disposal split		
Landfill	44.7 %	(Eurostat 2021) municipal waste statistic, data for 2019
Incineration	55.3 %	

2.5 Distribution of filled packages from filler to point of sale

Table 2-8 shows the applied distribution distances in this study. The distribution distances for the European market from filling to point of sale were provided by SIG Combibloc. The distances have been cross-checked by ifeu based on internal and confidential studies on distribution.

For the distribution in Europe, a total distribution distance of 530 km has been assumed. In addition to regional and nationwide filling and distribution in Europe also cross-national distribution is considered which leads to a longer average distance.

The transport distance is implemented in the model as a two-stage delivery to retailers, where the first step indicates the transport to a central warehouse, and the second represents the delivery from a central warehouse to the supermarket (point-of-sale). For distribution step 2 as an expert estimate based on the same data mentioned above, a minimum empty transport distance of 30 km is assumed for the European market. The distance for distribution step 1 is obtained by subtracting the 30 km from the total distribution distance.

As no first-hand information was available on average empty return distances of lorries for the respective markets, it was assumed that lorries have an empty return trip with 30% of the distance of the fully loaded trip. However, internally available (confidential) distribution data for other beverage markets indicate that for short-distance transports, the 30% rule typically underestimates the empty return trip of the lorry. Therefore, as an expert estimate, a minimum empty transport distance of 30 km is applied for distribution step 2.

In the life cycle model, environmental loads related to distribution have been allocated between beverage and packaging based on respective masses and on the degree of utilisation of the lorry. The distribution distances for the European market are summarised in **Table 2-8**.

Table 2-8: Distribution distances in Europe for the examined beverage cartons

	Distribution distance			
	Distribution Step 1		Distribution step 2	
Market	Filler → distribution centre (delivery)	Distribution centre → filler (return trip)	Distribution centre → POS (delivery)	POS → distribution centre (return trip)
EU	500 km	150 km	30 km	30 km

2.6 Scenario modelling: End-of-life allocation

For each of the studied beverage cartons a scenario for the European market is defined, which is intended to reflect the most realistic situation under the described scope. These scenarios are clustered into groups within the same volume group. Following the ISO standard's recommendation, a variation of the allocation procedure shall be conducted. Therefore, the allocation factor for system allocation is set at 50% and 100% for the scenario models I and II. For further details on allocation factors and system allocation see **section 1.7.2**. An overview of the modelled baseline scenarios in this study is provided in **Table 2-9**.

Table 2-9: Modelled baseline scenarios for the European market

	Scenario I:	**Scenario II:**
Examined volumes	500 mL, 1000 mL	
Geographic scope	EU	EU
Allocation factor	**AF: 50 %**	**AF: 100 %**
BC recycling rate	**average** (EU: 51 %)	**average** (EU: 51 %)
Total amount of beverage cartons	14	14

In the following, these scenarios are described.

2.6.1 Scenario I (50 % allocation) and II (100 % allocation)

Following the ISO standard's recommendation, a variation of the allocation procedure shall be conducted. Therefore, two equal scenarios regarding the open-loop allocation are defined for the European market:

- Scenario I with a system allocation factor of 50 %
- Scenario II with a system allocation factor of 100 %

3 Life Cycle Inventory

Data on processes for packaging material production and converting were either collected in cooperation with the industry or taken from literature and the ifeu database. Concerning background processes (energy generation, transportation as well as waste treatment and recycling), the most recent version of ifeu's internal, continuously updated database was used. The use of different sources of the data sets can be justified methodologically by the fact that there is a conflict - the choice of consistently the same source often does not mean high quality. Therefore, the choice was made to always use the data sets with comparable background systems or system assumptions in combination with the best available data quality. **Table 3-1** gives an overview of important datasets applied in the current study.

Table 3-1: Overview on inventory/process datasets used in the current study

Material / process	Source	Reference year/ period	Geographic scope
Intermediate goods			
Fossil PP	(PlasticsEurope 2014a)	2011	Europe
Fossil HDPE	(PlasticsEurope 2014a)	2011	Europe
Fossil LDPE	(PlasticsEurope 2014a)	2011	Europe
Fossil PS	(PlasticsEurope 2012)	2010	Europe
Fossil PA	From producer, confidential	2015	Europe
Mass-balanced- PE	Based on information provided by SIG Combibloc, literature and ifeu database	2016	Finland/Europe
Mass-balanced PP	Based on information provided by SIG Combibloc, literature and ifeu database	2016	Finland/Europe
Mass-balanced PA	From producer, confidential and literature	2015	Europe
Aluminium (primary)	(EAA 2018)	2015	Europe
Aluminium foil	(EAA 2013)	2010	Europe
Corrugated cardboard	(FEFCO / Cepi Container Board 2018)	2017	Europe
Liquid packaging board	ifeu data, obtained from ACE (ACE / ifeu 2020)	2018	Finland/Sweden
Production			
BC converting data	SIG Combibloc	2019	Europe
- **Sleeve production cb3**			Germany
- **Sleeve production cb8**			Austria
Injection moulding of caps	SIG Combibloc	2019	Europe

Material / process	Source	Reference year/ period	Geographic scope
- Cap production cb3			
- cSwift LP			Europe
- cSwift			Europe
- cMaxx			Switzerland
- Cap production cb8			
- cSwift LP			Europe
- cSwift			Europe
- cMaxx			Switzerland
Filling			
Filling of beverage cartons	SIG Combibloc	2019	Europe
Recovery			
Beverage carton recycling	ifeu database, based on data from various European recycling plants	2004	Europe
Background data			
Electricity production	ifeu database, based on statistics and power plant models	2018	Europe
Municipal waste incineration	ifeu database, based on statistics and incineration plant models	2016-2020	Europe
Landfill	ifeu database, based on statistics and landfill models	2019	Europe
Thermal recovery in cement kilns	ifeu database, German cement industry association (VDZ)	2006	Europe
Lorry transport	ifeu database, based on statistics and transport models, emission factors based on HBEFA 4.1 (INFRAS 2019).	2017	Europe
Rail transport	(EcoTransIT World 2016)	2016	Europe
Sea ship transport	(EcoTransIT World 2016)	2016	Europe

3.1 Manufacture of plastic raw materials

The following plastics are used within the beverage cartons under study:

3.1.1 Polypropylene (PP)

PP is produced by catalytic polymerisation of propylene into long-chained polypropylene. The two important processing methods are low pressure precipitation polymerisation and gas phase polymerisation. In a subsequent processing stage the polymer powder is converted to granulate using an extruder.

The present LCA study utilises data published by Plastics Europe (PlasticsEurope 2014a). The dataset covers the production of PP from cradle to the polymer factory gate. The polymerisation data refer to the 2011 time period and were acquired from a total of 35 polymerisation plants producing. The total PP production in Europe (EU27+2) in 2011/2012 was 8,500,000 tonnes. The Plastics Europe data set hence represents 77% of PP production in Europe.

3.1.2 Low Density Polyethylene (LDPE)

LDPE is manufactured in a high pressure process and contains a high number of long side chains. The present LCA study uses the ecoprofile published on the website of Plastics Europe (PlasticsEurope 2014b).

The data set covers the production of LDPE granulates from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the year 2011. Data from a total of 22 participating polymerisation units were collected. The data set represents 72% of LDPE production in Europe (EU27+2).

3.1.3 High Density Polyethylene (HDPE)

HDPE is produced by a variety of low pressure methods and has fewer side-chains than LDPE. The present LCA study uses the eco-profile published on the website of Plastics Europe (PlasticsEurope 2014b).

The dataset covers the production of HDPE-granulate from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the year 2011 and were acquired from a total of 21 participating polymerisation units. The data set represents 68% of HDPE production in Europe (EU27+2).

3.1.4 Polystyrene (PS)

PS is produced by polymerisation of styrene monomer, a chain-growth reaction which is induced by any known initiation techniques such as heat, free radical organic initiator, anionic or cationic initiating systems, or coordination-insertion organo-metallic initiating complexes. The present LCA study uses the ecoprofile published on the website of Plastics Europe (PlasticsEurope 2012). The dataset covers 95% of the European production capacity (EU-27) and refers to the year 2010.

3.1.5 Polyamide (PA 6)

PA 6 is manufactured from the precursors benzene and hydroxylamine. The present LCA study uses the ecoprofile provided by a specific supplier within Europe. The applied dataset covers the production of Polyamide granulates right from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the year 2015 and is specific for the supplier of SIG Combibloc. Due to confidentiality reason the data cannot disclosed within this study.

3.1.6 Mass-balanced PE, mass-balanced PA 6 and mass-balanced-PP dataset based on tall oil pitch

The production processes of mass-balanced PE, mass-balanced PA 6 and mass-balanced PP are based on tall oil pitch. Tall oil pitch is a wood-based by-product from pulp production. Carbon stored in wood, the base input material for the production processes of the mass-balanced plastics, has been absorbed from the atmosphere during plant growth and is referred as biogenic carbon. As there is no additional carbon added in the production processes of mass-balanced plastics the carbon stored mass-balanced HDPE, LDPE, PP and PA is biogenic. In order to derive the biogenic carbon content of the mass-balanced plastics, the carbon content is calculated with the corresponding chemical formulas of HDPE, LDPE, PP and PA6. The total balance of biogenic carbon of the regarded packaging systems in the LCA is shown exemplarily in **Table 1-1** in **section 1.7.3**.

The production of tall oil pitch is modelled as described in (Cashman et al. 2016) covering the production steps kraft pulping, acidulation and distillation and their related transportation. Allocation was necessary in the main processes of pulping and distillation. This is done on mass basis. Because crude tall oil produced from Black Liquor Soap (BLS) is a useful output a share of the pulping burdens is assigned to the tall oil.

For kraft pulping a kraftliner pulp process based on (FEFCO 2012) is used. The share of BLS in kraft pulp production is 4% (Cashman et al. 2016). By applying mass allocation 4% of pulp production’s burdens are taken for BLS.

The acidulation step to produce crude tall oil from BLS is modelled with the in- and outputs of Table 2 in (Cashman et al. 2016) (see **Table 3-2**)

Table 3-2: In- and outputs Acidulation. Table 2 in (Cashman et al. 2016)

Inputs			Outputs		
Black Liquor Soap (BLS)	2,000.00	kg	Crude tall oil	1,000.00	kg
electric energy	110,000.00	kJ			
heat energy from oil*	50,164.92	kJ			
heat energy from natural gas**	8,114.40	kJ			
steam (process)	1,623.000.00	kJ			
sodium hydroxide, 50% in H2O, production mix, at plant [RER]	25.00	kg			
sulphuric acid, liquid, at plant [RER]	200.00	kg			

*converted from kg to kJ with calorific value: 11.91kWh/kg
** converted from m³ to kJ with calorific value: 46MJ/kg and density of natural gas: 0.84 kg/m

Tall oil pitch is only one output of the tall oil distillation process. 27% of the total output mass of all distillation products is tall oil pitch. The distillation process is modelled with the in-and outputs of Table 1b in (Cashman et al. 2016).

Table 3-3: In- and outputs Distillation. Table 1b in (Cashman et al. 2016)

Inputs			Outputs		
Crude Tall Oil	299.70	kg	Tall Oil Pitch	1,000.00	kg
electric energy	168,210.00	kJ	sewage (process) Sweden, Finland	5.67	kg
heat energy from oil*	49,200.21	kJ			
heat energy from natural gas**	68,543.50	kJ			
steam (process)	157,680.00	kJ			
nitrogen	2.27	kg			

Applied allocation factor 0.27 for tall oil pitch based on Table 1a in (Cashman et al. 2016)
*converted from kg to kJ with calorific value: 11.91kWh/kg
** converted from m³ to kJ with calorific value: 46MJ/kg and density of natural gas: 0.84 kg/m³ (ifeu)

Mass-balanced PA 6 is based on the same data set as fossil-based PA 6 (see **section 3.1.5**). Naphta is substituted by tall oil pitch. The amount of naphtha needed for 1 kg of PA6 was calculated based on the used oil feedstock in MJ for the production of 1kg of fossil-based PA6 and the used oil feedstock in MJ for the production of 1 kg of naphtha.

The corresponding amount of tall oil pitch was calculated by equating the input of naphtha with the replacing tall oil pitch based on their energy values. For this purpose the following lower heating values were used:

Table 3-4: Lower heating values of naphtha and tall oil pitch

	lower heating value
Naphtha	41.8 kg/MJ
Tall oil pitch	38 kg/MJ

Mass-balanced PE and PP are produced by cracking and polymerization of bio-diesel. The bio-diesel is based on tall oil pitch. It is a distillation product of crude tall oil, gained through acidulation of BLS which is a by-product of paper pulp production (as described above).

Bio-diesel is produced from tall oil pitch by hydrotreatment. The confidential dataset of this process is based on the studies (Reinhardt et al. 2006) and (Nikander 2008). Both studies provide process data of the so-called NExBTL process of Neste Oil. According to several press releases[5] of Neste Oil bio-diesel based on tall oil pitch is produced in its plant in Finland. The location of the plant was therefore set accordingly. The co-products fuel gas and bio-gasoline are produced as well. Bio-gasoline is internally used as thermal energy. Allocation was done by mass and calorific value of bio-diesel and fuel gas. Bio-diesel accounts for 93.5% of the processes in- and outputs.

The cracking and polymerization processes for PE and PP are taken from the ifeu database. They are based on data representing the average from several polymerisation units in Europe.

3.2 Production of liquid packaging board (LPB)

LPB production dataset represents the LPB production in Europe and is produced by ifeu. The production of LPB was modelled using data gathered from board producers in Sweden and Finland. It covers data from four different production sites where more than 95% of European LPB is produced. The reference year of these data is 2018. It is the most recent available and also published in the ELCD database.

The four datasets based on similar productions volumes were combined to one average. They cover all process steps including pulping, bleaching and board manufacture. They were combined with data sets

[5] https://www.neste.com/en/neste-oil-uses-tall-oil-pitch-produce-traffic-fuel

for the process chemicals used from ifeu´s database and Ecoinvent 3.6 including a forestry model to calculate inventories for this sub-system. Energy required is supplied by electricity as well as by renewable on-site energy production by incineration of wood and bark. The specific energy sources were taken into account.

3.3 Production of primary material for aluminium bars and foils

The data set for primary aluminium covers the manufacture of aluminium ingots starting from bauxite extraction, via aluminium oxide manufacture and on to the manufacture of the final aluminium bars. This includes the manufacture of the anodes and the electrolysis. The data set is based on information acquired by the European Aluminium Association (EAA) covering the year 2015. The data are covering primary aluminium used in Europe consisting of 51% European aluminium data and 49% IAI data developed by the International Aluminium Institute (IAI) for imported aluminium (EAA 2018).

The data set for aluminium foil (5-200 µm) is based on data acquired by the EAA together with EAFA covering the year 2010 for the manufacture of semi-finished products made of aluminium. For aluminium foils, this represents 51% of the total production in Europe (EU27 + EFTA countries). Aluminium foil for the packages examined in this study are assumed to be sourced in Europe. According to EAA (2013), the foil production is modelled with 57% of the production done through strip casting technology and 43% through classical production route. The dataset includes the electricity upstream chains which are specific for the actual practice and are not an European average electricity mix.

3.4 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO (FEFCO / Cepi Container Board 2018) were used. More specifically, the data sets for the manufacture of 'Kraftliners' (predominantly based on primary fibres), 'Testliners' and 'Wellenstoff' (both based on recycled fibres) as well as for corrugated cardboard packaging were used. The data sets represent weighted average values from European locations recorded in the FEFCO data set. They refer to the year 2017. All corrugated board and cardboard trays are assumed to be sourced from European production.

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated card-board trays. According to FEFCO / Cepi Container Board (2018), this fraction on average is 12% in Europe. Due to a lack of more specific information this split was also used for this study.

3.5 Converting

Converting of beverage cartons

The manufacture of composite board was modelled using data provided by the commissioner of the current study, SIG Combibloc, and refers to the year 2019. Process data has been collected from the converting site in Linnich, Germany. Due to very similar technology at other (and smaller) converting sites the collected data is considered as representative for all European converting sites by SIG Combibloc. The converting process covers the lamination of LPB, LDPE and aluminium or PA respectively, printing, cutting and packing of the composite material. The examined combibloc beverage cartons are produced at an Austrian and German converting site of SIG Combibloc and printed with a rotogravure process. The packaging materials used for shipping of combiblocSlimline (cb3) and combiblocMidi (cb8) sleeves to fillers are included in the model as well as the transportation of the package material.

Process data provided by SIG Combibloc was then coupled with required upstream chains, such as process heat, grid electricity, and inventory data for transport packaging used for shipping the coated composite board to the filler (**Table 3-5**).

Closure production

The closures made of fossil and mass-balanced PP and HDPE are produced by injection moulding. The data for the production were provided by SIG Combibloc and are based on values measured in SIG's plant in Switzerland and Europe. The process data were coupled with required upstream chains such as the production of PE and grid electricity **Table 3-5**.

3.6 Filling

Filling processes for the examined combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons are very similar in regard to material and energy flows. The respective data for this study was provided by SIG Combibloc, distinguishing between the consumption of electric and thermal energy as well as of water and air demand. A cross-check has been conducted with filling data from ifeu's internal database, which relies on information from different fillers and filling machine manufacturers. Data provided by SIG Combibloc are similar and therefore considered plausible.

3.7 Transport settings

The following Table 3.2 provides an overview of the transport settings (distances and modes) applied for packaging materials. Data were obtained from SIG Combibloc and several producers of raw materials. Where no such data were available expert judgements were made, e.g. exchanges with representatives from the logistic sector and supplier.

Table 3-5: Transport distances and means: Transport defined by distance and mode (km/mode)

Packaging element Geographic scope (Reference)	**Distance of material producer to converter (km)**	**Distance of converter to filler (km)**
Fossil PE, PP, PA Europe	500 / road[1]	
Mass-balanced PE, PP Europe	700 / road[1]	
Mass-balanced PA Europe	500 / road[1]	
Aluminium EU27 + Norway, Switzerland, Iceland (EAA 2013), (EAA 2018)	460 / road[1]	
Paper board for composite board Sweden, Finland	300 / road[2] 950 / sea[2] 800 / rail[2]	
Cardboard for trays EU 27 + Norway, Switzerland (FEFCO / Cepi Container Board 2018)	primary fibres: 500 / sea, 400 / rail, 250 / road[2] secondary fibres: 300/road[2]	
Wood for pallets Northern Europe	100 / road[3]	
LDPE stretch foil based on several plants in Europe (PlasticsEurope 2005), (PlasticsEurope 2014a), (PlasticsEurope 2014b), (PlasticsEurope 2017)	500/road (material production site = converter)[3]	
Trays EU28		500 / road[3]
Pallets EU28		100 / road[3]
Converted carton rolls EU28		500 / road[4]

[1]calculation
[2]taken from published LCI reports
[3]assumption
[4]SIG data

3.8 Recovery and recycling

Beverage cartons are typically positively sorted into a beverage carton fraction, which subsequently is sent to a paper recycling facility for fibre recovery. The secondary fibre material is used e.g. as a raw material for cardboard. The rejects (plastics and aluminium compounds) are assumed to undergo either a thermal treatment in cement kilns or are finally disposed in a MSWI plant or on landfill (**see Table 2-7**). Related process data used are taken from ifeu's internal database, referring to the year 2004 and are based on data from various European recycling plants collected by ifeu.

3.9 Background data

3.9.1 Transport processes

Lorry transport

The dataset used is based on standard emission data that were collated, validated, extrapolated and evaluated for the Austrian, German, French, Norwegian, Swedish and Swiss Environment Agencies in the 'Handbook of emission factors' (Notter et al. 2019). The 'Handbook' is a database application referring to the year 2017 and giving as a result the transport distance related fuel consumption and the emissions differentiated into lorry size classes and road categories**.** Data are based on average fleet compositions within several lorry size classes. The emission factors used in this study refer to the year 2017.

Based on the above-mentioned parameters – lorry size class and road category – the fuel consumption and emissions as a function of the transport load and distance were determined. The average capacity utilization of 50% combines load factors and empty trip factors based on (EcoTransIT World 2016) and communication with the logistics sector.

Ship transport

The data used for the present study represent freight transport with an overseas container ship (10.5 t/TEU[6]) and an utilisation capacity of 70%. Energy use is based on an average fleet composition of this ship category with data taken from (EcoTransIT World 2016). The Ecological Transport Information Tool (EcoTransIT) calculates environmental impacts of any freight transport. Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on (EcoTransIT World 2016). For the consideration of well-to-tank emissions data were taken from ifeu's internal database.

Rail transport

[6] Twenty-foot Equivalent Unit

The data used for rail transport for the present study also is based on data from (EcoTransIT World 2016). Emission factors and fuel consumption have been applied for direct emissions based on (EcoTransIT World 2016). The needed electricity is modelled with the electricity mix of the country the train is operating (see also **section 3.9.2**).

3.9.2 Electricity generation

Modelling of electricity generation is particularly relevant for the production of base materials as well as for converting, filling processes and recycling processes. Electric power supply is modelled using country specific grid electricity mixes, since the environmental burdens of power production varies strongly depending on the electricity generation technology. The country-specific electricity mixes are obtained from a base network for grid power modelling maintained and annually updated at ifeu as described in (Fehrenbach et al. 2016). It is based on national electricity mix data by the International Energy Agency (IEA)[7]. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2018 for the production of LPB and the European mix of energy suppliers in the year 2018 for all other processes. The applied shares of energy sources to the related market are given in **Table 3-6**: .

Table 3-6: Share of energy source to specific energy mix, reference year 2018.

		Geographic scope		
		EU 28	Sweden	Finland
Energy source	**Hard coal**	9.59%	0.20%	8.11%
	Brown coal	9.45%	0.18%	4.86%
	Fuel oil	1.47%	0.18%	0.32%
	Natural gas	20.05%	0.56%	6.98%
	Nuclear energy	25.36%	41.00%	32.26%
	Hydropower, wind, solar & geothermal	27.48%	49.90%	28.66%
	Hydropower	41.18%	78.53%	69.18%
	Wind power	44.36%	20.98%	30.37%
	Solar energy	13.72%	0.49%	0.45%
	Geothermal energy	0.74%	0.00%	0.00%
	Biomass energy	5.10%	6.07%	17.15%
	Waste	1.50%	1.91%	1.66%

[7] http://www.iea.org/statistics/

3.9.3 Municipal waste incineration

The electrical and thermal efficiencies of the municipal solid waste incineration plants (MSWI) are shown in table **Table 3-7**.

Table 3-7: Electrical and thermal efficiencies of the incineration plants for Europe

Geographic Scope	Electrical efficiency	Thermal efficiency	Reference period	Source
EU	14.9%	34.6%	2010	(CEWEP 2012)

The efficiencies are used as parameters for the incineration model, which assumes a technical standard (especially regarding flue gas cleaning) that complies with the requirements given by the EU incineration directive (EU 2018).

It is assumed that the electrical energy generated in MSWI plants substitute the market specific grid electricity and that the thermal energy recovered in MSWI plants serves as process heat. The model takes into account that there are MSWI plants which do not provide thermal energy. However, if thermal energy is provided, it is used 100%.

3.9.4 Landfill

The landfill model accounts for the emissions and the consumption of resources for the deposition of domestic wastes on a sanitary landfill site. Besides electric and mechanical energy for maintenance and operation of the landfill, burdens from treatment of short-term leakage (0-100a) in a waste treatment plant are included in the model. As information regarding an average landfill standard in Europe is currently not available, assumptions regarding the equipment with and the efficiency of the landfill gas capture system (the two parameters which determine the net methane recovery rate) had to be made.

Besides the parameters determining the landfill standard, another relevant system parameter is the degree of degradation of the beverage carton material on a landfill. Empirical data regarding degradation rates of laminated beverage cartons are not known to be available by the authors of the present study.

The following assumptions, especially relevant for the degradable board material, underlay the landfill model applied in this LCA study:

Regarding the degradation of the beverage carton board under landfill conditions, it is assumed that it behaves like coated paper-based material in general. According to (Micales / Skog 1997), 30% of paper is decomposed anaerobically on landfills. 70% remain in the landfill and maintenance and operation emissions are still allocated them as well. Potential long-term emissions (i.e. >100a) are not considered anymore.

It is assumed that the degraded carbon is converted into landfill gas with 50% methane content by volume (IPCC 2006) Emissions of methane from biogenic materials (e.g. during landfill) are always accounted at the inventory level and in form of GWP.

3.9.5 Thermal recovery in cement kilns

The process data for thermal recovery in cement kilns refer to the year 2006 and are taken from ifeu's database based on information provided by the German Cement Works Association (VDZ). The applied process data cover emissions from the treatment in the clinker burning process. Parameters are restricted to those which change compared to the use of primary fuels. The output cement clinker is a function of the energy potential of the fuel and considers the demand of base material. The primarily substitution of hard coal in cement kilns was confirmed by the economic, technical and scientific association for the German cement industry (VDZ e.V.) (VDZ 2019). As no further information regarding the substituted fuel is available for the European scope, hard coal substitution based on the information for Germany is applied.

4 Results and discussion

4.1 Presentation of results

4.1.1 Numerical values and figures

In this section the results of the examined beverage cartons are presented separately for the different categories in graphic form.

The following individual life cycle elements are shown in sectoral (stacked) bar charts. Life cycle steps which include only the production of primary packaging are referred as cradle to gate. As SIG Combibloc as the producer of the analyzed packaging systems has direct influence on these **cradle to gate** life cycle steps, these are separately shown in the numerical result tables. The remaining life cycle steps which also include transport packaging, filling, distribution and the end of life as well as the connected credits and the CO_2 uptake are referred as **gate to grave**. Net results are referred to **cradle to grave**.

<u>**Cradle to gate:**</u>

- Production and transport of liquid packaging board (‘**LPB**’)
- Production and transport of plastics and additives for combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons
  (‘**plastics for sleeve**’)
- Production and transport of aluminium & converting to foil (‘**aluminium foil**’)
- Converting processes of cartons (**‘converting’**)
- Production and transport of base materials for closure and related converting (**‘closure’**)

<u>**Gate to grave:**</u>

- Production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil
  and corrugated cardboard trays (**‘transport packaging’**)
- Filling process including packaging handling **(‘filling’**)
- Retail of the packages from filler to the point-of-sale (**‘distribution’**)
- Collection, sorting, recycling and disposal processes (**‘recycling/disposal**’)
- Biogenic (regenerative) CO_2 emissions from incineration and landfilling of biobased materials (‘**CO_2 reg (EOL)**’)

Secondary products (recycled materials and recovered energy) are obtained through recovery processes of used packaging materials, e.g. recycled fibres from cartons may replace primary fibres. It is assumed, that those secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental loads of the substituted material.

The credits are shown in form of separate bars in the LCA results graphs. They are broken down into:

- Credits for energy recovery (replacing e.g. grid electricity) (**'credits energy'**)
- Credits for material recycling (**'credits material'**)
- Uptake of atmospheric CO_2 during the plant growth phase ('**CO_2 uptake'**)

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. Therefore, **the category indicator results represent potential environmental impacts per functional unit.**

Each impact category graph includes three bars per packaging system under investigation, which illustrate (from left to right):

- Sectoral results of the packaging system itself (stacked bar 'environmental burdens')
- Credits given for secondary products leaving the system (negative stacked bar 'credits')

Cradle to grave:

- Net results as a result of the subtraction of credits from overall environmental loads (grey bar **'net results'**)

All category results refer to the primary and transport packaging systems flows required for the delivery of 1000 L beverage to the point of sale including the end-of-life of the packaging systems.

4.1.2 Comparison between systems

The net result comparison of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons is illustrated by tables that include the comparison between the beverage cartons for both scenarios: scenario I (allocation factor 50) and scenario II (allocation factor 100) along all impact categories.

The colors green and red illustrate the distinction between more (green) and less (red) favorable net results in the respective categories. Percentages lower than 10% are considered as insignificant differences and therefore marked by a grey shading of the respective fields.

4.2 Europe combiblocSlimline (cb3) beverage cartons 1000 mL

4.2.1 Scenario I (50 % allocation): numerical values and graphs

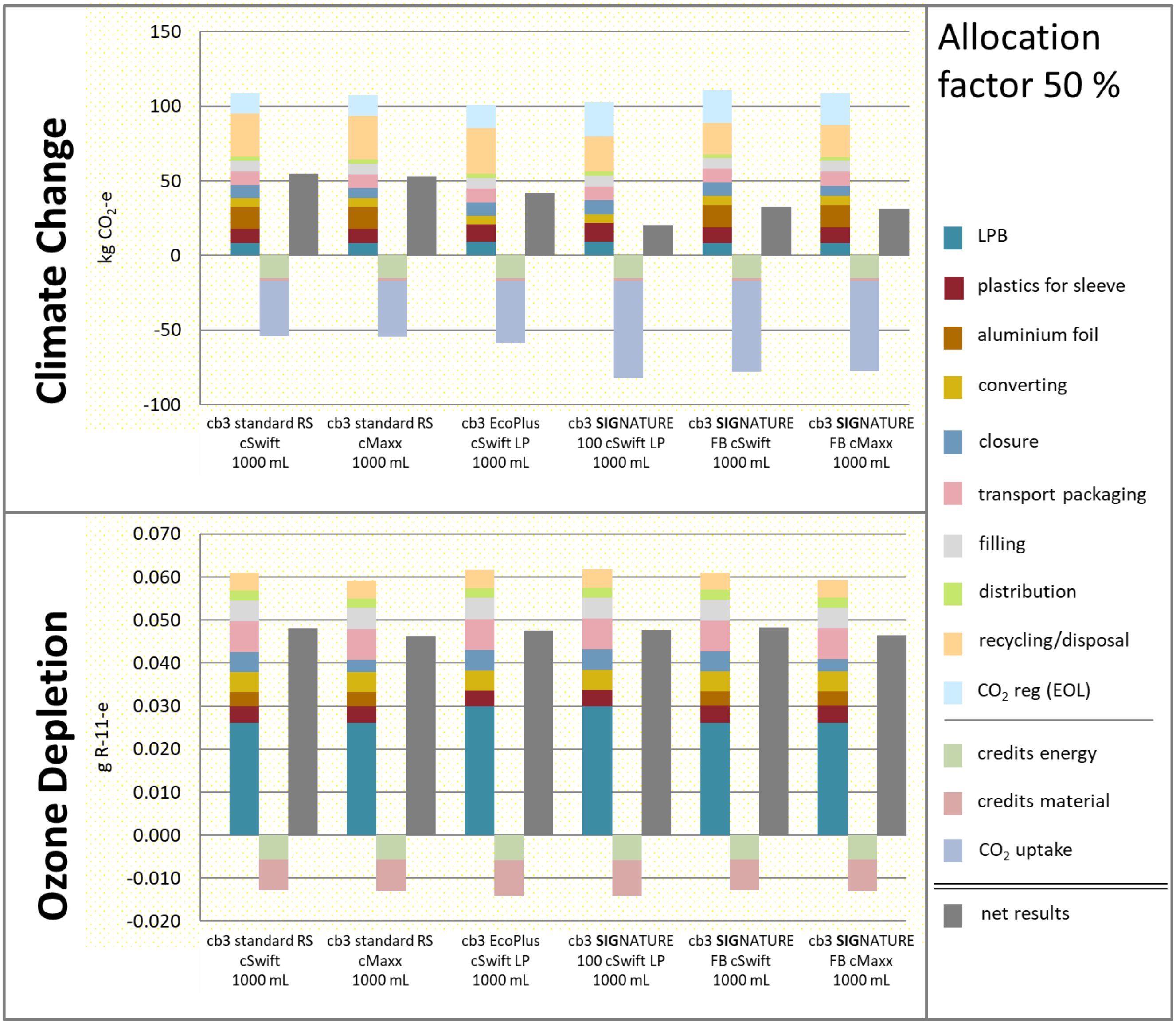

Figure 4-1: Indicator results for **scenario I Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 50 % (Part 1)

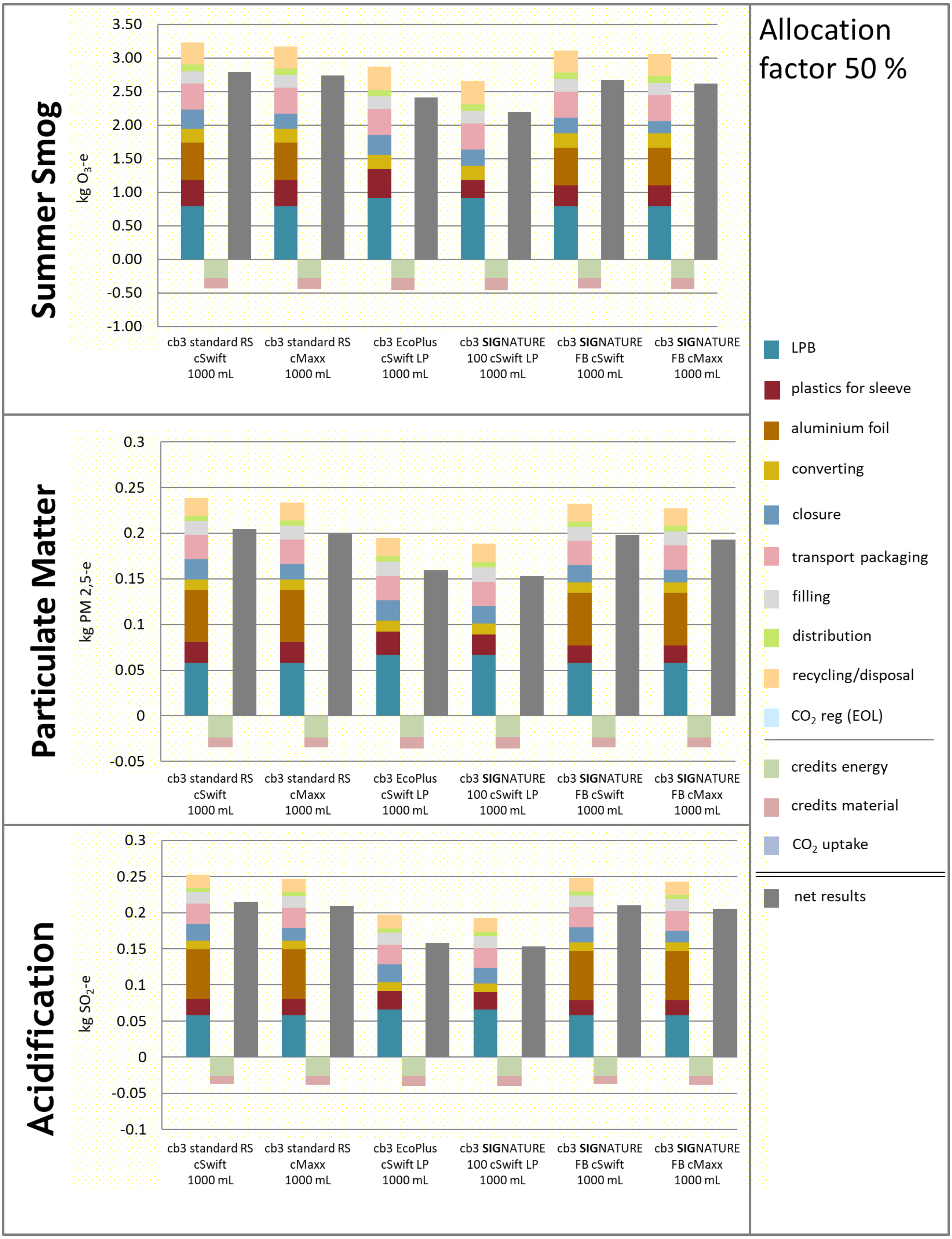

Figure 4-2: Indicator results for **scenario I Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 50 % (Part 2)

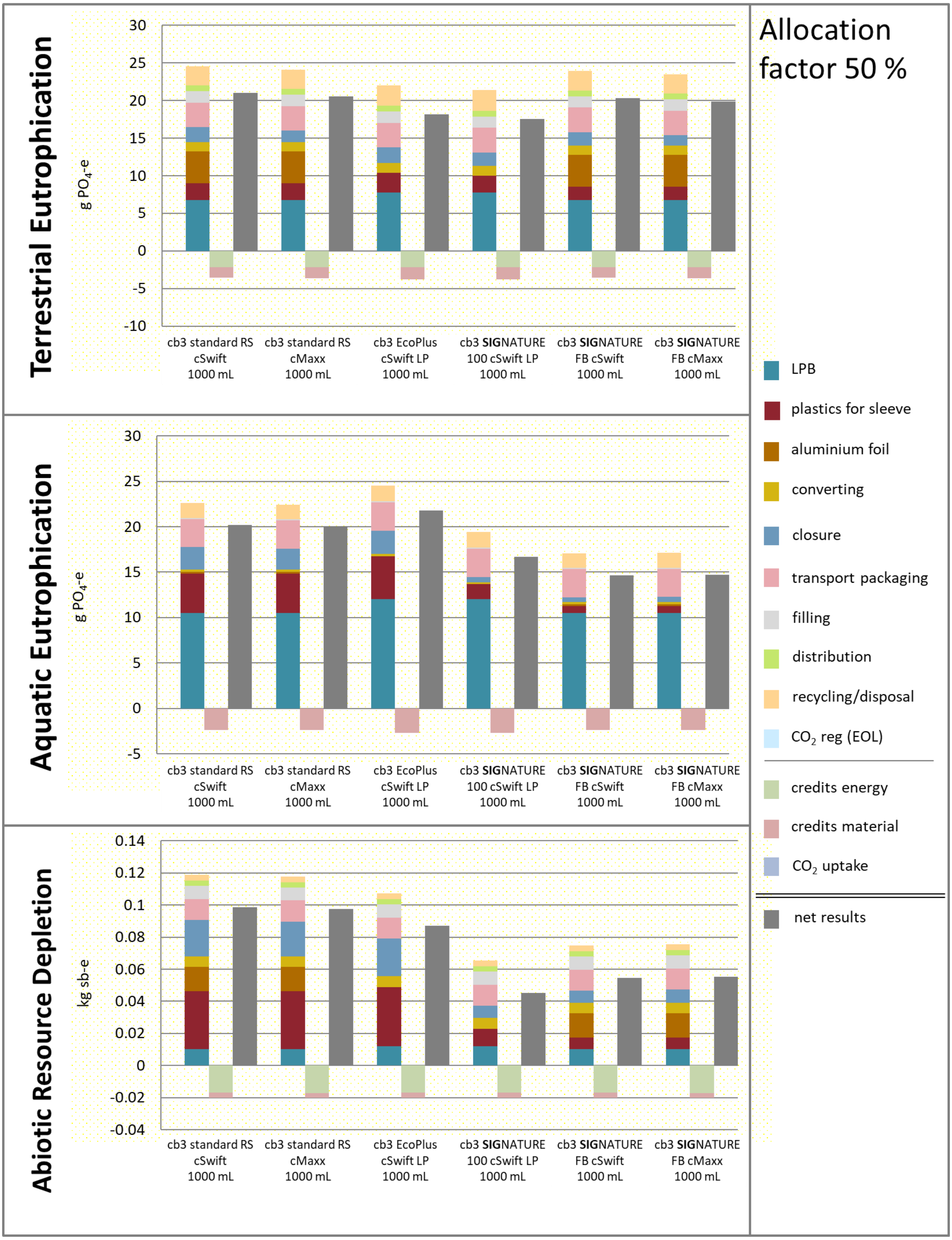

Figure 4-3: Indicator results for **scenario I Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 50 % (Part 3)

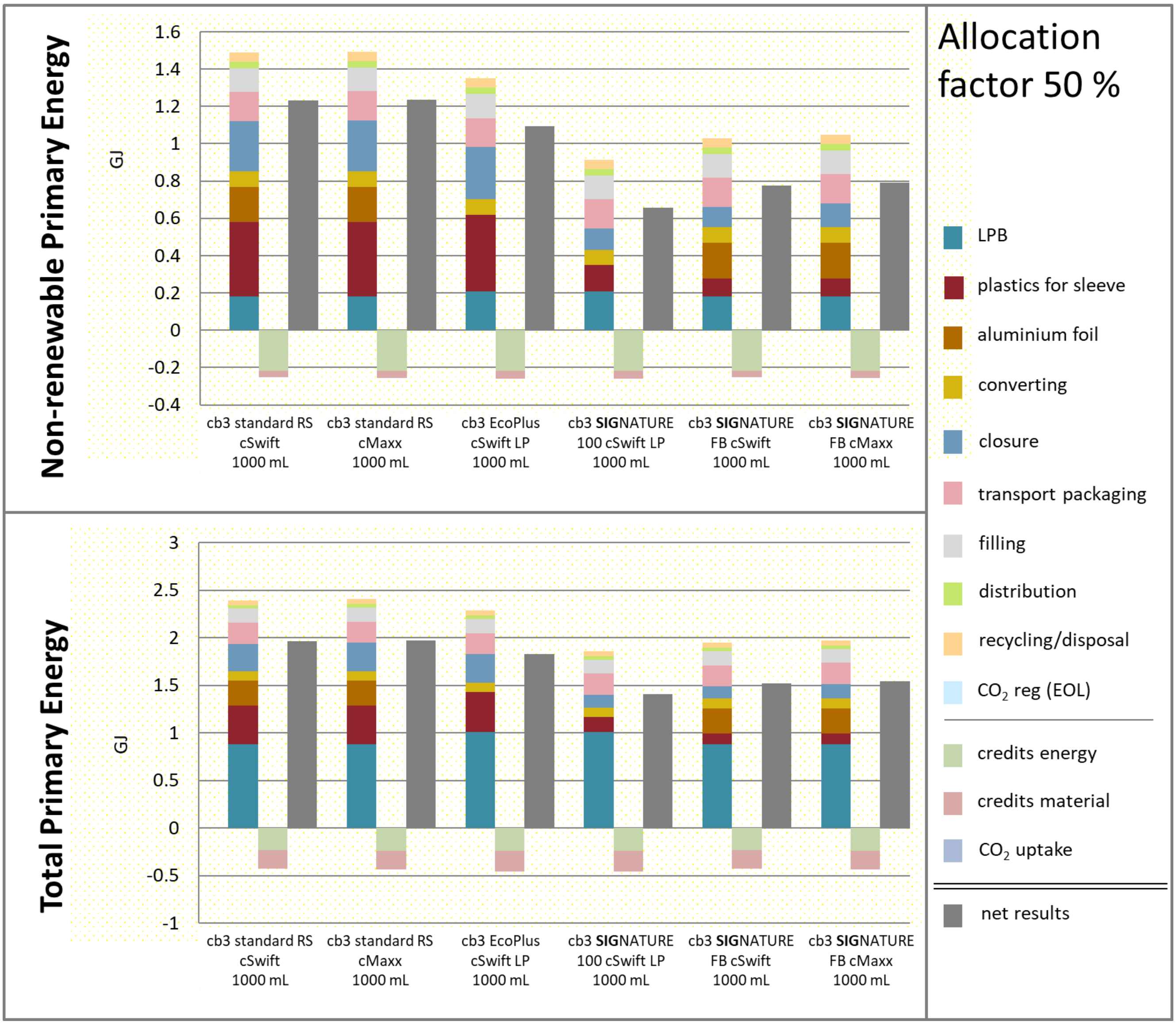

Figure 4-4: Indicator results for **scenario I Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 50 % (Part 4)

Table 4-1: Category indicator results for **scenario I Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Europe, allocation factor 50 %			cb3 standard RS cSwift 1000 mL	cb3 standard RS cMaxx 1000 mL	cb3 EcoPlus cSwift LP 1000 mL	cb3 SIGNATURE 100 cSwift LP 1000 mL	cb3 SIGNATURE FB cSwift 1000 mL	cb3 SIGNATURE FB cMaxx 1000 mL
Climate change [kg CO_2-equivalents]	cradle to gate	Burdens	47.07	45.16	35.46	36.97	48.76	46.78
	gate to grave	Burdens	47.88	48.19	49.79	42.65	40.14	40.71
		CO_2 (reg)	14.01	14.01	15.71	22.85	21.74	21.49
		Credits	-17.04	-17.22	-17.07	-17.07	-17.04	-17.23
		CO_2 uptake*	-37.19	-37.20	-41.87	-65.27	-61.13	-60.32
	cradle to grave	Net results (∑)	54.71	52.94	42.02	20.12	32.46	31.43
Acidification [g SO_2-equivalents]	cradle to gate	Burdens	0.18	0.18	0.13	0.12	0.18	0.17
	gate to grave	Burdens	0.07	0.07	0.07	0.07	0.07	0.07
		Credits	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
	cradle to grave	Net results (∑)	0.22	0.21	0.16	0.15	0.21	0.21
Summer smog [g O_3-equivalents]	cradle to gate	Burdens	2.23	2.17	1.85	1.64	2.11	2.06
	gate to grave	Burdens	1.00	1.00	1.02	1.02	1.00	1.00
		Credits	-0.43	-0.44	-0.46	-0.46	-0.43	-0.44
	cradle to grave	Net results (∑)	2.79	2.74	2.41	2.20	2.67	2.62
Ozone Depletion [g R-11-equivalents]	cradle to gate	Burdens	0.04	0.04	0.04	0.04	0.04	0.04
	gate to grave	Burdens	0.02	0.02	0.02	0.02	0.02	0.02
		Credits	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
	cradle to grave	Net results (∑)	0.05	0.05	0.05	0.05	0.05	0.05
Terrestrial eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	14.48	14.48	11.71	11.33	14.08	14.08
	gate to grave	Burdens	10.08	9.64	10.29	10.04	9.83	9.41
		Credits	-3.58	-3.60	-3.81	-3.81	-3.58	-3.60
	cradle to grave	Net results (∑)	20.97	20.52	18.19	17.56	20.32	19.89
Aquatic eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	17.77	17.60	19.57	14.47	12.25	12.26
	gate to grave	Burdens	4.84	4.85	4.93	4.93	4.84	4.85
		Credits	-2.41	-2.41	-2.73	-2.73	-2.41	-2.41
	cradle to grave	Net results (∑)	20.20	20.04	21.78	16.67	14.68	14.71
Particulate matter [g PM 2,5- equivalents]	cradle to gate	Burdens	0.17	0.17	0.13	0.12	0.16	0.16
	gate to grave	Burdens	0.07	0.07	0.07	0.07	0.07	0.07
		Credits	-0.03	-0.03	-0.04	-0.04	-0.03	-0.03
	cradle to grave	Net results (∑)	0.20	0.20	0.16	0.15	0.20	0.19
Abiotic resource depletion [kg sb-equivalents]	cradle to gate	Burdens	0.09	0.09	0.08	0.04	0.05	0.05
	gate to grave	Burdens	0.03	0.03	0.03	0.03	0.03	0.03
		Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	cradle to grave	Net results (∑)	0.10	0.10	0.09	0.05	0.05	0.06
Non-renewable primary energy [GJ]	cradle to gate	Burdens	1.12	1.12	0.98	0.54	0.66	0.68
	gate to grave	Burdens	0.37	0.37	0.37	0.37	0.37	0.37
		Credits	-0.25	-0.26	-0.26	-0.26	-0.25	-0.26
	cradle to grave	Net results (∑)	1.23	1.24	1.09	0.66	0.78	0.79
Total Primary Energy [GJ]	cradle to gate	Burdens	1.94	1.95	1.83	1.40	1.49	1.51
	gate to grave	Burdens	0.46	0.46	0.46	0.46	0.46	0.46
		Credits	-0.43	-0.43	-0.46	-0.46	-0.43	-0.43
	cradle to grave	Net results (∑)	1.97	1.97	1.83	1.41	1.52	1.54

*CO2 uptake is part of the production, but cannot be included in cradle to gate without the consideration of the end of life (grave).

