INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Comparative Life Cycle Assessment of Tetra Pak® carton packages and alternative packaging systems for beverages and liquid food on the European market

Final Report

commissioned by Tetra Pak

Heidelberg, March 9th 2020

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Abbreviations

ACE	Alliance for Beverage Cartons and the Environment
BC	Beverage carton
CED	Cumulative energy demand
CML	Centrum voor Milieukunde (Center of Environmental Science), Leiden University, Netherlands
COD	Chemical oxygen demand
CRD	Cumulative raw material demand
EAA	European Aluminium Association
EEA	European Environment Agency
EU27+2	European Union & Switzerland and Norway
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (Brussels)
GWP	Global Warming Potential
HBEFA	Handbuch für Emissionsfaktoren (Handbook for Emission Factors)
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
JNSD	Juice, nectars and still drinks
LCA	Life cycle assessment
LCI	Life cycle inventory
LDPE	Low density polyethylene
LPB	Liquid packaging board
MIR	Maximum Incremental Reactivity
MSWI	Municipal solid waste incineration
NMIR	Nitrogen-Maximum Incremental Reactivity
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides
ODP	Ozone Depletion Potential
OW	One way
pc	packs

PM2.5	Particulate matter with an aerodynamic diameter of 2.5 µm or smaller
PP	Polypropylene
rPET	recycled PET
SBM	Stretch blow moulding
SD	Still drinks
SUP	Stand up pouch
TB	Tetra Brik
TBA	Tetra Brik Aseptic
TiO_2	Titanium dioxide
TPA	Tetra Prisma Aseptic
TR	Tetra Rex
TT	Tetra Top
UBA	Umweltbundesamt (German Federal Environmental Agency)
UHT	Ultra-heat treatment
VOC	Volatile organic compounds
WMO	World Meteorological Organization

1 Goal and scope

1.1 Background and objectives

As one of the world's leading suppliers, Tetra Pak® provides complete processing and carton packaging systems and machines for beverages, dairy products and food. Currently, the range of packaging systems comprises eleven alternatives, e.g. Tetra Brik®, Tetra Rex®, Tetra Top® [Tetra Pak 2020]. Tetra Pak® is part of the Tetra Laval Group, which was formed in January 1993. The three industry groups Tetra Pak, DeLaval and Sidel are currently included in the group.

An integral part of Tetra Pak's business strategy and activities is the systematic work on the efficient use of resources and energy. The 2020 environmental targets of Tetra Pak focus on the use of sustainable materials to continuously improve the entire value chain and the increase of recycling to further reduce the impact on the environment. Since 2006, Tetra Pak has had a partnership with the WWF, based on a shared commitment to promote responsible forest management. Tetra Pak are active members in the WWF's Global Forest & Trade Network (GFTN). Also, all paperboard sourced by Tetra Pak comes from wood from Forest Stewardship Council™ (FSC™)-certified forests and other controlled sources.

Tetra Pak has recently finalized LCA studies for several packaging formats including plant-based alternatives in several European markets. However, the results are only valid for the indicated geographic scope and cannot be assumed to be valid in other geographic regions, even for the same packaging systems.

The approach of this study aims to deliver information about the environmental performance of different packaging systems on a higher number of individual markets in a more efficient way. This shall be done without sacrificing the robust assessment methodology that LCA provides. To realise that, the work is divided into two separate streams:

(1) This present study as a baseline study: This study is conducted as a fully ISO 14040/14044 compliant LCA study for the European market. It uses average European parameters like production data and end-of-life- rates.

(2) Additional local supplement studies: These are country specific studies for single country markets for specific locally relevant packaging solutions. These will focus on Climate Change and will refer to the European baseline study for other environmental impact categories.

Therefore, Tetra Pak commissioned the Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research, ifeu) to conduct a comparative LCA study for key carton packages as well as key competing packages in different beverage segments covering the European market.

The goal of the study is to conduct an LCA analysing the environmental performance of Tetra Pak's beverage and liquid food carton systems compared to alternative beverage and liquid food packaging systems.

Competing packaging systems on the European market include:

- PET bottles
- HDPE bottles
- Stand up pouches (SUP).
- Single use glass bottles
- Aluminium cans
- Steel cans
- Single use Glass jars

All analysed packaging systems are divided into the segments

- 'Family Packs' (FP) with volumes from 1000 mL to 2000 mL
- 'Portion Packs' (PoP) with volumes from 200 mL to 500 mL.

The analysed packaging systems are divided into the following chilled and ambient beverage and food segments:

- DAIRY products like milk or coffee drinks
  - Chilled family packs with the volume of 1000 mL
  - Ambient family packs with the volume of 1000 mL
  - Chilled portion packs with the volume of 200 mL
- Juice, Nectars and still drinks (JNSD)
  - Ambient family packs with the volume of 1000 mL
  - Ambient portion packs with volumes from 200 mL to 250 mL
- still, unflavoured WATER
  - Ambient portion packs with the volume of 500 mL
- liquid food (tomato sauce)
  - Ambient portion packs with the volume of 390 mL

In order to address the goal of the project, the main objectives of the study are:

(1) to provide knowledge of the environmental strengths and weaknesses of carton packaging systems that also use a degree of plant-based materials in the described segments and markets.

(2) to compare the environmental performance of these cartons with those of the competing packaging systems with high market relevance on the European market.

Further objectives are addressed through scenario variants:

(3) to provide knowledge regarding the environmental performance of carton packaging systems compared to HDPE bottles with plant-based material content

(4) to provide knowledge regarding the environmental performance of carton packaging systems compared to PET bottles with up to 100% recycled material content.

(5) to provide knowledge regarding the environmental performance of carton packaging systems compared to PET and HDPE bottles with reduced weights.

The results of this study shall be used for internal and external communication. The comparative results of this study are intended to be used by the commissioner (Tetra Pak). Further they shall serve for information purposes of Tetra Pak's customers, e.g. fillers and retail customers. The study and/or its results are therefore intended to be disclosed.

The study is critically reviewed according to ISO 14040/14044.

1.2 Organisation of the study

This study was commissioned by Tetra Pak in 2019. It is conducted by the Institute for Energy and Environmental Research Heidelberg GmbH (ifeu).

The members of the project panel are:

- **Tetra Pak:** Dina Epifanova, Erika Kloow, Erik Lindroth
- **ifeu:** Samuel Schlecht, Frank Wellenreuther

The modelling of the Life Cycle Assessment was done with the software UMBERTO 5.5.

1.3 Use of the study and target audience

The comparative results of this study are intended to be used by the commissioner (Tetra Pak). Further they shall serve for information purposes of Tetra Pak's customers, e.g. fillers and retail customers. The study and/or its results are therefore intended to be disclosed. According to the ISO standards on LCA [ISO 14040 and 14044 (2006)], this requires a critical review process undertaken by a critical review panel. In the experience of Tetra Pak and ifeu the most cost- and time-efficient way to run the critical review is to have it as an accompanying process. Thus, the critical reviewers were able to comment on the project from the time the goal and scope description was available.

The members of the critical review panel are

- Birgit Grahl (chair), INTEGRAHL, Germany
- Leigh Holloway, eco3 Design, UK
- Alessandra Zamagni, ecoinnovazione, Italy

Additional to the critical review panel no other interested parties were part in the conduction of the study.

1.4 Functional unit

The function examined in this LCA study is the packaging of beverages or liquid food for retail. The functional unit for this study is the provision of 1000 L packaging volume for chilled or ambient beverage or liquid food 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. Even though the shelf life of chilled packaging systems is only a few days, the function regarding liquid food safety stays the same for all examined packaging solutions.

The primary packages examined are technically equivalent regarding the mechanical protection of the packaged beverage or liquid food during transport, the storage at the point-of-sale and the use phase as described in the following section.

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

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, converting, recycling and final disposal of the primary base materials used in the primary packaging elements from the studied systems including closures and straws.
- production, converting, recycling and final disposal of primary packaging elements 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 converters and 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

- environmental effects of cooling during transport where relevant (chilled dairy and juice products).

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 et al. 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 liquid food and transport to fillers as no relevant differences between the systems under examination are to be expected
- distribution of beverage and liquid food from the filler to the point-of-sale (distribution of packages is included).
- environmental effects from accidents like breakages during transportation.
- losses of beverage and liquid food 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 and liquid food 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. Some data about beverage and liquid food losses in houshoulds is available, these losses though cannot be allocated to the different beverage and liquid food packaging systems. Further no data is available for losses at the point of sale. Therefore, possible beverage and liquid food loss differences are not quantifiable. In consequence, a sensitivity analysis regarding beverage and liquid food 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 and liquid food waste treatment aspects.
- activities at the points of sale, as no relevant differences between the systems under examination are to be expected. This includes that also further cooling at the points of sale is excluded.
- 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 or chilling at home) and the implementation would be highly speculative as no reliable data is available.

The following simplified flow charts shall illustrate the system boundaries considered for the packaging systems beverage and liquid food carton (Figure 1), PET bottle (Figure 2), HDPE bottle (Figure 3), SUP (Figure 4), glass bottle/jar(Figure 5) , aluminium can (Figure 6) and steel can (Figure 7).

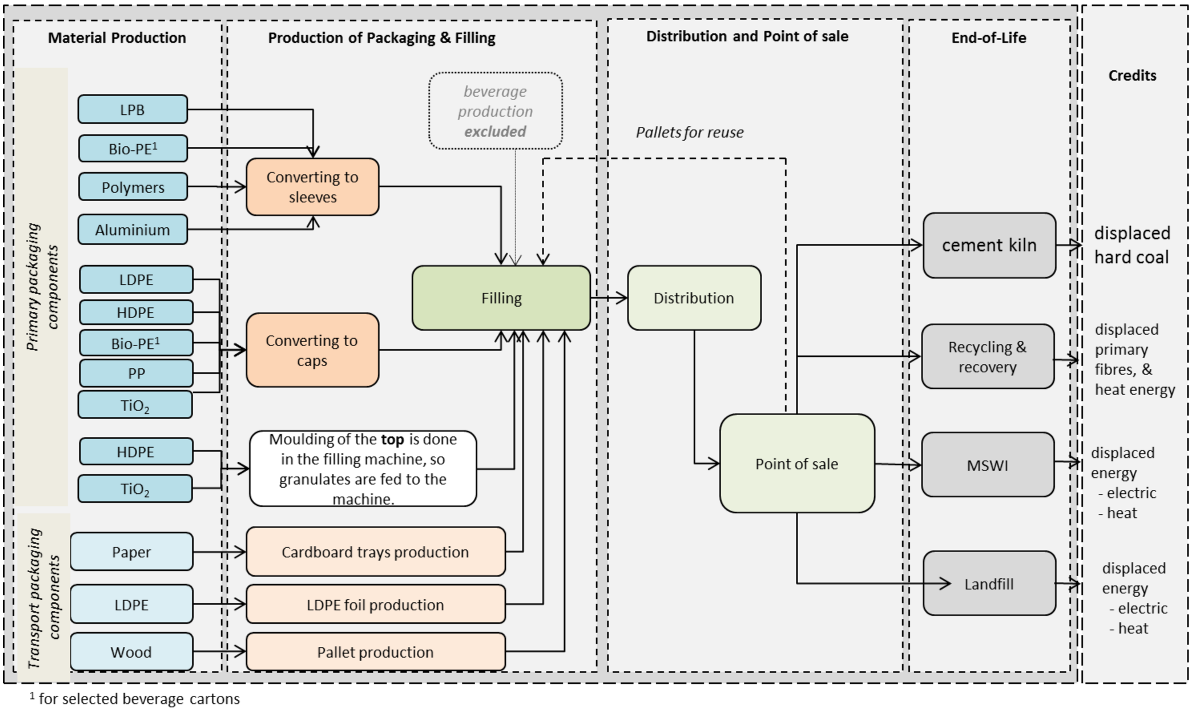


Figure 1: System boundaries of beverage and liquid food cartons

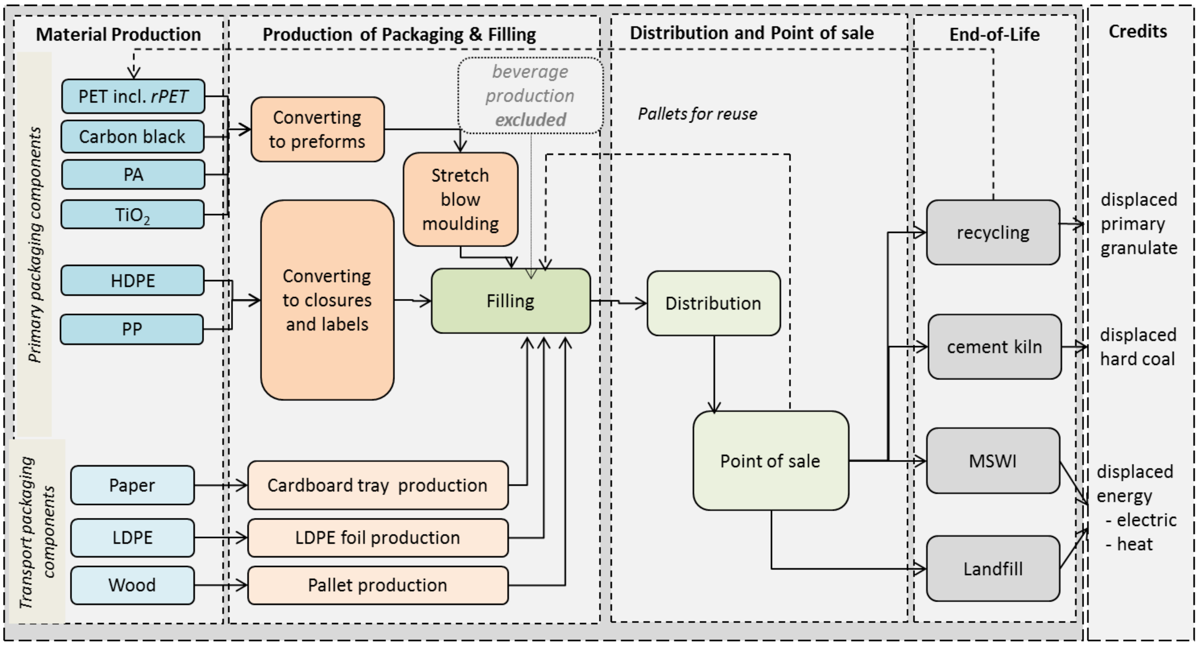


Figure 2: System boundaries of PET bottles

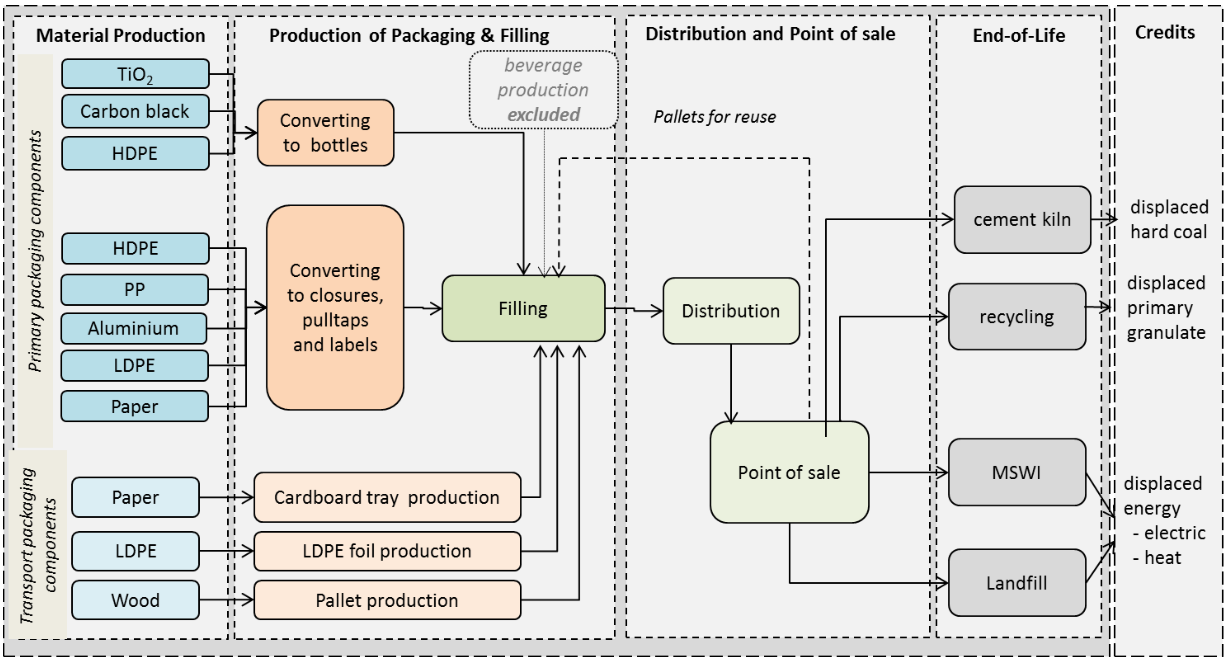


Figure 3: System boundaries of HDPE bottles

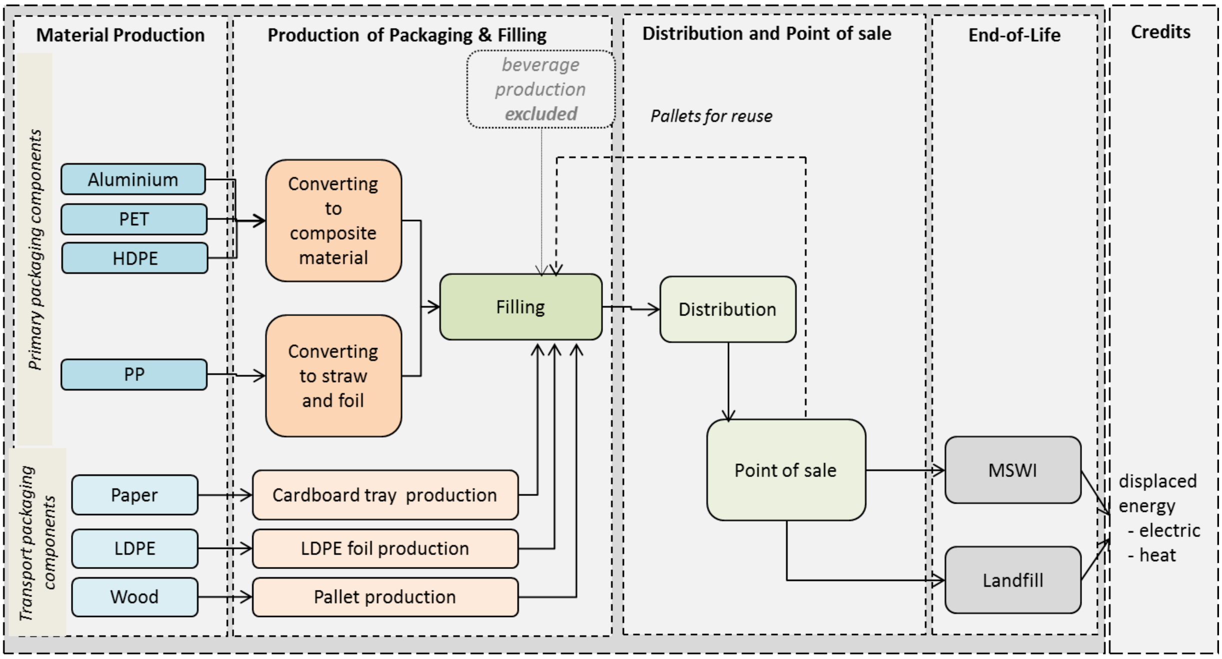


Figure 4: System boundaries of SUP

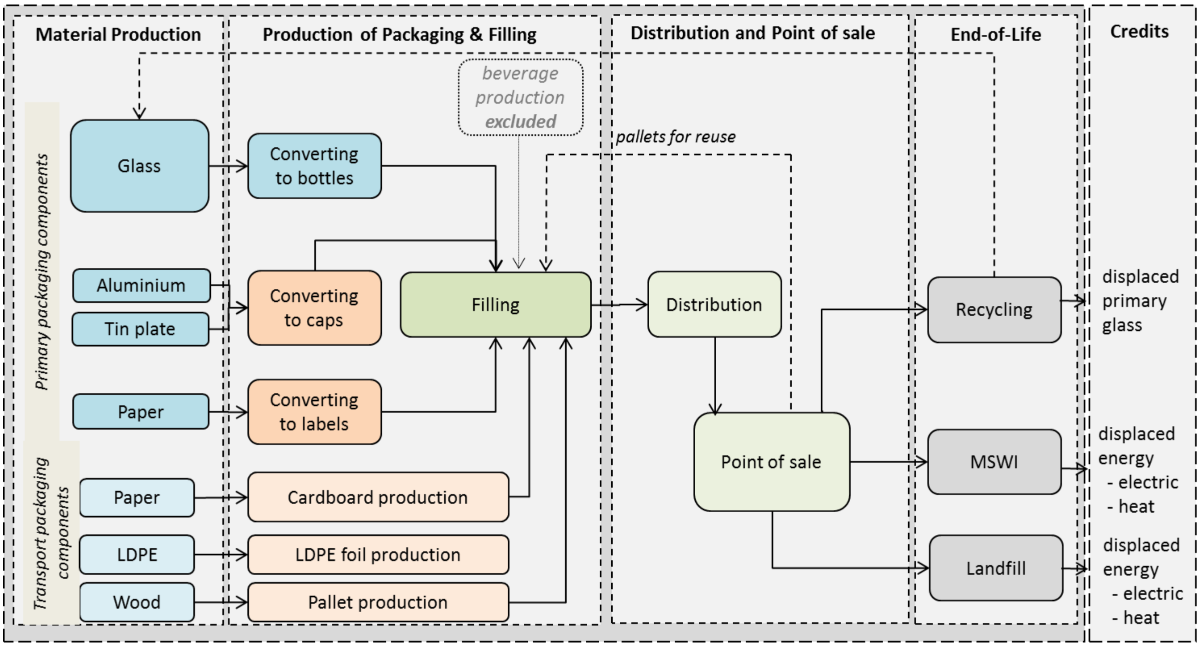


Figure 5: System boundaries of glass bottles/jars

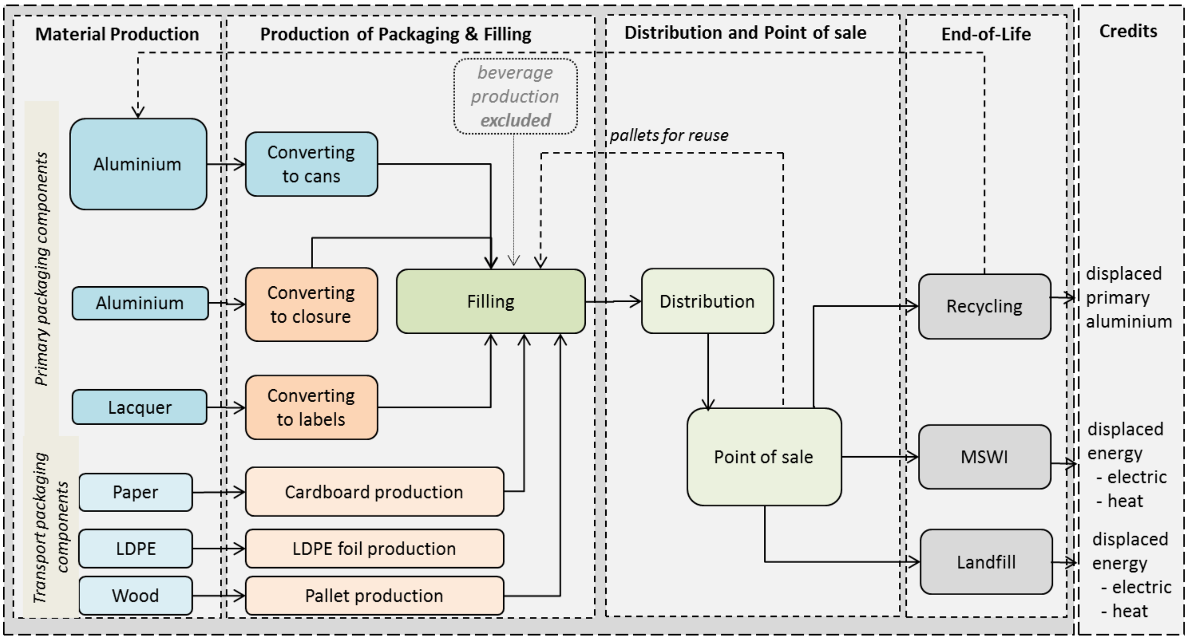


Figure 6: System boundaries aluminium can

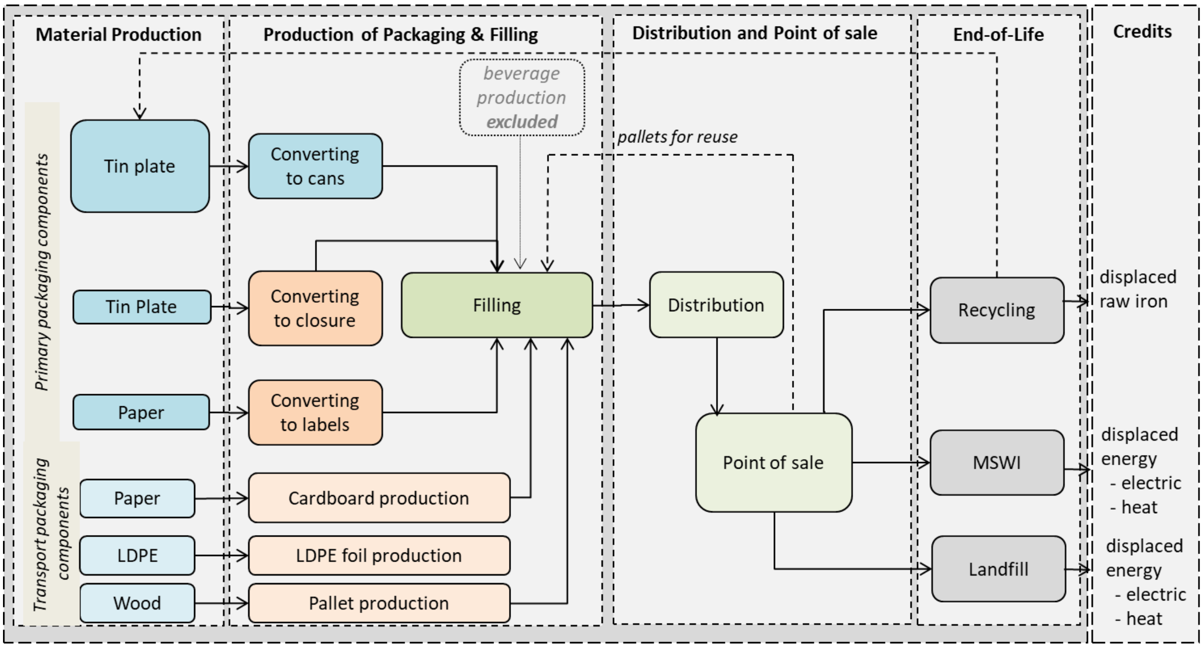


Figure 7: System boundaries steel can

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], cut-off criteria shall consider mass, energy or environmental significance.

Regarding mass-related cut-off, prechains from preceeding 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. In rare cases low input material shares may show environmental relevance, for example flows that include known toxic substances. In these cases no cut off of these low input materials is applied. Based on the mass-related cut-off the amount of printing ink used for the surface of beverage and liquid food cartons and labels of the bottles was excluded in this study. The mass of ink used per packaging never exceeds 1% of the total mass of the primary packaging for any beverage and liquid food carton examined in this study. Due to the fact that the printed surface of the labels on the bottles is smaller than the surface of a beverage and liquid food carton, the authors of the study assume, that the printing ink used for the labels will not exceed 1% of the total mass of the primary packaging as well. Environmental relevance of ink in beverage and liquid food packaging systems is low. Ruttenborg (2017) included ink in a LCA of beverage cartons. The contribution of ink in all analysed impact categories is less than 0.2%. According to Tetra Pak, inks are not in direct food contact. However, the requirements on inks are that they need to fulfil food safety requirements. This is also valid for all base materials included in the packages. From the toxicological point of view therefore no relevance is to be expected.

1.6 Data gathering and data quality

The datasets used in this study are described in section 3. The general requirements and characteristics regarding data gathering and data quality are summarised in the following paragraphs.

Geographic scope

In terms of the geographic scope, the LCA study focuses on the production, distribution and disposal of the packaging systems in Europe. A certain share of the raw material production for packaging systems takes place in specific European countries. For these, country-specific data is used. In other cases mostly European average data are used, as Tetra Pak sources its materials mainly from Europe. Examples are the liquid packaging board production process (country-specific) and the production of aluminium foil (available only as European average).

Time scope

The packaging specifications listed in section 2 as well as the market situation for the choice of beverage and liquid food packaging systems refers to 2019. Therefore, the reference time period for the comparison of packaging systems is 2019. 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.

Most of the applied data refers to the period between 1999 and 2019 (see Table 32 in section 3). The datasets for transportation, energy generation and waste treatment processes (except recycling process for beverage and liquid food cartons) are taken from ifeu's internal database in the most recent version. The data for plastic production originates from the Plastics Europe datasets and refer to different years, depending on material and year of publication.

More detailed information on the applied life cycle inventory data sets can be found in section 3.

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.

Completeness

The study is designed as a 'cradle-to-grave' LCA and intended to be used in comparative assertions. To ensure that all the relevant data needed for the interpretation are available and complete, all life cycle steps of the packaging systems under study have been subjected to a plausibility and completeness check. The summary of the completeness check according to [ISO 14044] is presented in the following table:

Table 1: The summary of the completeness check according to [ISO 14044]

Life cycle steps	Beverage / liquid food cartons	HDPE/PET bottles	Alu/steel cans	Glass bottles	SUP	Complete?	Repre-sentative?
x: inventory data for all processes available							
Base material production	x	x	x	x	x	yes	yes
Production of packaging (converting)	x	x	x	x	x	yes	yes
Filling	x	x	x	x	x	yes	yes
Distribution	x	x	x	x	x	yes	yes
End of life							
Recycling processes	x	x	x	x	x	yes	yes
MSWI	x	x	x	x	x	yes	yes
Landfill	x	x	x	x	x	yes	yes

Credits	x	x	x	x	x	yes	yes
Transportation of materials to the single production steps	x	x	x	x	x	yes	yes
Life Cycle Impact Assessment							
Climate Change	x	x	x	x	x	yes	yes
Acidification	x	x	x	x	x	yes	yes
Photo-Oxidant Formation	x	x	x	x	x	yes	yes
Ozone Depletion Potential	x	x	x	x	x	yes	yes
Terrestrial Eutrophication	x	x	x	x	x	yes	yes
Aquatic Eutrophication	x	x	x	x	x	yes	yes
Particulate Matter	x	x	x	x	x	yes	yes
Use of Nature	x	x	x	x	x	yes	yes

Consistency

All data intended to be used are considered to be consistent for the described goal and scope regarding: applied data, data accuracy, technology coverage, time-related coverage and geographical coverage (see section 3 for further details).

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 summarized in Table 32 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. To define the significance of differences of results, an estimated significance threshold of 10 % is chosen as pragmatic approach. This can be considered a common practice for LCA studies comparing different product systems [Kupfer et al. 2017]. This means differences ≤ 10 % are considered as insignificant.

1.7 Methodological aspects

1.7.1 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, 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 and liquid food 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 and liquid food through all scenarios. Impacts related to transporting the beverage and liquid food itself would be the same in all scenarios. There they don't need to be included in this comparative study of beverage and liquid food 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 thermal 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 8 illustrates the general allocation approach used for uncoupled systems and systems which are coupled through recycling. In Figure 8 (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 8. 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.

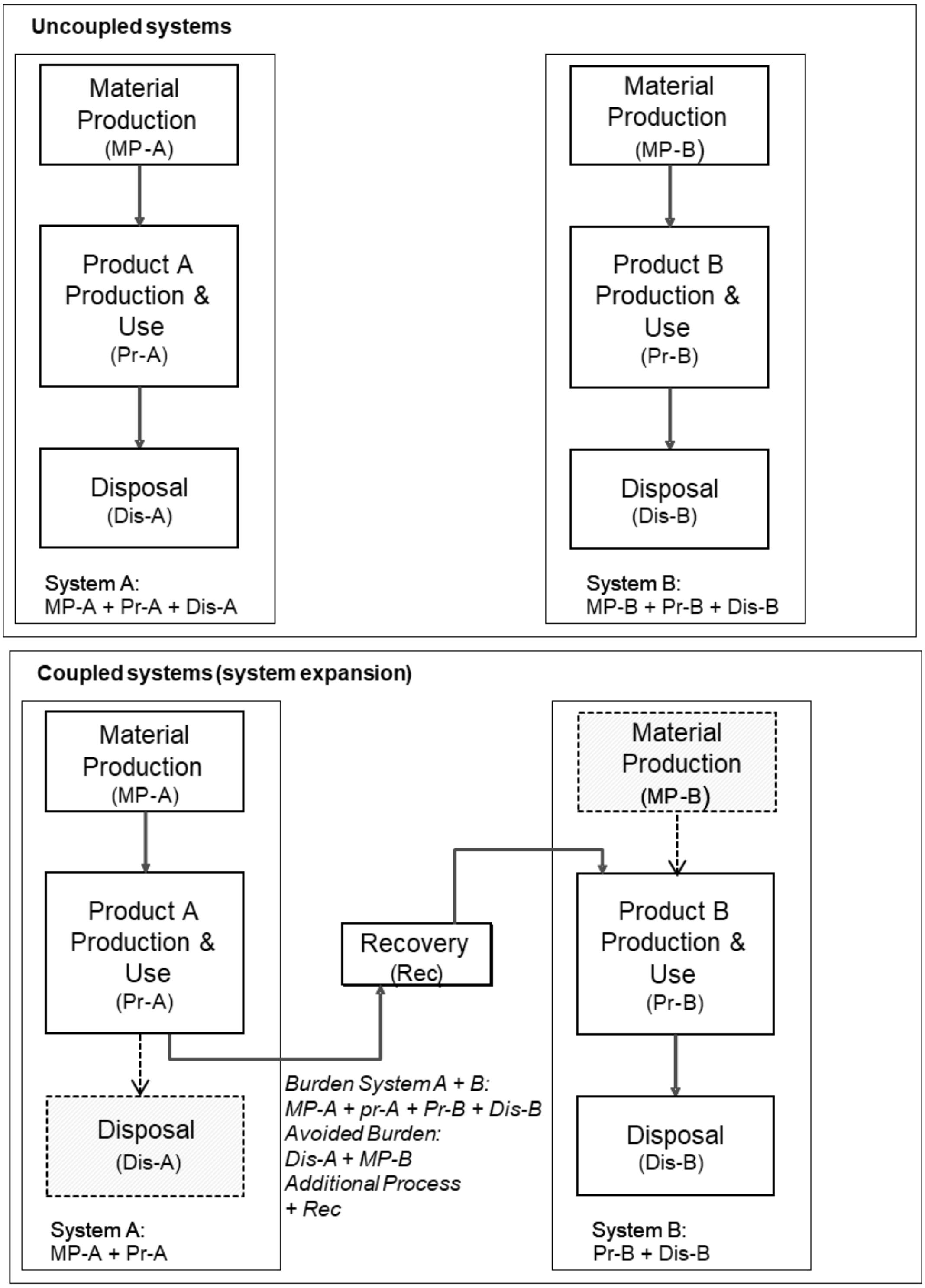


Figure 8: Additional system benefit/burden through recycling (schematic flow chart)[1]

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

[1] shaded boxes are avoided processes

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 9 and Figure 10. 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.

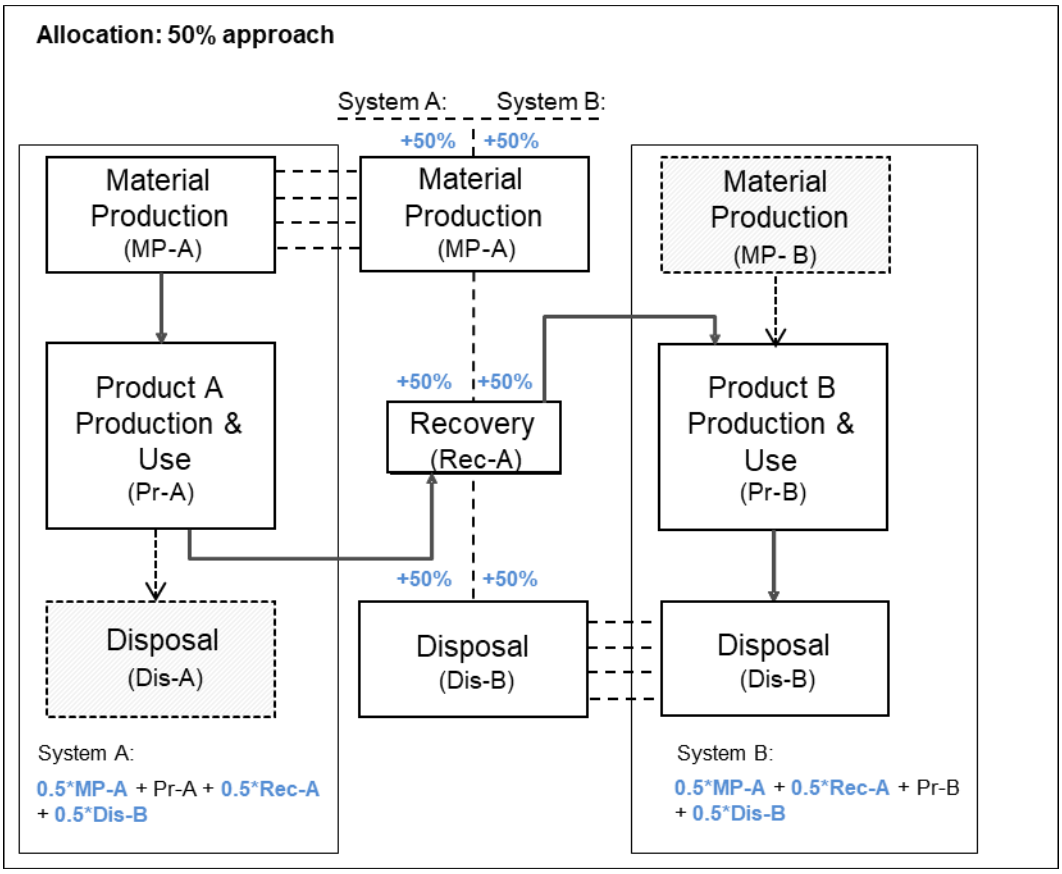


Figure 9: Principles of 50% allocation (schematic flow chart)[1]

[1] shaded boxes are avoided processes

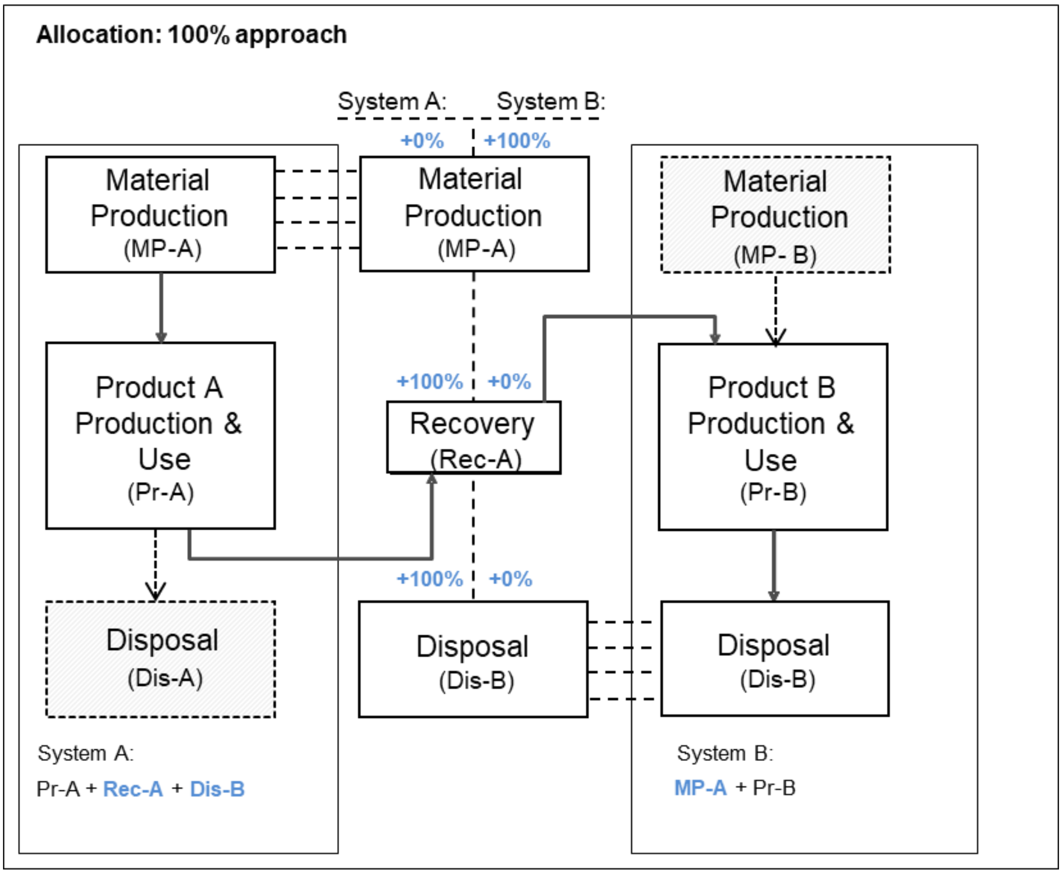


Figure 10: Principles of 100% allocation (schematic flow chart) [1]

Allocation with the 50% method (Figure 9)

In this method, benefits and burdens of 'MP-A', 'Rec-A' and 'Dis-B' are equally shared between 'system A' and 'system B' (50:50 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'.

The 50% method has often been discussed in the context of open loop recycling, see [Fava et al. 1991], [Frischknecht 1998], [Klöpffer 1996] and [Kim et al. 1997]. 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 align with §21 of the German packaging law [VerpackG 2017].

[1] shaded boxes are avoided processes

The 50:50 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] and [UBA 2016].

This allocation approach is similar to the approach described in the European guidelines for product environmental footprints (PEF).

Allocation with the 100% method (Figure 10)

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 thermal 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’.

The application of the allocation 100% is considered as a conservative approach from the view of the beverage and liquid food carton. It means that a comparatively unfavourable case for the beverage and liquid food 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 8 to Figure 10

The graphs are intended to support a general understanding of the allocation process and for that reason they are strongly simplified. The graphs 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 (Figure 12 - Figure 19) 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] and [UBA 2016] and additionally this approach – beyond the UBA methodology – is also in accordance with [ISO 14044].
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. For further details regarding substitution factors please see subsection 'Application of allocation rules'.

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 expert judgments from German waste sorting operator "Der Grüne Punkt – Duales System Deutschland GmbH" from the year 2003 [DSD 2003]. The substitution factor for PET from bottles has been raised to 1.0 since that date, as technical advancements made a bottle-to-bottle recycling process possible. Recycled granulate from PET bottles containing PA as barrier material has a lower quality than granulate from PET bottles without PA. Therefore the substitution factor recycled PET from PET bottles containing PA is reduced from 1 to 0.9.

- Paper fibres
  - from LPB (carton-based primary packaging): 0.9
  - in cardboard trays (secondary packaging): 0.9
- LDPE from foils: 0.94
- PET in bottles (bottle-to-bottle recycling): 1.0
- PET in bottles containing PA (bottle-to-bottle recycling): 0.9
- HDPE: 0.8
- Glass from bottles: 1
- Aluminium: 1
- Steel: 1 (substitution of raw iron)

1.7.2 Biogenic carbon

Renewable materials like paper fibres or plant-based 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 fixation of CO_2 by the 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 regenerative 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 GWP values and the corresponding re-emissions at end of life with positive ones. In this study regenerative 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 §21 of the German packaging law [VerpackG 2017] 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 credits.

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 regenerative 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 regenerative 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 regenerative materials are materially recycled, and if the substituted processes for the material credits are the production of other primary regenerative 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 regenerative materials like liquid packaging board, the application of the CO_2 uptake in credits would deter from recycling efforts of packaging containing regenerative 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 regenerative 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 regenerative materials sourced from recycling processes would not be benefited. As no packaging systems which contain recycled regenerative 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 regenerative CO_2 of 'system A' and 'system B' together stays the same.

As described in section 1.7.1 system-related allocation is applied in this study for thermal recovery processes like MSWI with energy recovery and incineration in cement kilns. Therefore system-related allocation applies for the emissions of CO_2 reg. from thermal recovery of regenerative materials. In case of allocation 50%, half of the CO_2 reg. emissions are attributed to the examined system and half of the CO_2 reg. emissions are attributed to the following system, for example the MSWI plants with thermal 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 regenerative carbon is the same after and before allocation following ISO 14040 and 14044. Regarding the LCA results for 'Climate Change', packaging systems containing regenerative 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 regenerative materials can promote the increase of use of regenerative 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 regenerative materials receive by only getting allocated 50% of the CO_2 reg. 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 is intended to increase the understanding of the potential environmental impacts for a product system throughout the whole life cycle [ISO 14040 and 14044].

1.8.1 Mandatory elements

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 this 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. The choice is also based on the German Federal Environmental Agency (UBA) approach 2016 [UBA 2016], which is fully consistent with the requirements of ISO 14040 and ISO 14044. 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.

The description of the different inventory categories and their indicators is based on the terminology by [ISO 14044]. It has to be noted that the impact categories, represent the environmental issues of concern, to which life cycle inventory analysis results per functional unit are assigned, but do not reflect actual environmental damages. The results of the impact categories are expressed by category indicators, which represent potential environmental impacts per functional unit. The category indicator results also do not quantify an actual environmental damage. Table 2 gives one example how the terms are applied in this study.

Table 2: Applied terms of ISO 14044 for the environmental impact assessment using the impact category stratospheric ozone depletion as example

Term	Example
Impact category	Stratospheric ozone depletion
LCI results	Amount of ozone depleting gases per functional unit
Characterisation model	Recent semi empirical steady-state model by the World Meteorological Organisation (WMO).
Category indicator	Ozone depletion potential (ODP)
Characterisation factor	Ozone depletion potential ODP_i [kg CFC-11eq. / kg emission i]
Category indicator result	Kilograms of CFC-11-equivalents per functional unit

Impact categories related to emissions

The selected impact categories related to emissions to be assessed in this study are listed and briefly addressed below. Table 3 includes an overview of elementary flows per category.

Table 3: Examples of elementary flows and their classification into impact categories

Impact categories	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
Stratospheric Ozone Depletion	CFC-11	N_2O	HBFC-123	HCFC-22	Halon-1211	Methyl Bromide	Methyl Chloride	Tetrachlor-methane	kg CFC-11-e
Photo-Oxidant Formation	CH_4	NMVOC	Benzene	Formal-dehyde	Ethyl acetate	VOC	TOC	Ethanol	kg O_3-e
Acidification	NOx	NH_3	SO_2	TRS***	HCl	H_2S	HF		kg SO_2-e
Terrestrial Eutrophication	NOx	NH_3							kg PO_4-e
Aquatic Eutrophication	COD	N	NH_4+	NO_3-	NO_2-	P			kg PO_4-e
Particulate Matter	PM2.5	SO_2	NOX	NH_3	NMVOC				kg PM2.5-e

* CO_2 fossil and biogenic / ** CH_4 fossil and CH_4 biogenic included / *** Total Reduced Sulphur

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 [IPCC 2013]. In reference to the functional unit (fu), the category indicator results, GWP results, are expressed as kg CO_2-e per functional unit.

Note on biogenic carbon: At the impact assessment level, it must be decided how to model and calculate CO_2-based GWP. 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 GWP values and the corresponding re-emissions at end of life with positive ones. For more details see section 1.7.2.

Stratospheric Ozone Depletion

In this impact category 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 is addressed. 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 potential (ODP) compiled by the World Meteorological Organisation (WMO) in 2011 [WMO 2011] is used as category indicator. In reference to the functional unit, the unit for Ozone Depletion Potential is kg CFC-11-e/fu.

Photo-Oxidant Formation

Photo-oxidant formation, also known as summer smog, 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 photo-oxidant formation. MIRs expressed as kg O_3-equivalents are used in several reactivity-based VOC (Volatile Organic Compounds) regulations by the California Air Resources Board (CARB 1993, 2000). The recent approach of William P. L. Carter includes characterisation factors for individual VOC, unspecified VOC and 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 recent 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+NMIR 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.

Characterisation factors proposed by [CML 2002] and [ReCiPe 2008] are based on European conditions regarding background concentrations and climate conditions. The usage of this characterisation factors could lead to an underestimation of the photo-oxidant formation potential in regions with e.g. a high solar radiation.

The unit for Photo-Oxidant Formation Potential is kg O_3-e/fu.

Acidification

Acidification affects aquatic and terrestrial eco-systems by changing the acid-basic-equilibrium through the input of acidifying substances. The acidification potential expressed as SO_2-equivalents according to [Heijungs et al. 1992] is applied here as category indicator.

The characterisation model by [Heijungs et al. 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 et al. 1992] is, in contrast to methods using European dispersion models, applicable for emissions outside Europe. 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/functional unit (fu).

Eutrophication and oxygen-depletion

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]:

[1] Simplification, as airborne emissions can also enter the water, but the contamination path of water through airborne emissions is of secondary importance compared to direct emissions into the water

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

Compounds containing nitrogen and phosphorus are among the most eutrophicating 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 by [Heijungs et al. 1992, CML 2002] category was chosen as impact indicator.

The environmental impacts regarding eutrophication and oxygen depletion are therefore addressed by the following impact categories:

Terrestrial Eutrophication (including eutrophication of oligotrophic systems)

Category indicator: terrestrial eutrophication potential

Characterisation factors: EP_i [kg PO_4^{3-}-e/kg $emission_i$] based on [Heijungs et al. 1992]

Emissions to compartment: emissions to air

Aquatic Eutrophication

Category indicator: aquatic eutrophication potential

Characterisation factors: EP_i [kg PO_4^{3-}-e/kg $emission_i$] based on [Heijungs et al. 1992]

Emissions to compartment: emissions to water

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 NO_x 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. This approach addresses the potential impacts on human health and nature independent of the population density.

The characterisation models suggested by [ReCiPe 2008] 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.

<u>Note on human toxicity:</u> The potential impacts of particulate matter on human health are part of the often addressed impact category "human toxicity". But, a generally accepted approach covering the whole range of toxicological concerns is not available. The inclusion

of particulate matter in USEtox is desired but not existent. In general, 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 (GSD²):

Characterisation factor	GSD²
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

Figure 11: Model uncertainty estimates for USEtox characterisation factors (reference: [Rosenbaum et al. 2008])

To define the borders of the 95% confidence interval, the mean value of each substance would have to be divided and respectively multiplied by the GSD². To draw comparative conclusions based on the existing characterisation models for toxicity categories is therefore not possible.

Impact categories related to the use/consumption of resources

Use of nature

The UNEP/SETAC Life Cycle Initiative Programme on Life Cycle Impact Assessment developed recommendations for the design of characterisation models for the impact category land use. Both biodiversity and ecosystem services are taken into account [Koellner et al. 2013]. However, neither low species diversity nor low productivity alone may be interpreted as a certain sign of poor ecosystem quality or performance. Biodiversity should always be defined in context with the biome, i.e. the natural potential for development, and the stage of succession. In consequence, an indicator for species quantification alone may not lead to correct interpretation. The choice and definition of indicators should be adapted to the conservation asset with a clear focus on the natural optimal output potential. The quantification of ecosystem services also requires a reduction of complexity, e.g. soil productivity may be quantified with the simplifying indicator soil carbon content ([Mila i Canals et al. 2007], [Brandao & Mila i Canals 2013]), which is directly correlated with the impact category indicator. Such reductions of complexity are always based on the assumption that no critical information is lost in the process of simplification.

Recently, [Fehrenbach et al. 2015] have developed the so called hemeroby concept in order to provide an applicable and meaningful impact category indicator for the integration of land use and biodiversity into the Life Cycle (Impact) Assessment. The central idea to the hemeroby concept follows the logic that intact ecosystems are not prone to higher levels of disturbance and negative impacts.

Within the hemeroby concept, the areas of concern are classified into seven hemeroby classes. The hemeroby approach is appropriate to be applied on any type of land-use type accountable in LCA. Particularly production systems for biomass (wood from forests, all kinds of biomass from agriculture) are assessed in a differentiated way:

To describe forest systems three criteria are defined: (1) natural character of the soil, (2) natural character of the forest vegetation, (3) natural character of the development conditions. The degree of performance is figured out by applying by 7 metrics for each criterion.

Agricultural systems are assessed by four criteria: (1) diversity of weeds, (2) Diversity of structures, (3) Soil conservation, (4) Material input. Three metrics are used for each criterion to calculate the grade of hemeroby.

The concept has been applied to almost any form of land use in central and northern Europe as well as for individual agricultural productions in North- and South America (Kauertz et al. (2011), [Fehrenbach et al. 2016]). Data quality for its application in this study is considered to be sufficient enough to deliver robust results for this study. Due to the data uncertainties connected to forestry data and sugar cane cultivation, the results of this category in this study though cannot be used without hesitation. Nevertheless the results of this impact category are included to the comparisons and final conclusions of the study as the mentioned data uncertainties do not change the large difference in land use between materials from forests or other plant-based materials and materials from fossil sources.

The used inventory data for paper production have been determined by Tiedemann (2000). The classification of forest is shown in Table 4. Inventory data for the plant-based PE dataset compiled by ifeu are based on [Fehrenbach et.al 2016], where sugar cane is classified in equal shares to class V and VI. As a conservative assumption, the land use for sugar cane cultivation is classified to class VI in the applied plant-based PE dataset from Braskem.

To adress land use by a methodology without loosing crucial information, the impact category use of nature is adressed in this study by the category indicator 'Distance-to-Nature-Potential' (DNP) (m^2-e* 1a) based on the hemeroby concept by [Fehrenbach et al. 2015]. The DNP is a midpoint metric, focussing on the occupation impact. In reference to the functional unit (fu), the unit for use of nature is m^2-e*1a/fu.

Table 4: Examples of use of nature and their classification into hemeroby categories

	Hemeroby categories						Unit
Use of Nature	class II	class III	class IV	class V	class VI	class VII	m^2-e*a
Forest for LPB production	2%	23%	61%	14%			
plant-based PE					100%		

Raw materials

The published approaches addressing the impact on primary natural resources are currently limited to abiotic raw materials (with energy and without energy content). Currently there is no model applicable which addresses impacts for all types of primary natural resources (minerals and metals, biotic resources, energy carriers) [JRC 2016].

Even the complex models which refer to statistics on stock reserves do not cover all resources especially biotic ones. Furthermore, potential impacts on the environment are not addressed by the available LCIA models as required by ISO 14044.

The method proposed by Giegrich et al. (2012) aims to address potential impacts on the environment by introducing the safeguard subject loss of material goods. The approach covers the extraction of minerals, metals, fossil fuels and biotic materials. The category indicator is the loss potential of material resources. The required inventory to address this loss potential is the 'Cumulative raw material demand' (CRD). The CRD depicts the total of all material resources introduced into a system expressed in units of weight and takes the ore into account rather than just the refined metal. The unit for Cumulative raw material demand is kg. The proposed method by Giegrich et al. (2012) and recommended by UBA (2016) is still under development. Characterisation factors are not yet available for all materials to be considered.

Due to the lack of a comprehensive and applicable approach, the potential environmental impact on natural resources cannot be assessed on LCIA level. The CRD is therefore included on the inventory level only and is limited to abiotic raw materials. Inventory level information is not part of an environmental impact assessment and is therefore not be used for the drawing of conclusions.

Additionally, the Cumulative Energy Demand (CED) is included in the inventory categories as indication for the loss potential of energy resources (see below). It is included due to the fact, that the energy demand of the production of its materials and processes is one of Tetra Pak's priority areas of concern. Of course it also will not be considered for the drawing of conclusions within this study.

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.

Water scarcity

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. This drives the need for a better understanding of water related impacts as a basis for improved water management at local, regional, national and global levels (ISO 14046). To ensure consistency in assessing the so called water footprint ISO 14046 was published in 2014. It provides guidance in principles and requirements to assess water related impacts based on life cycle assessment (according to ISO 14044).

In general, the available methods to assess the impact of water consumption can be divided into volumetric and impact-oriented water footprints [Berger/Finkbeiner 2010]. The volumetric methods determine the freshwater consumption of products on an inventory level. The impact-based water footprints addressing the consequences resulting from water consumption and require a characterization of individual flows prior to aggregation [Berger/Finkbeiner 2010]. The safeguard subjects of most of the impact-oriented water footprint methods focussing on regional water scarcity.

According to ISO 14046, the consideration of spatial water scarcity is mandatory to assess the related environmental impacts of the water consumption. Water consumption occurs due to evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea (ISO 14046). Thus information on the specific geographic location and quantity of water withdrawal and release is requisite.
In order to provide an ISO compliant method, the working group "Water Use in LCA (WULCA[1])" of the UNEP –SETAC Life Cycle Initiative was working on the development of a consensus-based water scarcity midpoint method for the use in LCA over the last three years. The working group recommended the method AWaRe [Boulay et al. 2017]: It is based on the quantification of the relative available water remaining per area once the demand of humans and aquatic ecosystems has been met. According to the authors this method represents the state of the art of the current knowledge on how to assess potential impacts from water use in LCA. However, most of the inventories applied in this study still do not include the water released from the products and processes. Therefore, the required amount of water consumed cannot be determined. For the inventory assessment of freshwater, a consistent differentiation and consistent water balance in the inventory data is requisite as basis for a subsequent impact assessment.

Due to the lack of mandatory information to assess the potential environmental impact, water scarcity cannot be assessed on LCIA level within this study. However, the use of water will be included in the inventory categories. A differentiation between process water, cooling water and water, unspecified is made. However, it includes neither any reference to the origin of this water, nor to its quality at the time of output/release. The respective results in this category are therefore of mere indicative nature and are not suited for conclusive quantitative statements related to either of the analysed packaging systems. The unit is m^3.

[1] http://wulca-waterlca.org

Primary Energy (Cumulative Energy Demand)

The *total Primary Energy Demand (CED total)* and the *non-renewable Primary Energy Demand (CED non-renewable)* serve primarily as a source of information regarding the energy intensity of a system.

Total Primary Energy (Cumulative Energy Demand, total)

The Total Cumulative Energy Demand 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 calculation of the energy content of biomass, e.g. wood, is based on the lower heating value of the dry mass. The unit for Total Primary Energy is MJ.

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

The category non-renewable primary energy (CED non-renewable) 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.

Table 5: Examples of elementary flows and their classification into inventory level categories

Categories at inventory level	Elementary Flows							Unit
Total Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore	hydro energy	other renewable	MJ
Non-renewable Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore			MJ
Freshwater Use	Process water	Cooling water	Water, unspecified					m^3

1.8.2 Optional elements

[ISO 14044] (§4.4.3) provides three optional elements for impact assessment which can be used depending on the goal and scope of the LCA:

1. Normalisation: calculating the magnitude of category results relative to reference information
2. Grouping: sorting and possibly ranking of the impact categories
3. Weighting: converting and possibly aggregating category results across impact categories using numerical factors based on value-choices (not allowed for comparative assertion disclosed to public)

In the present study none of the optional elements are applied.

2 Packaging systems and scenarios

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 elements 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.