4.2.2 Scenario II (100 % allocation): numerical values and graphs

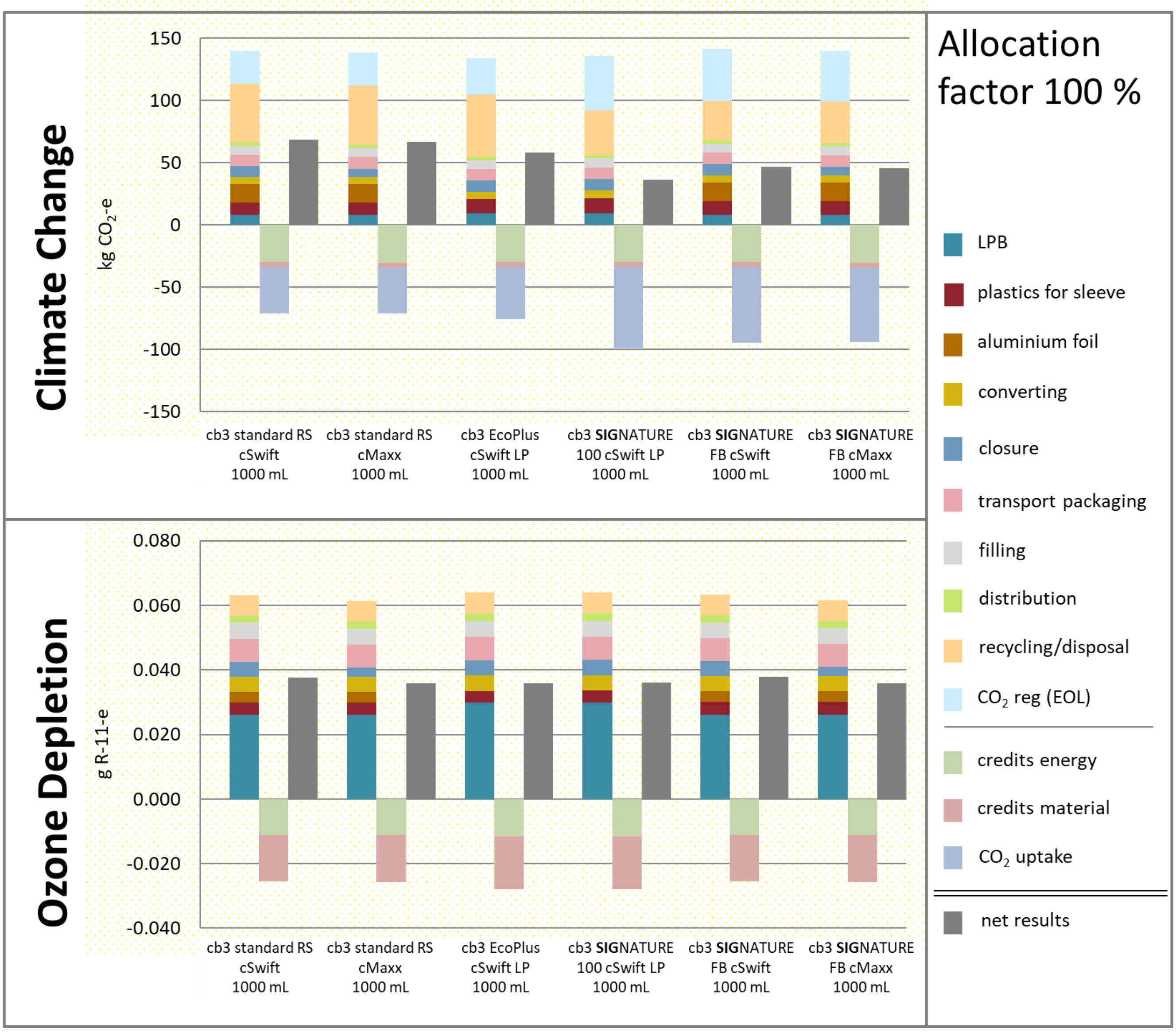

Figure 4-5: Indicator results for **scenario II Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 100 % (Part 1)

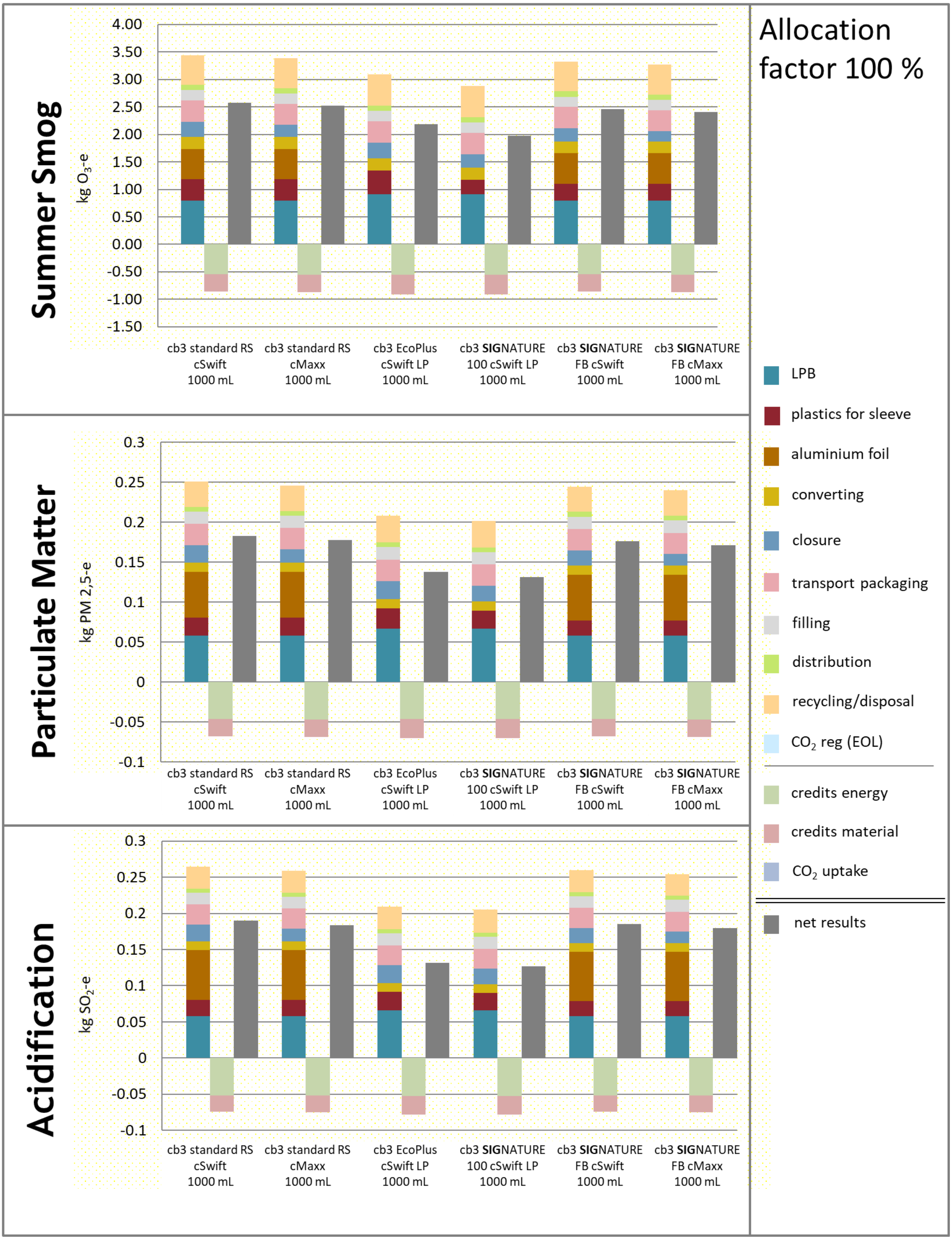

Figure 4-6: Indicator results for **scenario II Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 100 % (Part 2)

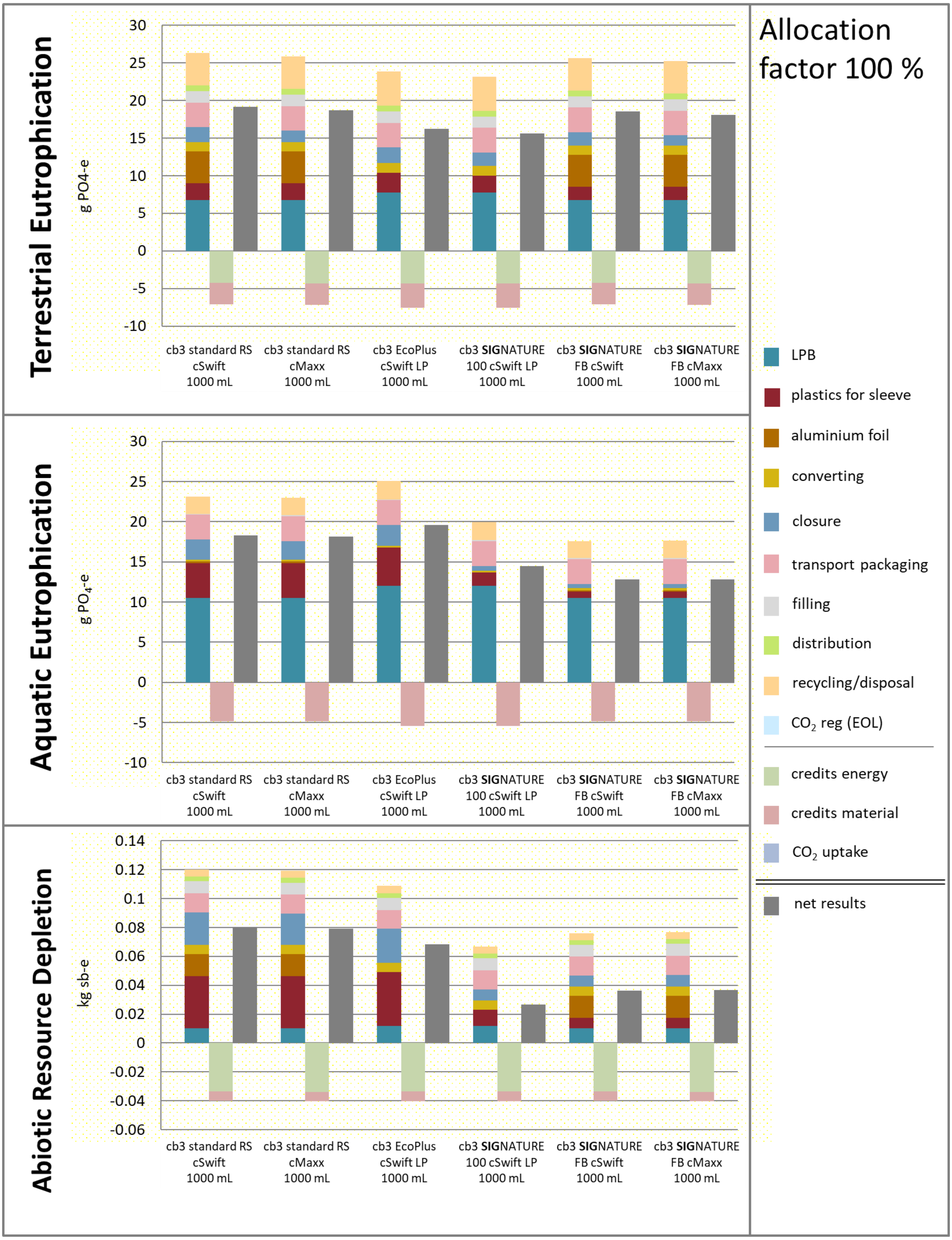

Figure 4-7: Indicator results for **scenario II Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 100 % (Part 3)

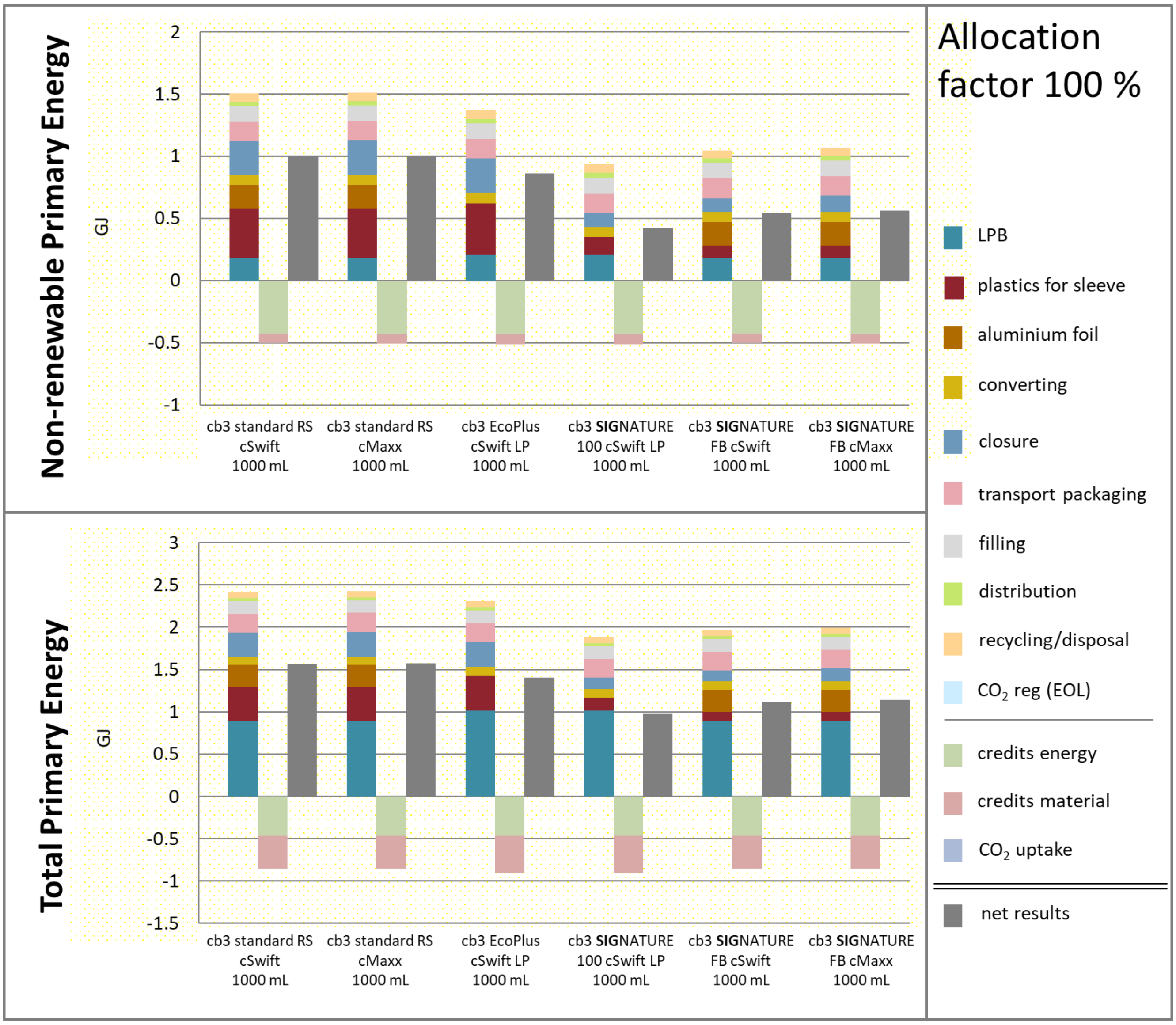

Figure 4-8: Indicator results for **scenario II Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 100 % (Part 4)

Table 4-2: Category indicator results for **scenario II Europe, combiblocSlimline (cb3) beverage cartons** with allocation factor 100 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario II Europe, allocation factor 100 %			cb3 standard RS cSwift 1000 mL	cb3 standard RS cMaxx 1000 mL	cb3 EcoPlus cSwift LP 1000 mL	cb3 SIGNATURE 100 cSwift LP 1000 mL	cb3 SIGNATURE FB cSwift 1000 mL
Climate change [kg CO_2-equivalents]	cradle to gate	Burdens	47.07	45.16	35.46	36.97	48.76
	gate to grave	Burdens	66.44	67.05	69.23	54.95	50.96
		CO_2 (reg)	26.18	26.19	29.39	43.66	41.64
		Credits	-33.82	-34.19	-33.84	-33.84	-33.82
		CO_2 uptake*	-37.19	-37.20	-41.87	-65.27	-61.13
	cradle to grave	Net results (∑)	68.67	67.01	58.36	36.46	46.41
Acidification [g SO_2-equivalents]	cradle to gate	Burdens	0.18	0.18	0.13	0.12	0.18
	gate to grave	Burdens	0.08	0.08	0.08	0.08	0.08
		Credits	-0.07	-0.07	-0.08	-0.08	-0.07
	cradle to grave	Net results (∑)	0.19	0.18	0.13	0.13	0.19
Summer smog [g O_3-equivalents]	cradle to gate	Burdens	2.23	2.17	1.85	1.64	2.11
	gate to grave	Burdens	1.21	1.22	1.24	1.24	1.21
		Credits	-0.86	-0.87	-0.91	-0.91	-0.86
	cradle to grave	Net results (∑)	2.58	2.52	2.18	1.97	2.46
Ozone Depletion [g R-11-equivalents]	cradle to gate	Burdens	0.04	0.04	0.04	0.04	0.04
	gate to grave	Burdens	0.02	0.02	0.02	0.02	0.02
		Credits	-0.03	-0.03	-0.03	-0.03	-0.03
	cradle to grave	Net results (∑)	0.04	0.04	0.04	0.04	0.04
Terrestrial eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	14.47	14.47	11.70	11.32	14.07
	gate to grave	Burdens	11.81	11.39	12.13	11.87	11.56
		Credits	-7.11	-7.15	-7.56	-7.56	-7.11
	cradle to grave	Net results (∑)	19.17	18.71	16.27	15.63	18.52
Aquatic eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	17.77	17.60	19.57	14.47	12.25
	gate to grave	Burdens	5.34	5.36	5.48	5.48	5.34
		Credits	-4.81	-4.82	-5.45	-5.45	-4.81
	cradle to grave	Net results (∑)	18.30	18.14	19.60	14.50	12.78
Particulate matter [g PM 2,5- equivalents]	cradle to gate	Burdens	0.17	0.17	0.13	0.12	0.16
	gate to grave	Burdens	0.08	0.08	0.08	0.08	0.08
		Credits	-0.07	-0.07	-0.07	-0.07	-0.07
	cradle to grave	Net results (∑)	0.18	0.18	0.14	0.13	0.18
Abiotic resource depletion [kg sb-equivalents]	cradle to gate	Burdens	0.09	0.09	0.08	0.04	0.05
	gate to grave	Burdens	0.03	0.03	0.03	0.03	0.03
		Credits	-0.04	-0.04	-0.04	-0.04	-0.04
	cradle to grave	Net results (∑)	0.08	0.08	0.07	0.03	0.04
Non-renewable primary energy [GJ]	cradle to gate	Burdens	1.12	1.12	0.98	0.54	0.66
	gate to grave	Burdens	0.39	0.39	0.39	0.39	0.39
		Credits	-0.50	-0.51	-0.51	-0.51	-0.50
	cradle to grave	Net results (∑)	1.00	1.00	0.86	0.42	0.55
Total Primary Energy [GJ]	cradle to gate	Burdens	1.94	1.95	1.83	1.40	1.49
	gate to grave	Burdens	0.48	0.48	0.48	0.48	0.48
		Credits	-0.85	-0.86	-0.91	-0.91	-0.85
	cradle to grave	Net results (∑)	1.57	1.57	1.40	0.98	1.12

*CO2 uptake is part of the production, but cannot be included in cradle to gate without the consideration of the end of life (grave).

4.2.3 Description and interpretation

combiblocSlimline (cb3) beverage cartons 1000 mL

The **LPB** shows the largest contribution in the results of 'Summer Smog', 'Particulate Matter', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Total Primary Energy'.

The production of the paper based materials generates emissions that cause contributions to both 'Aquatic Eutrophication' and 'Terrestrial Eutrophication', the latter to a lesser extent. Approximately half of the aquatic Eutrophication potential is caused by the high COD. As the production of LPB causes high contributions of organic compounds into the surface water an overabundance of oxygen-consuming reactions takes place which therefore may lead to oxygen shortage in the water. In the terrestrial Eutrophication potential nitrogen oxides are determined as main contributor. For the separation of the cellulose needed for paper production from the ligneous wood fibres, the so called 'Kraft process' is applied, in which sodium hydroxide and sodium sulphide are used. This leads to additional emissions of SO_2, thus contributing significantly to the acidifying potential. The required energy for paper production mainly originates from recovered process internal residues (hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. That explains its relatively small influence on 'Climate Change'.

For the **plastic for sleeve and the closure** the highest share on the environmental loads can be observed in 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' as well as in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'. The main material for the plastic for sleeve and closure of combiblocSlimline (cb3) **SIG**NATURE PACK 100 and combiblocSlimline (cb3) **SIG**NATURE PACK FB is allocated to bio-based feedstock via applying the mass balance principle. Nevertheless, the same cracking and polymerisation process is needed as for fossil plastics. These production steps play a major role in all impact categories. In addition, energy and hydrogen used by the hydrotreatment process for the production of bio-diesel lead to major contributions to the results of 'Climate Change' 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial and Aquatic Eutrophication', 'Abiotic Resource Depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy'. Nitrogen dioxide and sulphur dioxide emissions related to the acidulation process to produce crude tall oil from BLS play a dominant role in the category 'Acidification'. The additional information on the impacts of 'Summer Smog' related to VOCs show, that VOC emissions from plastic for sleeve contribute to approximately one third to the net results. These results from ethylene and Non-methane volatile organic compounds (NMVOC) emissions released during cracking of the bio-diesel and the polymerization of the plant-based ethylene or propylene to PE or PP.

The production of **aluminium foil** for the sleeves of the ambient beverage cartons containing aluminium foil show burdens in most impact categories. High shares of burdens are shown in the impact categories 'Acidification', 'Particulate Matter' and 'Terrestrial Eutrophication'. These result from SO_2 and NOx emissions from the aluminium production. The beverage cartons EcoPlus cSwift LP and **SIG**NATURE PACK 100 cSwift LP do not contain aluminium foil and therefore have no burdens in this process of production.

The largest contribution by the **filling** and **converting** process is observed in 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication', 'Abiotic Resource Depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy'. This results from the thermal energy and electricity input.

The **transport packaging** contributes to all examined categories. The results are dominated by the production of corrugated cardboard boxes. The paper production plays a major role in the most impact/inventory categories. The pallet and the stretch foil production play a minor role.

The life cycle step **distribution** shows similar burdens in all impact categories for all beverage carton systems.

The end-of-life phase (**recycling/disposal**) of the considered combiblocSlimline (cb3) beverage carton formats is clearly most relevant in the impact category 'Climate change', however the emissions also visibly contribute to 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication' and 'Aquatic Eutrophication' . A share of the greenhouse gases is related to energy generation required in the respective processes. Material recycling processes are commonly run on electricity, thus this end-of-life treatment contributes directly to the result values for the impact on 'Climate Change'. When the packaging materials are used as fuel in cement kilns or incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification' and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

The **energy credits** arise from incineration plants, where energy recovery takes place and from the use of the rejects as fuel in cement kilns.

Material credits are only given for material that is effectively recycled. The majority is received by the recycling of paper. The paper production causes high waterborne emissions, especially due to the transformation of raw wood to paper fibres. Therefore, the post-consumer recycling of paper fibres from LPB avoids this determining process step (as secondary paper fibres substitute for primary fibres), which leads to material credits.

The **uptake of CO_2** by the trees harvested for the production of paperboard and the mass-balanced plastic plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration or be forwarded to the next product system in a recycled product.

If an allocation factor of 100 % is applied, all burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes) and all credits from recovery processes (i.e. avoided electricity generation due to energy recovery at MSWIs, avoided primary material production due to recycling) are allocated to the examined systems. In the European market, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are slightly lower with an applied allocation factor of 100 % (scenario II) compared to scenario I (allocation factor 50%) apart from 'Climate Change'. For 'Climate Change' the benefit from receiving more credits does not outweigh the extra burdens obtained. The main reasons for this are the emissions of the waste incineration plants which are now fully allocated to the examined system. **Regenerative CO_2** emissions are accounted for 'Climate Change' in the same way as fossil CO_2 emissions.

For the European scope, the credits for energy recovery have the same importance than the material credits in categories that are driven by thermal energy and electricity generation: ‘Climate Change’, ‘Ozone Depletion’, ‘Summer Smog’, ‘Particulate Matter’, ‘Acidification’, ‘Terrestrial and Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ and ‘Non-renewable Primary Energy. This results from the relative high electrical and thermal efficiencies of the MWSI plants.

4.2.4 Comparison between systems

The percentages in the **Table 4-3** show the difference of net results between all considered formats of combiblocSlimline (cb3) beverage cartons in the same volume segment. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 4-3: Comparison of net results **combiblocSlimline (cb3) beverage cartons** (Europe)

	The net results of									
	combiblocSlimline (cb3) EcoPlus cSwift LP 1000 mL		**combiblocSlimline (cb3) SIGNATURE 100 cSwift LP 1000 mL**				**combiblocSlimline (cb3) SIGNATURE FB cSwift 1000 mL**		**combiblocSlimline (cb3) SIGNATURE FB cMaxx 1000 mL**	
	are lower (green)/higher (red) than those of									
	combiblocSlimline (cb3) standard RS cSwift 1000 mL		combiblocSlimline (cb3) standard RS cSwift 1000 mL		combiblocSlimline (cb3) EcoPlus cSwift LP 1000 mL		combiblocSlimline (cb3) standard RS cSwift 1000 mL		combiblocSlimline (cb3) standard RS cMaxx 1000 mL	
	AF 50	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**
Impact categories										
Climate Change	-23%	-15%	-63%	-47%	-52%	-38%	-41%	-32%	-41%	-32%
Ozone Depletion	-1%	-5%	-1%	-4%	+0%	+0%	+0%	+0%	+0%	+0%
Summer Smog	-14%	-15%	-21%	-24%	-9%	-10%	-4%	-5%	-4%	-5%
Particulate Matter	-22%	-25%	-25%	-28%	-4%	-5%	-3%	-3%	-3%	-3%
Acidification	-26%	-31%	-29%	-33%	-3%	-4%	-2%	-2%	-2%	-2%
Terrestrial Eutrophication	-13%	-15%	-16%	-18%	-3%	-4%	-3%	-3%	-3%	-3%
Aquatic Eutrophication	+8%	+7%	-17%	-21%	-23%	-26%	-27%	-30%	-27%	-29%
Abiotic Resource Depletion	-12%	-15%	-54%	-67%	-48%	-61%	-45%	-55%	-44%	-54%
Non-renewable Primary Energy	-11%	-14%	-47%	-58%	-40%	-51%	-37%	-46%	-36%	-44%
Total Primary Energy	-7%	-10%	-29%	-38%	-23%	-30%	-23%	-29%	-22%	-28%

Description and discussion

In both scenarios, the **combiblocSlimline (cb3) EcoPlus cSwift LP** shows lower net results than the combiblocSlimline (cb3) standard RS cSwift in the impact categories 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication' and 'Abiotic Resource Depletion' and in the inventory category 'Non-renewable Primary Energy'.

Due to the higher 'LPB', 'closure' and 'plastics for sleeve' material share, which also includes the material share of the barrier material fossil PA, the combiblocSlimline (cb3) EcoPlus cSwift LP carton shows minimally higher burdens in these packaging components as well as in the 'converting'. The decisive factor that causes the overall higher burdens of the combiblocSlimline (cb3) standard RS cSwift in the above-mentioned categories is the 'aluminium foil' (barrier material), which is also the only part of the packaging system that shows higher burdens compared to the combiblocSlimline (cb3) EcoPlus cSwift LP carton.

In both scenarios, the **combiblocSlimline (cb3) SIGNATURE 100 cSwift LP** shows lower net results than the combiblocSlimline (cb3) standard RS cSwift in all impact and inventory categories except in the category 'Ozone Depletion'.

The comparison of the combiblocSlimline (cb3) **SIG**NATURE 100 cSwift LP with the combiblocSlimline (cb3) standard RS cSwift shows most considerable differences in net results in the categories considered. The mass-balanced PA, PE and PP in the sleeve and closure of the combiblocSlimline (cb3) **SIG**NATURE 100 cSwift LP lead to additional significantly lower net results in the categories of 'Aquatic Eutrophication' and 'Total Primary Energy' compared to the combiblocSlimline (cb3) standard RS cSwift than in the comparison of combiblocSlimline (cb3) EcoPlus cSwift LP vs. combiblocSlimline (cb3) standard RS cSwift.

In both scenarios, the **combiblocSlimline (cb3) SIGNATURE 100 cSwift LP** shows lower net results than the combiblocSlimline (cb3) EcoPlus cSwift LP in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PA, PE and PP in the sleeve and closure of the combiblocSlimline (cb3) **SIG**NATURE 100 cSwift LP is the only difference to the combiblocSlimline (cb3) EcoPlus cSwift LP, that leads to significantly lower net results in the categories mentioned.

In both scenarios, the **combiblocSlimline (cb3) SIGNATURE FB cSwift** shows lower net results than the combiblocSlimline (cb3) standard cSwift in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PE and PP in the sleeve and closure of the combiblocSlimline (cb3) **SIG**NATURE FB cSwift is the only difference to the combiblocSlimline (cb3) EcoPlus cSwift LP, that leads to significantly lower net results in the categories mentioned.

In both scenarios, the **combiblocSlimline (cb3) SIGNATURE FB cMaxx** shows lower net results than the combiblocSlimline (cb3) standard RS cMaxx in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PE and PP in the sleeve and closure of the combiblocSlimline (cb3) **SIG**NATURE FB cMaxx is the only difference to the combiblocSlimline (cb3) standard RS cMaxx, that leads to significantly lower net results in the categories mentioned.

Summary

To summarise, the LCIA categories showing advantages for mass-balanced plastics are 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy'. LCIA categories showing advantages for beverage cartons with PA-based barrier, instead of aluminium, material are 'Summer Smog', 'Particulate Matter', 'Acidification' and 'Terrestrial Eutrophication'. The category 'Ozone Depletion' shows similar results for all examined carton packaging systems.

A higher allocation factor implies the allocation of more burdens from the end-of-life processes (for example emissions from incineration, emissions from the production of electricity for recycling processes). It also implies the allocation of more credits for the substitution of other processes (for example energy credits for avoided electricity generation due to energy recovery at MSWIs or material credits for avoided production of new materials). When applying an allocation factor of 100%, all burdens and all credits are allocated to the regarded system.

Since the compared cartons only differ in material composition and/or material share and the material credits are more significant in scenario ll (AF 100) than in scenario l (AF 50), the differences between the developed carton packaging systems (EcoPlus, **SIG**NATURE PACKS) and the comparison cartons in scenario ll are larger in all impact categories except 'Climate Change'.

In case of 'Climate Change', applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor does not affect the CO_2 uptake, therefore the values for the CO_2 uptake don't increase when applying the 100% allocation factor.

4.3 Europe combiblocMidi (cb8) beverage cartons 1000 mL

4.3.1 Scenario I (50 % allocation): Numerical values and graphs

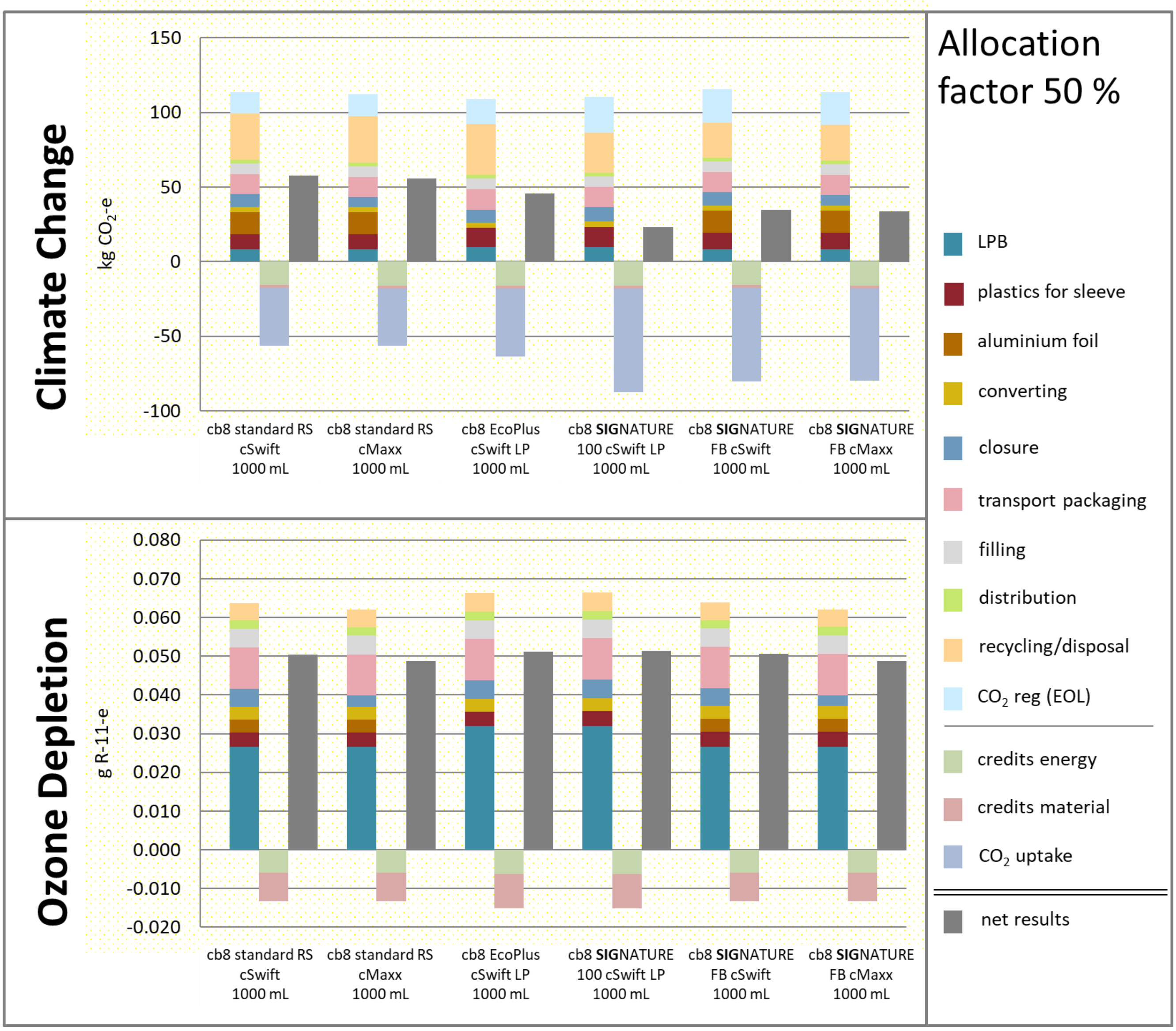

Figure 4-9: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50 % (Part 1)

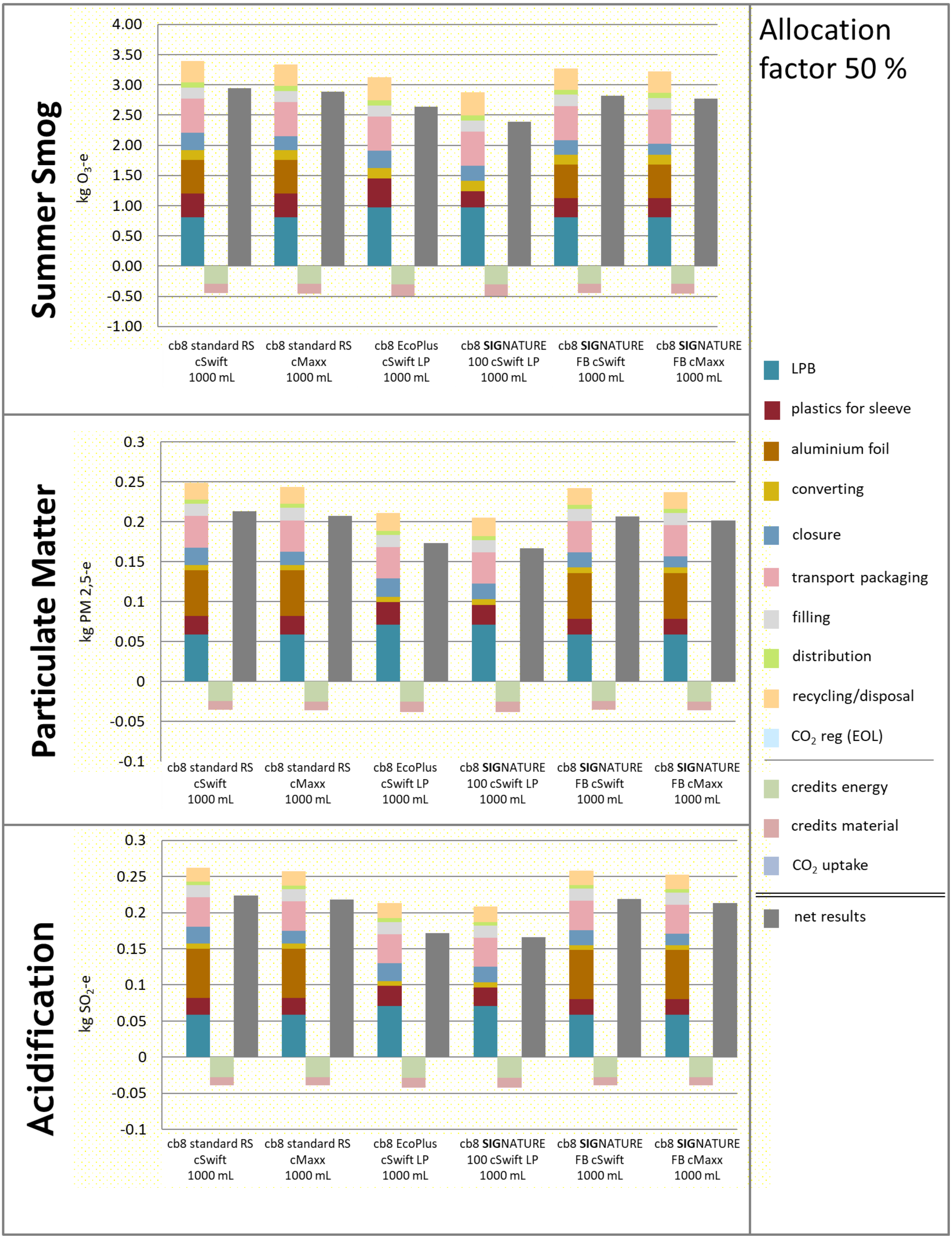

Figure 4-10: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50 % (Part 2)

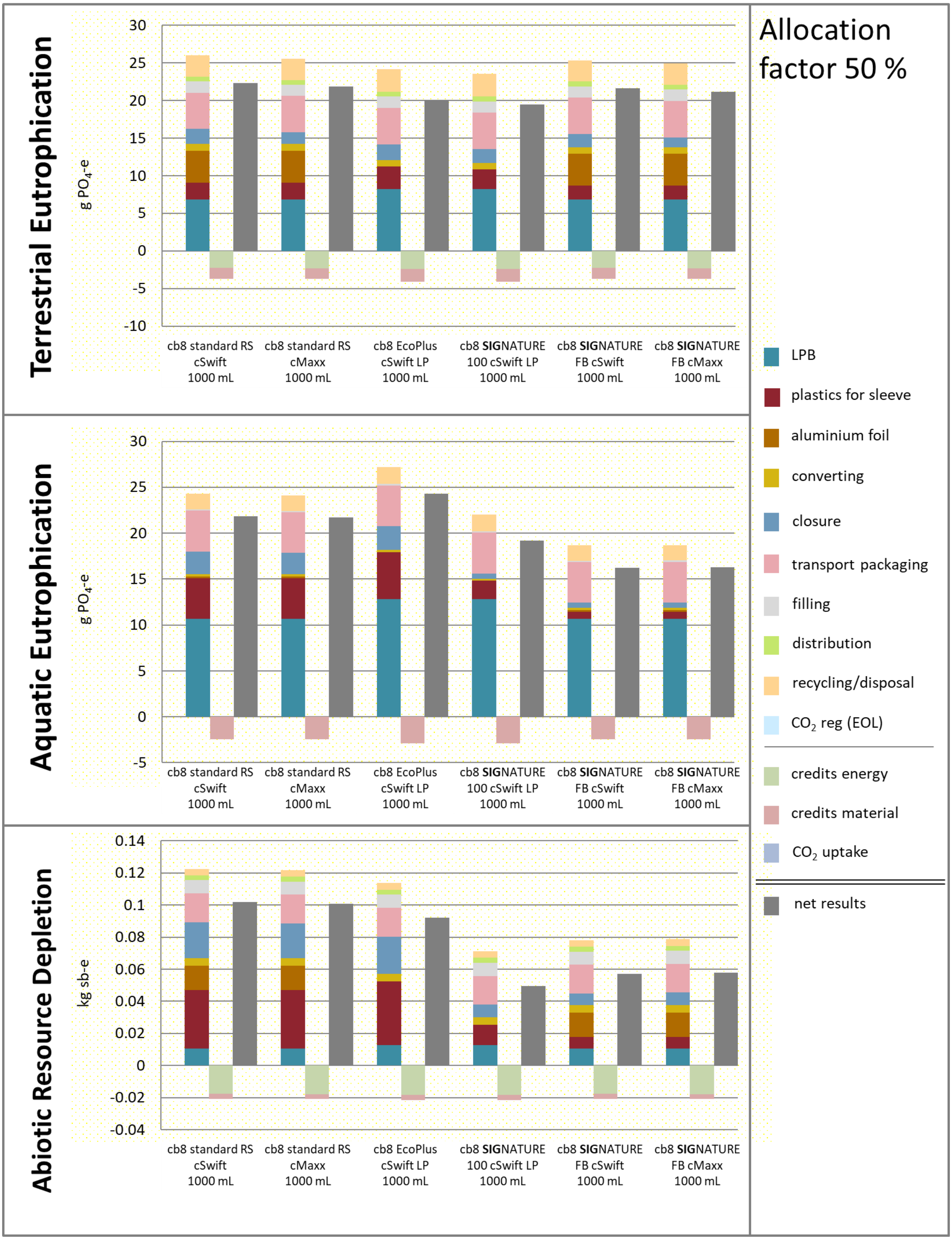

Figure 4-11: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50 % (Part 3)