All packaging systems examined in this study are presented in the following sections (2.1 & 2.2), including the applied end-of-life settings (2.3). Section 2.4 provides information on all regarded scenarios, including those chosen for sensitivity analyses.

2.1 Selection of packaging systems

The focuses of this study are the beverage and liquid food cartons produced by Tetra Pak for which this study aims to provide knowledge of their strengths and weaknesses regarding environmental aspects. The beverage and liquid food cartons are compared with corresponding competing packaging systems.

The choice of beverage and liquid food cartons has been made by Tetra Pak based on market relevance. Cartons of different volumes for the packaging of dairy, JNSD (Juice, nectars, still drinks), still, unflavoured water and liquid food have been chosen for examination. For each of these segments typical alternative packaging systems have also been chosen by Tetra Pak. This choice is based on Tetra Pak's knowledge of the European market and what packaging systems Tetra Pak considers as the main competitors to their own products. In case of glass bottles only single use bottles are included in the study. Refillable glass bottles are not included in the study as they have only a very small share on the European market.

The following tables show which beverage and liquid food cartons are compared with the selected competing systems. The comparison will be conducted as follows:

- Only packaging systems in the same segment are compared to each other
- Chilled and ambient beverage and liquid food packaging systems are not compared to each other.

Table 6: List of Tetra Pak beverage cartons in segment **DAIRY, Family Pack, Chilled** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Rex (TR) OSO 34 1000 ml	C	Europe	HDPE bottle 1 1000 ml	C	Europe
			PET bottle 1 1000 ml	C	Europe
			Glass bottle 1 1000 ml	C	Europe
Tetra Rex (TR) OSO 34 plant-based 1000 ml	C	Europe	HDPE bottle 1 1000 ml	C	Europe
			PET bottle 1 1000 ml	C	Europe
			Glass bottle 1 1000 ml	C	Europe
Tetra Top (TT) O38 1000 ml	C	Europe	HDPE bottle 1 1000 ml	C	Europe
			PET bottle 1 1000 ml	C	Europe
			Glass bottle 1 1000 ml	C	Europe

Table 7: List of Tetra Pak beverage cartons in segment **DAIRY, Family Pack, Ambient** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Brik Aseptic (TBA) LC30 1000 ml	A	Europe	HDPE bottle 2 1000 ml	A	Europe
			PET bottle 2 1000 ml	A	Europe
Tetra Brik Aseptic (TBA) LC30 plant-based 1000 ml	A	Europe	HDPE bottle 2 1000 ml	A	Europe
			PET bottle 2 1000 ml	A	Europe

Table 8: List of Tetra Pak beverage cartons in segment **DAIRY, Portion Pack, Chilled** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Brik (TB) Mid Straw 200 ml	C	Europe	HDPE bottle 3 200 ml	C	Europe

Table 9: List of Tetra Pak beverage cartons in segment **JNSD, Family Pack, Ambient** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Brik Aseptic (TBA) Slim Helicap 23 1000 ml	A	Europe	PET bottle 3 1000 ml	A	Europe
			Glass bottle 2 1000 ml	A	Europe
Tetra Rex (TR)MiniPlus TwistCap OSO Barrier 34 1000 ml	A	Europe	PET bottle 3 1000 ml	A	Europe
			Glass bottle 2 1000 ml	A	Europe

Table 10: List of Tetra Pak beverage cartons in segment **JNSD, Portion Pack, Ambient** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Brik Aseptic (TBA) Base Straw 200 ml	A	Europe	Glass bottle 3 250 ml	A	Europe
			SUP 1 200 ml	A	Europe
Tetra Prisma Aseptic (TPA) DC26 330 ml	A	Europe	Glass bottle 3 250 ml	A	Europe
			SUP 1 200 ml	A	Europe

Table 11: List of Tetra Pak beverage cartons in segment **Water, Portion Pack, Ambient** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Prisma Aseptic (TPA) Square StreamCap 500 ml	A	Europe	PET bottle 4 500 ml	A	Europe
			Glass bottle 4 500 mL	A	Europe
			Aluminium can 1 500 mL	A	Europe
Tetra Top (TT) Midi C38 plant-based 500 ml	A	Europe	PET bottle 4 500 ml	A	Europe
			Glass bottle 4 500 mL	A	Europe
			Aluminium can 1 500 mL	A	Europe

Table 12: List of Tetra Pak liquid food cartons in segment **Liquid Food, Portion Pack, Ambient** and corresponding competing packaging systems

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Recart 390 ml	A	Europe	Steel can 1 390 ml	A	Europe
			Glass Jar 1 390 ml	A	Europe

2.2 Packaging specifications

Specifications of beverage and liquid food carton packaging systems are listed in Table 13 to Table 19 and were provided by Tetra Pak. In Tetra Pak's internal database typical specifications of all primary packages sold are registered. The specifications of individual packages of one single carton system may vary to a small degree over different production batches or production sites. To get the final specifications per beverage and liquid food carton type the exact specifications of different batches were averaged taking into consideration the production volumes of each production batch. For confidentially in case of the polymers used in the beverage and liquid food carton systems no differentiation to specific polymers are shown in the tables. The calculations are calculated with the specific shares of each polymer used. These are disclosed to the critical review panel.

Data on secondary and tertiary packaging for beverage and liquid food cartons was also provided by Tetra Pak from its internal packaging system model. The data is periodically updated and the most recent data of 2019 is used in this LCA.

Specifications of the competing packaging types that have been identified as relevant in the examined segments are listed in Table 20 to Table 26. Specifications of many different packaging systems available on several European countries have been taken by ifeu as a base for determining specifications for virtual typical packaging systems for Europe. The underlying knowledge has been accumulated by ifeu through several country specific LCA studies and a continuous observation of the European packaging market. Additionally the specifications have been checked for plausibility by an expert on competing packaging systems at Tetra Pak. The data quality of these specifications is considered to be sufficient as they are based on specification data from physically analysed samples of actual packaging systems. Specifications regarding secondary packaging of the competing packaging types aim to represent typical packaging. Secondary packaging can be LDPE shrink packs or cardboard trays depending on the packaging type and segment. The weight of secondary packaging depends on the material itself and also on the arrangement of packs per secondary packaging unit. For example the cardboard tray for the Steel can 1 is heavier than the cardboard tray for the Glass jar 1 for stability reasons due to its larger base area. As there are no competing packaging systems which are available throughout the European markets, these data aim to represent typical specifications of packaging systems that can be considered representative for the identified packaging types in each segment. In the additional local supplement studies specific competing packages are analysed.

These specifications are used to calculate the base scenarios for all packaging systems.

2.2.1 Specifications of beverage and liquid food carton systems

Table 13: Packaging specifications for regarded carton systems for the *packaging of Dairy Family Packs (chilled)*

		DAIRY FAMILY PACK CHILLED		
	Unit	TR OSO 34	TR OSO 34 bb	TT O38
volume	ml	1000	1000	1000
geographic Scope	-	Europe	Europe	Europe
chilled / ambient	-	chilled	chilled	chilled
primary packaging (sum)[1]	**g**	**30.4**	**30.4**	**33.6**
composite material (sleeve)	**g**	**27.8**	**27.8**	**25.0**
- liquid packaging board	g	24.2	24.2	21.0
- polymer	g	3.6		4.0
- plant-based polymer	g		3.6	
closure	**g**	**2.6**	**2.6**	**3.4**
- polymer	g	2.6		3.4
- plant-based polymer	g		2.6	
top	**g**			**5.2**
- polymer	g			5.2
secondary packaging (sum)[2]	**g**	**165.0**	**165.0**	**122.0**
tray/box (corr.cardboard)	g	165.0	165.0	**122.0**
tertiary packaging (sum)[3]	**g**	**25170**	**25170**	**25170**
pallet (wood)	g	25000	25000	25000
type of pallet	-	EURO	EURO	EURO
number of use cycles	-	25	25	25
stretch foil (per pallet) (LDPE)	g	170	170	170
pallet configuration				
cartons per tray	pc	10	10	10
trays / packs per layer	pc	15	15	15
layers per pallet	pc	5	5	5
cartons per pallet	pc	750	750	750

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

Table 14: Packaging specifications for regarded carton systems for the *packaging of Dairy Family Packs (ambient)*

		DAIRY FAMILY PACK AMBIENT	
	Unit	TBA Edge LC 30	TBA Edge LC 30 plant-based
volume	ml	1000	1000
geographic Scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
primary packaging (sum)[1]	**g**	**31.6**	**31.6**
composite material (sleeve)	**g**	**28.6**	**28.6**
- liquid packaging board	g	22.5	22.5
- polymer	g	4.7	2.0
- plant-based polymer	g		2.7
- aluminium	g	1.4	1.4
closure	**g**	**3.0**	**3.0**
- polymer	g	3.0	1.6
- plant-based polymer	g		1.4
secondary packaging (sum)[2]	**g**	**145.0**	**145.0**
tray/box (corr.cardboard)	g	145.0	145.0
tertiary packaging (sum)[3]	**g**	**25170**	**25170**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles	-	25	25
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
cartons per tray	pc	10	10
trays / packs per layer	pc	16	16
layers per pallet	pc	5	5
cartons per pallet	pc	800	800

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

Table 15: Packaging specifications for regarded carton systems for the *packaging of Dairy Portion Packs (chilled)*

		DAIRY PORTION PACK CHILLED
	Unit	TB Mid Straw
volume	ml	200
geographic Scope	-	Europe
chilled / ambient	-	chilled
primary packaging (sum)[1]	g	**7.9**
composite material (sleeve)	g	**7.4**
- liquid packaging board	g	5.8
- polymer	g	1.6
straw	g	**0.5**
- polymer	g	0.5
secondary packaging (sum)[2]	g	**79.9**
tray/box (corr.cardboard)	g	77.8
film (LDPE)	g	2.1
tertiary packaging (sum)[3]	g	**25170**
pallet (wood)	g	25000
type of pallet	-	EURO
number of use cycles	-	25
stretch foil (per pallet) (LDPE)	g	170
pallet configuration		
cartons per tray	pc	24
trays / packs per layer	pc	13
layers per pallet	pc	12
cartons per pallet	pc	3744

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

Table 16: Packaging specifications for regarded carton systems for the *packaging of JNSD Family Packs (ambient)*:

		JNSD FAMILY PACK AMBIENT	
	Unit	TBA Slim Helicap 23	TR MiniPlus TwistCap OSO Barrier 34
volume	ml	1000	1000
geographic Scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
primary packaging (sum)[1]	**g**	**32.7**	**37.6**
composite material (sleeve)	**g**	**30.0**	**33.5**
- liquid packaging board	g	22.1	24.2
- polymer	g	6.5	7.8
- Aluminium	g	1.4	1.5
closure	**g**	**2.7**	**4.10**
- polymer	g	2.7	4.1
secondary packaging (sum)[2]	**g**	**156.8**	**133.3**
tray/box (corr.cardboard)	g	**156.8**	133.3
tertiary packaging (sum)[3]	**g**	**25170**	**25170**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles	-	25	25
stretch foil (per pallet) (LDPE)	g	170	170
pallet/ configuration			
cartons per tray	pc	12	8
trays / packs per layer	pc	12	17
layers per pallet	pc	6	5
cartons per pallet	pc	864	680

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

Table 17: Packaging specifications for regarded carton systems for the *packaging of JNSD Portion Packs (ambient)*

		JNSD PORTION PACK AMBIENT	
	Unit	TBA Base Straw	TPA DreamCap26
volume	ml	200	330
geographic Scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
primary packaging (sum)[1]	g	**8.5**	**16.6**
composite material (sleeve)	g	**8.0**	**12.9**
- liquid packaging board	g	5.7	8.8
- polymer	g	1.8	3.2
- aluminium	g	0.5	0.9
straw	g	**0.5**	
- polymer	g	0.5	
closure	g		**3.7**
- polymer	g		3.7
secondary packaging (sum)[2]	g	**80.2**	**105.8**
tray/box (corr.cardboard)	g	78.4	105.8
film (LDPE)	g	1.8	
tertiary packaging (sum)[3]	g	**25170**	**25170**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles	-	25	25
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
cartons per tray	pc	24	12
trays / packs per layer	pc	13	19
layers per pallet	pc	12	8
cartons per pallet	pc	3744	1824

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

Table 18: Packaging specifications for regarded carton systems for the *packaging of Water Portion Packs (ambient)*

		WATER PORTION PACK AMBIENT	
	Unit	TPA Square StreamCap	TT C38 bb
volume	ml	500	500
geographic Scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
primary packaging (sum)[1]	g	22.6	21.8
composite material (sleeve)	g	19.3	15.0
- liquid packaging board	g	13.4	11.6
- polymer	g	4.7	2.7
- aluminium	g	1.2	0.7
closure	g	3.3	2.9
- polymer	g	3.3	
- plant-based polymer	g		2.9
top	g		3.9
- polymer	g		0.5
- plant-based polymer	g		3.4
secondary packaging (sum)[2]	g	202.8	110.0
tray/box (corr.cardboard)	g	202.8	110.0
tertiary packaging (sum)[3]	g	25170	25170
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles	-	25	25
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
cartons per tray	pc	12	12
trays / packs per layer	pc	14	19
layers per pallet	pc	6	6
cartons per pallet	pc	1008	1368

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

Table 19: Packaging specifications for regarded carton systems for the *packaging of Liquid Food Portion Packs (ambient)*

		LIQUID FOOD PORTION PACK AMBIENT
	Unit	Tetra Recart
volume	ml	390
geographic Scope	-	Europe
chilled / ambient	-	ambient
primary packaging (sum)[1]	g	**17.7**
composite material (sleeve)	g	**17.7**
- liquid packaging board	g	12.6
- polymer	g	4.3
- aluminium	g	0.8
secondary packaging (sum)[2]	g	**52.0**
tray/box (corr.cardboard)	g	52.0
tertiary packaging (sum)[3]	g	**25170**
pallet (wood)	g	25000
type of pallet	-	EURO
number of use cycles	-	25
stretch foil (per pallet) (LDPE)	g	170
pallet configuration		
cartons per tray	pc	16
trays / packs per layer	pc	12
layers per pallet	pc	10
cartons per pallet	pc	1920

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

2.2.2 Specifications of alternative packaging systems

Table 20: Packaging specifications for regarded alternative systems in the segment *Dairy Family Pack (chilled)*

		DAIRY FAMILY PACK CHILLED		
	Unit	HDPE bottle 1	PET bottle 1	Glass bottle 1
volume	ml	1000	1000	1000
geographic scope	-	Europe	Europe	Europe
chilled / ambient	-	chilled	chilled	chilled
clear / opaque	-	opaque	opaque	clear
primary packaging (sum)[1]	g	**32.3**	**29.0**	**600**
bottle (sum)	g	**26.0**	**24.0**	**595**
- glass	g			595
- PET	g		23.6	
- recycled PET			12%	
- HDPE	g	24.1		
- TiO2	g	1.3	0.4	
- carbon black	g	0.6		
label	g	**3.5**	**2.0**	**1.5**
- paper	g	3.5	2.0	1.5
closure	g	**2.4**	**3.0**	**3.5**
- HDPE	g	2.4	3.0	
- aluminium	g			3.5
pull tap	g	**0.4**		
- LDPE	g	0.2		
- aluminium	g	0.2		
secondary packaging (sum)[2]	g	**17.2**	**230.0**	**98.0**
- shrink pack (LDPE)	g	17.0		
- tray/box/paper handle	g	0.2	230.0	98.0
tertiary packaging (sum)[3]	g	**26570**	**26920**	**26570**
pallet (wood)	g	25000	25000	25000
type of pallet	-	EURO	EURO	EURO
number of use cycles		25	25	25
cardboard layer	g	350	350	350
number of cardboard layers		4	5	4
stretch foil (per pallet) (LDPE)	g	170	170	170
pallet configuration				
bottles per sec. packaging	pc	6	12	6
sec. packaging units per layer	pc	25	8	21
layers per pallet	pc	5	6	5
bottles per pallet	pc	750	576	630

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

Table 21: Packaging specifications for regarded alternative systems in the segment *Dairy Family Pack (ambient)*

		DAIRY FAMILY PACK AMBIENT	
	Unit	HDPE bottle 2	PET bottle 2
volume	ml	1000	1000
geographic scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
clear / opaque	-	opaque	opaque
primary packaging (sum)[1]	g	**37.2**	**28.0**
bottle (sum)	g	**32.0**	**24.0**
- PET	g		22.2
- recycled PET			12%
- HDPE	g	29.6	
- TiO2	g	1.6	1.2
- carbon black	g	0.8	0.6
label	g	**2.0**	**1.0**
- paper	g	2.0	
- PP	g		1.0
closure	g	**3.0**	**3.0**
- HDPE	g	3.0	
- PP	g		3.0
pull tap	g	**0.2**	
- aluminium	g	0.2	
secondary packaging (sum)[2]	g	**17.2**	**15.0**
- shrink pack (LDPE)	g	17.0	15.0
- tray/box/paper handle	g	0.2	
tertiary packaging (sum)[3]	g	**26570**	**26220**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles		25	25
cardboard layer	g	350	350
number of cardboard layers		4	3
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
bottles per sec. packaging	pc	6	6
sec. packaging units per layer	pc	25	25
layers per pallet	pc	5	4
bottles per pallet	pc	750	600

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

Table 22: Packaging specifications for regarded alternative systems in the segment *Dairy Portion Pack (chilled)*

		DAIRY PORTION PACK CHILLED
	Unit	HDPE bottle 3
volume	ml	200
geographic scope	-	Europe
chilled / ambient	-	chilled
clear / opaque	-	opaque
primary packaging (sum)[1]	g	**20.0**
bottle (sum)	g	**17.0**
- HDPE	g	16.15
- TiO2	g	0.85
label	g	**0.2**
- PP	g	0.2
closure	g	**2.8**
- HDPE	g	2.8
secondary packaging (sum)[2]	g	**88.0**
- tray/box/paper handle	g	88.0
tertiary packaging (sum)[3]	g	**27970**
pallet (wood)	g	25000
type of pallet	-	EURO
number of use cycles		25
cardboard layer	g	350
number of cardboard layers		8
stretch foil (per pallet) (LDPE)	g	170
pallet configuration		
bottles per sec. packaging	pc	10
sec. packaging units per layer	pc	27
layers per pallet	pc	9
bottles per pallet	pc	2430

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

Table 23: Packaging specifications for regarded alternative systems in the segment *JNSD Family Pack (ambient)*

		JNSD FAMILY PACK AMBIENT	
	Unit	PET bottle 3	Glass bottle 2
volume	ml	1000	1000
geographic scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
clear / opaque	-	opaque	clear
primary packaging (sum)[1]	g	**33.0**	**520**
bottle (sum)	g	**28.5**	**515**
- glass	g		515
- PET	g	26.2	
- recycled PET		12%	
- PA	g	2.3	
label	g	**0.8**	**1.5**
- paper	g		1.5
- PP	g	0.8	
closure	g	**3.7**	**3.5**
- HDPE	g	3.7	
- aluminium	g		3.5
secondary packaging (sum)[2]	g	**17.9**	**98.0**
- shrink pack (LDPE)	g	17.3	
- tray/box/paper handle	g	0.6	98.0
tertiary packaging (sum)[3]	g	**26220**	**26570**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles		25	25
cardboard layer	g	350	350
number of cardboard layers		3	4
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
bottles per sec. packaging	pc	6	6
sec. packaging units per layer	pc	26	21
layers per pallet	pc	4	5
bottles per pallet	pc	624	630

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

Table 24: Packaging specifications for regarded alternative systems in the segment *JNSD Portion Pack (ambient)*

		JNSD PORTION PACK AMBIENT	
	Unit	Glass bottle 3	SUP 1
volume	ml	250	200
geographic scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
clear / opaque	-	clear	opaque
primary packaging (sum)[1]	**g**	**195**	**4.1**
bottle/composite pouch (sum)	**g**	**190**	**3.8**
- glass	g	190	
- PET	g		0.6
- LDPE	g		2.5
- aluminium	g		0.7
label	**g**	**1.0**	
- paper	g	1.0	
straw	**g**		**0.3**
- PP	g		0.3
closure	**g**	**4.0**	
- tin plate	g	4.0	
secondary packaging (sum)[2]	**g**	**51.0**	**88.0**
- shrink pack (LDPE)	g		
- tray/box/paper handle	g	51.0	88.0
tertiary packaging (sum)[3]	**g**	**26920**	**27970**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles		25	25
cardboard layer	g	350	350
number of cardboard layers		5	8
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
bottles/SUP per sec. packaging	pc	8	10
sec. packaging units per layer	pc	27	27
layers per pallet	pc	6	9
bottles per pallet	pc	1296	2430

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

Table 25: Packaging specifications for regarded alternative systems in the segment *Water Portion Pack (ambient)*

		WATER PORTION PACK AMBIENT		
	Unit	PET bottle 4	Glass bottle 4	Aluminium can 1
volume	ml	500	500	500
geographic scope	-	Europe	Europe	Europe
chilled / ambient	-	ambient	ambient	ambient
clear / opaque	-	clear	clear	-
primary packaging (sum)[1]	g	**18.2**	**230.0**	**16.0**
bottle/body (sum)	g	**15.0**	**227.5**	**12.9**
- glass	g		227.5	
- PET	g	15.0		
- recycled PET		30%		
- aluminium	g			12.9
- recycled aluminium				50%
label	g	**0.2**	**1.0**	**0.4**
- paper	g		1.0	
- PP	g	0.2		
- lacquer	g			0.4
closure	g	**3.0**	**1.5**	**2.7**
- HDPE	g	3.0		
- aluminium	g		1.5	2.7
- recycled aluminium				50%
secondary packaging (sum)[2]	g	**14.0**	**90.0**	**160.0**
- shrink pack (LDPE)	g	14.0		
- tray/box/paper handle	g		90.0	160.0
tertiary packaging (sum)[3]	g	**26920**	**27270**	**25170**
pallet (wood)	g	25000	25000	25000
type of pallet	-	EURO	EURO	EURO
number of use cycles		25	25	25
cardboard layer	g	350	350	350
number of cardboard layers		5	6	0
stretch foil (per pallet) (LDPE)	g	170	170	170
pallet configuration				
bottles/cans per sec. packaging	pc	8	20	24
sec. packaging units per layer	pc	27	8	9
layers per pallet	pc	6	7	7
bottles per pallet	pc	1296	1120	1512

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

Table 26: Packaging specifications for regarded alternative systems in the segment *Liquid Food Portion Pack (ambient)*

		LIQUID FOOD PORTION PACK AMBIENT	
	Unit	Glass Jar 1	Steel can 1
volume	ml	390	390
geographic scope	-	Europe	Europe
chilled / ambient	-	ambient	ambient
clear / opaque	-	clear	-
primary packaging (sum)[1]	g	**220.0**	**59.0**
bottle/body (sum)	g	**214.0**	**50.0**
- glass	g	214.0	
- tin plate	g		50.0
label	g	**1.0**	**2.0**
- paper	g	1.0	2.0
closure	g	**5.0**	**7.0**
- tin plate	g	5.0	7.0
secondary packaging (sum)[2]	g	**27.0**	**56.0**
- tray	g	27.0	56.0
tertiary packaging (sum)[3]	g	**25170**	**25170**
pallet (wood)	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles		25	25
cardboard layer	g	350	350
number of cardboard layers		0	0
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
jars/cans per sec. packaging	pc	12	12
sec. packaging units per layer	pc	6	6
layers per pallet	pc	12	12
bottles per pallet	pc	864	864

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

2.3 End-of-life

For each packaging system regarded in the study, a base scenario is modelled and calculated assuming an average recycling rate for post-consumer packaging for the European market. The applied recycling quotas are based on published quotas. The recycling quota represents the actual amount of material undergoing a material recycling process after sorting took place. The collection quota represents the amount of material before sorting. It is calculated from the recycling quota. The applied quotas and the related references are given in Table 27.

Table 27: Applied collection and recycling quotas for beverage and liquid food cartons, plastic and glass bottles, pouches and cans:

Geographical scope	Packaging system	Collection quota	Material recycling quota	Reference year	Source
Europe	Beverage and liquid food carton	53%	48%	2017	[ACE 2019]
	PET bottles	58%	52%[1]	2017	[PETCORE 2018]
	HDPE bottles[2]	46%	41%[1]	2016	[PlasticsEurope 2018]
	Glass bottles/jars	75%	74%	2016	[FEVE 2019]
	SUP	0%	0%	2011	[WRAP 2011]
	Aluminium cans	77%	74%	2015	[European Aluminium 2018]
	Steel cans	84%	81%	2017	[APEAL 2019]

1 white plastic bottles are not materially recycled but undergo thermal treatment in cement kilns (See section 3.14)

2 rates for all plastic packaging material

The remaining part of the post-consumer packaging waste is modelled and calculated according to the average disposal split between landfilling and incineration (MSWI) in Europe. The applied quotas and the related references are given in Table 28. The material treated in MSWI is energetically recovered.

Table 28: Applied disposal split for landfilling and incineration

Geographical scope	MSWI/Landfill	Quota	Reference year	Source
Europe	MSWI	54 %	2016	calculated based on [Eurostat 2019]
	Landfill	46 %		

The following simplified flow charts Figure 12 to Figure 19 illustrate the applied end-of-life model of beverage and liquid food cartons, PET and HDPE bottles, glass bottles and jars, SUP, aluminium cans as well as steel cans. The percentage going into the recycling path in each flowchart corresponds to the material recycling quotas in Table 27.

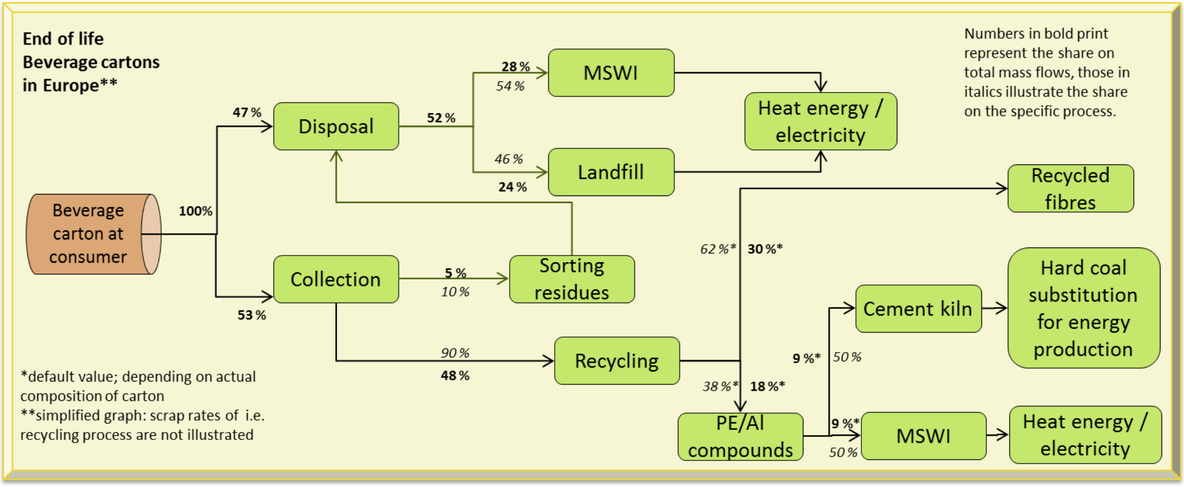


Figure 12: Applied average end-of-life quotas for beverage and liquid food cartons in Europe

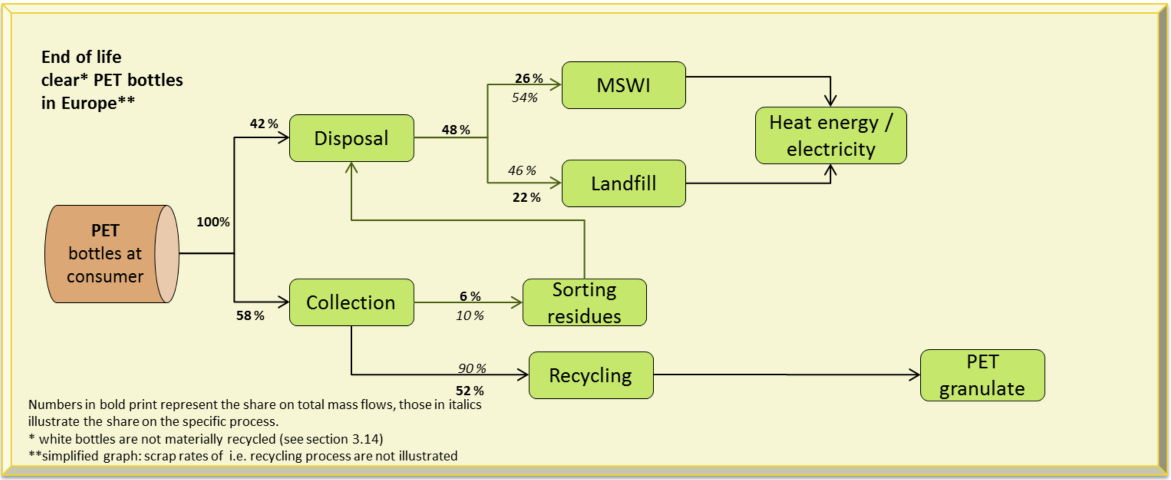


Figure 13: Applied average end-of-life quotas for clear PET bottles in Europe

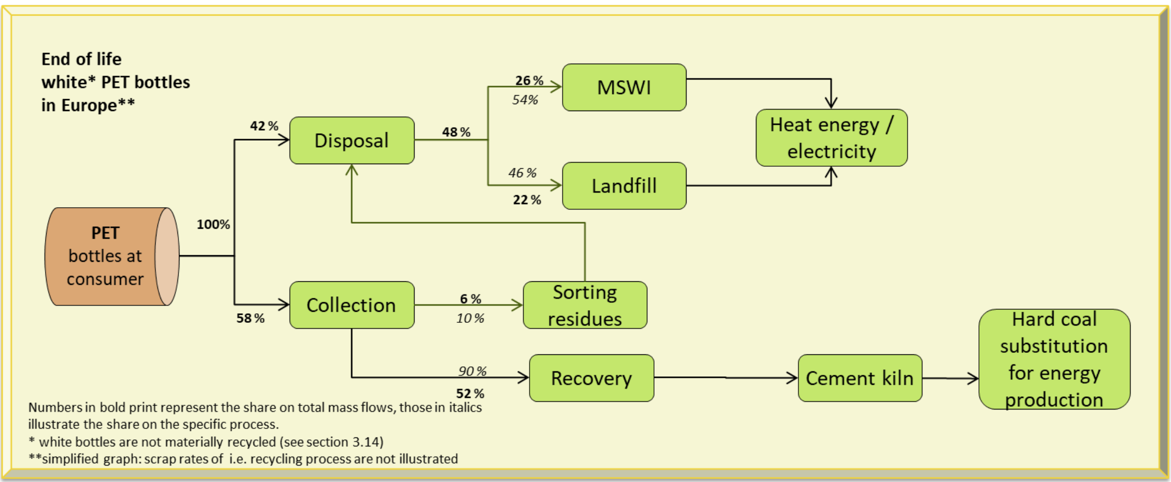


Figure 14: Applied average end-of-life quotas for white PET bottles in Europe

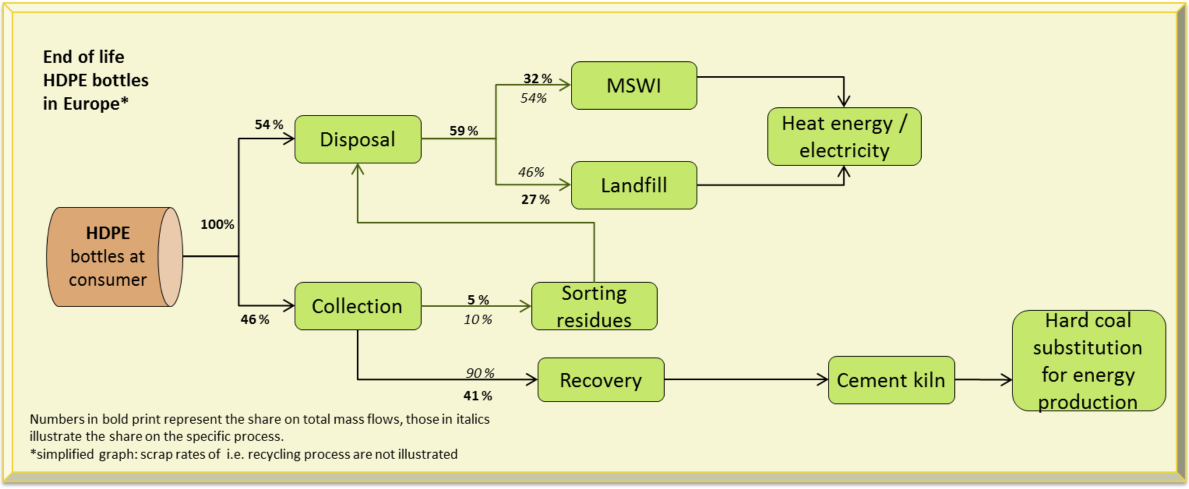


Figure 15: Applied average end-of-life quotas for HDPE bottles in Europe

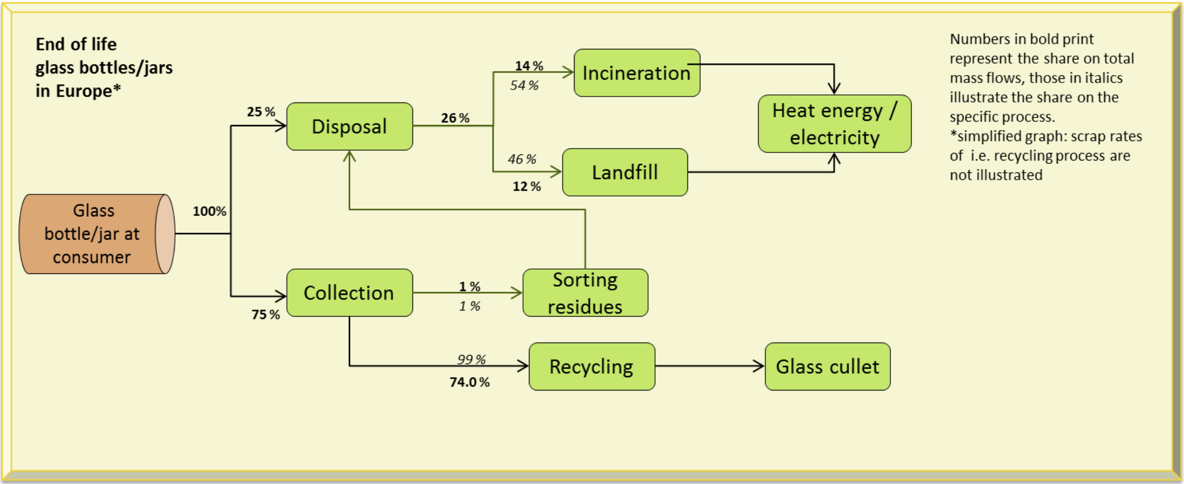


Figure 16: Applied average end-of-life quotas for glass bottles/jars in Europe

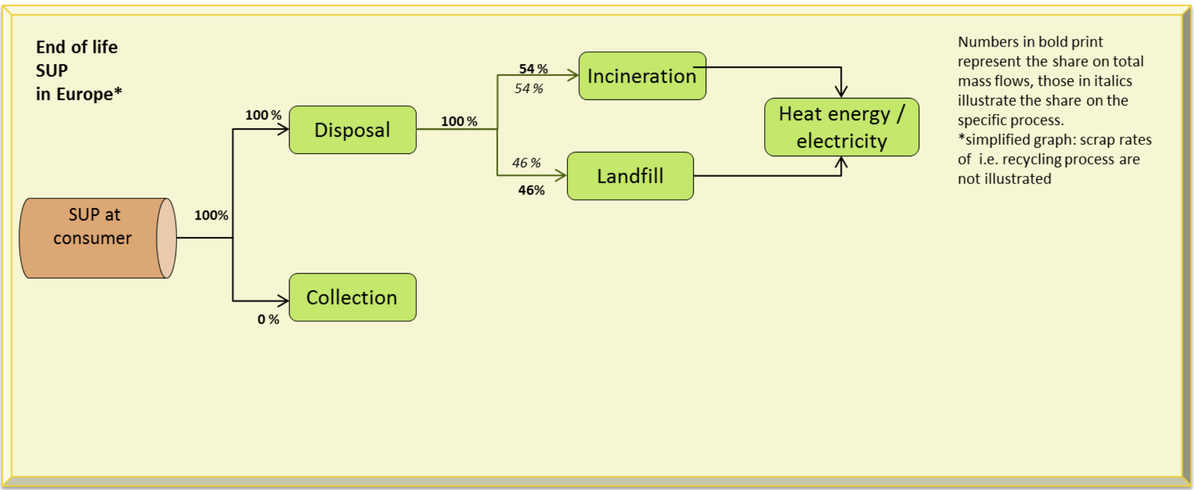


Figure 17: Applied average end-of-life quotas for SUP in Europe

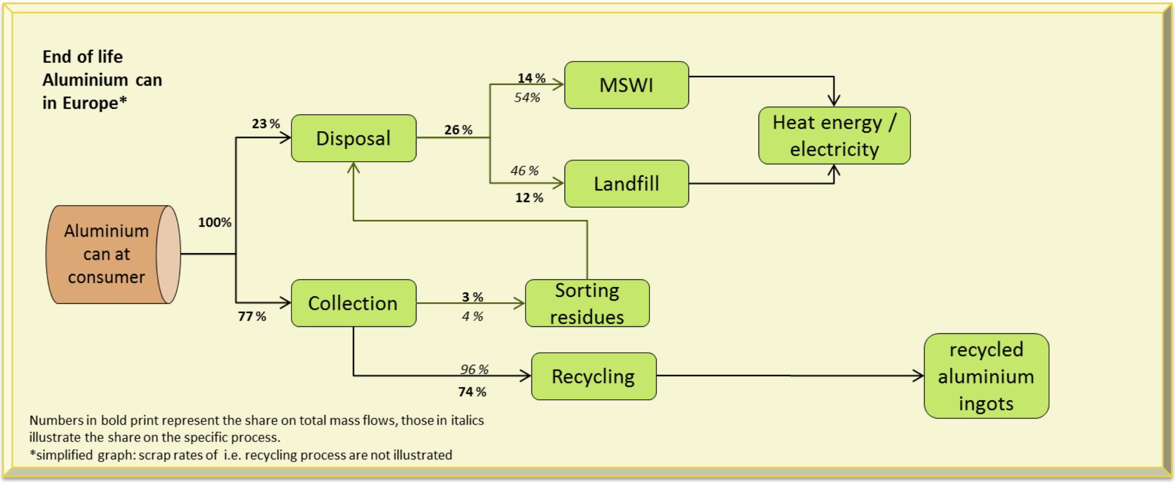


Figure 18: Applied average end-of-life quotas for aluminium cans in Europe

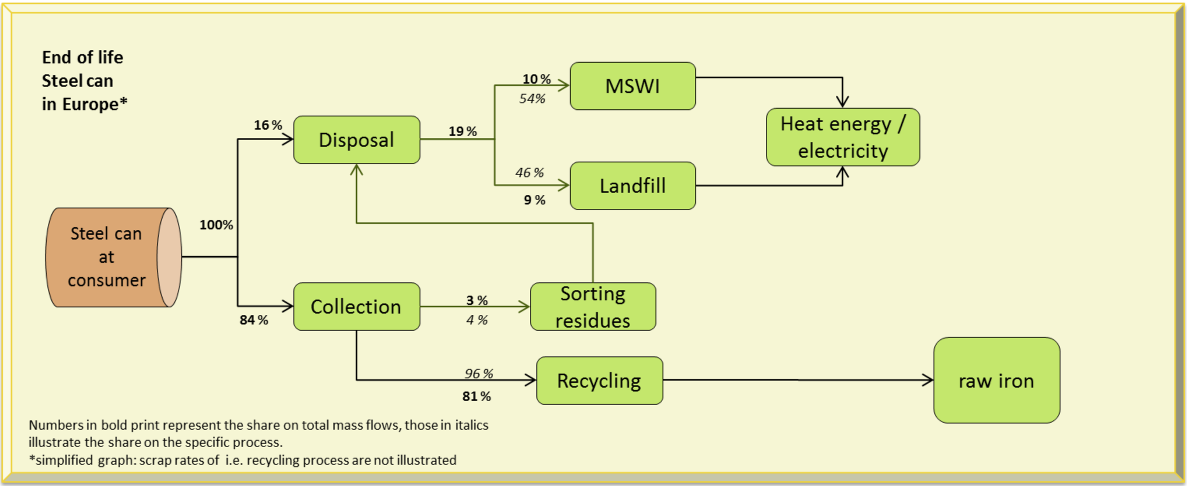


Figure 19: Applied average end-of-life quotas for steel cans in Europe

2.4 Scenarios

2.4.1 Base scenarios

For each of the studied packaging systems 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 segment and volume group. 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 calculated for each packaging system:

- with a system allocation factor of 50 %
- with a system allocation factor of 100 %

2.4.2 Scenario variants regarding plant-based plastics in HDPE bottles

The study includes beverage cartons containing plant-based plastic materials. In order to take also plant-based material in plastic bottles into account, scenario variants are calculated for the packaging systems listed in Table 29. In these analyses, the allocation factor applied for open-loop-recycling is 50%.

Table 29: Scenario variants: plant-based PE in HDPE bottles

Base packaging system	Scenario variant	Comparing packaging systems	Geographic scope	Volume	Segment
HDPE bottle 1	100% plant-based PE	TR OSO 34 TR OSO 34 plant-based TT O38	Europe	1000 mL	Dairy, Family Pack, Chilled
HDPE bottle 2	100% plant-based PE	TBA LC30 TBA LC30 plant-based	Europe	1000 mL	Dairy, Family Pack, Ambient
HDPE bottle 3	100% plant-based PE	TB Mid Straw	Europe	200 mL	Dairy, Portion Pack, Ambient

2.4.3 Scenario variants regarding recycled content in PET bottles

PET bottles in the base scenarios are modelled with their specific share of recycled PET (rPET). As PET bottles could be produced with 100% recycled content, scenario variants are calculated for the packaging systems listed in Table 30. Additionally to the base scenarios the PET bottles are calculated with a recycled content of 30% and 100%. 30% is chosen as it is a common rate for PET bottles. 100% is chosen as the maximum possible. The results are shown in break-even graphs with a recycled content ranging from the value of the base scenario up to 100%. In these analyses, the allocation factor applied for open-loop-recycling is 50%.

Table 30: Scenario variants: recycled content in PET bottles

Base packaging system	Scenario variant	Comparing packaging systems	Geo-graphic scope	Volume	Segment
PET bottle 1	30% and 100% recycled PET	TR OSO 34 TR OSO 34 plant-based TT O38	Europe	1000 mL	Dairy, Family Pack, Chilled
PET bottle 2	30% and 100% recycled PET	TBA LC30 TBA LC30 plant-based	Europe	1000 mL	Dairy, Family Pack, Ambient
PET bottle 3	30% and 100% recycled PET	TBA Slim Helicap 23 TR MiniPlus TC 34	Europe	1000 ml	JNSD, Family Pack, Ambient
PET bottle 4	30% and 100% recycled PET	TPA Square StreamCap TT Midi C38 plant-based	Europe	500 ml	Water, Portion Pack, Ambient

2.4.4 Scenario variants regarding plastic bottle weight

To consider potential future developments in terms of weight of the plastic bottles, scenario variants with reduced bottle weight are performed for the packaging systems listed in Table 31. The results are shown in break-even graphs with bottle weights ranging from the value of the base scenario up to 30% weight reduction[1]. In these analyses the allocation factor applied for open-loop-recycling is 50%.

[1] technically possible bottle weight reduction based on expert judgment

Table 31: Scenario variants: reduced weight of plastic bottles

Base packaging system	Scenario variant	Comparing packaging systems	Geographic scope	Volume	Segment
HDPE bottle 1	10% and 30% reduced bottle weight	TR OSO 34 TR OSO 34 plant-based TT O38	Europe	1000 mL	Dairy, Family Pack, Chilled
HDPE bottle 2	10% and 30% reduced bottle weight	TBA LC30 TBA LC30 plant-based	Europe	1000 mL	Dairy, Family Pack, Ambient
HDPE bottle 3	10% and 30% reduced bottle weight	TB Mid Straw	Europe	200 mL	Dairy, Portion Pack, Ambient
PET bottle 1	10% and 30% reduced bottle weight	TR OSO 34 TR OSO 34 plant-based TT O38	Europe	1000 mL	Dairy, Family Pack, Chilled
PET bottle 2	10% and 30% reduced bottle weight	TBA LC30 TBA LC30 plant-based	Europe	1000 mL	Dairy, Family Pack, Ambient
PET bottle 3	10% and 30% reduced bottle weight	TBA Slim Helicap 23 TR MiniPlus TC 34	Europe	1000 ml	JNSD, Family Pack, Ambient
PET bottle 4	10% and 30% reduced bottle weight	TPA Square StreamCap TT Midi C38 plant-based	Europe	500 ml	Water, Portion Pack, Ambient

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. Table 32 gives an overview of important datasets applied in the current study. Primary data collected in 2019 for example for filling processes are not extrapolated for the end of the year as the data are based on machine consumption. All data used meet the general requirements and characteristics regarding data gathering and data quality as summarised in section 1.6.

Table 32: Overview on inventory/process datasets used in the current study

Material / Process step	Source	Reference period	primary / secondary data
Intermediate goods			
PP	Plastics Europe, published online April 2014	2011	secondary
HDPE	Plastics Europe, published April 2014	2011	secondary
LDPE	Plastics Europe, published April 2014	2011	secondary
Plant-based PE	[Braskem 2018]	2015	secondary
PET	Plastics Europe, published online June 2017	2015	secondary
PA6	Plastics Europe, last online retrieval in 2005	1999	secondary
Titanium dioxide	Ecoinvent V.3.4	2017	secondary
Carbon Black	Ecoinvent V.3.4	2011-2015	secondary
Tinplate	[World Steel 2018]	2014	secondary
Aluminium (primary)	EAA Environmental Profile report 2018 [EAA 2018]	2015	secondary
Aluminium sheet	EAA Environmental Profile report 2018 [EAA 2018]	2015	secondary
Aluminium foil	EAA Environmental Profile report 2013 [EAA 2013]	2010	secondary
Corrugated cardboard	[FEFCO 2015]	2014	secondary
Liquid packaging board	ifeu data, obtained from ACE [ACE 2012]	2009	secondary
Production			
BC converting	Tetra Pak	2017	primary
Glass bottle converting including glass production	UBA 2000 (bottle glass); energy prechains 2012	2000/2012	secondary
Preform production	Data provided by Tetra Pak, gathered in 2019	2019	primary
HDPE bottle production	Data provided by Tetra Pak, gathered in 2019	2019	primary

Material / Process step	Source	Reference period	primary / secondary data
Filling			
Filling of beverage and liquid food cartons	Data provided by Tetra Pak	2019	primary
Filling plastic bottles	Data provided by Tetra Pak, gathered in 2019, ifeu data obtained from various fillers SBM is included in data for PET bottles	2019	primary
Filling glass bottles	ifeu data obtained from various fillers	2012	primary
Recovery			
Beverage and liquid food carton recycling	ifeu database, based on data from various European recycling plants	2004	primary
PET bottle	ifeu database, data collected from different recyclers in Germany and Europe	2009	primary
HDPE bottle	ifeu database, data collected from different recyclers in Germany and Europe	2008	primary
Glass bottle	ifeu database, [FEVE 2006]	2004/2005	primary/ secondary
Aluminium can (post-consumer)	EAA Environmental Profile report 2013 [EAA 2013]	2010	secondary
Aluminium can (post-industrial)	EAA Environmental Profile report 2018 [EAA 2018]	2015	secondary
Steel can	ifeu database	2008	primary
Background data			
electricity production	ifeu database, based on statistics and power plant models	2015	secondary
Municipal waste incineration	ifeu database, based on statistics and incineration plant models	2008	secondary
Landfill	ifeu database, based on statistics and landfill models	2008	secondary
lorry transport	ifeu database, based on statistics and transport models, emission factors based on HBEFA 3.3 [INFRAS 2017].	2009	secondary
rail transport	[EcoTransIT 2016]	2016	secondary
sea ship transport	[EcoTransIT 2016]	2016	secondary

3.1 Plastics

The following plastics are used within the packaging systems under study:

- Polypropylene (PP)
- High density polyethylene (HDPE)
- Low density polyethylene (LDPE)
- Plant-based PE
- Polyethylene terephthalate (PET)
- Polyamide 6 (PA6)

3.1.1 Polypropylene (PP)

Polypropylene (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 represented 77% of PP production in Europe.

3.1.2 High Density Polyethylene (HDPE)

High density polyethylene (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 [Plastics Europe 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 2011 time period and were acquired from a total of 21 participating polymerisation units. The data set represented 68% of HDPE production in Europe (EU27+2).

3.1.3 Low Density Polyethylene (LDPE)

Low density polyethylene (LDPE) is manufactured in a high pressure process and contains a high number of long side chains. The present LCA study uses the eco-profile published on the website of Plastics Europe [Plastics Europe 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 2011 time period. Data were acquired from a total of 22 participating polymerisation units. The data set represent 72% of LDPE production in Europe (EU27+2).

3.1.4 Plant-based Polyethylene

All packaging systems analysed in this study, which contain plant-based Polyethylene (PE) are beverage carton systems. The only exceptions are the two sensitivity analyses with 100% plant-based HDPE bottles. The plant-based PE used by Tetra Pak in the regarded beverage carton systems is supplied by Braskem in Brazil. The PE is produced from ethanol based on sugar cane. The plant-based PE has the same characteristics as fossil-based PE. Therefore the same end of life applies to plant-based PE and fossil-based PE. The plant-based PE in this study shall not be mistaken with biodegradable plastics. This study uses two LCA datasets provided by Braskem, one for plant-based HDPE and one for plant-based LDPE [Braskem 2018]. In order to address co-products in the plant-based PE production, the LCA datasets used in this study use the approach of economical allocation. Credits for land use change have been excluded from the datasets as underlying assumptions and models are not known.

3.1.5 PET (polyethylene terephthalate)

Polyethylene terephthalate (PET) is produced by direct esterification and melt polycondensation of purified terephthalic acid (PTA) and ethylene glycol. The model underlying this LCA study uses the Eco-profile published on the website of Plastics Europe with a reference year of 2015 [Plastics Europe 2017], that represents the production in European PET plants. Data for foreground processes of PTA production are taken from the PTA eco-profile [CPME 2016] which is based on primary data from five European PTA producers covering 79% of the PTA production in Europe. The foreground process of ethylene glycol production is taken from the Eco-profile of steam cracker products [PlasticEurope 2012b]. For PET production data from 12 production lines at 10 productions sites in Belgium, Germany, Lithuania (2 lines), the Netherlands, Poland, Spain (4 lines) and United Kingdom (2 lines) supplied data with an overall PTA volume of 2.9 million tonnes – this represents 85% of the European production volume (3.4 million tonnes).

3.1.6 PA6 (polyamide)

Polyamide 6 is manufactured from the precursors benzene and hydroxylamine. The present LCA study uses the ecoprofile published on the website of Plastics Europe (data last calculated March 2005) and referring to the year 1999 [Plastics Europe 2005]. A more recent dataset is available provided by PlasticsEurope. However in this dataset ammonium sulphate is seen as a by-product of the PA6 production process of the PA6 pre-product caprolactam. This is the main production process for ammonium sulphate. Impacts of caprolactam production are allocated between caprocaltam and ammonium sulphate. "System expansion should only be used where there is a dominant, identifiable displaced product, and if there is a dominant, identifiable production path for the displaced product" [Plastics Europe 2019]. As basically all ammonium sulphate on the market is derived from the PA6 production to the view of the authors, this approach is not consistent. Also as other datasets of plastics, which are used alongside in this study, don't allocate side products. Unfortunately, no dataset applying another approach apart from the substitution approach is available.

3.2 Production of primary material for aluminium bars, aluminium sheet 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 [EEA 2018].

The data set for aluminium sheet covers the production of cold rolled steel starting from aluminium bars. It includes homogenization, hot rolling, cold rolling and annealing. The data set is based on 88% of the cold rolled steel production in 2015 [EEA 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 [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 prechains which are based on actual practice and are not an European average electricity mix.

3.3 Manufacture of tinplate

Data for the production of tinplate refer to the year 2014 and was provided by WORLD STEAL [WORLD STEAL 2018]. The data set is based on a weighted average site-specific data (gate-to-gate) of European steel producers whereas the electricity grid mix included in the data is country-specific. According to Word Steal the dataset represents about 95% of the annual European supply or production volume. A recycled content of approximately 2% is reported for tinplate.

3.4 Glass and glass bottles

The data used for the manufacture are data acquired by Bundesverband Glasindustrie e.V. (BVGlas) and represents the German production in 2012. The energy consumption and the emissions for the glass manufacturing process are determined by the composition of the raw mineral material and in particular by the scrubbing and the fossil energy resource used for the direct heating. The applied electricity prechains also represent the situation in 2012. A newer 2016 data set from FEVE [Bettens & Bagard 2016] is not applied, because of its methodological approach of substituting gas, coal and oil based thermal energy on the market with sold heat surplus of the glass production process. As the dataset used in this study has lower impacts as the FEVE dataset from 2016, a conservative approach in the perspective of the beverage and liquid food carton systems is applied. As the dataset represents the German glass production the representativeness on the European market is not known.

3.5 Production of liquid packaging board (LPB)

The production of liquid packaging board (LPB) was modelled using data gathered from all 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 2009. 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 for the process chemicals used from ifeu´s database and Ecoinvent 2.2 (same datasets as in Ecoinvent 3.1), including a forestry model to calculate inventories for this sub-system. Energy required is supplied by electricity as well as by on-site energy production by incineration of wood and bark. The specific energy sources were taken into account.

3.6 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2015 [FEFCO 2015] were used. More specifically, the data sets for the manufacture of 'Kraftliners' (predominantly based on primary fibres), 'Testliners' and 'Wellenstoff' (both based on waste paper) 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 2014. All corrugated board and cardboard trays are assumed to be sourced from European production. The data represents about 70% of the European cardboard production.

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated cardboard trays. According to [FEFCO 2015] this fraction on average is 12% in Europe. Due to a lack of more specific information this split was also used for the present study.

3.7 Titanium dioxide

Titanium dioxide (TiO_2) can be produced via different processes. The two most prevalent are the chloride process and the sulfate process. For the chloride process, the crude ore is reduced with carbon and oxidized with chlorine. After distillation of the resulting tetrachloride it is re-oxidized to get pure titanium dioxide. In the alternative sulfate process, the TiO_2 is won by hydrolysis from Ilmenite, a titanium-iron oxide, which leads to a co-production of sulfuric acid.

The data used in this study are a mix of both production processes and are taken from Ecoinvent database 3.4 The data refers to the years 1997 – 2017 and is representative for Europe.

3.8 Carbon Black

Carbon black is mostly produced by an oil-furnace process, a partial combustion process of liquid aromatic residual hydrocarbons. [Ecoinvent 3.4, Voll & Kleinschmitt 2010, Dannenberg & Paquin 2000].

The data used in this study is based on the ecoinvent 3.4 database.

3.9 Converting

3.9.1 Converting of beverage and liquid food cartons

The manufacture of composite board was modelled using European average converting data from Tetra Pak that refer to the year 2017. The converting process covers the lamination of LPB with LDPE and aluminium including, cutting and packing of the composite material. The packaging materials used for shipping of carton sleeves to fillers are included in the model as well as the transportation of the package material.

Process data provided by Tetra Pak were then coupled with required prechains, such as process heat, grid electricity and inventory data for transport packaging used for shipping the coated composite board to the filler.

3.9.2 PET preform and bottle production

The production of PET bottles is usually split into two different processes: the production of preforms from PET granulate, including drying of granulate, and the stretch-blow-moulding (SBM) of the actual bottles. While energy consumption of the preform production strongly correlates with preform weight one of the major factors influencing energy consumption of SBM is the volume of the produced bottles. Data for the SBM and preform production were provided by Tetra Pak and crosschecked with the internal ifeu database.

3.9.3 HDPE bottle production

Unlike PET bottle production HDPE bottle production is not split into two different processes. Blow moulding takes place at the same site as the extrusion of HDPE. Data for these converting processes were provided by Tetra Pak and crosschecked with the internal ifeu database.

3.9.4 Converting of aluminium can

Data for the converting step from aluminium sheets to aluminium cans and aluminium closures are taken from the internal ifeu data base and are based on confidentially collected datasets from two European beverage can producers in 2009.

3.9.5 Converting of steel can

Data gathering for the manufacturing of 3-piece tinplate food cans has been attempted within this study, but unfortunately without success. Thus older food can manufacturing data had to be used. The converting dataset was taken from the literature [BUWAL 1998] and related prechains were taken in their most current version from the ifeu internal database. The process data refer to the year 1996. According to APEAL [APEAL 2008], the BUWAL converting process dataset is the only available food can converting dataset for the time being.

3.10 Closure production

The closures made of fossil and plant-based polymers and fossil based polypropylene are produced by injection moulding. The data for the production were taken from ifeu's internal database and are based on values measured in Germany and other European countries and data taken from literature. The process data were coupled with required prechains such as the production of PE and grid electricity of the relevant country of manufacturing.

3.11 Filling

Filling processes are similar for beverage and liquid food cartons and alternative packaging systems regarding material and energy flows. The respective data for beverage and liquid food cartons were provided by Tetra Pak in 2019 distinguishing between the consumption of electric and thermal energy as well as of water and air demand. Those were cross-checked by ifeu with data collected for earlier studies. The data for the filling of plastic bottles was provided by Tetra Pak and crosschecked with the internal ifeu database. The data for PET bottles includes the electricity demand for stretch blow moulding. For the filling of glass bottles, data collected from various fillers (confidential) with a reference year of 2011 has been used. The data were still evaluated to be valid for 2019, as filling machines and technologies have not changed since then. Filling data for the analysed aluminium can is based on the ifeu internal database. Filling data for the analysed steel can were provided by Tetra Recart based on machine consumption data specifications referring to the year 2005. Within this study the same data were used.

3.12 Transport settings

Table 33 provides an overview of the transport settings (distances and modes) applied for packaging materials. Data were obtained from Tetra Pak, ACE 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 suppliers.

Table 33: Transport distances and means: Transport defined by distance and mode [km/mode]

Packaging element	Material producer to converter Distance [km]	Converter to filler Distance [km]
HDPE, LDPE, PP, PET granulate for all packages	200 / road*	
Plant-based PE	10800 / sea* 500 / road*	
Aluminium	250 / road*	
Paper board for composite board	200 / road** 1300 / sea** 400 / rail**	
Cardboard for trays	primary fibres: 500 / sea, 400 / rail, 250 / road** secondary fibres: 300/road**	
Wood for pallets	100 / road*	
LDPE stretch foil	500/road (material production site = converter)*	
Trays		500 / road*
Pallets		100 / road*
Converted carton rolls		700 / road*

*Assumption/Calculation; **taken from published LCI reports

3.13 Distribution of filled packs from filler to point of sale

Table 34 shows the applied distribution distances in this study. Distribution centres are the places where the products are temporarily stored and then distributed to the different point of sales (i.e. supermarkets). Distances for the segments dairy and JNSD are based on a LCA study on packaging for beverages on the European market for ACE from 2018 [ifeu 2018]. For the segment water the same distances as for JNSD are assumed. Regarding liquid food, according to information provided by Tetra Pak in 2013, canned tomatoes are exclusively filled in the Parma region in Italy and then transported to the point-of sale in the different countries. The applied distances for the segment liquid food are based on canned tomatoes as applied in the study for Tetra Recart in 2013 [ifeu 2013].