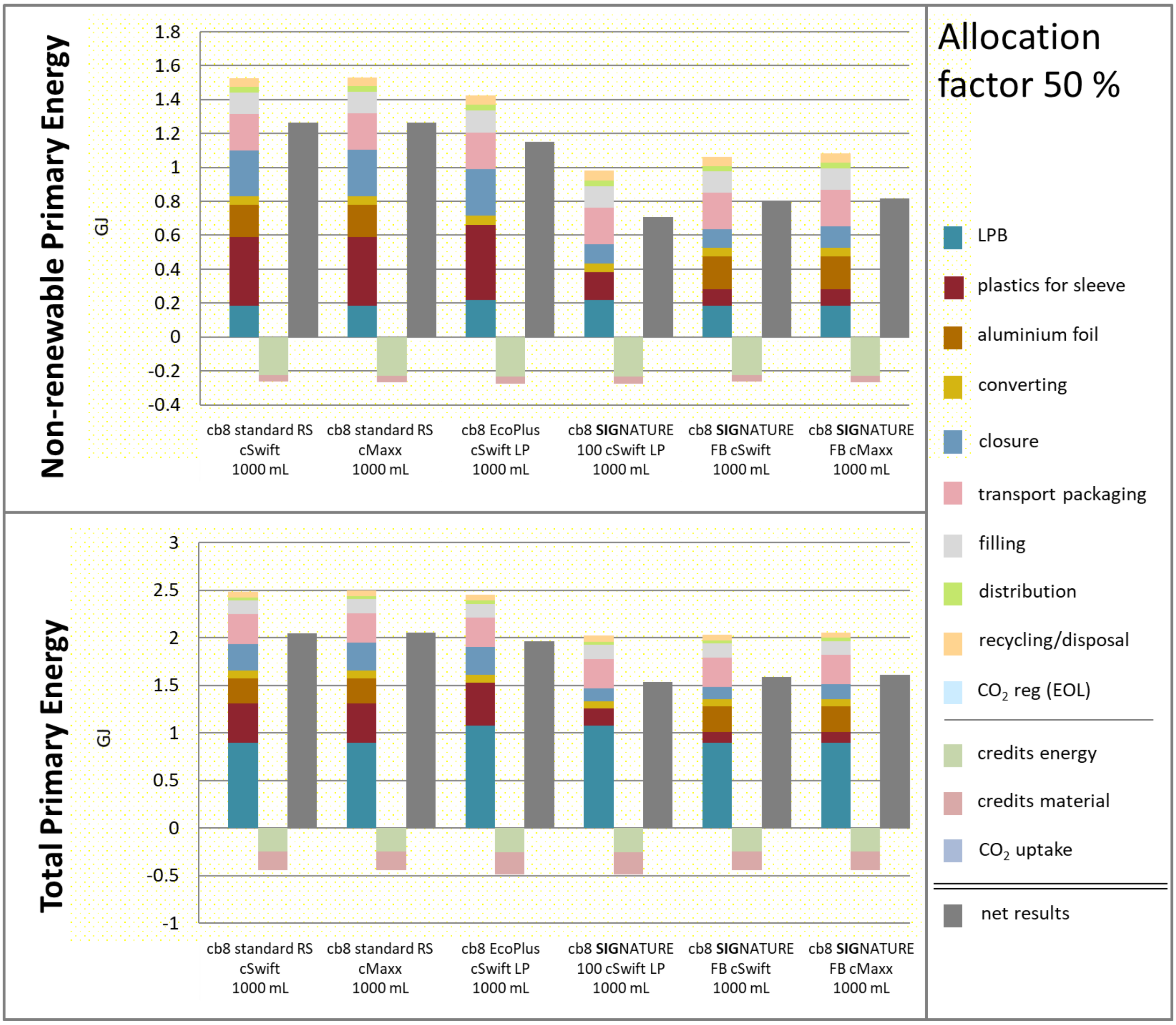

Figure 4-12: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50 % (Part 4)

Table 4-4: Category indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Europe, allocation factor 50 %			cb8 standard RS cSwift 1000 mL	cb8 standard RS cMaxx 1000 mL	cb8 EcoPlus cSwift LP 1000 mL	cb8 SIGNATURE 100 cSwift LP 1000 mL	cb8 SIGNATURE FB cSwift 1000 mL	cb8 SIGNATURE FB cMaxx 1000 mL
Climate change [kg CO_2-equivalents]	cradle to gate	Burdens	44.95	43.05	34.83	36.33	46.67	44.69
	gate to grave	Burdens	54.18	54.50	57.15	49.95	46.34	46.91
		CO_2 (reg)	14.61	14.62	17.02	24.22	22.45	22.20
		Credits	-17.70	-17.88	-18.22	-18.22	-17.70	-17.88
		CO_2 uptake*	-38.68	-38.69	-45.29	-69.32	-62.93	-62.12
	cradle to grave	Net results (∑)	57.38	55.61	45.50	22.96	34.83	33.80
Acidification [g SO_2-equivalents]	cradle to gate	Burdens	0.18	0.18	0.13	0.13	0.18	0.17
	gate to grave	Burdens	0.08	0.08	0.08	0.08	0.08	0.08
		Credits	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
	cradle to grave	Net results (∑)	0.22	0.22	0.17	0.17	0.22	0.21
Summer smog [g O_3-equivalents]	cradle to gate	Burdens	2.20	2.15	1.91	1.66	2.08	2.03
	gate to grave	Burdens	1.19	1.19	1.22	1.22	1.19	1.19
		Credits	-0.45	-0.45	-0.49	-0.49	-0.45	-0.45
	cradle to grave	Net results (∑)	2.94	2.88	2.64	2.39	2.82	2.77
Ozone Depletion [g R-11-equivalents]	cradle to gate	Burdens	0.04	0.04	0.04	0.04	0.04	0.04
	gate to grave	Burdens	0.02	0.02	0.02	0.02	0.02	0.02
		Credits	-0.01	-0.01	-0.02	-0.02	-0.01	-0.01
	cradle to grave	Net results (∑)	0.05	0.05	0.05	0.05	0.05	0.05
Terrestrial eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	14.25	14.24	12.14	11.75	13.83	13.83
	gate to grave	Burdens	11.74	11.30	12.05	11.80	11.49	11.08
		Credits	-3.71	-3.73	-4.09	-4.09	-3.71	-3.73
	cradle to grave	Net results (∑)	22.28	21.82	20.11	19.46	21.61	21.18
Aquatic eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	18.01	17.84	20.75	15.61	12.41	12.43
	gate to grave	Burdens	6.27	6.28	6.43	6.43	6.27	6.28
		Credits	-2.43	-2.43	-2.88	-2.88	-2.43	-2.43
	cradle to grave	Net results (∑)	21.85	21.69	24.30	19.16	16.25	16.28
Particulate matter [g PM 2,5- equivalents]	cradle to gate	Burdens	0.17	0.16	0.13	0.12	0.16	0.16
	gate to grave	Burdens	0.08	0.08	0.08	0.08	0.08	0.08
		Credits	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
	cradle to grave	Net results (∑)	0.21	0.21	0.17	0.17	0.21	0.20
Abiotic resource depletion [kg sb-equivalents]	cradle to gate	Burdens	0.09	0.09	0.08	0.04	0.04	0.05
	gate to grave	Burdens	0.03	0.03	0.03	0.03	0.03	0.03
		Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	cradle to grave	Net results (∑)	0.10	0.10	0.09	0.05	0.06	0.06
Non-renewable primary energy [GJ]	cradle to gate	Burdens	1.10	1.10	0.99	0.55	0.63	0.65
	gate to grave	Burdens	0.43	0.43	0.43	0.43	0.43	0.43
		Credits	-0.26	-0.27	-0.27	-0.27	-0.26	-0.27
	cradle to grave	Net results (∑)	1.26	1.27	1.15	0.71	0.80	0.82
Total Primary Energy [GJ]	cradle to gate	Burdens	1.94	1.95	1.90	1.47	1.48	1.51
	gate to grave	Burdens	0.55	0.55	0.55	0.55	0.55	0.55
		Credits	-0.44	-0.44	-0.49	-0.49	-0.44	-0.44
	cradle to grave	Net results (∑)	2.04	2.05	1.97	1.54	1.59	1.61

*CO2 uptake is part of the production, but cannot be included in cradle to gate without the consideration of the end of life (grave).

4.3.2 Scenario II (100 % allocation): Numerical values and graphs

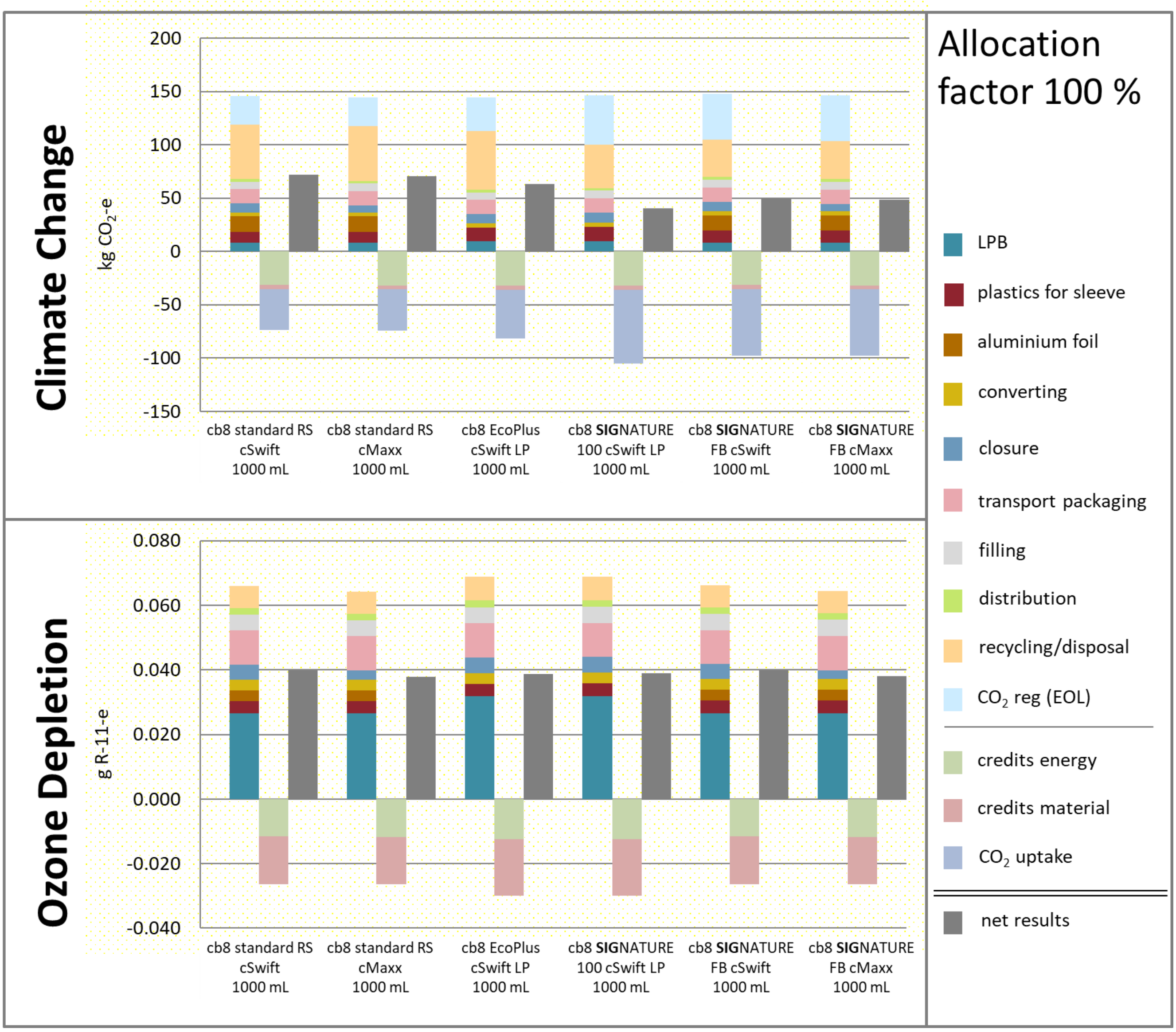

Figure 4-13: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 % (Part 1)

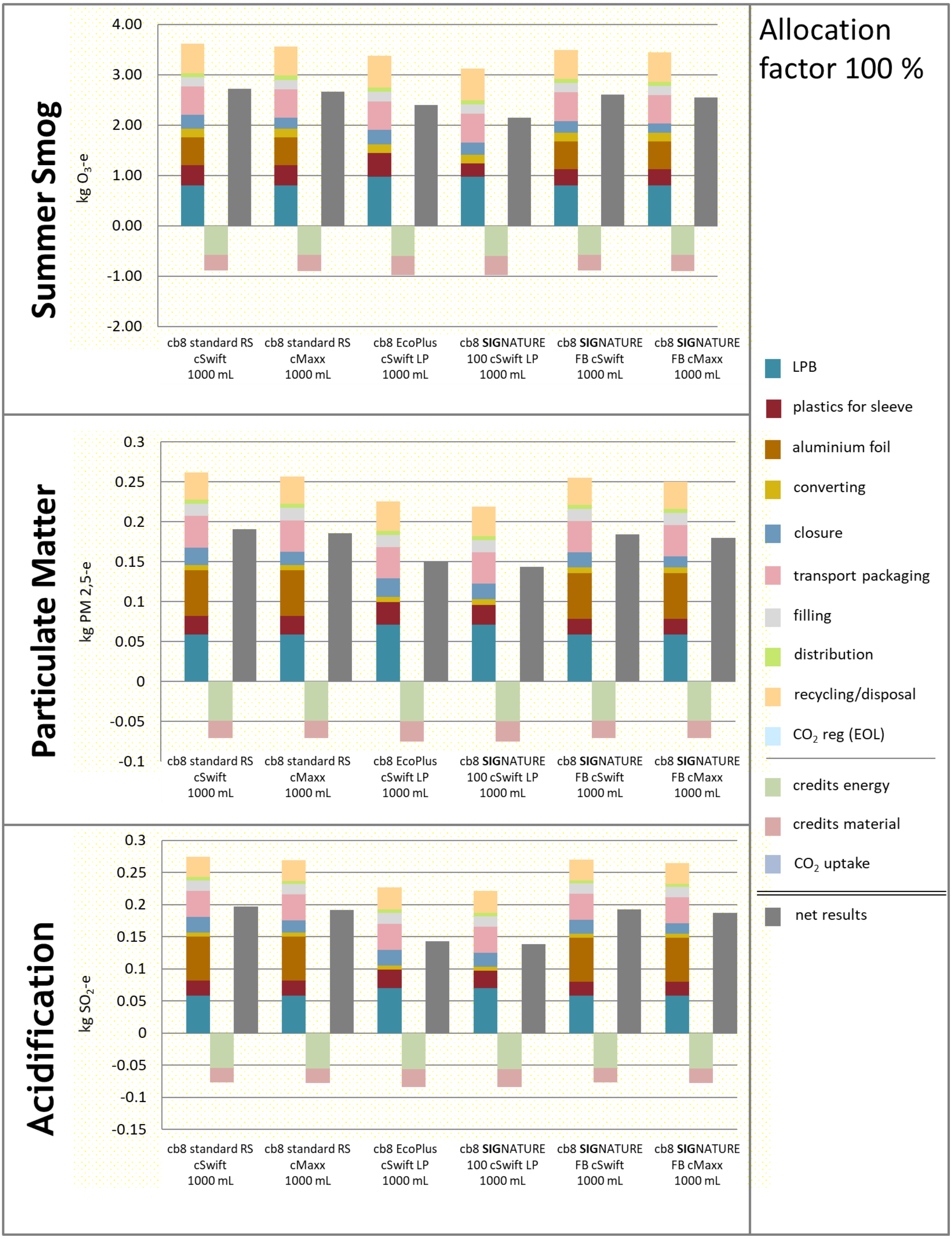

Figure 4-14: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 % (Part 2)

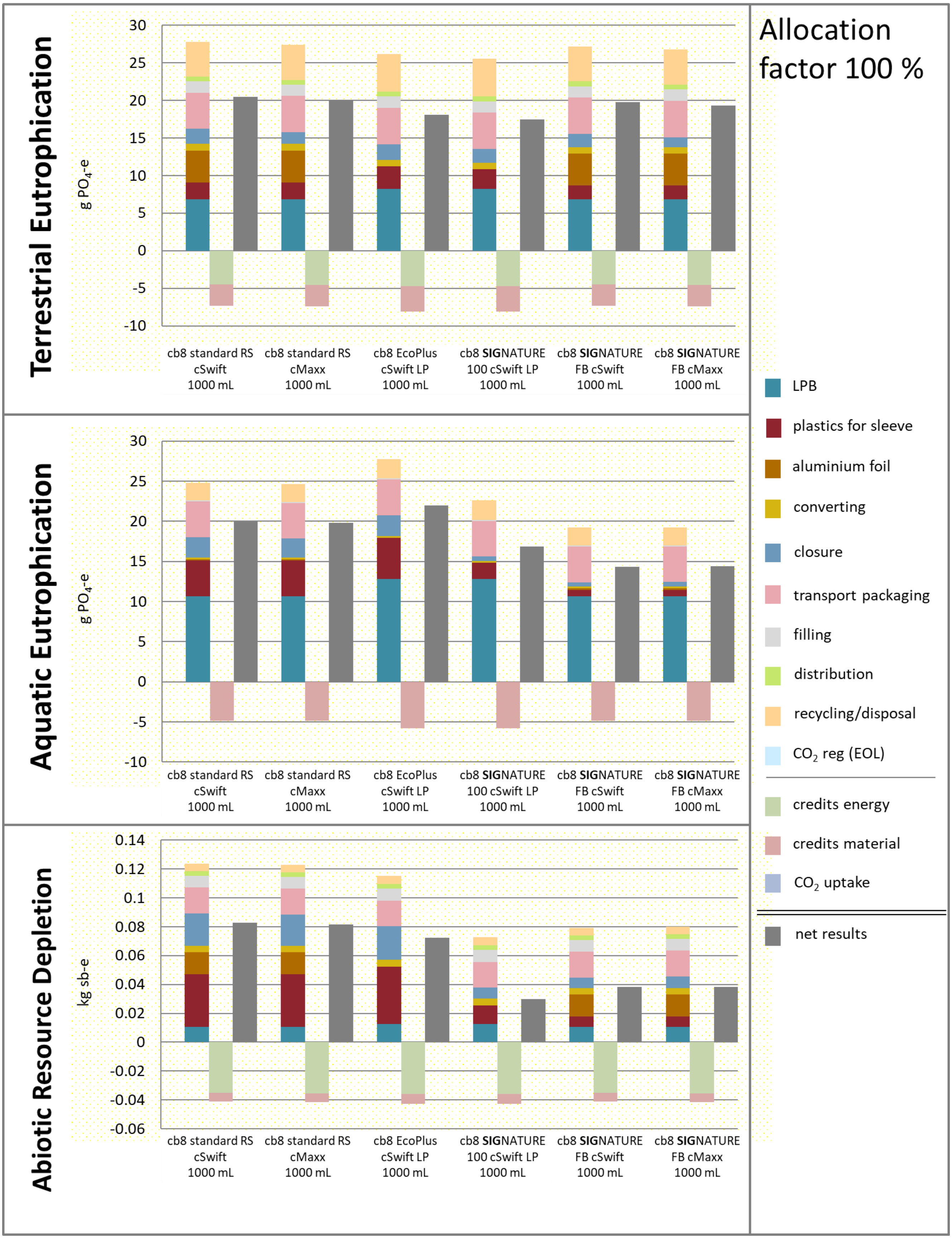

Figure 4-15: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100% (Part 3)

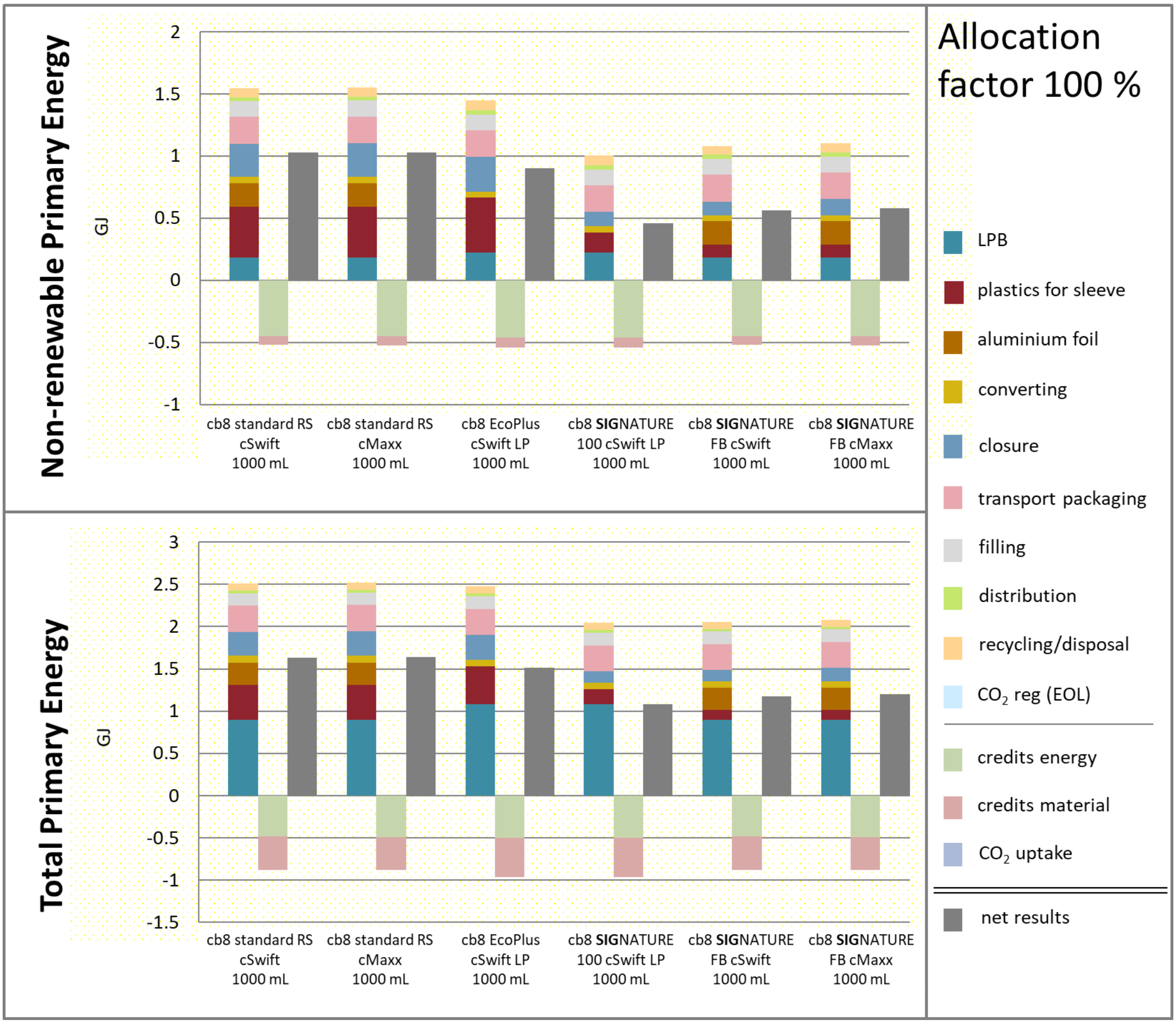

Figure 4-16: Indicator results for **scenario ll Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100% (Part 4)

Table 4-5: Category indicator results for **scenario ll Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100%: burdens, credits and net results per functional unit of 1000 L beverage

Scenario ll Europe, allocation factor 100 %			cb8 standard RS cSwift 1000 mL	cb8 standard RS cMaxx 1000 mL	cb8 EcoPlus cSwift LP 1000 mL	cb8 SIGNATURE 100 cSwift LP 1000 mL	cb8 SIGNATURE FB cSwift 1000 mL	cb8 SIGNATURE FB cMaxx 1000 mL
Climate change [kg CO_2-equivalents]	cradle to gate	Burdens	44.95	43.05	34.83	36.33	46.67	44.69
	gate to grave	Burdens	73.71	74.32	78.15	63.75	58.03	59.14
		CO_2 (reg)	27.18	27.19	31.72	46.11	42.86	42.36
		Credits	-35.10	-35.46	-36.10	-36.10	-35.10	-35.46
		CO_2 uptake*	-38.68	-38.69	-45.29	-69.32	-62.93	-62.12
	cradle to grave	Net results (∑)	72.07	70.42	63.31	40.76	49.52	48.60
Acidification [g SO_2-equivalents]	cradle to gate	Burdens	0.18	0.18	0.13	0.13	0.18	0.17
	gate to grave	Burdens	0.09	0.09	0.10	0.10	0.09	0.09
		Credits	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08
	cradle to grave	Net results (∑)	0.20	0.19	0.14	0.14	0.19	0.19
Summer smog [g O_3-equivalents]	cradle to gate	Burdens	2.20	2.15	1.91	1.66	2.08	2.03
	gate to grave	Burdens	1.41	1.42	1.47	1.47	1.41	1.42
		Credits	-0.89	-0.90	-0.98	-0.98	-0.89	-0.90
	cradle to grave	Net results (∑)	2.73	2.67	2.40	2.15	2.60	2.55
Ozone Depletion [g R-11-equivalents]	cradle to gate	Burdens	0.04	0.04	0.04	0.04	0.04	0.04
	gate to grave	Burdens	0.02	0.02	0.03	0.03	0.02	0.02
		Credits	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
	cradle to grave	Net results (∑)	0.04	0.04	0.04	0.04	0.04	0.04
Terrestrial eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	14.24	14.23	12.13	11.74	13.82	13.82
	gate to grave	Burdens	13.57	13.15	14.04	13.79	13.32	12.92
		Credits	-7.36	-7.40	-8.10	-8.10	-7.36	-7.40
	cradle to grave	Net results (∑)	20.45	19.99	18.07	17.42	19.79	19.35
Aquatic eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	18.01	17.84	20.75	15.61	12.41	12.43
	gate to grave	Burdens	6.78	6.79	7.01	7.01	6.78	6.79
		Credits	-4.86	-4.86	-5.76	-5.76	-4.86	-4.86
	cradle to grave	Net results (∑)	19.93	19.77	22.00	16.86	14.34	14.37
Particulate matter [g PM 2,5- equivalents]	cradle to gate	Burdens	0.17	0.16	0.13	0.12	0.16	0.16
	gate to grave	Burdens	0.09	0.09	0.10	0.10	0.09	0.09
		Credits	-0.07	-0.07	-0.08	-0.08	-0.07	-0.07
	cradle to grave	Net results (∑)	0.19	0.19	0.15	0.14	0.18	0.18
Abiotic resource depletion [kg sb-equivalents]	cradle to gate	Burdens	0.09	0.09	0.08	0.04	0.04	0.05
	gate to grave	Burdens	0.03	0.03	0.03	0.03	0.03	0.03
		Credits	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
	cradle to grave	Net results (∑)	0.08	0.08	0.07	0.03	0.04	0.04
Non-renewable primary energy [GJ]	cradle to gate	Burdens	1.10	1.10	0.99	0.55	0.63	0.65
	gate to grave	Burdens	0.45	0.45	0.45	0.45	0.45	0.45
		Credits	-0.52	-0.53	-0.54	-0.54	-0.52	-0.53
	cradle to grave	Net results (∑)	1.03	1.03	0.90	0.46	0.56	0.58
Total Primary Energy [GJ]	cradle to gate	Burdens	1.94	1.95	1.90	1.47	1.48	1.51
	gate to grave	Burdens	0.57	0.57	0.58	0.58	0.57	0.57
		Credits	-0.88	-0.88	-0.97	-0.97	-0.88	-0.88
	cradle to grave	Net results (∑)	1.63	1.64	1.51	1.08	1.18	1.20

*CO2 uptake is part of the production, but cannot be included in cradle to gate without the consideration of the end of life (grave).

4.3.3 Description and interpretation

combiblocMidi (cb8) beverage cartons 1000 mL

The **LPB** shows the largest contribution in the results of 'Summer Smog', 'Particulate Matter', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Ozone Depletion'.

The production of the paper based materials generates emissions that cause contributions to both 'Aquatic Eutrophication' and 'Terrestrial Eutrophication', the latter to a lesser extent. Approximately half of the Aquatic Eutrophication potential is caused by the high COD. As the production of LPB causes high contributions of organic compounds into the surface water an overabundance of oxygen-consuming reactions takes place which therefore may lead to oxygen shortage in the water. In the terrestrial Eutrophication potential nitrogen oxides are determined as main contributor. For the separation of the cellulose needed for paper production from the ligneous wood fibres, the so called 'Kraft process' is applied, in which sodium hydroxide and sodium sulphide are used. This leads to additional emissions of SO_2, thus contributing significantly to the acidifying potential. The required energy for paper production mainly originates from recovered process internal residues (hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. That explains its relatively small influence on 'Climate Change'.

For the **plastic for sleeve and the closure** the highest share on the environmental loads can be observed in 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' as well as in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'. The main material for the plastic for sleeve and closure of combiblocMidi (cb8) **SIG**NATURE PACK 100 and combiblocMidi (cb8) **SIG**NATURE PACK FB is allocated to bio-based feedstock via applying the mass balance principle. Nevertheless, the same cracking and polymerisation process is needed as for fossil plastics. These production steps play a major role in all impact categories. In addition, energy and hydrogen used by the hydrotreatment process for the production of bio-diesel lead to major contributions to the results of 'Climate Change' 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial and Aquatic Eutrophication', 'Abiotic Resource Depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy'. Nitrogen dioxide and sulphur dioxide emissions related to the acidulation process to produce crude tall oil from BLS play a dominant role in the category 'Acidification'. The additional information on the impacts of 'Summer Smog' related to VOCs show, that VOC emissions from plastic for sleeve contribute to approximately one third to the net results. These results from ethylene and NMVOC emissions released during cracking of the bio-diesel and the polymerization of the plant-based ethylene or propylene to PE or PP.

The production of **aluminium foil** for the sleeves of the ambient beverage cartons containing aluminium foil show burdens in most impact categories. High shares of burdens are shown in the impact categories 'Acidification', 'Particulate Matter' and 'Terrestrial Eutrophication'. These result from SO_2 and NOx emissions from the aluminium production. The beverage cartons EcoPlus cSwift LP and **SIG**NATURE PACK 100 cSwift LP do not contain aluminium foil and therefore have no burdens in this process of production.

The largest contribution by the **filling** and **converting** process is observed in 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication', 'Abiotic Resource Depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy'. This results from the thermal energy and electricity input.

The **transport packaging** contributes to all examined categories. The results are dominated by the production of corrugated cardboard boxes. The paper production plays a major role in the most impact/inventory categories. The pallet and the stretch foil production play a minor role.

The life cycle step **distribution** shows similar burdens in all impact categories for all beverage carton systems.

The end-of-life phase (**recycling/disposal**) of the considered combiblocMidi (cb8) beverage carton formats is clearly most relevant in the impact category 'Climate change', however the emissions also visibly contribute to 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication' and 'Aquatic Eutrophication' . A share of the greenhouse gases is related to energy generation required in the respective processes. Material recycling processes are commonly run on electricity, thus this end-of-life treatment contributes directly to the result values for the impact on 'Climate Change'. When the packaging materials are used as fuel in cement kilns or incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification' and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

The **energy credits** arise from incineration plants, where energy recovery takes place and from the use of the rejects as fuel in cement kilns.

Material credits are only given for material that is effectively recycled. The majority is received by the recycling of paper. The paper production causes high waterborne emissions, especially due to the transformation of raw wood to paper fibres. Therefore, the post-consumer recycling of paper fibres from LPB avoids this determining process step (as secondary paper fibres substitute for primary fibres), which leads to material credits.

The **uptake of CO_2** by the trees harvested for the production of paperboard and the mass-balanced plastic plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration or be forwarded to the next product system in a recycled product.

If an allocation factor of 100% is applied, all burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes) and all credits from recovery processes (i.e. avoided electricity generation due to energy recovery at MSWIs, avoided primary material production due to recycling) are allocated to the examined systems. In the European market, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are slightly lower with an applied allocation factor of 100% (scenario ll) compared to allocation factor 50% (scenario l) apart from 'Climate Change'. For 'Climate Change' the benefit from receiving more credits does not outweigh the extra burdens obtained. The main reasons for this are the emissions of the waste incineration plants which are now fully allocated to the examined system. **Regenerative CO_2** emissions are accounted for 'Climate Change' in the same way as fossil CO_2 emissions.

For the European scope, the credits for energy recovery have the same importance than the material credits in categories that are driven by thermal energy and electricity generation: 'Climate Change', 'Ozone Depletion', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial and Aquatic Eutrophication', 'Abiotic Resource Depletion' and 'Non-renewable Primary Energy. This results from the relative high electrical and thermal efficiencies of the MWSI plants.

4.3.4 Comparison between systems

The percentages in **Table 4-6** show the difference of net results between all considered formats of combiblocMidi (cb8) beverage cartons in the same volume segment. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 4-6: Comparison of net results **combiblocMidi (cb8) beverage cartons** (Europe)

	The net results of									
	combiblocMidi (cb8) EcoPlus cSwift LP 1000 mL		**combiblocMidi (cb8) SIGNATURE 100 cSwift LP 1000 mL**				**combiblocMidi (cb8) SIGNATURE FB cSwift 1000 mL**		**combiblocMidi (cb8) SIGNATURE FB cMaxx 1000 mL**	
	are lower (green)/higher (red) than those of									
	combiblocMidi (cb8) standard RS cSwift 1000 mL		combiblocMidi (cb8) standard RS cSwift 1000 mL		combiblocMidi (cb8) EcoPlus cSwift LP 1000 mL		combiblocMidi (cb8) standard RS cSwift 1000 mL		combiblocMidi (cb8) standard RS cMaxx 1000 mL	
	AF 50	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**
Impact categories										
Climate Change	-21%	-12%	-60%	-43%	-50%	-36%	-39%	-31%	-39%	-31%
Ozone Depletion	+1%	-2%	+2%	-2%	+0%	+0%	+0%	+0%	+0%	+0%
Summer Smog	-10%	-12%	-19%	-21%	-10%	-10%	-4%	-4%	-4%	-4%
Particulate Matter	-19%	-22%	-22%	-25%	-4%	-4%	-3%	-3%	-3%	-3%
Acidification	-23%	-28%	-26%	-30%	-3%	-3%	-2%	-2%	-2%	-2%
Terrestrial Eutrophication	-10%	-12%	-13%	-15%	-3%	-4%	-3%	-3%	-3%	-3%
Aquatic Eutrophication	+11%	+10%	-12%	-15%	-21%	-23%	-26%	-28%	-25%	-27%
Abiotic Resource Depletion	-9%	-12%	-51%	-64%	-46%	-59%	-44%	-54%	-43%	-53%
Non-renewable Primary Energy	-9%	-12%	-44%	-55%	-39%	-49%	-37%	-45%	-36%	-44%
Total Primary Energy	-4%	-7%	-25%	-34%	-22%	-29%	-22%	-28%	-21%	-27%

Description and discussion

In both scenarios, the **combiblocMidi (cb8) EcoPlus cSwift LP** shows lower net results than the combiblocMidi (cb8) standard RS cSwift in the impact categories 'Climate Change', 'Particulate Matter' and 'Acidification. In scenario I (AF 50), the impact category 'Aquatic Eutrophication' of the assessed beverage carton shows higher net results than the combiblocMidi (cb8) standard RS cSwift. Further-more in scenario II (AF 100), in the impact categories 'Summer Smog', 'Terrestrial Eutrophication', 'Abi-otic Resource Depletion' and in the inventory category 'Non-renewable Primary Energy' the combiblocMidi (cb8) EcoPlus cSwift LP shows lower net results than the combiblocMidi (cb8) standard RS cSwift.

Due to the higher 'LPB', 'closure' and 'plastics for sleeve' material share, which also includes the mate-rial share of the barrier material fossil PA, the combiblocMidi (cb8) EcoPlus cSwift LP carton shows minimally higher burdens in these packaging components as well as in the 'converting'. The decisive factor that causes the overall higher burdens of the combiblocMidi (cb8) standard RS cSwift in the above-mentioned categories is the 'aluminium foil' (barrier material), which is also the only part of the packaging system that shows higher burdens compared to the combiblocMidi (cb8) EcoPlus cSwift LP carton. The impact of aluminium foil in the category 'Aquatic Eutrophication' is limited, though because the high impacts of aluminium foil production originates from its high energy demand. In the category 'Aquatic Eutrophication', the production of LPB and plastics for sleeve show the highest share of the net results. This has a negative effect for the heavier EcoPlus cSwift LP carton. As the material credits in scenario II (AF 100) are higher than in scenario I (AF 50), only significant differences are observed in scenario I.

In both scenarios, the **combiblocMidi (cb8) SIGNATURE 100 cSwift LP** shows lower net results than the combiblocMidi (cb8) standard RS cSwift in all impact and inventory categories except in the category 'Ozone Depletion'.

The comparison of the combiblocMidi (cb8) **SIG**NATURE 100 cSwift LP with the combiblocMidi (cb8) standard RS cSwift shows most considerable differences in net results in the categories considered. The mass-balanced PA, PE and PP in the sleeve and closure of the combiblocMidi (cb8) **SIG**NATURE 100 cSwift LP lead to additional significantly lower net results in the categories of 'Aquatic Eutrophication' and 'Total Primary Energy' compared to the combiblocMidi (cb8) standard RS cSwift than in the com-parison of combiblocMidi (cb8) EcoPlus cSwift LP vs. combiblocMidi (cb8) standard RS cSwift.

In both scenarios, the **combiblocMidi (cb8) SIGNATURE 100 cSwift LP** shows lower net results than the combiblocMidi (cb8) EcoPlus cSwift LP in the impact categories 'Climate Change', 'Aquatic Eutrophica-tion', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PA, PE and PP in the sleeve and closure of the combiblocMidi (cb8) **SIG**NATURE 100 cSwift LP is the only difference to the combiblocMidi (cb8) EcoPlus cSwift LP, that leads to significantly lower net results in the categories mentioned.

In both scenarios, the **combiblocMidi (cb8) SIGNATURE FB cSwift** shows lower net results than the combiblocMidi (cb8) standard RS cSwift in the impact categories 'Climate Change', 'Aquatic Eutrophi-cation', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PE and PP in the sleeve and closure of the combiblocMidi (cb8) **SIG**NATURE FB cSwift is the only difference to the combiblocMidi (cb8) standard RS cSwift, that leads to significantly lower net results in the categories mentioned.

In both scenarios, the **combiblocMidi (cb8) SIGNATURE FB cMaxx** shows lower net results than the combiblocMidi (cb8) standard RS cMaxx in the impact categories ‘Climate Change’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ and in the inventory categories ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

The mass-balanced PE and PP in the sleeve and closure of the combiblocMidi (cb8) **SIG**NATURE FB cMaxx is the only difference to the combiblocMidi (cb8) standard RS cMaxx, that leads to significantly lower net results in the categories mentioned.

Summary

To summarise, the LCIA categories showing advantages for mass-balanced plastics are ‘Climate Change’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’, ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’. LCIA categories showing advantages for beverage cartons with PA-based barrier material, instead of aluminium, are ‘Summer Smog’, ‘Particulate Matter’, ‘Acidification’ and ‘Terrestrial Eutrophication’. The category ‘Ozone Depletion’ shows similar results for all examined carton packaging systems.

A higher allocation factor implies the allocation of more burdens from the end-of-life processes (for example emissions from incineration, emissions from the production of electricity for recycling processes). It also implies the allocation of more credits for the substitution of other processes (for example energy credits for avoided electricity generation due to energy recovery at MSWIs or material credits for avoided production of new materials). When applying an allocation factor of 100%, all burdens and all credits are allocated to the regarded system.

Since the compared cartons only differ in material composition and/or material share and the material credits are more significant in scenario ll (AF 100) than in scenario l (AF 50), the differences between the developed carton packaging systems (EcoPlus, **SIG**NATURE PACKS) and the comparison cartons in scenario ll are larger in all impact categories except ‘Climate Change’.

In case of ‘Climate Change’, applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor does not affect the CO_2 uptake, therefore the values for the CO_2 uptake don’t increase when applying the 100% allocation factor.

4.4 Europe combiblocMidi (cb8) beverage cartons 500 mL

4.4.1 Scenario I (50% allocation): Numerical values and graphs

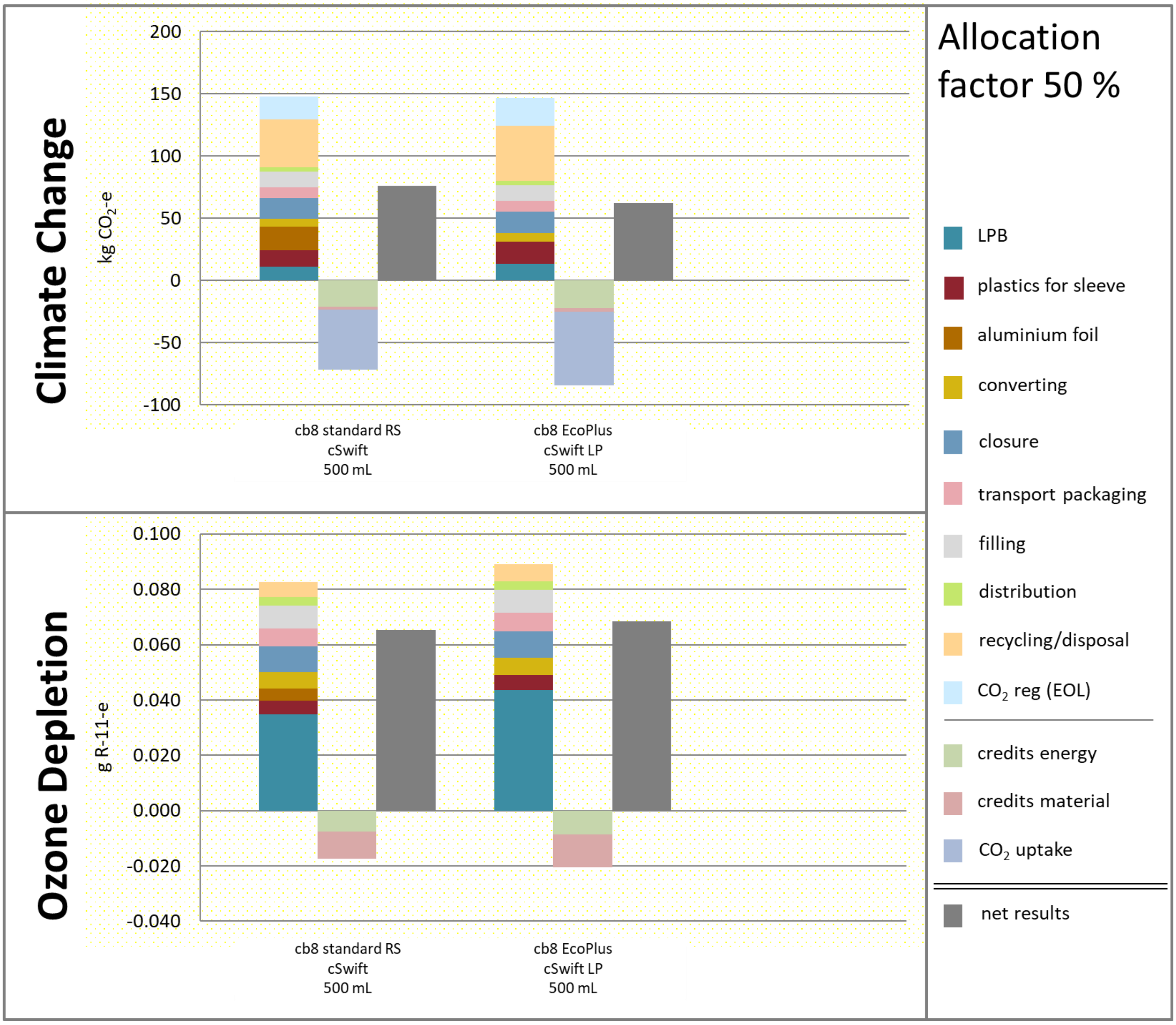

Figure 4-17: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50% (Part 1)

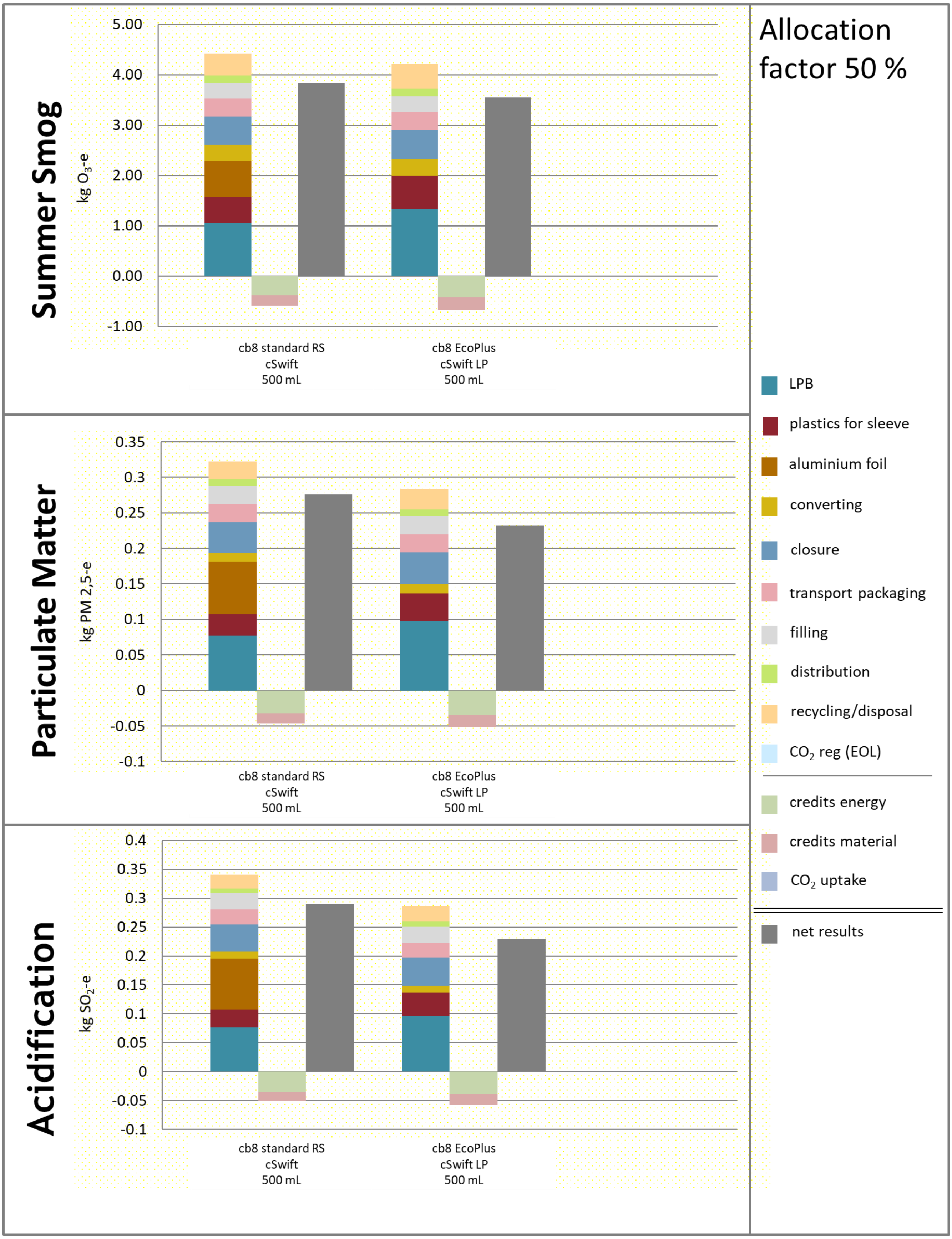

Figure 4-18: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50% (Part 2)

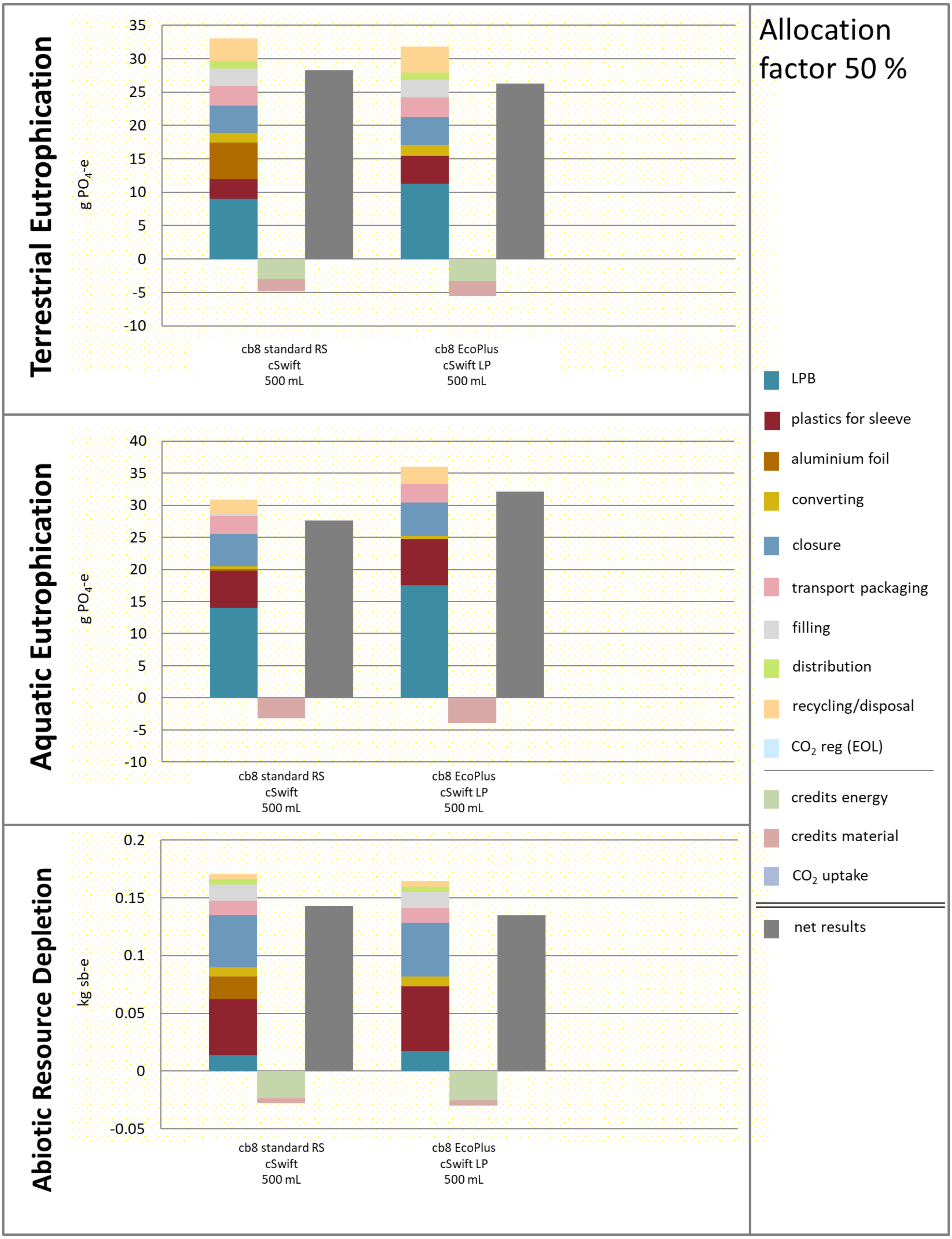

Figure 4-19: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50% (Part 3)

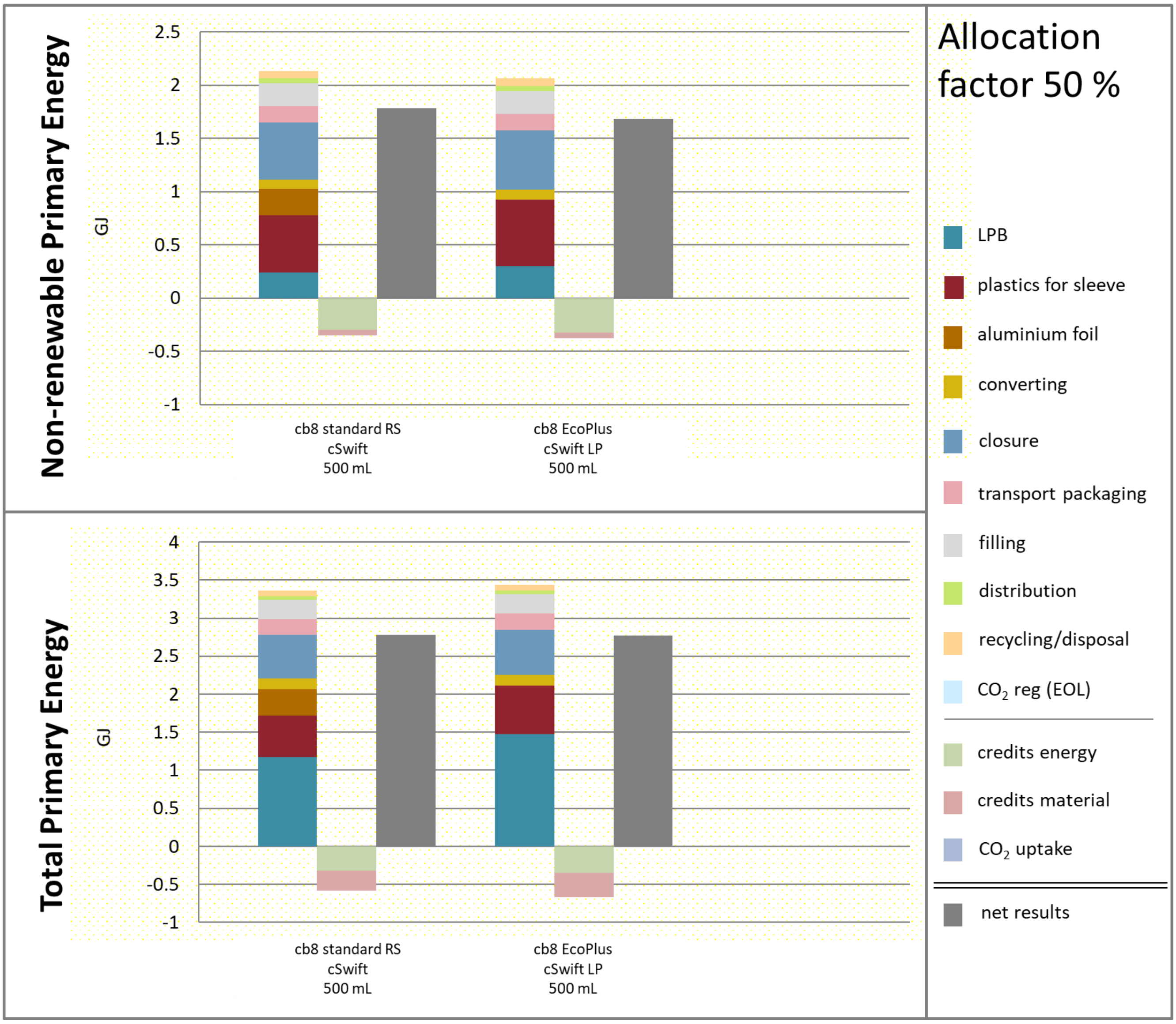

Figure 4-20: Indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50% (Part 4)

Table 4-7: Category indicator results for **scenario I Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 50%: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Europe, allocation factor 50 %			cb8 standard RS cSwift 500 mL	cb8 EcoPlus cSwift LP 500 mL
Climate change [kg CO_2-equivalents]	cradle to gate	Burdens	66.28	55.41
	gate to grave	Burdens	63.31	69.03
		CO_2 (reg)	18.08	22.09
		Credits	-23.78	-25.41
		CO_2 uptake*	-48.24	-59.21
	cradle to grave	Net results (∑)	75.66	61.90
Acidification [g SO_2-equivalents]	cradle to gate	Burdens	0.25	0.20
	gate to grave	Burdens	0.09	0.09
		Credits	-0.05	-0.06
	cradle to grave	Net results (∑)	0.29	0.23
Summer smog [g O_3-equivalents]	cradle to gate	Burdens	3.16	2.90
	gate to grave	Burdens	1.26	1.32
		Credits	-0.59	-0.67
	cradle to grave	Net results (∑)	3.83	3.55
Ozone Depletion [g R-11-equivalents]	cradle to gate	Burdens	0.06	0.06
	gate to grave	Burdens	0.02	0.02
		Credits	-0.02	-0.02
	cradle to grave	Net results (∑)	0.07	0.07
Terrestrial eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	19.00	17.13
	gate to grave	Burdens	14.07	14.68
		Credits	-4.85	-5.55
	cradle to grave	Net results (∑)	28.21	26.26
Aquatic eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	25.51	30.39
	gate to grave	Burdens	5.32	5.64
		Credits	-3.19	-3.94
	cradle to grave	Net results (∑)	27.65	32.09
Particulate matter [g PM 2,5- equivalents]	cradle to gate	Burdens	0.24	0.19
	gate to grave	Burdens	0.09	0.09
		Credits	-0.05	-0.05
	cradle to grave	Net results (∑)	0.28	0.23
Abiotic resource depletion [kg sb-equivalents]	cradle to gate	Burdens	0.14	0.13
	gate to grave	Burdens	0.04	0.04
		Credits	-0.03	-0.03
	cradle to grave	Net results (∑)	0.14	0.13
Non-renewable primary energy [GJ]	cradle to gate	Burdens	1.65	1.57
	gate to grave	Burdens	0.48	0.49
		Credits	-0.35	-0.38
	cradle to grave	Net results (∑)	1.78	1.68
Total Primary Energy [GJ]	cradle to gate	Burdens	2.78	2.85
	gate to grave	Burdens	0.58	0.59
		Credits	-0.58	-0.67
	cradle to grave	Net results (∑)	2.78	2.77

*CO2 uptake is part of the production, but cannot be included in cradle to gate without the consideration of the end of life (grave).

4.4.2 Scenario II (100 % allocation): Numerical values and graphs

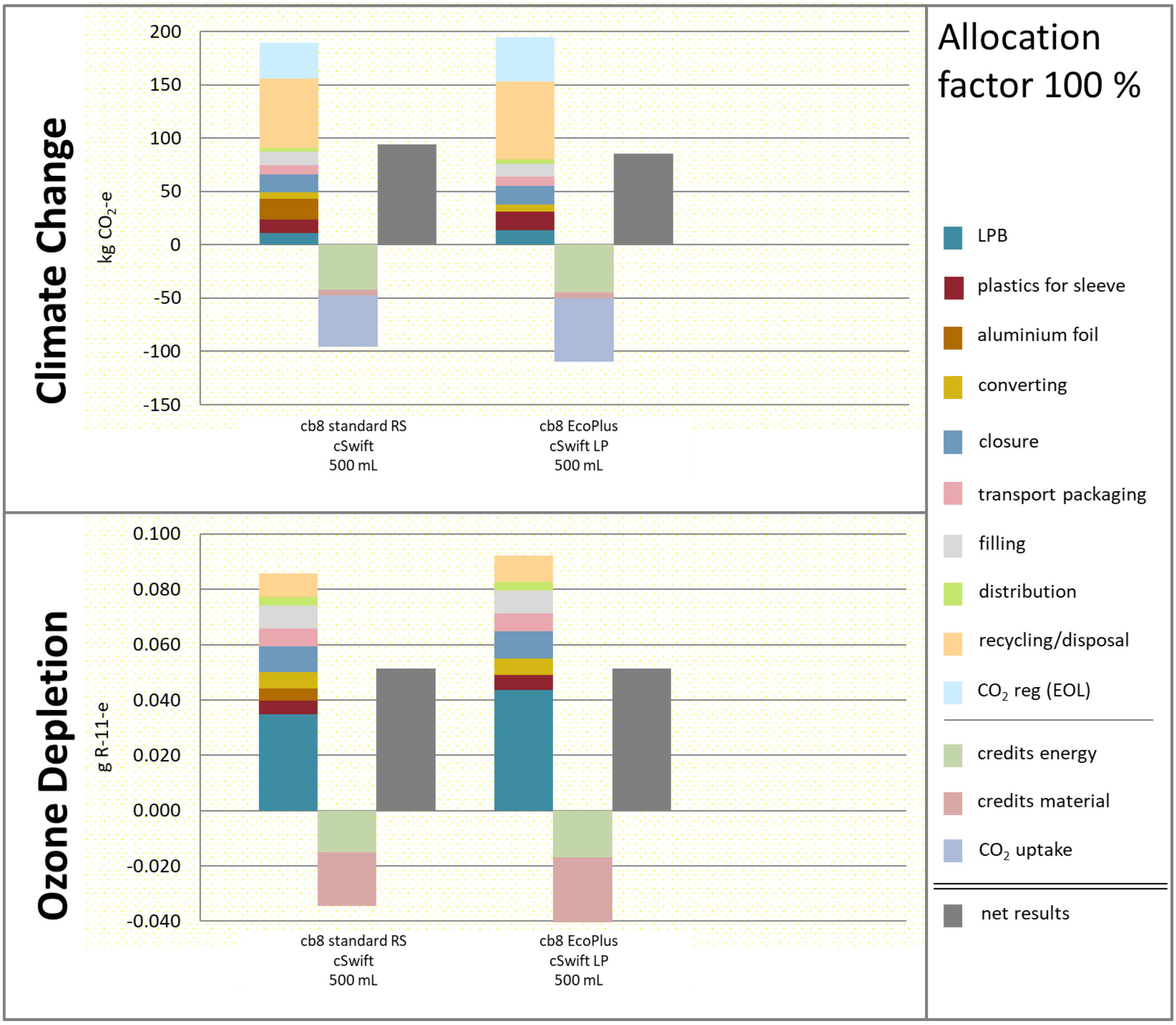

Figure 4-21: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 % (Part 1)

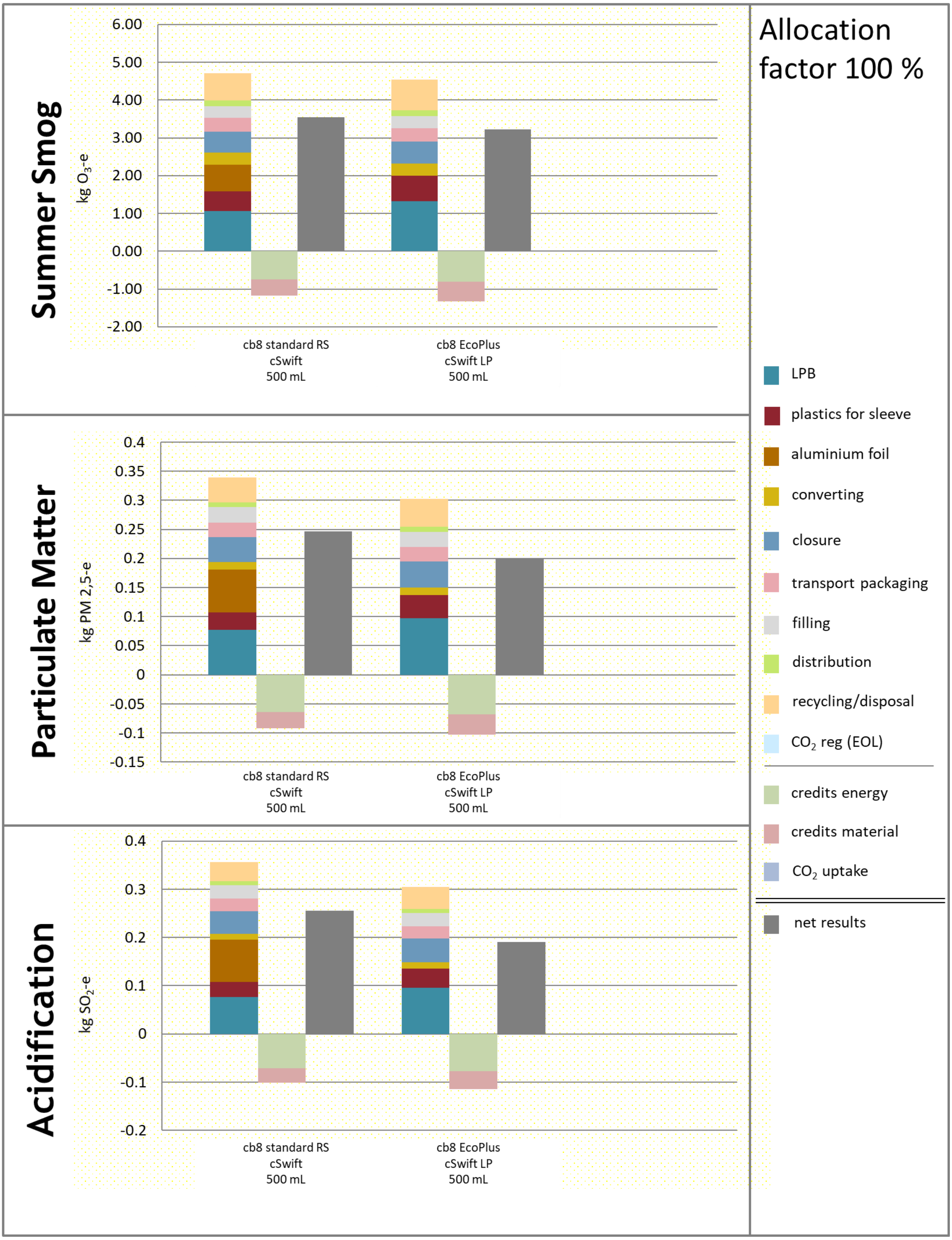

Figure 4-22: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 % (Part 2)

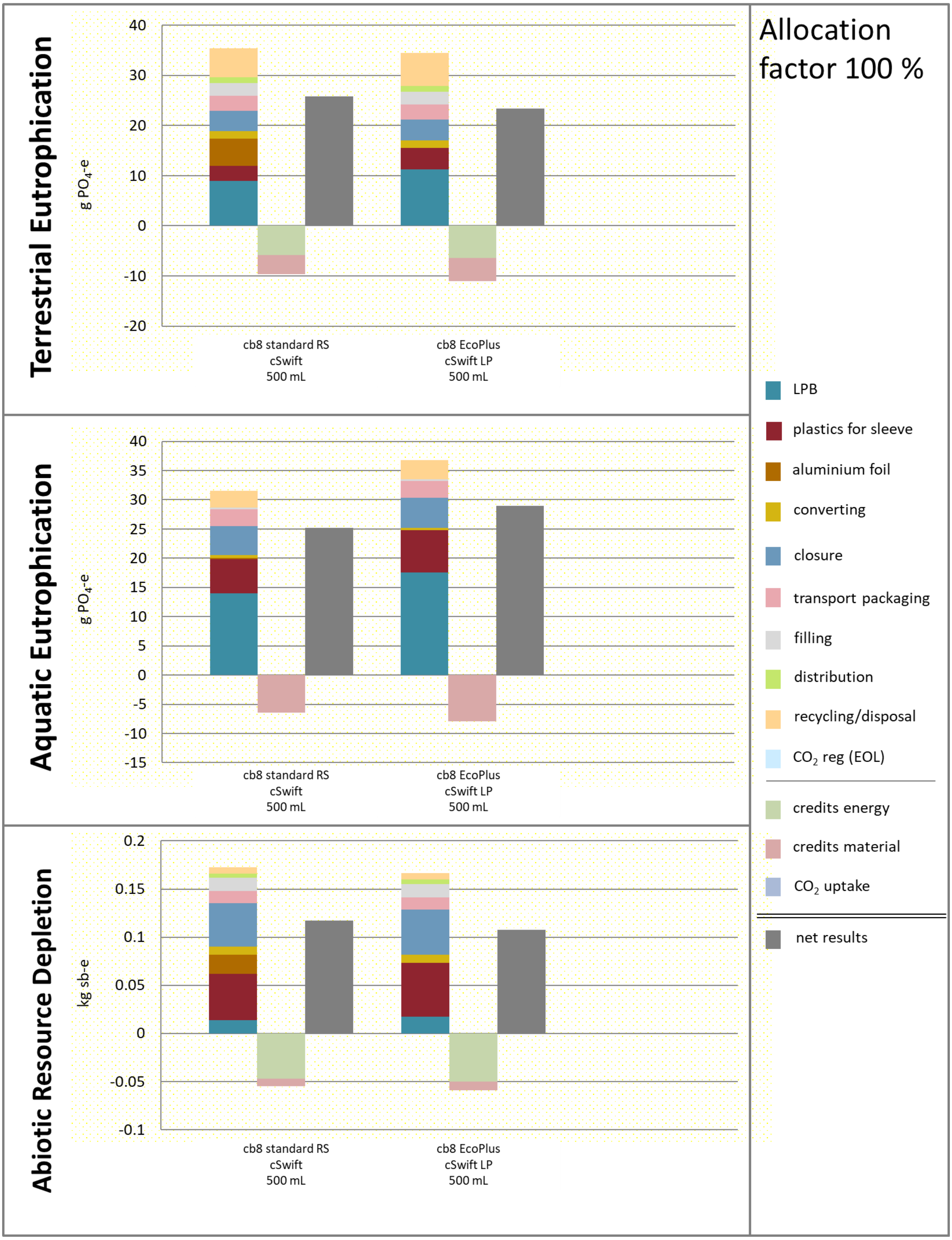

Figure 4-23: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 % (Part 3)

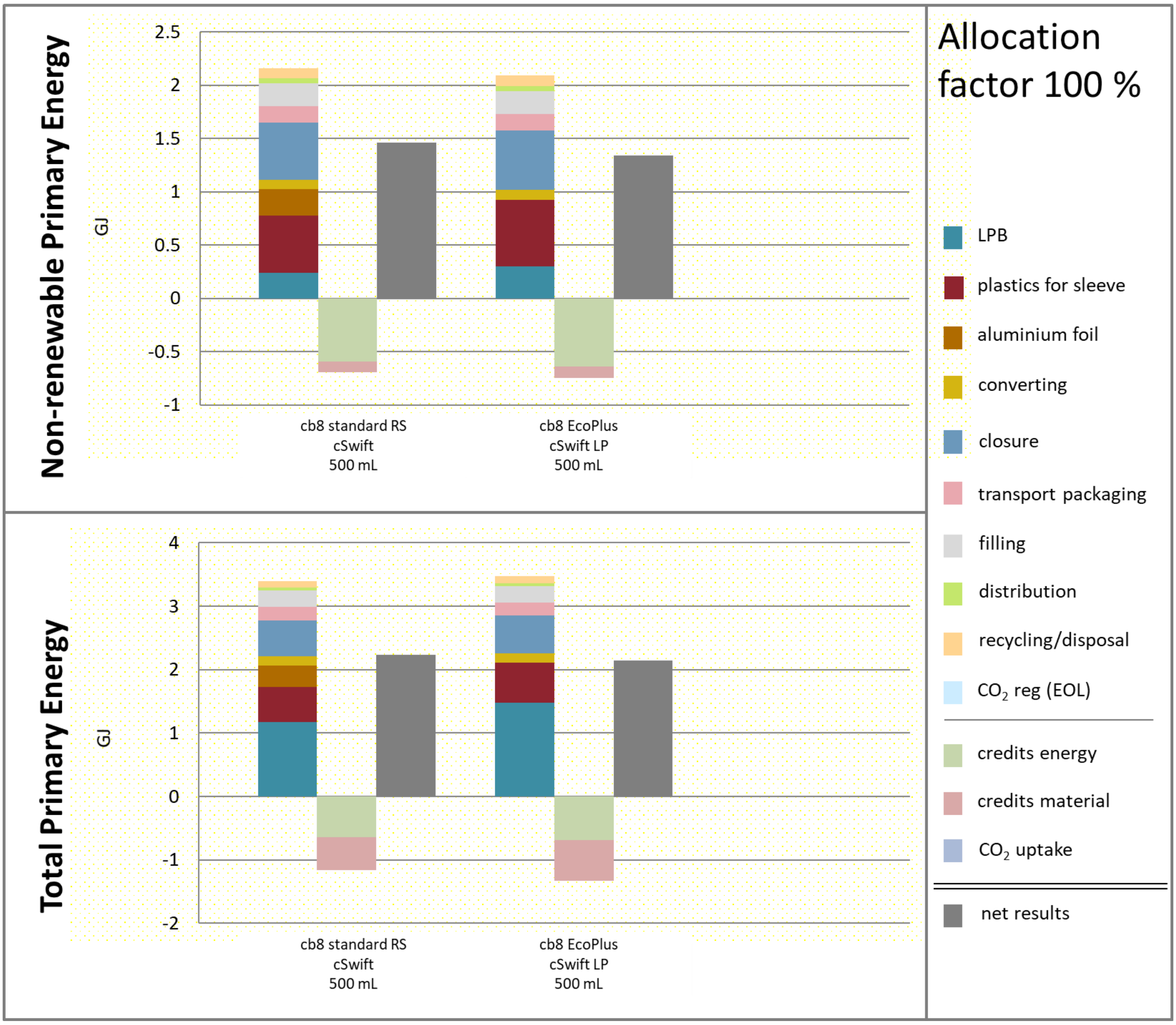

Figure 4-24: Indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 % (Part 4)

Table 4-8: Category indicator results for **scenario II Europe, combiblocMidi (cb8) beverage cartons** with allocation factor 100 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario II Europe, allocation factor 100 %			**cb8 standard RS cSwift 500 mL**	**cb8 EcoPlus cSwift LP 500 mL**
Climate change [kg CO_2-equivalents]	cradle to gate	Burdens	66.28	55.42
	gate to grave	Burdens	89.35	97.91
		CO_2 (reg)	33.86	41.39
		Credits	-47.22	-50.41
		CO_2 uptake*	-48.24	-59.21
	cradle to grave	Net results (∑)	94.03	85.10
Acidification [g SO_2-equivalents]	cradle to gate	Burdens	0.25	0.20
	gate to grave	Burdens	0.10	0.11
		Credits	-0.10	-0.11
	cradle to grave	Net results (∑)	0.26	0.19
Summer smog [g O_3-equivalents]	cradle to gate	Burdens	3.16	2.90
	gate to grave	Burdens	1.55	1.64
		Credits	-1.17	-1.33
	cradle to grave	Net results (∑)	3.54	3.22
Ozone Depletion [g R-11-equivalents]	cradle to gate	Burdens	0.06	0.06
	gate to grave	Burdens	0.03	0.03
		Credits	-0.03	-0.04
	cradle to grave	Net results (∑)	0.05	0.05
Terrestrial eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	18.98	17.12
	gate to grave	Burdens	16.43	17.34
		Credits	-9.63	-11.02
	cradle to grave	Net results (∑)	25.78	23.43
Aquatic eutrophication [g PO_4-equivalents]	cradle to gate	Burdens	25.51	30.39
	gate to grave	Burdens	6.01	6.44
		Credits	-6.38	-7.88
	cradle to grave	Net results (∑)	25.14	28.95
Particulate matter [g PM 2,5- equivalents]	cradle to gate	Burdens	0.24	0.19
	gate to grave	Burdens	0.10	0.11
		Credits	-0.09	-0.10
	cradle to grave	Net results (∑)	0.25	0.20
Abiotic resource depletion [kg sb-equivalents]	cradle to gate	Burdens	0.14	0.13
	gate to grave	Burdens	0.04	0.04
		Credits	-0.06	-0.06
	cradle to grave	Net results (∑)	0.12	0.11
Non-renewable primary energy [GJ]	cradle to gate	Burdens	1.65	1.57
	gate to grave	Burdens	0.51	0.52
		Credits	-0.69	-0.75
	cradle to grave	Net results (∑)	1.46	1.34
Total Primary Energy [GJ]	cradle to gate	Burdens	2.78	2.85
	gate to grave	Burdens	0.61	0.63
		Credits	-1.16	-1.33
	cradle to grave	Net results (∑)	2.23	2.15

*CO2 uptake is part of the production, but cannot be included in cradle to gate without the consideration of the end of life (grave).

4.4.3 Description and interpretation

combiblocMidi (cb8) beverage cartons 500 mL

The **LPB** shows the largest contribution in the results of ‘Summer Smog’, ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Aquatic Eutrophication’, ‘Ozone Depletion’ and ‘Abiotic Depletion Potential’.

The production of the paper based materials generates emissions that cause contributions to both ‘Aquatic Eutrophication’ and ‘Terrestrial Eutrophication’, the latter to a lesser extent. Approximately half of the aquatic Eutrophication potential is caused by the high COD. As the production of LPB causes high contributions of organic compounds into the surface water an overabundance of oxygen-consuming reactions takes place which therefore may lead to oxygen shortage in the water. In the terrestrial Eutrophication potential nitrogen oxides are determined as main contributor. For the separation of the cellulose needed for paper production from the ligneous wood fibres, the so called ‘Kraft process’ is applied, in which sodium hydroxide and sodium sulphide are used. This leads to additional emissions of SO_2, thus contributing significantly to the acidifying potential. The required energy for paper production mainly originates from recovered process internal residues (hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. That explains its relatively small influence on ‘Climate Change’.

For the **plastic for sleeve and the closure** the highest share on the environmental loads can be observed in ‘Climate Change’, ‘Summer Smog’, ‘Particulate Matter’, ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ as well as in the inventory categories ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’. The main material for the fossil plastic for the sleeve and closure requires the cracking and polymerisation process. These production steps play a major role in all impact categories. In addition, energy and hydrogen used by the hydrotreatment process for the production of bio-diesel lead to major contributions to the results of ‘Climate Change’ ‘Summer Smog’, ‘Particulate Matter’, ‘Acidification’, ‘Terrestrial and Aquatic Eutrophication’, ‘Abiotic Resource Depletion’, ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’. Nitrogen dioxide and sulphur dioxide emissions related to the acidulation process to produce crude tall oil from BLS play a dominant role in the category ‘Acidification’. The additional information on the impacts of ‘Summer Smog’ related to VOCs show, that VOC emissions from plastic for sleeve contribute to approximately one third to the net results. These results from ethylene and NMVOC emissions released during cracking of the bio-diesel and the polymerization of the plant-based ethylene or propylene to PE or PP. For the combiblocMidi (cb8) beverage carton formats with the volume of 500 mL, which have a smaller size, the burdens for the closure are higher. This results from the same closure weight for all filling in connection with the functional unit. For example, the combiblocMidi (cb8) EcoPlus cSwift LP 500 mL needs twice as much closure compared to the combiblocMidi (cb8) EcoPlus cSwift LP 1000 mL.

The production of **aluminium foil** for the sleeves of the combiblocMidi (cb8) standard RS cSwift containing aluminium foil shows burdens in most impact categories. High shares of burdens are shown in the impact categories ‘Acidification’, ‘Particulate Matter’ and ‘Terrestrial Eutrophication’. These result from SO_2 and NOx emissions from the aluminium production. The beverage carton EcoPlus cSwift LP does not contain aluminium foil and therefore has no burdens in this process of production.

The largest contribution by the **filling** and **converting** process is observed in ‘Climate Change’, ‘Summer Smog’, ‘Particulate Matter’, ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Abiotic Resource Depletion’, 'Non-renewable Primary Energy' and 'Total Primary Energy'. This results from the thermal energy and electricity input.

The **transport packaging** contributes to all examined categories. The results are dominated by the production of corrugated cardboard boxes. The paper production plays a major role in the most impact/inventory categories. The pallet and the stretch foil production play a minor role.

The life cycle step **distribution** shows similar burdens in all impact categories for all beverage carton systems.

The end-of-life phase (**recycling/disposal**) of the considered combiblocMidi (cb8) beverage carton formats is clearly most relevant in the impact category 'Climate change', however the emissions also visibly contribute to 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication' and 'Aquatic Eutrophication'. A share of the greenhouse gases is related to energy generation required in the respective processes. Material recycling processes are commonly run on electricity, thus this end-of-life treatment contributes directly to the result values for the impact on 'Climate Change'. When the packaging materials are used as fuel in cement kilns or incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification' and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

The **energy credits** arise from incineration plants, where energy recovery takes place and from the use of the rejects as fuel in cement kilns.

Material credits are only given for material that is effectively recycled. The majority is received by the recycling of paper. The paper production causes high waterborne emissions, especially due to the transformation of raw wood to paper fibres. Therefore, the post-consumer recycling of paper fibres from LPB avoids this determining process step (as secondary paper fibres substitute for primary fibres), which leads to material credits.

The **uptake of CO_2** by the trees harvested for the production of paperboard and the mass-balanced plastic plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration or be forwarded to the next product system in a recycled product.

If an allocation factor of 100 % is applied, all burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes) and all credits from recovery processes (i.e. avoided electricity generation due to energy recovery at MSWIs, avoided primary material production due to recycling) are allocated to the examined systems. In the European market, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are slightly lower with an applied allocation factor of 100 % (scenario II) compared to allocation factor 50% (scenario I) apart from 'Climate Change'. For 'Climate Change' the benefit from receiving more credits does not outweigh the extra burdens obtained. The main reasons for this are the emissions of the waste incineration plants which are now fully allocated to the examined system. **Regenerative CO_2** emissions are accounted for 'Climate Change' in the same way as fossil CO_2 emissions.

For the European scope, the credits for energy recovery have the same importance than the material credits in categories that are driven by thermal energy and electricity generation: 'Climate Change', 'Ozone Depletion', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial and Aquatic Eutrophication', 'Abiotic Resource Depletion' and 'Non-renewable Primary Energy. This results from the relative high electrical and thermal efficiencies of the MWSI plants.

4.4.4 Comparison between systems

The percentages in **Table 4-9** show the difference of net results between all considered formats of combiblocMidi (cb8) beverage cartons in the same volume segment. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 4-9: Comparison of net results **combiblocMidi (cb8) beverage cartons** (Europe)

	The net results of	
	combiblocMidi (cb8) EcoPlus cSwift LP 500 mL	
	are lower (green)/higher (red) than those of	
	combiblocMidi (cb8) standard RS cSwift 500 mL	
	AF 50	**AF 100**
Impact categories		
Climate Change	-18%	-10%
Ozone Depletion	+5%	+0%
Summer Smog	-7%	-9%
Particulate Matter	-16%	-19%
Acidification	-21%	-25%
Terrestrial Eutrophication	-7%	-9%
Aquatic Eutrophication	+16%	+15%
Abiotic Resource Depletion	-6%	-8%
Non-renewable Primary Energy	-5%	-8%
Total Primary Energy	+0%	-4%

Description and discussion

In both scenarios, the combiblocMidi (cb8) EcoPlus cSwift LP shows lower net results than the combiblocMidi (cb8) standard RS cSwift in the impact categories 'Particulate Matter' and 'Acidification. In the impact category 'Aquatic Eutrophication' the assessed beverage carton shows higher net results than the combiblocMidi (cb8) standard RS cSwift due to a higher share of LPB. Furthermore in scenario I (AF 50), in the impact category 'Climate Change', the combiblocMidi (cb8) EcoPlus cSwift LP shows lower net results than the combiblocMidi (cb8) standard RS cSwift. No significant differences were found in the other impact and inventory categories.

Due to the higher 'LPB', 'closure' and 'plastics for sleeve' material share, which also includes the material share of the barrier material fossil PA, the combiblocMidi (cb8) EcoPlus cSwift LP carton shows minimally higher burdens in these packaging components as well as in the 'converting'. The decisive factor that causes the overall higher burdens of the combiblocMidi (cb8) standard RS cSwift in the above-mentioned categories is the 'aluminium foil' (barrier material), which is also the only part of the packaging system that shows higher burdens compared to the combiblocMidi (cb8) EcoPlus cSwift LP carton. The impact of aluminium foil in the category 'Aquatic Eutrophication' is limited, though because the high impacts of aluminium foil production originates from its high energy demand. In the category 'Aquatic Eutrophication', the production of LPB and plastics for sleeve show the highest share of the net results. This has a negative effect for the heavier EcoPlus cSwift LP carton.

Summary

A higher allocation factor implies the allocation of more burdens from the end-of-life processes (for example emissions from incineration, emissions from the production of electricity for recycling processes). It also implies the allocation of more credits for the substitution of other processes (for example energy credits for avoided electricity generation due to energy recovery at MSWIs or material credits for avoided production of new materials). When applying an allocation factor of 100%, all burdens and all credits are allocated to the regarded system.

Since the compared cartons only differ in material composition and/or material share and the material credits are more significant in scenario II (AF 100) than in scenario I (AF 50), the differences between the developed carton packaging systems (EcoPlus) and the comparison cartons in scenario II are larger in all impact categories except 'Climate Change'.

In case of 'Climate Change', applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor does not affect the CO_2 uptake, therefore the values for the CO_2 uptake don't increase when applying the 100% allocation factor.

5 Data quality evaluation and limitations

5.1 Data quality evaluation

The relevant information and data used for evaluating the examined packaging systems in this study were available. In the authors' opinion no errors affecting the results were found.

The complete life cycle was considered (except the use phase), including the extraction and production of raw materials, converting processes, all transports and the final disposal or recycling of the packaging system, in each case in modeling for the examined packaging systems. Data was acquired along the entire supply chain of packaging production.

Allocation rules, system boundaries and calculations as to impact assessment were applied uniformly and consistently to all examined packaging systems and the scenarios based on them. An exception may be infrastructure which is generally excluded in this study. In case of some aggregated datasets taken from public databases it may be included without being probably documented.

Following the ISO standard's recommendation on subjective choices, the 50% and 100% allocation factors for system allocation are applied equally in this study.

Section 1.6 (Data gathering and data quality) gives an overview of

- The overall completeness check: The relevant information from all life cycle phases are available and complete.
- The consistency evaluation: Data of the same level of detail were used for all considered beverage carton formats**.**
- The overall representative evaluation: The used data can be regarded as representative for the intended purpose of this study.
- Consistency is considered to be sufficient even if data from different data sources are used. Therefore no serious data asymmetries are to be expected.

However, for potentially occurring uncertainties between the considered beverage carton formats, an estimated significance threshold of 10% is chosen as approach as it is aimed to apply a consistent approach for all impact categories examined. This means differences in the impact category indicator results between the comparative systems ≤ 10% are considered as insignificant.

The quality of the data on beverage distribution in the present study is limited due to a lack of data availability. The distribution model is based on assumptions, whereby the same distribution distances were assumed for all systems in order to avoid asymmetries.

In summary, in the author's view the quality and symmetry of the data in this LCA is good or very good and is appropriate to the study's objectives.

5.2 Limitations

The results of the scenarios and analysed packaging systems and the respective comparisons between beverage cartons are valid within the framework conditions described in **section 1 (Goal and Scope)** and **section 2 (Packaging systems and scenarios)**. The following limitations must be taken into account however.

Limitations concerning selection of packaging systems

The results are valid only for the exact packaging systems of SIG Combibloc. It has to be noted, that this study puts the focus on single-use packaging for packed beverages. Refillable packaging systems are not included in this study. Therefore, it is not possible to transfer the results of this study to refillable packages.

Limitations concerning packaging system specifications

The results are valid only for the examined packaging systems as defined by the specific system parameters, since any alternation of the latter may potentially change the overall environmental profile. All packaging specifications were provided by SIG Combibloc. Packaging specifications different from the ones used in this study cannot be compared directly with the results of this study.

The filling volume and weight of a certain type of packaging can vary considerably for all packaging types that were studied. It is not possible to transfer the results of this study to packages with other filling volumes or weight specifications.

Limitations concerning distribution data

The quality of the data on beverage distribution in the present study is limited due to a lack of data availability. The distribution model is based on assumptions, whereby the same distribution distances were assumed for all systems in order to avoid asymmetries. The results of the study apply only to the distribution model used in this study, and are not easily transferable to other distribution models

Limitations concerning the chosen environmental impact potentials and applied assessment method

The selection of the environmental categories applied in this study covers impact categories and assessment methods considered by the authors to be the most appropriate to assess the potential environmental impact. It should be noted that the use of different impact assessment methods could lead to other results concerning the environmental ranking of packaging systems. The results are valid only for the specific characterisation model used for the step from inventory data to impact assessment.

Limitations concerning the analysed categories

The results are valid only for the environmental impact categories, which were examined. The category indicator results represent potential environmental impacts per functional unit. They are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

Limitations concerning the significance of the differences

In evaluating the results of the present study, a significance threshold of 10% was applied for comparative results. The application of other significance thresholds could possibly lead to a different assessment of the systems' comparison.

Limitations concerning geographic boundaries

The results are valid only for the indicated geographic scope and cannot be assumed to be valid in geographic regions other than Europe, even for the same packaging systems.

Further results of combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons regarding the markets Spain, France, Germany, Belgium, Netherlands, Poland and UK are assessed in separate extensions.

This applies particularly for the end-of-life settings as the mix of waste treatment routes (recycling and incineration) and specific technologies used within these routes may differ, e.g. in other countries.

Regarding the production of tall oil based polymers the results are only valid as long as the tall oil originates from Finland as the tall oil related processes are modelled with Finnish electricity for this study.

Limitations concerning the reference period

The results are valid only for the indicated time scope and cannot be assumed to be valid for (the same) packaging systems at a different point in time.

Limitations concerning system boundaries

The results are valid only for described system boundaries. The listed exclusions are not considered relevant for the comparison, though.

Limitations concerning data quality

The results are valid only for the data used and described in this report: To the knowledge of the authors, the data mentioned in **section 3** represents the best available and most appropriate data for the purpose of this study. It is based on figures provided by the commissioner, data from ifeu's internal database and industry data.

There are potential limitations on used data, e.g. regarding inclusion of infrastructure, but they are considered as not sufficient to cast doubt on the results.

The data quality evaluation shows, that no major data asymmetries are to be expected that would influence the overall conclusions and recommendations of this study.

6 Conclusions and Recommendations

The present report provides environmental profiles of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons on the European market (EU27+3).

In the following section, the most important significant parameters of combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons is summarised and conclusions and recommendations are drawn from the results presented and discussed in the previous sections

The comparison of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage carton's environmental performance with its competing formats is carried out verbal argumentatively and takes into account all the impact categories examined in the life cycle assessment. If the comparison result pattern is quite differentiated, no clear statements can be made about ecological advantages or disadvantages for the respective comparison.

6.1 Significant parameters

The study shows that the production of base materials for the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons is a main contributor to most of the examined environmental impact indicators. Particularly in the impact categories 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Abiotic Resource Depletion', the raw materials dominate the results.

The production of LPB for combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons plays a somewhat less important role in many impact categories though it still is a main contributor to the net results in the impact categories 'Summer Smog', 'Particulate Matter', 'Terrestrial Eutrophication', 'Aquatic Eutrophication', 'Acidification' and 'Ozone Depletion'.

The production of plastics for sleeve is one of the two main contributors to the category 'Summer Smog' due to NMVOC and Ethylene emissions from polymerisation. Furthermore, the plastic production for sleeve plays a considerable role in almost all other impact categories.

The production of aluminium foil has considerable impacts in most categories. The largest contributors are 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication', 'Abiotic resource depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy'. The manufacturing of the aluminium foil is energy intensive and is therefore connected to high environmental impacts. Nearly 60 % of the consumed energy comes from fossil fuels. For this reason, the impact/inventory categories are affected, in which energy plays a major role.

The production and converting of closures is the other main contributor to the category 'Summer Smog'. The closure plays also an important role in most of the other impact categories. Especially for the 500 mL cartons, the closure plays a predominant role compared to the other life cycle steps. This results from the same closure weight for all filling volumes.

Contributions to the net results in the impact categories 'Aquatic Eutrophication' and to a lesser extent to 'Acidification' as well as 'Terrestrial Eutrophication' and 'Particulate Matter' arise from the production of corrugated cardboard for secondary packaging.

The life cycle steps converting and filling contribute visibly to all impact categories that are driven by energy generation.

The end-of-life phase of the regarded combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons is relevant in the impact category 'Climate Change', however the emissions also visibly contribute to 'Summer Smog', 'Particulate Matter', 'Acidification' and 'Terrestrial Eutrophication'. A share of the greenhouse gases is related to energy generation required in the respective processes. Material recycling processes are commonly run on electricity, thus this end-of-life treatment contributes directly to the result values for the impact on 'Climate Change'. When the packaging materials are used as fuel in cement kilns or incinerated in MSWI facilities, this also leads to GHG emissions.