It is assumed, that not the full return distance is driven with an empty load, as lorries and trains load other goods (outside the system boundaries of this study) for at least part of their journey. As these other goods usually cannot be loaded at the final point of the beverage packaging delivery it is assumed that a certain part of the return trip is made without any load and so has to be allocated to the distribution system. No primary data is available on average empty return distances. For this reason an estimation of 30% of the delivery distance is calculated as an empty return trip. A minimum return trip of 60km is assumed in cases the delivery distance is lower than 180km. If distances are lower than 60 km, the same distance is applied for the empty return trip. This is only valid for the distribution steps to the distribution centres. Usually no utilisation of lorries on their return trips from the point of sale to the warehouse is possible as the full return trip to the warehouse is attributed as an empty return trip to the examined system.

Table 34: Distribution distances in km for the examined packaging systems

	Distribution distance [km] as applied in this study			
	Distribution Step 1		Distribution step 2	
segment	**filler > distribution center** (delivery)	**distribution center > filler** (return trip)	**distribution center > POS** (delivery)	**POS > distribution center** (return trip)
Dairy chilled	150	45	75	75
Dairy ambient	300	90	100	100
JNSD	300	90	100	100
Water	300	90	100	100
Liquid food	1500	450	100	100

3.14 Recovery and recycling

Beverage and liquid food cartons

Beverage and liquid food cartons which are collected and sorted are subsequently sent to a paper recycling facility for fibre recovery. The secondary fibre material is used e.g. as a raw material for cardboard. A substitution factor 0.9 is applied. Rejects, in term of plastics and aluminium compounds undergo thermal treatment. In the European scope for 50% of the rejects, energy is recovered in municipal solid waste incineration (MWSI) plants and for the other 50% hard coal is substituted in cement kilns. The shares of 50% are based on [ifeu 2018]. 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.

Plastic bottles

Plastic bottles which are collected and sorted are usually followed by a regranulation process. Ultimately the different plastics are separated by density (PET, PE, PP). They are shredded to flakes, other plastic components are separated and the flakes are washed before further use. The data used in the current study is based on ifeu's internal database based on data from various recycling plants.

White opaque PET plastic bottles used for the packaging of dairy products are not sorted into specific recycling fractions. A mix of opaque bottles into the recycling stream of clear bottles reduces the quality of the produced recycled plastic. Therefore opaque PET bottles are removed from the recycling stream of a large amount of recycling plants [EPBP 2018]. Therefore in the model of this study white plastic bottles end up in a mixed plastic fraction and undergo thermal treatment (cement kiln) instead of regranulation.

Stand up pouches (SUP)

As SUPs are currently not recycled no recycling process for SUP is included the study.

Glass bottles and jars

The glass of collected glass bottles and jars is shredded and the ground glass serves as an input in the glass production, the share of external cullet is modelled as 69.5%. The data used in the current study is drawn from ifeu's internal database, and furthermore information received from 'The European Container Glass Federation' [FEVE 2006]. The reference period is 2012. Process data are coupled with required prechains and the market related electricity grid mix.

Aluminium cans

The dataset for recycling of post-consumer aluminium cans is based on the recycling process for end-of-life aluminium products which includes the preparation of post-consumer scrap [EEA 2013]. The dataset for recycling of post-industrial aluminium scrap is based on the remelting process for scrap coming directly from the fabricators. This dataset does not include scrap preparation [EEA 2018].

Steel cans

Steel cans, as a traditional food package, are sorted into a steel fraction in sorting plants. The sorted post-consumer steel packaging waste fraction is then assumed to substitute pig iron in the steelmaking process (without further pre-treatment). It is implemented in the life cycle model partly as closed-loop and partly as open-loop recycling with the criterion being the scrap input per ton steel product (as it is specified in the steel inventory dataset). Data are taken from the ifeu database based on collected data from the European Steel industry. If the recovery rate of steel packaging is higher than what is required to cover the defined scrap input the remaining post-consumer steel waste is assumed to leave the steel can system. In the model, it substitutes pig iron for a steelmaking process in a subsequent product system (Substitution factor 1.0).

3.15 Background data

3.15.1 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' [INFRAS 2017]. 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. Data in this study refer to lorries with a loading capacity of 23 tonnes. The emission factors used in this study refer to the year 2016.

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. Wherever cooling during transport is required, additional fuel consumption is modelled accordingly based on data from ifeu's internal database.

Ship transport

The data used for the present study represent freight transport with an overseas container ship (10.5 t/TEU[1]) and an utilisation capacity of 70% [EcoTransIT World 2016]. 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

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 3.15.2).

3.15.2 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 master network for grid power modelling maintained and annually updated at ifeu as described in [ifeu 2013].

[1] Twenty-foot Equivalent Unit

It is based on national electricity mix data by the International Energy Agency (IEA)[1]. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2015 for the production of LPB and the European mix of energy suppliers in the year 2015 for all other processes. The applied shares of energy sources to the related market are given in Table 35.

Table 35: Share of energy source to specific energy mix, reference year 2015.

geographic scope Energy source	EU 28	Sweden	Finland
Hard coal	14.11%	0.23%	7.34%
Brown coal	10.32%	0.00%	0.00%
Fuel oil	1.65%	0.15%	0.30%
Natural gas	16.51%	0.67%	12.65%
Nuclear energy	26.70%	33.85%	33.66%
Hydropower/Wind/Solar /Geothermal	24.50%	57.99%	29.14%
Hydropower	45.74%	82.15%	87.77%
Wind power	40.42%	17.75%	12.18%
Solar energy	13.01%	0.10%	0.04%
Geothermal energy	0.83%	0.00%	0.00%
Biomass energy	4.84%	5.36%	15.69%
Waste	1.35%	1.75%	1.23%

3.15.3 Municipal waste incineration

The electrical and thermal efficiencies of the municipal solid waste incineration plants (MSWI) are shown in Table 36.

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

Table 36: Electrical and thermal efficiencies of the incineration plants for Europe.

Geographic Scope	Electrical efficiency	Thermal efficiency	Reference period	Source
Europe	12%	29%	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, ([EC 2000] Council Directive 2000/76/EC).

The electric energy generated in MSWI plants is assumed to substitute market specific grid electricity. Thermal energy recovered in MSWI plants is assumed to serve as process heat. The latter mix of energy sources represents an European average. According to the knowledge of the authors of this study, official data regarding this aspect are not available.

3.15.4 Landfill

The landfill model accounts for the emissions and the consumption of resources for the deposition of domestic wastes on a sanitary landfill site. As information regarding an average landfill standard in specific countries is hardly 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 and liquid food carton material on a landfill. Empirical data regarding degradation rates of laminated 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:

In this study the 100 years perspective is applied. It is assumed that 50% of methane generated is actually recovered via landfill gas capture systems. This assumption is based on data from National Inventory Reports (NIR) under consideration of different catchment efficiencies at different stages of landfill operation. The majority of captured methane is used for energy conversion. The remaining share is flared.

Regarding the degradation of the carton board under landfill conditions, it is assumed that it behaves like coated paper-based material in general. According to [Micales and Skog 1997], 30% of paper is decomposed anaerobically on landfills.

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.

3.15.5 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 industry 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]

4 Results

In this section, the results of the examined packaging systems for Europe are presented separately for the different categories in graphic form.

The following individual life cycle elements are shown in sectoral (stacked) bar charts

- production and transport of glass including converting to bottle (**'Glass'**)
- production and transport of PET, HDPE including additives, e.g. carbon black for the body of plastic bottles, composite material for SUPs, aluminium and steel for can bodies (**'Plastic/Alu/Steel for body'**)
- production and transport of liquid packaging board **('LPB')**
- production and transport of plastics and additives for beverage and liquid food carton **('plastics for sleeve')**
- production and transport of aluminium & converting to foil for beverage and liquid food cartons **('aluminium foil for sleeve')**
- converting processes of cartons, plastic bottles, SUP and cans **('converting')**
- production, converting and transport of closures, tops, straws and labels and their base materials **('top, closure & label')**
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink wrap and corrugated cardboard trays **('transport packaging')**
- filling process including packaging handling **('filling')**
- retail of the packages from filler to the point-of-sale including cooling during transport if relevant **('distribution')**
- sorting, recycling and disposal processes **('recycling & disposal')**
- CO_2 emissions from incineration of plant-based and renewable materials **('CO_2 reg. (EOL)')**; in the following also the term regenerative CO_2 emissions is used
- Uptake of athmospheric CO_2 during the plant growth phase (**'CO_2-uptake'**)

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 burdens of the substituted material. Following the ISO standard's recommendation on subjective choices, both, the 50% and 100% allocation approach are used for the recycling and recovery as well as crediting procedure to verify the influence of the allocation method on the final results. (see section 1.7). For each segment the results are shown for the allocation factor 50% and allocation factor 100%.

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

- credits for material recycling **('credits material')**
- credits for energy recovery (replacing e.g. grid electricity) **('credits energy')**

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
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 (first stacked bar with positive values)
- credits given for secondary products leaving the system and CO_2 uptake (second stacked bar with negative values)
- net results as a results of the substraction of credits from overall environmental burdens (grey bar)

All category results refer to the primary and transport packaging material flows required for the delivery of 1000 L beverage and liquid food to the point of sale including the end-of-life of the packaging materials.
The results for *water use* are shown on the inventory level. Due to the lack of mandatory information to assess the potential environmental impact, water scarcity cannot be assessed on LCIA level within this study. However, the use of freshwater is included in the inventory categories. A differentiation between process water, cooling water and water, unspecified is made. However, it includes neither any reference to the origin of this water, nor to its quality at the time of output/release. The respective results in this category are therefore of mere indicative nature and are not suited for conclusive quantitative statements related to either of the analysed packaging systems.

<u>A note on significance:</u> For studies intended to be used in comparative assertions intended to be disclosed to the public ISO 14044 asks for an analysis of results for sensitivity and uncertainty. It's often not possible to determine uncertainties of datasets and chosen parameters 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. To define the significance of differences of results an estimated significance threshold of 10% is chosen. This can be considered a common practice for LCA studies comparing different product systems. This means differences ≤ 10% are considered as insignificant.

4.1 Results allocation factor 50%; DAIRY FAMILY PACK CHILLED

4.1.1 Presentation of results DAIRY FAMILY PACK CHILLED

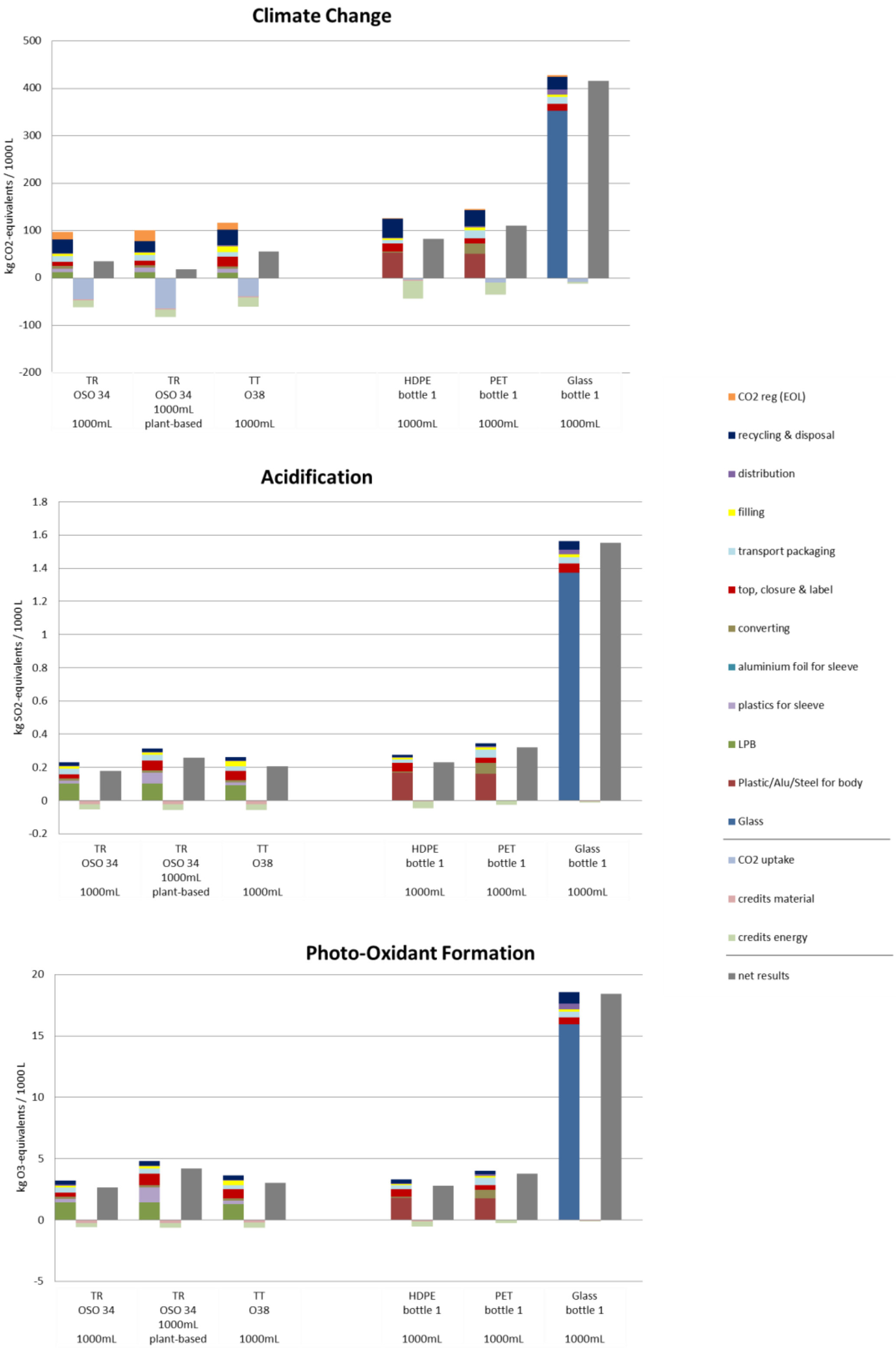


Figure 20: Indicator results of segment DAIRY FAMILY PACK CHILLED, allocation factor 50% (Part 1)

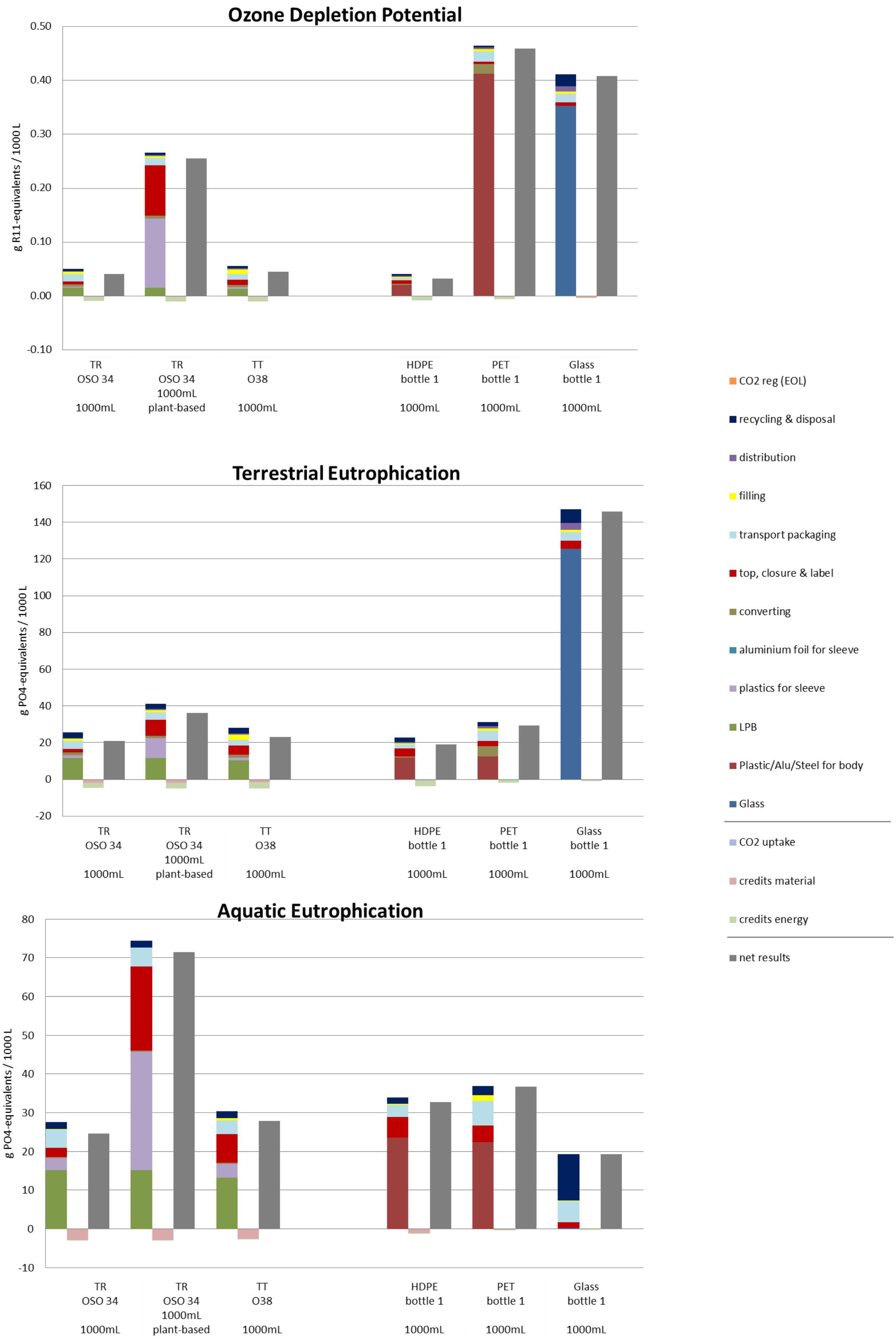


Figure 21 Indicator results of **segment DAIRY FAMILY PACK CHILLED**, allocation factor 50% (Part 2)

Figure 22: Indicator results of **segment DAIRY FAMILY PACK CHILLED**, allocation factor 50% (Part 3)

Figure 23: Indicator results of segment DAIRY FAMILY PACK CHILLED, allocation factor 50% (Part 4)

Table 37: Category indicator results per impact category of segment DAIRY FAMILY PACK CHILLED - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		TR OSO 34 1000mL	TR OSO 34 plant-based 1000mL	TT O38 1000mL		HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change [kg CO_2-e/1000 L]	Burdens	80.93	78.36	101.64		124.61	142.65	424.44
	CO2 (reg)	16.56	22.13	14.45		1.18	3.08	3.01
	Credits	-16.92	-18.00	-20.96		-39.85	-25.55	-4.19
	CO2 uptake	-44.60	-63.78	-38.93		-2.92	-9.53	-7.62
	net results	35.96	18.71	56.21		83.01	110.65	415.64
Acidification [kg SO_2-e/1000 L]	Burdens	0.23	0.31	0.26		0.28	0.34	1.56
	Credits	-0.05	-0.06	-0.06		-0.05	-0.02	-0.01
	Net results	0.18	0.26	0.21		0.23	0.32	1.55
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	3.22	4.80	3.65		3.30	4.02	18.54
	Credits	-0.58	-0.62	-0.62		-0.51	-0.25	-0.12
	Net results	2.64	4.18	3.03		2.78	3.76	18.42
Ozone Depletion [g R11 e/1000 L]	Burdens	0.05	0.27	0.06		0.04	0.46	0.41
	Credits	-0.01	-0.01	-0.01		-0.01	-0.01	0.00
	Net results	0.04	0.26	0.05		0.03	0.46	0.41
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	25.42	41.12	28.06		22.72	31.19	146.95
	Credits	-4.54	-4.83	-4.83		-3.80	-1.96	-0.96
	Net results	20.89	36.29	23.22		18.91	29.23	145.99
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	27.54	74.43	30.45		33.96	36.90	19.35
	Credits	-2.93	-2.93	-2.61		-1.16	-0.20	-0.10
	Net results	24.61	71.49	27.84		32.81	36.70	19.25
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	220.73	341.98	252.18		250.59	313.95	1538.69
	Credits	-48.05	-51.01	-50.88		-40.44	-21.24	-10.71
	Net results	172.68	290.98	201.30		210.15	292.71	1527.98
Total Primary Energy [GJ/1000 L]	Burdens	1.98	1.97	2.49		3.08	3.06	5.61
	Credits	-0.52	-0.55	-0.55		-0.56	-0.31	-0.07
	Net results	1.46	1.42	1.94		2.52	2.75	5.54
Non-renewable Primary Energy [GJ/1000 L]	Burdens	1.28	0.92	1.85		2.99	2.85	5.40
	Credits	-0.28	-0.30	-0.33		-0.54	-0.30	-0.07
	Net results	1.00	0.62	1.52		2.45	2.56	5.33
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	42.27	32.16	62.94		298.26	146.55	415.56
	Credits	-8.61	-9.24	-10.14		-16.52	-9.62	-4.42
	Net results	33.67	22.93	52.80		281.74	136.93	411.14
Use of Nature [m²e*year/1000 L]	Burdens	24.20	38.16	21.01		0.47	3.13	3.12
	Credits	-4.15	-4.16	-3.68		-0.04	-0.03	-0.02
	Net results	20.05	34.01	17.33		0.43	3.10	3.11
Water use [m³/1000 L]	water cool	1.41	1.37	1.80		1.75	3.45	2.05
	water process	1.89	1.88	1.98		0.40	1.05	0.28
	water unspecified	0.47	0.60	0.50		0.70	1.02	0.43

4.1.2 Description and interpretation

Beverage carton systems (specifications see section 2.2.1)

For the beverage carton systems considered in the DAIRY FAMILY PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the beverage carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (20%-55%) and 'Use of Nature' (57%-91%). It is also relevant regarding 'Photo-Oxidant Formation' (30%-45%) 'Acidification' (33%-45%), 'Terrestrial Eutrophication' (28%-46%), 'Particulate Matter' (29%-45%) and also the consumption of 'Total Primary Energy' (31%-45%). Regarding 'Climate Change' the production of LPB is responsible for only 10%-13% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The chilled beverage cartons in this segment do not contain aluminium foil. Therefore the step 'aluminium foil for sleeve' shows no burdens.

The production of 'plastics for sleeve' of the beverage cartons with fossil based plastics shows considerable burdens in most impact categories (up to 23%). These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The exceptions are climate change and the inventory categories 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)', where plastics and LPB contribute about the same. If 'plastics for sleeve' contains plant-based plastics, this life cycle step plays a major role (21%-49%) for the overall burdens in all categories apart from 'Climate Change' (9%), 'Cumulative Raw material Demand (abiotic)' (11%), 'Non-renewable Primary Energy' (8%) and 'Total Primary Energy' (14%).

The life cycle step 'top, closure & label' for TR cartons with fossil based plastics contributes from a small up to a considerable amount in almost all impact categories (0%-27%). In case the plastics used for 'top, closure & label' are plant-based, the results (up to 35% of the total burdens) are considerably higher than cartons with fossil based plastics in all categories except 'Climate Change', 'Cumulative Raw material Demand (abiotic)', 'Total Primary Energy Demand' and 'Non-renewable Primary Energy'. In case of the TT carton this life cycle step contributes to a substantial share in almost all impact categories (1%-45%).

The reason for the big influence of plant-based plastics on all impact categories apart from 'Climate Change' is the high energy demand, and the cultivation of sugar cane. The latter is reflected especially in the impact category 'Ozone Depletion Potential'. This is due to the field emissions of N2O from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of plant-based PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'.

The 'converting' process generally plays a minor role (0%-10%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show from small to considerable impacts in most categories (6%-22%). The exception is 'Ozone Depletion Potential' for the cartons with fossil based plastics. In these cases 'transport packaging' has a higher share of 19%-28% of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle step 'filling' shows only small shares of burdens (up to 9%) for all TR beverage carton systems in all impact categories. In case of the TT beverage carton system the shares are higher (up to 15%) due to the additional moulding process of the top.

The life cycle step 'distribution' shows only minor burdens in all impact categories for all beverage carton systems (max. 3%).

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact category 'Climate Change' (23%-29%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. In case of beverage cartons these derive mainly from the incineration of plant-based plastics and paper. They play an important role (12%-22%) for the results of all beverage carton systems in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal' they represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-27% of the total burdens. Material credits from material recycling are lower (1%-17%). Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section1.7.2)

Plastic bottles (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY FAMILY PACK segment, the biggest part of the environmental burdens is also caused by the production of the base materials of the bottles in most impact and inventory categories. In case of 'Ozone Depletion Potential' the main contributor to the high impacts is methyl bromide which is emitted in the production process for purified terephthalic acid (PTA) which is a pre-product of PET.

The 'converting' process shows for the PET bottle in this segment a small to minor share of burdens (up to 19%) in most categories apart from 'Aquatic Eutrophication', for which the share of burdens is less than 1%. Emissions from the 'converting' process almost exclusively derive from electricity production. In case of the HDPE bottle, the shares of burdens (up to 5%) are lower because HDPE bottles are produced in only one step, whereas PET bottles are produced in two steps.

The life cycle step 'top, closure & label' shows small to minor impact shares (1%-19%) in most categories mainly attributed to the different plastics used for the closures and the aluminium pull tab.

The production and provision of 'transport packaging' for the bottle system show small to minor impact shares (2%-17%) in most categories. The exception is 'Use of Nature' for which 94% of the burdens are caused from 'transport packaging' resulting from the used cardboard and wood for pallets. The PET bottle shows higher burdens as the HDPE bottle for 'Use of Nature' as its secondary packaging material is cardboard whereas the secondary packaging material of the HDPE bottle is LDPE.

The life cycle step 'filling' shows only small shares of burdens (max. 6%) for all bottle systems in all impact categories.

The life cycle step 'distribution' shows only small burdens in all impact categories for all bottle systems (max. 4%).

The impact of the plastic bottles' 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (23%-31%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

Energy credits have a considerable influence on the net results in most categories (up to 18% of the total burdens). The exception is 'Climate Change', where the credits reduce the overall burdens by around 17%-30%. The energy credits mainly originate from the incineration plants and cement kilns.

Material credits are low and result only from the recycling of secondary and tertiary packaging material as the white plastic bottles are not materially recycled.

Glass bottle (specifications see section 2.2.2)

Even more than for the other regarded packaging systems, the production of the 'glass' material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results (79%-91%) in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'.

All other life cycle steps play only a minor role compared to the glass production. For the impact categories, 'Aquatic Eutrophication' (28%) and 'Use of Nature' (79%) transport packaging also plays a visible role due do the cardboard used for secondary and tertiary packaging.

Energy credits play only a minor role for the glass bottle, as the little energy that can be generated in end-of-life mainly comes from the incineration of secondary and tertiary packaging.

Material credits from glass recycling have a small impact on the overall net results as the cullet is used in a closed loop. The use of closed loop cullet can be seen in the reduced impacts of the life cycle step for the production of 'glass'.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.1.3 Comparison between packaging systems

The following tables show the net results per functional unit of the studied beverage carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 38: Comparison of net results: **TR OSO 34 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50%

DAIRY FAMILY PACK (chilled), Europe, Allocation 50	The net results of **TR OSO 34 1000mL** are lower (green)/ higher (orange) than those of				
	TR OSO 34 plant-based 1000mL	TT O38 1000mL	HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change	+92%	-36%	-57%	-67%	-91%
Acidification	-31%	-14%	-24%	-45%	-89%
Photo-Oxidant Formation	-37%	-13%	-5%	-30%	-86%
Ozone Depletion Potential	-84%	-9%	+27%	-91%	-90%
Terrestrial Eutrophication	-42%	-10%	+10%	-29%	-86%
Aquatic Eutrophication	-66%	-12%	-25%	-33%	+28%
Particulate Matter	-41%	-14%	-18%	-41%	-89%
Use of Nature	-41%	+16%	+4599%	+547%	+545%

Table 39: Comparison of net results: **TR OSO 34 1000mL plant-based** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50%

DAIRY FAMILY PACK (chilled), Europe, Allocation 50	The net results of **TR OSO 34 1000mL plant-based** are lower (green)/ higher (orange) than those of				
	TR OSO 34 1000mL	TT O38 1000mL	HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change	-48%	-67%	-77%	-83%	-95%
Acidification	+45%	+25%	+11%	-20%	-84%
Photo-Oxidant Formation	+58%	+38%	+50%	+11%	-77%
Ozone Depletion Potential	+518%	+463%	+686%	-44%	-37%
Terrestrial Eutrophication	+74%	+56%	+92%	+24%	-75%
Aquatic Eutrophication	+191%	+157%	+118%	+95%	+271%
Particulate Matter	+69%	+45%	+38%	-1%	-81%
Use of Nature	+70%	+96%	+7871%	+997%	+995%

Table 40: Comparison of net results: **TT O38 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50%

DAIRY FAMILY PACK (chilled), Europe, Allocation 50	The net results of **TT O38 1000mL** are lower (green)/ higher (orange) than those of				
	TR OSO 34 1000mL	TR OSO 34 plant-based 1000mL	HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change	+56%	+200%	-32%	-49%	-86%
Acidification	+16%	-20%	-11%	-36%	-87%
Photo-Oxidant Formation	+15%	-28%	+9%	-19%	-84%
Ozone Depletion Potential	+10%	-82%	+40%	-90%	-89%
Terrestrial Eutrophication	+11%	-36%	+23%	-21%	-84%
Aquatic Eutrophication	+13%	-61%	-15%	-24%	+45%
Particulate Matter	+17%	-31%	-4%	-31%	-87%
Use of Nature	-14%	-49%	3963%	459%	458%

4.2 Results allocation factor 100%; DAIRY FAMILY PACK CHILLED

4.2.1 Presentation of results DAIRY FAMILY PACK CHILLED

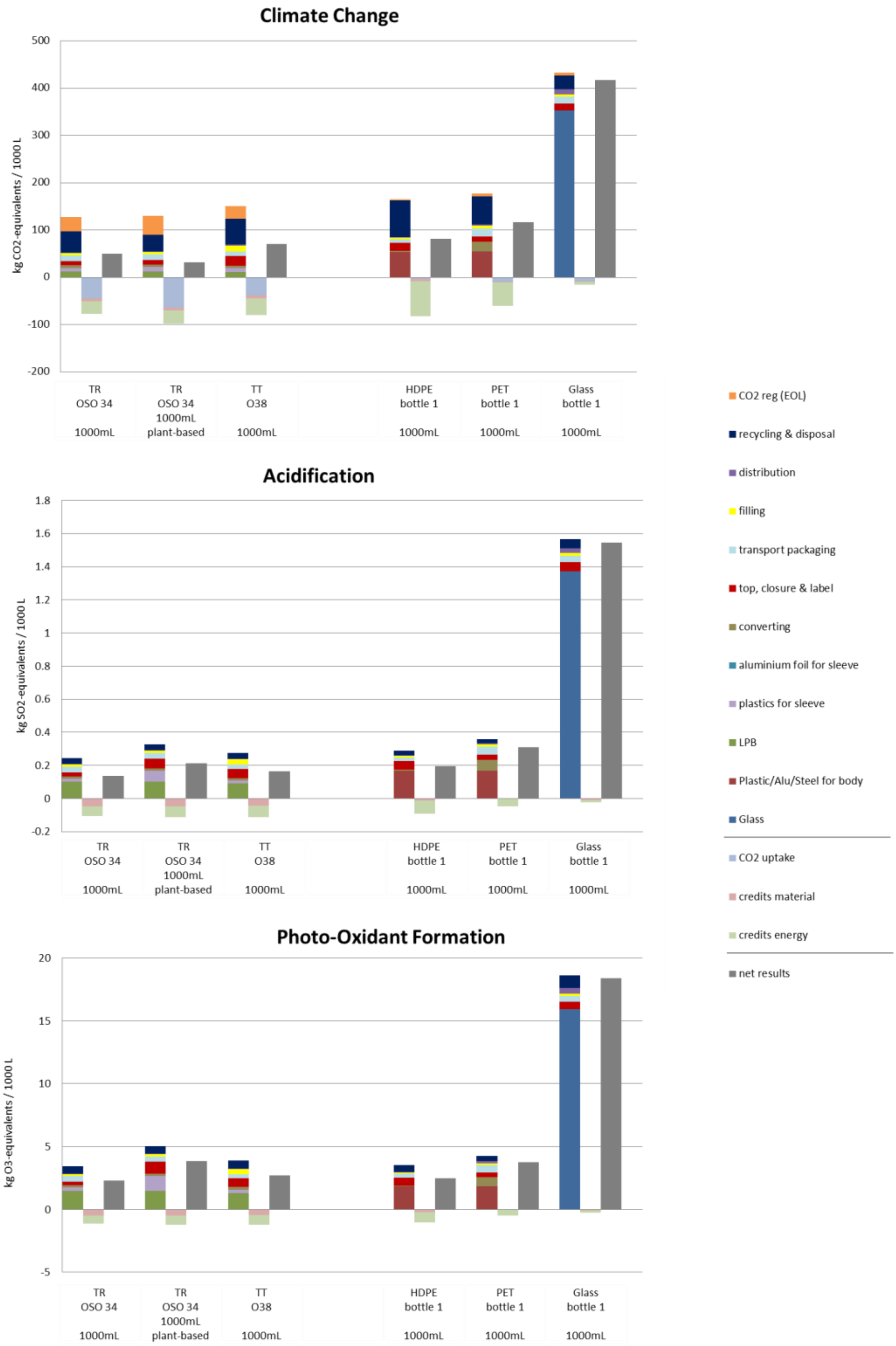


Figure 24: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK CHILLED**, allocation factor 100% (Part 1)

Figure 25: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK CHILLED**, allocation factor 100% (Part 2)

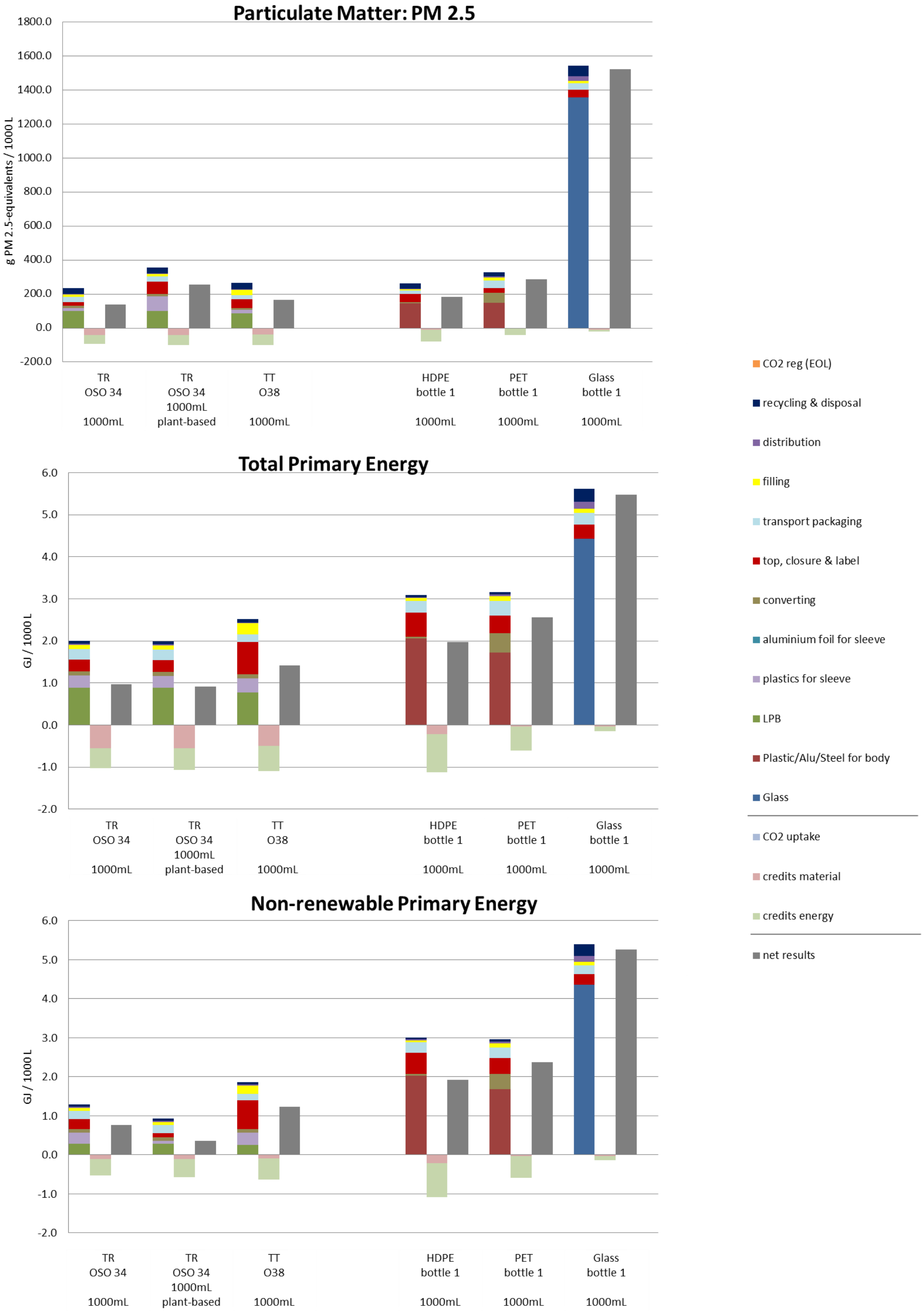


Figure 26: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK CHILLED**, allocation factor 100% (Part 3)

Figure 27: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK CHILLED**, allocation factor 100% (Part 4)

Table 41: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment DAIRY FAMILY PACK CHILLED** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		TR OSO 34 1000mL	TR OSO 34 plant-based 1000mL	TT O38 1000mL		HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change [kg CO_2-e/1000 L]	Burdens	97.21	89.37	123.82		162.33	170.78	426.81
	CO2 (reg)	30.56	41.14	26.75		2.35	6.15	6.02
	Credits	-32.92	-34.64	-41.12		-79.73	-50.59	-8.35
	CO2 uptake	-44.60	-63.78	-38.93		-2.92	-9.53	-7.62
	net results	50.24	32.09	70.53		82.03	116.80	416.86
Acidification [kg SO_2-e/1000 L]	Burdens	0.24	0.33	0.28		0.29	0.36	1.57
	Credits	-0.11	-0.11	-0.11		-0.09	-0.05	-0.02
	Net results	0.14	0.21	0.16		0.20	0.31	1.55
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	3.44	5.02	3.91		3.52	4.24	18.61
	Credits	-1.14	-1.20	-1.22		-1.03	-0.50	-0.25
	Net results	2.31	3.82	2.69		2.49	3.75	18.36
Ozone Depletion [g R11 e/1000 L]	Burdens	0.05	0.27	0.06		0.04	0.49	0.41
	Credits	-0.02	-0.02	-0.02		-0.02	-0.01	-0.01
	Net results	0.03	0.25	0.04		0.03	0.48	0.40
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	27.20	42.87	30.14		24.57	32.94	147.49
	Credits	-8.89	-9.36	-9.50		-7.61	-3.81	-1.92
	Net results	18.31	33.51	20.64		16.96	29.13	145.57
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	28.04	74.93	30.94		34.08	38.27	19.73
	Credits	-5.86	-5.86	-5.22		-2.32	-0.41	-0.20
	Net results	22.18	69.06	25.72		31.76	37.87	19.53
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	233.64	354.75	267.37		263.34	328.96	1542.40
	Credits	-94.44	-99.28	-100.35		-80.93	-41.34	-21.32
	Net results	139.19	255.47	167.02		182.41	287.62	1521.07
Total Primary Energy [GJ/1000 L]	Burdens	2.00	1.99	2.51		3.10	3.17	5.62
	Credits	-1.03	-1.07	-1.09		-1.13	-0.61	-0.14
	Net results	0.97	0.92	1.42		1.97	2.56	5.47
Non-renewable Primary Energy [GJ/1000 L]	Burdens	1.29	0.93	1.87		3.01	2.96	5.40
	Credits	-0.54	-0.57	-0.64		-1.08	-0.58	-0.13
	Net results	0.76	0.36	1.22		1.93	2.37	5.27
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	42.88	32.77	63.60		298.79	149.16	415.66
	Credits	-16.77	-17.79	-19.89		-33.05	-18.99	-8.82
	Net results	26.11	14.98	43.71		265.73	130.17	406.84
Use of Nature [m^2e*year/1000 L]	Burdens	24.20	38.17	21.02		0.47	3.13	3.13
	Credits	-8.30	-8.31	-7.36		-0.09	-0.06	-0.04
	Net results	15.90	29.86	13.66		0.39	3.07	3.09
Water use [m^3/1000 L]	water cool	0.93	0.86	1.26		1.36	3.34	1.97
	water process	1.73	1.71	1.83		0.40	1.06	0.28
	water unspecified	0.46	0.59	0.49		0.67	1.05	0.43

4.2.2 Description and interpretation

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.

In the cases of beverage cartons in the segment DAIRY FAMILY PACK CHILLED applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. In case of beverage cartons with plant-based plastics, net results stay similar in the categories which have high burdens from the production of plant-based plastics. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

In the case of the PET bottle, lower net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. The exceptions are 'Climate Change' and 'Aquatic Eutrophication'. For these impacts categories net results stay about the same when applying the 100% allocation factor, as the additionally allocated credits and burdens show similar absolute values.

In the case of the HDPE bottle, similar net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is similar than that of the burdens from recycling and disposal regardless of the allocation factor.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for beverage cartons and plastic bottles in this segment when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

In the case of single use glass bottle, net results of all categories stay about the same when applying the 100% allocation factor as burdens from recycling and disposal are similar than energy and material credits due to the closed loop use of cullet.

4.2.3 Comparison between packaging systems

The following tables show the net results per functional unit of the regarded beverage cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 42: Comparison of net results: **TR OSO 34 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 100%

DAIRY FAMILY PACK (chilled), Europe, Allocation 100	The net results of **TR OSO 34 1000mL** are lower (green)/ higher (orange) than those of				
	TR OSO 34 plant-based 1000mL	TT O38 1000mL	HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change	+57%	-29%	-39%	-57%	-88%
Acidification	-36%	-17%	-31%	-56%	-91%
Photo-Oxidant Formation	-40%	-14%	-7%	-38%	-87%
Ozone Depletion Potential	-86%	-8%	+33%	-93%	-91%
Terrestrial Eutrophication	-45%	-11%	+8%	-37%	-87%
Aquatic Eutrophication	-68%	-14%	-30%	-41%	+14%
Particulate Matter	-46%	-17%	-24%	-52%	-91%
Use of Nature	-47%	+16%	+4016%	+418%	+414%

Table 43: Comparison of net results: **TR OSO 34 1000mL plant-based** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 100%

DAIRY FAMILY PACK (chilled), Europe, Allocation 100	The net results of **TR OSO 34 plant-based 1000mL** are lower (green)/ higher (orange) than those of				
	TR OSO 34 1000mL	TT O38 1000mL	HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change	-36%	-55%	-61%	-73%	-92%
Acidification	+57%	+31%	+8%	-31%	-86%
Photo-Oxidant Formation	+66%	+42%	+53%	+2%	-79%
Ozone Depletion Potential	+612%	+554%	+848%	-48%	-38%
Terrestrial Eutrophication	+83%	+62%	+98%	+15%	-77%
Aquatic Eutrophication	+211%	+168%	+117%	+82%	+254%
Particulate Matter	+84%	+53%	+40%	-11%	-83%
Use of Nature	+88%	+119%	+7628%	+872%	+866%

[1] ((|net result heading – net result column|) / net result column)*100

Table 44: Comparison of net results: **TT O38 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 100%

DAIRY FAMILY PACK (chilled), Europe, Allocation 100	The net results of **TT O38 1000mL** are lower (green)/ higher (orange) than those of				
	TR OSO 34 1000mL	TR OSO 34 plant-based 1000mL	HDPE bottle 1 1000mL	PET bottle 1 1000mL	Glass bottle 1 1000mL
Climate Change	+40%	+120%	-14%	-40%	-83%
Acidification	+20%	-23%	-17%	-47%	-89%
Photo-Oxidant Formation	+17%	-30%	+8%	-28%	-85%
Ozone Depletion Potential	+9%	-85%	+45%	-92%	-91%
Terrestrial Eutrophication	+13%	-38%	+22%	-29%	-86%
Aquatic Eutrophication	+16%	-63%	-19%	-32%	+32%
Particulate Matter	+20%	-35%	-8%	-42%	-89%
Use of Nature	-14%	-54%	3435%	345%	342%

4.3 Results allocation factor 50%; DAIRY FAMILY PACK AMBIENT

4.3.1 Presentation of results DAIRY FAMILY PACK AMBIENT

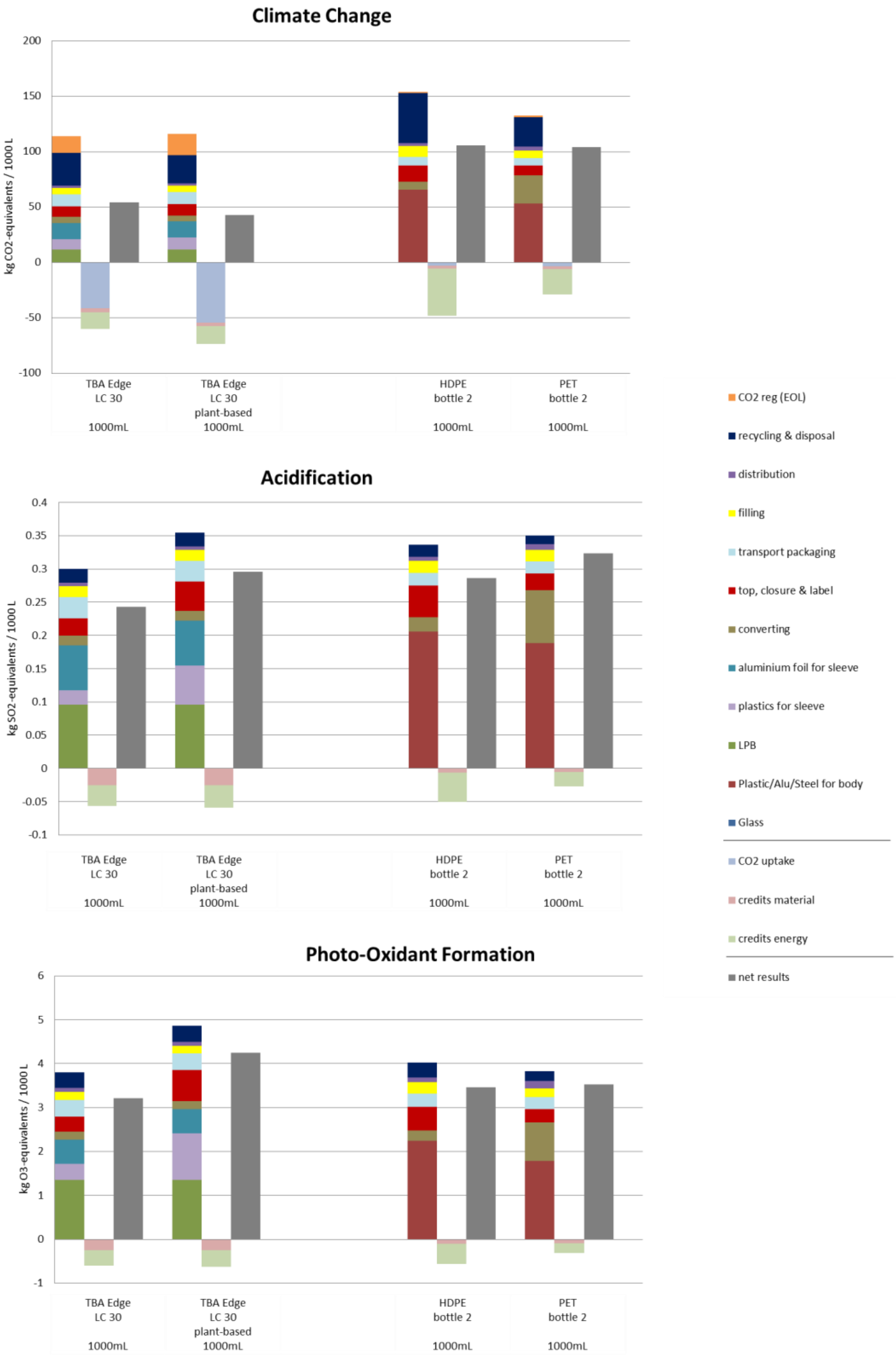


Figure 28: Indicator results of segment DAIRY FAMILY PACK AMBIENT, allocation factor 50% (Part 1)

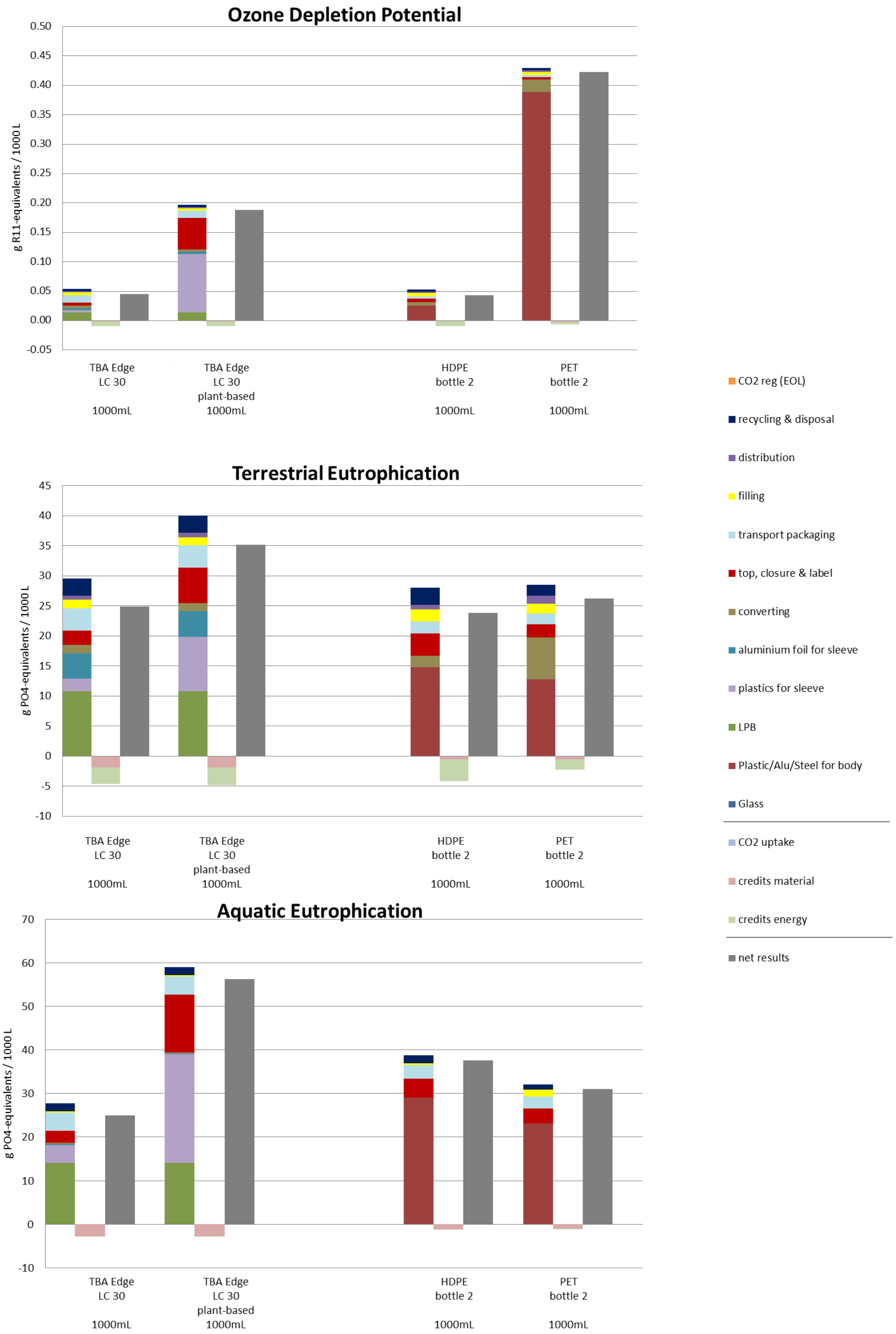


Figure 29 Indicator results of segment DAIRY FAMILY PACK AMBIENT, allocation factor 50% (Part 2)

Figure 30: Indicator results of segment DAIRY FAMILY PACK AMBIENT, allocation factor 50% (Part 3)

Figure 31: Indicator results of segment DAIRY FAMILY PACK AMBIENT, allocation factor 50% (Part 4)

Table 45: Category indicator results per impact category of **segment DAIRY FAMILY PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		TBA Edge LC 30 1000mL	TBA Edge LC 30 plant-based 1000mL		HDPE bottle 2 1000mL	PET bottle 2 1000mL
Climate Change [kg CO_2-e/1000 L]	Burdens	98.79	97.18		152.91	131.46
	CO2 (reg)	15.26	18.97		1.17	1.40
	Credits	-18.44	-19.15		-45.17	-25.07
	CO2 uptake	-41.27	-54.11		-2.90	-3.39
	net results	54.35	42.88		106.02	104.40
Acidification [kg SO_2-e/1000 L]	Burdens	0.30	0.35		0.34	0.35
	Credits	-0.06	-0.06		-0.05	-0.03
	Net results	0.24	0.30		0.29	0.32
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	3.80	4.86		4.02	3.83
	Credits	-0.60	-0.62		-0.57	-0.31
	Net results	3.21	4.24		3.46	3.52
Ozone Depletion [g R11 e/1000 L]	Burdens	0.05	0.20		0.05	0.43
	Credits	-0.01	-0.01		-0.01	-0.01
	Net results	0.04	0.19		0.04	0.42
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	29.51	39.99		28.02	28.49
	Credits	-4.67	-4.86		-4.21	-2.24
	Net results	24.84	35.13		23.81	26.25
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	27.71	59.01		38.74	32.03
	Credits	-2.74	-2.74		-1.18	-1.07
	Net results	24.98	56.27		37.56	30.96
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	279.11	359.98		305.40	313.81
	Credits	-50.29	-52.27		-44.85	-23.96
	Net results	228.82	307.72		260.55	289.85
Total Primary Energy [GJ/1000 L]	Burdens	2.32	2.31		3.71	3.01
	Credits	-0.53	-0.54		-0.63	-0.36
	Net results	1.79	1.77		3.09	2.65
Non-renewable Primary Energy [GJ/1000 L]	Burdens	1.58	1.34		3.60	2.83
	Credits	-0.29	-0.30		-0.60	-0.35
	Net results	1.29	1.04		3.00	2.48
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	59.41	51.11		365.58	274.66
	Credits	-9.77	-10.19		-18.51	-10.58
	Net results	49.64	40.92		347.07	264.08
Use of Nature [m²e*year/1000 L]	Burdens	22.43	31.77		0.51	0.55
	Credits	-3.86	-3.87		-0.05	-0.03
	Net results	18.57	27.90		0.46	0.52
Water use [m³/1000 L]	water cool	1.51	1.50		2.33	3.82
	water process	2.10	2.10		0.44	1.11
	water unspecified	0.77	0.86		0.81	0.81

4.3.2 Description and interpretation

Beverage carton systems (specifications see section 2.2.1)

For the beverage carton systems considered in the DAIRY FAMILY PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the beverage carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (24%-51%) and 'Use of Nature' (64%-90%). It is also relevant regarding 'Photo-Oxidant Formation' (28%-35%) 'Acidification' (27%-32%), 'Terrestrial Eutrophication' (27%-37%), 'Particulate Matter' (26%-33%) and also the consumption of 'Total Primary Energy' (35%-36%). Regarding 'Climate Change' the production of LPB is responsible for only 10% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The production of 'aluminium foil' for the sleeves of the ambient beverage carton shows burdens in most impact categories. Considerable shares of burdens can be seen for the impact categories 'Acidification' (19%-23%) and 'Particulate Matter' (16%-20%). These result from SO_2 and NOx emissions from the aluminium production. Also the inventory category 'Cumulative Raw material Demand (abiotic)' shows considerable shares of burdens (25%-29%).

The production of 'plastics for sleeve' of the beverage cartons with fossil based plastics shows small to considerable burdens in most impact categories (7%-24%). These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The exceptions are climate change and the inventory categories 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)', where plastics and LPB contribute about the same. If 'plastics for sleeve' contains plant-based plastics, this life cycle step plays a major role (13%-50%) for the overall burdens in all categories apart from 'Climate Change' (9%).

The life cycle step 'top, closure & label' for cartons with fossil based plastics contributes to from a small to a considerable amount in almost all impact categories (0%-21%). In case the plastics used for 'top, closure & label' are plant-based, the shares of burdens (up to 27%) are considerably higher than cartons with fossil based plastics in all categories except 'Climate Change', 'Cumulative Raw material Demand (abiotic)', 'Total Primary Energy Demand' and 'Non-renewable Primary Energy'.

The reason for the big influence of plant-based plastics on all impact categories apart from 'Climate Change' is the high energy demand, and the cultivation of sugar cane. The latter is reflected especially in the impact category 'Ozone Depletion Potential'. This is due to the field emissions of N2O from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of plant-based PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'.

The 'converting' process generally plays a small role (0%-8%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show minor impacts in most categories (6%-15%). The exception is 'Ozone Depletion Potential' for the cartons with fossil based plastics. In these cases 'transport packaging' has a higher share of 9%-23% of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle step 'filling' shows only small shares of burdens (up to 8%) for the TBA beverage carton system in all impact categories.

The life cycle step 'distribution' shows only small burdens in all impact categories for all beverage carton systems (max. 4%).

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact category 'Climate Change' (22%-26%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. In case of beverage cartons these derive mainly from the incineration of plant-based plastics and paper. They play an important role (13%-16%) for the results of all beverage carton systems in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-18% of the total burdens. Material credits from material recycling are lower (1%-17%). Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section 1.7.2)

Plastic bottles (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY FAMILY PACK segment, the biggest part of the environmental burdens is also caused by the production of the base materials of the bottles in most impact and inventory categories. In case of 'Ozone Depletion Potential' the main contributor to the high impacts is methyl bromide which is emitted in the production process for purified terephthalic acid (PTA) which is a pre-product of PET.

The 'converting' process shows for the PET bottle in this segment a small to considerable share of burdens (5%-25%) in all categories apart from 'Aquatic Eutrophication', for which the share of burdens is less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production. In case of the HDPE bottle the shares of burdens are lower (4%-11%) because HDPE bottles are produced in only one step, whereas PET bottles are produced in two steps.

The life cycle step 'top, closure & label' shows small to considerable impacts shares (1%-14%) in most categories mainly attributed to the different plastics used for the closures and the aluminium pull tab.

The production and provision of 'transport packaging' for the bottle system show minor impact shares (1%-9%) in most categories. The exception is 'Use of Nature' for which (64%-68%) of the burdens are caused from 'transport packaging' resulting from the used cardboard and wood for pallets. The PET bottle shows higher burdens as the HDPE bottle for 'Use of Nature' as its secondary packaging material is cardboard whereas the secondary packaging material of the HDPE bottle is LDPE.