6.2 Comparison between beverage cartons

6.2.1 Comparisons of combiblocSlimline (cb3) and combiblocMidi (cb8) 1000 mL beverage cartons with the corresponding formats

Compared to the combiblocSlimline (cb3) standard RS cSwift, the combiblocSlimline (cb3) EcoPlus cSwift LP show more favourable results in the impact categories ‘Climate Change’, ‘Summer Smog’, ‘Particulate Matter’, ‘Acidification’, ‘Terrestrial Eutrophication’ and ‘Abiotic resource depletion’ and in the inventory category ‘Non-renewable Primary Energy’ in the European market.

Compared to the combiblocMidi (cb8) standard RS cSwift, the combiblocMidi (cb8) EcoPlus cSwift LP show more favourable results in the impact categories ‘Climate Change’, ‘Particulate Matter’, and ‘Acidification’ in the European market.

In all comparisons the **SIG**NATURE 100 cSwift LP formats show in all scenarios for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower net results than the compared standard RS cSwift formats in all impact and inventory categories except in the category ‘Ozone Depletion’.

The **SIG**NATURE 100 cSwift LP formats show in all scenarios for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower net results than the compared EcoPlus cSwift LP formats in the impact categories ‘Climate Change’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ and in the inventory categories ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

The **SIG**NATURE FB cSwift formats show in all scenarios for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower net results than the compared standard RS cSwift formats in the impact categories ‘Climate Change’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ and in the inventory categories ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

Furthermore, the **SIG**NATURE FB cMaxx formats show in all scenarios for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower net results than the compared standard RS cMaxx formats in the impact categories ‘Climate Change’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ and in the inventory categories ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

In the impact category ‘Aquatic Eutrophication’, the combiblocMidi (cb8) EcoPlus cSwift LP shows higher results in both scenarios (AF50, AF100) on the European market compared to the combiblocMidi (cb8) standard RS cSwift due to a higher share of LPB.

The beverage carton combiblocSlimline (cb3) **SIG**NATURE 100 has the lowest net results in the corresponding format in most impact categories and all inventory categories examined. These are ‘Climate Change’, ‘Summer Smog’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’, ‘Abiotic Resource Depletion’, ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

The beverage carton combiblocMidi (cb8) **SIG**NATURE 100 cSwift LP has the lowest net results in the corresponding format in most impact categories and all inventory categories examined. These are ‘Climate Change’, ‘Summer Smog’, ‘Terrestrial Eutrophication’, ‘Abiotic Resource Depletion’, ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

6.2.2 Comparisons of combiblocMidi (cb8) 500 mL beverage cartons with the corresponding formats

In both scenarios (AF 50, AF 100) the combiblocMidi (cb8) EcoPlus cSwift LP beverage carton shows lower net results than the combiblocMidi (cb8) standard RS cSwift in the impact categories 'Particulate Matter' and 'Acidification. In the impact category 'Aquatic Eutrophication' the assessed beverage carton shows higher net results than the combiblocMidi (cb8) standard RS cSwift due to a higher share of LPB. Furthermore in scenario I, in the impact category 'Climate Change', the combiblocMidi (cb8) EcoPlus cSwift LP shows lower net results than the combiblocMidi (cb8) standard RS cSwift. No significant differences were found in the other impact and inventory categories.

With the volume of 1000 mL, the combiblocMidi (cb8) EcoPlus cSwift LP benefits more from the material composition compared to the combiblocMidi (cb8) standard RS cSwift than with the packaging size of 500 mL, as the closures carry weight. For this reason, more significant differences in other impact categories in the comparisons of 1000 mL can be observed.

6.3 Comparison between beverage cartons (cradle to gate)

As the producer of the analysed packaging systems, SIG Combibloc has the strongest influence on the life cycle steps related to the production of primary packaging components. Therefore additionally to the cradle to grave results in this study, this section provides the comparison between beverage cartons based on cradle to gate results. The numerical cradle to gate results are shown separately in the numerical result tables in **section 4**. As the life cycle steps included in the cradle to gate results are only connected with the regarded system, there is no difference between 50 % and 100 % allocation factor.

6.3.1 Comparisons of combiblocSlimline (cb3) and combiblocMidi (cb8) 1000 mL beverage cartons with the corresponding formats (cradle to gate)

The comparison of the cradle to gate results show differences which are directly connected to the material type and material weights of the primary packaging components.

Compared to the combiblocSlimline (cb3) standard RS cSwift, the combiblocSlimline (cb3) EcoPlus cSwift LP show more favourable cradle to gate results in the impact categories 'Climate Change', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial Eutrophication' and 'Abiotic resource depletion' and in the inventory category 'Non-renewable Primary Energy' in the European market mainly due to the usage of PA instead of aluminium in beverage cartons sleeves.

Compared to the combiblocMidi (cb8) standard RS cSwift, the combiblocMidi (cb8) EcoPlus cSwift LP show more favourable cradle to gate results in the impact categories 'Climate Change', 'Summer Smog', 'Particulate Matter', and 'Acidification' and 'Terrestrial Eutrophication' in the European market mainly due to the usage of PA instead of aluminium in beverage cartons sleeves. In the impact category 'Aquatic Eutrophication', the combiblocMidi (cb8) EcoPlus cSwift LP shows higher cradle to gate results on the European market compared to the combiblocMidi (cb8) standard RS cSwift due to a higher share of LPB.

The **SIG**NATURE 100 cSwift LP formats show for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower cradle to gate results than the compared standard RS cSwift formats in all impact and inventory categories except in the category 'Ozone Depletion' mainly due to the usage of PA instead of aluminium in beverage cartons sleeves.

The cb **SIG**NATURE 100 cSwift LP show for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower cradle to gate results than the compared cb EcoPlus cSwift LP format in the impact categories 'Summer Smog', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy' mainly due to the usage of mass-balanced plastics instead of fossil plastics.

The **SIG**NATURE FB cSwift formats show for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower cradle to gate results than the compared standard RS cSwift formats in the impact categories 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy' mainly due to the usage of mass-balanced plastics instead of fossil plastics.

The **SIG**NATURE FB cMaxx formats show for combiblocSlimline (cb3) and combiblocMidi (cb8) cartons lower cradle to gate results than the compared standard RS cMaxx formats in the impact categories 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy' mainly due to the usage of mass-balanced plastics instead of fossil plastics.

Benefits of **SIG**NATURE cartons in 'Climate Change' due to the CO_2 uptake of mass-balanced plastics are technically part of the material production life cycle step. In order to have a biogenic carbon balance, the CO_2 uptake can only be shown together with the corresponding biogenic CO_2 emissions in the end of life. Therefore these benefits can only be seen in cradle to grave cradle to gate results.

6.3.2 Comparisons of combiblocMidi (cb8) 500 mL beverage cartons with the corresponding formats (cradle to gate)

The combiblocMidi (cb8) EcoPlus cSwift LP beverage carton shows lower cradle to gate results than the combiblocMidi (cb8) standard RS cSwift in the impact categories 'Climate Change', 'Particulate Matter' and 'Acidification' mainly due to the usage of PA instead of aluminium in beverage cartons sleeves. In the impact category 'Aquatic Eutrophication' the assessed beverage carton shows higher cradle to gate results than the combiblocMidi (cb8) standard RS cSwift due to a higher share of LPB. No significant differences were found in the other impact and inventory categories.

With the volume of 1000 mL, the combiblocMidi (cb8) EcoPlus cSwift LP benefits more from the material composition compared to the combiblocMidi (cb8) standard RS cSwift than with the packaging size of 500 mL, as the closures carry weight. For this reason, more significant differences in other impact categories in the comparisons of 1000 mL can be observed.

6.4 Recommendations

Based on the findings summarised in the previous sections and the limitations listed in **section 5.2** the authors developed the following recommendations:

- Since the environmental result of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage carton format is significantly influenced by the production of its main components, the sleeve and closure, measures to ensure the same functionality by the use of less material are recommended.
- It is shown in this study that the closures play a crucial role in the life cycle of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage carton formats, especially for smaller volumes. However, to improve the overall environmental performance, it is recommended to assess the possibilities of using smaller and lighter closures for all combiblocSlimline (cb3) and combiblocMidi (cb8) beverage carton formats.
- The comparative results do not show that any beverage carton system has lower results in all impact and inventory categories compared to another beverage carton. However, the beverage cartons combiblocSlimline (cb3) and combiblocMidi (cb8) **SIG**NATURE 100 with the closure cSwift LP (1000 mL) show lower environmental impacts in several impact categories and no higher impacts in any other category. Therefore, from an environmental viewpoint it is recommended to prefer the combiblocSlimline (cb3) and combiblocMidi (cb8) **SIG**NATURE 100 cSwift LP (1000 mL) over the other beverage carton formats examined in this study on the European market.
- Based on the comparison of the closure results of the examined combiblocSlimline (cb3) and combiblocMidi (cb8) **SIG**NATURE FB cSwift (1000 mL) and combiblocSlimline (cb3) and combiblocMidi (cb8) standard RS cSwift beverage cartons on the European market, it can be concluded, that the substitution of fossil polymers by mass-balanced polymers based on tall oil leads to lower net results in some environmental impact categories including 'Climate Change' and no higher impacts in any of the other categories. The implementation of polymers based on tall oil via a mass-balance approach is therefore recommended.
- It is also recommended to actually achieve a more significant physical share of tall oil based input materials for the production of polymers, as the by-product of the pulp industry is currently mainly dedicated to direct thermal use. The utilisation and demand of mass-balanced polymers by SIG Combibloc might be a driver to do so.

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Appendix 1: Analysis of combiblocMidi **SIG**NATURE FULL BARRIER 9µ on the European market

Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach

CB-100734

commissioned by SIG Combibloc

Heidelberg, May 2022

1 Introduction

The focus of the main report is to investigate combiblocSlimline (cb3) and combiblocMidi (cb8) cartons on the European market. In this appendix 1, additional combiblocMidi (cb8) carton formats on the European market are assessed. The beverage cartons examined are listed in **Table 1-1**. The specific name 9µ stands for the thickness (9 µm) of the aluminium layer in the sleeves of the beverage cartons. The comparisons of the beverage cartons are structured according to the same scheme as in the main report.

As the SIG packaging combifitMidi (cf8) 9µ is identical to the combiblocMidi (cb8) 9µ with regard to all packaging specifications (including secondary and tertiary packaging), the results of the combiblocMidi (cb8) 9µ 1000 mL also apply to the combifitMidi (cf8) 9µ 1000 mL.

Table 1-1: List of beverage cartons examined in Europe (1000 mL)

combiblocMidi (cb8) 9µ beverage cartons and closure
cb8 standard RS 9µ (cSwift)
cb8 standard RS 9µ (cMaxx)
cb8 **SIG**NATURE Pack FB 9µ (cSwift)
cb8 **SIG**NATURE Pack FB 9µ (cMaxx)

Except for the specifications listed in **section 1.1**, this appendix 1 follows the same structure and methodology as the main report.

1.1 Packaging specifications

The composition of the beverage carton sleeves differ from the main report in the share of liquid packaging board, PE share and the aluminium share. The specifications of closures, secondary and tertiary packaging and all background parameters remain identical. The packaging systems examined in this appendix 1 and their corresponding specifications are listed in **Table 1-2:**.

Table 1-2: Packaging specifications of the beverage cartons in EU: combiblocMidi (cb8) 9µ 1000 mL

combiblocMidi (cb8) 9µ 1000

Specification	Unit	Packaging system			
		cb8 standard RS 9µ		cb8 SIGNATURE PACK FB 9µ	
closure	-	cSwift	cMaxx	cSwift	cMaxx
volume	mL	1000		1000	
geographic Scope	-	EU			
chilled	-				
ambient					
primary packaging (sum)[1]	**g**	**31.15**	**31.4**	**31.15**	**31.4**
primary packaging (per FU)	**g/FU**	**31150**	**31400**	**31150**	**31400**
composite material (sleeve)	g	28.40		28.40	
- liquid packaging board	g	20.20		20.20	
- fossil PE	g	6.10		-	
- mass-balanced PE	g	-		6.10	
- Aluminium foil	g	2.10		2.10	
closure	g	2.75	3.00	2.75	3.00
- fossil PP	g	1.47	1.25	-	-
- fossil PE	g	1.28	1.23	-	-
- mass-balanced PP	g	-	-	1.47	1.25
- mass-balanced PE	g	-	-	1.28	1.23
- fossil PS	g	-	0.52	-	0.52

[1] per primary packaging unit

2 Results and discussion

2.1 Europe combiblocMidi (cb8) 9µ beverage cartons 1000 mL

2.1.1 Scenario I (50% allocation): numerical values and graphs

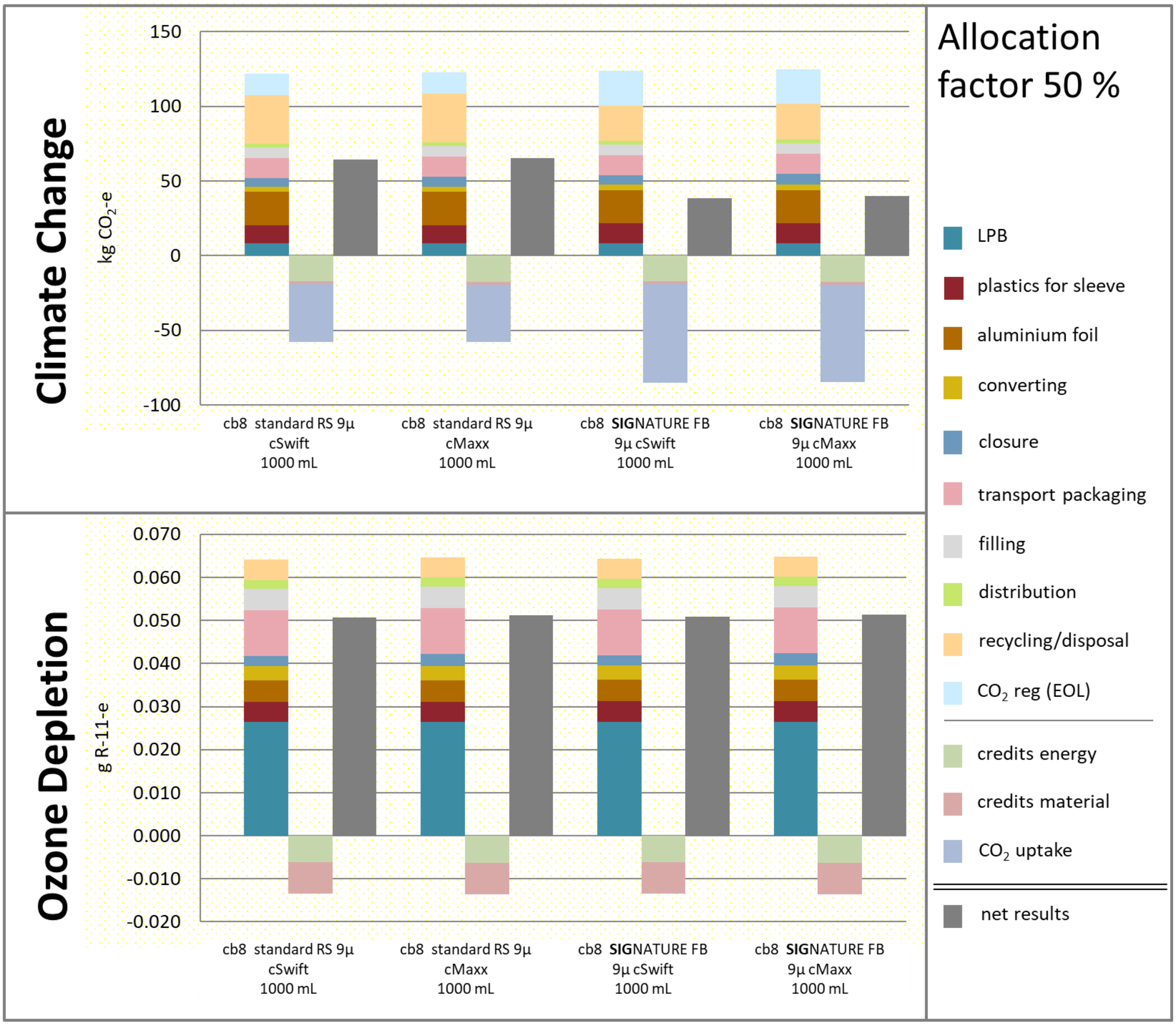

Figure 2-1: Indicator results for scenario **I Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 50% (Part 1)

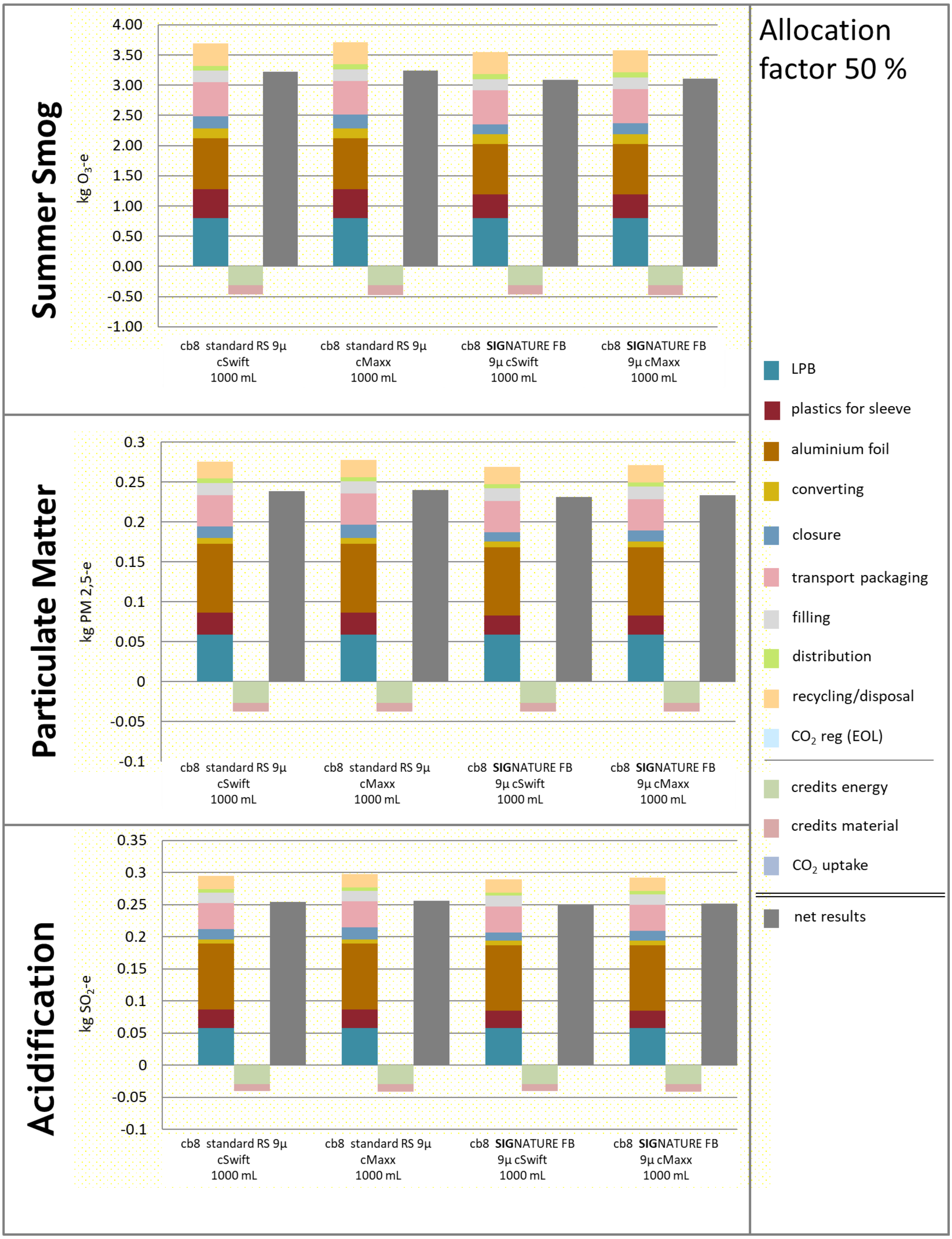

Figure 2-2: Indicator results for scenario **I Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 50% (Part 2)

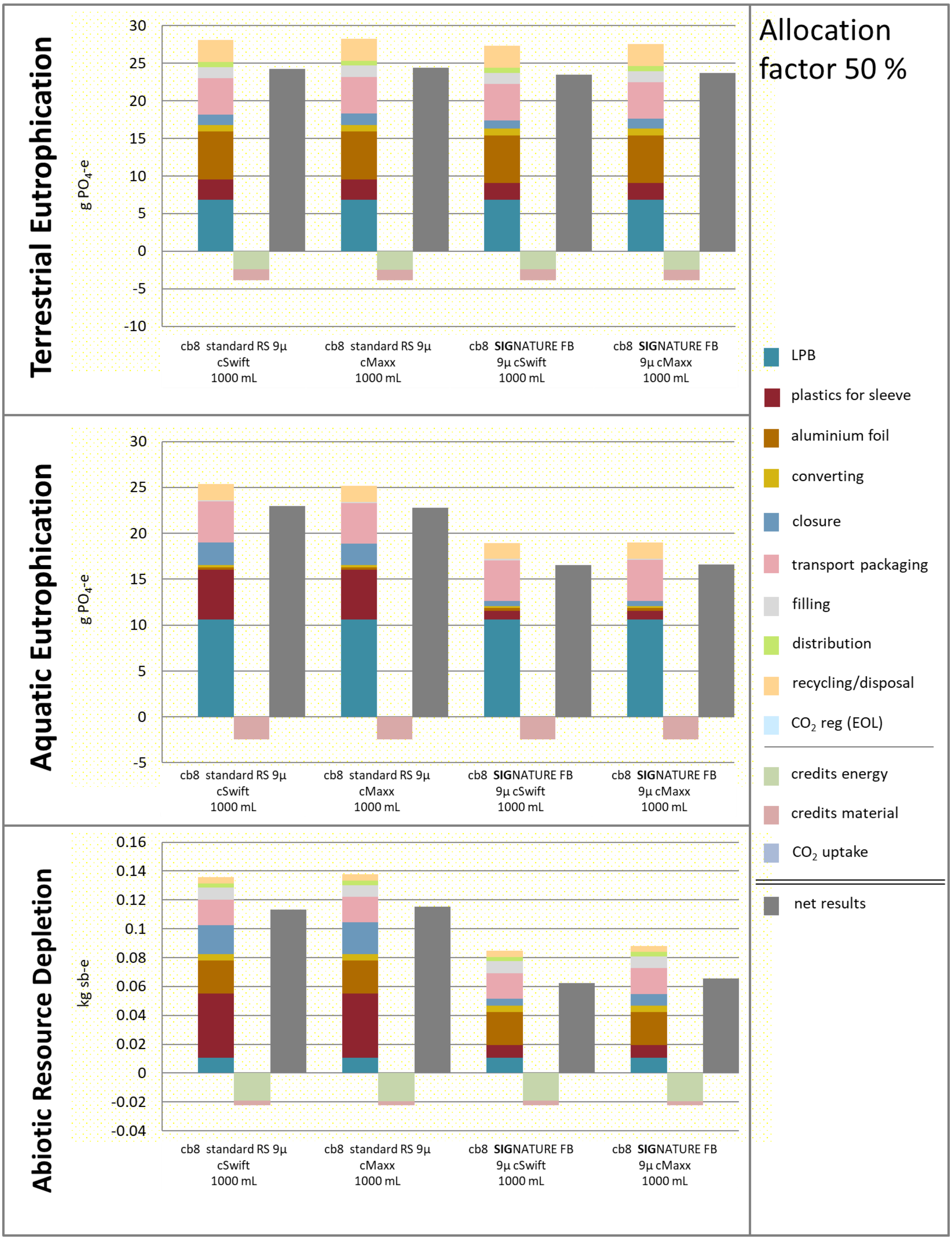

Figure 2-3: Indicator results for scenario **I Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 50% (Part 3)

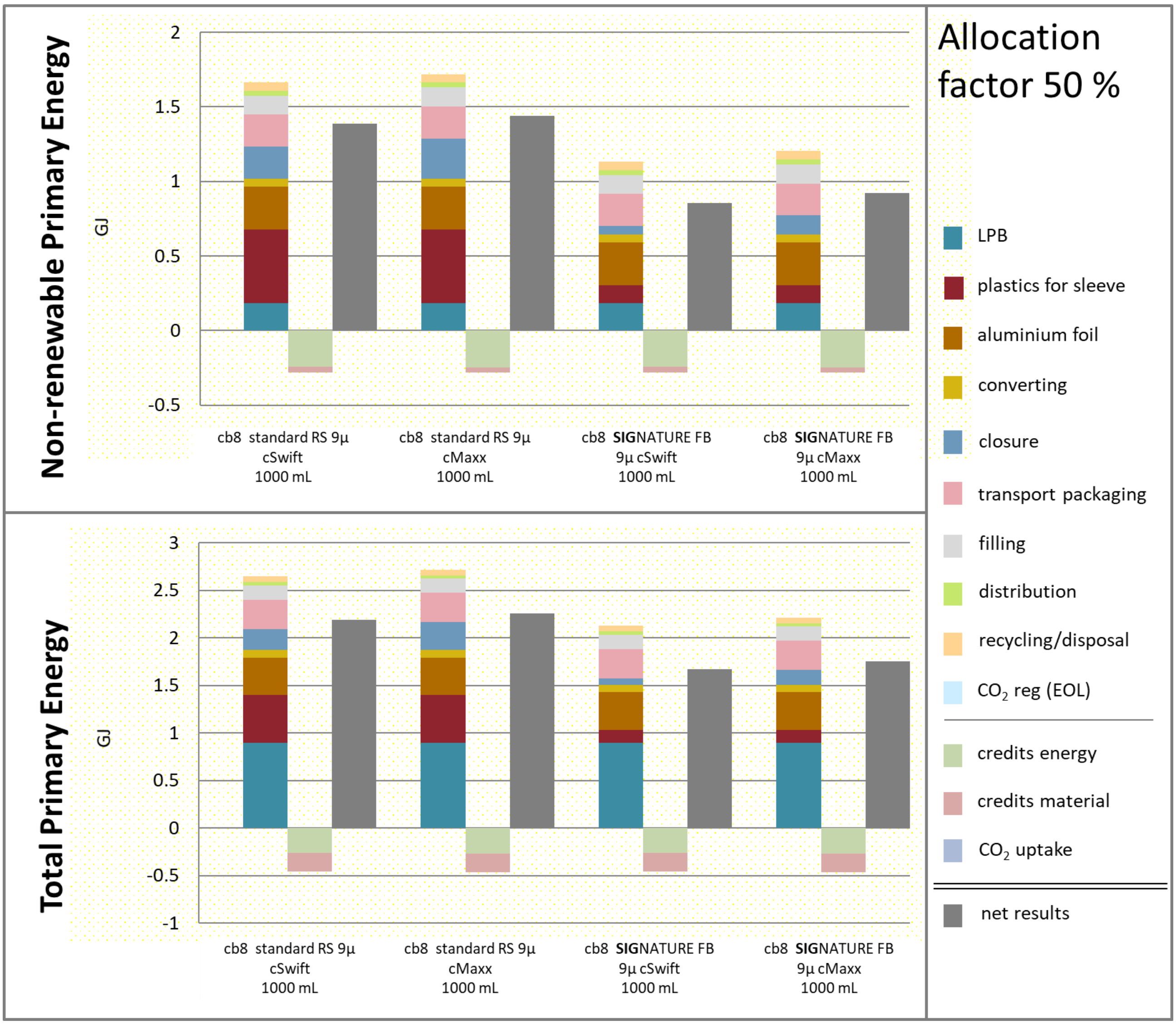

Figure 2-4: Indicator results for scenario **I Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 50% (Part 4)

Table 2-1: Category indicator results for **scenario I Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Europe, allocation factor 50 %		**cb8 standard RS 9µ cSwift 1000 mL**	**cb8 standard RS 9µ cMaxx 1000 mL**	**cb8 SIGNATURE FB cSwift 9µ 1000 mL**	**cb8 SIGNATURE FB cMaxx 9µ 1000 mL**
Climate change [kg CO_2-equivalents]	Burdens	107.25	108.45	100.21	101.58
	CO_2 (reg)	14.56	14.56	23.55	23.30
	Credits	-19.12	-19.30	-19.12	-19.30
	CO_2 uptake	-38.51	-38.53	-66.27	-65.46
	Net results (∑)	64.17	65.18	38.36	40.11
Acidification [g SO_2-equivalents]	Burdens	0.29	0.30	0.29	0.29
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.25	0.26	0.25	0.25
Summer smog [g O_3-equivalents]	Burdens	3.69	3.72	3.55	3.58
	Credits	-0.47	-0.47	-0.47	-0.47
	Net results (∑)	3.22	3.24	3.08	3.11
Ozone Depletion [g R-11-equivalents]	Burdens	0.06	0.06	0.06	0.06
	Credits	-0.01	-0.01	-0.01	-0.01
	Net results (∑)	0.05	0.05	0.05	0.05
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	28.05	28.26	27.30	27.53
	Credits	-3.85	-3.87	-3.85	-3.87
	Net results (∑)	24.20	24.39	23.45	23.66
Aquatic eutrophication [g PO_4-equivalents]	Burdens	25.36	25.21	18.97	19.00
	Credits	-2.42	-2.42	-2.42	-2.42
	Net results (∑)	22.94	22.79	16.55	16.58
Particulate matter [g PM 2,5- equivalents]	Burdens	0.28	0.28	0.27	0.27
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.24	0.24	0.23	0.23
Abiotic resource depletion [kg sb-equivalents]	Burdens	0.14	0.14	0.08	0.09
	Credits	-0.02	-0.02	-0.02	-0.02
	Net results (∑)	0.11	0.12	0.06	0.07
Non-renewable primary energy [GJ]	Burdens	1.66	1.72	1.13	1.20
	Credits	-0.28	-0.28	-0.28	-0.28
	Net results (∑)	1.38	1.44	0.85	0.92
Total Primary Energy [GJ]	Burdens	2.65	2.72	2.13	2.21
	Credits	-0.46	-0.46	-0.46	-0.46
	Net results (∑)	2.19	2.26	1.67	1.75

2.1.1.1 Scenario II (100% allocation): numerical values and graphs

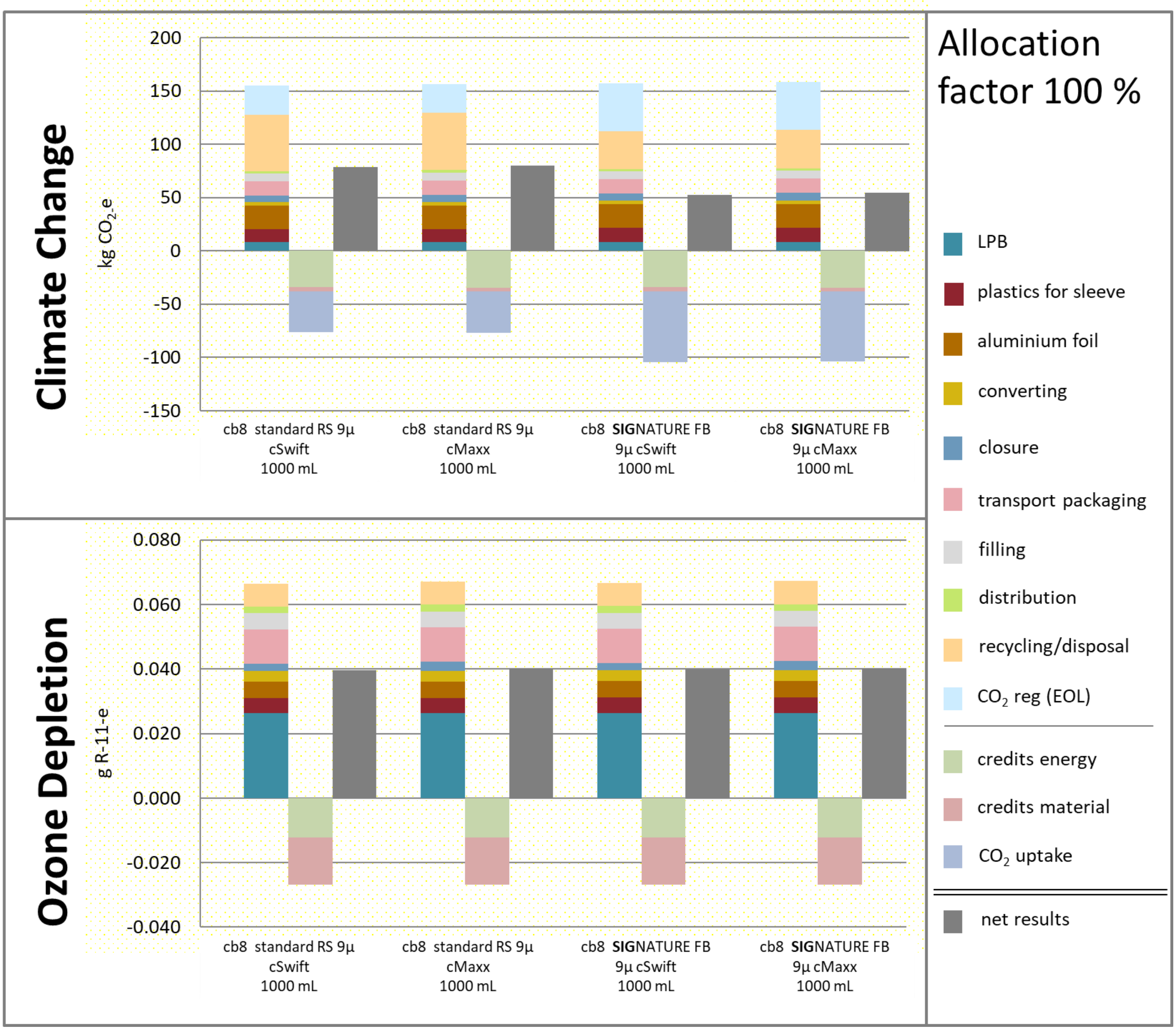

Figure 2-5: Indicator results for scenario **ll Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 100% (Part 1)

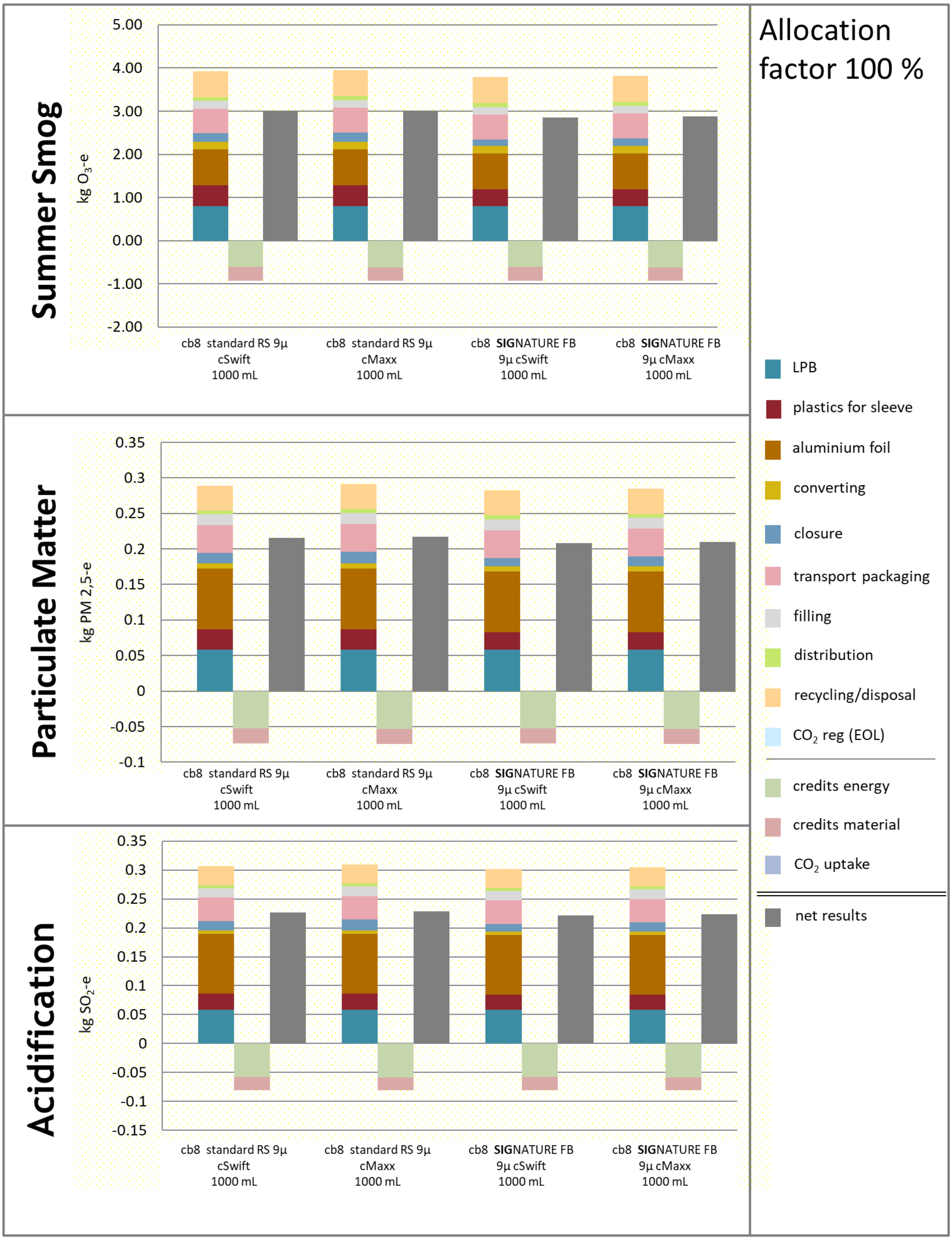

Figure 2-6: Indicator results for scenario **II Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 100% (Part 2)

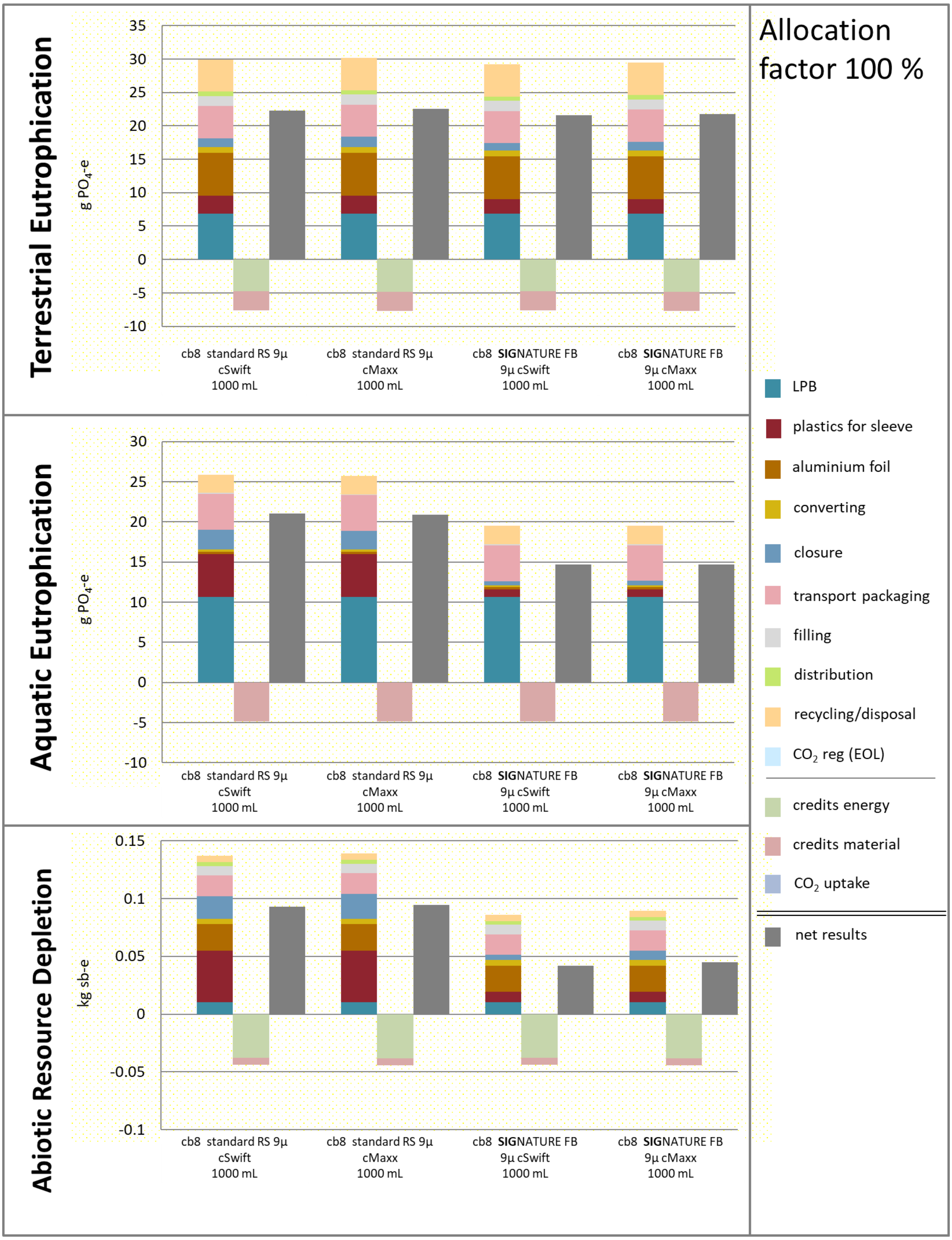

Figure 2-7: Indicator results for scenario **ll Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 100% (Part 3)

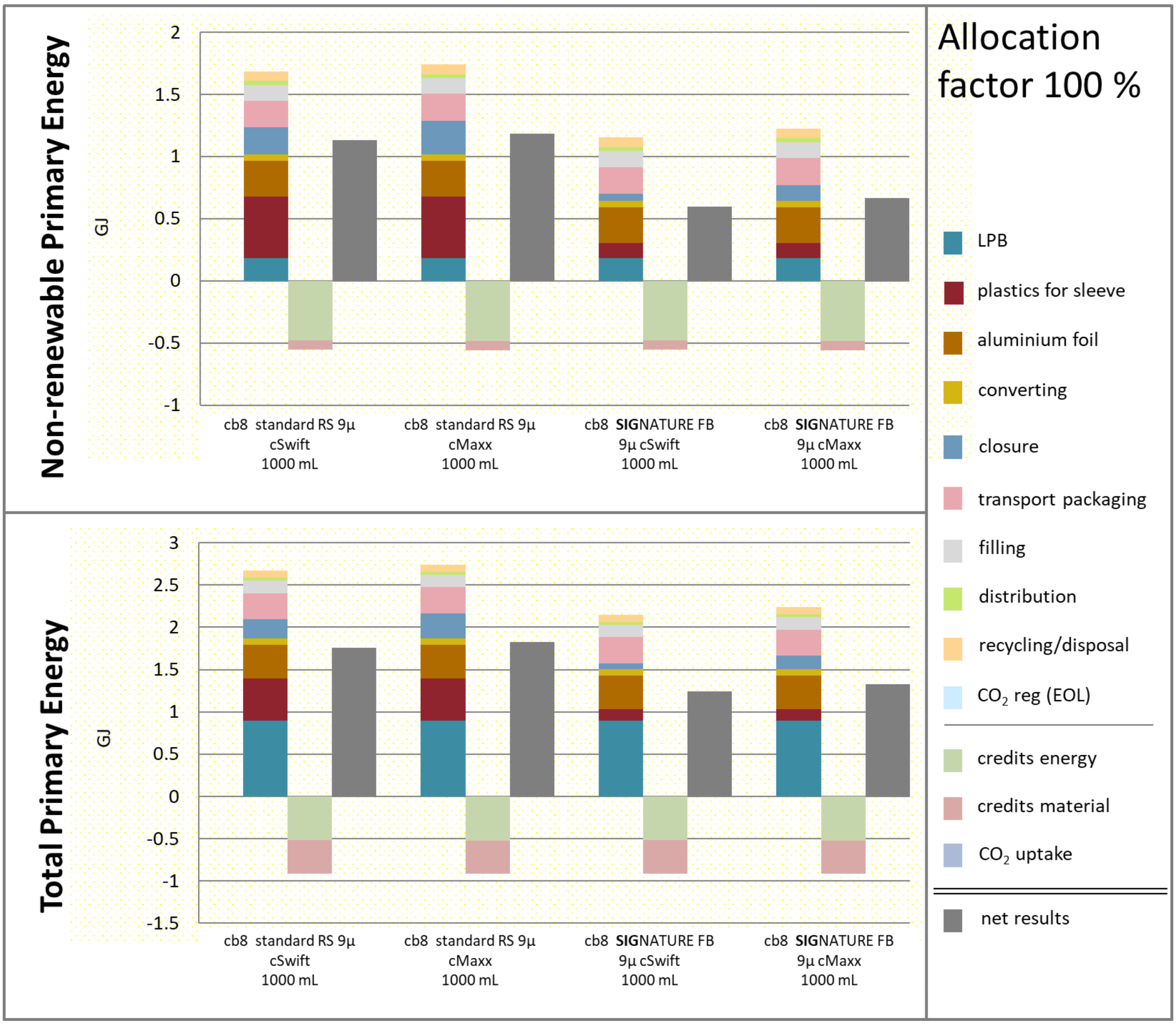

Figure 2-8: Indicator results for scenario **ll Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 100% (Part 4)

Table 2-2: Category indicator results for **scenario II Europe, combiblocMidi (cb8) 9µ** beverage cartons with allocation factor 100 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario II Europe, allocation factor 100 %		cb8 standard RS 9µ cSwift 1000 mL	cb8 standard RS 9µ cMaxx 1000 mL	cb8 SIGNATURE FB 9µ cSwift 1000 mL	cb8 SIGNATURE FB 9µ cMaxx 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	128.00	129.49	111.96	113.88
	CO_2 (reg)	27.08	27.09	45.06	44.56
	Credits	-37.95	-38.31	-37.95	-38.31
	CO_2 uptake	-38.51	-38.53	-66.27	-65.46
	Net results (∑)	78.61	79.74	52.79	54.66
Acidification [g SO_2-equivalents]	Burdens	0.31	0.31	0.30	0.30
	Credits	-0.08	-0.08	-0.08	-0.08
	Net results (∑)	0.23	0.23	0.22	0.22
Summer smog [g O_3-equivalents]	Burdens	3.92	3.95	3.79	3.82
	Credits	-0.93	-0.93	-0.93	-0.93
	Net results (∑)	3.00	3.02	2.86	2.88
Ozone Depletion [g R-11-equivalents]	Burdens	0.07	0.07	0.07	0.07
	Credits	-0.03	-0.03	-0.03	-0.03
	Net results (∑)	0.04	0.04	0.04	0.04
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	29.94	30.17	29.19	29.44
	Credits	-7.63	-7.67	-7.63	-7.67
	Net results (∑)	22.31	22.50	21.56	21.77
Aquatic eutrophication [g PO_4-equivalents]	Burdens	25.89	25.74	19.49	19.53
	Credits	-4.83	-4.84	-4.83	-4.84
	Net results (∑)	21.05	20.90	14.66	14.70
Particulate matter [g PM 2,5- equivalents]	Burdens	0.29	0.29	0.28	0.28
	Credits	-0.07	-0.07	-0.07	-0.07
	Net results (∑)	0.22	0.22	0.21	0.21
Abiotic resource depletion [kg sb-equivalents]	Burdens	0.14	0.14	0.09	0.09
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.09	0.09	0.04	0.05
Non-renewable primary energy [GJ]	Burdens	1.69	1.74	1.15	1.22
	Credits	-0.55	-0.56	-0.55	-0.56
	Net results (∑)	1.13	1.18	0.60	0.66
Total Primary Energy [GJ]	Burdens	2.67	2.74	2.15	2.24
	Credits	-0.91	-0.92	-0.91	-0.92
	Net results (∑)	1.76	1.83	1.24	1.32

2.1.1.2 Comparison between systems

The percentages in **Table 2-3** show the difference of net results between all considered formats of combiblocMidi (cb8) 9µ beverage cartons in the same volume segment. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 2-3: Comparison of net results of **combiblocMidi (cb8) 9µ** beverage cartons (Europe)

	The net results of			
	combiblocMidi (cb8) SIGNATURE FB 9µ cSwift 1000 mL		**combiblocMidi (cb8) SIGNATURE FB 9µ cMaxx 1000 mL**	
	are lower (green)/higher (red) than those of			
	combiblocMidi (cb8) standard RS 9µ cSwift 1000 mL		combiblocMidi (cb8) standard RS 9µ cMaxx 1000 mL	
	AF 50	**AF 100**	**AF 50**	**AF 100**
Impact categories				
Climate Change	-40%	-21%	-38%	-22%
Ozone Depletion	0%	0%	0%	0%
Summer Smog	-4%	-3%	-4%	-3%
Particulate Matter	-3%	-2%	-3%	-2%
Acidification	-2%	-1%	-2%	-1%
Terrestrial Eutrophication	-3%	-2%	-3%	-2%
Aquatic Eutrophication	-28%	-22%	-27%	-23%
Abiotic Resource Depletion	-45%	-39%	-43%	-41%
Non-renwable Primary Energy	-38%	-32%	-36%	-33%
Total Primary Energy	-24%	-20%	-22%	-21%

In both scenarios, the **combiblocMidi (cb8) SIGNATURE FB 9µ cSwift** shows lower net results than the combiblocMidi (cb8) standard RS 9µ cSwift in the impact categories ‘Climate Change’, ‘Aquatic Eutrophication’, ‘Abiotic Resource Depletion’ and in the inventory categories ‘Non-renewable Primary Energy’ and ‘Total Primary Energy’.

The mass-balanced PE and PP in the sleeve and closure of the combiblocMidi (cb8) **SIG**NATURE FB 9µ cSwift is the only difference to the combiblocMidi (cb8) standard RS cSwift, that leads to significantly lower net results in the categories mentioned.

In both scenarios, the **combiblocMidi (cb8) SIGNATURE FB 9µ cMaxx** shows lower net results than the combiblocMidi (cb8) standard RS 9µ cMaxx in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PE and PP in the sleeve and closure of the combiblocMidi (cb8) **SIG**NATURE FB 9µ cMaxx is the only difference to the combiblocMidi (cb8) standard RS cMaxx, that leads to significantly lower net results in the categories mentioned.

3 Conclusions and Recommendations

Conclusions

- In both scenarios, the combiblocMidi (cb8) **SIG**NATURE FB 9µ cSwift shows lower net results than the combiblocMidi (cb8) standard RS 9µ cSwift in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.
- In both scenarios, the combiblocMidi (cb8) **SIG**NATURE FB 9µ cMaxx shows lower net results than the combiblocMidi (cb8) standard RS 9µ cMaxx in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.
- The comparison of combiblocMidi (cb8) **SIG**NATURE FB 9µ packaging systems show a similar picture as combiblocMidi (cb8) **SIG**NATURE FB packaging systems (1000 mL) of the main report.

Recommendations

- Since the environmental result of the combiblocMidi (cb8) 9µ beverage carton formats are significantly influenced by the production of its main components, the sleeve and closure, measures to ensure the same functionality by the use of less material are recommended.
- It is shown in this study that the closures play a crucial role in the life cycle of the combiblocMidi (cb8) 9µ beverage carton formats. To improve the overall environmental performance, it is recommended to assess the possibilities of using smaller and lighter closures for all beverage carton formats.
- It is also recommended to actually achieve a more significant physical share of tall oil based input materials for the production of polymers, as the by-product of the pulp industry is currently only dedicated to direct thermal use. The utilisation and demand of mass-balanced polymers by SIG Combibloc might be a driver to do so.

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Eurostat (2021): Municipal waste by waste management operations. https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do. (18.05.2021).

EXTR:ACT (2020): Recycling rates EU. Personal communication with Raymond De Schrevel, November 2021.

Appendix 2a: Analysis of combismile **SIG**NATURE FULL BARRIER for combismileSmall and combismileBig on the European market

Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach

CB-100734

commissioned by SIG Combibloc

Heidelberg, May 2022

1 Introduction

The focus of the main report is to investigate combiblocSlimline (cb3) and combiblocMidi (cb8) cartons on the European market. In this appendix 2a, combismileSmall (ci17) and combismileBig (ci18) carton formats on the European market are assessed. The beverage cartons examined are listed in **Table** 1-1. The comparisons of the beverage cartons are structured according to the same scheme as in the main report.

The following abbreviations, which are included in the packaging names are applied in this study:

- combismileSmall (ci17)
- combismileBig (ci18)
- standard RS/TS (robust structure, structure with aluminium foil barrier)
- cGoSmall (combiGoSmall, closure)
- cGoBig (combiGoBig, closure)
- **SIG**NATURE PACK FB (full barrier, containing aluminium)

Table 1-1: List of beverage cartons examined for the European market

combismileSmall (ci17) beverage cartons and closure	combismileBig (ci18) beverage cartons and closure
ci17 standard TS 200 mL	ci18 standard RS 200 mL
ci17 standard TS 200 mL (cGoSmall)	ci18 **SIG**NATURE FB 200 mL
ci17 **SIG**NATURE FB 200 mL	ci18 standard RS 250 mL
ci17 **SIG**NATURE FB 200 mL (cGoSmall)	ci18 **SIG**NATURE FB 250 mL
ci17 standard TS 250 mL	ci18 standard RS 300 mL (cGoBig)
ci17 standard TS 250 mL (cGoSmall)	ci18 **SIG**NATURE FB 300 mL (cGoBig)
ci17 **SIG**NATURE FB 250 mL	ci18 standard RS 330 mL (cGoBig)
ci17 **SIG**NATURE FB 250 mL (cGoSmall)	ci18 **SIG**NATURE FB 330 mL (cGoBig)
	ci18 standard RS 350 mL (cGoBig)
	ci18 **SIG**NATURE FB 350 mL (cGoBig)

Except for the specifications listed in **section 1.1**, this appendix 2a follows the same structure and methodology as the main report.

1.1 Packaging specifications

The packaging systems examined in this appendix 2a and their corresponding specifications are listed in Table 1-2:, Table 1-3 and Table 1-4.

Table 1-2: Packaging specifications of the beverage cartons in EU: combismileBig (ci18) and combismileSmall (ci17) **SIG**NATURE PACK 200-350 mL

combismileBig (ci18) and combismileSmall (ci17) SIGNATURE Pack 200-350 mL

Specification	Unit	Packaging system						
		ci18 SIGNATURE PACK FB	ci18 SIGNATURE PACK FB	ci18 SIGNATURE PACK FB	ci18 SIGNATURE PACK FB	ci18 SIGNATURE PACK FB	ci17 SIGNATURE PACK FB	ci17 SIGNATURE PACK FB
volume	mL	200	250	300	330	350	200	250
geographic Scope	-	EU						
chilled / ambient	-							
primary packaging (sum)[1]	**g**	**9.30**	**10.40**	**13.50**	**14.21**	**14.75**	**10.00**	**11.30**
primary packaging (per FU)	**g/FU**	**46500**	**41600**	**45000**	**43061**	**42143**	**50000**	**45200**
composite material (sleeve)	g	9.30	10.40	11.30	12.01	12.55	8.40	9.70
- liquid packaging board	g	7.00	7.80	8.50	9.04	9.45	6.10	70
- fossil PE	g	-	-	-	-	-	-	-
- mass-balanced PE	g	1.80	2.00	2.20	2.30	2.40	1.80	2.10
- Aluminium foil	g	0.50	0.60	0.60	0.67	0.70	0.50	0.60
closure	g	-	-	2.20	2.20	2.20	1.60	1.60
- mass-balanced PP	g	-	-	1.20	1.20	1.20	0.90	0.90
- mass-balanced PE	g	-	-	1.00	1.00	1.00	0.70	0.70
- fossil PS	g	-	-	-	-	-	-	-

[1] per primary packaging unit

Table 1-3: Packaging specifications of the beverage cartons in EU: combismileBig (ci18) standard RS and combismileSmall (ci17) standard TS 200-350 mL

combismileBig (ci18) and combismileSmall (ci17) standard RS 200-350 mL

Specification	Unit	Packaging system						
		ci18 standard RS	**ci18 standard RS**	**ci18 standard RS**	**ci18 standard RS**	**ci18 standard RS**	**ci17 standard TS**	**ci17 standard TS**
volume	mL	200	250	300	330	350	200	250
geographic Scope	-	EU						
chilled ambient	-							
primary packaging (sum)[1]	**g**	**9.30**	**10.40**	**13.50**	**14.21**	**14.75**	**10**	**11.3**
primary packaging (per FU)	**g/FU**	**46500**	**41600**	**45000**	**43061**	**42143**	**50000**	**45200**
composite material (sleeve)	g	9.30	10.40	11.30	12.01	12.55	8.40	9.70
- liquid packaging board	g	7.00	7.80	8.50	9.04	9.45	6.10	7.00
- fossil PE	g	1.80	2.00	2.20	2.30	2.40	1.80	2.10
- mass-balanced PE	g	-	-	-	-	-	-	-
- Aluminium foil	g	0.50	0.60	0.60	0.67	0.70	0.50	0.60
closure	g	-	-	2.20	2.20	2.20	1.60	1.60
- fossil PP	g	-	-	1.20	1.20	1.20	0.90	0.90
- fossil PE	g	-	-	1.00	1.00	1.00	0.70	0.70
- fossil PS	g	-	-	-	-	-	-	-

[1] per primary packaging unit

Table 1-4: Secondary packaging, tertiary packaging and pallet configuration of the beverage cartons in EU: combismileBig (ci18) and combismileSmall (ci17) 200-350 mL

Specification	Unit	ci18 200	ci18 250	ci18 300	ci18 330	ci18 350	ci17 200	ci17 250
					EU			
secondary packaging (sum)[2]	g	150	155	169	181	140	170	224
- tray/box (corrugated cardboard)	g	150	155	169	181	140	170	224
Tertiary packaging (sum)[3]	g	25350	25350	25350	25350	26430	25350	25350
- pallet	g	25000	25000	25000	25000	25000	25000	25000
type of pallet	-	Industry pallet	Industry pallet	Industry pallet	Industry pallet	Industry pallet	Industry pallet	Industry pallet
number of use cycles	-	25	25	25	25	25	25	25
- stretch foil (per pallet) (LDPE)	g	350	350	350	350	350	350	350
Cardboard layers	g	-	-	-	-	1080		
pallet configuration								
cartons per tray	pcs	24	24	24	24	24	32	32
trays / packs per layer	pcs	15	15	15	15	15	20	20
layers per pallet	pcs	11	10	9	8	7	10	8
cartons per pallet	pcs	3960	3600	3240	2880	2520	6400	5120

[2] per secondary packaging unit; [3] per tertiary packaging unit (pallet)

2 Results and discussion

2.1 Europe combismileSmall (ci17) beverage cartons 200 – 250 mL

2.1.1 Scenario I (50% allocation): numerical values and graphs

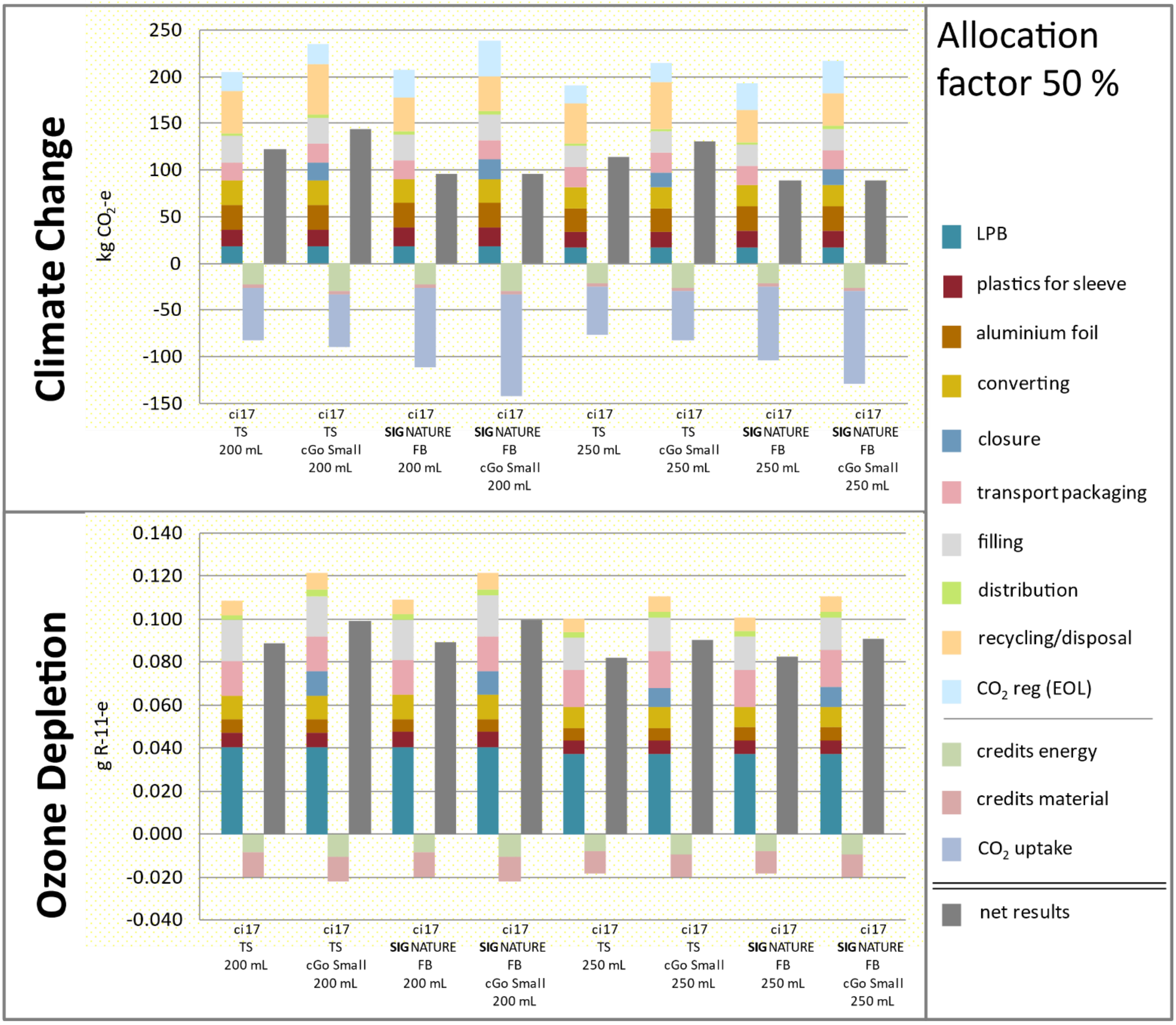

Figure 2-1: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 50 % (Part 1)

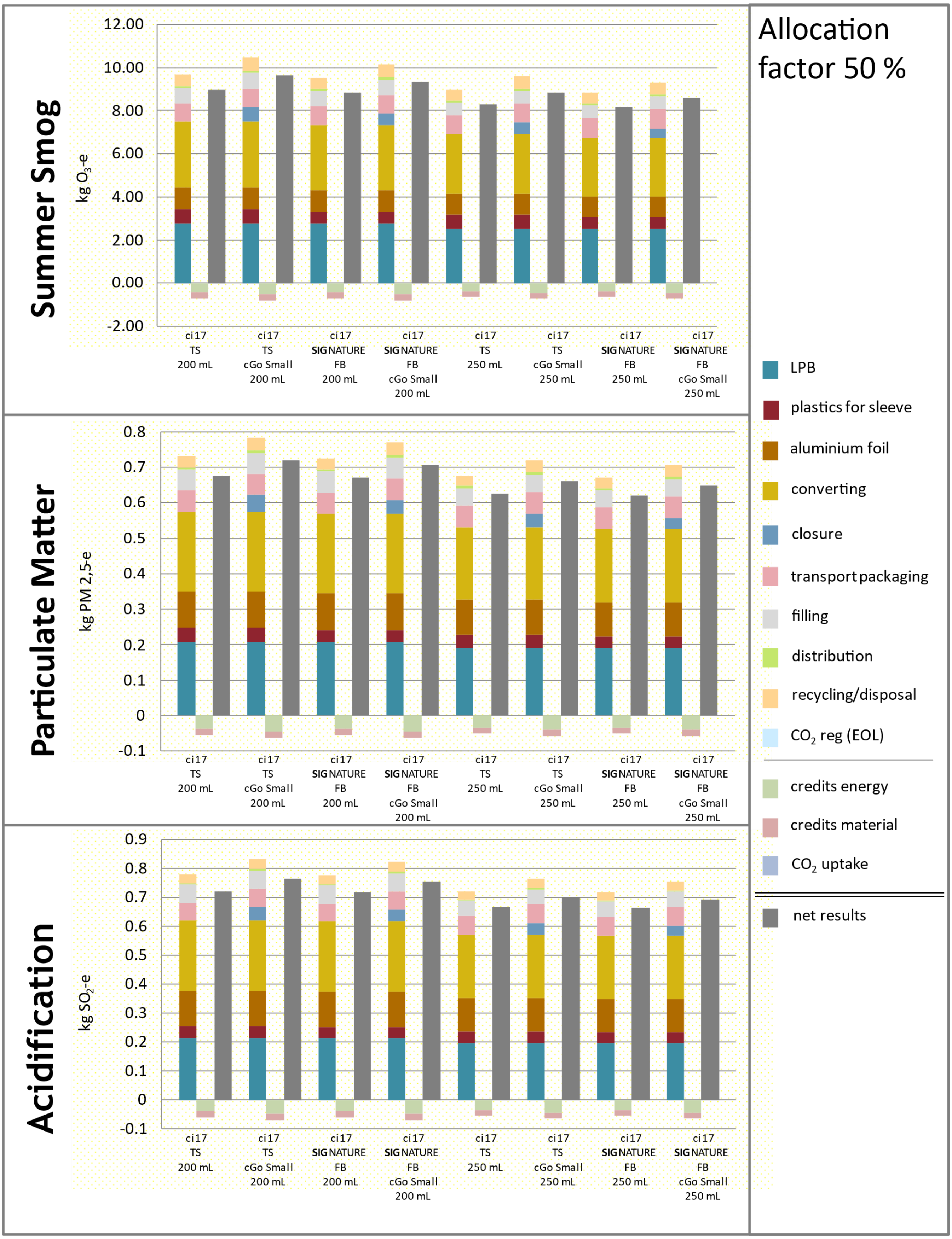

Figure 2-2: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 50 % (Part 2)

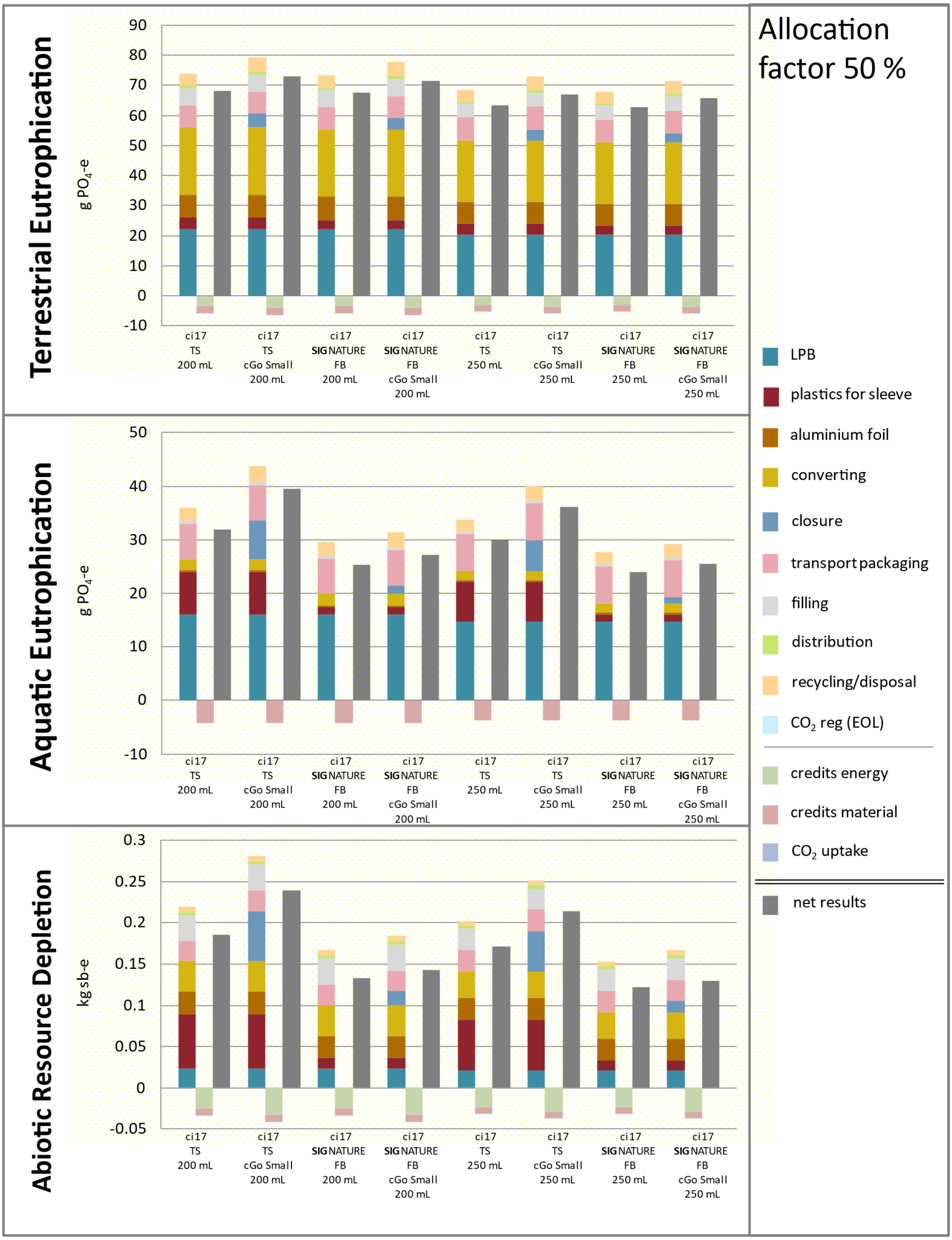

Figure 2-3: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 50 % (Part 3)

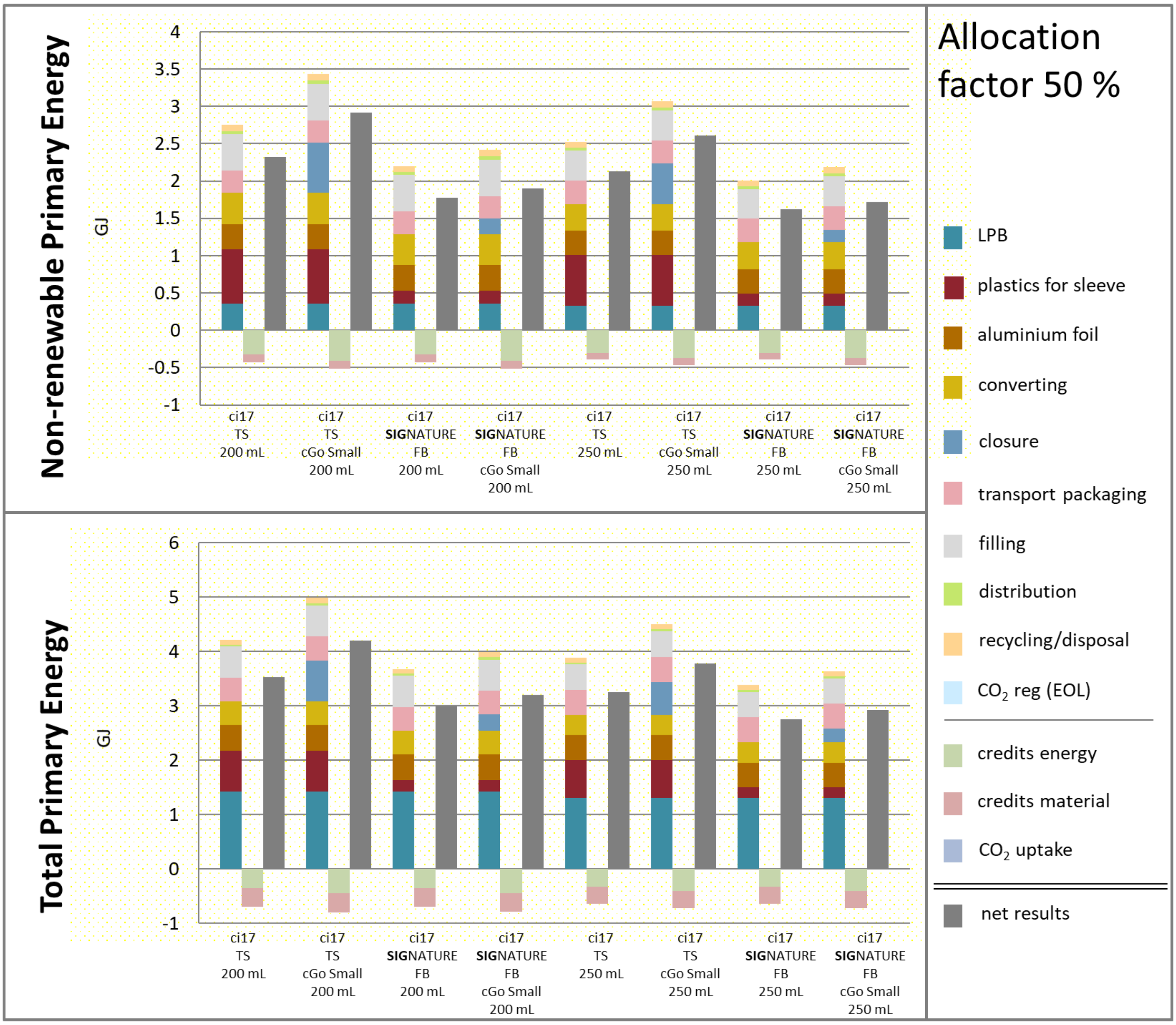

Figure 2-4: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 50 % (Part 4)

Table 2-1: Category indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Europe, allocation factor 50 %		ci17 TS 200 mL	ci17 TS cGo Small 200 mL	ci17 SIGNATURE FB 200 mL	ci17 SIGNATURE FB cGo Small 200 mL	ci17 TS 250 mL	ci17 TS cGo Small 250 mL	ci17 SIGNATURE FB 250 mL	ci17 SIGNATURE FB cGo Small 250 mL
Climate change [kg CO_2-equivalents]	Burdens	184.43	213.30	176.94	199.98	171.11	194.21	164.12	182.55
	CO_2 (reg)	21.11	21.26	30.54	38.20	19.73	19.85	28.54	34.66
	Credits	-26.37	-33.45	-26.37	-33.45	-24.46	-30.12	-24.46	-30.12
	CO_2 uptake	-56.31	-56.65	-84.95	-109.41	-52.49	-52.76	-79.23	-98.79
	Net results (∑)	122.86	144.47	96.16	95.32	113.89	131.17	88.97	88.30
Acidification [g SO_2-equivalents]	Burdens	0.78	0.83	0.78	0.82	0.72	0.77	0.72	0.76
	Credits	-0.06	-0.07	-0.06	-0.07	-0.05	-0.06	-0.05	-0.06
	Net results (∑)	0.72	0.76	0.72	0.76	0.67	0.70	0.66	0.69
Summer smog [g O_3-equivalents]	Burdens	9.67	10.45	9.53	10.15	8.95	9.58	8.82	9.32
	Credits	-0.70	-0.81	-0.70	-0.81	-0.65	-0.73	-0.65	-0.73
	Net results (∑)	8.96	9.64	8.82	9.34	8.30	8.85	8.17	8.59
Ozone Depletion [g R-11-equivalents]	Burdens	0.11	0.12	0.11	0.12	0.10	0.11	0.10	0.11
	Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	Net results (∑)	0.09	0.10	0.09	0.10	0.08	0.09	0.08	0.09
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	73.96	79.34	73.22	77.85	68.58	72.88	67.89	71.59
	Credits	-5.69	-6.50	-5.69	-6.49	-5.25	-5.90	-5.25	-5.89
	Net results (∑)	68.27	72.84	67.53	71.36	63.33	66.98	62.64	65.70
Aquatic eutrophication [g PO_4-equivalents]	Burdens	36.04	43.70	29.49	31.44	33.83	39.96	27.72	29.28
	Credits	-4.17	-4.22	-4.17	-4.22	-3.76	-3.79	-3.76	-3.79
	Net results (∑)	31.87	39.48	25.31	27.23	30.08	36.17	23.96	25.49
Particulate matter [g PM 2,5- equivalents]	Burdens	0.73	0.78	0.72	0.77	0.68	0.72	0.67	0.71
	Credits	-0.05	-0.06	-0.05	-0.06	-0.05	-0.06	-0.05	-0.06
	Net results (∑)	0.68	0.72	0.67	0.71	0.63	0.66	0.62	0.65
Abiotic resource depletion [kg sb-equivalents]	Burdens	0.22	0.28	0.17	0.18	0.20	0.25	0.15	0.17
	Credits	-0.03	-0.04	-0.03	-0.04	-0.03	-0.04	-0.03	-0.04
	Net results (∑)	0.19	0.24	0.13	0.14	0.17	0.21	0.12	0.13
Non-renewable primary energy [GJ]	Burdens	2.75	3.44	2.20	2.42	2.52	3.07	2.01	2.18
	Credits	-0.42	-0.52	-0.42	-0.52	-0.39	-0.46	-0.39	-0.46
	Net results (∑)	2.33	2.92	1.78	1.90	2.13	2.61	1.62	1.72
Total Primary Energy [GJ]	Burdens	4.22	4.99	3.68	3.99	3.88	4.50	3.38	3.63
	Credits	-0.69	-0.79	-0.69	-0.79	-0.63	-0.72	-0.63	-0.71
	Net results (∑)	3.53	4.20	2.99	3.20	3.25	3.79	2.75	2.92

2.1.2 Scenario II (100% allocation): numerical values and graphs

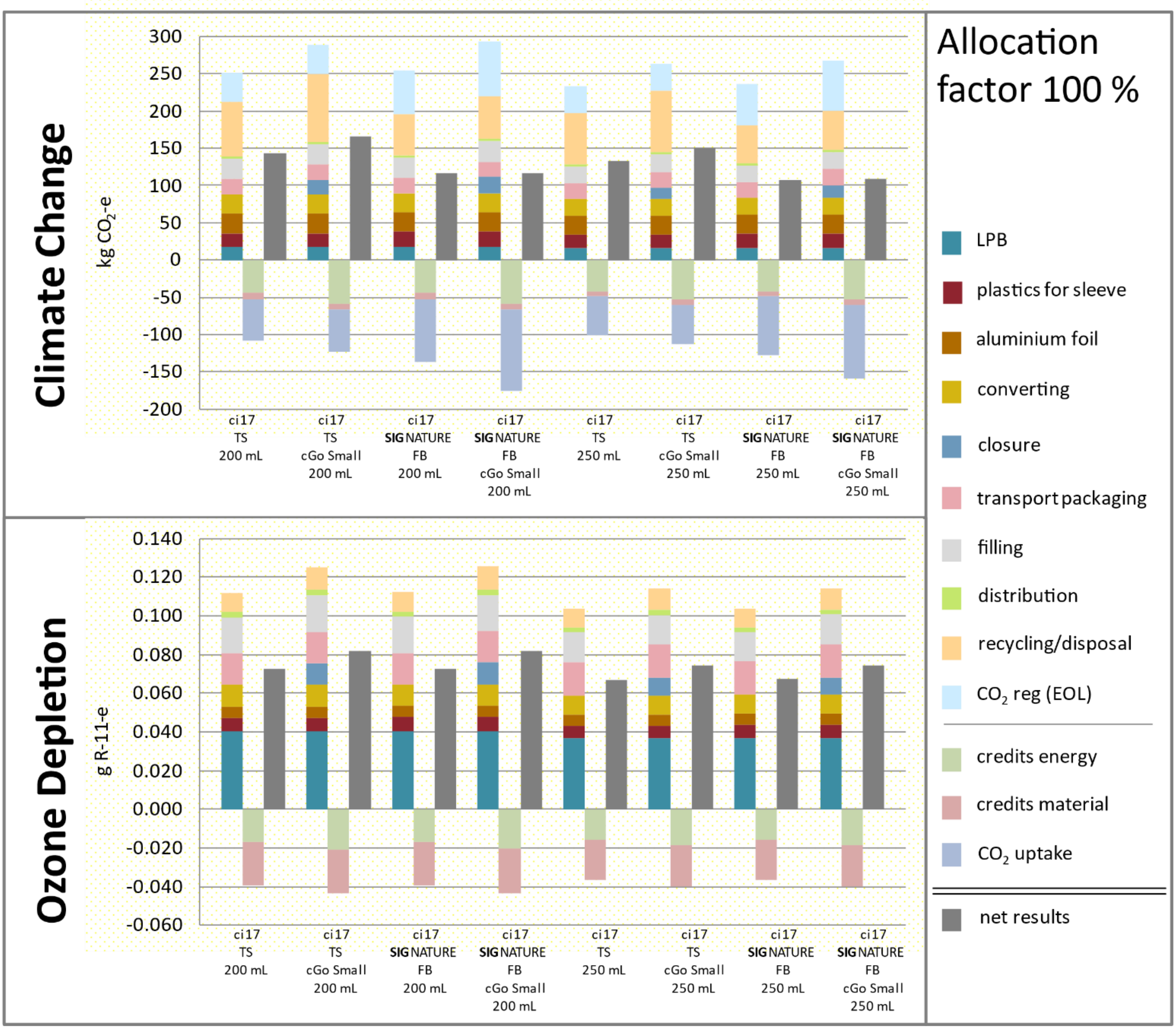

Figure 2-5: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 100 % (Part 1)

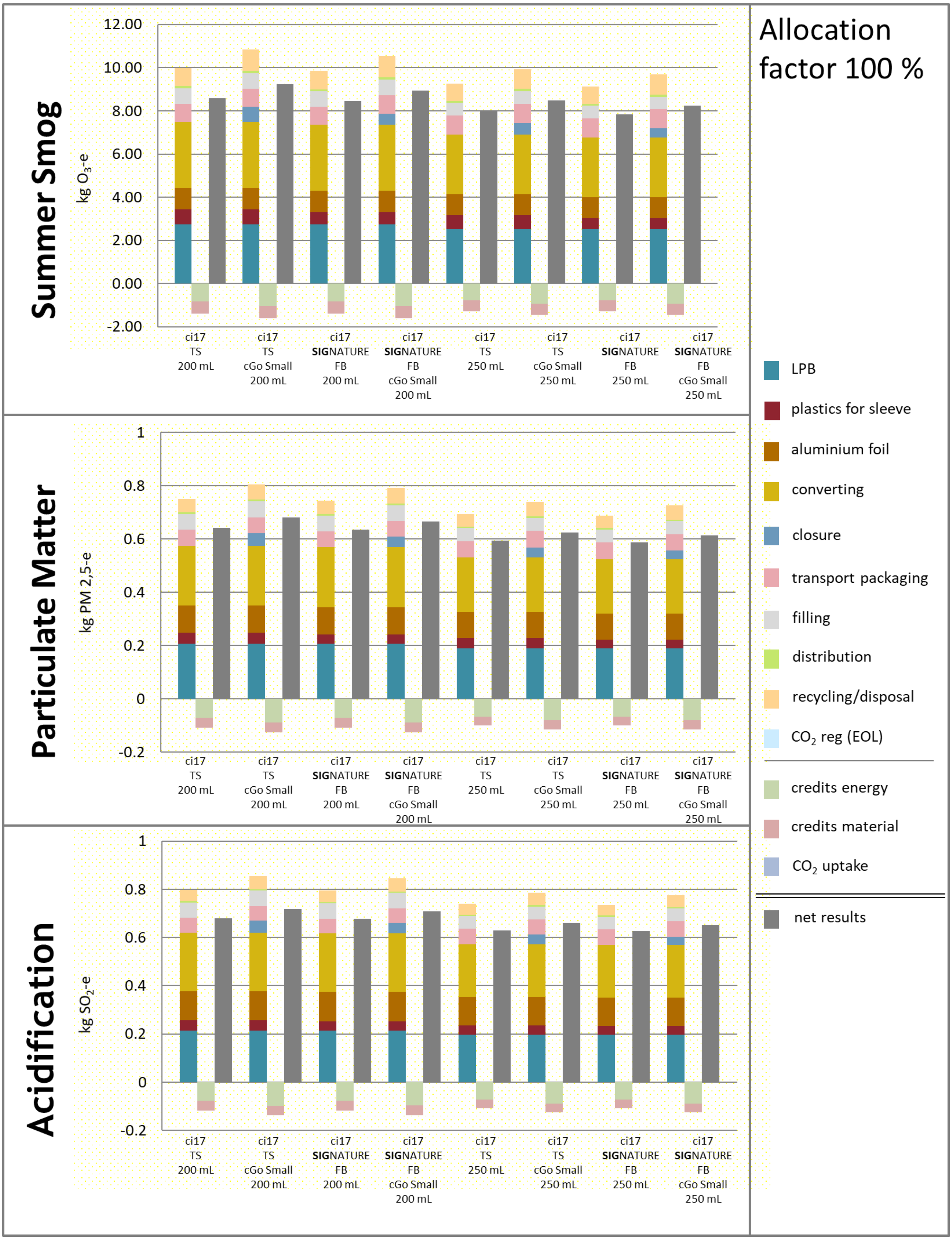

Figure 2-6: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 100 % (Part 2)

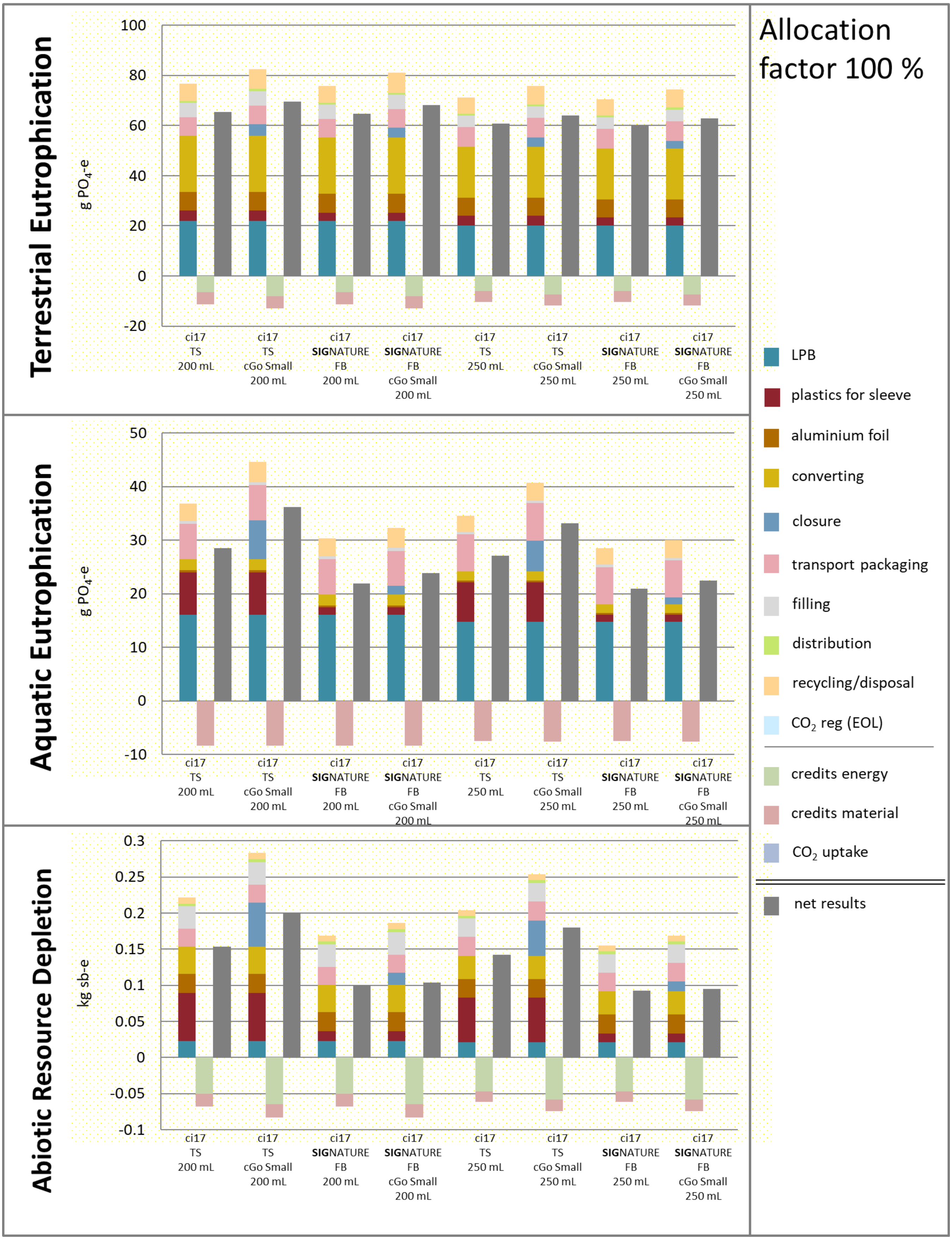

Figure 2-7: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 100 % (Part 3)