The life cycle step 'filling' shows only small shares of burdens (max. 10%) for all bottle systems in all impact categories.

The life cycle step 'distribution' shows only minor burdens in all impact categories for all bottle systems (max. 5%).

The impact of the plastic bottles' 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (20%-29%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

Energy credits have a considerable influence on the net results of most categories (up to 15% of the total burdens). The exception is 'Climate Change', where the credits reduce the overall burdens by around 17%-28%. The energy credits mainly originate from the incineration plants and cement kilns.

Material credits are low and result only from the recycling of secondary and tertiary packaging material as the white plastic bottles are not materially recycled.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.3.3 Comparison between packaging systems

The following tables show the net results per functional unit of the studied beverage carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 46: Comparison of net results: **TBA Edge LC 30 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50%

DAIRY FAMILY PACK (ambient), Europe, Allocation 50	The net results of **TBA Edge LC 30 1000mL** are lower (green)/ higher (orange) than those of		
	TBA Edge LC 30 plant-based 1000mL	HDPE bottle 2 1000mL	PET bottle 2 1000mL
Climate Change	+27%	-49%	-48%
Acidification	-18%	-15%	-25%
Photo-Oxidant Formation	-24%	-7%	-9%
Ozone Depletion Potential	-76%	+3%	-89%
Terrestrial Eutrophication	-29%	+4%	-5%
Aquatic Eutrophication	-56%	-33%	-19%
Particulate Matter	-26%	-12%	-21%
Use of Nature	-33%	+3915%	+3489%

Table 47: Comparison of net results: **TBA Edge LC 30 plant-based 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50%

DAIRY FAMILY PACK (ambient), Europe, Allocation 50	The net results of **TBA Edge LC 30 plant-based 1000mL** are lower (green)/ higher (orange) than those of		
	TBA Edge LC 30 1000mL	HDPE bottle 2 1000mL	PET bottle 2 1000mL
Climate Change	-21%	-60%	-59%
Acidification	+22%	+4%	-9%
Photo-Oxidant Formation	+32%	+23%	+20%
Ozone Depletion Potential	+320%	+331%	-56%
Terrestrial Eutrophication	+41%	+48%	+34%
Aquatic Eutrophication	+125%	+50%	+82%
Particulate Matter	+34%	+18%	+6%
Use of Nature	+50%	+5931%	+5292%

4.4 Results allocation factor 100%; DAIRY FAMILY PACK AMBIENT

4.4.1 Presentation of results DAIRY FAMILY PACK AMBIENT

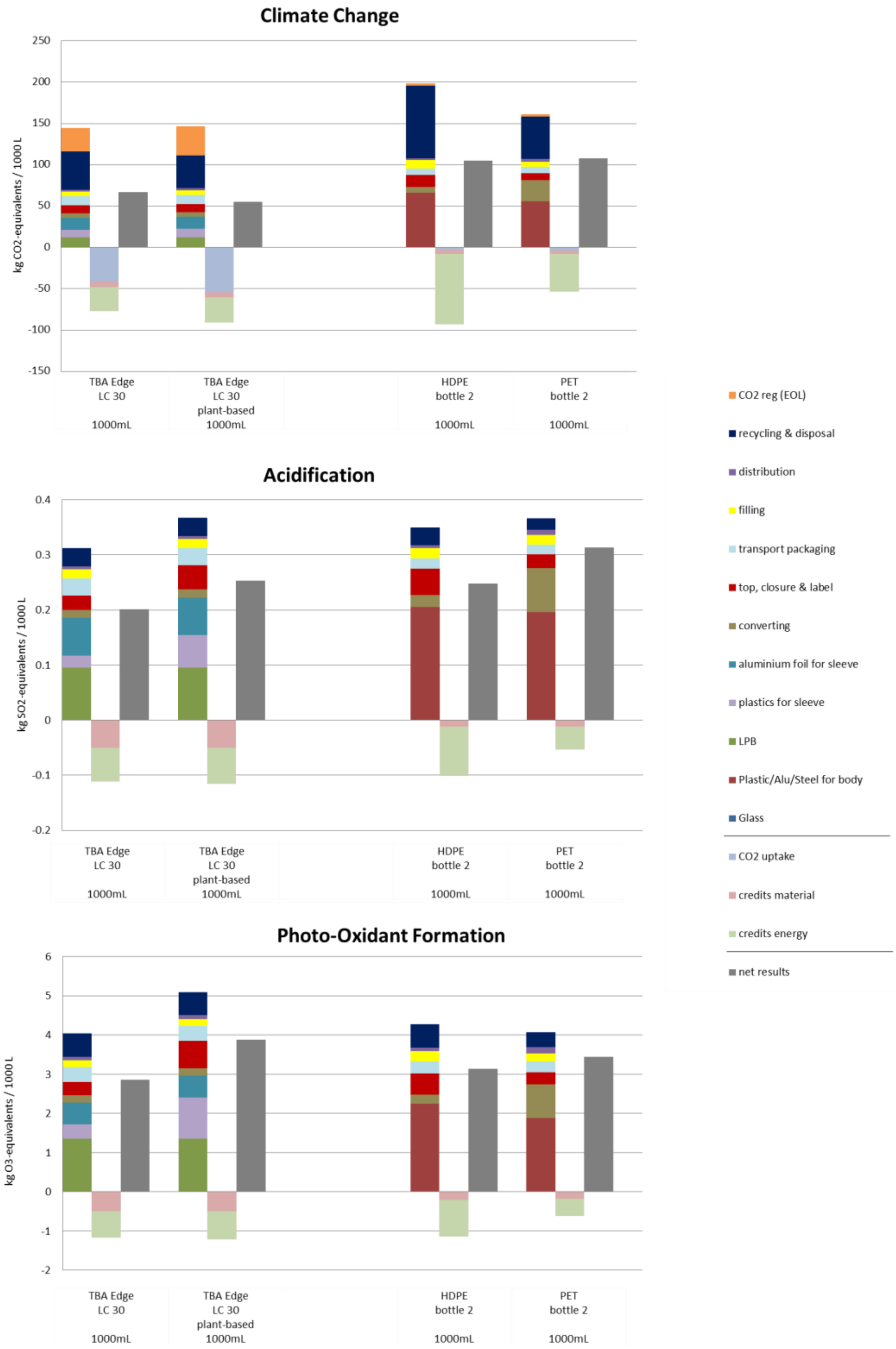


Figure 32: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK AMBIENT**, allocation factor 100% (Part 1)

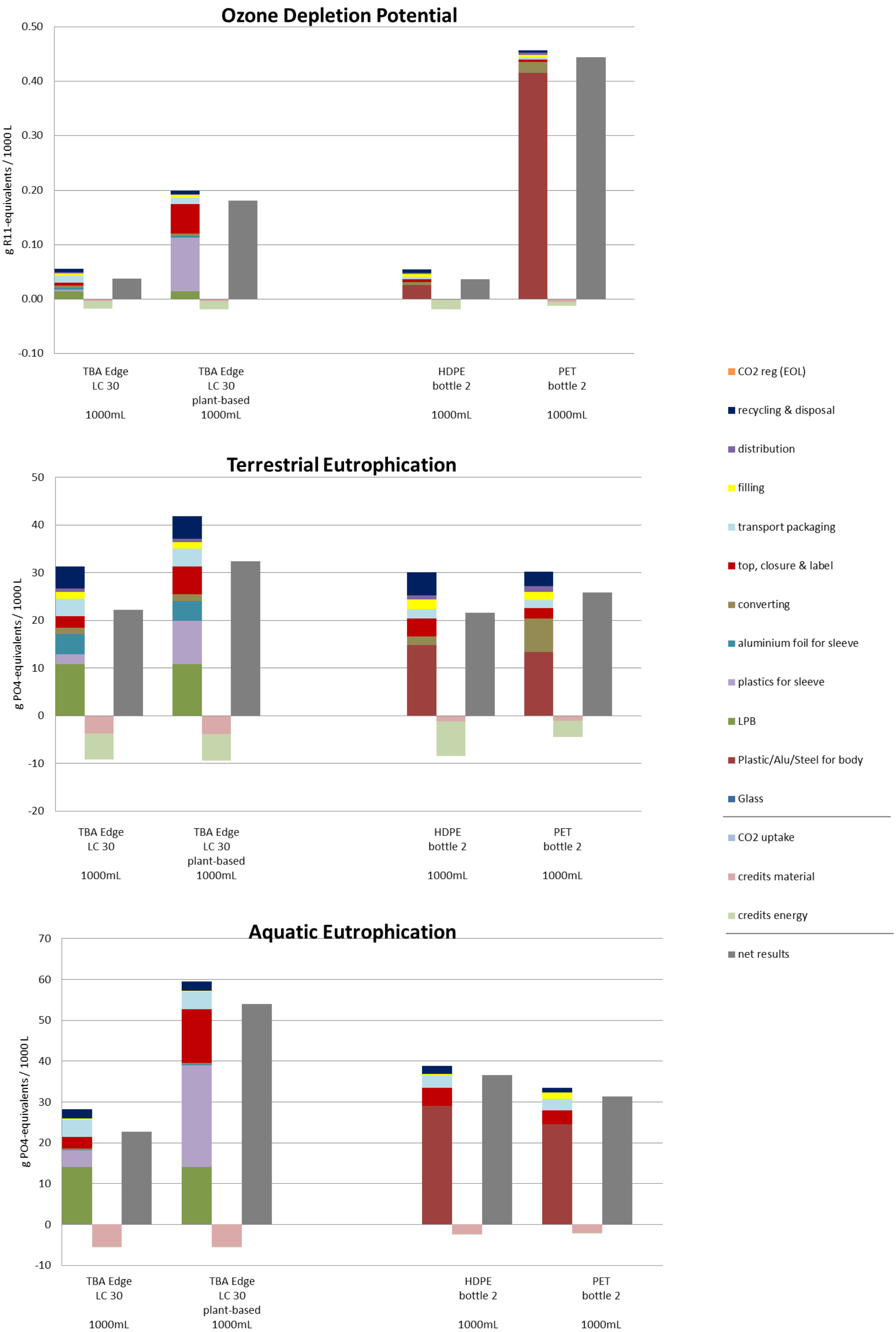


Figure 33: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK AMBIENT**, allocation factor 100% (Part 2)

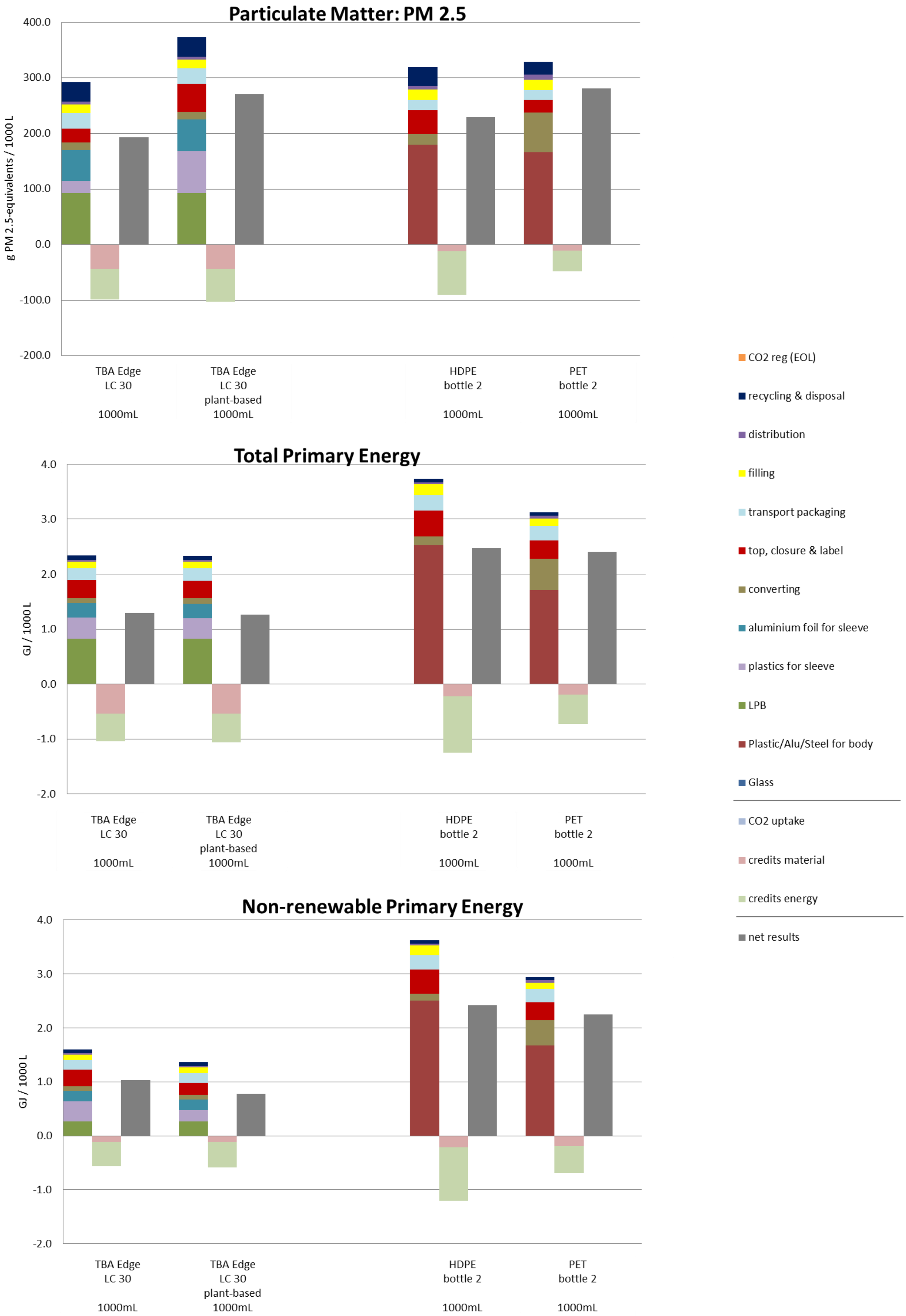


Figure 34: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK AMBIENT**, allocation factor 100% (Part 3)

Figure 35: Indicator results for sensitivity analysis on system allocation of **segment DAIRY FAMILY PACK AMBIENT**, allocation factor 100% (Part 4)

Table 48: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment DAIRY FAMILY PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		TBA Edge LC 30 1000mL	TBA Edge LC 30 plant-based 1000mL		HDPE bottle 2 1000mL	PET bottle 2 1000mL
Climate Change [kg CO_2-e/1000 L]	Burdens	116.33	111.25		195.92	158.38
	CO2 (reg)	28.14	35.18		2.34	2.80
	Credits	-36.01	-37.16		-90.37	-49.91
	CO2 uptake	-41.27	-54.11		-2.90	-3.39
	net results	67.19	55.15		105.00	107.89
Acidification [kg SO_2-e/1000 L]	Burdens	0.31	0.37		0.35	0.37
	Credits	-0.11	-0.12		-0.10	-0.05
	Net results	0.20	0.25		0.25	0.31
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	4.03	5.09		4.27	4.06
	Credits	-1.17	-1.21		-1.13	-0.62
	Net results	2.86	3.88		3.13	3.45
Ozone Depletion [g R11 e/1000 L]	Burdens	0.06	0.20		0.05	0.46
	Credits	-0.02	-0.02		-0.02	-0.01
	Net results	0.04	0.18		0.04	0.44
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	31.34	41.81		30.08	30.26
	Credits	-9.16	-9.47		-8.43	-4.43
	Net results	22.18	32.34		21.65	25.83
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	28.21	59.50		38.86	33.49
	Credits	-5.47	-5.48		-2.36	-2.13
	Net results	22.74	54.02		36.50	31.36
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	292.54	373.33		319.51	329.08
	Credits	-99.05	-102.28		-89.77	-47.46
	Net results	193.49	271.06		229.74	281.62
Total Primary Energy [GJ/1000 L]	Burdens	2.34	2.33		3.73	3.12
	Credits	-1.04	-1.06		-1.25	-0.72
	Net results	1.30	1.27		2.48	2.40
Non-renewable Primary Energy [GJ/1000 L]	Burdens	1.60	1.36		3.62	2.94
	Credits	-0.57	-0.59		-1.20	-0.70
	Net results	1.03	0.77		2.41	2.24
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	60.05	51.75		366.15	277.35
	Credits	-19.13	-19.80		-37.02	-21.06
	Net results	40.92	31.95		329.13	256.29
Use of Nature [m^2e*year/1000 L]	Burdens	22.44	31.78		0.51	0.55
	Credits	-7.72	-7.73		-0.09	-0.06
	Net results	14.72	24.04		0.42	0.49
Water use [m^3/1000 L]	water cool	1.04	1.00		1.89	3.67
	water process	1.94	1.93		0.43	1.11
	water unspecified	0.73	0.82		0.78	0.83

4.4.2 Description and interpretation

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.

In the cases of beverage cartons in the segment DAIRY FAMILY PACK AMBIENT applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. In case of beverage cartons with plant-based plastics, net results stay similar in the categories which have high burdens from the production of plant-based plastics. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

In the case of the PET bottle, lower net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. The exceptions are 'Climate Change' and 'Aquatic Eutrophication'. For these impacts categories net results stay about the same when applying the 100% allocation factor, as the additionally allocated credits and burdens show similar absolute values.

In the case of the HDPE bottle, similar net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is similar than that of the burdens from recycling and disposal regardless of the allocation factor.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for beverage cartons and plastic bottles in this segment when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

4.4.3 Comparison between packaging systems

The following tables show the net results per functional unit of the regarded beverage cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 49: Comparison of net results: **TBA Edge LC 30 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 100%

DAIRY FAMILY PACK (ambient), Europe, Allocation 100	The net results of **TBA Edge LC 30 1000mL** are lower (green)/ higher (orange) than those of		
	TBA Edge LC 30 plant-based 1000mL	HDPE bottle 2 1000mL	PET bottle 2 1000mL
Climate Change	+22%	-36%	-38%
Acidification	-20%	-19%	-36%
Photo-Oxidant Formation	-26%	-9%	-17%
Ozone Depletion Potential	-79%	+4%	-91%
Terrestrial Eutrophication	-31%	+2%	-14%
Aquatic Eutrophication	-58%	-38%	-27%
Particulate Matter	-29%	-16%	-31%
Use of Nature	-39%	+3410%	+2921%

Table 50: Comparison of net results: **TBA Edge LC 30 plant-based 1000mL** versus competing carton based and alternative packaging systems in **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 100%

DAIRY FAMILY PACK (ambient), Europe, Allocation 100	The net results of **TBA Edge LC 30 plant-based 1000mL** are lower (green)/ higher (orange) than those of		
	TBA Edge LC 30 1000mL	HDPE bottle 2 1000mL	PET bottle 2 1000mL
Climate Change	-18%	-47%	-49%
Acidification	+26%	+2%	-19%
Photo-Oxidant Formation	+36%	+24%	+13%
Ozone Depletion Potential	+374%	+394%	-59%
Terrestrial Eutrophication	+46%	+49%	+25%
Aquatic Eutrophication	+138%	+48%	+72%
Particulate Matter	+40%	+18%	-4%
Use of Nature	+63%	+5633%	+4834%

[1] ((|net result heading – net result column|) / net result column)*100

4.5 Results allocation factor 50%; DAIRY PORTION PACK CHILLED

4.5.1 Presentation of results DAIRY PORTION PACK CHILLED

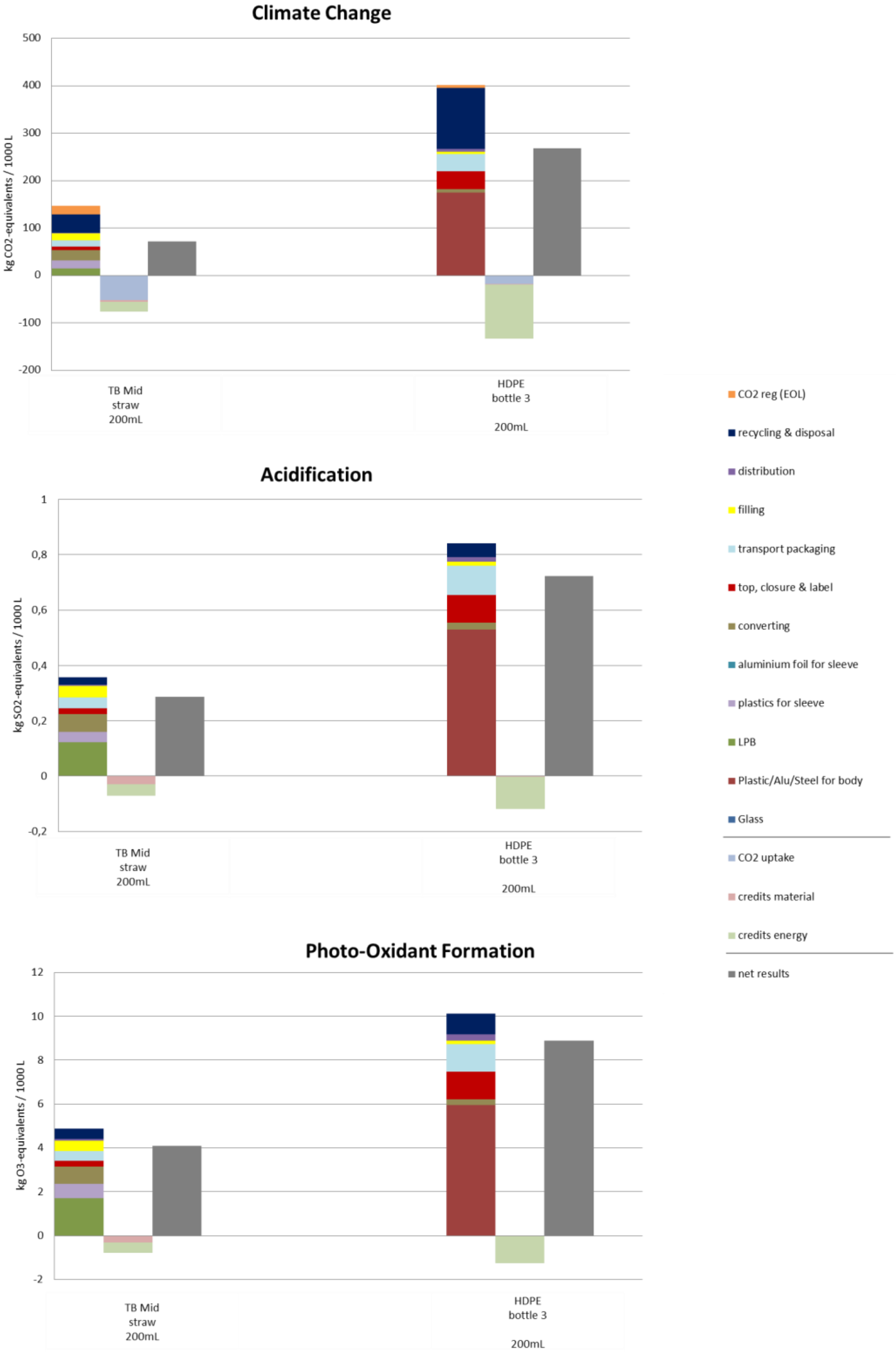


Figure 36: Indicator results of segment DAIRY PORTION PACK CHILLED, allocation factor 50% (Part 1)

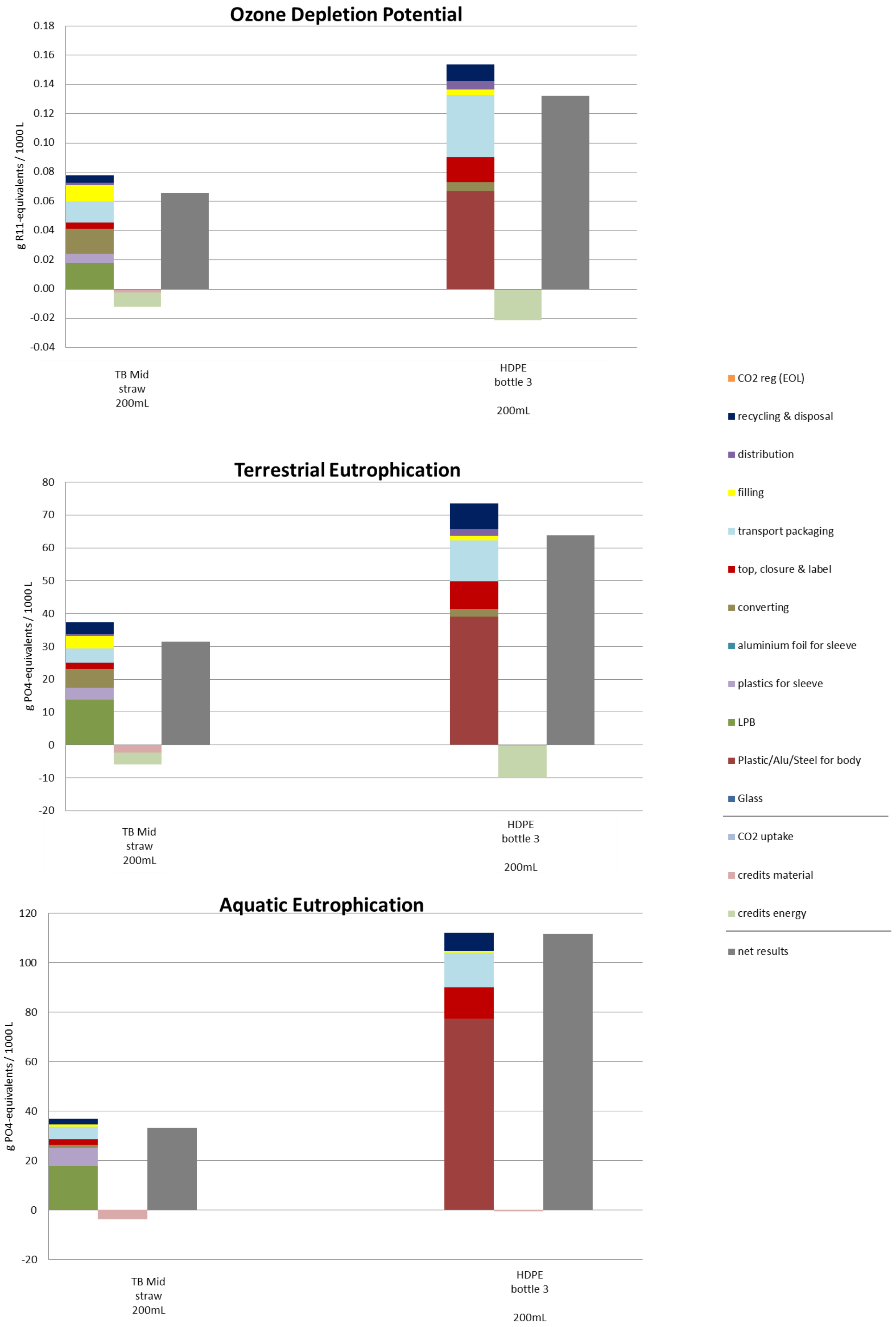


Figure 37 Indicator results of **segment DAIRY PORTION PACK CHILLED**, allocation factor 50% (Part 2)

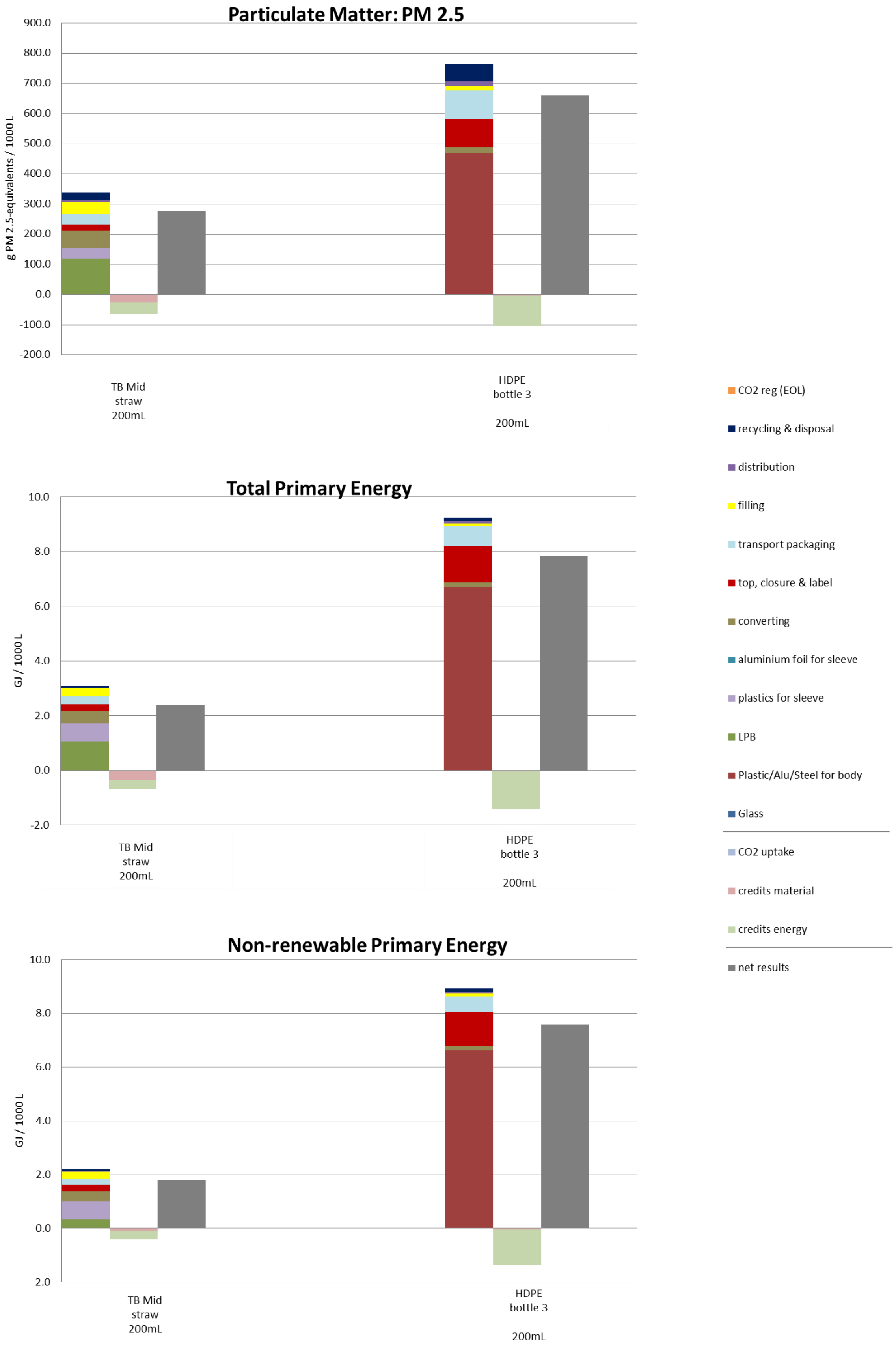


Figure 38: Indicator results of segment DAIRY PORTION PACK CHILLED, allocation factor 50% (Part 3)

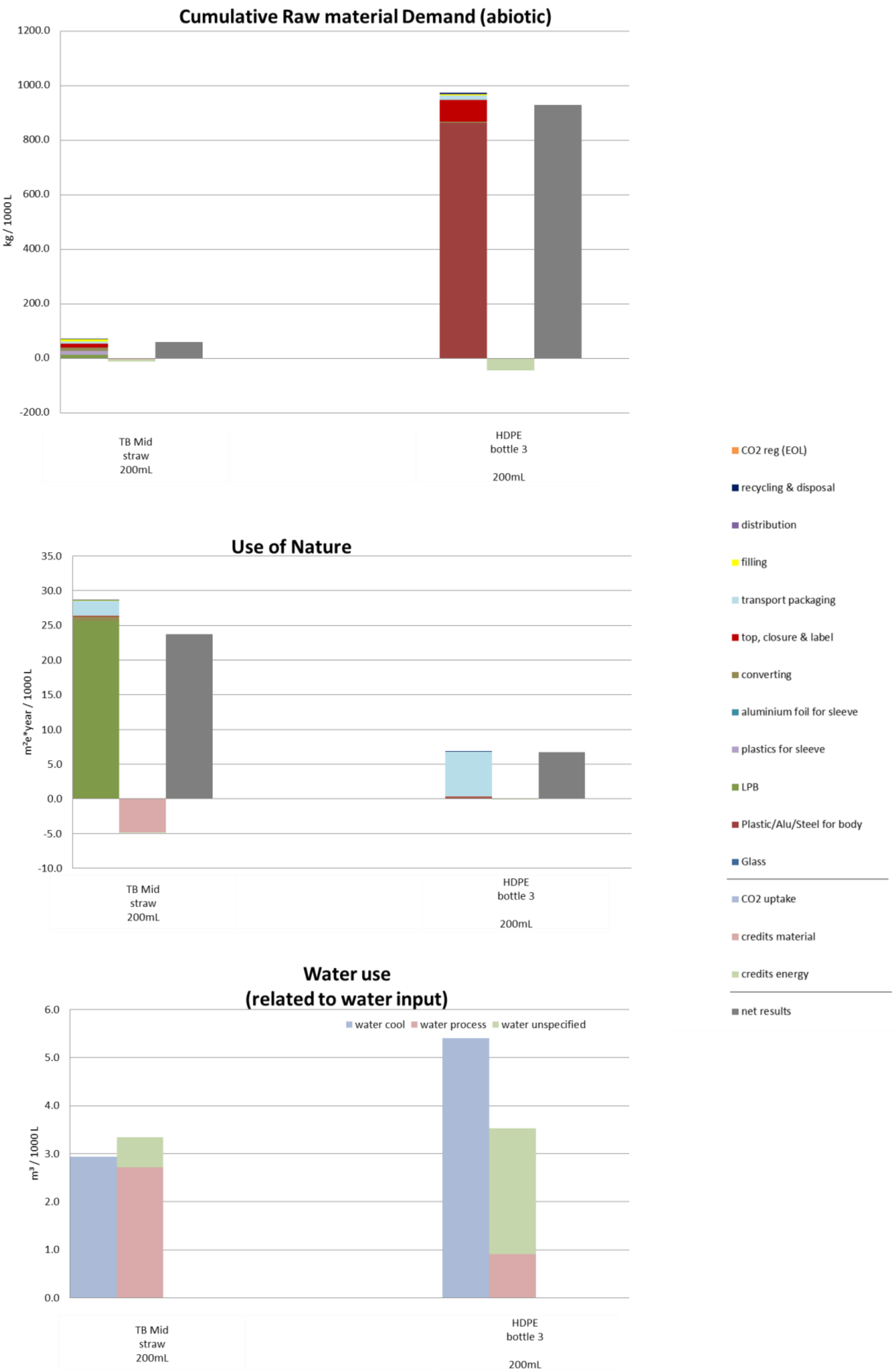


Figure 39: Indicator results of **segment DAIRY PORTION PACK CHILLED**, allocation factor 50% (Part 4)

Table 51: Category indicator results per impact category of segment DAIRY PORTION PACK CHILLED - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		TB Mid Straw 200mL		HDPE bottle 3 200mL
Climate Change [kg CO_2-e/1000 L]	Burdens	128.15		395.57
	CO2 (reg)	19.21		5.48
	Credits	-24.09		-115.25
	CO2 uptake	-51.90		-18.12
	net results	71.38		267.68
Acidification [kg SO_2-e/1000 L]	Burdens	0.36		0.84
	Credits	-0.07		-0.12
	Net results	0.29		0.72
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	4.87		10.12
	Credits	-0.77		-1.25
	Net results	4.10		8.88
Ozone Depletion [g R11 e/1000 L]	Burdens	0.08		0.15
	Credits	-0.01		-0.02
	Net results	0.07		0.13
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	37.42		73.55
	Credits	-6.02		-9.68
	Net results	31.41		63.87
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	36.80		112.05
	Credits	-3.64		-0.44
	Net results	33.16		111.61
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	339.64		763.93
	Credits	-63.46		-103.74
	Net results	276.18		660.18
Total Primary Energy [GJ/1000 L]	Burdens	3.09		9.24
	Credits	-0.69		-1.41
	Net results	2.40		7.83
Non-renewable Primary Energy [GJ/1000 L]	Burdens	2.19		8.93
	Credits	-0.40		-1.35
	Net results	1.80		7.58
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	71.94		973.63
	Credits	-12.19		-43.70
	Net results	59.74		929.94
Use of Nature [m²e*year/1000 L]	Burdens	28.60		6.86
	Credits	-4.89		-0.10
	Net results	23.71		6.75
Water use [m³/1000 L]	water cool	2.93		5.40
	water process	2.72		0.91
	water unspecified	0.62		2.61

4.5.2 Description and interpretation

Beverage carton systems (specifications see section 2.2.1)

For the beverage carton system considered in the DAIRY PORTION PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the beverage carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (49%) and 'Use of Nature' (90%). It is also relevant regarding 'Photo-Oxidant Formation' (35%) 'Acidification' (34%), 'Terrestrial Eutrophication' (37%), 'Particulate Matter' (35%) and also the consumption of 'Total Primary Energy' (34%). Regarding 'Climate Change' the production of LPB is responsible for only 10% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The chilled beverage carton in this segment does not contain aluminium foil. Therefore the step 'aluminium foil for sleeve' shows no burdens.

The production of 'plastics for sleeve' of the beverage carton shows small to considerable burdens in most impact categories (0%-30%). These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The exceptions are climate change and the inventory category 'Cumulative Raw material Demand (abiotic)', where plastics and LPB contribute about the same as well as the inventory category 'Non-renewable Primary Energy', where the plastics (30%) contribute about the doubled share of the total burdens than LPB (15%).

The life cycle step 'top, closure & label' for TB cartons contributes to a minor amount in almost all impact categories (0%-11%). The exception is 'Cumulative Raw material Demand (abiotic)' with a share of 20% of the total burdens in this life cycle step.

The 'converting' process generally plays a minor role (2%-22%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton system shows minor impacts in most categories (8%-14%). The exception is 'Ozone Depletion Potential' for the carton with fossil based plastics. In these cases 'transport packaging' has a higher share of 18% of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle step 'filling' shows only minor shares of burdens (up to 15%) for the TB beverage carton system in all impact categories.

The life cycle step 'distribution' shows only minor burdens in all impact categories for all beverage carton systems (max. 2%).

The life cycle step 'recycling & disposal' of the regarded beverage carton is most relevant in the impact category 'Climate Change' (26%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. They play an important role (13%) for the result of the beverage carton system in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-14% of the total burdens. Material credits from material recycling are lower (3%-17%) in most categories. Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section 1.7.2)

Plastic bottles (specifications see section 2.2.2)

In the regarded plastic bottle system in the DAIRY PORTION PACK segment, the biggest part of the environmental burdens is also caused by the production of the base materials of the bottle in most impact and inventory categories.

The 'converting' process for the HDPE bottle in this segment plays a small role (up to 4%).

The life cycle step 'top, closure & label' shows small to minor impacts shares (1%-14%) in most categories mainly attributed to the different plastics used for the closures and the aluminium pull tab.

The production and provision of 'transport packaging' for the bottle system show minor impact shares (6%-27%) in most categories. The exception is 'Use of Nature' for which (95%) of the burdens are caused from 'transport packaging' resulting from the used cardboard and wood for pallets.

The life cycle step 'filling' shows only small shares of burdens (max. 3%) for the bottle system in all impact categories.

The life cycle step 'distribution' shows only minor burdens in all impact categories for the bottle system (max. 4%).

The impact of the plastic bottles' 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (32%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

Energy credits have a considerable influence on the net results of most categories (up to 15% of the total burdens). The exception is 'Climate Change', where the credits reduce the overall burdens by around 29%. The energy credits mainly originate from the incineration plants and cement kilns.

Material credits are low and result only from the recycling of secondary and tertiary packaging material as the white plastic bottle is not materially recycled.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.5.3 Comparison between packaging systems

The following table shows the net results per functional unit of the studied beverage carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following table show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 52: Comparison of net results: **TB Mid Straw 200mL** versus competing carton based and alternative packaging systems in **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 50%

DAIRY PORTION PACK (chilled), Europe, Allocation 50	The net results of **TB Mid Straw 200mL** are lower (green)/ higher (orange) than those of
	HDPE bottle 3 200mL
Climate Change	-73%
Acidification	-60%
Photo-Oxidant Formation	-54%
Ozone Depletion Potential	-50%
Terrestrial Eutrophication	-51%
Aquatic Eutrophication	-70%
Particulate Matter	-58%
Use of Nature	+251%

[1] ((|net result heading – net result column|) / net result column)*100

4.6 Results allocation factor 100%; DAIRY PORTION PACK CHILLED

4.6.1 Presentation of results DAIRY PORTION PACK CHILLED

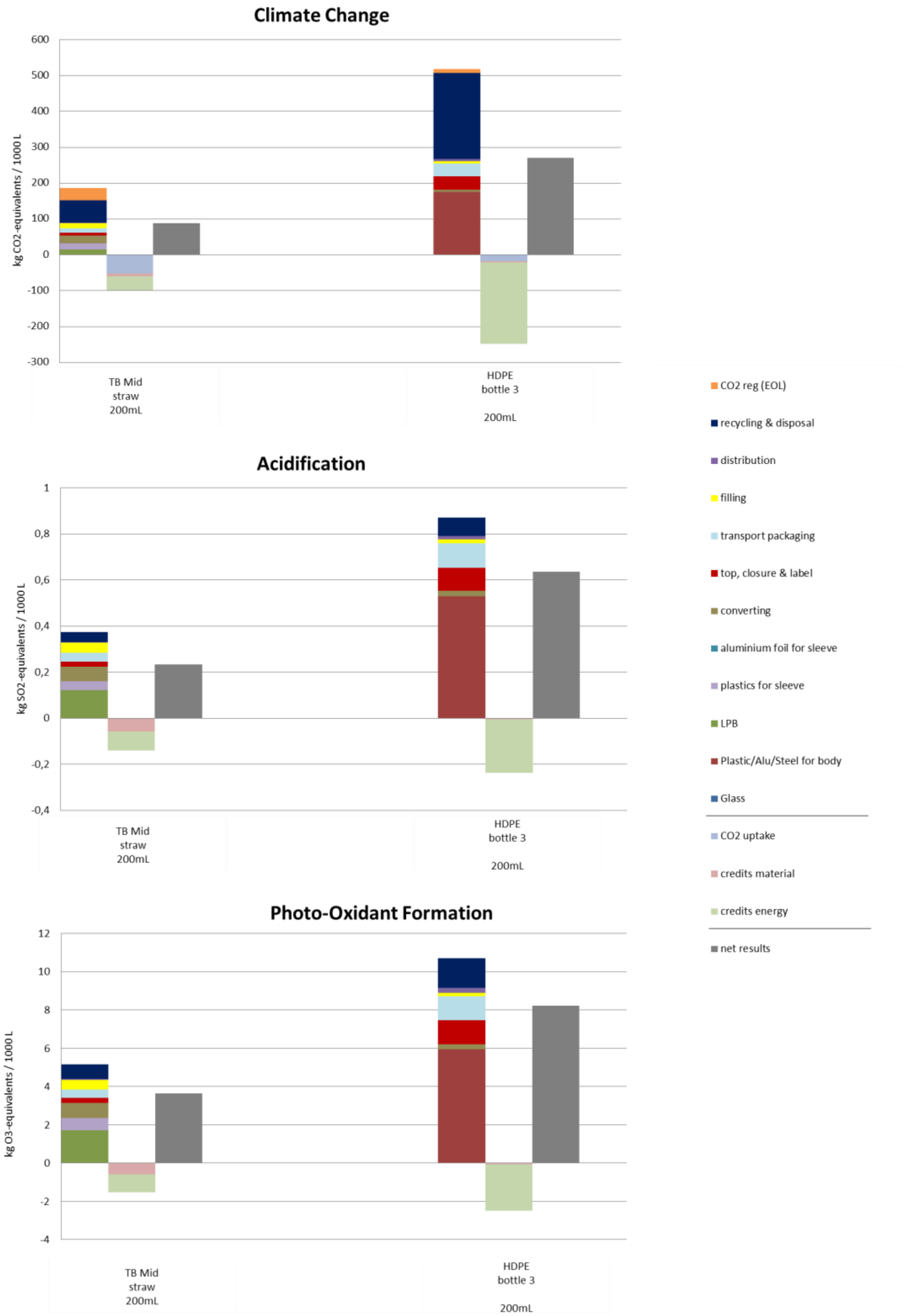


Figure 40: Indicator results for sensitivity analysis on system allocation of **segment DAIRY PORTION PACK CHILLED**, allocation factor 100% (Part 1)

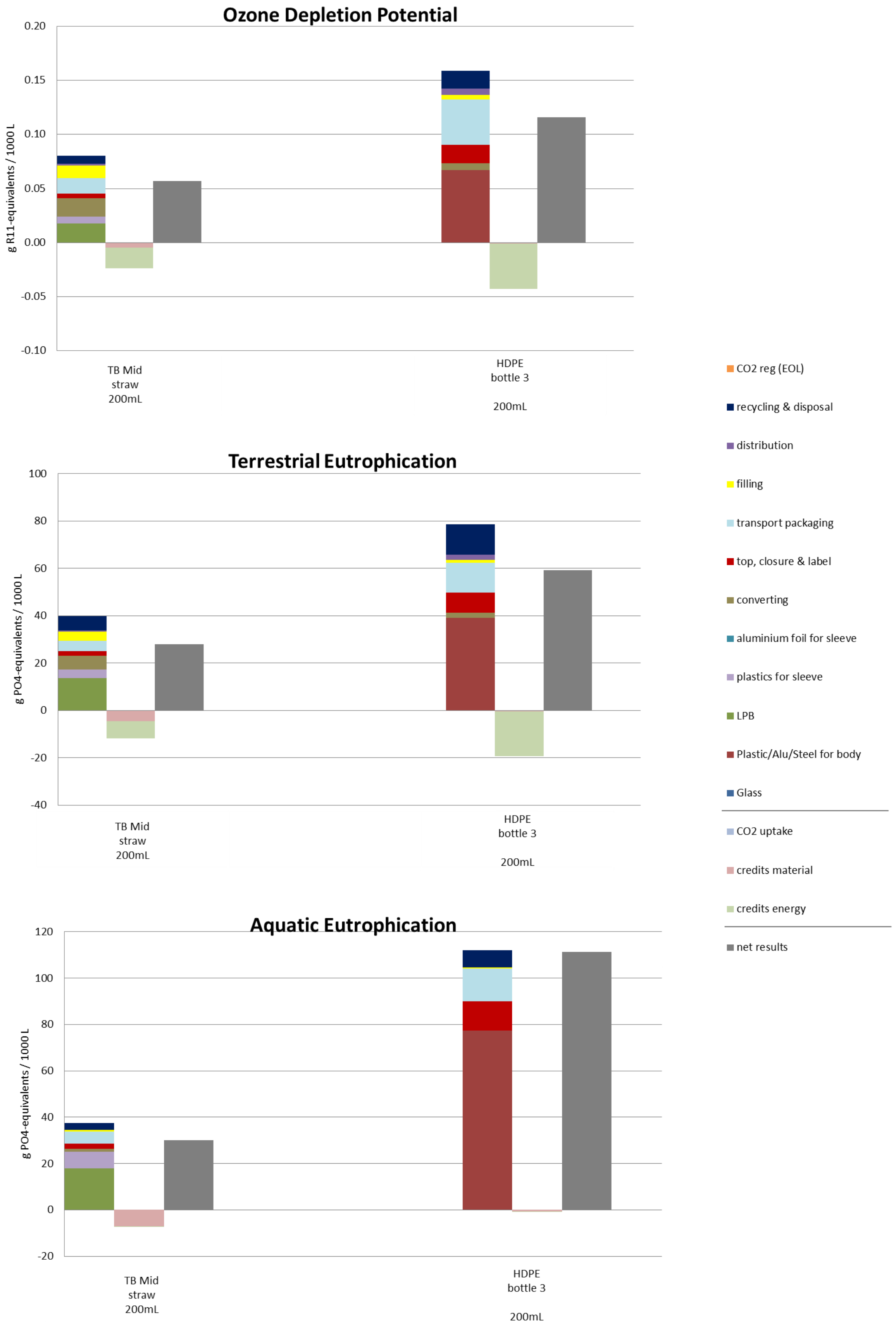


Figure 41: Indicator results for sensitivity analysis on system allocation of **segment DAIRY PORTION PACK CHILLED**, allocation factor 100% (Part 2)

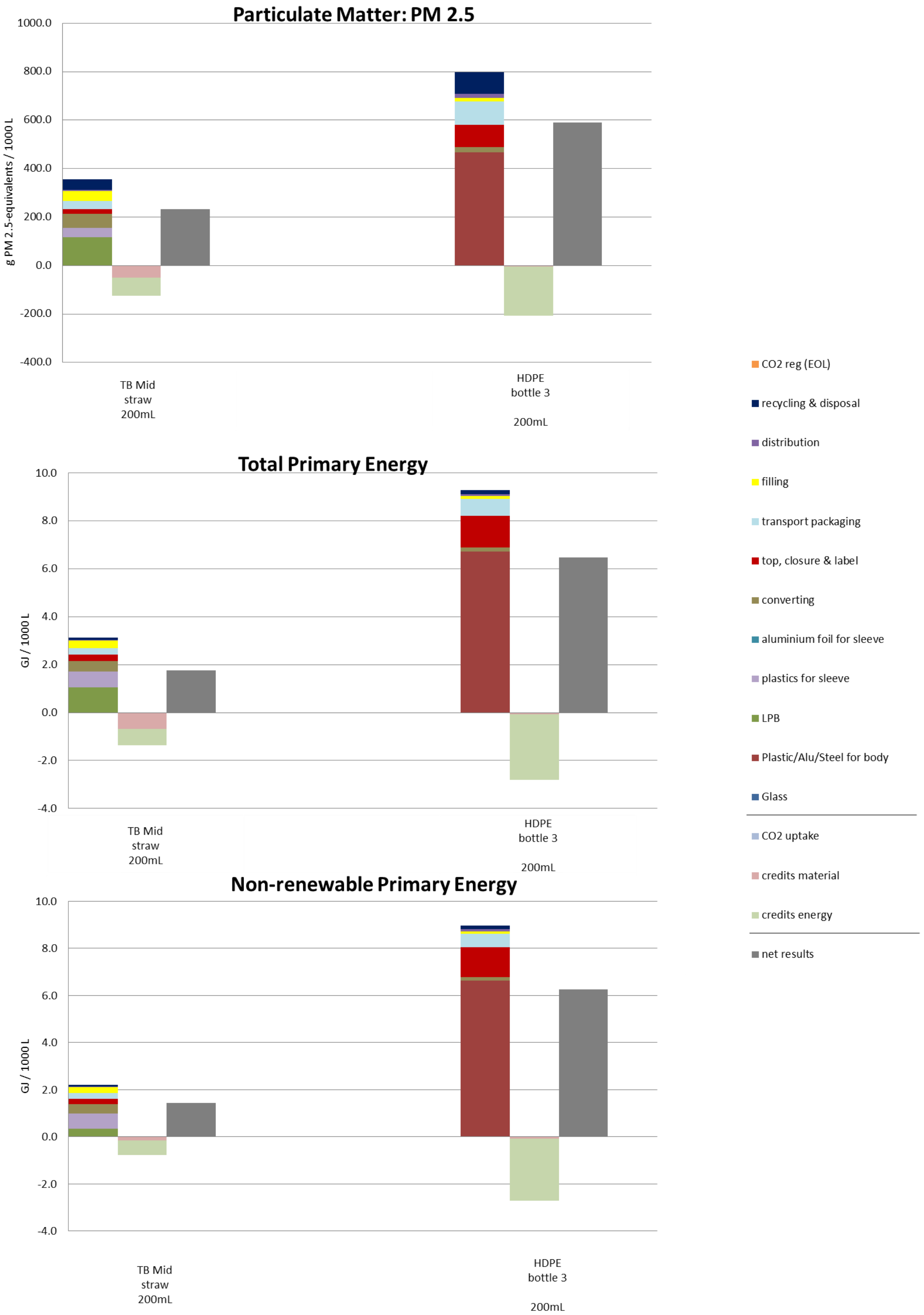


Figure 42: Indicator results for sensitivity analysis on system allocation of **segment DAIRY PORTION PACK CHILLED**, allocation factor 100% (Part 3)


Cumulative Raw material Demand (abiotic)
kg / 1000 L
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
-200.0
TB Mid straw 200mL
HDPE bottle 3 200mL
Use of Nature
m²e*year / 1000 L
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
TB Mid straw 200mL
HDPE bottle 3 200mL
Water use (related to water input)
m³ / 1000 L
water cool
water process
water unspecified
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
TB Mid straw 200mL
HDPE bottle 3 200mL
CO2 reg (EOL)
recycling & disposal
distribution
filling
transport packaging
top, closure & label
converting
aluminium foil for sleeve
plastics for sleeve
LPB
Plastic/Alu/Steel for body
Glass
CO2 uptake
credits material
credits energy
net results

Figure 43: Indicator results for sensitivity analysis on system allocation of **segment DAIRY PORTION PACK CHILLED**, allocation factor 100% (Part 4)

Table 53: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment DAIRY PORTION PACK CHILLED** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		TB Mid Straw 200mL		HDPE bottle 3 200mL
Climate Change [kg CO_2-e/1000 L]	Burdens	151.72		508.04
	CO2 (reg)	35.46		10.97
	Credits	-47.09		-230.12
	CO2 uptake	-51.90		-18.12
	net results	88.19		270.76
Acidification [kg SO_2-e/1000 L]	Burdens	0.37		0.87
	Credits	-0.14		-0.24
	Net results	0.23		0.64
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	5.17		10.71
	Credits	-1.52		-2.48
	Net results	3.65		8.23
Ozone Depletion [g R11 e/1000 L]	Burdens	0.08		0.16
	Credits	-0.02		-0.04
	Net results	0.06		0.12
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	39.81		78.47
	Credits	-11.81		-19.26
	Net results	28.00		59.21
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	37.42		112.11
	Credits	-7.27		-0.87
	Net results	30.15		111.23
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	357.07		796.86
	Credits	-125.02		-206.47
	Net results	232.05		590.39
Total Primary Energy [GJ/1000 L]	Burdens	3.12		9.28
	Credits	-1.37		-2.82
	Net results	1.75		6.46
Non-renewable Primary Energy [GJ/1000 L]	Burdens	2.22		8.97
	Credits	-0.77		-2.70
	Net results	1.44		6.26
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	72.74		974.72
	Credits	-23.86		-87.18
	Net results	48.88		887.55
Use of Nature [m^2e*year/1000 L]	Burdens	28.61		6.86
	Credits	-9.77		-0.20
	Net results	18.83		6.66
Water use [m^3/1000 L]	water cool	2.27		4.44
	water process	2.52		0.91
	water unspecified	0.61		2.58

4.6.2 Description and interpretation

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.