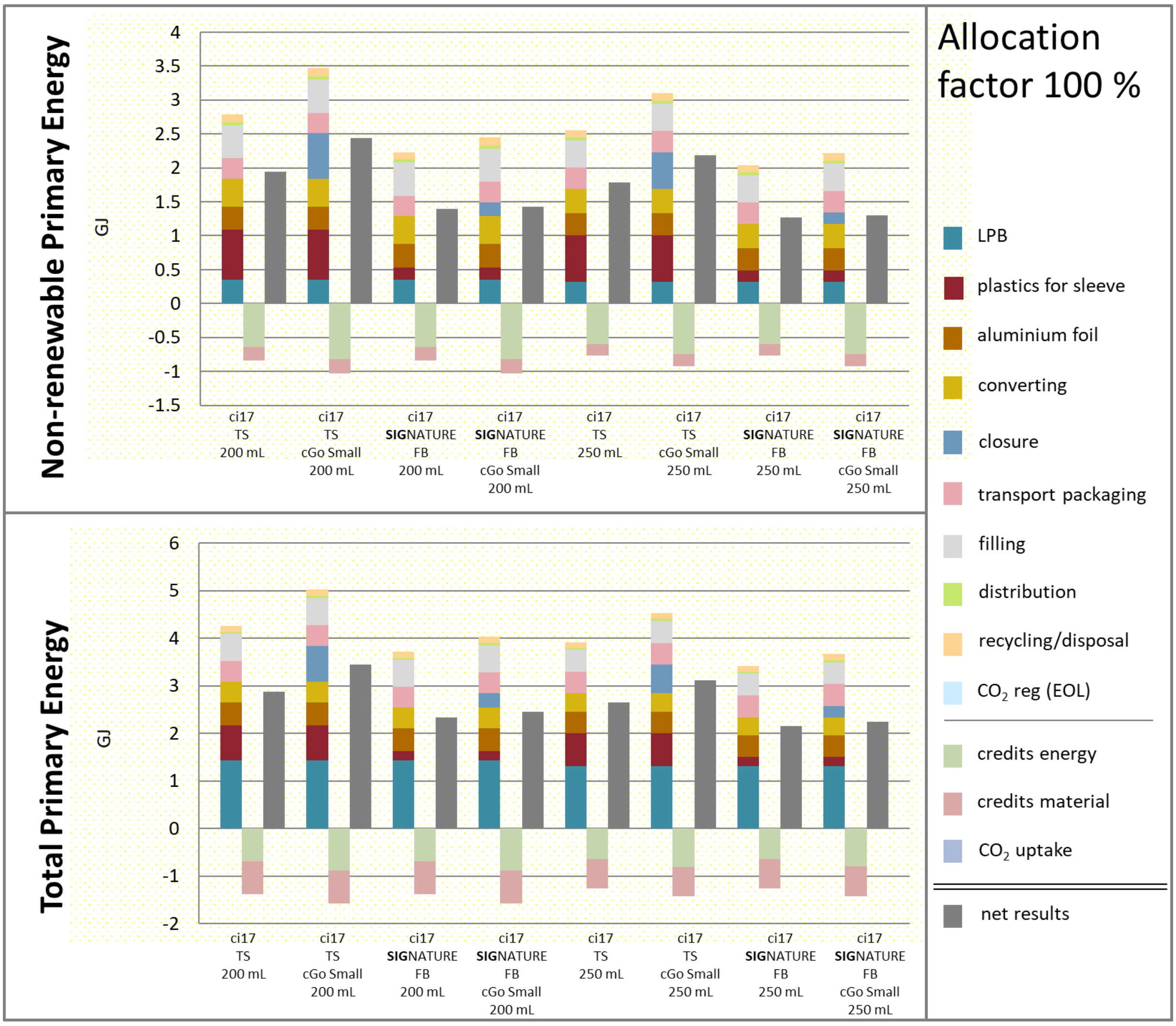

Figure 2-8: Indicator results for **scenario I Europe, combismileSmall (ci17)** beverage cartons with allocation factor 100 % (Part 4)

Table 2-2: Category indicator results for **scenario II Europe, combismileSmall (ci17)** beverage cartons with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario II Europe, allocation factor 100 %		ci17 TS 200 mL	ci17 TS cGo Small 200 mL	ci17 SIGNATURE FB 200 mL	ci17 SIGNATURE FB cGo Small 200 mL	ci17 TS 250 mL	ci17 TS cGo Small 250 mL	ci17 SIGNATURE FB 250 mL	ci17 SIGNATURE FB cGo Small 250 mL
Climate change [kg CO_2-equivalents]	Burdens	212.52	249.81	195.59	219.46	197.34	227.17	181.53	200.63
	CO_2 (reg)	39.15	39.41	58.03	73.29	36.54	36.74	54.15	66.36
	Credits	-52.32	-66.47	-52.32	-66.47	-48.51	-59.84	-48.51	-59.84
	CO_2 uptake	-56.31	-56.65	-84.95	-109.41	-52.49	-52.76	-79.23	-98.79
	Net results (∑)	143.05	166.10	116.35	116.87	132.87	151.31	107.94	108.35
Acidification [g SO_2-equivalents]	Burdens	0.80	0.86	0.79	0.85	0.74	0.78	0.74	0.78
	Credits	-0.12	-0.14	-0.12	-0.14	-0.11	-0.12	-0.11	-0.12
	Net results (∑)	0.68	0.72	0.68	0.71	0.63	0.66	0.63	0.65
Summer smog [g O_3-equivalents]	Burdens	10.00	10.85	9.86	10.54	9.26	9.94	9.13	9.68
	Credits	-1.40	-1.61	-1.40	-1.60	-1.28	-1.45	-1.28	-1.45
	Net results (∑)	8.60	9.24	8.46	8.94	7.97	8.49	7.84	8.23
Ozone Depletion [g R-11-equivalents]	Burdens	0.11	0.13	0.11	0.13	0.10	0.11	0.10	0.11
	Credits	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.07	0.08	0.07	0.08	0.07	0.07	0.07	0.07
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	76.62	82.54	75.88	81.05	71.07	75.80	70.37	74.51
	Credits	-11.29	-12.91	-11.29	-12.89	-10.41	-11.70	-10.41	-11.69
	Net results (∑)	65.33	69.64	64.59	68.16	60.66	64.10	59.96	62.82
Aquatic eutrophication [g PO_4-equivalents]	Burdens	36.84	44.56	30.28	32.30	34.56	40.74	28.45	30.06
	Credits	-8.35	-8.43	-8.35	-8.43	-7.51	-7.58	-7.51	-7.58
	Net results (∑)	28.49	36.13	21.94	23.87	27.05	33.16	20.94	22.48
Particulate matter [g PM 2,5- equivalents]	Burdens	0.75	0.81	0.74	0.79	0.69	0.74	0.69	0.73
	Credits	-0.11	-0.13	-0.11	-0.13	-0.10	-0.11	-0.10	-0.11
	Net results (∑)	0.64	0.68	0.64	0.67	0.59	0.62	0.59	0.61
Abiotic resource depletion [kg sb-equivalents]	Burdens	0.22	0.28	0.17	0.19	0.20	0.25	0.15	0.17
	Credits	-0.07	-0.08	-0.07	-0.08	-0.06	-0.07	-0.06	-0.07
	Net results (∑)	0.15	0.20	0.10	0.10	0.14	0.18	0.09	0.10
Non-renewable primary energy [GJ]	Burdens	2.78	3.47	2.23	2.45	2.55	3.10	2.04	2.22
	Credits	-0.84	-1.03	-0.84	-1.03	-0.77	-0.92	-0.77	-0.92
	Net results (∑)	1.94	2.44	1.39	1.42	1.78	2.18	1.27	1.30
Total Primary Energy [GJ]	Burdens	4.25	5.03	3.72	4.03	3.92	4.54	3.42	3.67
	Credits	-1.37	-1.58	-1.37	-1.57	-1.26	-1.42	-1.26	-1.42
	Net results (∑)	2.88	3.45	2.34	2.46	2.66	3.12	2.15	2.25

2.1.3 Comparison between systems

The percentages in Table 2-3 show the difference of net results between all considered formats of combismileSmall (ci17) beverage cartons in the same volume segment. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 2-3: Comparison of net results **combismileSmall (ci17)** beverage cartons (Europe)

	The net results of							
	combismileSmall (ci17) SIGNATURE FB 200 mL		**combismileSmall (ci17) SIGNATURE FB cGoSmall 200 mL**		**combismileSmall (ci17) SIGNATURE FB 250 mL**		**combismileSmall (ci17) SIGNATURE FB cGoSmall 250 mL**	
	are lower (green)/higher (red) than those of							
	combismileSmall (ci17) standard TS 200 mL		combismileSmall (ci17) standard TS cGoSmall 200 mL		combismileSmall (ci17) standard TS 250 mL		combismileSmall (ci17) standard TS cGoSmall 250 mL	
	AF 50	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**
Impact category								
Climate Change	-22%	-19%	-34%	-30%	-22%	-19%	-33%	-28%
Ozone Depletion	0%	0%	0%	0%	0%	0%	0%	0%
Summer Smog	-2%	-2%	-3%	-3%	-2%	-2%	-3%	-3%
Particulate Matter	-1%	-1%	-2%	-2%	-1%	-1%	-2%	-2%
Acidification	0%	0%	-1%	-1%	0%	0%	-1%	-1%
Terrestrial Eutrophication	-1%	-1%	-2%	-2%	-1%	-1%	-2%	-2%
Aquatic Eutrophication	-21%	-23%	-31%	-34%	-20%	-23%	-30%	-32%
Abiotic Resource Depletion	-29%	-34%	-41%	-48%	-29%	-35%	-40%	-47%
Non-renwable Energy	-24%	-28%	-35%	-42%	-24%	-29%	-34%	-41%
Total Primary Energy	-15%	-19%	-24%	-29%	-15%	-19%	-23%	-28%

In both scenarios, all the **combismileSmall (ci17) SIGNATURE FB** show lower net results than the combismileSmall (ci17) standard TS in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PE and PP in the sleeve and closure of the combismileSmall (ci17) **SIG**NATURE FB is the only difference to the combismileSmall (ci17) standard TS, that leads to significantly lower net results in the categories mentioned.

2.2 Europe combismile big (ci18) beverage cartons 200 – 350 mL

2.2.1 Scenario I (50% allocation): Numerical values and graphs

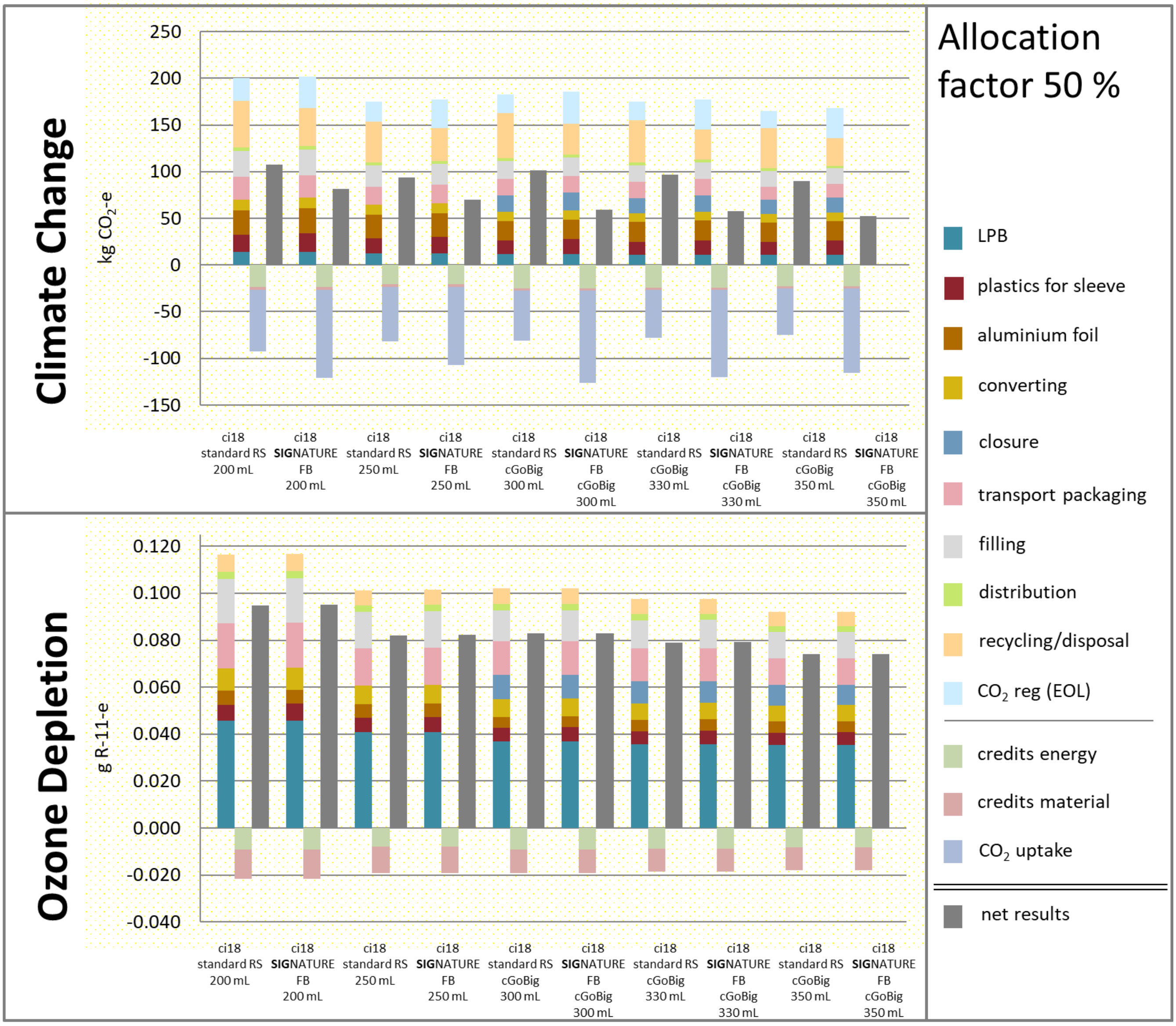

Figure 2-9: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 50 % (Part 1)

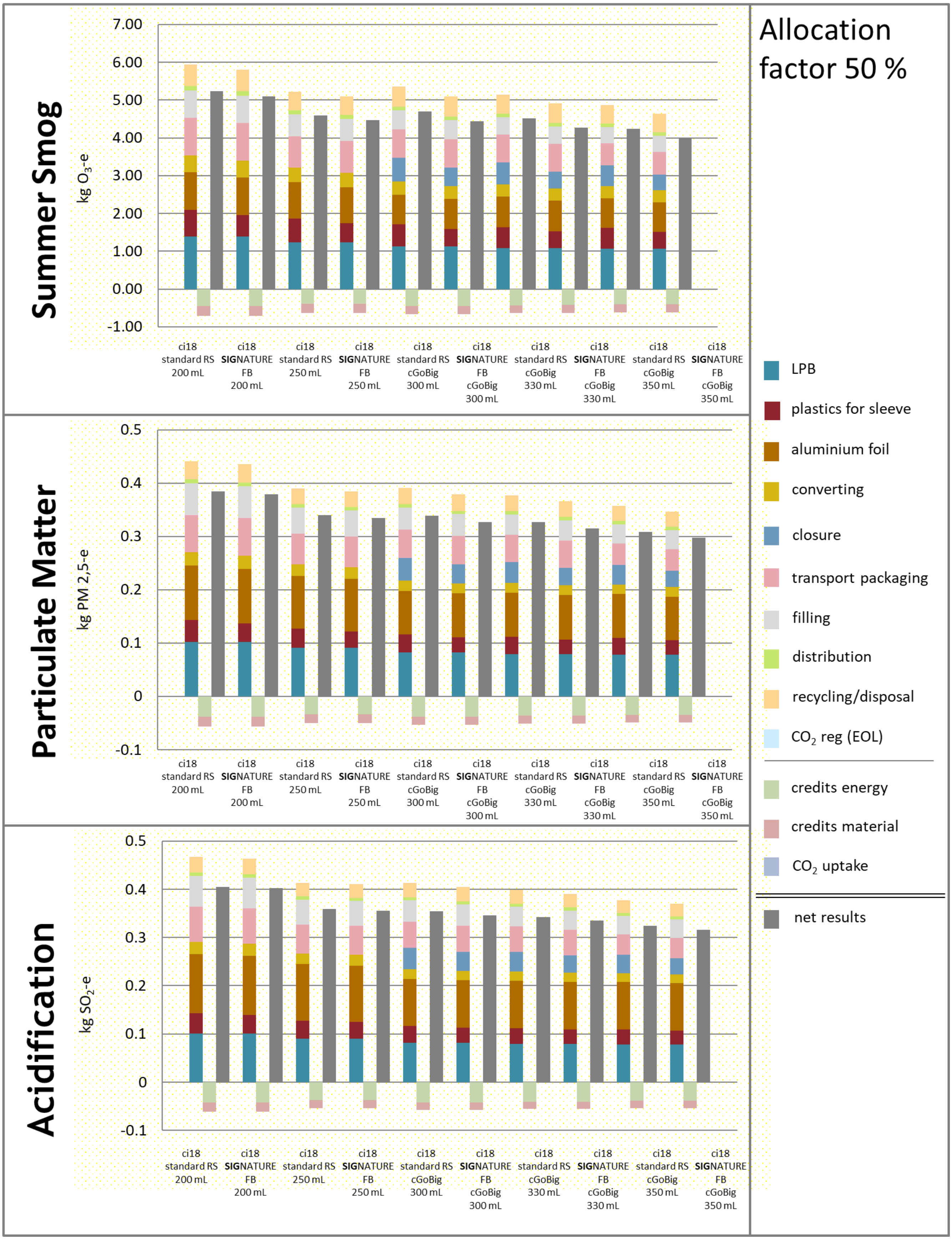

Figure 2-10: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 50 % (Part 2)

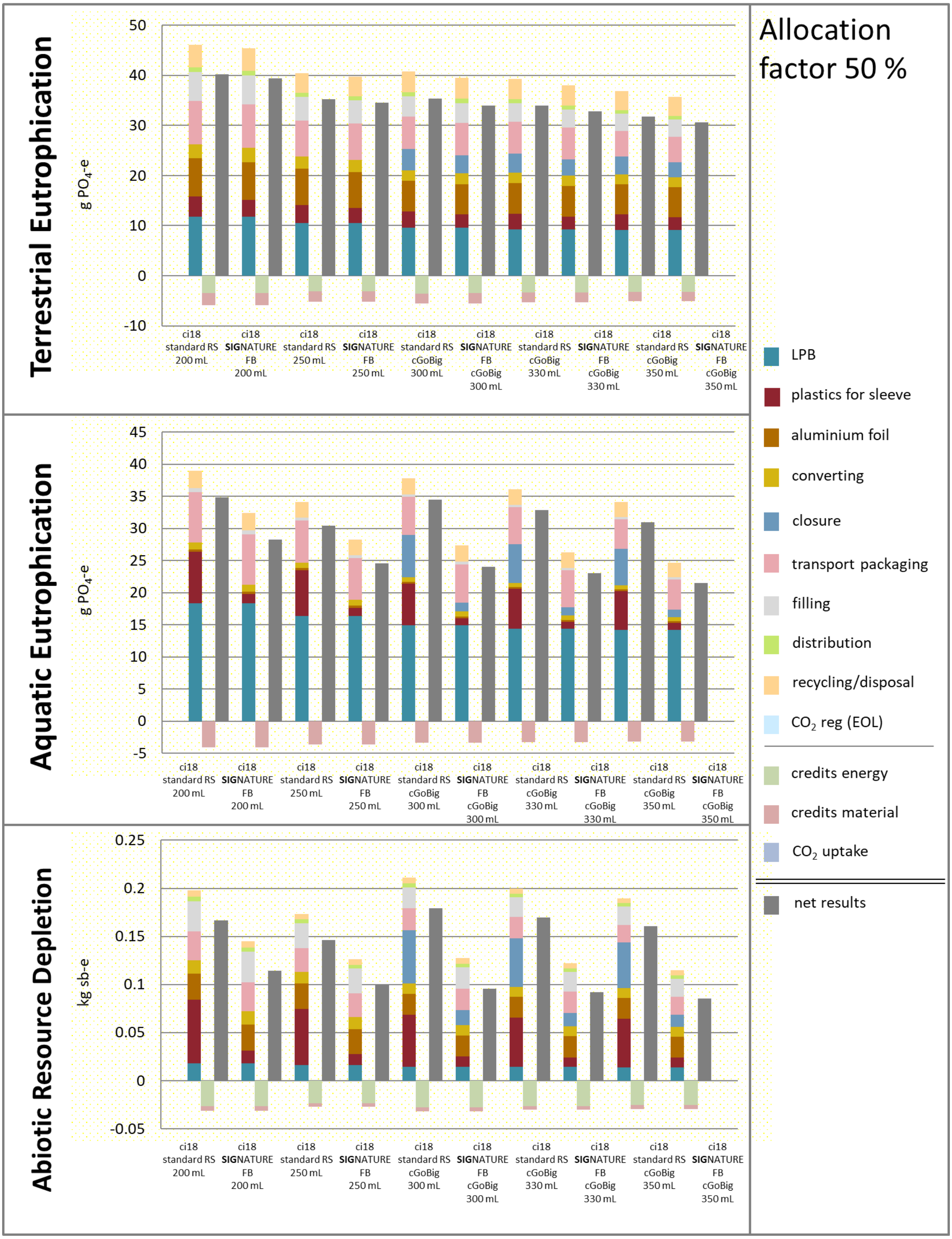

Figure 2-11: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 50 % (Part 3)

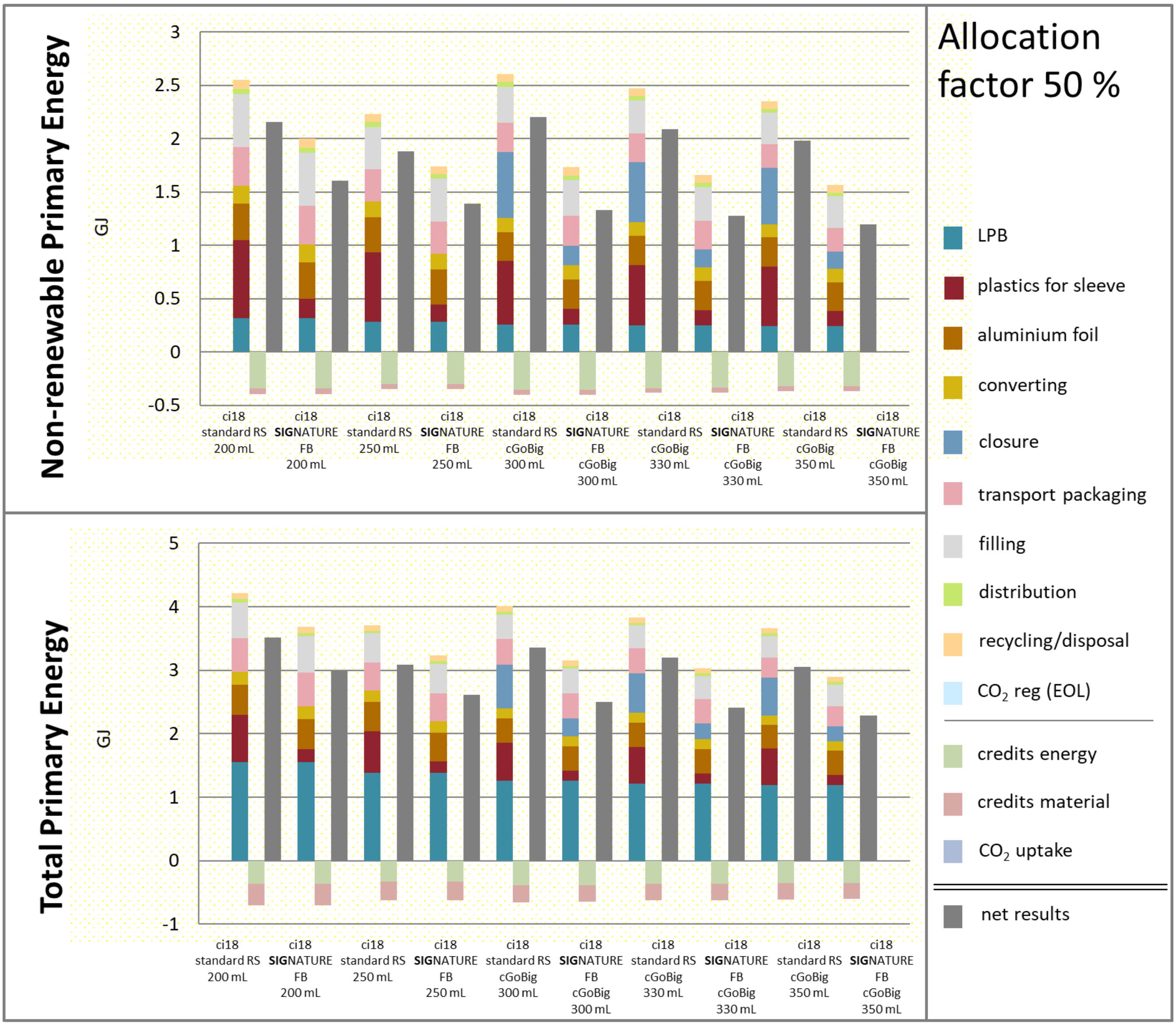

Figure 2-12: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 50 % (Part 4)

Table 2-4: Category indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Europe, allocation factor 50 %		ci18 standard RS 200 mL	ci18 SIGNATURE FB 200 mL	ci18 standard RS 250 mL	ci18 SIGNATURE FB 250 mL	ci18 standard RS cGoBig 300 mL	ci18 SIGNATURE FB cGoBig 300 mL	ci18 standard RS cGoBig 330 mL	ci18 SIGNATURE FB cGoBig 330 mL	ci18 standard RS cGoBig 350 mL	ci18 SIGNATURE FB cGoBig 350 mL
Climate change [kg CO_2-equivalents]	Burdens	175.43	167.93	153.41	146.75	162.48	151.06	155.42	144.78	146.42	136.16
	CO_2 (reg)	24.73	34.17	21.82	30.21	19.95	34.47	19.33	32.84	18.71	31.75
	Credits	-26.57	-26.57	-23.50	-23.50	-27.73	-27.73	-26.41	-26.41	-25.40	-25.40
	CO_2 uptake	-65.75	-94.39	-58.10	-83.57	-53.06	-98.35	-51.39	-93.52	-49.84	-90.48
	Net results (∑)	107.83	81.13	93.63	69.90	101.64	72.47	96.95	67.41	89.89	63.22
Acidification [g SO_2-equivalents]	Burdens	0.47	0.46	0.41	0.41	0.41	0.40	0.40	0.39	0.38	0.37
	Credits	-0.06	-0.06	-0.05	-0.05	-0.06	-0.06	-0.06	-0.06	-0.05	-0.05
	Net results (∑)	0.41	0.40	0.36	0.36	0.35	0.35	0.34	0.33	0.32	0.32
Summer smog [g O_3-equivalents]	Burdens	5.94	5.80	5.23	5.10	5.36	5.10	5.15	4.91	4.86	4.63
	Credits	-0.71	-0.71	-0.63	-0.63	-0.67	-0.67	-0.64	-0.64	-0.62	-0.62
	Net results (∑)	5.23	5.09	4.60	4.47	4.69	4.43	4.51	4.27	4.24	4.01
Ozone Depletion [g R-11-equivalents]	Burdens	0.12	0.12	0.10	0.10	0.10	0.10	0.10	0.10	0.09	0.09
	Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02
	Net results (∑)	0.09	0.10	0.08	0.08	0.08	0.08	0.08	0.08	0.07	0.07
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	46.11	45.36	40.44	39.78	40.78	39.50	39.22	38.03	36.88	35.74
	Credits	-5.92	-5.92	-5.24	-5.24	-5.49	-5.49	-5.26	-5.26	-5.09	-5.09
	Net results (∑)	40.19	39.44	35.20	34.54	35.30	34.02	33.96	32.77	31.79	30.65
Aquatic eutrophication [g PO_4-equivalents]	Burdens	38.96	32.41	34.08	28.26	37.86	27.33	36.10	26.31	34.14	24.70
	Credits	-4.10	-4.10	-3.64	-3.64	-3.34	-3.34	-3.24	-3.24	-3.20	-3.20
	Net results (∑)	34.86	28.31	30.44	24.61	34.52	23.99	32.87	23.08	30.94	21.51
Particulate matter [g PM 2,5- equivalents]	Burdens	0.44	0.43	0.39	0.38	0.39	0.38	0.38	0.37	0.36	0.35
	Credits	-0.06	-0.06	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05
	Net results (∑)	0.38	0.38	0.34	0.33	0.34	0.33	0.33	0.32	0.31	0.30
Abiotic resource depletion [kg sb-equivalents]	Burdens	0.20	0.15	0.17	0.13	0.21	0.13	0.20	0.12	0.19	0.11
	Credits	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03	-0.03
	Net results (∑)	0.17	0.11	0.15	0.10	0.18	0.10	0.17	0.09	0.16	0.09
Non-renewable primary energy [GJ]	Burdens	2.55	2.00	2.23	1.74	2.61	1.73	2.47	1.66	2.35	1.56
	Credits	-0.40	-0.40	-0.35	-0.35	-0.40	-0.40	-0.38	-0.38	-0.37	-0.37
	Net results (∑)	2.16	1.61	1.88	1.39	2.20	1.33	2.09	1.28	1.98	1.20
Total Primary Energy [GJ]	Burdens	4.22	3.68	3.71	3.23	4.01	3.16	3.83	3.03	3.66	2.89
	Credits	-0.70	-0.70	-0.62	-0.62	-0.65	-0.65	-0.63	-0.63	-0.61	-0.61
	Net results (∑)	3.52	2.98	3.09	2.61	3.36	2.50	3.20	2.41	3.05	2.28

2.2.2 Scenario II (100% allocation): Numerical values and graphs

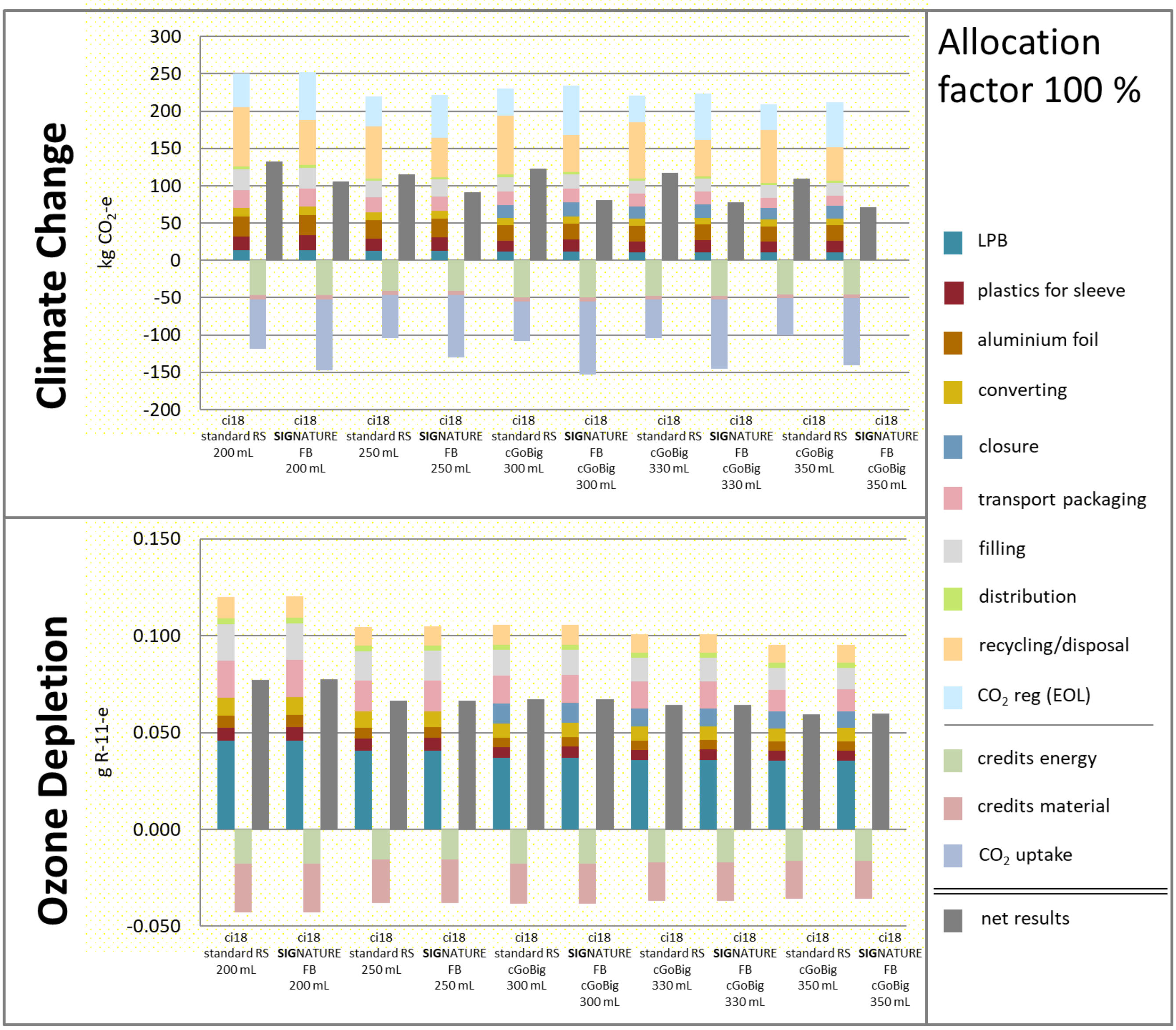

Figure 2-13: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 100 % (Part 1)

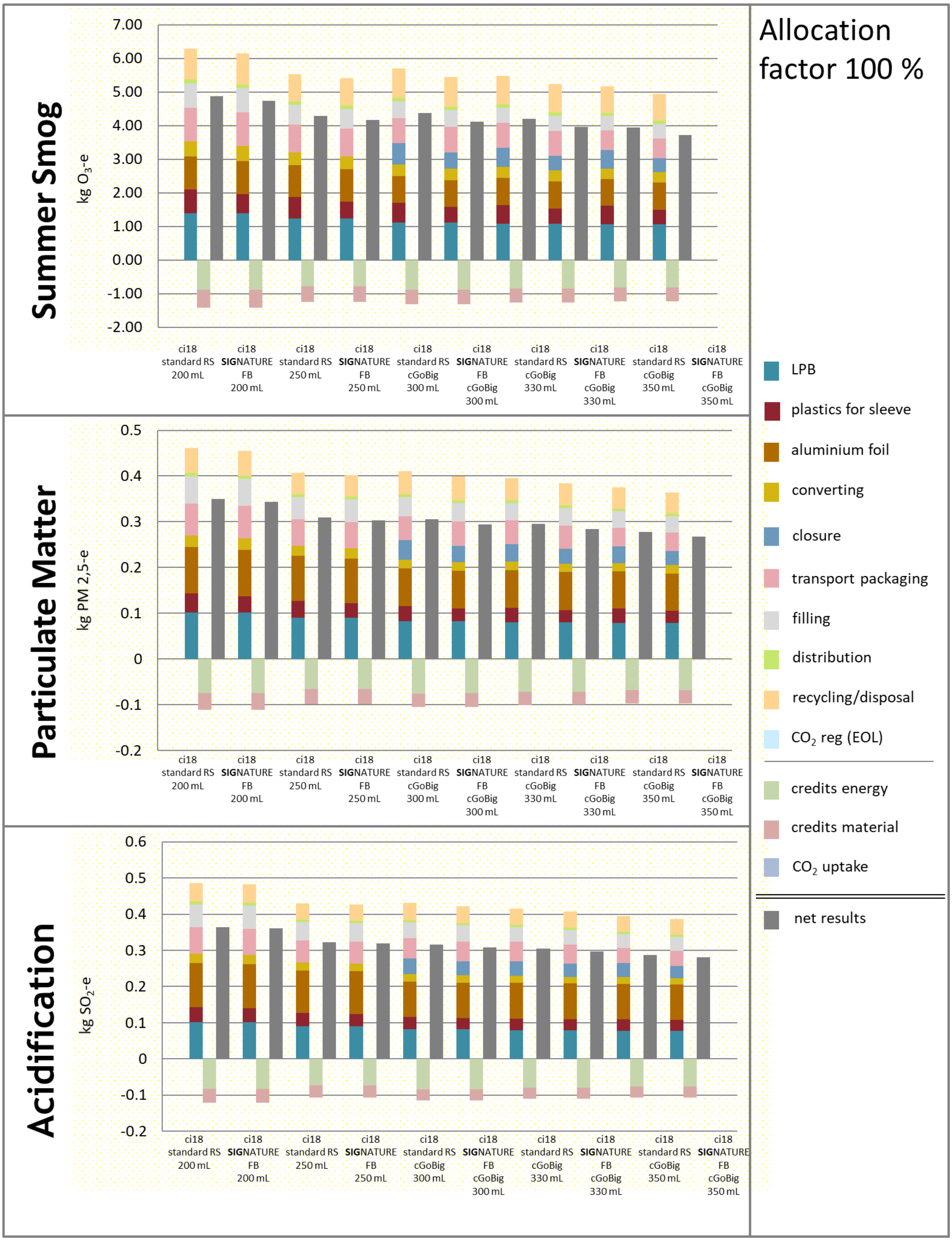

Figure 2-14: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 100 % (Part 2)

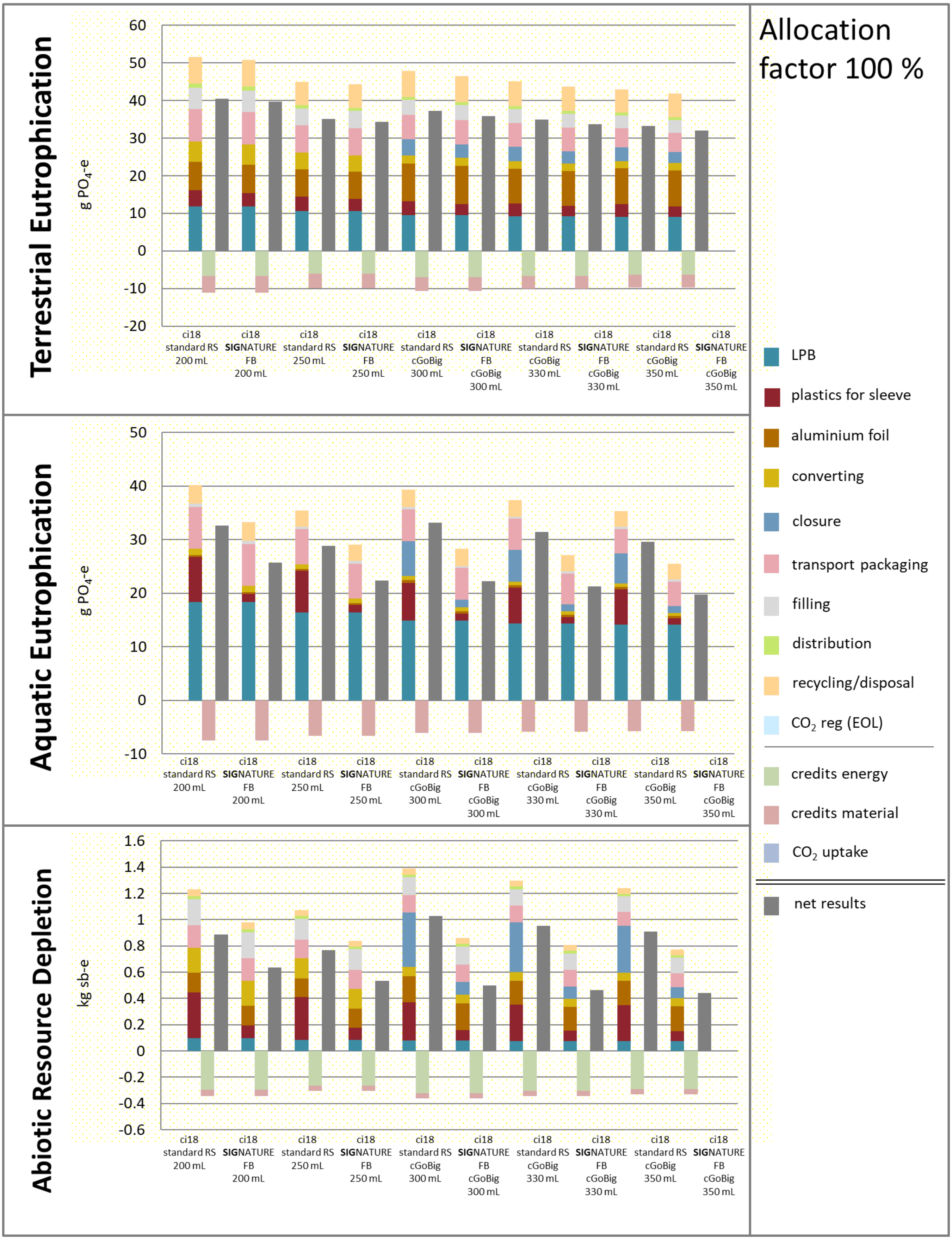

Figure 2-15: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 100 % (Part 3)

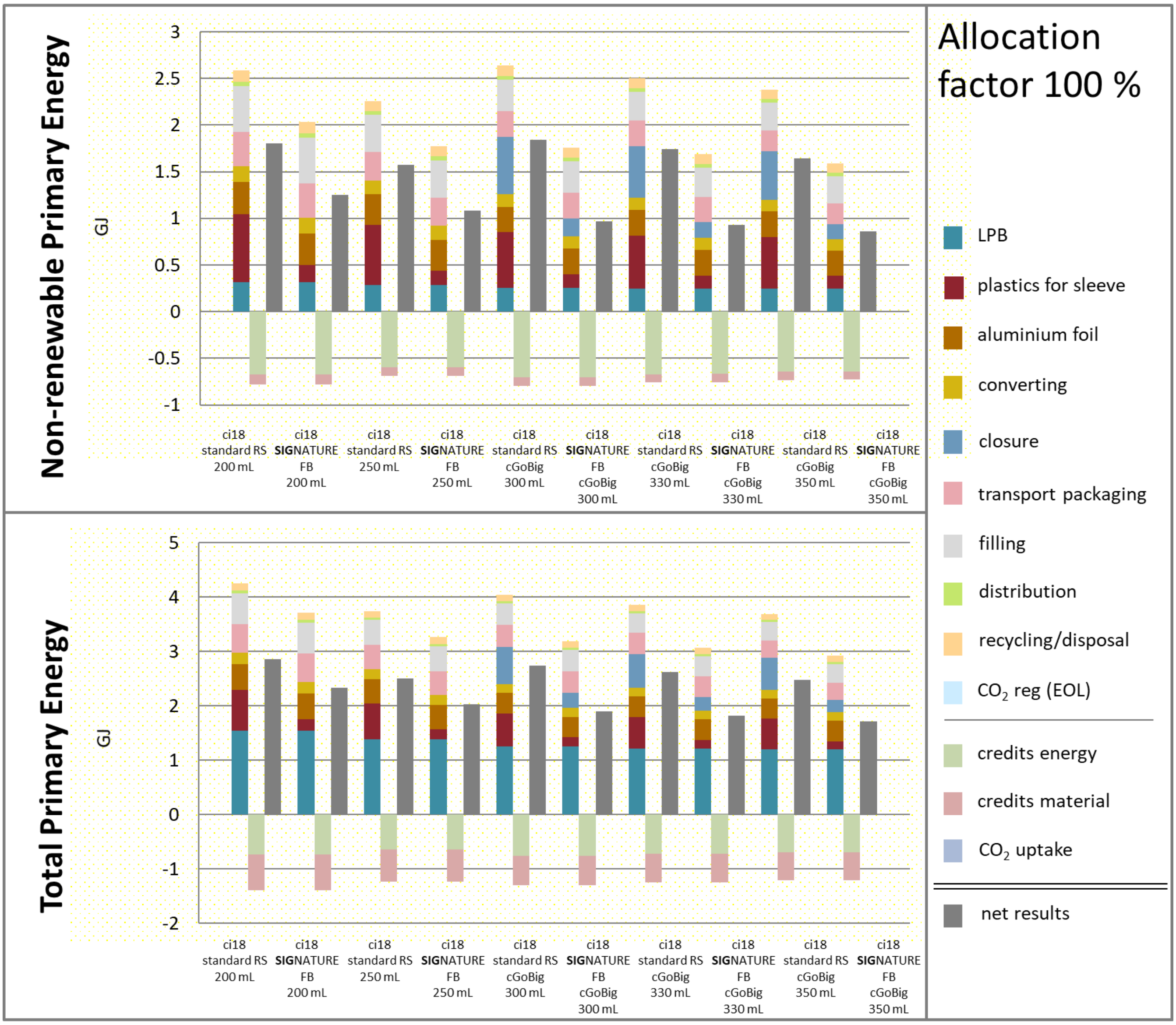

Figure 2-16: Indicator results for **scenario I Europe, combismileBig (ci18)** beverage cartons with allocation factor 100 % (Part 4)

Table 2-5: Category indicator results for **scenario ll Europe, combismileBig (ci18)** beverage cartons with allocation factor 50 %: burdens, credits and net results per functional unit of 1000 L beverage

Scenario ll Europe, allocation factor 100 %		**ci18 standard RS 200 mL**	**ci18 SIGNATURE FB 200 mL**	**ci18 standard RS 250 mL**	**ci18 SIGNATURE FB 250 mL**	**ci18 standard RS cGoBig 300 mL**	**ci18 SIGNATURE FB cGoBig 300 mL**	**ci18 standard RS cGoBig 330 mL**	**ci18 SIGNATURE FB cGoBig 330 mL**	**ci18 standard RS cGoBig 350 mL**	**ci18 SIGNATURE FB cGoBig 350 mL**
Climate change [kg CO_2-equivalents]	Burdens	204.85	187.91	179.28	164.23	193.66	167.65	185.01	160.80	174.68	151.31
	CO_2 (reg)	45.85	64.73	40.51	57.29	37.02	66.05	35.87	62.90	34.82	60.90
	Credits	-52.62	-52.62	-46.54	-46.54	-55.04	-55.04	-52.42	-52.42	-50.42	-50.42
	CO_2 uptake	-65.75	-94.39	-58.10	-83.57	-53.06	-98.35	-51.39	-93.52	-49.84	-90.48
	Net results (∑)	132.34	105.63	115.15	91.41	122.57	92.76	117.08	86.89	109.23	81.92
Acidification [g SO_2-equivalents]	Burdens	0.49	0.48	0.43	0.43	0.43	0.42	0.42	0.41	0.39	0.39
	Credits	-0.12	-0.12	-0.11	-0.11	-0.12	-0.12	-0.11	-0.11	-0.11	-0.11
	Net results (∑)	0.36	0.36	0.32	0.32	0.32	0.31	0.31	0.30	0.29	0.28
Summer smog [g O_3-equivalents]	Burdens	6.30	6.15	5.54	5.41	5.70	5.44	5.47	5.23	5.17	4.94
	Credits	-1.41	-1.41	-1.25	-1.25	-1.32	-1.32	-1.27	-1.27	-1.23	-1.23
	Net results (∑)	4.88	4.74	4.29	4.16	4.38	4.12	4.21	3.96	3.95	4.18
Ozone Depletion [g R-11-equivalents]	Burdens	0.12	0.12	0.10	0.10	0.11	0.11	0.10	0.10	0.10	0.10
	Credits	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06	0.06	0.06
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	48.95	48.20	42.93	42.27	43.55	42.26	41.86	40.66	39.40	38.25
	Credits	-11.73	-11.73	-10.38	-10.38	-10.88	-10.88	-10.44	-10.44	-10.10	-10.10
	Net results (∑)	37.22	36.47	32.55	31.89	32.67	35.55	31.42	33.35	29.30	28.17
Aquatic eutrophication [g PO_4-equivalents]	Burdens	39.80	33.25	34.83	29.01	38.59	28.07	36.81	27.02	34.84	25.40
	Credits	-8.19	-8.19	-7.28	-7.28	-6.69	-6.69	-6.47	-6.47	-6.39	-6.39
	Net results (∑)	31.61	25.06	27.55	21.72	31.91	21.38	30.34	20.55	28.44	19.01
Particulate matter [g PM 2,5- equivalents]	Burdens	0.46	0.46	0.41	0.40	0.41	0.40	0.40	0.38	0.37	0.36
	Credits	-0.11	-0.11	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10	-0.10
	Net results (∑)	0.35	0.34	0.31	0.30	0.31	0.29	0.30	0.28	0.28	0.27
Abiotic resource depletion [kg sb-equivalents]	Burdens	0.20	0.15	0.18	0.13	0.21	0.13	0.20	0.12	0.19	0.12
	Credits	-0.06	-0.06	-0.05	-0.05	-0.06	-0.06	-0.06	-0.06	-0.06	-0.06
	Net results (∑)	0.14	0.09	0.12	0.07	0.15	0.07	0.14	0.06	0.13	0.06
Non-renewable primary energy [GJ]	Burdens	2.58	2.03	2.26	1.77	2.64	1.76	2.50	1.69	2.38	1.59
	Credits	-0.78	-0.78	-0.69	-0.69	-0.80	-0.80	-0.76	-0.79	-0.73	-0.73
	Net results (∑)	1.80	1.25	1.57	1.08	1.84	0.97	1.74	0.93	1.64	0.86
Total Primary Energy [GJ]	Burdens	4.25	3.71	3.74	3.26	4.04	3.19	3.86	3.07	3.69	2.92
	Credits	-1.39	-1.39	-1.23	-1.23	-1.30	-1.30	-1.24	-1.24	-1.21	-1.21
	Net results (∑)	2.87	2.33	2.51	2.03	2.74	1.89	2.62	1.82	2.48	1.72

2.2.3 Comparison between systems

The percentages in Table 2-6 show the difference of net results between all considered formats of combismile big (ci18) beverage cartons in different volume segments. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 2-6: Comparison of net results **combismileBig (ci18)** beverage cartons (Europe)

	The net results of									
	combismileBig (ci18) SIGNATURE FB 200 mL		**combismileBig (ci18) SIGNATURE FB 250 mL**		**combismileBig (ci18) SIGNATURE FB cGoBig 300 mL**		**combismileBig (ci18) SIGNATURE FB cGoBig 330 mL**		**combismileBig (ci18) SIGNATURE FB cGoBig 350 mL**	
	are lower (green)/higher (red) than those of									
	combismileBig (ci18) standard RS 200 mL		combismileBig (ci18) standard RS 250 mL		combismileBig (ci18) standard RS cGoBig 300 mL		combismileBig (ci18) standard RS cGoBig 330 mL		combismileBig (ci18) standard RS cGoBig 350 mL	
	AF 50	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**
Impact category										
Climate Change	-25%	-20%	-25%	-21%	-29%	-24%	-30%	-26%	-30%	-25%
Ozone Depletion	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Summer Smog	-3%	-3%	-3%	-3%	-6%	-6%	-5%	-6%	-5%	6%
Particulate Matter	-2%	-2%	-2%	-2%	-4%	-4%	-3%	-4%	-3%	-4%
Acidification	-1%	-1%	-1%	-1%	-2%	-3%	-2%	-3%	-2%	-3%
Terrestrial Eutrophication	-2%	-2%	-2%	-2%	-4%	9%	-3%	6%	-4%	-4%
Aquatic Eutrophication	-19%	-21%	-19%	-21%	-30%	-33%	-30%	-32%	-31%	-33%
Abiotic Resource Depletion	-32%	-38%	-32%	-39%	-47%	-56%	-46%	-55%	-47%	-56%
Non-renwable Energy	-26%	-31%	-26%	-31%	-40%	-47%	-39%	-47%	-40%	-48%
Total Primary Energy	-15%	-19%	-15%	-19%	-25%	-31%	-25%	-30%	-30%	-25%

In both scenarios, all the **combismileBig (ci18) SIGNATURE FB** show lower net results than the combismileBig (ci18) standard RS in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

The mass-balanced PE and PP in the sleeve and closure of the combismileBig (ci18) **SIG**NATURE FB is the only difference to the combismileBig (ci18) standard RS, that leads to significantly lower net results in the categories mentioned.