In the cases of beverage cartons in the segment DAIRY PORTION PACK CHILLED applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

In the case of the HDPE bottle, lower net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. The exceptions are 'Climate Change', 'Aquatic Eutrophication' and 'Use of Nature'. For these impacts categories net results stay about the same when applying the 100% allocation factor, as the additionally allocated credits and burdens show similar absolute values.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for beverage cartons and plastic bottles in this segment when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

4.6.3 Comparison between packaging systems

The following table shows the net results per functional unit of the regarded beverage cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following table show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 54: Comparison of net results: **TB Mid Straw 200mL** versus competing carton based and alternative packaging systems in **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 100%

DAIRY PORTION PACK (chilled), Europe, Allocation 100	The net results of **TB Mid Straw 200mL** are lower (green)/ higher (orange) than those of
	HDPE bottle 3 200mL
Climate Change	-67%
Acidification	-63%
Photo-Oxidant Formation	-56%
Ozone Depletion Potential	-51%
Terrestrial Eutrophication	-53%
Aquatic Eutrophication	-73%
Particulate Matter	-61%
Use of Nature	+183%

[1] ((|net result heading – net result column|) / net result column)*100

4.7 Results allocation factor 50%; JNSD FAMILY PACK AMBIENT

4.7.1 Presentation of results JNSD FAMILY PACK AMBIENT

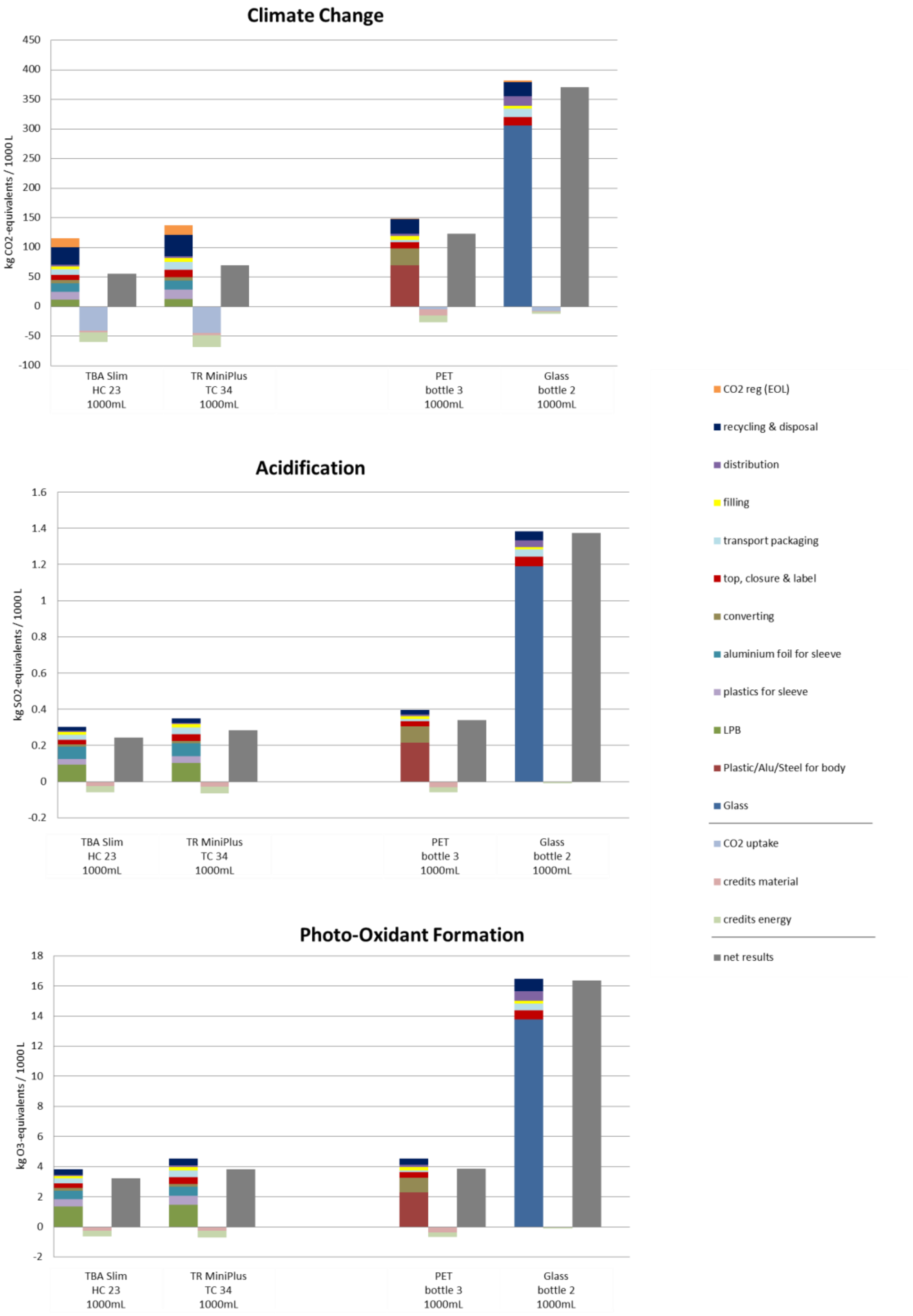


Figure 44: Indicator results of segment JNSD FAMILY PACK AMBIENT, allocation factor 50% (Part 1)

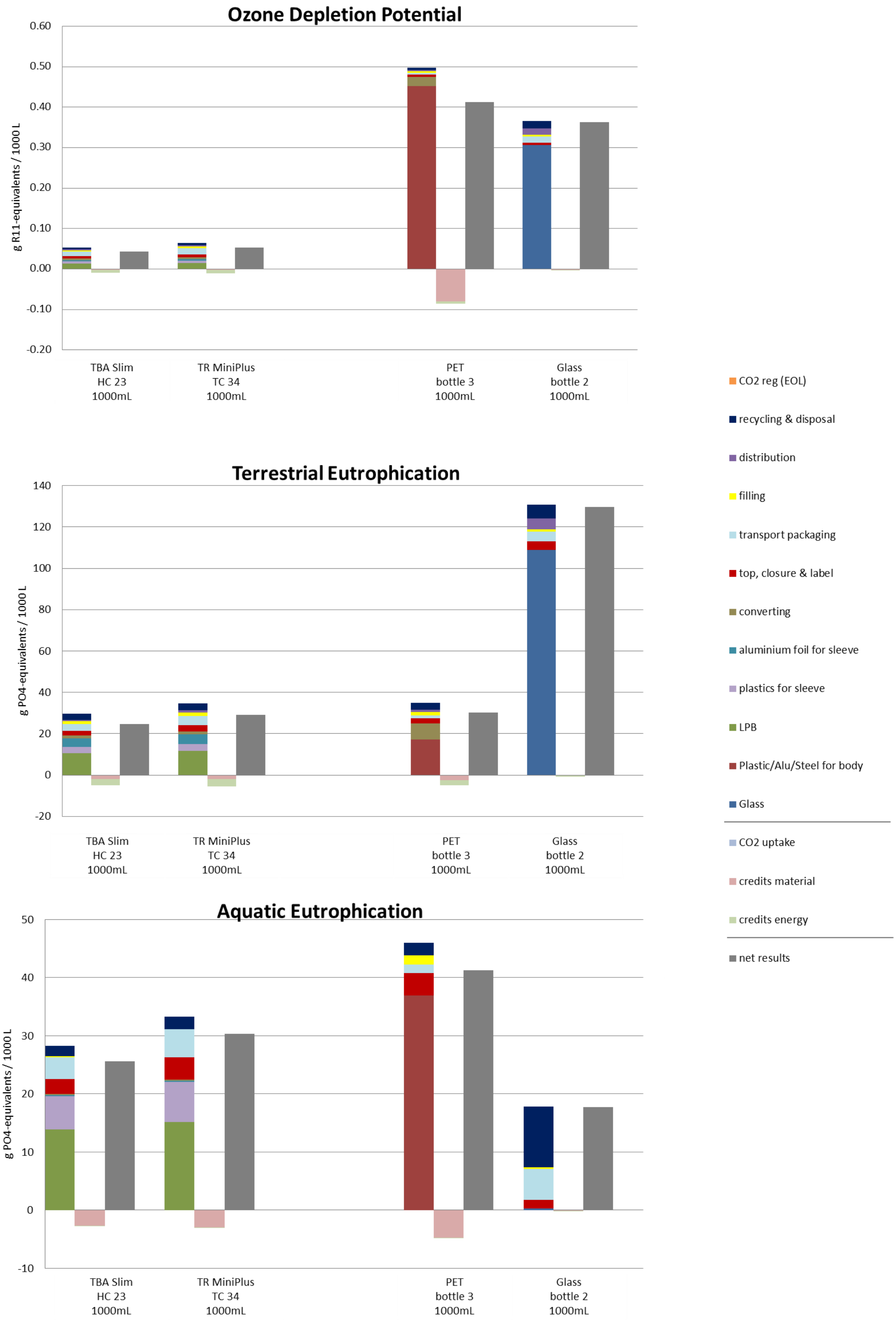


Figure 45 Indicator results of segment JNSD FAMILY PACK AMBIENT, allocation factor 50% (Part 2)

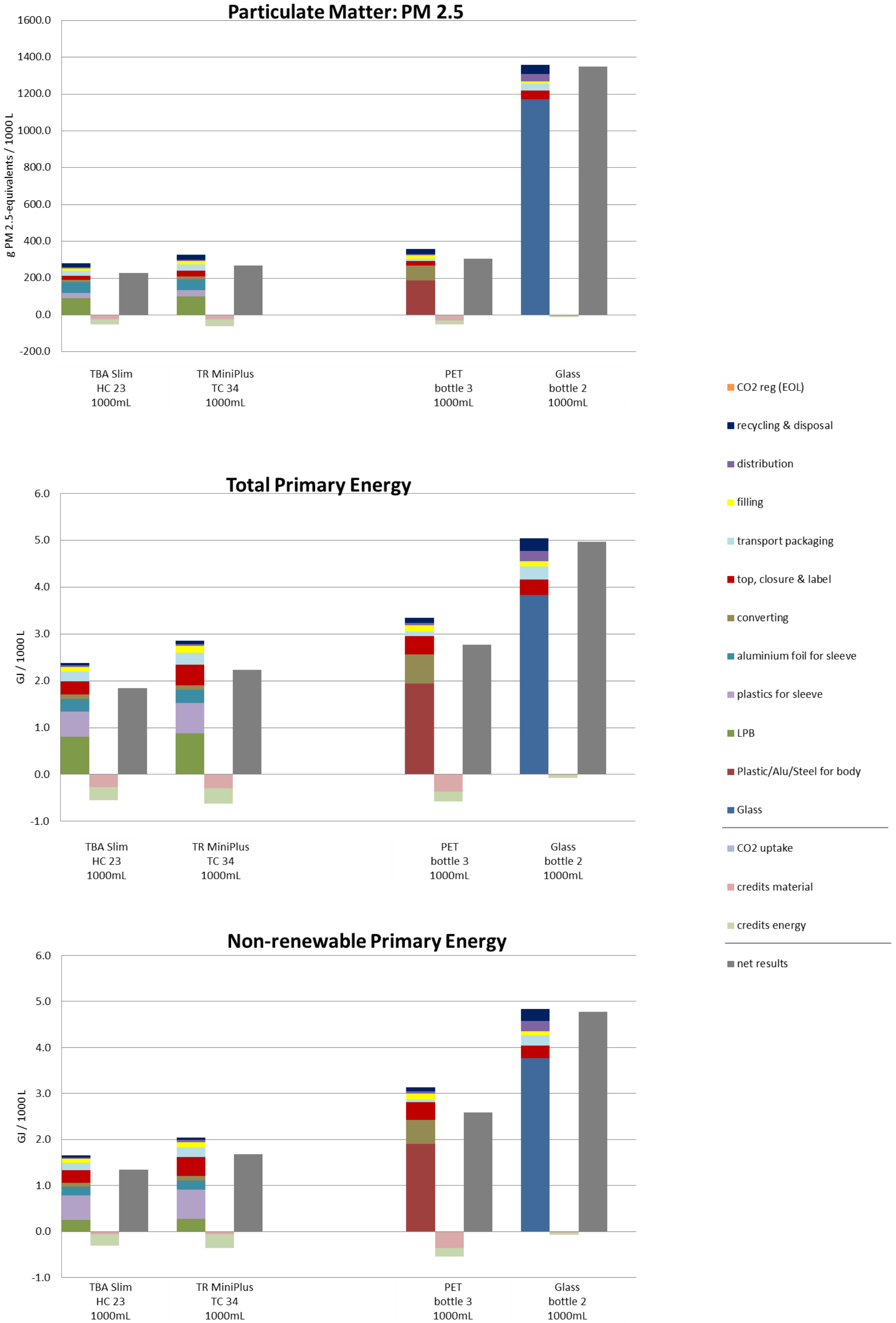


Figure 46: Indicator results of **segment JNSD FAMILY PACK AMBIENT**, allocation factor 50% (Part 3)

Figure 47: Indicator results of **segment JNSD FAMILY PACK AMBIENT**, allocation factor 50% (Part 4)

Table 55: Category indicator results per impact category of **segment JNSD FAMILY PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		TBA Slim HC 23 1000mL	TR MiniPlus TC 34 1000mL		PET bottle 3 1000mL	Glass bottle 2 1000mL
Climate Change [kg CO_2-e/1000 L]	Burdens	100.57	120.67		147.56	378.82
	CO2 (reg)	14.88	16.70		1.58	3.01
	Credits	-19.79	-23.22		-22.33	-4.06
	CO2 uptake	-40.32	-44.88		-4.14	-7.62
	net results	55.34	69.28		122.67	370.15
Acidification [kg SO_2-e/1000 L]	Burdens	0.30	0.35		0.40	1.38
	Credits	-0.06	-0.07		-0.06	-0.01
	Net results	0.24	0.28		0.34	1.37
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	3.83	4.54		4.53	16.47
	Credits	-0.62	-0.70		-0.66	-0.12
	Net results	3.21	3.83		3.87	16.35
Ozone Depletion [g R11 e/1000 L]	Burdens	0.05	0.06		0.50	0.37
	Credits	-0.01	-0.01		-0.09	0.00
	Net results	0.04	0.05		0.41	0.36
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	29.53	34.74		35.02	130.61
	Credits	-4.84	-5.50		-4.89	-0.92
	Net results	24.68	29.23		30.12	129.69
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	28.29	33.28		46.01	17.81
	Credits	-2.70	-2.96		-4.80	-0.10
	Net results	25.59	30.32		41.20	17.71
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	280.64	327.33		359.30	1360.45
	Credits	-52.09	-59.04		-52.08	-10.17
	Net results	228.56	268.29		307.22	1350.28
Total Primary Energy [GJ/1000 L]	Burdens	2.38	2.85		3.34	5.04
	Credits	-0.54	-0.62		-0.57	-0.07
	Net results	1.84	2.23		2.77	4.97
Non-renewable Primary Energy [GJ/1000 L]	Burdens	1.66	2.05		3.14	4.84
	Credits	-0.31	-0.36		-0.54	-0.07
	Net results	1.35	1.68		2.59	4.77
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	65.47	73.75		95.52	364.45
	Credits	-10.34	-11.95		-14.11	-4.04
	Net results	55.13	61.80		81.40	360.41
Use of Nature [m²e*year/1000 L]	Burdens	21.96	24.33		0.93	3.07
	Credits	-3.82	-4.16		-0.04	-0.02
	Net results	18.14	20.17		0.89	3.05
Water use [m³/1000 L]	water cool	1.47	1.87		3.49	1.86
	water process	2.00	2.14		1.01	0.28
	water unspecified	0.77	0.89		0.65	0.43

4.7.2 Description and interpretation

Beverage carton systems (specifications see section 2.2.1)

For the beverage carton systems considered in the JNSD FAMILY PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the beverage carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (45%-49%) and 'Use of Nature' (89%-91%). It is also relevant regarding 'Photo-Oxidant Formation' (32%-35%) 'Acidification' (29%-31%), 'Terrestrial Eutrophication' (33%-36%), 'Particulate Matter' (31%-33%) and also the consumption of 'Total Primary Energy' (31%-34%). Regarding 'Climate Change' the production of LPB is responsible for only 9%-10% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The production of 'aluminium foil' for the sleeves of the ambient beverage carton shows burdens in most impact categories. Considerable shares of burdens can be seen for the categories 'Acidification' (20%-23%) and 'Particulate Matter' (18%-20%). These result from SO_2 and NOx emissions from the aluminium production. Also the inventory category 'Cumulative Raw material Demand (abiotic)' shows considerable shares of burdens (21%-22%).

The production of 'plastics for sleeve' of the beverage cartons shows considerable burdens in most impact categories (up to 32%). These are considerably lower than those of the LPB

production, which is easily explained by its lower material share than that of LPB. The exceptions are climate change and the inventory category 'Cumulative Raw material Demand (abiotic)', where plastics and LPB contribute about the same as well as the inventory category 'Non-renewable Primary Energy', where the plastics contribute about the doubled share of the total burdens than LPB.

The life cycle step 'top, closure & label' for beverage cartons contributes with small to minor shares in almost all impact categories (0%-20%). Considerable shares of burdens are seen for 'Cumulative Raw material Demand (abiotic)' (23%-24%).

The 'converting' process generally plays a minor role (0%-8%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show small to minor impacts in most categories (7%-15%). The exception is 'Ozone Depletion Potential' for the cartons with fossil based plastics. In these cases 'transport packaging' has a higher share of (21%-22%) of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle step 'filling' shows only small shares of burdens (up to 8%) for all beverage carton systems in all impact categories.

The life cycle step 'distribution' shows only small burdens in all impact categories for all beverage carton systems (max. 4%).

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact category 'Climate Change' (26%-26%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. In case of beverage cartons these derive mainly from the incineration of plant-based plastics and paper. They play an important role (12%-13%) for the results of all beverage carton systems in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-15% of the total burdens. Material credits from material recycling are in most categories lower (3%-17%). Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'.

The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section 1.7.2)

Plastic bottles (specifications see section 2.2.2)

In the regarded plastic bottle system in the JNSD FAMILY PACK segment, the biggest part of the environmental burdens is also caused by the production of the base materials of the bottles in most impact and inventory categories. In case of 'Ozone Depletion Potential' the main contributor to the high impacts is methyl bromide which is emitted in the production process for purified terephthalic acid (PTA) which is a pre-product of PET.

The 'converting' process shows for the PET bottle in this segment a small to considerable share of burdens (5%-22%) in all categories apart from 'Aquatic Eutrophication', for which the share of burdens is less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows small to minor impacts shares (1%-12%) in most categories mainly attributed to the different plastics used for the closures and the aluminium pull tab. Considerable shares of burdens are seen for 'Cumulative Raw material Demand (abiotic)' (23%).

The production and provision of 'transport packaging' for the bottle system show small impact shares (1%-4%) in most categories. The exception is 'Use of Nature' for which 76% of the burdens are caused from 'transport packaging' resulting from the used cardboard and wood for pallets.

The life cycle step 'filling' shows only small shares of burdens (max. 5%) for all bottle systems in all impact categories.

The life cycle step 'distribution' shows only small shares of burdens in all impact categories for all bottle systems (max. 3%).

The impact of the plastic bottles' 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (17%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

Energy credits have a small influence of on the net results in all categories (up to 8% of the total burdens). The energy credits mainly originate from the incineration plants and cement kilns.

Material credits have considerable influence on the net results in all categories (2%-16% of the total burdens). They result from the substitution of primary PET with recycled PET from the bottles.

Glass bottle (specifications see section 2.2.2)

Even more than for the other regarded packaging systems, the production of the 'glass' material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results (76%-91%) in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'.

All other life cycle steps play only a minor role compared to the glass production. For the impact categories, 'Aquatic Eutrophication' (30%) and 'Use of Nature' (81%) transport packaging also plays a visible role due do the cardboard used for secondary and tertiary packaging.

Energy credits play only a minor role for the glass bottle, as the little energy that can be generated in end-of-life mainly comes from the incineration of secondary and tertiary packaging.

Material credits from glass recycling have a small impact on the overall net results as the cullet is used in a closed loop. The use of closed loop cullet can be seen in the reduced impacts of the life cycle step for the production of 'glass'.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.7.3 Comparison between packaging systems

The following tables show the net results per functional unit of the studied beverage carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 56: Comparison of net results: **TBA Slim HC 23 1000mL** versus competing carton based and alternative packaging systems in **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 50%

JNSD FAMILY PACK (ambient), Europe, Allocation 50	The net results of **TBA SlimHC 23 1000mL** are lower (green)/ higher (orange) than those of		
	TR MiniPlus TC 34 1000mL	PET bottle 3 1000mL	Glass bottle 2 1000mL
Climate Change	-20%	-55%	-85%
Acidification	-14%	-28%	-82%
Photo-Oxidant Formation	-16%	-17%	-80%
Ozone Depletion Potential	-19%	-90%	-88%
Terrestrial Eutrophication	-16%	-18%	-81%
Aquatic Eutrophication	-16%	-38%	+45%
Particulate Matter	-15%	-26%	-83%
Use of Nature	-10%	+1938%	+494%

Table 57: Comparison of net results: **TR MiniPlus TC 34 1000mL** versus competing carton based and alternative packaging systems in **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 50%

JNSD FAMILY PACK (ambient), Europe, Allocation 50	The net results of **TR MiniPlus TC 34 1000mL** are lower (green)/ higher (orange) than those of		
	TBA Slim HC 23 1000mL	PET bottle 3 1000mL	Glass bottle 2 1000mL
Climate Change	+25%	-44%	-81%
Acidification	+17%	-16%	-79%
Photo-Oxidant Formation	+19%	-1%	-77%
Ozone Depletion Potential	+23%	-87%	-85%
Terrestrial Eutrophication	+18%	-3%	-77%
Aquatic Eutrophication	+18%	-26%	+71%
Particulate Matter	+17%	-13%	-80%
Use of Nature	+11%	+2165%	+561%

4.8 Results allocation factor 100%; JNSD FAMILY PACK AMBIENT

4.8.1 Presentation of results JNSD FAMILY PACK AMBIENT

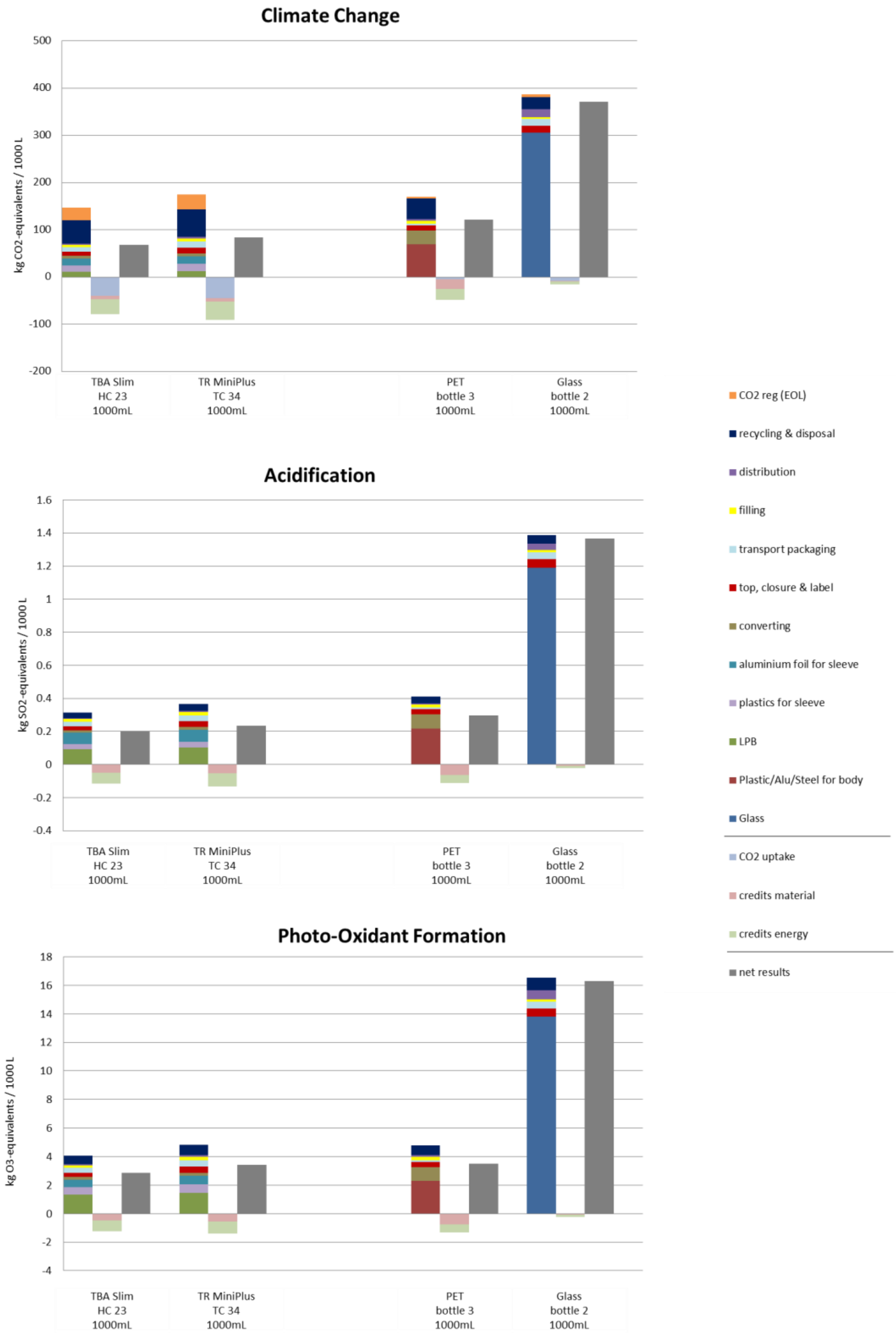


Figure 48: Indicator results for sensitivity analysis on system allocation of **segment JNSD FAMILY PACK AMBIENT**, allocation factor 100% (Part 1)

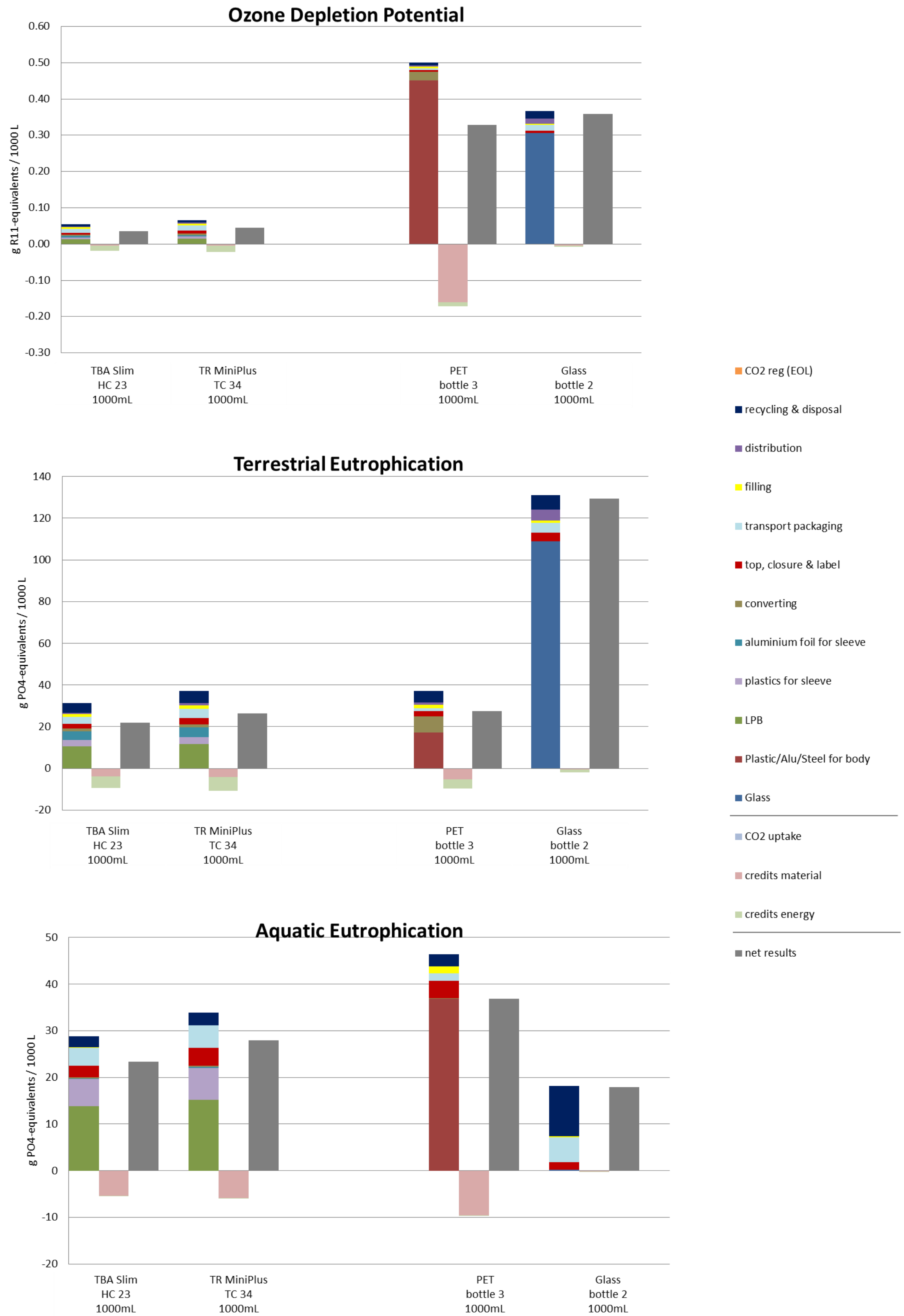


Figure 49: Indicator results for sensitivity analysis on system allocation of **segment JNSD FAMILY PACK AMBIENT**, allocation factor 100% (Part 2)

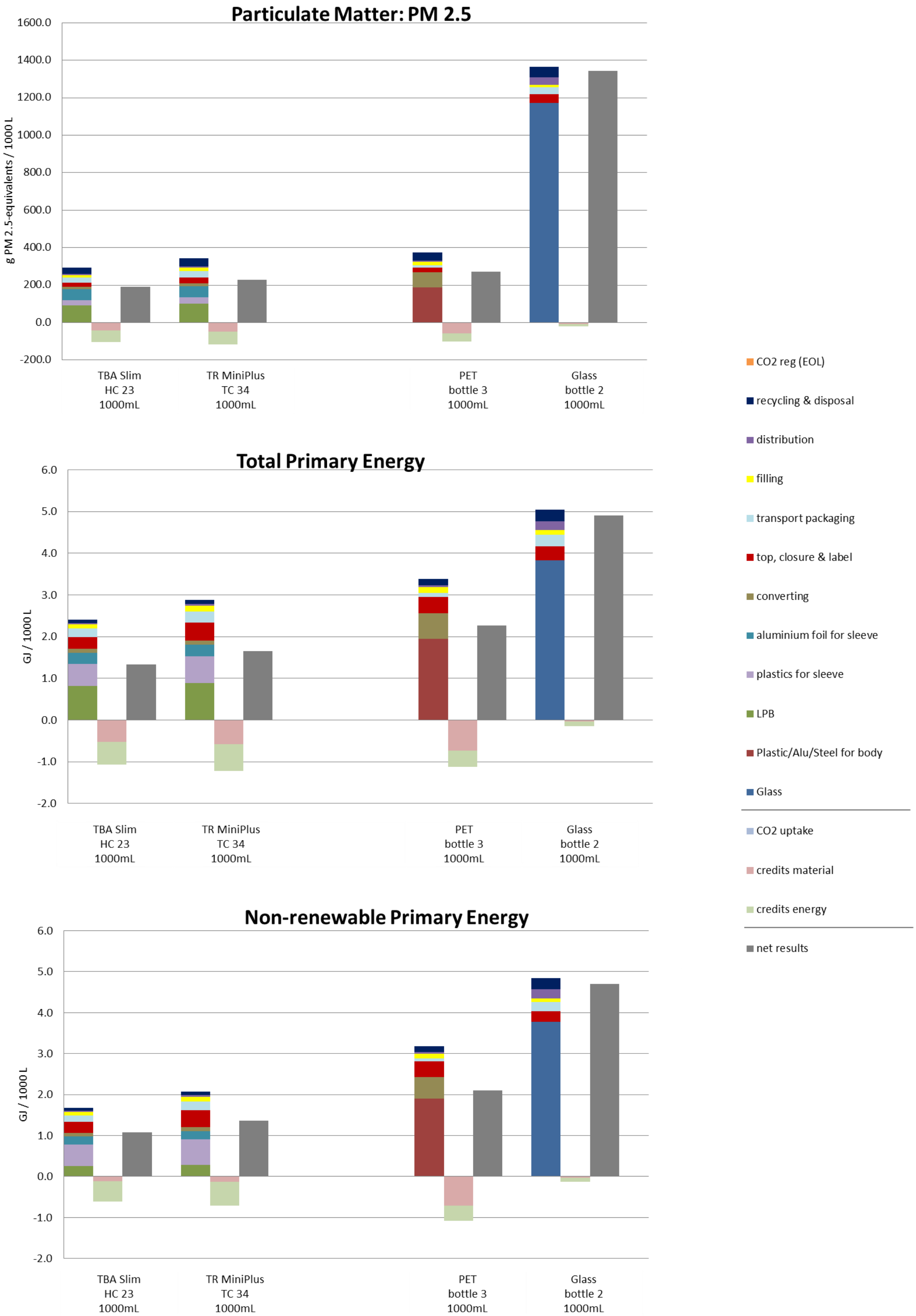


Figure 50: Indicator results for sensitivity analysis on system allocation of **segment JNSD FAMILY PACK AMBIENT**, allocation factor 100% (Part 3)

Figure 51: Indicator results for sensitivity analysis on system allocation of **segment JNSD FAMILY PACK AMBIENT**, allocation factor 100% (Part 4)

Table 58: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment JNSD FAMILY PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		TBA Slim HC 23 1000mL	TR MiniPlus TC 34 1000mL		PET bottle 3 1000mL	Glass bottle 2 1000mL
Climate Change [kg CO_2-e/1000 L]	Burdens	119.66	143.72		166.47	381.16
	CO2 (reg)	27.46	30.82		3.15	6.02
	Credits	-38.74	-45.51		-43.64	-8.08
	CO2 uptake	-40.32	-44.88		-4.14	-7.62
	net results	68.07	84.15		121.85	371.48
Acidification [kg SO_2-e/1000 L]	Burdens	0.32	0.37		0.41	1.39
	Credits	-0.12	-0.13		-0.11	-0.02
	Net results	0.20	0.24		0.30	1.37
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	4.07	4.82		4.78	16.53
	Credits	-1.22	-1.38		-1.30	-0.24
	Net results	2.86	3.43		3.48	16.30
Ozone Depletion [g R11 e/1000 L]	Burdens	0.05	0.07		0.50	0.37
	Credits	-0.02	-0.02		-0.17	-0.01
	Net results	0.04	0.04		0.33	0.36
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	31.44	37.01		37.09	131.13
	Credits	-9.52	-10.82		-9.57	-1.83
	Net results	21.93	26.19		27.51	129.29
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	28.79	33.83		46.40	18.14
	Credits	-5.40	-5.91		-9.60	-0.20
	Net results	23.39	27.92		36.80	17.95
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	294.72	343.99		374.95	1364.00
	Credits	-102.68	-116.42		-102.01	-20.24
	Net results	192.04	227.57		272.94	1343.76
Total Primary Energy [GJ/1000 L]	Burdens	2.40	2.87		3.39	5.04
	Credits	-1.07	-1.22		-1.12	-0.14
	Net results	1.33	1.65		2.26	4.90
Non-renewable Primary Energy [GJ/1000 L]	Burdens	1.68	2.07		3.18	4.84
	Credits	-0.61	-0.71		-1.07	-0.13
	Net results	1.08	1.36		2.11	4.71
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	66.14	74.51		96.87	364.55
	Credits	-20.28	-23.44		-27.75	-8.06
	Net results	45.86	51.06		69.12	356.49
Use of Nature [m²e*year/1000 L]	Burdens	21.96	24.34		0.94	3.07
	Credits	-7.64	-8.32		-0.08	-0.04
	Net results	14.33	16.01		0.86	3.04
Water use [m³/1000 L]	water cool	0.97	1.30		3.02	1.78
	water process	1.84	1.96		0.99	0.28
	water unspecified	0.73	0.85		0.52	0.42

4.8.2 Description and interpretation

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.

In the cases of beverage cartons in the segment JNSD FAMILY PACK AMBIENT applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

In the case of the PET bottle, lower net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. The exceptions are 'Climate Change'. For 'Climate Change' net results stay about the same when applying the 100% allocation factor, as the additionally allocated credits and burdens show similar absolute values.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for beverage cartons and plastic bottles in this segment when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

In the case of single use glass bottle, net results of all categories stay about the same when applying the 100% allocation factor as burdens from recycling and disposal are similar than energy and material credits due to the closed loop use of cullet.

4.8.3 Comparison between packaging systems

The following tables show the net results per functional unit of the regarded beverage cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 59: Comparison of net results: **TBA Slim HC 23 1000mL** versus competing carton based and alternative packaging systems in **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 100%

JNSD FAMILY PACK (ambient), Europe, Allocation 100	The net results of **TBA SlimHC 23 1000mL** are lower (green)/ higher (orange) than those of		
	TR MiniPlus TC 34 1000mL	PET bottle 3 1000mL	Glass bottle 2 1000mL
Climate Change	-19%	-44%	-82%
Acidification	-15%	-33%	-85%
Photo-Oxidant Formation	-17%	-18%	-82%
Ozone Depletion Potential	-20%	-89%	-90%
Terrestrial Eutrophication	-16%	-20%	-83%
Aquatic Eutrophication	-16%	-36%	+30%
Particulate Matter	-16%	-30%	-86%
Use of Nature	-11%	+1567%	+372%

Table 60: Comparison of net results: **TR MiniPlus TC 34 1000mL** versus competing carton based and alternative packaging systems in **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 100%

JNSD FAMILY PACK (ambient), Europe, Allocation 100	The net results of **TR MiniPlus TC 34 1000mL** are lower (green)/ higher (orange) than those of		
	TBA Slim HC 23 1000mL	PET bottle 3 1000mL	Glass bottle 2 1000mL
Climate Change	+24%	-31%	-77%
Acidification	+18%	-21%	-83%
Photo-Oxidant Formation	+20%	-1%	-79%
Ozone Depletion Potential	+24%	-86%	-87%
Terrestrial Eutrophication	+19%	-5%	-80%
Aquatic Eutrophication	+19%	-24%	+56%
Particulate Matter	+19%	-17%	-83%
Use of Nature	+12%	+1763%	+428%

[1] ((|net result heading – net result column|) / net result column)*100

4.9 Results allocation factor 50%; JNSD PORTION PACK AMBIENT

4.9.1 Presentation of results JNSD PORTION PACK AMBIENT

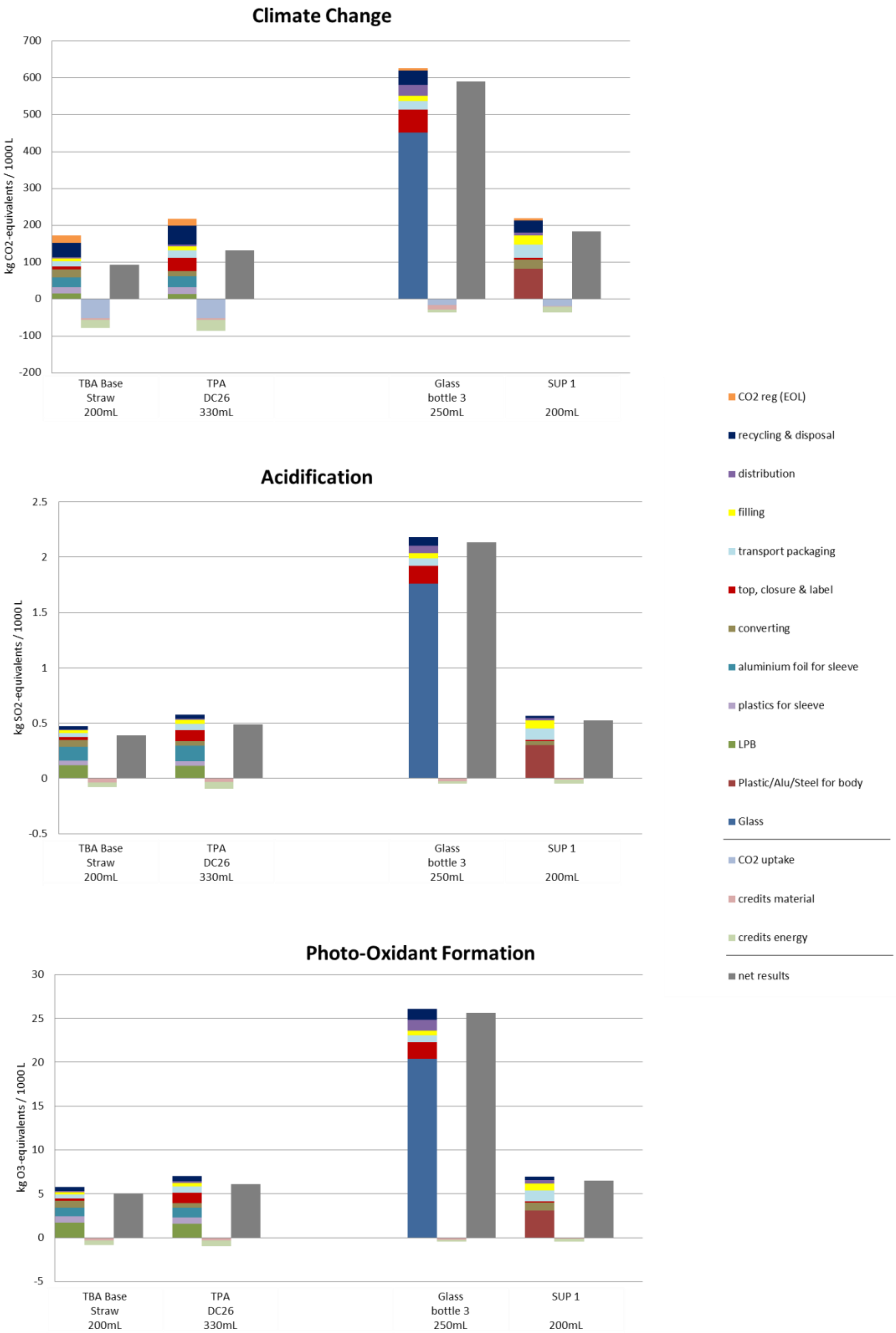


Figure 52: Indicator results of **segment JNSD PORTION PACK AMBIENT**, allocation factor 50% (Part 1)

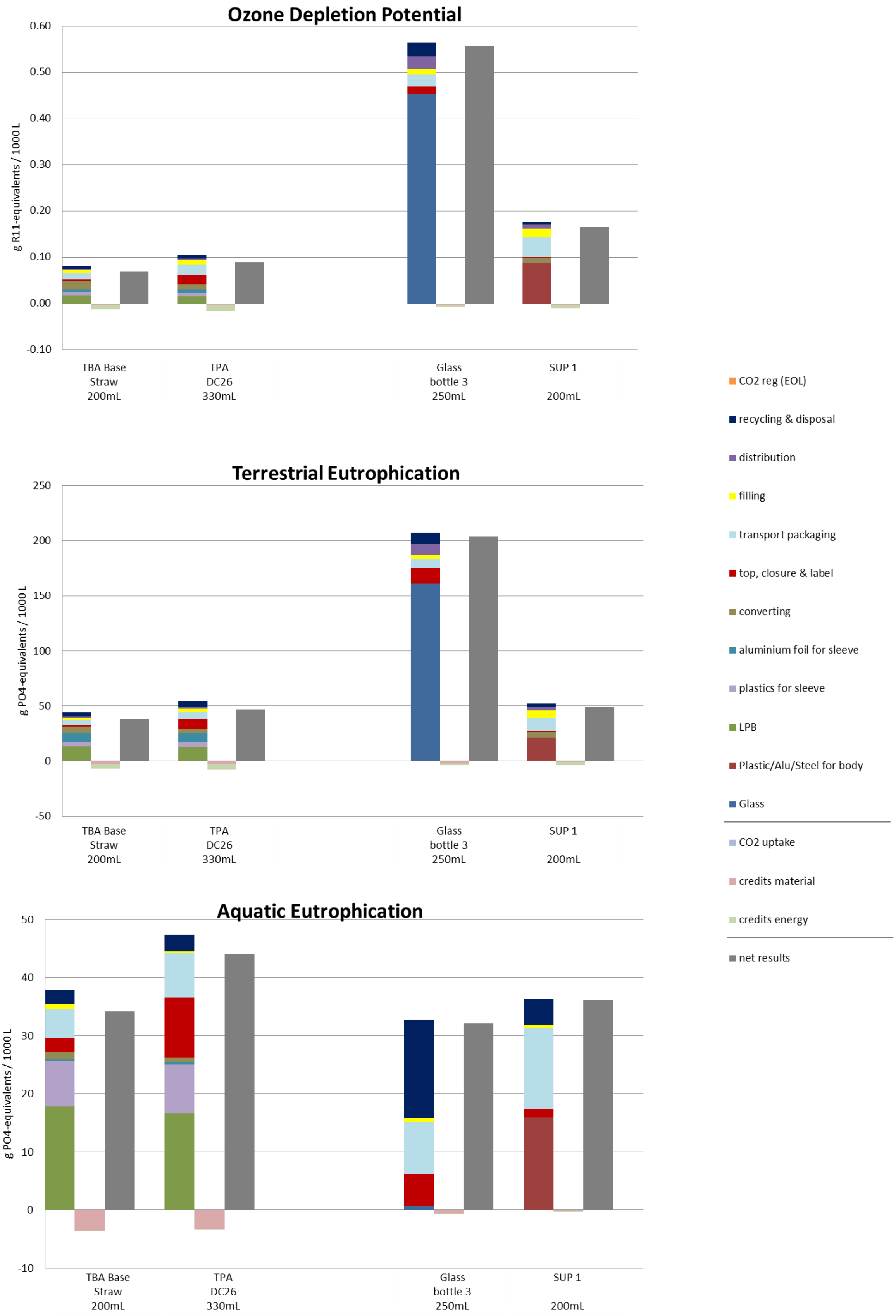


Figure 53 Indicator results of segment JNSD PORTION PACK AMBIENT, allocation factor 50% (Part 2)

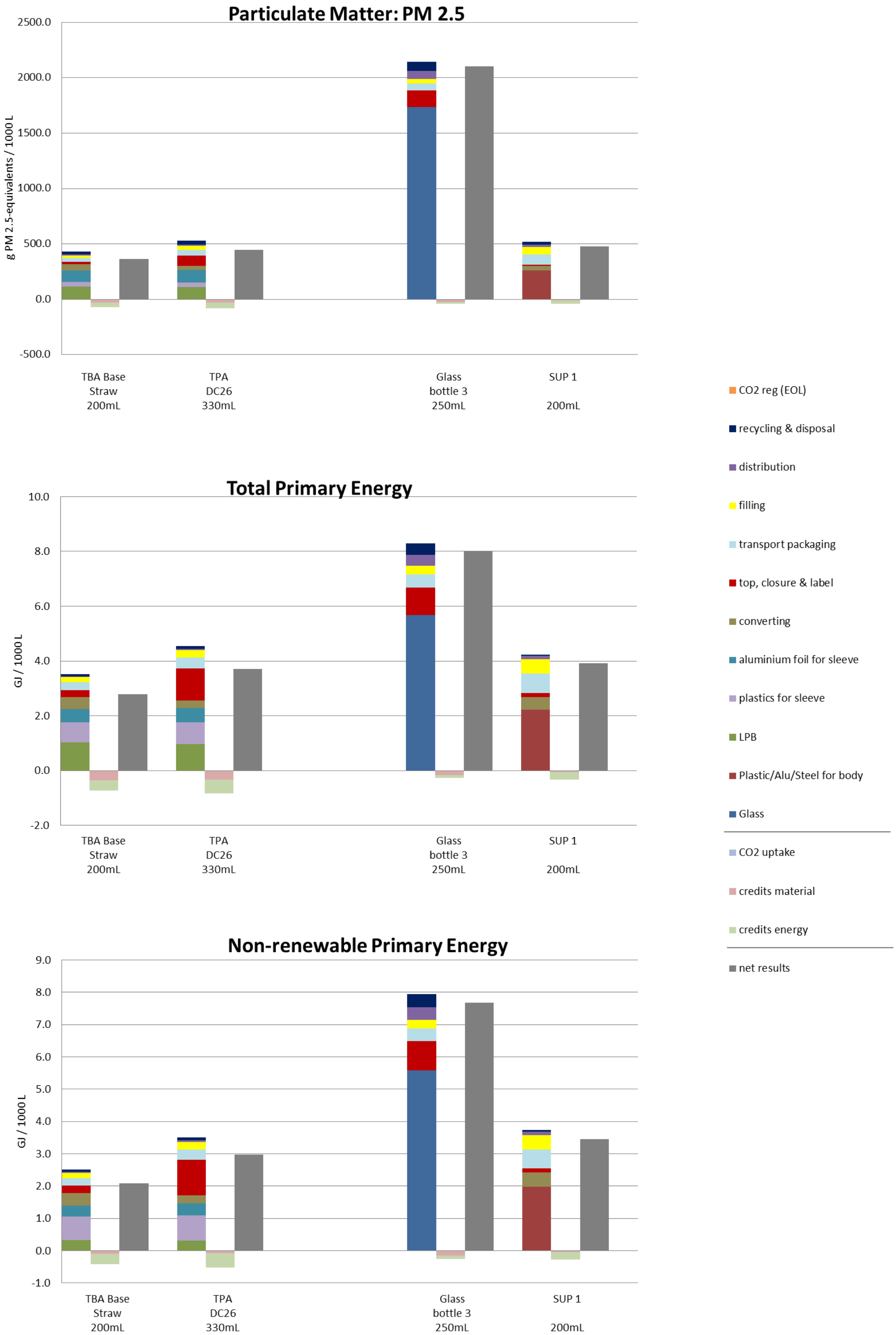


Figure 54: Indicator results of **segment JNSD PORTION PACK AMBIENT**, allocation factor 50% (Part 3)

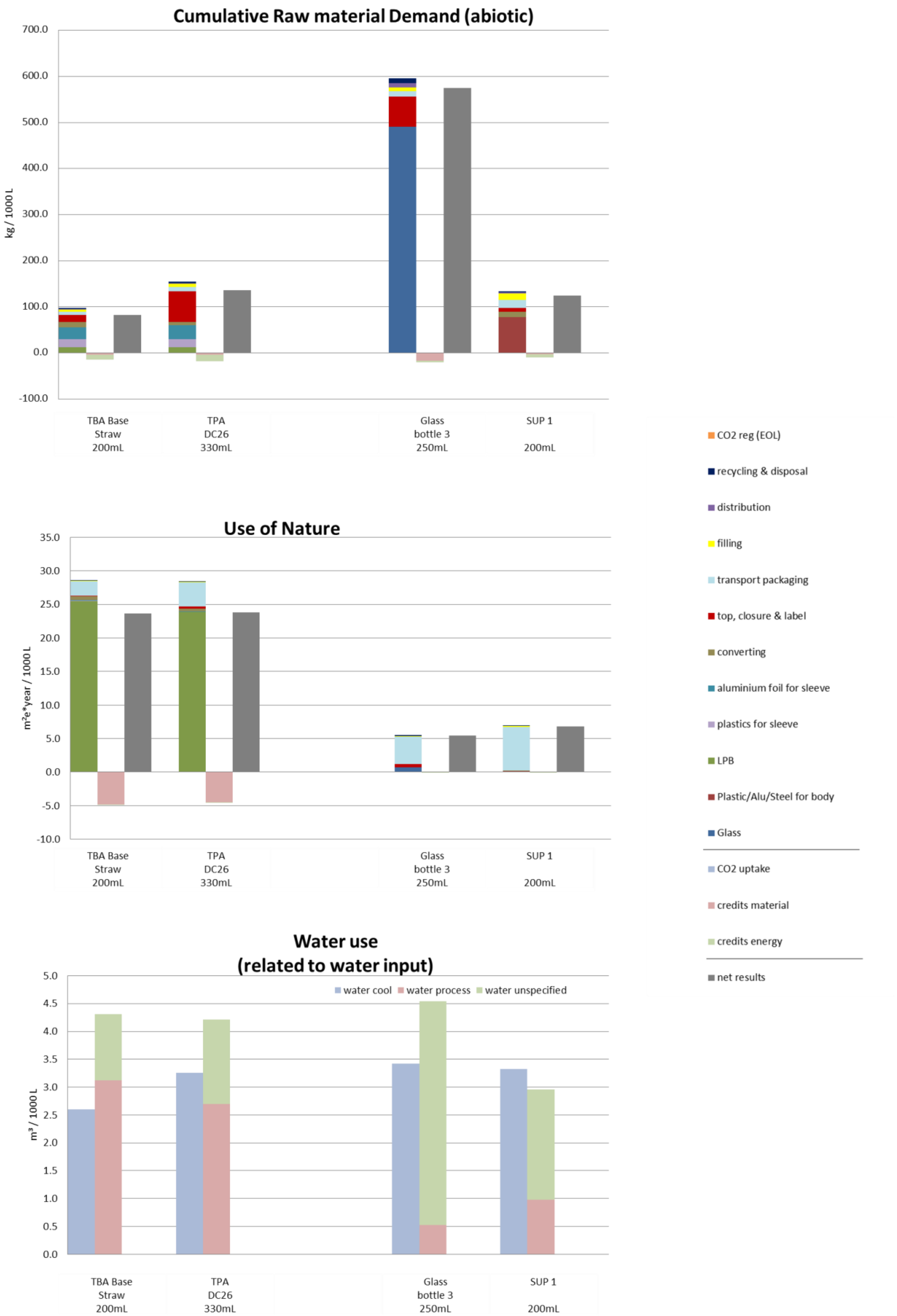


Figure 55: Indicator results of segment JNSD PORTION PACK AMBIENT, allocation factor 50% (Part 4)

Table 61: Category indicator results per impact category of **segment JNSD PORTION PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		TBA Base Straw 200mL	TPA DC 26 330mL		Glass bottle 3 250mL	SUP 1 200mL
Climate Change [kg CO_2-e/1000 L]	Burdens	153.15	199.07		619.96	213.33
	CO2 (reg)	19.14	19.25		6.56	5.48
	Credits	-26.63	-34.19		-19.32	-17.29
	CO2 uptake	-51.68	-51.51		-16.23	-18.12
	net results	93.98	132.63		590.97	183.40
Acidification [kg SO_2-e/1000 L]	Burdens	0.47	0.58		2.18	0.57
	Credits	-0.08	-0.09		-0.04	-0.05
	Net results	0.39	0.49		2.14	0.52
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	5.80	7.05		26.08	6.97
	Credits	-0.84	-0.97		-0.45	-0.48
	Net results	4.96	6.08		25.64	6.49
Ozone Depletion [g R11 e/1000 L]	Burdens	0.08	0.10		0.56	0.18
	Credits	-0.01	-0.02		-0.01	-0.01
	Net results	0.07	0.09		0.56	0.17
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	44.30	54.34		207.02	52.32
	Credits	-6.50	-7.56		-3.44	-3.70
	Net results	37.80	46.78		203.58	48.62
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	37.82	47.35		32.71	36.33
	Credits	-3.62	-3.33		-0.59	-0.24
	Net results	34.20	44.02		32.12	36.09
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	433.82	530.87		2143.23	517.42
	Credits	-70.28	-81.18		-40.34	-39.88
	Net results	363.54	449.69		2102.89	477.55
Total Primary Energy [GJ/1000 L]	Burdens	3.52	4.54		8.29	4.23
	Credits	-0.73	-0.83		-0.27	-0.32
	Net results	2.79	3.72		8.01	3.91
Non-renewable Primary Energy [GJ/1000 L]	Burdens	2.52	3.50		7.94	3.74
	Credits	-0.43	-0.53		-0.26	-0.28
	Net results	2.09	2.98		7.68	3.45
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	97.08	154.28		595.41	133.40
	Credits	-14.38	-17.64		-20.45	-9.53
	Net results	82.70	136.64		574.95	123.87
Use of Nature [m²e*year/1000 L]	Burdens	28.52	28.35		5.49	6.86
	Credits	-4.87	-4.60		-0.04	-0.06
	Net results	23.65	23.76		5.45	6.80
Water use [m³/1000 L]	water cool	2.60	3.26		3.42	3.32
	water process	3.12	2.69		0.53	0.98
	water unspecified	1.19	1.52		4.01	1.98

4.9.2 Description and interpretation

Beverage carton systems (specifications see section 2.2.1)

For the beverage carton systems considered in the JNSD PORTION PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the beverage carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (35%-47%) and 'Use of Nature' (84%-89%). It is also relevant regarding 'Photo-Oxidant Formation' (23%-29%) 'Acidification' (20%-26%), 'Terrestrial Eutrophication' (24%-31%), 'Particulate Matter' (21%-27%) and also the consumption of 'Total Primary Energy' (21%-30%). Regarding 'Climate Change' the production of LPB is responsible for only 9% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The production of 'aluminium foil' for the sleeves of the ambient beverage carton shows burdens in most impact categories. Considerable shares of burdens can be seen for the categories 'Acidification' (24%-26%) and 'Particulate Matter' (22%-24%). These result from SO_2 and NOx emissions from the aluminium production. Also the inventory category 'Cumulative Raw material Demand (abiotic)' shows considerable shares of burdens (19%-27%).

The production of 'plastics for sleeve' of the beverage cartons shows considerable burdens in most impact categories (up to 29%). These are considerably lower than those of the LPB

production, which is easily explained by its lower material share than that of LPB. The exceptions are climate change and the inventory category 'Cumulative Raw material Demand (abiotic)', where plastics and LPB contribute about the same as well as the inventory category 'Non-renewable Primary Energy', where the plastics contribute about the doubled share of the total burdens than LPB.

The life cycle step 'top, closure & label' for TBA carton contributes to a small to minor amount in almost all impact categories (0%-15%) resulting from the production of the straw. In case of the TPA carton this life cycle step contributes to 1%-43% of the burdens resulting from the production of the closure.

The 'converting' process plays a small to considerable role (1%-21%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show small to minor impacts in most categories (6%-16%). The exception is 'Ozone Depletion Potential' for the cartons with fossil based plastics. In these cases 'transport packaging' has a higher share of 18%-22% of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle step 'filling' shows only small shares of burdens (up to 9%) for all beverage carton systems in all impact categories.

The life cycle step 'distribution' shows only small burdens in all impact categories for all beverage carton systems (max. 4%).

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact category 'Climate Change' (23%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. In case of beverage cartons these derive mainly from the incineration of plant-based plastics and paper. They play an important role (9%-11%) for the results of all beverage carton systems in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-14% of the total burdens. Material credits from material recycling are lower in most categories (2%-17%). Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section 1.7.2)

Glass bottle (specifications see section 2.2.2)

Even more than for the other regarded packaging systems, the production of the 'glass' material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results (72%-82%) in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'.

All other life cycle steps play only a minor role compared to the glass production. For the impact categories, 'Aquatic Eutrophication' (27%) and 'Use of Nature' (76%) transport packaging also plays a visible role due do the cardboard used for secondary and tertiary packaging.

Energy credits play only a minor role for the glass bottle, as the little energy that can be generated in end-of-life mainly comes from the incineration of secondary and tertiary packaging.

Material credits from glass recycling have a small impact on the overall net results as the cullet is used in a closed loop. The use of closed loop cullet can be seen in the reduced impacts of the life cycle step for the production of 'glass'.

Stand up pouch (SUP) (specifications see section 2.2.2)

For the regarded SUP, the biggest part of the environmental burdens is caused by the production of the base materials (plastics and aluminium foil of the pouch in most categories (37%-58%).

The 'converting' process of the SUP shows minor shares of impacts (7%-13%) in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature' with shares of impacts less than 1%. Emissions from the 'converting' process almost exclusively derive from electricity production.

The production and provision of 'transport packaging' for the SUP show minor to considerable shares of impacts (13%-39%) in all categories except of 'Use of Nature' in which the paper production contributes to 95% of the burdens.

The life cycle step 'filling' shows small to minor shares of burdens (1%-13%) for the SUP in most impact categories.

The life cycle step 'distribution' shows only small shares of burdens (up to 6%) for the SUP in most impact categories.

The impact of the SUP's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (15%). The incineration of SUPs in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is low in most categories. With no recycling of SUPs all SUPs are incinerated or landfilled. The energy credits mainly originate from the incineration plants.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.9.3 Comparison between packaging systems

The following tables show the net results per functional unit of the studied beverage carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 62: Comparison of net results: **TBA Base Straw 200mL** versus competing carton based and alternative packaging systems in **segment JNSD PORTION PACK (ambient), Europe**, allocation factor 50%

JNSD PORTION PACK (ambient), Europe, Allocation 50	The net results of **TBA Base Straw 200mL** are lower (green)/ higher (orange) than those of		
	TPA DC 26 330mL	Glass bottle 3 250mL	SUP 1 200mL
Climate Change	-29%	-84%	-49%
Acidification	-20%	-82%	-25%
Photo-Oxidant Formation	-18%	-81%	-24%
Ozone Depletion Potential	-23%	-88%	-59%
Terrestrial Eutrophication	-19%	-81%	-22%
Aquatic Eutrophication	-22%	+6%	-5%
Particulate Matter	-19%	-83%	-24%
Use of Nature	-0%	+334%	+248%

Table 63: Comparison of net results: **TPA DC26 330mL** versus competing carton based and alternative packaging systems in **segment JNSD PORTION PACK (ambient), Europe**, allocation factor 50%

JNSD PORTION PACK (ambient), Europe, Allocation 50	The net results of **TPA DC26 330mL** are lower (green)/ higher (orange) than those of		
	TBA Base Straw 200mL	Glass bottle 3 250mL	SUP 1 200mL
Climate Change	+41%	-78%	-28%
Acidification	+24%	-77%	-7%
Photo-Oxidant Formation	+23%	-76%	-6%
Ozone Depletion Potential	+30%	-84%	-46%
Terrestrial Eutrophication	+24%	-77%	-4%
Aquatic Eutrophication	+29%	+37%	+22%
Particulate Matter	+24%	-79%	-6%
Use of Nature	+0%	+336%	+249%

4.10 Results allocation factor 100%; JNSD PORTION PACK AMBIENT

4.10.1 Presentation of results JNSD PORTION PACK AMBIENT

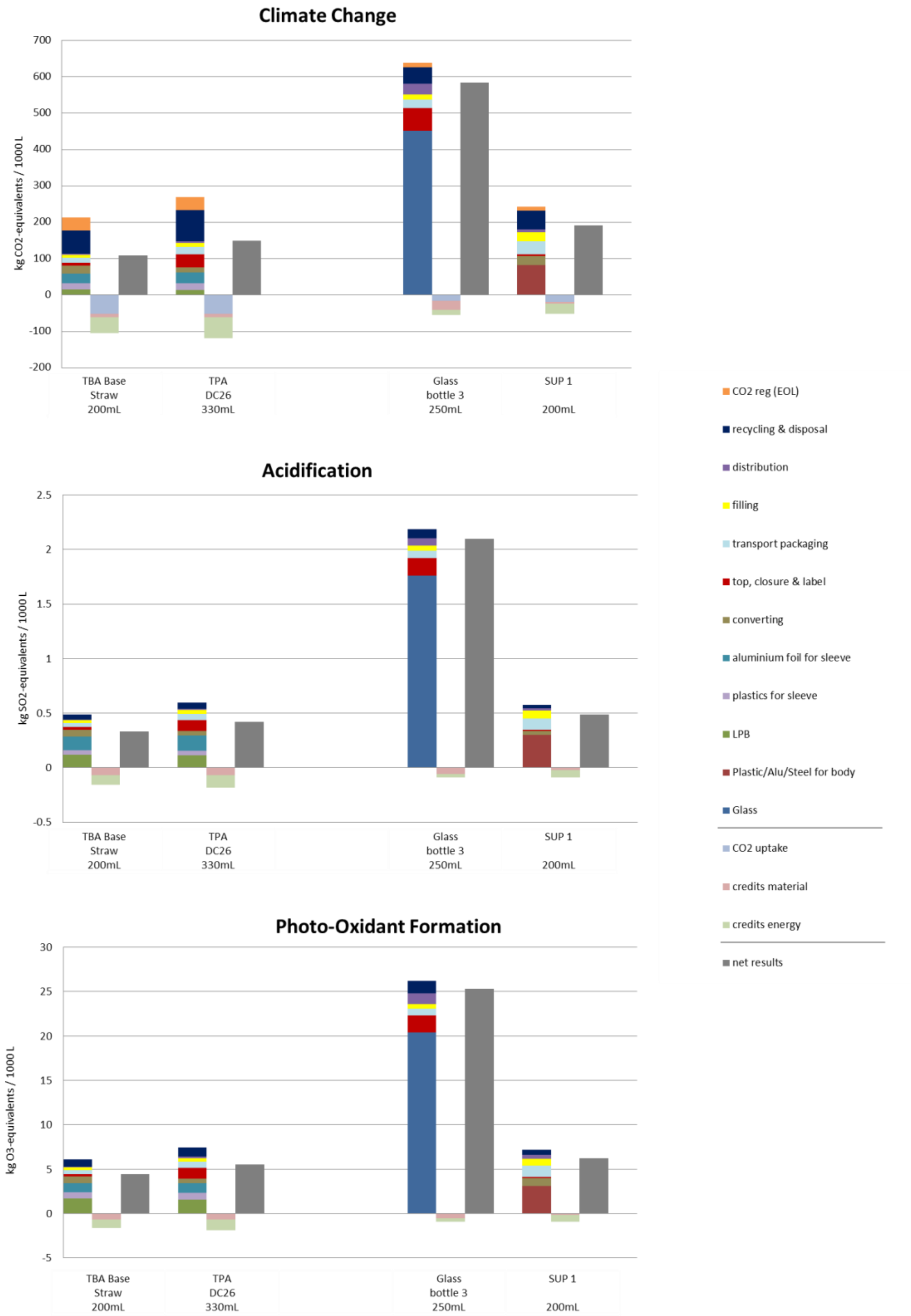


Figure 56: Indicator results for sensitivity analysis on system allocation of segment JNSD PORTION PACK AMBIENT, allocation factor 100% (Part 1)

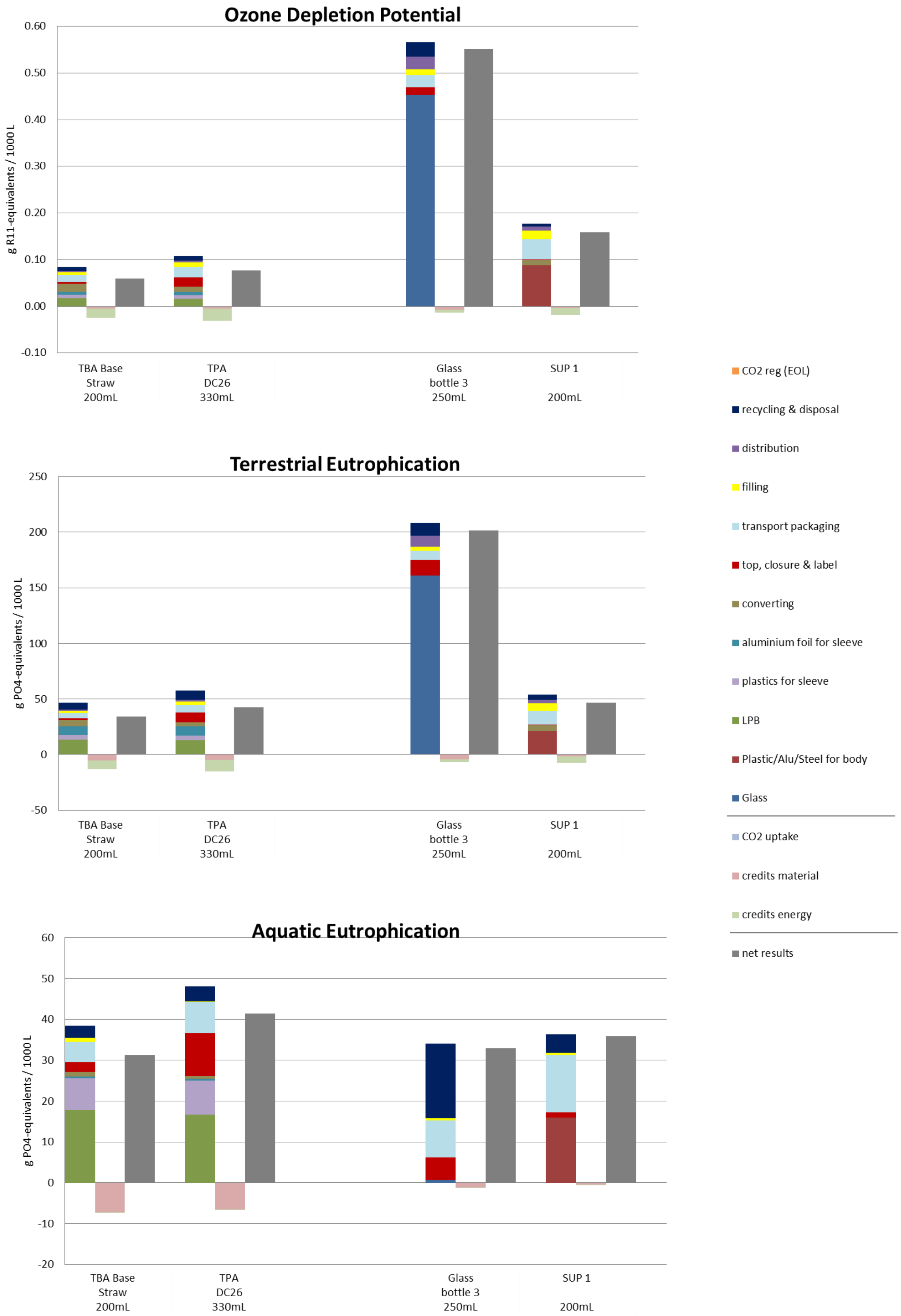


Figure 57: Indicator results for sensitivity analysis on system allocation of **segment JNSD PORTION PACK AMBIENT**, allocation factor 100% (Part 2)

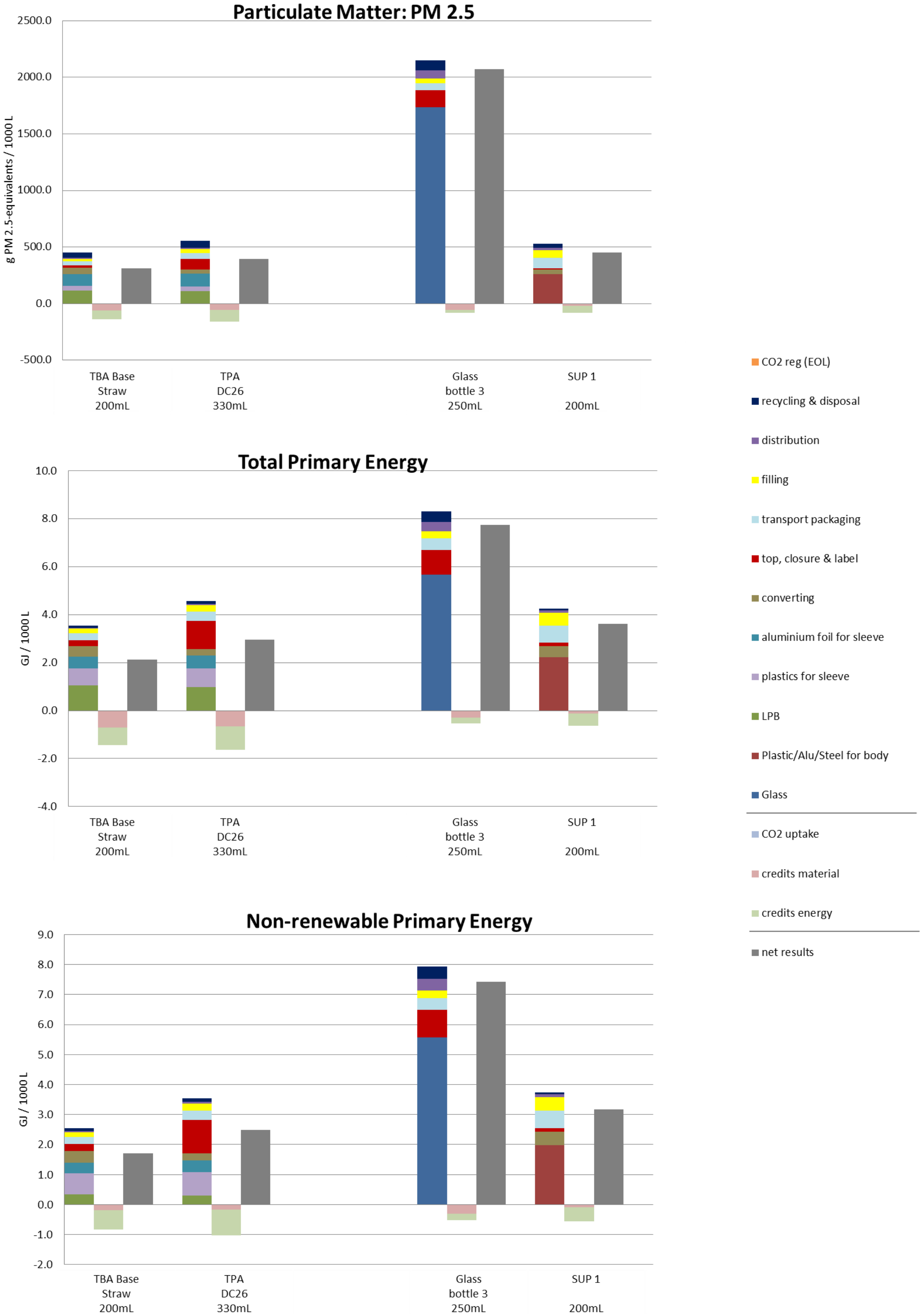


Figure 58: Indicator results for sensitivity analysis on system allocation of **segment JNSD PORTION PACK AMBIENT**, allocation factor 100% (Part 3)

Figure 59: Indicator results for sensitivity analysis on system allocation of **segment JNSD PORTION PACK AMBIENT**, allocation factor 100% (Part 4)

Table 64: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment JNSD PORTION PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		TBA Base Straw 200mL	TPA DC 26 330mL		Glass bottle 3 250mL	SUP 1 200mL
Climate Change [kg CO_2-e/1000 L]	Burdens	177.77	233.46		626.12	232.33
	CO2 (reg)	35.32	35.27		13.12	10.97
	Credits	-52.18	-67.29		-38.55	-34.20
	CO2 uptake	-51.68	-51.51		-16.23	-18.12
	net results	109.23	149.94		584.46	190.98
Acidification [kg SO_2-e/1000 L]	Burdens	0.49	0.60		2.19	0.58
	Credits	-0.16	-0.18		-0.09	-0.09
	Net results	0.33	0.42		2.10	0.49
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	6.11	7.44		26.22	7.17
	Credits	-1.64	-1.90		-0.89	-0.94
	Net results	4.47	5.54		25.33	6.23
Ozone Depletion [g R11 e/1000 L]	Burdens	0.08	0.11		0.57	0.18
	Credits	-0.02	-0.03		-0.01	-0.02
	Net results	0.06	0.08		0.55	0.16
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	46.81	57.53		208.12	54.03
	Credits	-12.78	-14.89		-6.86	-7.29
	Net results	34.03	42.64		201.26	46.74
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	38.47	48.03		34.12	36.36
	Credits	-7.24	-6.66		-1.17	-0.47
	Net results	31.23	41.37		32.94	35.89
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	452.34	554.20		2150.74	528.93
	Credits	-138.67	-160.39		-80.46	-78.72
	Net results	313.67	393.81		2070.27	450.21
Total Primary Energy [GJ/1000 L]	Burdens	3.55	4.58		8.29	4.24
	Credits	-1.44	-1.63		-0.54	-0.63
	Net results	2.11	2.95		7.75	3.61
Non-renewable Primary Energy [GJ/1000 L]	Burdens	2.54	3.53		7.94	3.74
	Credits	-0.83	-1.04		-0.52	-0.56
	Net results	1.71	2.50		7.42	3.18
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	97.98	155.29		595.59	133.68
	Credits	-28.24	-34.76		-40.86	-18.84
	Net results	69.73	120.53		554.74	114.85
Use of Nature [m²e*year/1000 L]	Burdens	28.53	28.36		5.49	6.86
	Credits	-9.73	-9.19		-0.07	-0.11
	Net results	18.79	19.17		5.42	6.75
Water use [m³/1000 L]	water cool	1.92	2.42		3.25	2.95
	water process	2.91	2.49		0.52	0.95
	water unspecified	1.12	1.43		4.01	1.91

4.10.2 Description and interpretation

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.

In the cases of beverage cartons in the segment JNSD PORTION PACK AMBIENT applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for beverage cartons in this segment when rising the allocation factor to 100% due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

In the case of single use glass bottle, net results of all categories stay about the same when applying the 100% allocation factor as burdens from recycling and disposal are similar than energy and material credits due to the closed loop use of cullet.

In the case of the SUP net results decrease slightly in most categories as the absolute value of the credits is slightly higher than that of the burdens from recycling and disposal regardless of the allocation factor. In case of 'Climate Change', applying the allocation factor 100% instead of 50% leads to slightly higher net results. This is because in this case the absolute value of the credits is slightly lower than that of the burdens from recycling and disposal regardless of the allocation factor.

4.10.3 Comparison between packaging systems

The following tables show the net results per functional unit of the regarded beverage cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 65: Comparison of net results: **TBA Base Straw 200mL** versus competing carton based and alternative packaging systems in **segment JNSD PORTION PACK (ambient), Europe**, allocation factor 100%

JNSD PORTION PACK (ambient), Europe, Allocation 100	The net results of **TBA Base Straw 200mL** are lower (green)/ higher (orange) than those of		
	TPA DC 26 330mL	Glass bottle 3 250mL	SUP 1 200mL
Climate Change	-27%	-81%	-43%
Acidification	-21%	-84%	-32%
Photo-Oxidant Formation	-19%	-82%	-28%
Ozone Depletion Potential	-23%	-89%	-63%
Terrestrial Eutrophication	-20%	-83%	-27%
Aquatic Eutrophication	-25%	-5%	-13%
Particulate Matter	-20%	-85%	-30%
Use of Nature	-2%	+247%	+179%

Table 66: Comparison of net results: **TPA DC26 330mL** versus competing carton based and alternative packaging systems in **segment JNSD PORTION PACK (ambient), Europe**, allocation factor 100%

JNSD PORTION PACK (ambient), Europe, Allocation 100	The net results of **TPA DC26 330mL** are lower (green)/ higher (orange) than those of		
	TBA Base Straw 200mL	Glass bottle 3 250mL	SUP 1 200mL
Climate Change	+37%	-74%	-21%
Acidification	+26%	-80%	-14%
Photo-Oxidant Formation	+24%	-78%	-11%
Ozone Depletion Potential	+30%	-86%	-51%
Terrestrial Eutrophication	+25%	-79%	-9%
Aquatic Eutrophication	+32%	+26%	+15%
Particulate Matter	+26%	-81%	-13%
Use of Nature	+2%	+254%	+184%

[1] ((|net result heading – net result column|) / net result column)*100

4.11 Results allocation factor 50%; WATER PORTION PACK AMBIENT

4.11.1 Presentation of results WATER PORTION PACK AMBIENT

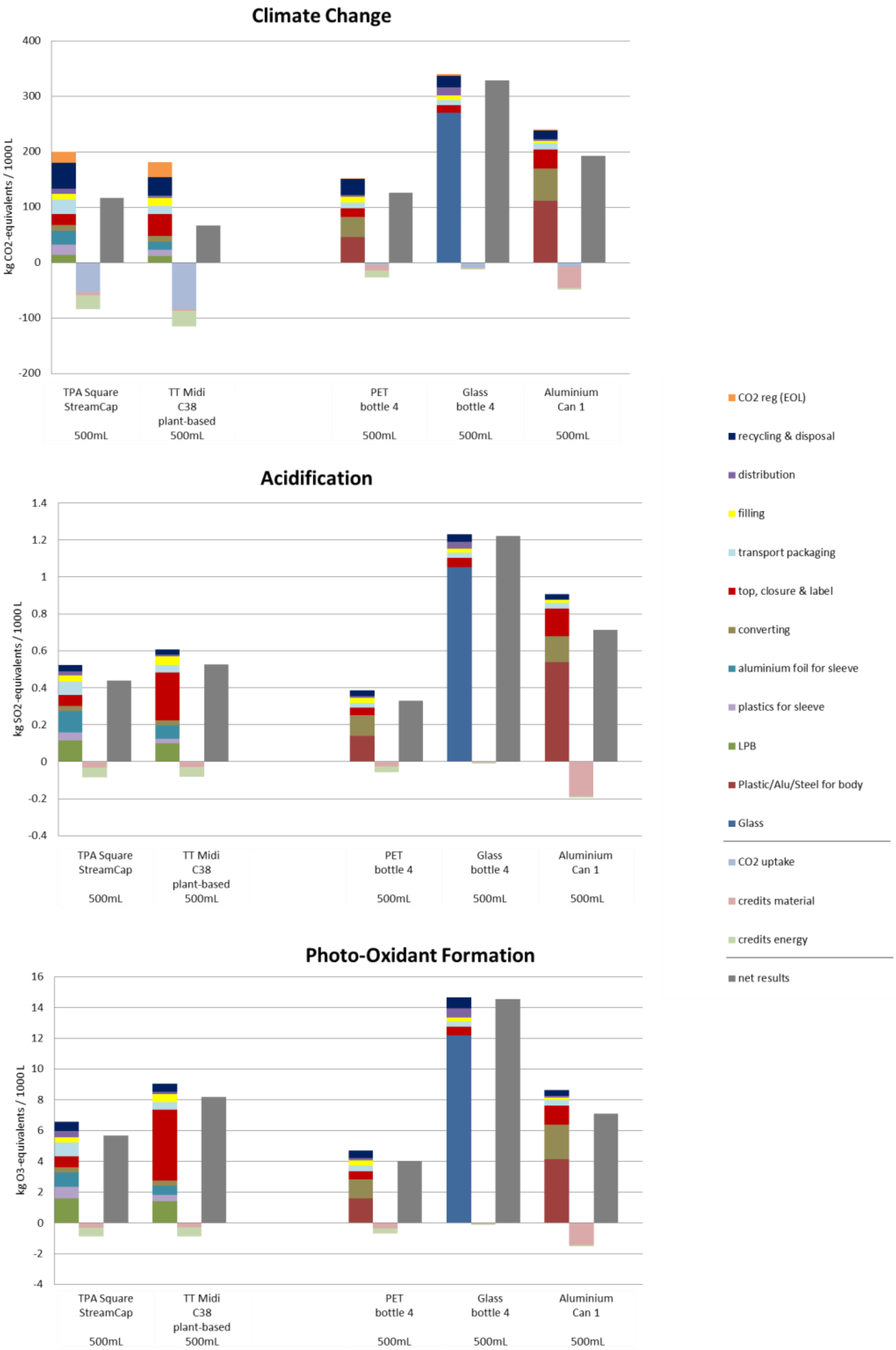


Figure 60: Indicator results of segment WATER PORTION PACK AMBIENT, allocation factor 50% (Part 1)

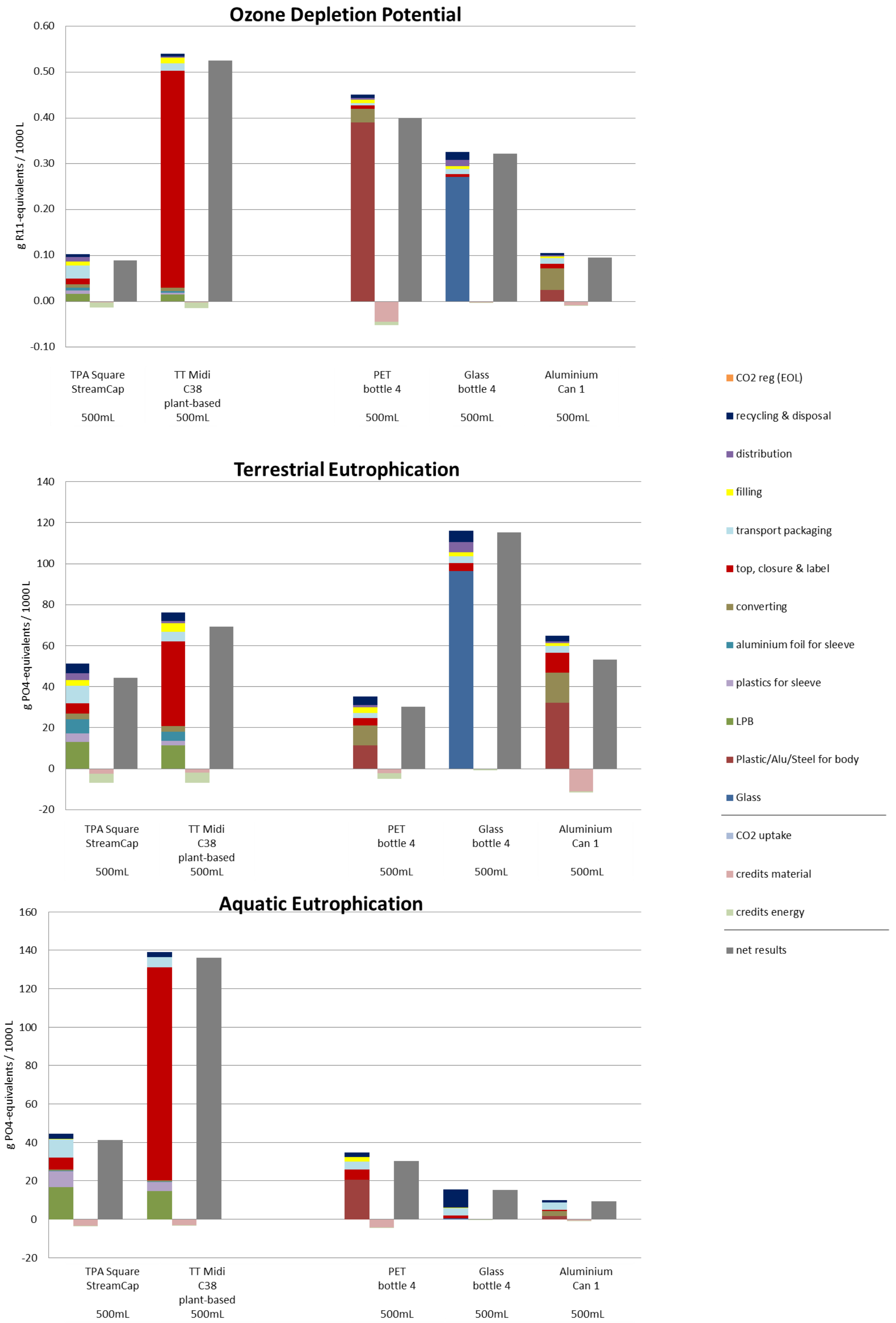


Figure 61 Indicator results of segment WATER PORTION PACK AMBIENT, allocation factor 50% (Part 2)

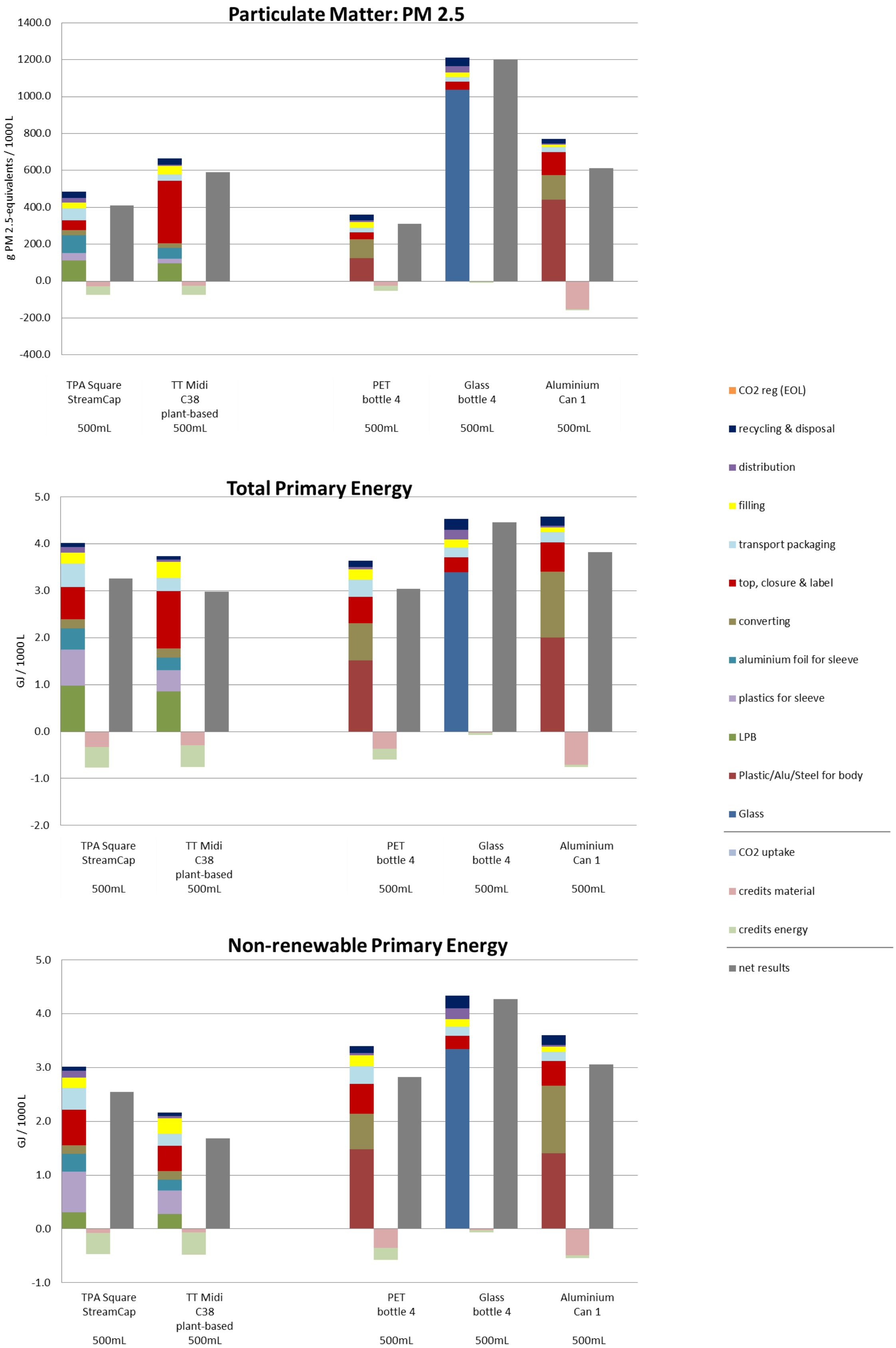


Figure 62: Indicator results of segment WATER PORTION PACK AMBIENT, allocation factor 50% (Part 3)

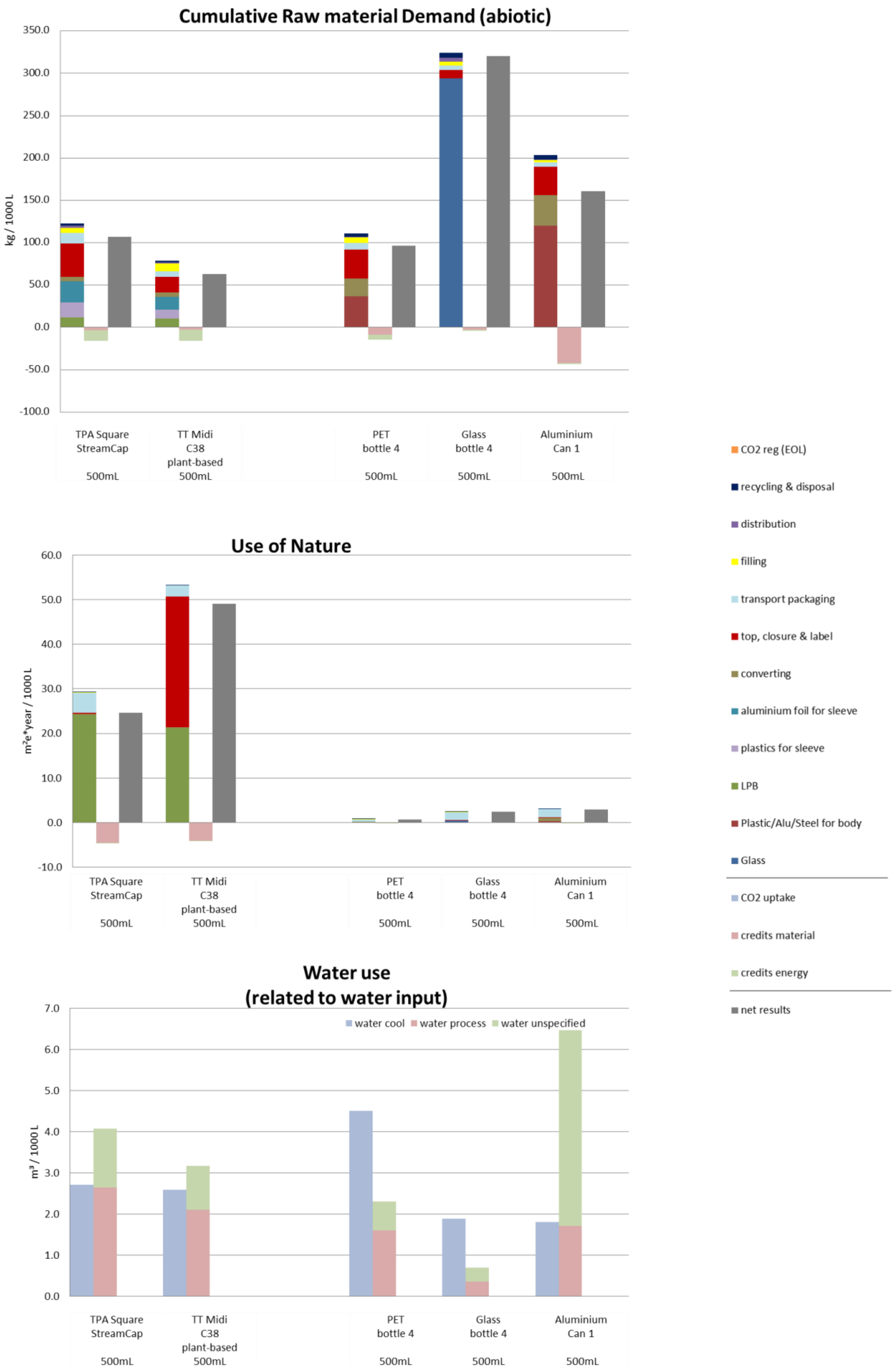


Figure 63: Indicator results of segment WATER PORTION PACK AMBIENT, allocation factor 50% (Part 4)

Allocation 50		TPA Square StreamCap 500mL	TT Midi C38 plant-based 500mL		PET bottle 4 500mL	Glass bottle 4 500mL	Aluminium Can 1 500mL
Climate Change [kg CO_2-e/1000 L]	Burdens	180.41	154.30		151.30	337.26	238.90
	CO2 (reg)	20.18	27.63		1.38	3.38	2.07
	Credits	-30.13	-31.19		-23.08	-3.93	-41.87
	CO2 uptake	-53.68	-83.30		-3.46	-8.22	-6.21
	net results	116.79	67.43		126.14	328.49	192.90
Acidification [kg SO_2-e/1000 L]	Burdens	0.52	0.61		0.39	1.23	0.91
	Credits	-0.08	-0.08		-0.06	-0.01	-0.19
	Net results	0.44	0.53		0.33	1.22	0.71
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	6.56	9.05		4.71	14.65	8.62
	Credits	-0.89	-0.88		-0.69	-0.11	-1.50
	Net results	5.67	8.17		4.02	14.54	7.11
Ozone Depletion [g R11 e/1000 L]	Burdens	0.10	0.54		0.45	0.33	0.11
	Credits	-0.01	-0.01		-0.05	0.00	-0.01
	Net results	0.09	0.53		0.40	0.32	0.10
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	51.22	76.23		35.16	116.08	64.84
	Credits	-6.92	-6.86		-4.94	-0.88	-11.68
	Net results	44.30	69.36		30.21	115.19	53.16
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	44.65	138.99		34.76	15.41	9.91
	Credits	-3.34	-2.94		-4.40	-0.11	-0.62
	Net results	41.31	136.05		30.36	15.30	9.29
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	484.39	663.59		361.36	1210.30	770.84
	Credits	-74.37	-72.92		-51.76	-9.70	-158.51
	Net results	410.02	590.67		309.60	1200.60	612.32
Total Primary Energy [GJ/1000 L]	Burdens	4.02	3.74		3.64	4.53	4.57
	Credits	-0.76	-0.75		-0.60	-0.07	-0.76
	Net results	3.26	2.98		3.04	4.46	3.82
Non-renewable Primary Energy [GJ/1000 L]	Burdens	3.02	2.17		3.40	4.33	3.60
	Credits	-0.47	-0.48		-0.57	-0.07	-0.54
	Net results	2.55	1.68		2.82	4.26	3.06
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	122.74	78.68		110.96	323.90	203.69
	Credits	-15.65	-15.67		-14.75	-3.76	-43.21
	Net results	107.10	63.01		96.21	320.14	160.49
Use of Nature [m^2e*year/1000 L]	Burdens	29.20	53.23		0.77	2.42	3.07
	Credits	-4.63	-4.11		-0.05	-0.02	-0.13
	Net results	24.56	49.12		0.72	2.40	2.94
Water use [m^3/1000 L]	water cool	2.71	2.58		4.51	1.88	1.80
	water process	2.65	2.10		1.60	0.36	1.71
	water unspecified	1.43	1.07		0.70	0.34	4.75

Table 67: Category indicator results per impact category of segment WATER PORTION PACK AMBIENT - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

4.11.2 Description and interpretation

Beverage carton systems (specifications see section 2.2.1)

For the beverage carton systems considered in the WATER PORTION PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the beverage carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (11%-38%) and 'Use of Nature' (40%-82%). It is also relevant regarding 'Photo-Oxidant Formation' (16%-25%) 'Acidification' (16%-22%), 'Terrestrial Eutrophication' (15%-25%), 'Particulate Matter' (15%-23%) and also the consumption of 'Total Primary Energy' (23%-24%). Regarding 'Climate Change' the production of LPB is responsible for only 7% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The production of 'aluminium foil' for the sleeves of the ambient beverage carton shows burdens in most impact categories. Considerable shares of burdens can be seen for the categories 'Acidification' (12%-22%) and 'Particulate Matter' (9%-20%). These result from SO_2 and NOx emissions from the aluminium production. Also the inventory category 'Cumulative Raw material Demand (abiotic)' shows considerable shares of burdens (20%-20%).

The production of 'plastics for sleeve' of the beverage carton shows considerable burdens in most impact categories (up to 25%). These are considerably lower than those of the LPB

production, which is easily explained by its lower material share than that of LPB. The exceptions are climate change and the inventory category 'Cumulative Raw material Demand (abiotic)', where plastics and LPB contribute about the same as well as the inventory category 'Non-renewable Primary Energy', where the plastics contribute about the doubled share of the total burdens than LPB.

The life cycle step 'top, closure & label' for TPA cartons with fossil based plastics contributes to a small to considerable amount in all impact categories (1%-32%). In case of the TT carton this life cycle step contributes to a substantial share in almost all impact categories (33%-88%) except 'Climate Change' (22%), 'Non-renewable Primary Energy' (21%) and 'Cumulative Raw material Demand (abiotic)' (24%), due to the plant-based materials in the top and closure.

The reason for the big influence of plant-based plastics on all impact categories apart from 'Climate Change' is the high energy demand, and the cultivation of sugar cane. The latter is reflected especially in the impact category 'Ozone Depletion Potential'. This is due to the field emissions of N2O from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of plant-based PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'.

The 'converting' process generally plays a small role (0%-8%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show small to considerable shares of impacts in most categories (3%-28%).

The life cycle step 'filling' shows only small shares of burdens (up to 8%) for the TPA beverage carton system in all impact categories. In case of the TT beverage carton system the shares are higher (up to 13%) due to the additional moulding process of the top.

The life cycle step 'distribution' shows only small shares of burdens in all impact categories for all beverage carton systems (max. 9%).

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact category 'Climate Change' (18%-23%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. In case of beverage cartons these derive mainly from the incineration of plant-based plastics and paper. They play an important role (10%-15%) for the results of all beverage carton systems in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-19% of the total burdens. Material credits from material recycling are lower (0%-16%). Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section 1.7.2)

Plastic bottles (specifications see section 2.2.2)

In the regarded plastic bottle system in the WATER PORTION PACK segment, the biggest part of the environmental burdens is also caused by the production of the base materials of the bottles in most impact and inventory categories. In case of 'Ozone Depletion Potential' the main contributor to the high impacts is methyl bromide which is emitted in the production process for purified terephthalic acid (PTA) which is a pre-product of PET.

The 'converting' process shows for the PET bottle in this segment small to considerable shares of burdens (7%-29%) in all categories apart from 'Aquatic Eutrophication', for which the share of burdens is less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows small to minor impacts shares (2%-16%) in most categories mainly attributed to the different plastics used for the closures and the aluminium pull tab. Considerable shares of burdens (31%) are shown for 'Cumulative Raw material Demand (abiotic)'.

The production and provision of 'transport packaging' for the bottle system show small to minor impact shares (1%-11%) in most categories. The exception is 'Use of Nature' for which 61% of the burdens are caused from 'transport packaging' resulting from the used cardboard and wood for pallets. Burdens from 'Use of Nature' are smaller for the PET bottle than the glass bottle and the aluminium can as the secondary packaging material for the PET bottle is LDPE, whereas it is cardboard for the glass bottle and the aluminium can.

The life cycle step 'filling' shows only small shares of burdens (max. 9%) for all bottle systems in all impact categories.

The life cycle step 'distribution' shows only small burdens in all impact categories for all bottle systems (max. 3%).

The impact of the plastic bottles' 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (20%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

Energy credits have a small influence of on the net results in most categories (up to 9% of the total burdens). The energy credits mainly originate from the incineration plants and cement kilns.

Material credits have small to minor influence on the net results in all categories (3%-13% of the total burdens). They result from the substitution of primary PET with recycled PET from the bottles.

Glass bottle (specifications see section 2.2.2)

Even more than for the other regarded packaging systems, the production of the 'glass' material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results (75%-91%) in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'.

All other life cycle steps play only a minor role compared to the glass production. For the impact categories, 'Aquatic Eutrophication' (24%) and 'Use of Nature' (73%) transport packaging also plays a visible role due do the cardboard used for secondary and tertiary packaging.

Energy credits play only a minor role for the glass bottle, as the little energy that can be generated in end-of-life mainly comes from the incineration of secondary and tertiary packaging.

Material credits from glass recycling have a small impact on the overall net results as the cullet is used in a closed loop.

Aluminium can (specifications see section 2.2.2)

In the regarded aluminium can system in the WATER PORTION PACK segment, the biggest part (11%-59%) of the environmental burdens for most categories is caused by the production of the aluminium of the can body.

The 'converting' process for the can body shows also a major share of burdens for most impact categories (16%-45%).

The life cycle step 'top, closure & label' shows small to minor impacts shares (6%-17%) attributed to the aluminium production and converting of the cap of the can.

The life cycle step 'transport packaging' shows only small to minor shares of burdens (3%-11%) for most categories. The exceptions are 'Aquatic Eutrophication' (39%) and 'Use of Nature' (59%) due do the cardboard used for secondary and tertiary packaging.

The life cycle steps, 'filling' (up to 4%) and 'distribution' (up to 2%) show only small shares of burdens.

The aluminium cans' 'recycling & disposal' life cycle step shows small to minor shares of burdens regarding in most categories (up to 11%). These result mainly from the recycling process of aluminium.

The influence of material credits on the net result is relevant in most categories. They reduce the overall burdens by 4%-21% due to the substitution of virgin aluminium with recycled aluminium from the cans. The influence of energy credits on the net result is low (up to 1% of total burdens) due to the low share of MSWI and the low heating value of aluminium.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.11.3 Comparison between packaging systems

The following tables show the net results per functional unit of the studied beverage carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 68: Comparison of net results: **TPA Square StreamCap 500mL** versus competing carton based and alternative packaging systems in **segment WATER PORTION PACK (ambient), Europe**, allocation factor 50%

WATER PORTION PACK (ambient), Europe, Allocation 50	The net results of **TPA Square StreamCap 500mL** are lower (green)/ higher (orange) than those of			
	TT Midi C38 plant-based 500mL	PET bottle 4 500mL	Glass bottle 4 500mL	Aluminium Can 1 500mL
Climate Change	+73%	-7%	-64%	-7%
Acidification	-17%	+33%	-64%	+33%
Photo-Oxidant Formation	-31%	+41%	-61%	+41%
Ozone Depletion Potential	-83%	-78%	-72%	-78%
Terrestrial Eutrophication	-36%	+47%	-62%	+47%
Aquatic Eutrophication	-70%	+36%	+170%	+36%
Particulate Matter	-31%	+32%	-66%	+32%
Use of Nature	-50%	+3320%	+924%	+3320%

Table 69: Comparison of net results: **TT Midi C38 plant-based 500mL** versus competing carton based and alternative packaging systems in **segment WATER PORTION PACK (ambient), Europe**, allocation factor 50%

WATER PORTION PACK (ambient), Europe, Allocation 50	The net results of **TT Midi C38 plant-based 500mL** are lower (green)/ higher (orange) than those of			
	TPA Square StreamCap 500mL	PET bottle 4 500mL	Glass bottle 4 500mL	Aluminium Can 1 500mL
Climate Change	-42%	-47%	-79%	-65%
Acidification	+20%	+60%	-57%	-26%
Photo-Oxidant Formation	+44%	+103%	-44%	+15%
Ozone Depletion Potential	+490%	+32%	+63%	+450%
Terrestrial Eutrophication	+57%	+130%	-40%	+30%
Aquatic Eutrophication	+229%	+348%	+789%	+1364%
Particulate Matter	+44%	+91%	-51%	-4%
Use of Nature	+100%	+6740%	+1948%	+1569%

4.12 Results allocation factor 100%; WATER PORTION PACK AMBIENT

4.12.1 Presentation of results WATER PORTION PACK AMBIENT

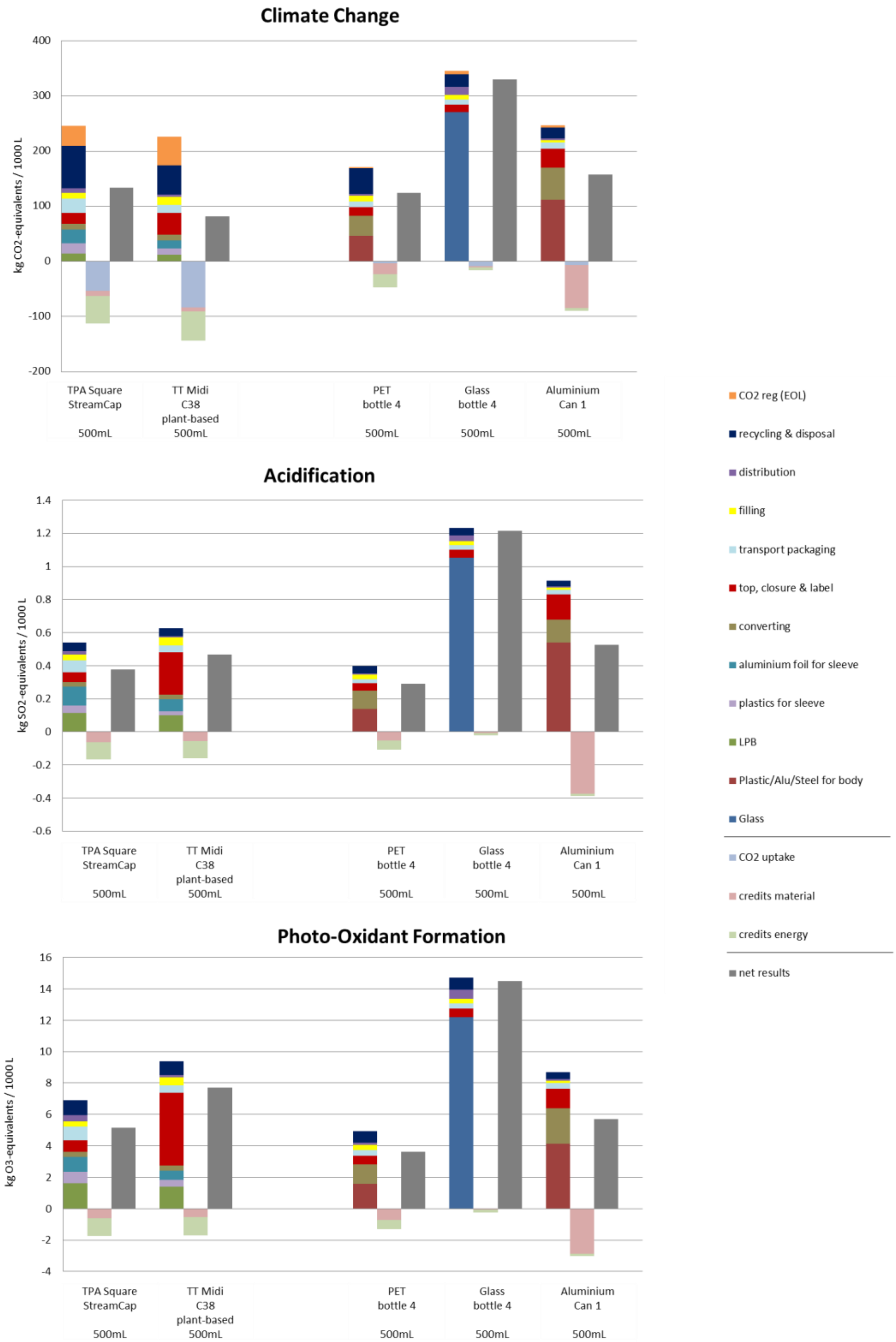


Figure 64: Indicator results for sensitivity analysis on system allocation of **segment WATER PORTION PACK AMBIENT**, allocation factor 100% (Part 1)

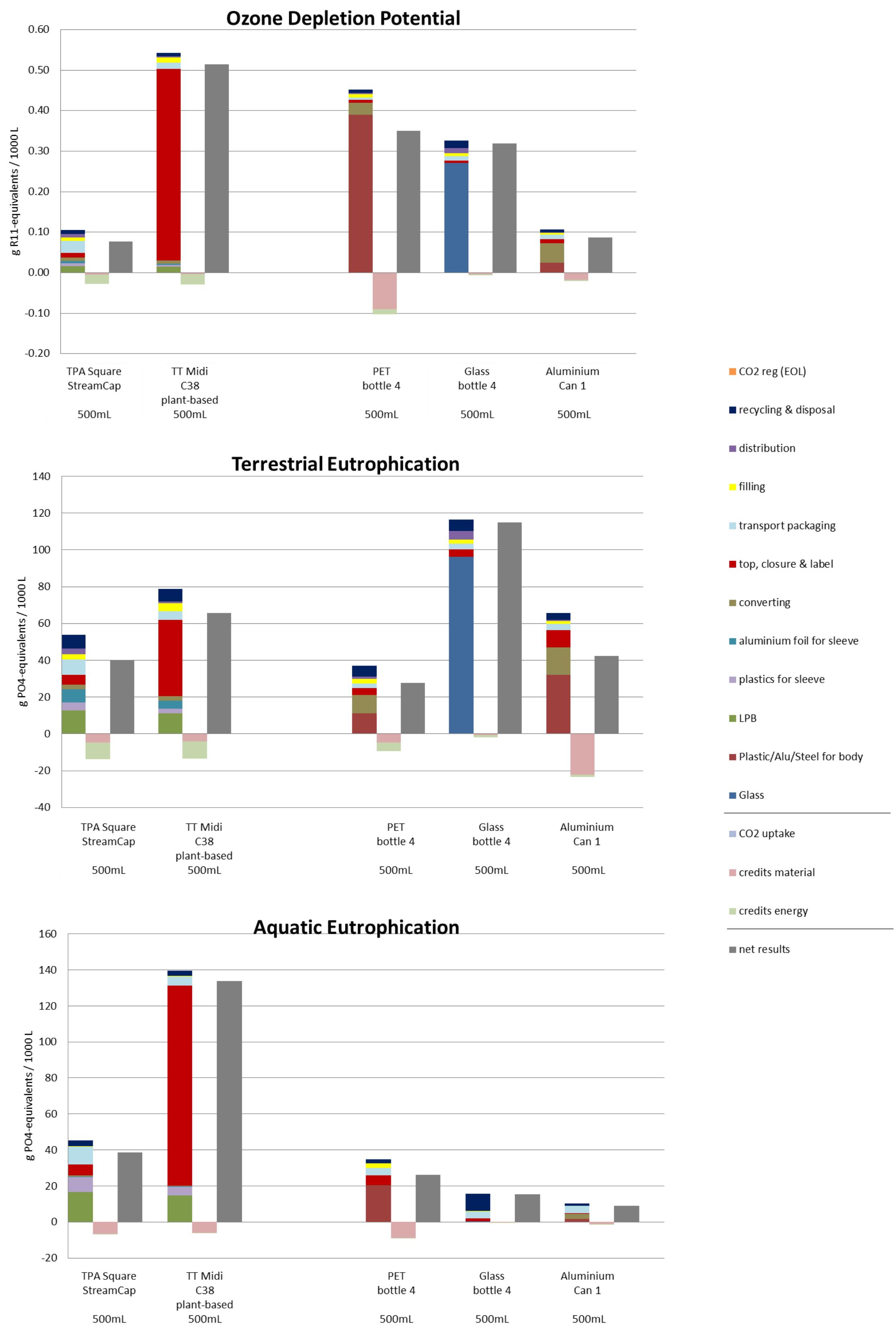


Figure 65: Indicator results for sensitivity analysis on system allocation of **segment WATER PORTION PACK AMBIENT**, allocation factor 100% (Part 2)

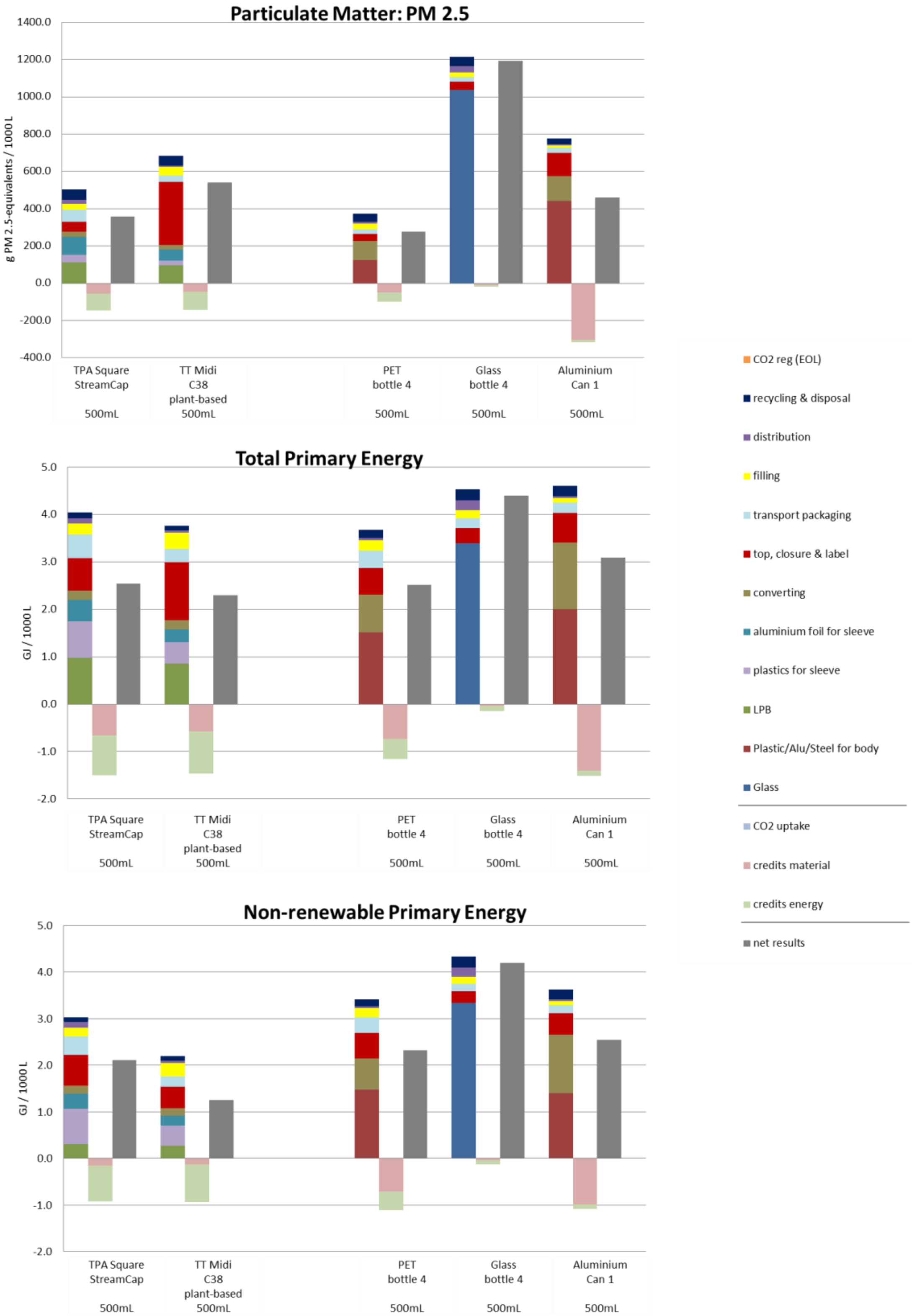


Figure 66: Indicator results for sensitivity analysis on system allocation of **segment WATER PORTION PACK AMBIENT**, allocation factor 100% (Part 3)

Figure 67: Indicator results for sensitivity analysis on system allocation of segment WATER PORTION PACK AMBIENT, allocation factor 100% (Part 4)

Table 70: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment WATER PORTION PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		TPA Square StreamCap 500mL	TT Midi C38 plant-based 500mL		PET bottle 4 500mL	Glass bottle 4 500mL	Aluminium Can 1 500mL
Climate Change [kg CO_2-e/1000 L]	Burdens	209.27	174.47		168.82	339.30	242.90
	CO2 (reg)	36.90	51.51		2.76	6.77	4.15
	Credits	-59.13	-60.59		-43.61	-7.82	-83.75
	CO2 uptake	-53.68	-83.30		-3.46	-8.22	-6.21
	net results	133.37	82.09		124.52	330.02	157.09
Acidification [kg SO_2-e/1000 L]	Burdens	0.54	0.63		0.40	1.23	0.91
	Credits	-0.16	-0.16		-0.11	-0.02	-0.39
	Net results	0.38	0.47		0.29	1.21	0.53
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	6.89	9.39		4.93	14.71	8.71
	Credits	-1.74	-1.70		-1.32	-0.23	-3.01
	Net results	5.15	7.69		3.61	14.48	5.70
Ozone Depletion [g R11 e/1000 L]	Burdens	0.11	0.54		0.45	0.33	0.11
	Credits	-0.03	-0.03		-0.10	-0.01	-0.02
	Net results	0.08	0.51		0.35	0.32	0.09
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	53.88	78.95		36.95	116.56	65.56
	Credits	-13.60	-13.32		-9.37	-1.76	-23.35
	Net results	40.27	65.63		27.58	114.80	42.21
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	45.30	139.59		34.90	15.71	10.18
	Credits	-6.67	-5.88		-8.79	-0.22	-1.24
	Net results	38.63	133.71		26.11	15.49	8.93
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	503.79	683.61		374.37	1213.60	776.90
	Credits	-146.66	-141.98		-98.24	-19.31	-317.00
	Net results	357.13	541.62		276.14	1194.28	459.91
Total Primary Energy [GJ/1000 L]	Burdens	4.04	3.76		3.67	4.53	4.61
	Credits	-1.51	-1.47		-1.15	-0.14	-1.51
	Net results	2.53	2.30		2.52	4.39	3.09
Non-renewable Primary Energy [GJ/1000 L]	Burdens	3.03	2.19		3.42	4.33	3.63
	Credits	-0.92	-0.93		-1.10	-0.13	-1.08
	Net results	2.12	1.26		2.32	4.20	2.54
Cumulative Raw material Demand (abiotic)	Burdens	123.47	79.55		111.82	323.99	204.70
	Credits	-30.74	-30.41		-28.30	-7.49	-86.41
	Net results	92.73	49.15		83.52	316.50	118.29
Use of Nature [m²e*year/1000 L]	Burdens	29.20	53.24		0.77	2.42	3.07
	Credits	-9.27	-8.22		-0.09	-0.04	-0.26
	Net results	19.93	45.02		0.68	2.38	2.82
Water use [m³/1000 L]	water cool	1.96	1.81		4.04	1.80	1.73
	water process	2.45	1.92		1.58	0.36	1.06
	water unspecified	1.36	1.02		0.60	0.33	3.73

4.12.2 Description and interpretation

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.

In the cases of beverage cartons in the segment WATER PORTION PACK AMBIENT applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. In case of beverage cartons with plant-based plastics, net results stay similar in the categories which have high burdens from the production of plant-based plastics. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

In the case of the PET bottle, lower net results in almost all impact categories are shown when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. The exceptions are 'Climate Change'. For 'Climate Change' net results stay about the same when applying the 100% allocation factor, as the additionally allocated credits and burdens show similar absolute values.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for beverage cartons and plastic bottles in this segment when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

In the case of single use glass bottle, net results of all categories stay about the same when applying the 100% allocation factor as burdens from recycling and disposal are similar than energy and material credits due to the closed loop use of cullet.

In case of the aluminium can net results decrease in all categories when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor.