3 Conclusions and Recommendations

Conclusions

- In both scenarios, all the combismileSmall (ci17) **SIG**NATURE FB show lower net results than the combismileSmall (ci17) standard TS in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.
- In both scenarios, all the combismileBig (ci18) **SIG**NATURE FB show lower net results than the combismileBig (ci18) standard RS in the impact categories 'Climate Change', 'Aquatic Eutrophication', 'Abiotic Resource Depletion' and in the inventory categories 'Non-renewable Primary Energy' and 'Total Primary Energy'.

Recommendations

- Since the environmental result of the combismileSmall (ci17) and combismileBig (ci18) beverage carton formats are significantly influenced by the production of its main components, the sleeve and closure, measures to ensure the same functionality by the use of less material are recommended.
- It is shown in this study that the closures play a crucial role in the life cycle of the combismileSmall (ci17) and combismileBig (ci18) beverage carton formats. To improve the overall environmental performance, it is recommended to assess the possibilities of using smaller and lighter closures for all beverage carton formats containing closures.
- By comparing the combiGo big (cGo big) standard closure results of the examined beverage cartons with the **SIG**NATURE closure formats, it can be concluded, that the substitution of fossil polymers by mass-balanced polymers based on tall oil leads to lower net results in 'Climate Change'. The implementation of polymers based on tall oil via a mass-balance approach is therefore recommended.
- It is also recommended to actually achieve a more significant physical share of tall oil based input materials for the production of polymers, as the by-product of the pulp industry is currently only dedicated to direct thermal use. The utilization and demand of mass-balanced polymers by SIG Combibloc might be a driver to do so.

References

CEWEP (2012): CEWEP Energy Report III (Status 2007-2010) Results of Specific Data for Energy, R1 Plant Efficiency Factor and NCV of 314 European Waste-to-Energy (WtE) Plants. CEWEP. S. 35.

EU (2018): Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 amending Directive 94/62/EC on packaging and packaging waste. https://eur-lex.europa.eu/eli/dir/2018/852/oj. (08.03.2022).

Eurostat (2021): Municipal waste by waste management operations. https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do. (18.05.2021).

EXTR:ACT (2020): Recycling rates EU. Personal communication with Raymond De Schrevel, November 2021.

INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Appendix 2b: Analysis of combismileBig **SIG**NATURE FULL BARRIER on the Dutch market

Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach

CB-100734

commissioned by SIG Combibloc

Heidelberg, May 2022

1 Introduction

The focus of the main report is to investigate combiblocSlimline (cb3) and combiblocMidi (cb8) cartons on the European market. In this appendix 2b, combismileBig (ci18) carton formats on the Dutch market are assessed. The beverage cartons examined are listed in **Table 1-1**. The comparisons of the beverage cartons are structured according to the same scheme as in the main report.

The following abbreviations, which are included in the packaging names are applied in this study:

- combismileBig (ci18)
- standard RS (robust structure, structure with aluminium foil barrier)
- cGoBig (combiGoBig, closure)
- **SIG**NATURE PACK FB (full barrier, containing aluminium)

Table 1-1: List of beverage cartons examined for the Dutch market

combismileBig (ci18) beverage cartons and closure
ci18 standard RS 200 mL
ci18 **SIG**NATURE FB 200 mL
ci18 standard RS 250 mL
ci18 **SIG**NATURE FB 250 mL
ci18 standard RS 300 mL (cGoBig)
ci18 **SIG**NATURE FB 300 mL (cGoBig)
ci18 standard RS 330 mL (cGoBig)
ci18 **SIG**NATURE FB 330 mL (cGoBig)
ci18 standard RS 350 mL (cGoBig)
ci18 **SIG**NATURE FB 350 mL (cGoBig)

This appendix 2b focusses only on one environmental impact category, ‘Climate Change’. Impacts on ‘Climate Change’ depend strongly on local settings like end-of-life processes or the local electricity mix. For other environmental impact categories, please refer to the results regarding the European market that are presented in the appendix 2a of the main report.

The following parameters correspond to the parameters of the main report on the European market:

- Functional unit
- System boundaries

- Data gathering and data quality
- Methodological aspects (mass-balanced renewable material approach, allocation, biogenic carbon)
- Manufacture of raw materials
- Process data for converting and filling
- Electricity mix for converting processes

Adjusted parameters for the geographic scope of the extension are:

- Distribution
- End-of-life
- Electricity mix for filling processes, recycling processes and credits
- Electrical and thermal efficiencies of the municipal waste incineration
- Landfill gas recovery rates

2 Adjusted parameters

2.1 Distribution

Table 2-1 shows the applied distribution distances in this extension. The distribution distances for the Dutch market from filling to POS were provided by SIG Combibloc.

Table 2-1: Distribution distances in Netherlands for the examined packaging systems

	Distribution distance			
	Distribution Step 1		Distribution step 2	
Market	**Filler → distribution centre** (delivery)	**Distribution centre → filler** (return trip)	**Distribution centre → POS** (delivery)	**POS → distribution centre** (return trip)
Netherlands	200 km	60 km	30 km	30 km

2.2 End-of-life

To model the end-of-life of the examined beverage cartons one needs to know their fate after their use by the consumers. It is aimed to apply the recycling rate and disposal split for the beverage cartons of the Dutch market. These data has been collected from different waste management reports and statistics. For beverage cartons specific recycling rates are publicly available for the market examined.

The applied recycling rate and the disposal split for Netherlands are listed in **Table 2-2**.

Table 2-2: End-of-life split of beverage cartons examined

Netherlands		Source
Recycling rate		
Beverage cartons	confidential	(EXTR:ACT 2020)
Disposal split		
Landfill	3.3%	(Eurostat 2021) municipal waste statistic, data for 2019
Incineration	96.7%	

2.3 Electricity mix

Modelling of electricity generation is particularly relevant for the production of base materials as well as for filling processes, recycling processes and credits. Electric power supply is modelled using country specific grid electricity mixes, since the environmental burdens of power production varies strongly depending on the electricity generation technology. A more detailed description is given in **section 3.9.2** of the main report.

The emission factor (Climate Change) for Netherlands is 510 g/kWh for the electricity mix used (reference year 2018) (Fehrenbach et al. 2016; IEA 2018), while the average EU electricity mix is 416 g/kWh. This means that the Dutch electricity mix is responsible for around 18% higher greenhouse gas emissions than the European one.

2.4 Municipal waste incineration

The electrical and thermal efficiencies of the municipal solid waste incineration plants (MSWI) are shown in table **Table 2-3**.

Table 2-3: Electrical and thermal efficiencies of the incineration plants for Netherlands

Geographic Scope	Electrical efficiency	Thermal efficiency	Reference period	Source
Netherlands	16.0%	8.0%	2010	(CEWEP 2012)

The efficiencies are used as parameters for the incineration model, which assumes a technical standard (especially regarding flue gas cleaning) that complies with the requirements given by the EU incineration directive (EU 2018). It is assumed that the electric energy generated in MSWI plants substitutes market specific grid electricity. Furthermore, it is assumed that the thermal energy recovered in MSWI plants is used as process heat.

3 Results and discussion

3.1 Netherlands combismileBig (ci18) beverage cartons 200-350 mL

3.1.1 Scenario I (50% allocation): numerical values and graphs

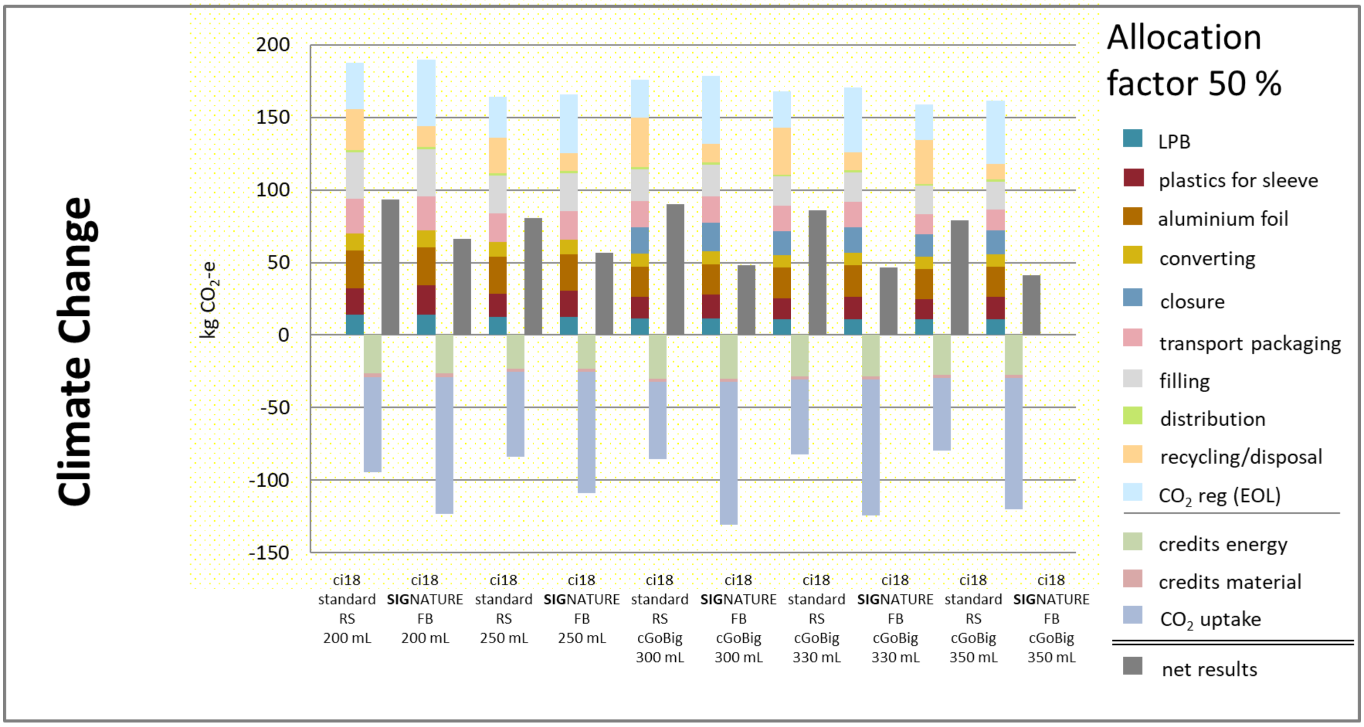

Figure 3-1: Climate Change results of **scenario I Netherlands, combismileBig (ci18)** beverage cartons with allocation factor 50%

Table 3-1: Climate Change results of **scenario I Netherlands, combismileBig (ci18) beverage cartons** with allocation factor 50%: burdens, credits and net results per functional unit of 1000 L beverage

Scenario I Netherlands, allocation factor 50 %		ci18 standard RS 200 mL	ci18 SIGNATURE FB 200 mL	ci18 standard RS 250 mL	ci18 SIGNATURE FB 250 mL
Climate change [kg CO_2-equivalents]	Burdens	155.66	143.80	135.80	125.25
	CO_2 (reg)	32.07	45.87	28.33	40.61
	Credits	-28.80	-28.80	-25.56	-25.56
	CO_2 uptake	-65.75	-94.39	-58.10	-83.57
	Net results (∑)	93.18	66.48	80.46	56.73

Scenario I Netherlands, allocation factor 50 %		ci18 standard RS cGoBig 300 mL	ci18 SIGNATURE FB cGoBig 300 mL	ci18 standard RS cGoBig 330 mL	ci18 SIGNATURE FB cGoBig 330 mL	ci18 standard RS cGoBig 350 mL	ci18 SIGNATURE FB cGoBig 350 mL
Climate change [kg CO_2-equivalents]	Burdens	149.95	131.50	142.87	125.70	134.49	117.92
	CO_2 (reg)	25.86	47.37	25.05	45.07	24.29	43.60
	Credits	-32.37	-32.37	-30.76	-30.76	-29.71	-29.71
	CO_2 uptake	-53.06	-98.35	-51.39	-93.52	-49.84	-90.48
	Net results (∑)	90.38	48.15	85.77	46.49	79.23	41.33

3.1.2 Scenario II (100% allocation): numerical values and graphs

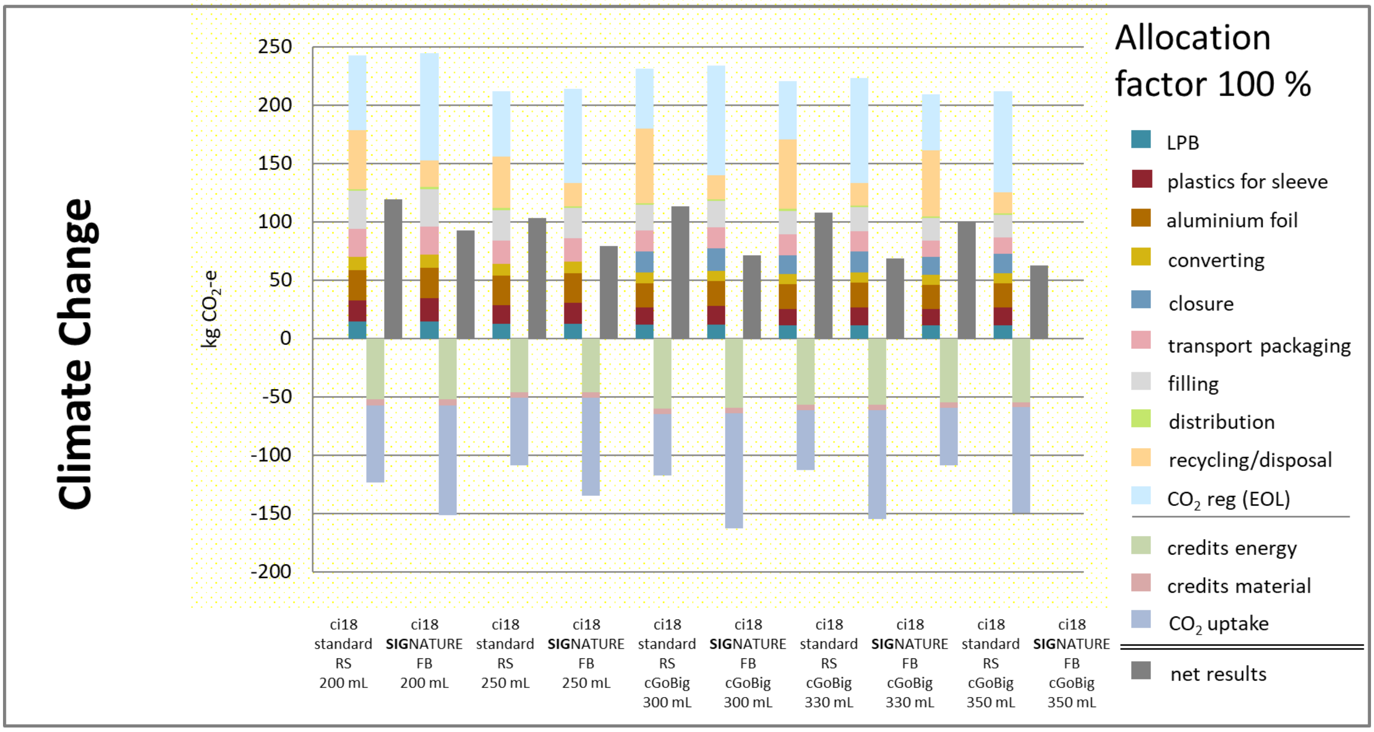

Figure 3-2: Climate Change results of **scenario II Netherlands, combismileBig (ci18)** beverage cartons with allocation factor 100%

Table 3-2: Climate Change results of **scenario II Netherlands, combismileBig (ci18)** beverage cartons with allocation factor 100%: burdens, credits and net results per functional unit of 1000 L beverage

Scenario II Netherlands, allocation factor 100 %		ci18 standard RS 200 mL	ci18 SIGNATURE FB 200 mL	ci18 standard RS 250 mL	ci18 SIGNATURE FB 250 mL		
Climate change [kg CO_2-equivalents]	Burdens	178.26	152.58	155.55	132.73		
	CO_2 (reg)	63.85	91.47	56.42	80.97		
	Credits	-57.56	-57.56	-51.10	-51.10		
	CO_2 uptake	-65.75	-94.39	-58.10	-83.57		
	Net results (∑)	118.80	92.09	102.78	79.04		
Scenario II Netherlands, allocation factor 100 %		**ci18 standard RS cGoBig 300 mL**	**ci18 SIGNATURE FB cGoBig 300 mL**	**ci18 standard RS cGoBig 330 mL**	**ci18 SIGNATURE FB cGoBig 330 mL**	**ci18 standard RS cGoBig 350 mL**	**ci18 SIGNATURE FB cGoBig 350 mL**
Climate change [kg CO_2-equivalents]	Burdens	179.52	139.44	170.64	133.35	160.81	124.83
	CO_2 (reg)	51.52	94.54	49.89	89.93	48.39	87.02
	Credits	-64.71	-64.71	-61.49	-61.49	-59.40	-59.40
	CO_2 uptake	-53.06	-98.35	-51.39	-93.52	-49.84	-90.48
	Net results (∑)	113.26	70.92	107.66	68.27	99.96	61.97

3.1.3 Comparison between systems

The percentages in **Table 3-3** show the difference of net results between all considered formats of cb8 beverage cartons in the same volume segment. The percentage is based on the net results of each compared packaging system. Both scenarios, scenario I (AF 50) and scenario II (AF 100), are equally used for the comparison between the systems. Differences of 10% or less are considered to be insignificant.

Table 3-3: Comparison of Climate Change net results of **combismileBig (ci18)** beverage cartons (Netherlands)

	The net results of									
	ci18 SIGNATURE FB 200 mL		**ci18 SIGNATURE FB 250 mL**		**ci18 SIGNATURE FB cGoBig 300 mL**		**ci18 SIGNATURE FB cGoBig 330 mL**		**ci18 SIGNATURE FB cGoBig 350 mL**	
	are lower (green)/higher (red) than those of									
	ci18 standard RS 200 mL		ci18 standard RS 250 mL		ci18 standard RS cGoBig 300 mL		ci18 standard RS cGoBig 330 mL		ci18 standard RS cGoBig 350 mL	
	AF 50	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**	**AF 50**	**AF 100**
Impact category										
Climate Change	-29%	-22%	-29%	-23%	-47%	-37%	-46%	-37%	-48%	-38%

All the combismileBig (ci18) **SIG**NATURE FB beverage cartons show lower net results in the 'Climate Change' category than the compared combismileBig (ci18) standard RS cartons in both scenario variants (AF 50, AF 100).

For this category and the comparison of combismileBig (ci18) packaging systems, the results for Netherlands (appendix 2b) show a similar picture as those of the European market (appendix 2a).

4 Conclusions and Recommendations

Conclusions

- All the combismileBig (ci18) **SIG**NATURE FB beverage cartons show lower net results in the 'Climate Change' category than the compared combismileBig (ci18) standard RS cartons in both scenario variants (AF 50, AF 100).
- The net results in 'Climate Change' for Netherlands differ significantly from the results of the appendix 2a (Europe). They are lower for all beverage cartons examined mainly because of the lower landfill rate in Netherlands, which leads to lower emissions of methane.
- To get an indication of how the packaging systems examined in this extension study perform in other environmental impact categories like 'Ozone Depletion', 'Summer Smog', 'Particulate Matter', 'Acidification', 'Terrestrial- and Aquatic Eutrophication', 'Abiotic Resource Depletion', 'Non-renewable Primary Energy' and 'Total Primary Energy', one can also refer to the appendix 2a in the main report regarding the European market. However, some background parameters are different due to the different geographical scopes. For this reason, the results of the European scope can only serve as an indication of the full set of environmental impact categories.

Recommendations

- Since the environmental result of the combismileBig (ci18) beverage carton format is significantly influenced by the production of its main components, the sleeve and closure, measures to ensure the same functionality by the use of less material are recommended.
- It is shown in this appendix that the closures play a crucial role in the life cycle of the combismileBig (ci18) beverage carton formats. To improve the overall environmental performance, it is recommended to assess the possibilities of using smaller and lighter closures for all combismileBig (ci18) beverage carton formats containing a closure.
- The **SIG**NATURE PACK FB beverage cartons show the lowest environmental impacts in 'Climate Change'. Therefore, from an environmental viewpoint it is recommended to prefer the **SIG**NATURE PACK FB over the other beverage carton formats examined in this appendix on the Dutch market.
- By comparing the combiGoBig (cGoBig) standard closure results of the examined beverage cartons with the **SIG**NATURE closure formats, it can be concluded, that the substitution of fossil polymers by mass-balanced polymers based on tall oil leads to lower net results in 'Climate Change'. The implementation of polymers based on tall oil via a mass-balance approach is therefore recommended.
- It is also recommended to actually achieve a more significant physical share of tall oil based input materials for the production of polymers, as the by-product of the pulp industry is currently only dedicated to direct thermal use. The utilisation and demand of mass-balanced polymers by SIG Combibloc might be a driver to do so.

References

CEWEP (2012): CEWEP Energy Report III (Status 2007-2010) Results of Specific Data for Energy, R1 Plant Efficiency Factor and NCV of 314 European Waste-to-Energy (WtE) Plants. CEWEP. S. 35.

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Eurostat (2021): Municipal waste by waste management operations. https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do. (18.05.2021).

EXTR:ACT (2020): Recycling rates EU. Personal communication with Raymond De Schrevel, November 2021.

Fehrenbach, H.; Lauwigi, C.; Liebich, A.; Ludmann, S. (2016): Documentation for the UMBERTO based ifeu electricity model. ifeu gGmbH, Heidelberg. S. 31.

IEA (2018): Data overview. In: *IEA*. https://www.iea.org/data-and-statistics. (31.03.2022).

Appendix A: Renewable polymers sustainability statement

Renewable Polymers Sustainability Statement

SABIC Sales Europe B.V.
Europaboulevard 1
6135 LD SITTARD
NETHERLANDS

Customer:	SIG Combibloc Procurement AG Laufengasse 18 CH-8212 NEUHAUSEN	**Your Purchase Order:**	51281582-212967
		Sales Order:	3034823
		Delivery / item:	801873639
		Delivery date:	22.11.2019
		Goods Issue date:	21.11.2019
		Certification system:	ISCC PLUS
		Certificate number:	ISCC-PLUS-Cert-DE129-35242411

Product related information

Product name:	LDPE 2005ECB 00900 161
Delivered quantity (Kg):	25.040
Claim:	This product is more than 99.0% made from certified renewable material* Renewable material is fuel produced from biomass waste (tall oil with Country of Origin: Finland). Herewith we confirm that our supplier was certified under the ISCC framework at the moment of receipt of the certified renewable feedstock. The entire supply chain is #ISCC Compliant#.

*Based on Mass Balance approach
The sales is acting under ISCC+ Certification of SABIC Sales Europe

Appendix B: Critical review statement

Critical Review Statement
according to ISO 14040 and 14044 of the Study

"SIGNATURE portfolio: Analysis of combibloc ECOPLUS & SIGNATURE 100 and SIGNATURE FULL BARRIER for combiblocSlim-line and combiblocMidi on the European market: Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach."

LCA study conducted by: ifeu Heidelberg gGmbh
(the "Practitioner")

for: SIG Combibloc,
(the "Commissioner")

Critical review statement prepared by:

Dr. Florian Antony
Bahnhofstr. 3
79199 Kirchzarten
Germany

June 2022

Table of Contents

1. Procedural Aspects of the Critical Review

This Critical Review was commissioned by SIG Combibloc in March 2022. The LCA study was conducted by the practitioner ifeu Heidelberg gGmbH. The reviewer received the first Draft Report of the study on 8th March 2022.

In the course of the review process, the reviewer sent a list of general and detailed comments to both the practitioner and the commissioner. This was followed by the respective Review Meetings (initial Online Meeting held on 10th March 2022 and the detailed review meeting with the discussion of comments held on 24th March 2022. During the conference calls, the comments were discussed in detail with the commissioner and the practitioner.

The reviewer received the Final Report on 23rd May 2022. The statements and comments below are based on this version.

The study "SIGNATURE portfolio: Analysis of combibloc ECOPLUS & SIGNATURE 100 and SIGNATURE FULL BARRIER for combiblocSlim-line and combiblocMidi on the European market: Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach." aims to examine the environmental performance of different beverage cartons on the European market (EU27+3) in 2021 with additional extensions on other beverage carton formats and – via country specific extensions – selected national markets, by using LCA.

The study aims to follow the requirements as set out in the ISO 14040 and 14040 standards. Furthermore, the study includes comparative assertions of bio-based (mass balance principle) and fossil-based feedstock alternatives for specific SIG Combibloc products. Formally, this critical review is a review by an independent external reviewer according to ISO 14040 section 7.3.2 [1] and ISO 14044 section 4.2.3.7 and 6.2 [2]. Since in the present LCA study only products of SIG Combibloc are compared, this type of review is an admissible option.

The reviewer is independent from the commissioner and practitioner of the study and declares no commercial interest in the topic or any consequences of the study, beyond those related to the critical review process. The reviewer had to be aware of issues relevant to other interested parties, as it was outside the scope of the present project to invite governmental or non-governmental organizations or other interested parties, e.g. competitors, business partners or consumers and the general public.

The reviewer would like to highlight the open and constructive working atmosphere throughout the review process. Upon request, all necessary data were presented to the reviewer and all issues raised by the reviewer were discussed openly. The comments of the reviewer have been addressed by the practitioner and the commissioner adequately in the final report. In cases where different viewpoints (e.g. with regard to modelling assumptions and choices) remained between the commissioner and the reviewer, this is stated in section 3 of this Critical Review Statement.

Disclaimer: The present CR statement is delivered to SIG Combibloc. The reviewer cannot be held responsible for the subsequent use of this statement, or the results in the report subjected to the review, by a third party. The conclusions of the reviewer refer strictly to the full report (including the extensions) from the study "SIGNATURE portfolio: Analysis of combibloc ECOPLUS & SIGNATURE 100 and SIGNATURE FULL BARRIER for combiblocSlim-line and combiblocMidi on the European market: Comparative life cycle assessment of beverage cartons containing polymers based on the mass-balanced renewable material approach" received 23rd May 2022, and no other report, extract thereof or subsequent publication. The reviewer's conclusions were based on the information the reviewer received and correspond to the state-of-the-art of critical reviews. The conclusions expressed by the reviewer are specific to the context and content of the present study and shall not be generalized beyond that.

2. General Comments

The reviewed LCA study investigates the life cycle environmental performance of different types and formats of beverage cartons, reflecting the situation given on the European market in 2021. The comparison includes beverage cartons containing polymers based on the so-called "mass-balanced renewable material approach". The study assesses the beverage cartons combiblocSlimline (cb3) SIGNATURE PACK 100 and combiblocSlimline (cb3) SIGNATURE PACK FB as well as combiblocMidi (cb8) SIGNATURE PACK 100 and combiblocMidi (cb8) SIGNATURE PACK FB which contain polymers that originate from renewable European wood sources via a mass balance approach. These replace conventional fossil-based polymers, which usually are contained in most aseptic beverage cartons.

The scope of the study is from cradle-to-grave (excluding the use phase) of the finished SIG Combibloc products. In the goal definition, the intended application is clearly described and thus provides an unambiguous reference framework for the interpretation:

- "*To provide knowledge about the environmental strengths and weaknesses of the combiblocSlimline (cb3) and combiblocMidi (cb8) beverage cartons in the sizes 1000 mL and 500 mL for the packaging at European market conditions and*";
- "*To examine two different combibloc SIGNATURE PACK cartons per format (combiblocSlimline (cb3) and combiblocMidi (cb8))*";
- "*To compare their environmental impact results with those of the respective standard RS variants) and in case of the SIGNATURE PACK 100 also with the respective EcoPlus carton*"
- It is stated explicitly that "*the results of this study shall be used for internal and external communication*".

In order to avoid potential misinterpretation, the reviewer emphasizes particularly that the results of the study refer exclusively to the investigated product systems and should not be used in any other contexts or for example, in cross-comparison with other beverage packaging systems.

For the purpose of this LCA study, the socalled "mass-balanced renewable material approach" is applied to specific SIG Combibloc products produced from tall oil, a product produced from Black Liquor Soap (BLS) which itself is a by-product of the paper production processes. According to the authors *"the application of the mass balance approach in the production of polymers is an important driver to enable increasing substitution of fossil resources with biogenic resources in the production of polymers*."

The compared beverage carton product systems have been selected as they represent typical and relevant packaging alternatives on the European market. The selection for the comparison follows the systematic behind earlier, also externally reviewed LCA studies on beverage cartons compiled by the practitioner and published by the commissioner on the commissioner's website. The LCA study at hand supplements these LCAs with new packaging systems that have been developed in the meantime. The selection of product systems under investigation is considered plausible. Also, the technical specifications of individual sub-processes within the system boundary of the study, including those sourced from commercial background LCI databases are clearly defined.

The results of the study are intended "*to be used by the commissioner (SIG Combibloc). Further they shall serve for information purposes of SIG Combibloc's customers, e.g. fillers and retail customers*. It should be noted that the subsequent conclusions by the reviewer only cover the specific products considered in the LCA report and should therefore not be generalized further.

3. Statements by the reviewer as required by ISO 14044

According to ISO 14044, section 6.1 *"The critical review process shall ensure that:*

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

These items are discussed in sections 3.1 to 3.5 according to the reviewer's best judgement and considering the ISO standards 14040 and 14044.

3.1. Consistency of the methods with ISO 14040 and 14044

The study under review has been performed according to the general structure of LCA required in ISO 14040 and ISO 14044. The structure of the report reflects the general structure of LCA (Goal & Scope definition – Life cycle inventory analysis (LCI) – Life cycle impact assessment (LCIA) and Interpretation). Conclusions, limitations and recommendations are clearly presented.

The definitions of functional unit and the system boundary are appropriate and discussed according to the goal of the study. The inventory analysis is consistent with the ISO standards 14040 and 14044. The choice of impact categories and characterization models is justified and meaningful. For specific environmental aspects not considered in the study, see the discussion in the following section (3.2.)

The "mass-balanced renewable material approach" serves to support assertions about the biogenic origin of feedstock attributed to specific product(s), produced within complex chemical processes from a mix of fossil- and bio-based feedstocks and alongside a variety of other co-products. These assertions are supported by the fact that a physical linkage (as tangible and uninterrupted mass and energy flows) exists between the input of (bio-based) feedstock and the final output. The study builds up an appropriate model that describes the key elements of physical product systems according to ISO 14040:2021. The study conforms with the ISO 14040 definition of a life cycle as *"consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal"*.

3.2. Scientific and technical validity of the methods used

The methods used in the study are appropriate. Some specific aspects performed in the study are highlighted below.

Basically, the review refers to the report and the information contained therein. A detailed analysis of the LCA model was not the subject of the critical review. As part of the review, the reviewer was introduced to the datasets used for relevant processes (e.g., from ifeu's own, not publicly available database). The reviewer was shown and explained selected aspects of the LCI modelling by the practitioner in the course of the two review meetings and was therefore able to check that the raw materials, product manufacturing steps, transport steps and EoL-treatment steps were logically connected and appropriately described in the report. Following the review meeting, the LCIA results for key process modules were provided to the reviewer by the practitioner and LCIA results were spot-checked. No material inconsistencies were identified during the review.

In ISO 14040/14044, the choice of impact categories must be substantiated, meaningful and support the goal and scope of the study. These have been selected appropriately in the study and the impact categories and the characterization models chosen are state of the art. However, the selection of LCIA categories did not take into account aspects of the use of water resources and land use related aspects. In general this would make sense in light of the use of bio-based feedstock in product systems and the comparison with fossil feedstock. The reviewer's recommendation to include at least land use-related aspects in the comparison was discussed with the practitioner and the commissioner. However, from the author’s point of view and with regard to considerable uncertainties and, in some cases, the lack of data, it was decided not to include a corresponding LCIA indicator. Resulting limitations of the study with respect to the exclusion of impacts (e.g., water use, land use related aspects) are discussed in the interpretation phase.

- “*It should be noted that the use of different impact assessment methods could lead to other results concerning the environmental ranking of packaging systems. The results are valid only for the specific characterisation model used for the step from inventory data to impact assessment*”; and
- “*The results are valid only for the environmental impact categories, which were examined.*”

It is important to highlight, that no conclusions can be drawn from this study regarding aspects of the use of water resources and land use-related environmental aspects.

The results of the Life Cycle Impact Assessment are clearly presented in tables and figures and are meaningfully discussed. In the country-specific appendices/extensions to the main report, no complete life cycle assessment was carried out, but only the potential Climate Change impacts of the beverage cartons systems were considered. From the reviewer's point of view, it is unfortunate that the corresponding extensions are each referred to as “LCA” in the respective Appendix titles, although only climate-relevant aspects are considered. However, a corresponding remark, drawing attention to the resulting limitation, is included in the interpretation of each appendix.

Likewise, it is important to emphasize that this study has considered sequestration of biogenic carbon by the raw materials for the bio-based feedstocks, crediting the system for the uptake of CO_2 from the atmosphere during plant growth. This requires to account for the release of the biogenic carbon as a climate change burden at the end of the product’s life cycle. Given that the system boundary in the study is from cradle to grave and given the fact that the release of the biogenic carbon at the end of the product’s life cycle is included, this requirement is kept by the study. As part of the revision of the study it was decided to also report "from cradle to gate" results in the respective results tables. Here, correctly, the uptake of biogenic carbon was not included. In order to avoid potential misinterpretations, it should be noted that it is of importance for future applications of the study results to clearly and unambiguously describe how biogenic carbon was handled. This applies in particular when reporting “to gate”-results.

In the present study, the modelling of biogenic carbon is of crucial importance. Especially with regard to the results for Climate Change, the consideration of the uptake of biogenic carbon is a key driver for the results and a major reason for the identified environmental benefit of SIGNATURE products compared to SIG’s standard beverage cartons. The procedure the authors followed in the present study is to be seen as common practice in LCA and corresponds to the current state of method development. At the same time, there are demands from science that it should be taken into account as well that the use of wood from managed forests negatively affects the forests function as carbon sink [3]. The discussion on additionally including this aspect in greenhouse gas balances of products has just started - in fact, the corresponding proposal hadn't even been published at the time of the required determination. Even though this aspect could not be taken into account in the present study, from the reviewer's point of view it should be kept in mind for future LCAs on wood-based products.

Overall, the results are discussed considering data and model limitations, completeness and consistency. The conclusions take these limitations into account. The results are carefully analyzed and the reasons and relevance of results are evaluated in a critical discussion. In the course of the interpretation of the study results the authors identified significant differences between the compared beverage cartons based on a heuristic approach of defining results as significantly different from each other, when the difference is larger than 10% in total.

"…, *to address potential uncertainties between the compared product systems, an estimated significance threshold of 10% is chosen as pragmatic approach. This means that differences in the results of the impact category indicators between the comparative systems of ≤ 10% are considered insignificant. Based on the data used for the impact categories considered in this study, the authors' point of view is that the significance threshold of 10% is an appropriate size and guarantees consistency for all impact categories examined"*

The reviewer pointed out that this significance criterion might be seen as rather optimistic at least for some of the selected impact categories and that the criterion for significant differences should be set higher, if necessary. The authors, on the other hand, argued that special emphasis has been put on selecting only highly robust LCIA-Methods and data of high quality and decided to stay with the original approach. The authors included a corresponding justification in the study report.

Even if significant processes and parameters were not explicitly identified as a stand-alone section in the interpretation, the presentation of the results (especially the results of the contribution analysis) allows to identify the main and most important influencing factors and drivers of the results.

Overall, the reviewer concludes that the methods used in the study are sufficiently scientifically and technically valid.

3.3. Appropriateness of data in relation to the goal of the study

Following the usual practice in critical reviews, the correctness of all primary and other data could not be checked but the type and sources of data used in the study were reviewed for appropriateness and plausibility.

The foreground data used are documented and presented in the report (to the extent allowed due to confidentially) and are deemed plausible and adequate for the purpose of the study. The production processes for the product systems investigated were based on primary production data provided by the study commissioner and these data are hence considered reliable.

The background data, especially those for the different feedstocks, are based on data from industry (e.g. Plastics Europe), the ifeu own database (based on statistics and data from various European recycling, incineration and landfill models) and supplemented from relevant literature (e.g. Cashman et al [4]). Limitations, such as the modest reliability and the considerable uncertainty of the secondary data used for the tall oil supply, are acknowledged in the data-quality assessment. Nonetheless, the results of the present study are dependent of the approach chosen to model the production of tall oil. The corresponding production steps are not the sphere of influence of the commissioner and no primary data could be collected from tall oil producers. For the modeling of the necessary process steps, the work of Cashman et al [4] was used. As a result of the discussion during the review meeting, the authors decided to integrate the corresponding Input-Output tables into the report. From the reviewer's point of view, this contributes to a higher transparency of the modelling. The chosen modelling approach seems plausible, even if there are some inconsistencies with regard to missing by-products in the original Input-Output tables of Cashman et al [4]. For the purpose of the study and with regard to the goal and scope the chosen approach can be considered suitable. Should better or more transparent data be available in the future, the reviewer suggests to consider updating the present modelling, especially with regard to build up a fully transparent biogenic carbon balance (C-balance) alongside all relevant production steps – from the forest to the final beverage carton products.

As mentioned above, the critical review process did not include a complete review of every single item of data and each calculation step in the study, as this was not possible because of the amount of data to be considered. Therefore, it was important to examine the data horizontally (general plausibility, plausibility of the relevance of certain impacts to the results) as well as vertically (detailed checks of parts of the calculation model – see section 3.2). The handling of data demonstrates sufficient robustness of the calculated data. The data and calculation methods were judged to be appropriate for the goal of the study. All data were available to the reviewer on request.

The reviewer concludes that the data used is appropriate and reasonable in relation to the goal of the study. However, there is room for improvement in terms of the modelling of the C-Balance alongside the production of tall oil-based feedstocks.

3.4. Assessment of interpretation referring to limitations and goal of the study

The interpretation is based on data analysis, discussion of underlying assumptions and limitations, data quality assessment and the assessment of two scenarios considering different allocation methods on system level, regarding handling of burdens and benefits (50/50 vs. 100/0). The discussion of the findings is transparent and congruent with the goal, the results and the limitations of the study.

The conclusions reflect the identified limitations and the recommendations are based on the interpretation of the results.

3.5. Transparency and consistency of the study report

The final report is clearly structured and follows the specifications and the general structure of ISO 14040 and 14044.

The quite large number of analyzed beverage carton product systems, especially with regard to the raw-material supply chains of bio-based feedstocks for SIGNATURE products, are rather complex and at least partially confidential data had to be used. Nonetheless, the practitioner succeeded in structuring the study as transparently as possible. Minor inconsistencies in the draft report have been have been fixed by the practitioner. In the final report no inconsistencies could be identified.

The reviewer concludes that the report is transparent and consistent.

4. Conclusion

The reviewer concludes that the final study report contains no direct contradictions with the requirements as set out by the ISO standards and the study can be considered ISO 14040/44 compliant.

Nonetheless, there are some key choices and LCI modelling aspects that could affect the results, interpretation and conclusions substantially. Therefore, it is of utmost importance that the corresponding assumptions and their influence on the results and conclusions are described and communicated transparently, whenever the study, or parts thereof, are disclosed to any stakeholders to avoid misinterpretation of the study. This includes:

- the decision not to consider water and land use relevant aspects in the present study;
- the fact that for the country-specific extensions only Climat Change Impacts have been considered; and
- the inclusion and approach to assessing biogenic carbon uptake in biobased feedstock supply.

With the condition that the commissioner of the study ensures that this is the case, the reviewer considers that the study has been conducted according to and in compliance with the ISO standards 14040 and 14044.

5. References

[1] DIN EN ISO 14040:2021: Environmental management - Life cycle assessment - Principles and framework
[2] DIN EN ISO 14044:2021: Environmental management - Life cycle assessment - Requirements and guidelines
[3] Fehrenbach, H.; Bischoff, M.; Böttcher, H.; Reise, J.; Hennenberg K. (2022): The missing limb: Including impacts of biomass extraction on forest carbon stocks in greenhouse gas balances of wood use. Forests 2022, 13(3), 365; https://doi.org/10.3390/f13030365

[4] Cashman, S. A.; Moran, K. M.; Gaglione, A. G. (2016): Greenhouse Gas and Energy Life Cycle Assessment of Pine Chemicals Derived from Crude Tall Oil and Their Substitutes: LCA of Crude Tall Oil-derived Chemicals and Their Substitutes. In: Journal of Industrial Ecology. Vol. 20, No.5, S. 1108–2230 1121.

6. Reviewer's signature

Dr. Florian Antony

Kirchzarten, den 27.06.2022