4.12.3 Comparison between packaging systems

The following tables show the net results per functional unit of the regarded beverage cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

Table 71: Comparison of net results: **TPA Square StreamCap 500mL** versus competing carton based and alternative packaging systems in **segment WATER PORTION PACK (ambient), Europe**, allocation factor 100%

WATER PORTION PACK (ambient), Europe, Allocation 100	The net results of **TPA Square StreamCap 500mL** are lower (green)/ higher (orange) than those of			
	TT Midi C38 plant-based 500mL	PET bottle 4 500mL	Glass bottle 4 500mL	Aluminium Can 1 500mL
Climate Change	+62%	+7%	-60%	+7%
Acidification	-20%	+29%	-69%	+29%
Photo-Oxidant Formation	-33%	+43%	-64%	+43%
Ozone Depletion Potential	-85%	-78%	-76%	-78%
Terrestrial Eutrophication	-39%	+46%	-65%	+46%
Aquatic Eutrophication	-71%	+48%	+149%	+48%
Particulate Matter	-34%	+29%	-70%	+29%
Use of Nature	-56%	+2828%	+737%	+2828%

Table 72: Comparison of net results: **TT Midi C38 plant-based 500mL** versus competing carton based and alternative packaging systems in **segment WATER PORTION PACK (ambient), Europe**, allocation factor 100%

WATER PORTION PACK (ambient), Europe, Allocation 100	The net results of **TT Midi C38 plant-based 500mL** are lower (green)/ higher (orange) than those of			
	TPA Square StreamCap 500mL	PET bottle 4 500mL	Glass bottle 4 500mL	Aluminium Can 1 500mL
Climate Change	-38%	-34%	-75%	-48%
Acidification	+24%	+61%	-61%	-11%
Photo-Oxidant Formation	+49%	+113%	-47%	+35%
Ozone Depletion Potential	+563%	+47%	+61%	+496%
Terrestrial Eutrophication	+63%	+138%	-43%	+55%
Aquatic Eutrophication	+246%	+412%	+763%	+1397%
Particulate Matter	+52%	+96%	-55%	+18%
Use of Nature	+126%	+6512%	+1790%	+1499%

[1] ((|net result heading – net result column|) / net result column)*100

4.13 Results allocation factor 50%; LIQUID FOOD PORTION PACK AMBIENT

4.13.1 Presentation of results LIQUID FOOD PORTION PACK AMBIENT

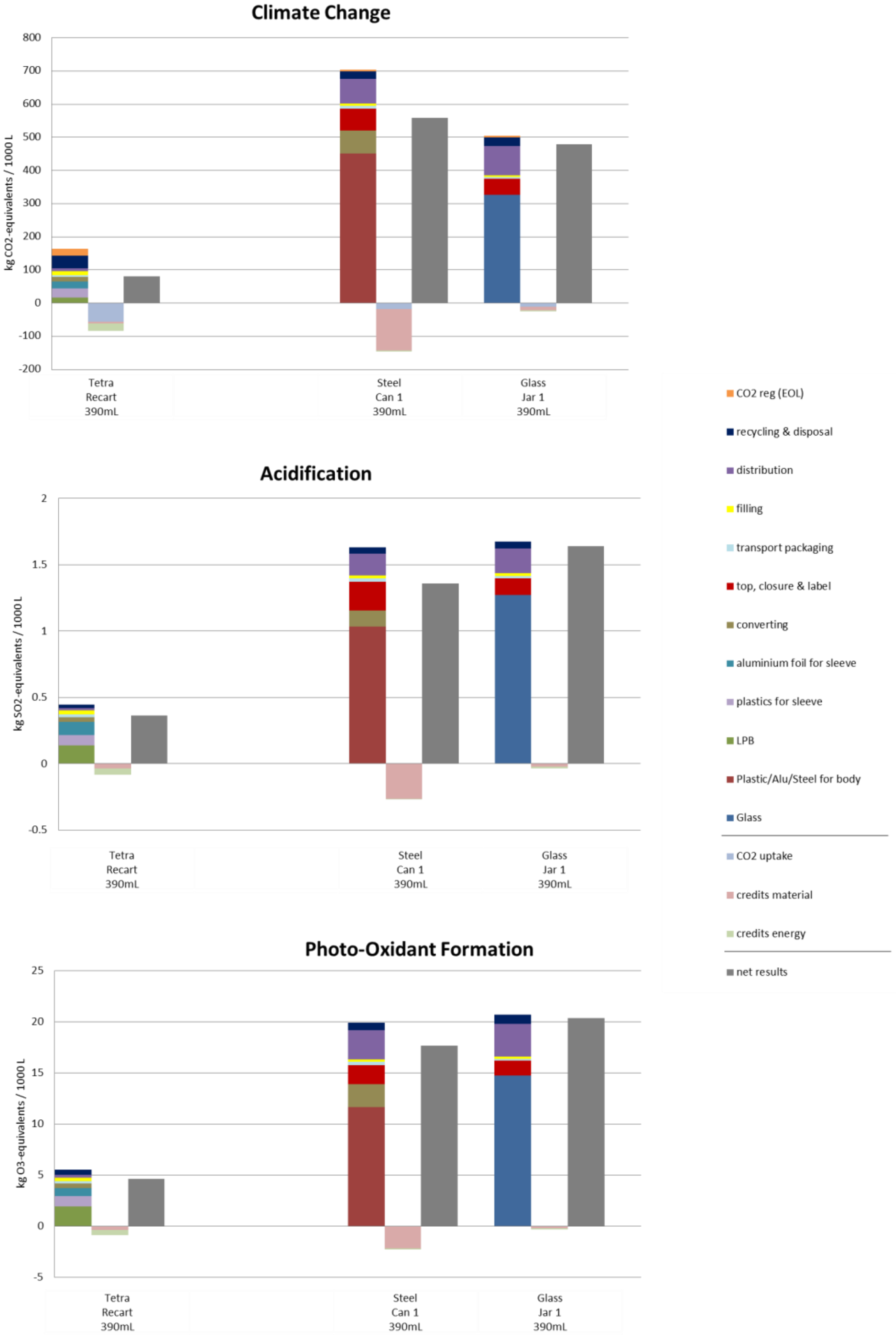


Figure 68: Indicator results of segment LIQUID FOOD PORTION PACK AMBIENT, allocation factor 50% (Part 1)

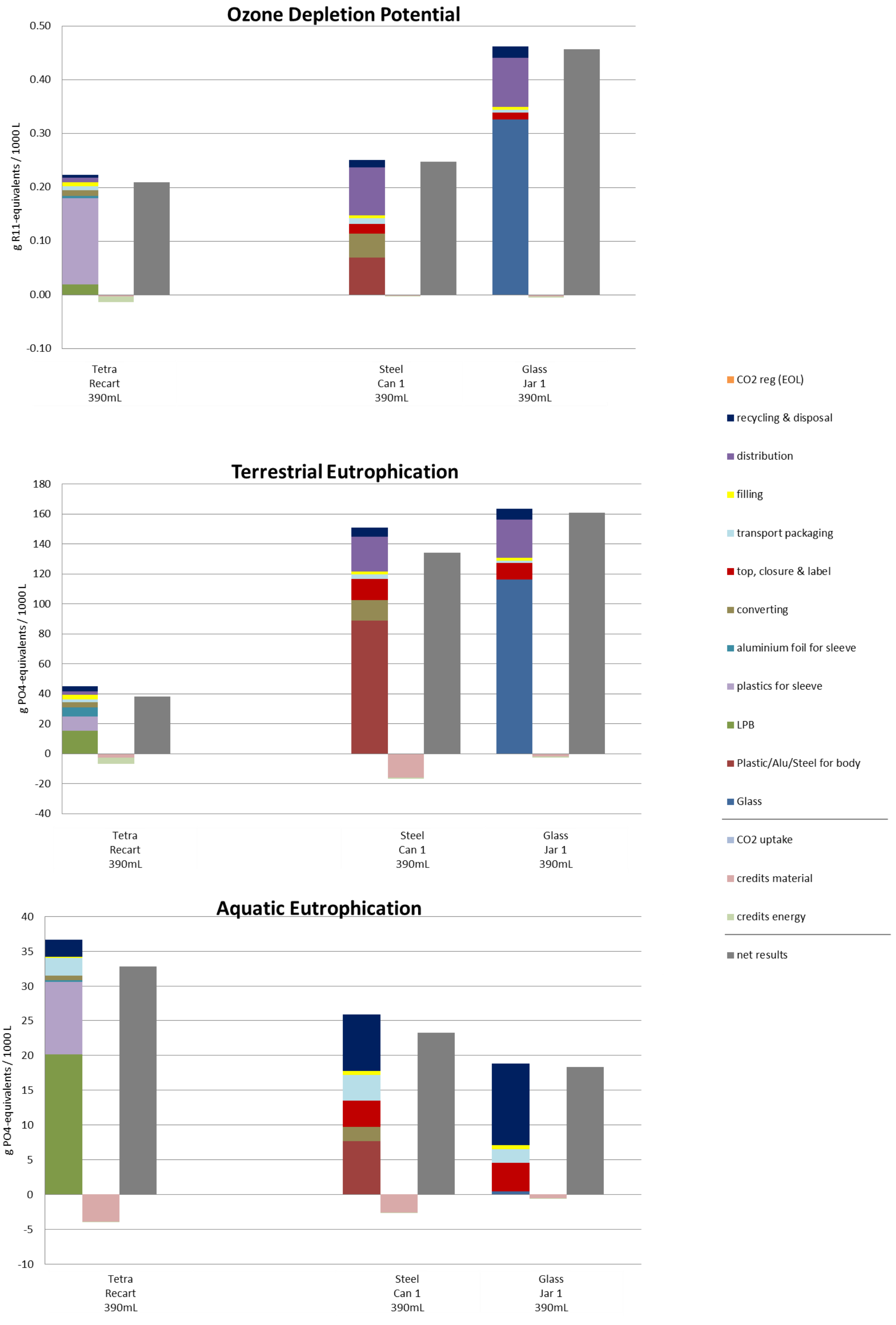


Figure 69 Indicator results of **segment LIQUID FOOD PORTION PACK AMBIENT**, allocation factor 50% (Part 2)

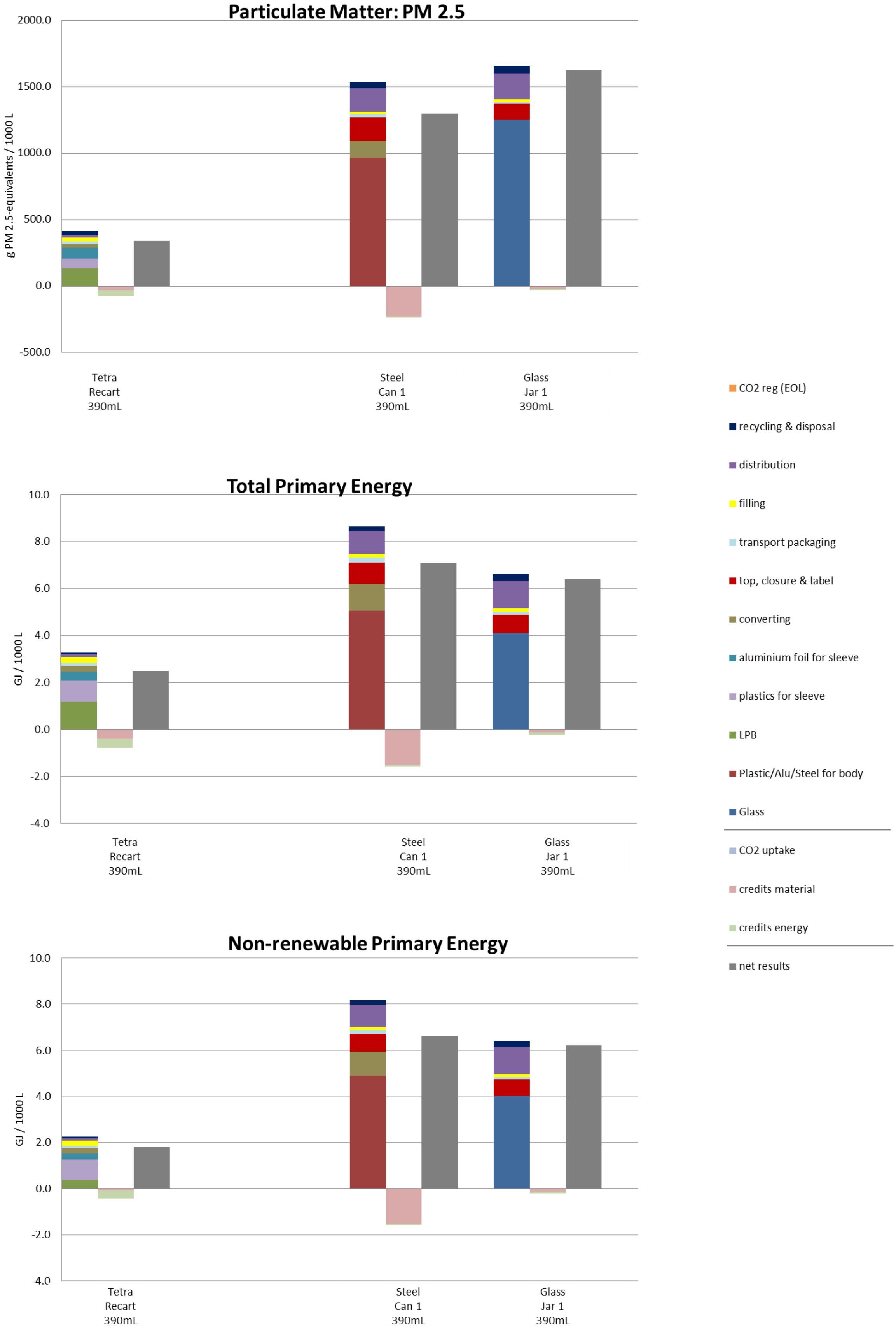


Figure 70: Indicator results of segment LIQUID FOOD PORTION PACK AMBIENT, allocation factor 50% (Part 3)

Figure 71: Indicator results of segment LIQUID FOOD PORTION PACK AMBIENT, allocation factor 50% (Part 4)

Table 73: Category indicator results per impact category of **segment LIQUID FOOD PORTION PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		Tetra Recart 390mL		Steel Can 1 390mL	Glass Jar 1 390mL
Climate Change [kg CO_2-e/1000 L]	Burdens	143.92		698.80	500.34
	CO2 (reg)	20.47		5.52	4.54
	Credits	-27.34		-127.49	-14.71
	CO2 uptake	-55.81		-17.93	-10.47
	net results	81.24		558.90	479.70
Acidification [kg SO_2-e/1000 L]	Burdens	0.45		1.63	1.67
	Credits	-0.08		-0.27	-0.03
	Net results	0.36		1.36	1.64
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	5.52		19.92	20.67
	Credits	-0.88		-2.28	-0.34
	Net results	4.64		17.64	20.33
Ozone Depletion [g R11 e/1000 L]	Burdens	0.22		0.25	0.46
	Credits	-0.01		0.00	-0.01
	Net results	0.21		0.25	0.46
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	45.21		150.78	163.38
	Credits	-6.90		-16.77	-2.59
	Net results	38.31		134.01	160.79
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	36.65		25.90	18.86
	Credits	-3.88		-2.61	-0.50
	Net results	32.77		23.28	18.36
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	413.55		1535.14	1655.61
	Credits	-74.21		-237.33	-30.53
	Net results	339.34		1297.81	1625.08
Total Primary Energy [GJ/1000 L]	Burdens	3.27		8.65	6.62
	Credits	-0.77		-1.57	-0.21
	Net results	2.50		7.08	6.41
Non-renewable Primary Energy [GJ/1000 L]	Burdens	2.25		8.17	6.42
	Credits	-0.43		-1.57	-0.20
	Net results	1.82		6.61	6.22
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	78.41		747.97	447.29
	Credits	-14.50		-171.23	-15.82
	Net results	63.91		576.73	431.47
Use of Nature [m²e*year/1000 L]	Burdens	30.52		4.90	1.85
	Credits	-5.52		-0.03	-0.03
	Net results	24.99		4.87	1.82
Water use [m³/1000 L]	water cool	1.76		2.70	2.10
	water process	2.89		0.02	0.39
	water unspecified	0.90		41.84	2.95

4.13.2 Description and interpretation

Liquid food carton systems (specifications see section 2.2.1)

For the liquid food carton systems considered in the LIQUID FOOD PORTION PACK segment, in most impact categories a considerable part of the environmental burdens is caused by the production of the material components of the liquid food carton.

The production of LPB is responsible for a substantial share of the burdens of the impact categories 'Aquatic Eutrophication' (55%) and 'Use of Nature' (95%). It is also relevant regarding 'Photo-Oxidant Formation' (35%) 'Acidification' (31%), 'Terrestrial Eutrophication' (34%), 'Particulate Matter' (32%) and also the consumption of 'Total Primary Energy' (36%). Regarding 'Climate Change' the production of LPB is responsible for only 10% of the burdens.

The key source of primary fibres for the production of LPB are trees, therefore an adequate land area is required to provide this raw material. The demand of LPB is covered by forest areas and the production sites in Northern Europe and reflected in the corresponding category.

The production of paperboard 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 Chemical Oxygen Demand (COD). As the production of paper causes 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 considerably to the acidifying potential.

The required energy for paper production mainly originates from the incineration of recovered process residues (for example hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. This and the additional electricity reflect the results for the categories 'Total Primary Energy' and 'Non-renewable Primary Energy'.

The production of 'aluminium foil' for the sleeves of the ambient liquid food carton shows burdens in most impact categories. Considerable shares of burdens can be seen for the categories 'Acidification' (22%) and 'Particulate Matter' (20%). These result from SO_2 and NOx emissions from the aluminium production.

The production of 'plastics for sleeve' of the liquid food cartons shows considerable burdens in most impact categories (up to 40%). These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. Exceptions are climate change, where plastics (17%) and LPB (10%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics (40%) contribute about the doubled the share of burdens than LPB (17%) as well as 'Cumulative Raw material Demand (abiotic)', where the share of burdens from plastics

(28% is considerable higher than the share of burdens from LPB (18%). Regarding 'Ozone Depletion Potential' this life cycle step has a substantial share of burdens of 72%

The life cycle step 'top, closure & label' shows no burdens for the Tetra Recart as the carton system does not include any additional closure.

The 'converting' process generally plays a small role (up to 9%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the liquid food carton systems show small shares of impacts in most categories (3%-7%).

The life cycle step 'filling' shows only small shares of burdens (up to 9%) for the liquid food carton system in all impact categories.

The life cycle step 'distribution' shows only small burdens in all impact categories for the liquid food carton system (max. 5%).

The life cycle step 'recycling & disposal' of the regarded liquid food cartons is most relevant in the impact category 'Climate Change' (23%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI or cement kilns.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. In case of liquid food cartons these derive mainly from the incineration of plant-based plastics and paper. They play an important role (12%) for the results of all liquid food carton systems in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants and cement kilns. They sum up to 0%-16% of the total burdens. Material credits from material recycling are lower in most categories (1%-18%). Especially they are low for 'Climate Change' because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard and by sugarcane for plant-based plastics plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees and sugarcane. 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. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section 1.7.2)

Steel can (specifications see section 2.2.2)

In the regarded steel can system in the LIQUID FOOD PORTION PACK segment, the biggest parts (27%-73%) of the environmental burdens of most categories is caused by the production of the steel of the can body.

The 'converting' process for the can body shows small to minor share of burdens for most categories (6%-18%).

The life cycle step 'top, closure & label' shows small to considerable impacts shares (7%-24%) attributed to the steel production and converting of the cap of the can as well as the production of the paper label.

'Distribution' for the steel can in this segment plays a major role (10%-36%) in all categories except of 'Aquatic Eutrophication' and 'Use of Nature' due to the long distance and comparatively high weight of the primary packaging units.

The life cycle steps 'transport packaging' and 'filling' shows only small shares of burdens (1%-4%) in most categories. The exceptions are 'Aquatic Eutrophication' (14%) and 'Use of Nature' (36%) which show higher shares of burdens from the production of cardboard for the secondary packaging.

The life cycle step 'filling' shows only small shares of burdens (1%-2%) for the can.

The steel cans' 'recycling & disposal' life cycle step shows small shares of burdens regarding most categories (1%-5%). The exception is 'Aquatic Eutrophication' with a share of 31% of the total burdens.

The influence of material credits on the net result is relevant for most categories. They reduce the overall burdens by up 23% due to the substitution of raw steel with recycled steel from the cans. The influence of energy credits on the net result is low (less than 1% of total burdens) due to the low share of MSWI and the low heating value of steel.

Glass jar (specifications see section 2.2.2)

Even more than for the other regarded packaging systems, the production of the 'glass' material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results (62%-79%) in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'.

'Distribution' for the glass jar in this segment plays a minor to considerable role (11%-20%) in all categories except of 'Aquatic Eutrophication' and 'Use of Nature' due to the long distance and comparatively high weight of the primary packaging units.

All other life cycle steps play only a minor role compared to the glass production. For the impact categories, 'Aquatic Eutrophication' (11%) and 'Use of Nature' (51%) transport packaging also plays a visible role due do the cardboard used for secondary and tertiary packaging.

Energy credits play only a minor role for the glass bottle, as the little energy that can be generated in end-of-life mainly comes from the incineration of secondary and tertiary packaging.

Material credits from glass recycling have a small impact on the overall net results as the cullet is used in a closed loop. The use of closed loop cullet can be seen in the reduced impacts of the life cycle step for the production of 'glass'.

Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.13.3 Comparison between packaging systems

The following table shows the net results per functional unit of the studied liquid food carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following table show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 74: Comparison of net results: **Tetra Recart 390mL** versus competing carton based and alternative packaging systems in **segment LIQUID FOOD PORTION PACK (ambient), Europe**, allocation factor 50%

FOOD PORTION PACK (ambient), Europe, Allocation 50	The net results of **TetraRecart 390mL** are lower (green)/ higher (orange) than those of	
	Steel Can 1 390mL	Glass Jar 1 390mL
Climate Change	-85%	-83%
Acidification	-73%	-78%
Photo-Oxidant Formation	-74%	-77%
Ozone Depletion Potential	-15%	-54%
Terrestrial Eutrophication	-71%	-76%
Aquatic Eutrophication	+41%	+79%
Particulate Matter	-74%	-79%
Use of Nature	+413%	+1277%

4.14 Results allocation factor 100%; LIQUID FOOD PORTION PACK AMBIENT

4.14.1 Presentation of results LIQUID FOOD PORTION PACK AMBIENT

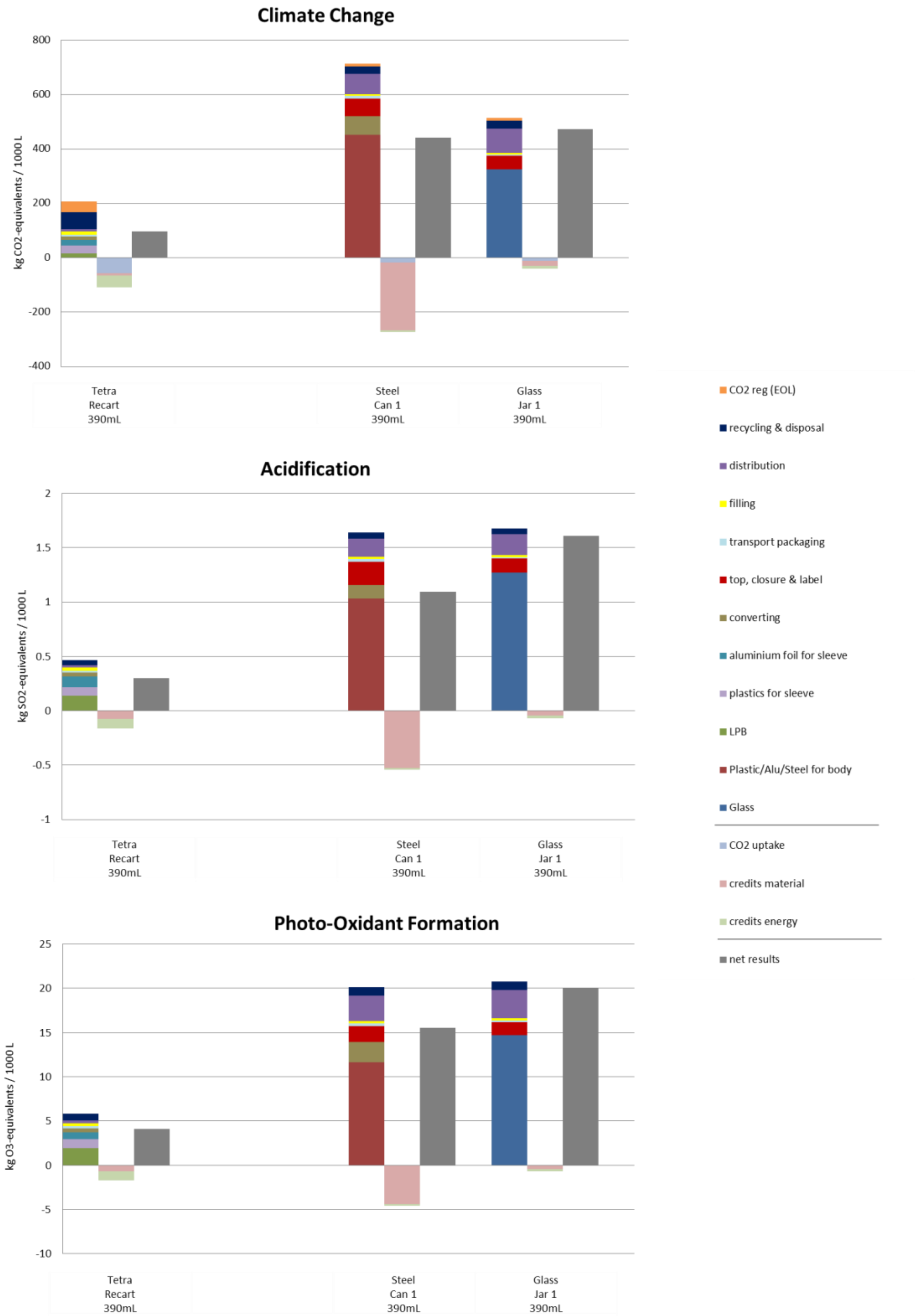


Figure 72: Indicator results for sensitivity analysis on system allocation of **segment LIQUID FOOD PORTION PACK AMBIENT**, allocation factor 100% (Part 1)

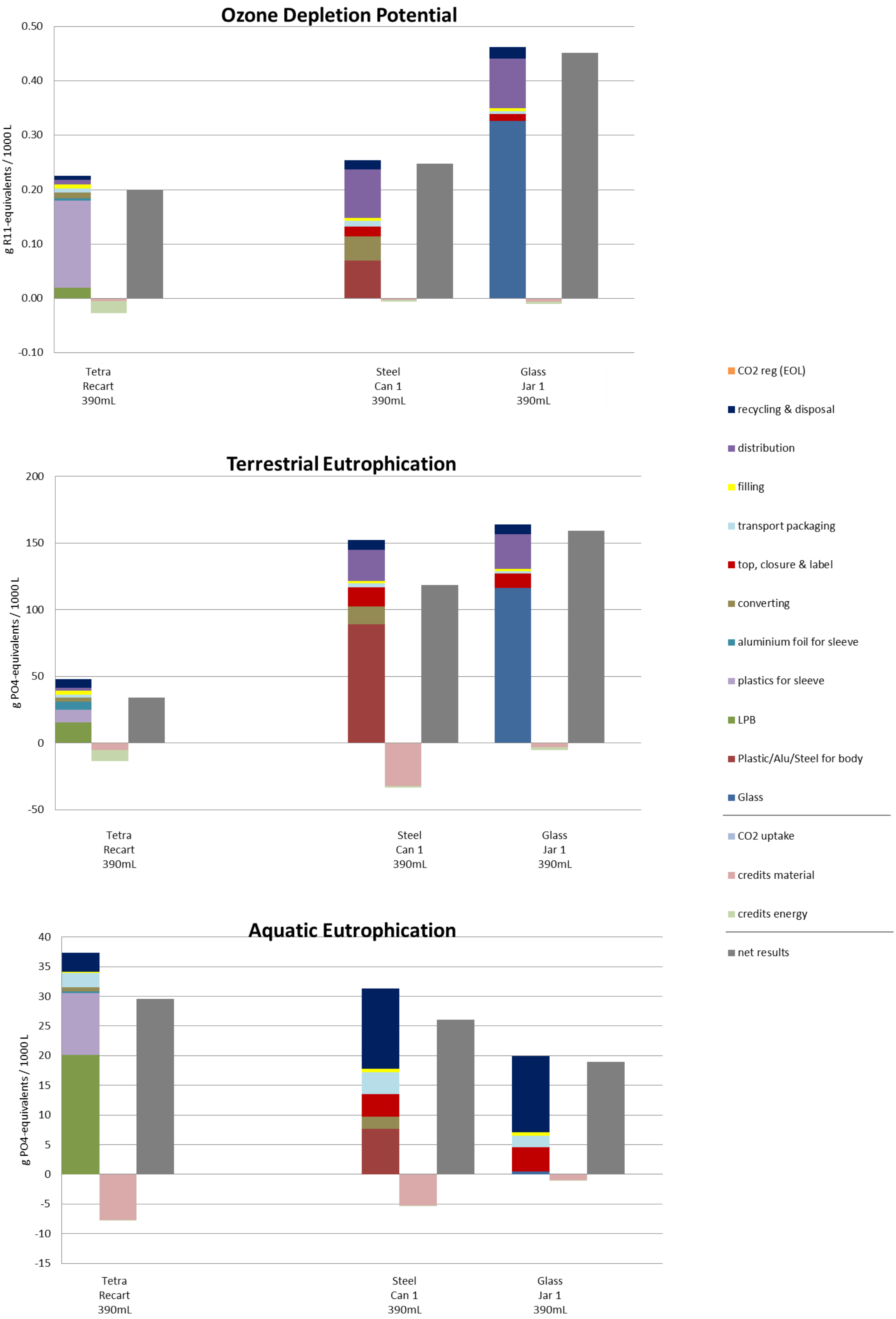


Figure 73: Indicator results for sensitivity analysis on system allocation of **segment LIQUID FOOD PORTION PACK AMBIENT**, allocation factor 100% (Part 2)

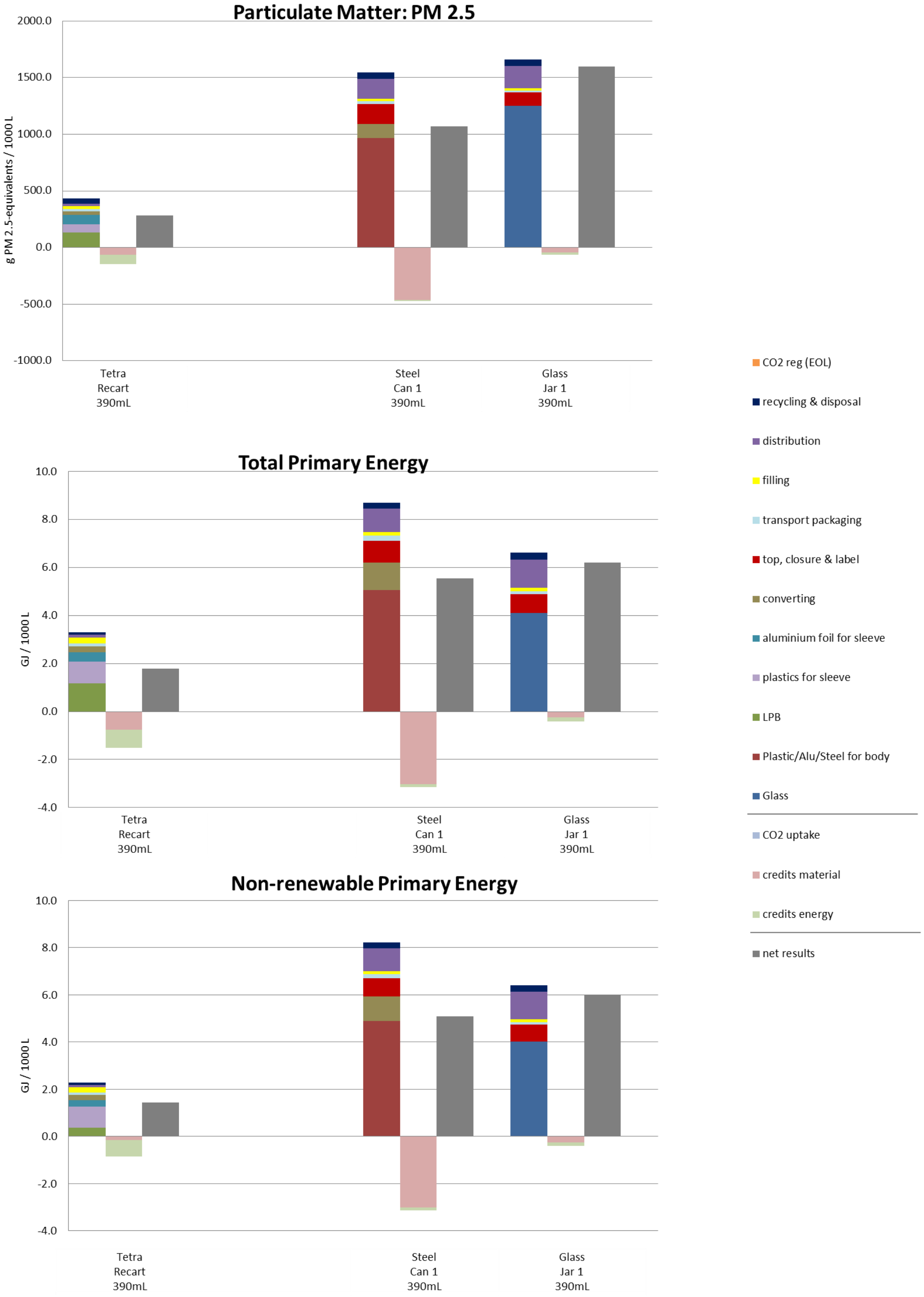


Figure 74: Indicator results for sensitivity analysis on system allocation of **segment LIQUID FOOD PORTION PACK AMBIENT**, allocation factor 100% (Part 3)

Figure 75: Indicator results for sensitivity analysis on system allocation of **segment LIQUID FOOD PORTION PACK AMBIENT**, allocation factor 100% (Part 4)

Table 75: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment LIQUID FOOD PORTION PACK AMBIENT** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		Tetra Recart 390mL		Steel Can 1 390mL	Glass Jar 1 390mL
Climate Change [kg CO_2-e/1000 L]	Burdens	168.48		703.22	504.72
	CO2 (reg)	38.01		11.29	9.07
	Credits	-53.52		-254.97	-29.38
	CO2 uptake	-55.81		-17.93	-10.47
	net results	97.16		441.61	473.93
Acidification [kg SO_2-e/1000 L]	Burdens	0.46		1.64	1.68
	Credits	-0.16		-0.54	-0.07
	Net results	0.30		1.10	1.61
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	5.83		20.09	20.75
	Credits	-1.73		-4.55	-0.67
	Net results	4.10		15.54	20.08
Ozone Depletion [g R11 e/1000 L]	Burdens	0.23		0.25	0.46
	Credits	-0.03		-0.01	-0.01
	Net results	0.20		0.25	0.45
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	47.71		152.14	164.10
	Credits	-13.56		-33.51	-5.17
	Net results	34.15		118.63	158.93
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	37.36		31.30	19.95
	Credits	-7.77		-5.23	-1.00
	Net results	29.59		26.07	18.95
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	432.06		1545.27	1660.53
	Credits	-146.43		-474.38	-60.99
	Net results	285.63		1070.89	1599.54
Total Primary Energy [GJ/1000 L]	Burdens	3.30		8.69	6.62
	Credits	-1.52		-3.15	-0.41
	Net results	1.78		5.54	6.20
Non-renewable Primary Energy [GJ/1000 L]	Burdens	2.28		8.21	6.42
	Credits	-0.84		-3.13	-0.40
	Net results	1.44		5.08	6.02
Cumulative Raw material Demand (abiotic)	Burdens	79.34		749.05	447.41
	Credits	-28.45		-342.43	-31.62
	Net results	50.88		406.62	415.79
Use of Nature [m^2e*year/1000 L]	Burdens	30.52		4.91	1.85
	Credits	-11.04		-0.05	-0.06
	Net results	19.48		4.86	1.79
Water use [m^3/1000 L]	water cool	1.03		2.64	1.97
	water process	2.66		0.02	0.39
	water unspecified	0.84		41.68	2.94

4.14.2 Description and interpretation

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.

In the cases of liquid food cartons in the segment LIQUID FOOD PORTION PACK AMBIENT applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. 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 extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' as well as 'Cumulative Raw material Demand (abiotic)' net results decrease for liquid food cartons in this segment when rising the allocation factor to 100% for both, liquid food carton systems and plastic bottles due to the lower energy and resource demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

In the case of the single use glass jar, net results of all categories stay about the same when applying the 100% allocation factor as burdens from recycling and disposal are similar than energy and material credits due to the closed loop use of cullet.

In case of the steel can net results decrease in most categories when applying the allocation factor 100% instead of 50% as the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor.

4.14.3 Comparison between packaging systems

The following table shows the net results per functional unit of the regarded liquid food cartons systems for all impact categories compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

The percentages in the following table show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system[1].

[1] ((|net result heading – net result column|) / net result column)*100

Table 76: Comparison of net results: **Tetra Recart 390mL**versus competing carton based and alternative packaging systems in **segment LIWUID FOOD PORTION PACK (ambient), Europe**, allocation factor 100%

FOOD FAMILY PACK (ambient), Europe, Allocation 100	The net results of **TetraRecart 390mL** are lower (green)/ higher (orange) than those of	
	Steel Can 1 390mL	Glass Jar 1 390mL
Climate Change	-78%	-79%
Acidification	-73%	-81%
Photo-Oxidant Formation	-74%	-80%
Ozone Depletion Potential	-20%	-56%
Terrestrial Eutrophication	-71%	-79%
Aquatic Eutrophication	+13%	+56%
Particulate Matter	-73%	-82%
Use of Nature	+301%	+991%

5 Scenario Variants

5.1 DAIRY FAMILY PACK CHILLED

5.1.1 Scenario variants regarding plant-based plastics in HDPE bottles

The study includes beverage cartons containing plant-based plastic materials. In order to take also plant-based material in plastic bottles into account, scenario variants are calculated for the packaging systems listed in Table 29. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

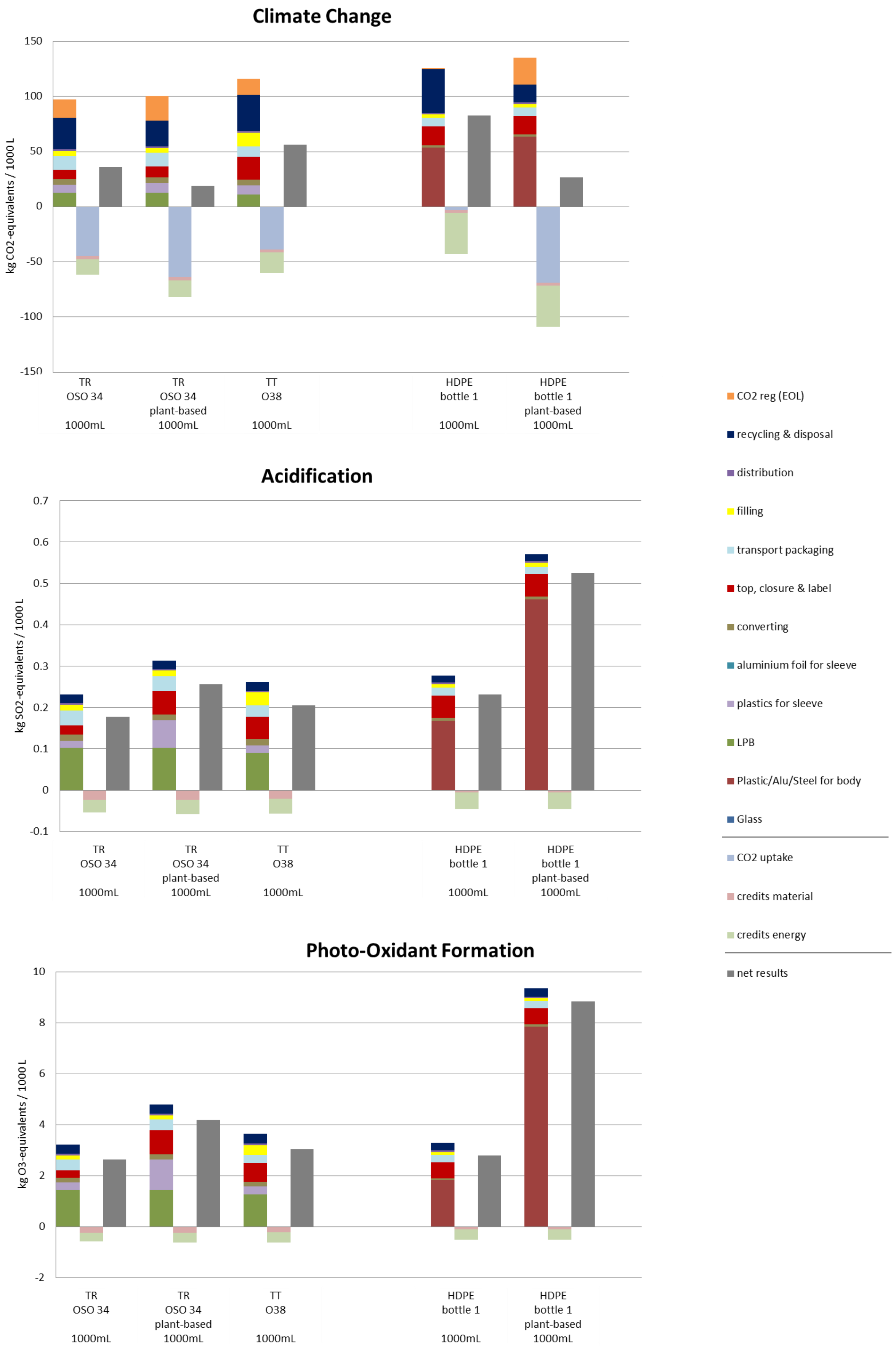


Figure 76: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50% (Part 1)

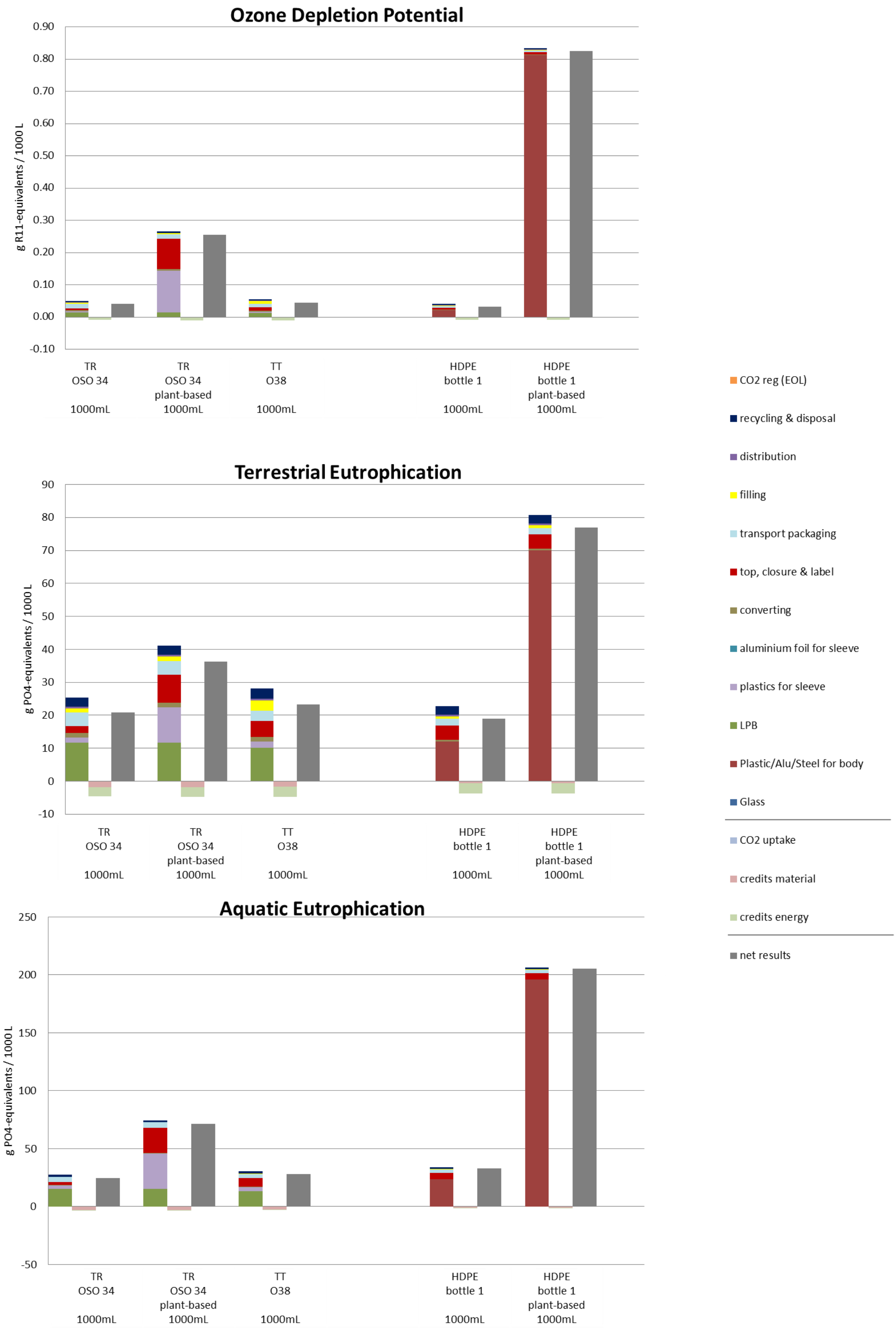


Figure 77: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50% (Part 2)

Figure 78: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (chilled), Europe,** allocation factor 50% (Part 3)

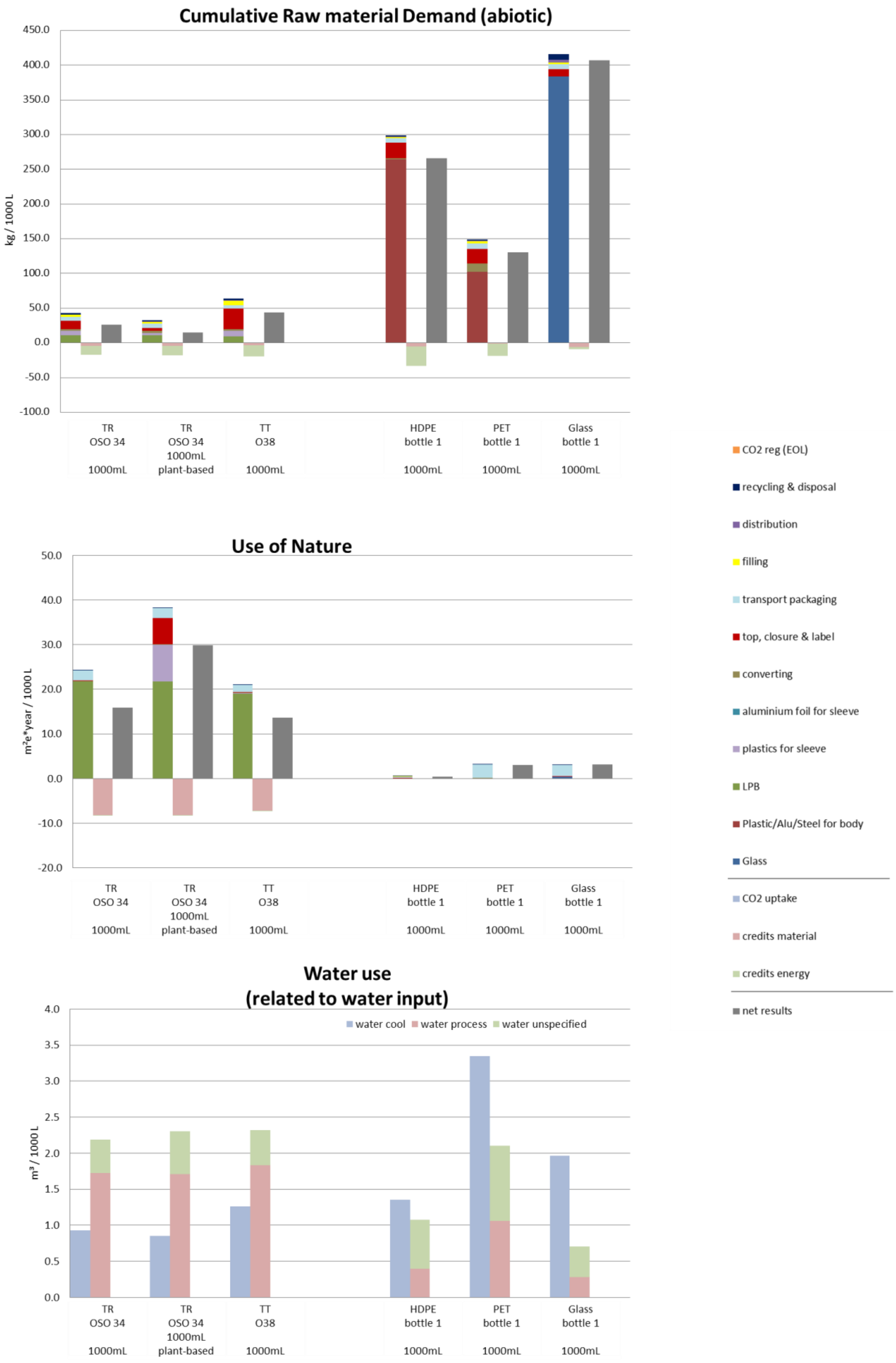


Figure 79: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (chilled), Europe,** allocation factor 50% (Part 4)

Description and Interpretation

The scenario variants regarding plant-based HDPE bottles show that a substitution of fossil plastics by plant-based plastics leads to lower environmental impacts in the categories 'Climate Change', 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)' but to substantial higher impacts in all other categories.

5.1.2 Scenario variants regarding recycled PET in PET bottles

PET bottles in the base scenarios are modelled with their specific share of recycled PET (rPET). As PET bottles could be produced with 100% recycled content scenario variants are calculated for the packaging systems listed in Table 30. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

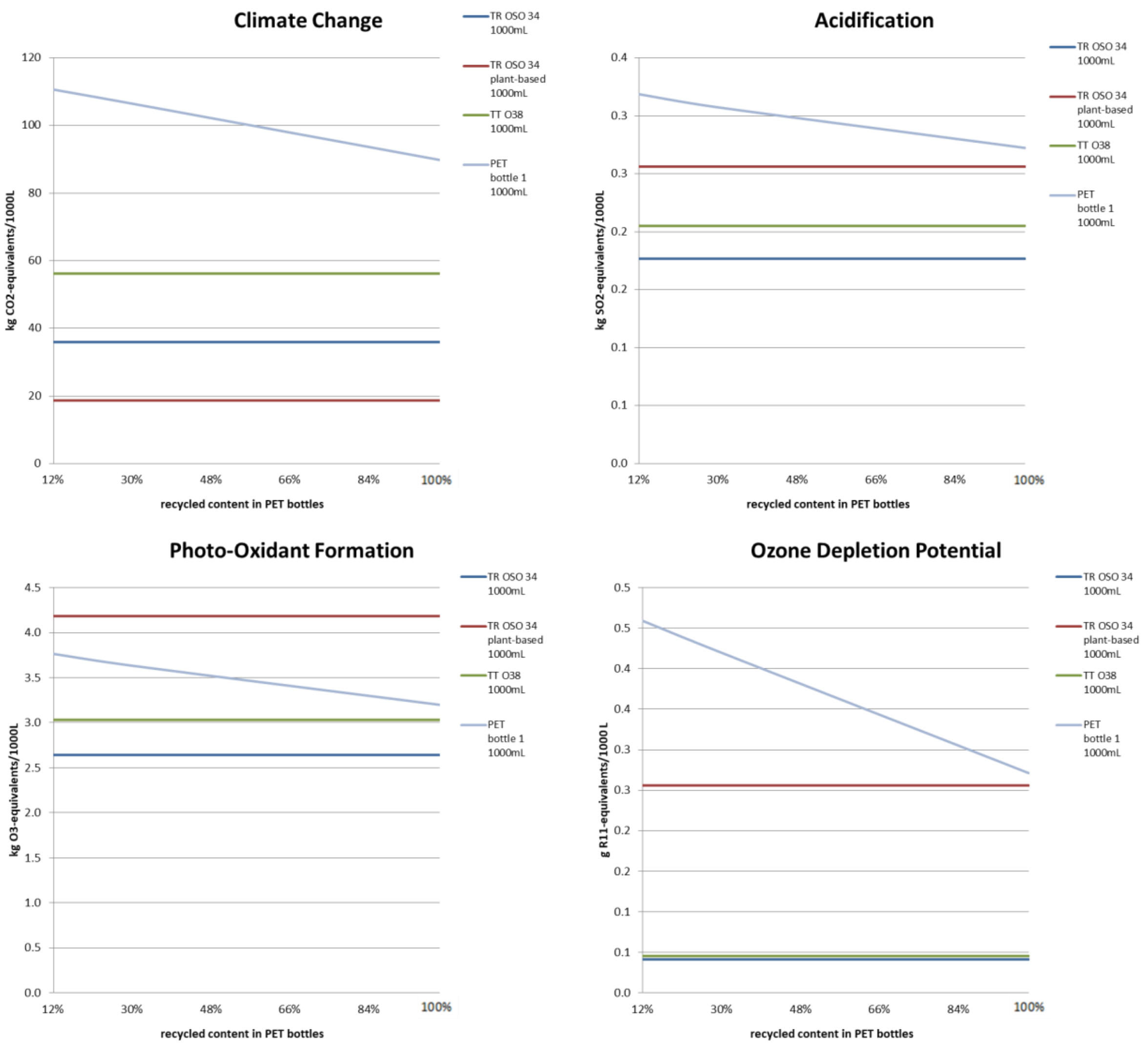


Figure 80: Indicator results for scenario variants recycled PET of **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50% (Part 1)

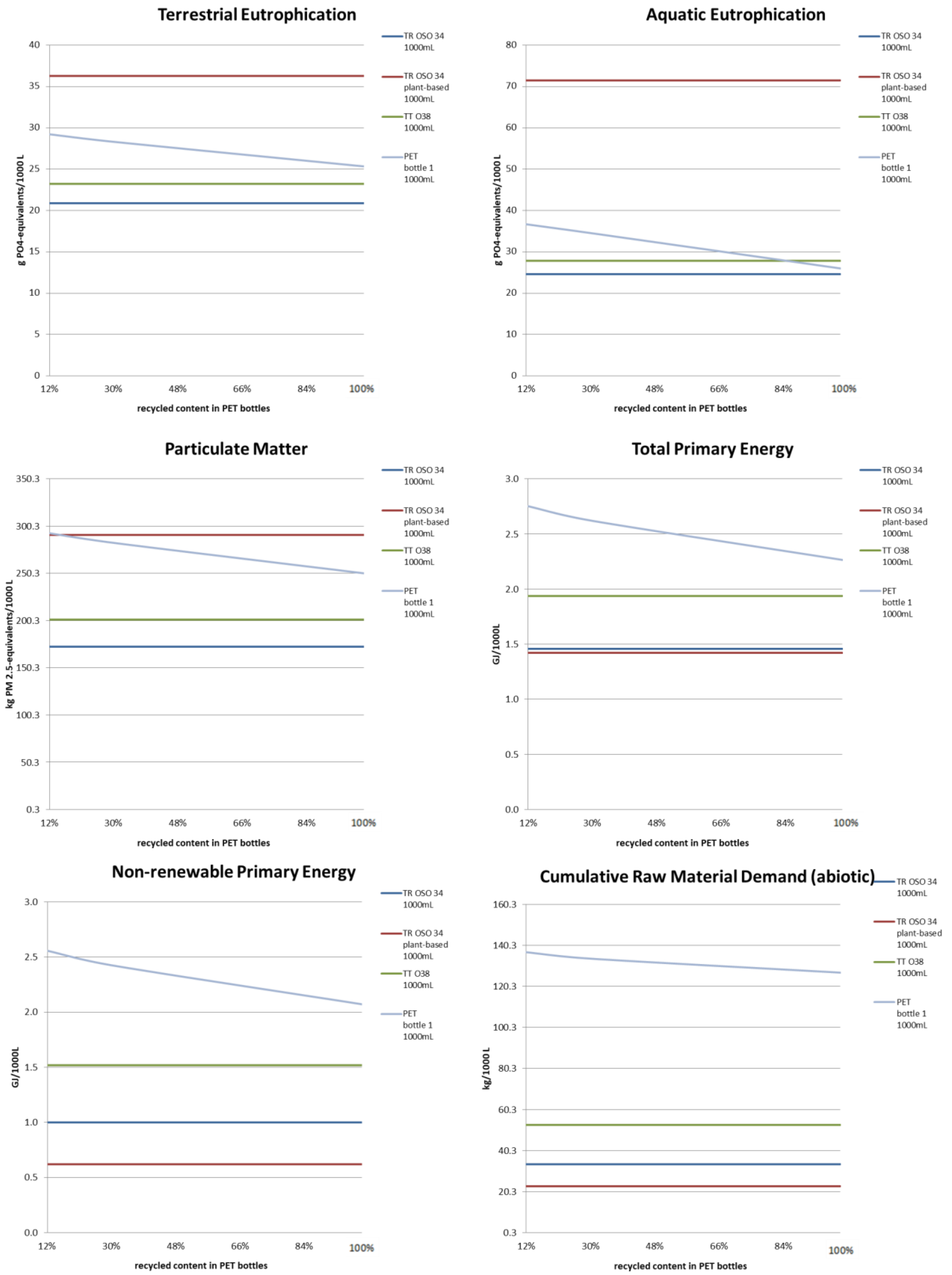


Figure 81: Indicator results for scenario variants recycled PET of **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

The ranking between the PET bottle with increased recycled content and the compared beverage cartons stays mostly the same with the regarded increase of recycled content. The exceptions are 'Aquatic Eutrophication' for which the PET bottle with a recycled content of more than approximately 85% will lead to lower results than the TT O38 1000mL and 'Particulate Matter' for which the increase of recycled content shows lower impacts than the TR OSO34 plant-based 1000mL.

5.1.3 Scenario variants regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, scenario variants with reduced bottle weight are performed for the packaging systems listed in and Table 31. In these analyses the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

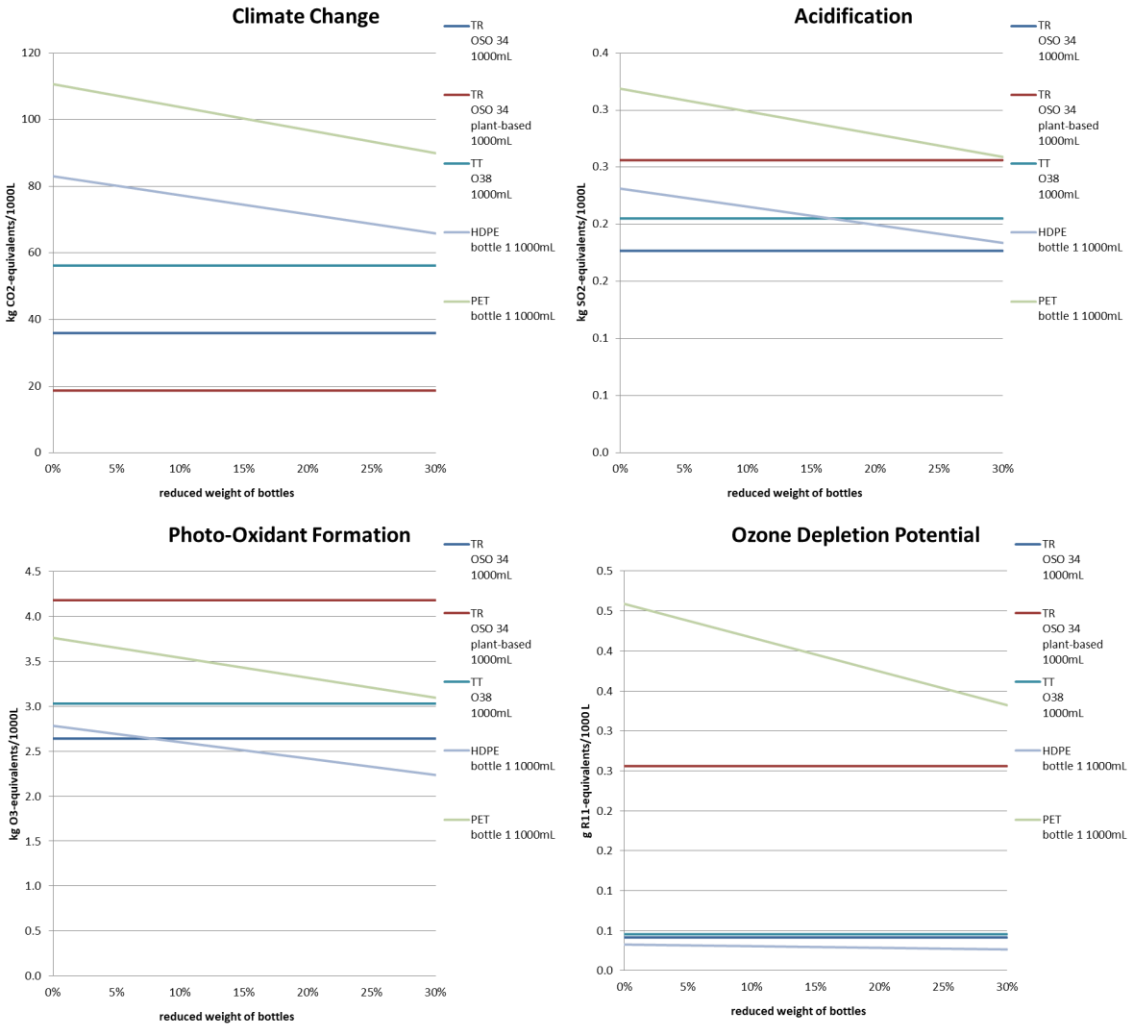


Figure 82: Indicator results for scenario variants on plastic bottle weight of **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50% (Part 1)

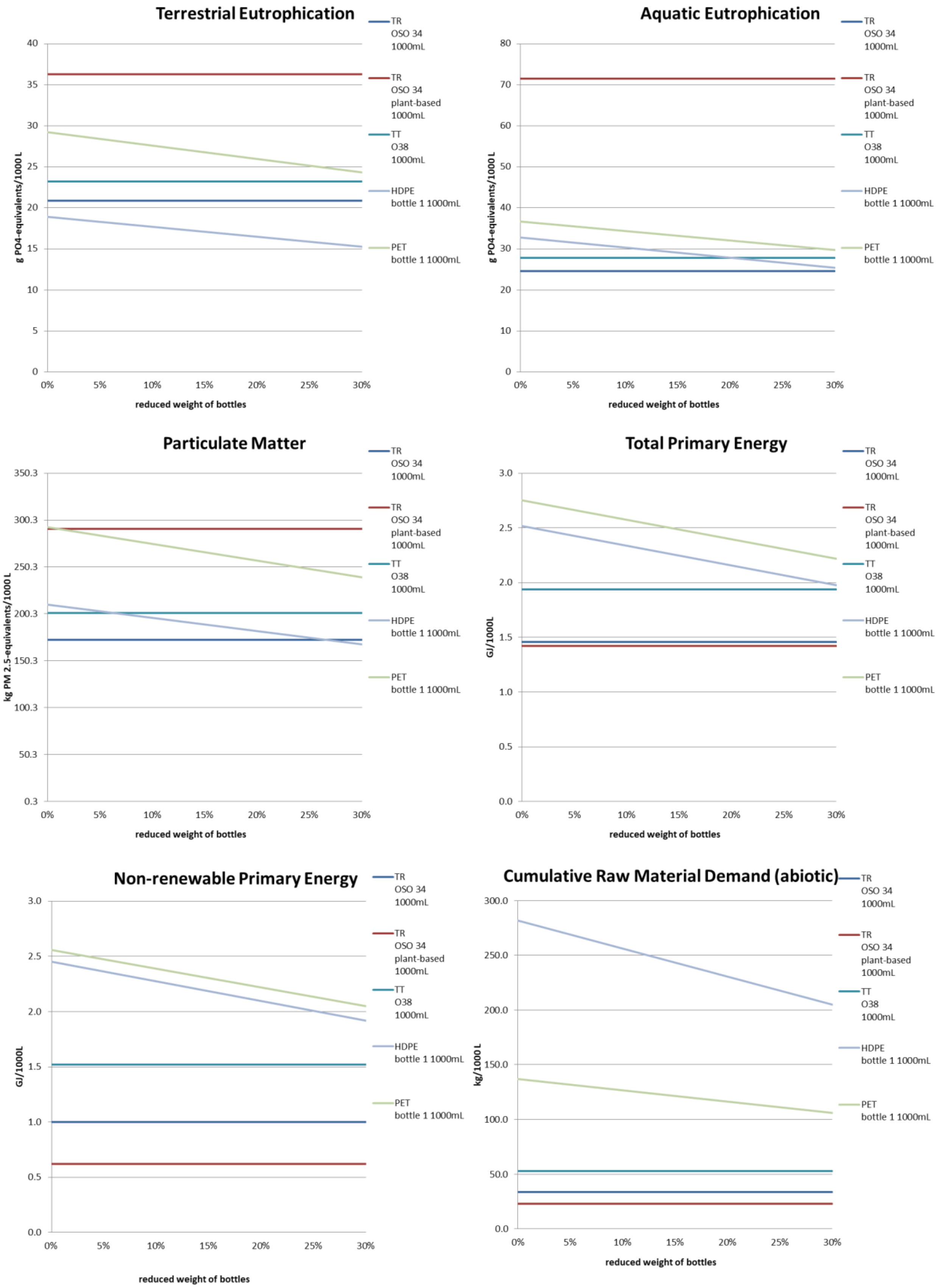


Figure 83: Indicator results for scenario variants on plastic bottle weight of **segment DAIRY FAMILY PACK (chilled), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

The scenario variants of plastic bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In the case of 'Climate Change' both plastic bottles show higher impacts than the compared beverage carton systems also with the regarded decrease of bottle weight.

Regarding the other categories, the ranking of beverage cartons and the PET bottle does not change with the decrease of bottle weight.

In the case of the HDPE bottle, in most other categories, the HDPE bottles breaks even with some beverage cartons when decreasing its weight.

5.2 DAIRY FAMILY PACK AMBIENT

5.2.1 Scenario variants regarding plant-based plastics in HDPE bottles

The study includes beverage cartons containing plant-based plastic materials. In order to take also plant-based material in plastic bottles into account, scenario variants are calculated for the packaging systems listed in Table 29. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

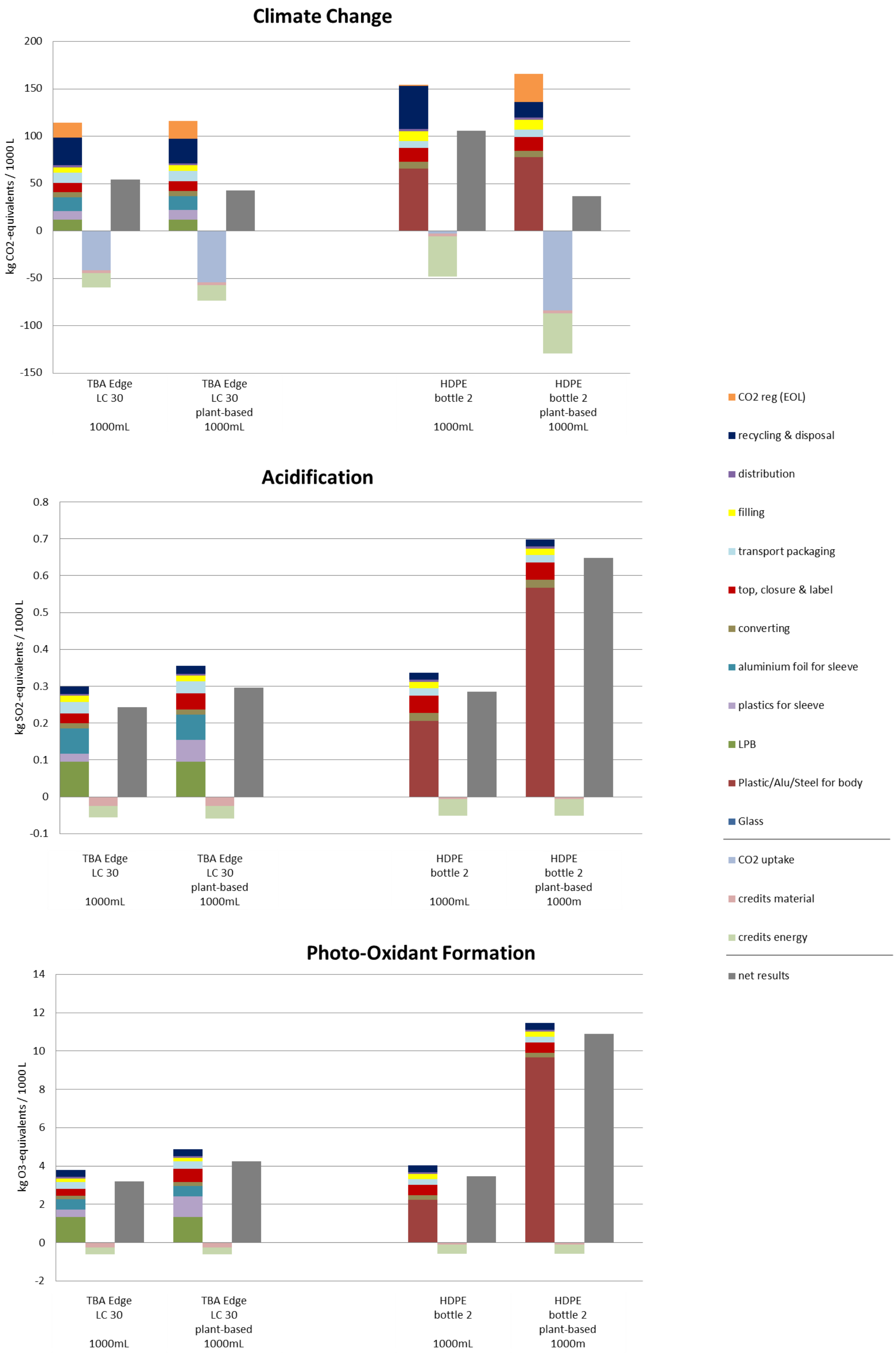


Figure 84: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 1)

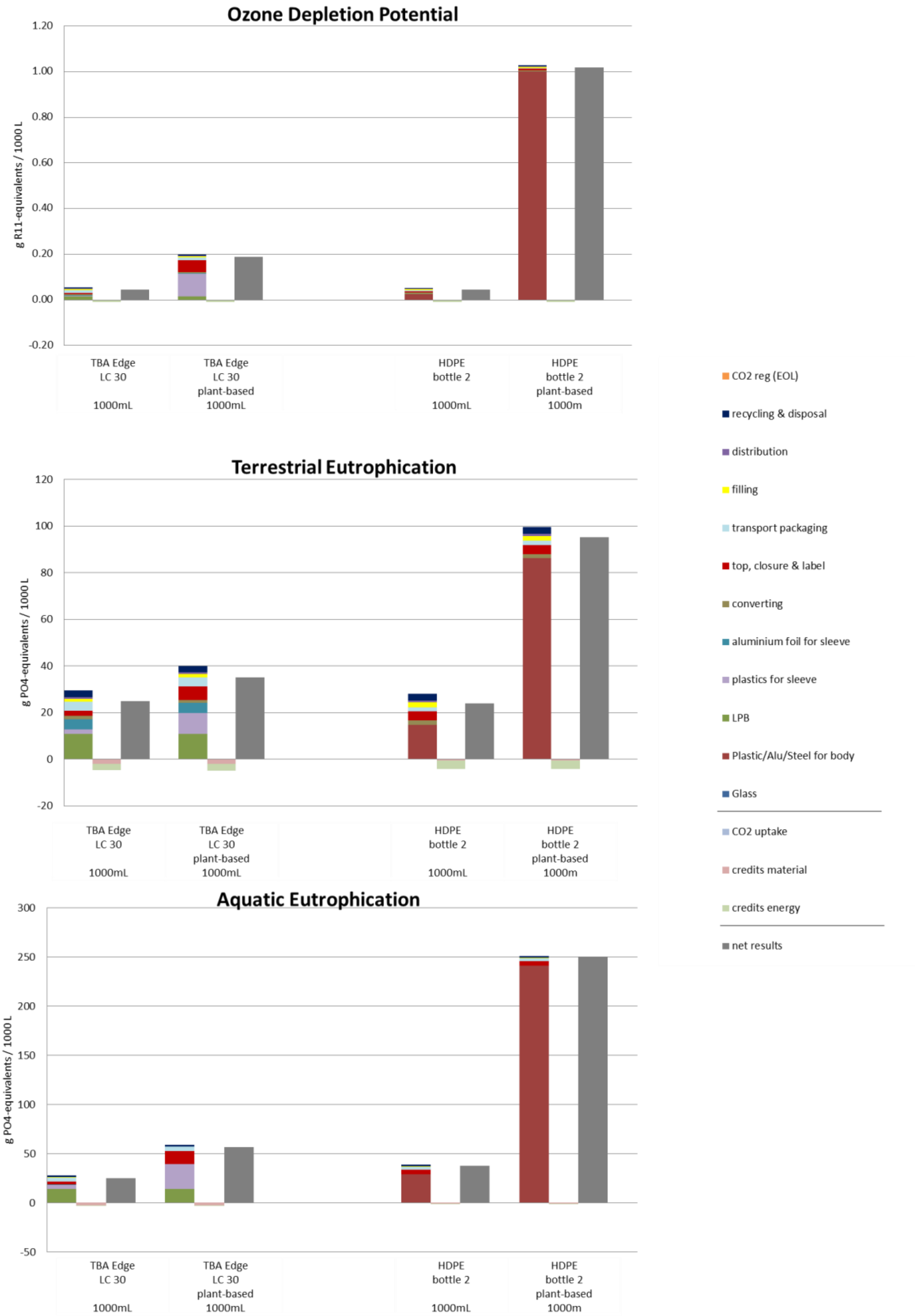


Figure 85: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 2)

Figure 86: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 3)

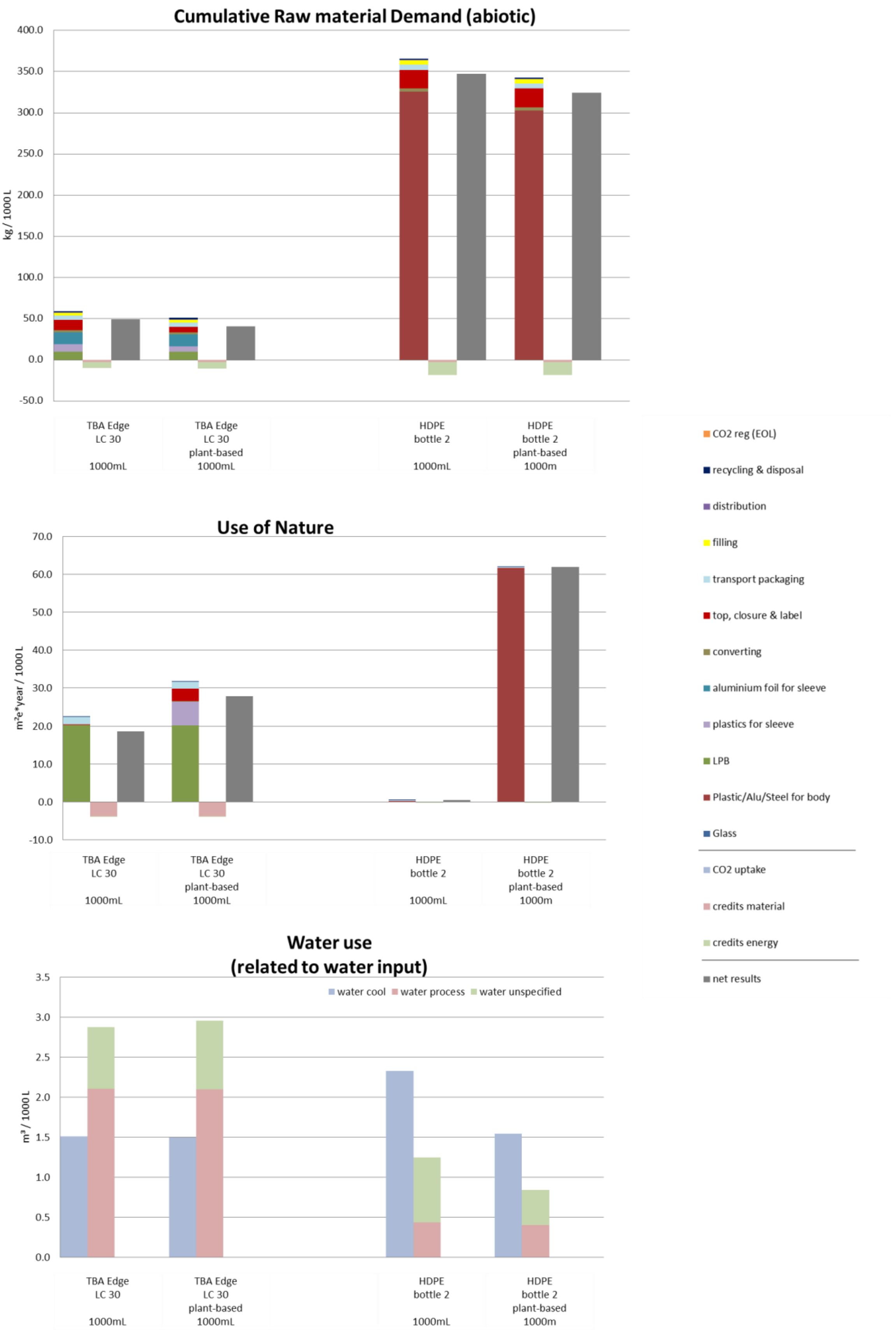


Figure 87: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 4)

Description and Interpretation

The scenario variant regarding the plant-based HDPE bottle shows that a substitution of fossil plastics by plant-based plastics leads to lower environmental impacts in the categories ‘Climate Change’, ‘Non-renewable Primary Energy’ and ‘Cumulative Raw material Demand (abiotic)’ but to substantial higher impacts in all other categories.

5.2.2 Scenario variants regarding recycled PET in PET bottles

PET bottles in the base scenarios are modelled with their specific share of recycled PET (rPET). As PET bottles could be produced with 100% recycled content scenario variants are calculated for the packaging systems listed in Table 30. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

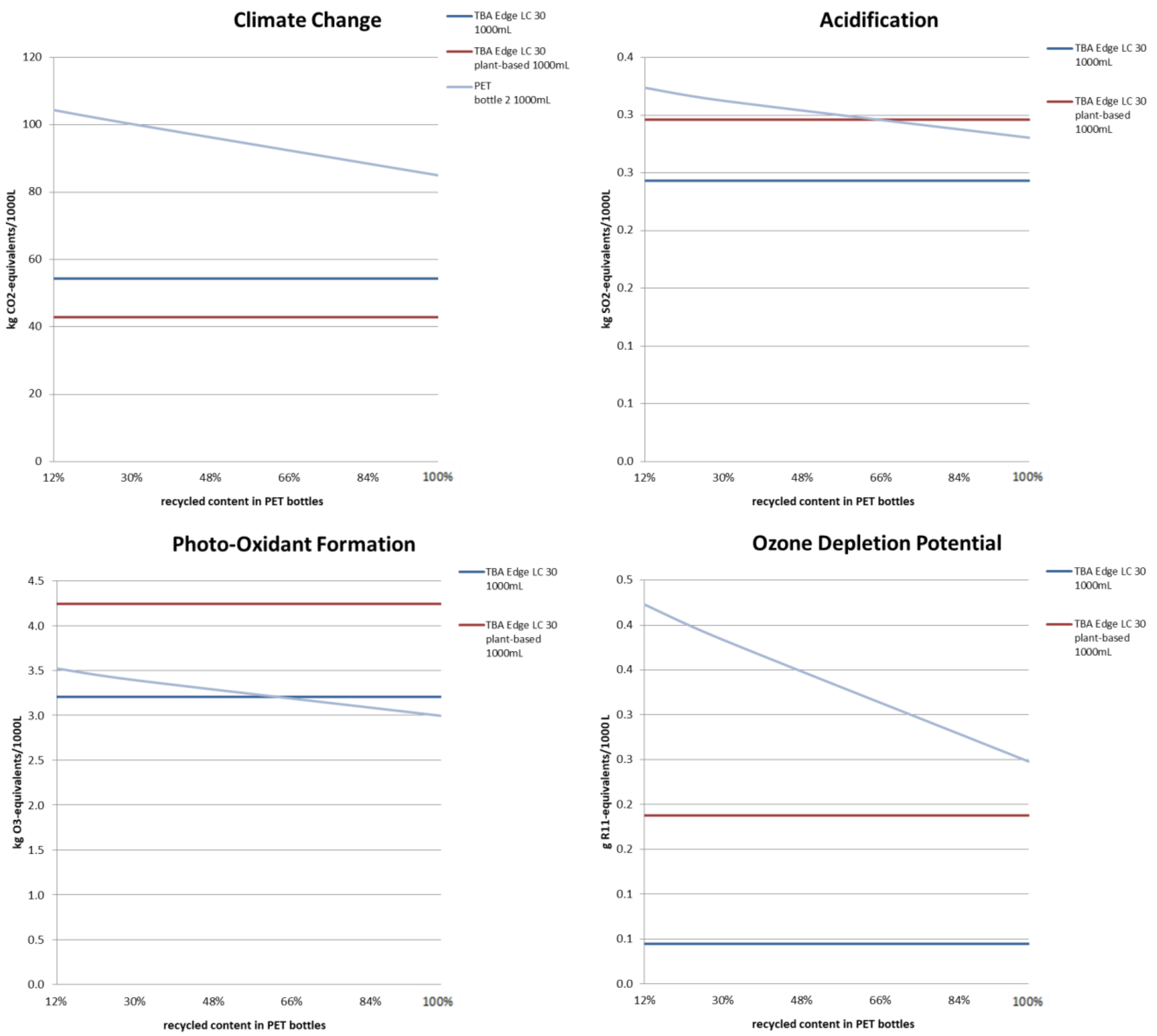


Figure 88: Indicator results for scenario variants recycled PET of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 1)

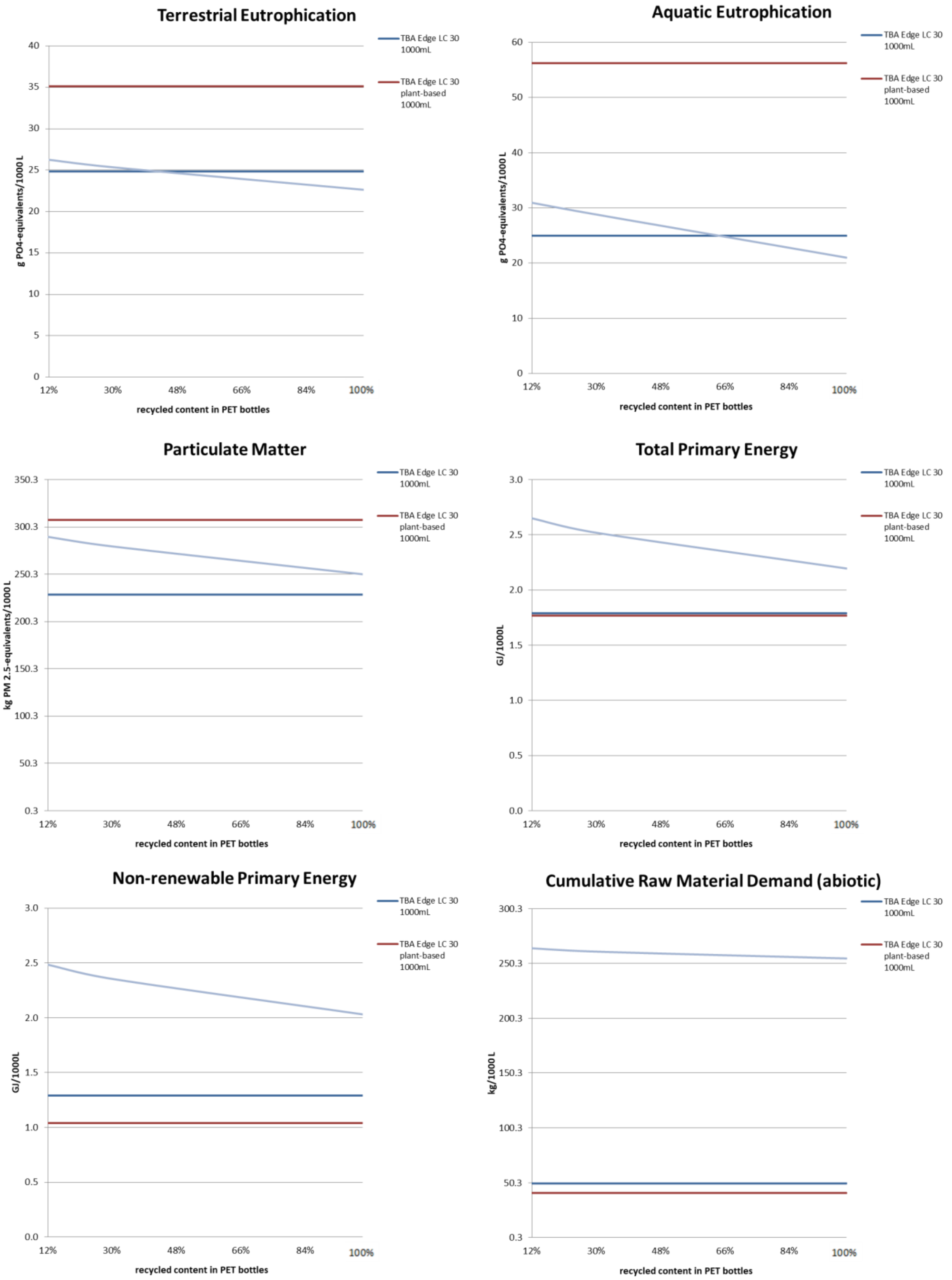


Figure 89: Indicator results for scenario variants recycled PET of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

In the cases of 'Climate Change', 'Ozone Depletion Potential' 'Total Primary Energy', 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)' the PET bottle shows higher impacts than the compared beverage carton systems also with the regarded increase of recycled content.

In most of the other categories, the PET bottle breaks even with some beverage cartons when increasing its recycled content.

5.2.3 Scenario variants regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, scenario variants with reduced bottle weight are performed for the packaging systems listed in Table 31. In these analyses the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

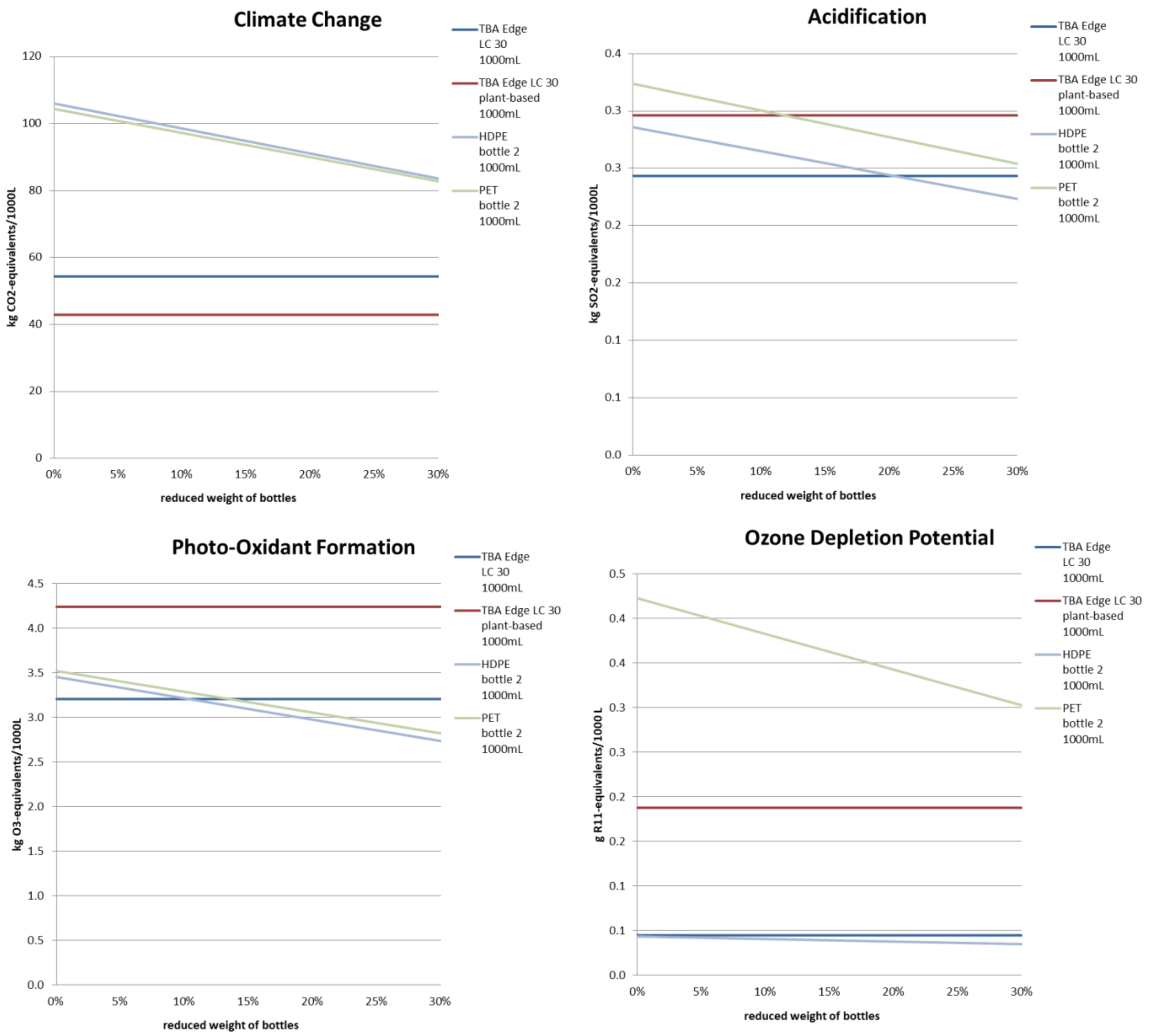


Figure 90: Indicator results for scenario variants on plastic bottle weight of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 1)

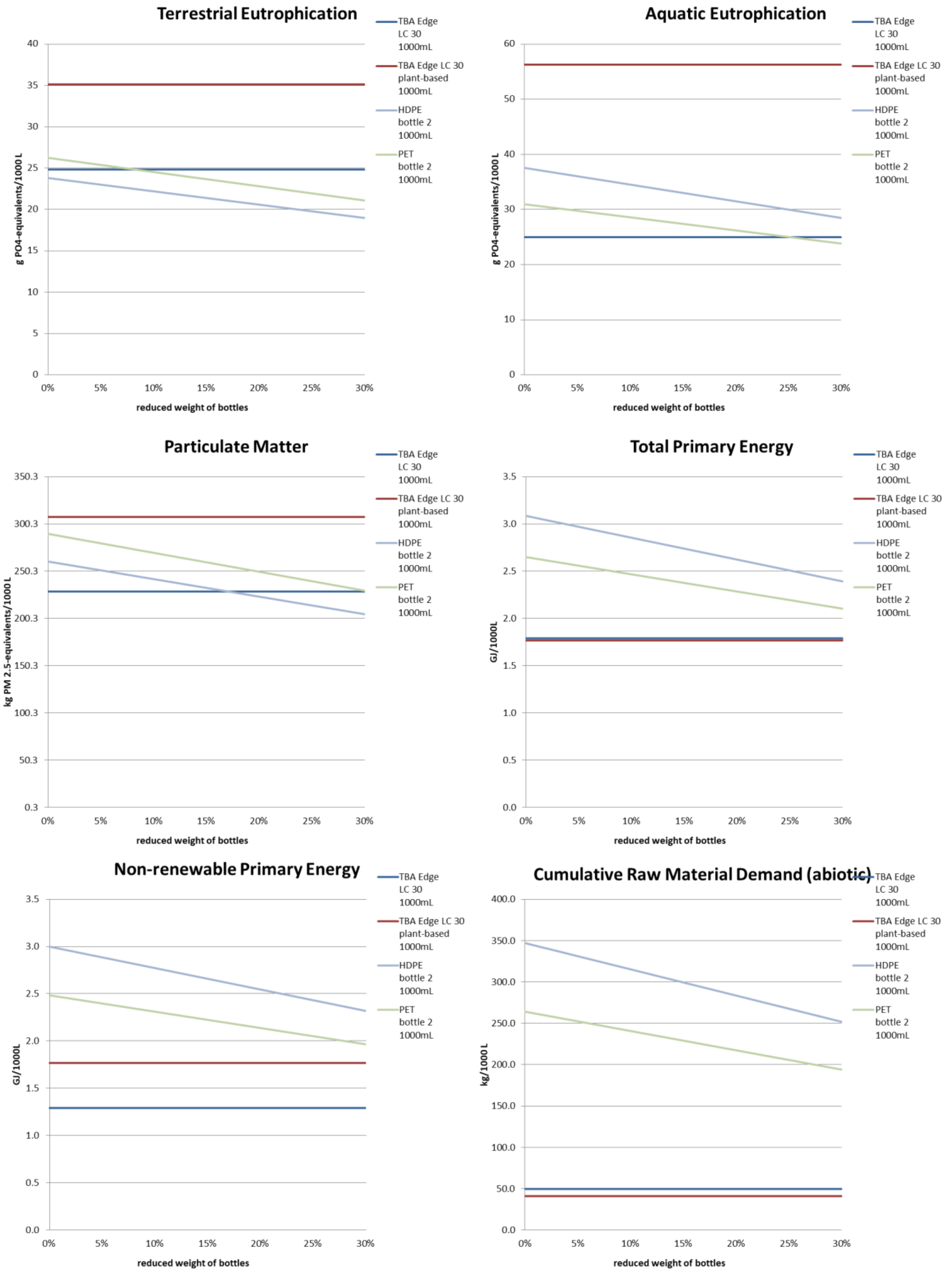


Figure 91: Indicator results for scenario variants on plastic bottle weight of **segment DAIRY FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

The scenario variants of plastic bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In the case of 'Climate Change' both plastic bottles show higher impacts than the compared beverage carton systems also with the regarded decrease of bottle weight.

Regarding the other categories, the plastic bottles break even with the compared beverage cartons in several categories.

5.3 DAIRY PORTION PACK CHILLED

5.3.1 Scenario variants regarding plant-based plastics in HDPE bottles

The study includes beverage cartons containing plant-based plastic materials. In order to take also plant-based material in plastic bottles into account, scenario variants are calculated for the packaging systems listed in Table 29. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

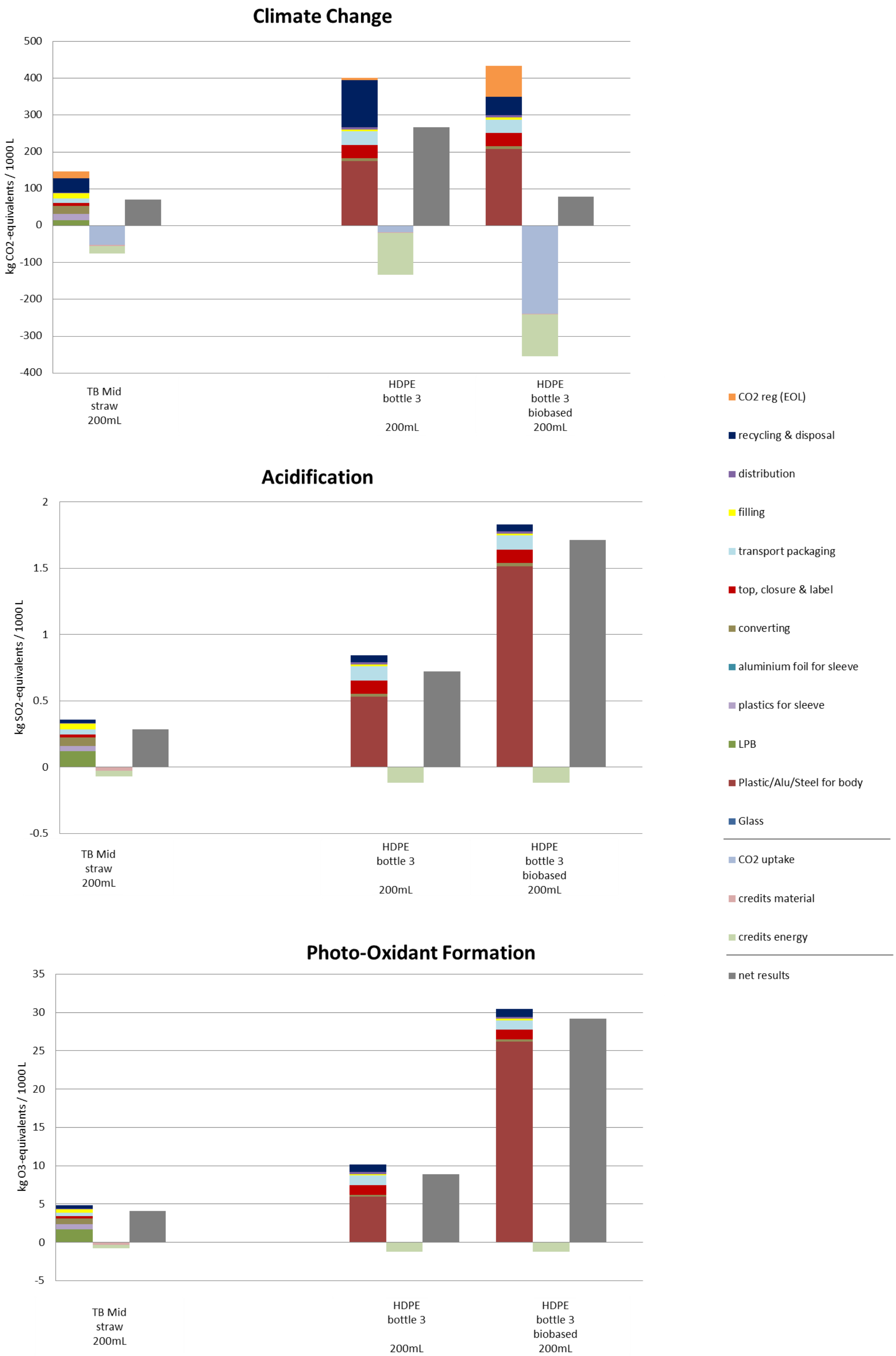


Figure 92: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 50% (Part 1)

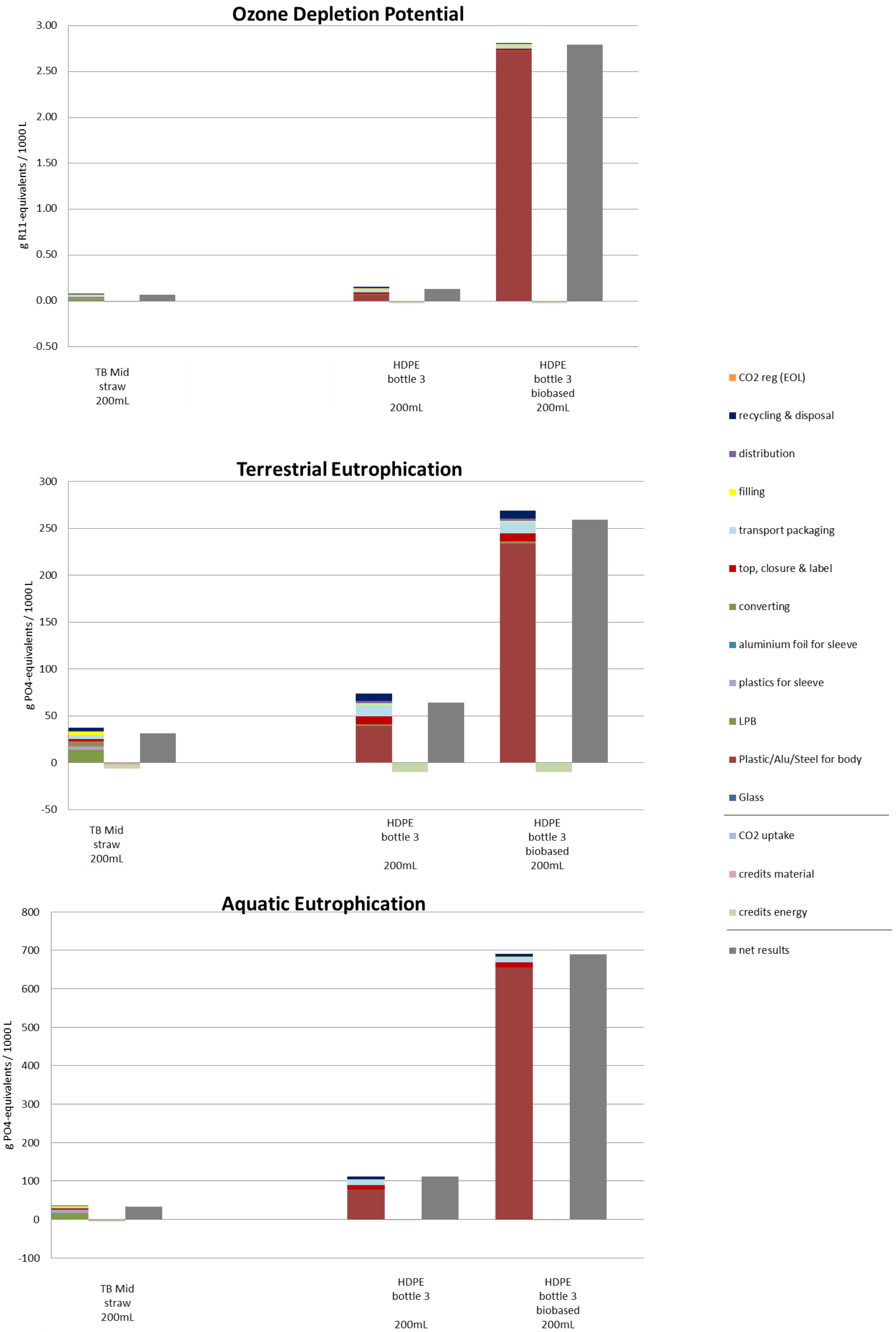


Figure 93: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 50% (Part 2)

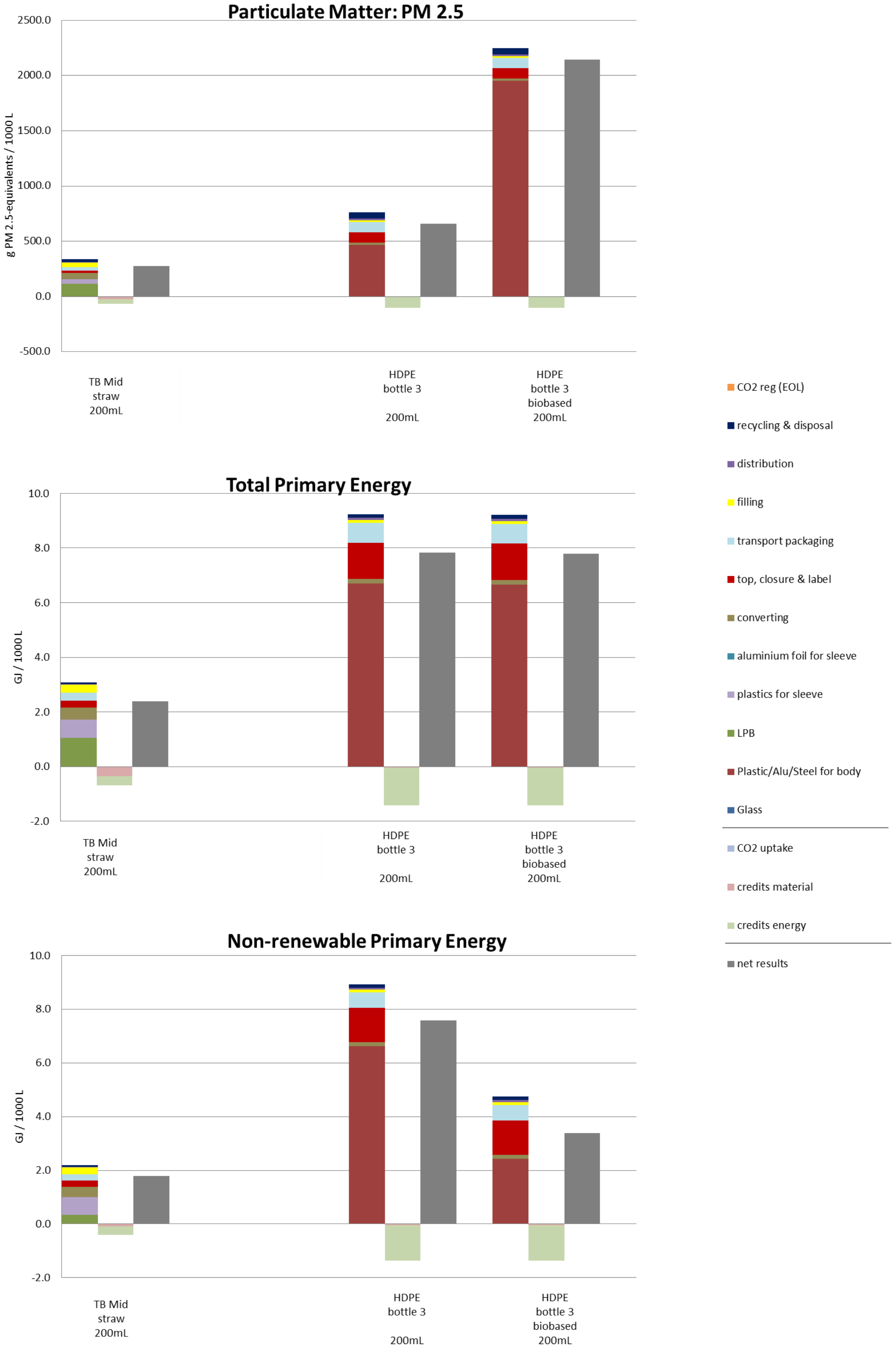


Figure 94: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of segment DAIRY PORTION PACK (chilled), Europe, allocation factor 50% (Part 3)

Figure 95: Indicator results for scenario variants regarding plant-based plastics in HDPE bottles of **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 50% (Part 4)

Description and Interpretation

The scenario variant regarding plant-based HDPE bottle shows that a substitution of fossil plastics by plant-based plastics leads to lower environmental impacts in the categories 'Climate Change', 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)' but to substantial higher impacts in all other categories.

5.3.2 Scenario variants regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, scenario variants with reduced bottle weight are performed for the packaging systems listed in Table 31. In these analyses the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

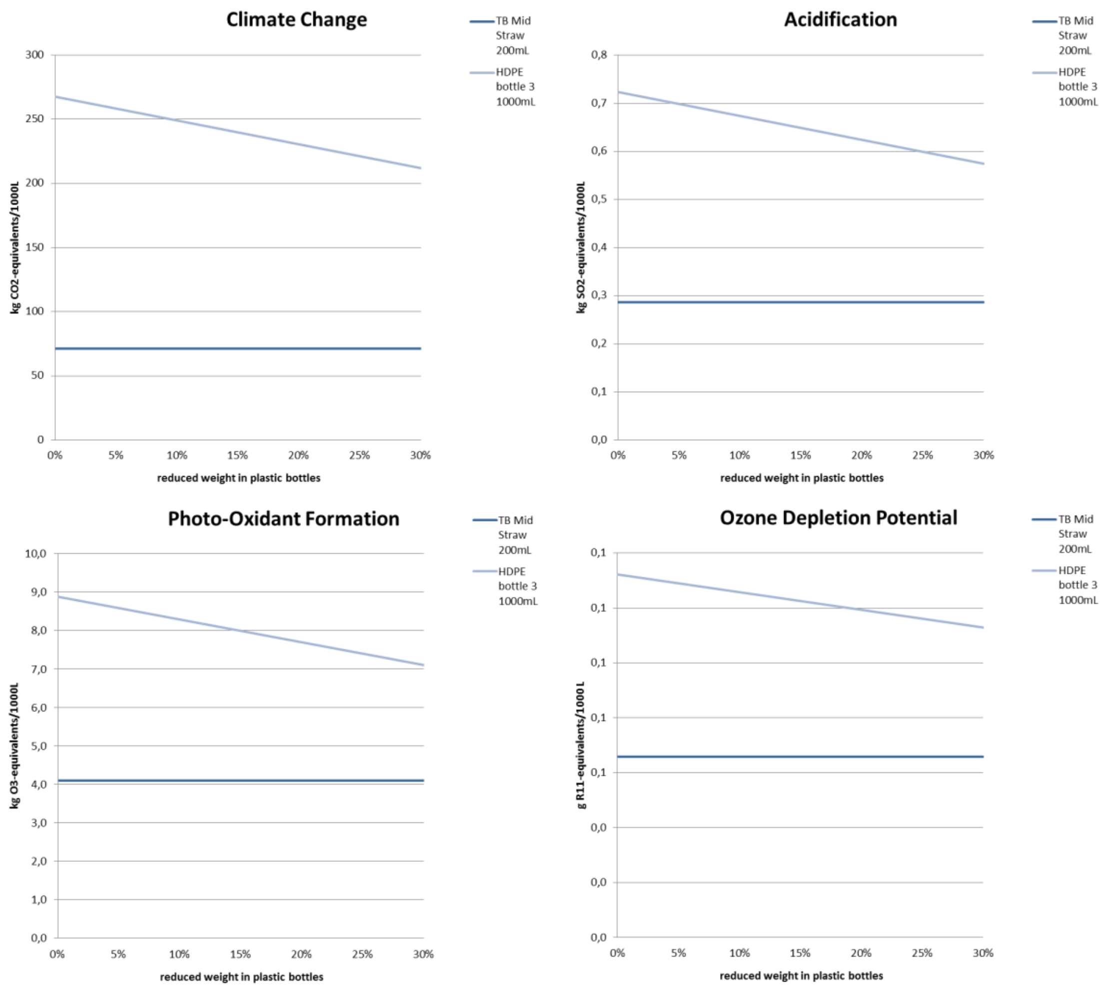


Figure 96: Indicator results for scenario variants on plastic bottle weight of **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 50% (Part 1)

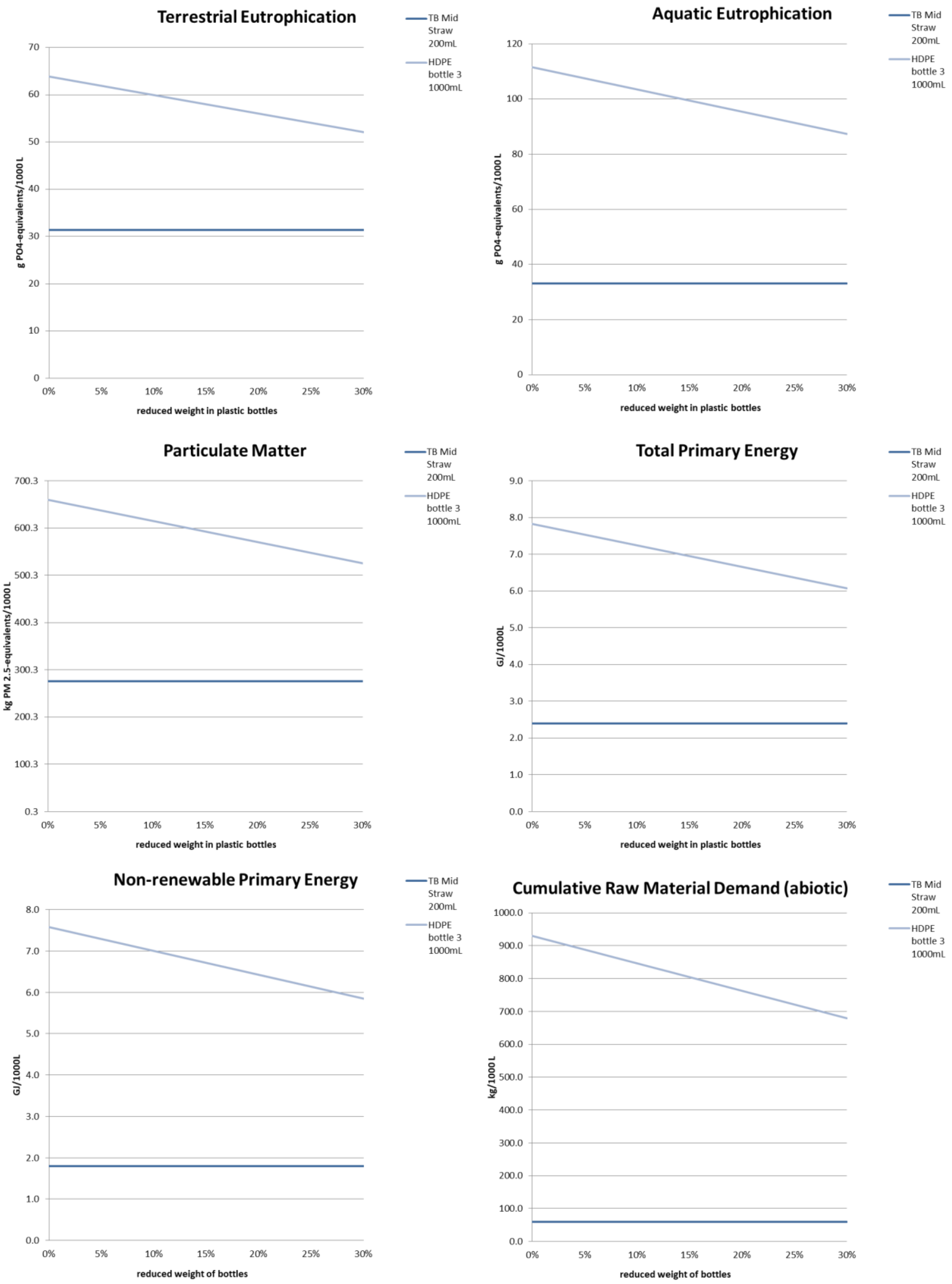


Figure 97: Indicator results for scenario variants on plastic bottle weight of **segment DAIRY PORTION PACK (chilled), Europe**, allocation factor 50% (Part 2)

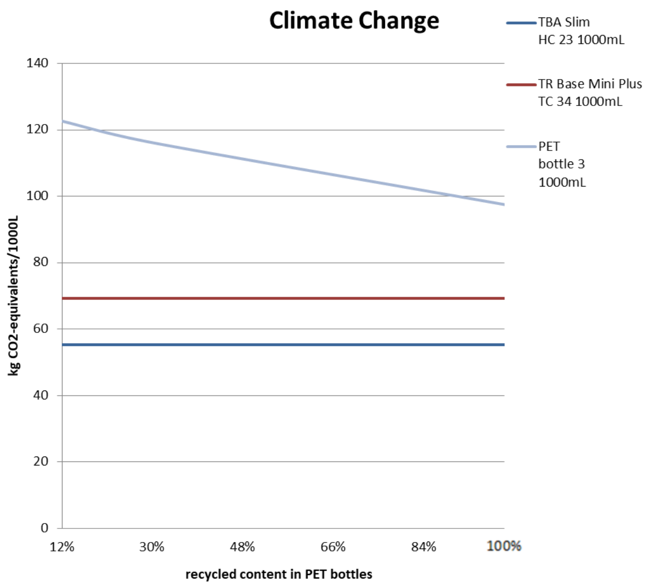
Description and Interpretation

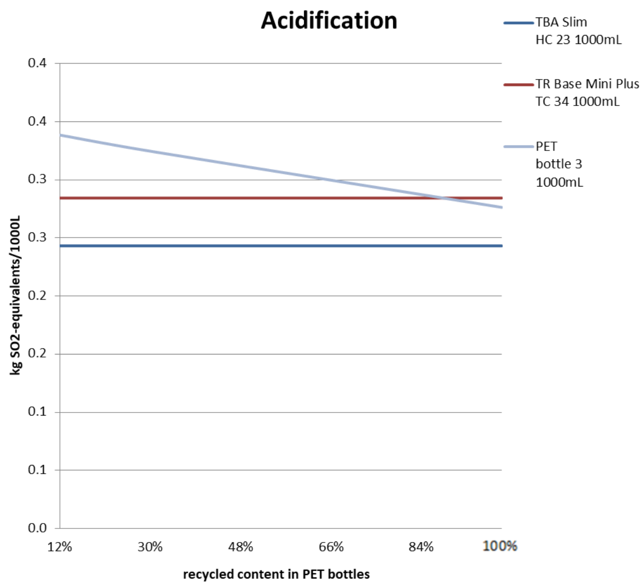
The scenario variant of the HDPE bottle with reduced weight shows that the impacts in all categories are lower if less material is used. In all categories the HDPE bottle shows higher impacts than the compared beverage carton system also with the regarded decrease of bottle weight.

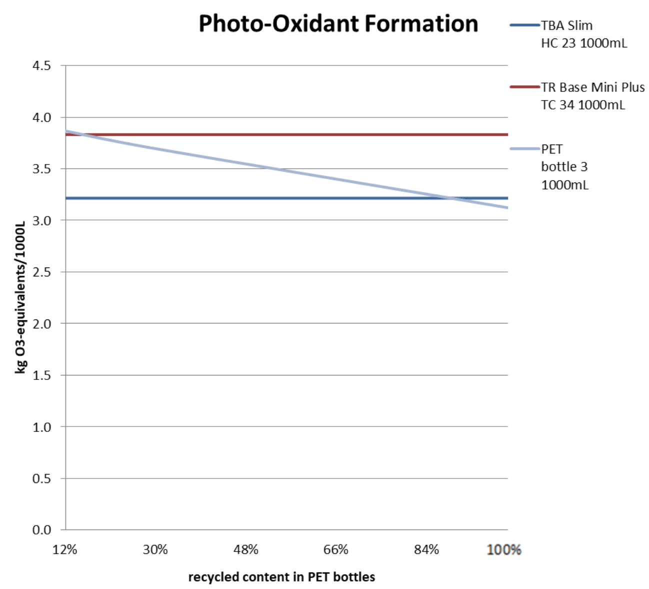
5.4 JNSD FAMILY PACK AMBIENT

5.4.1 Scenario variants regarding recycled PET in PET bottles

PET bottles in the base scenarios are modelled with their specific share of recycled PET (rPET). As PET bottles could be produced with 100% recycled content scenario variants are calculated for the packaging systems listed in Table 30. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.







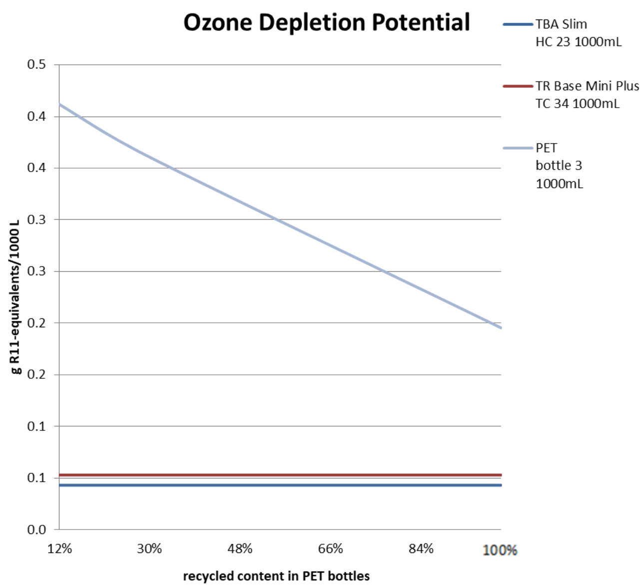


Figure 98: Indicator results for scenario variants recycled PET of **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 1)

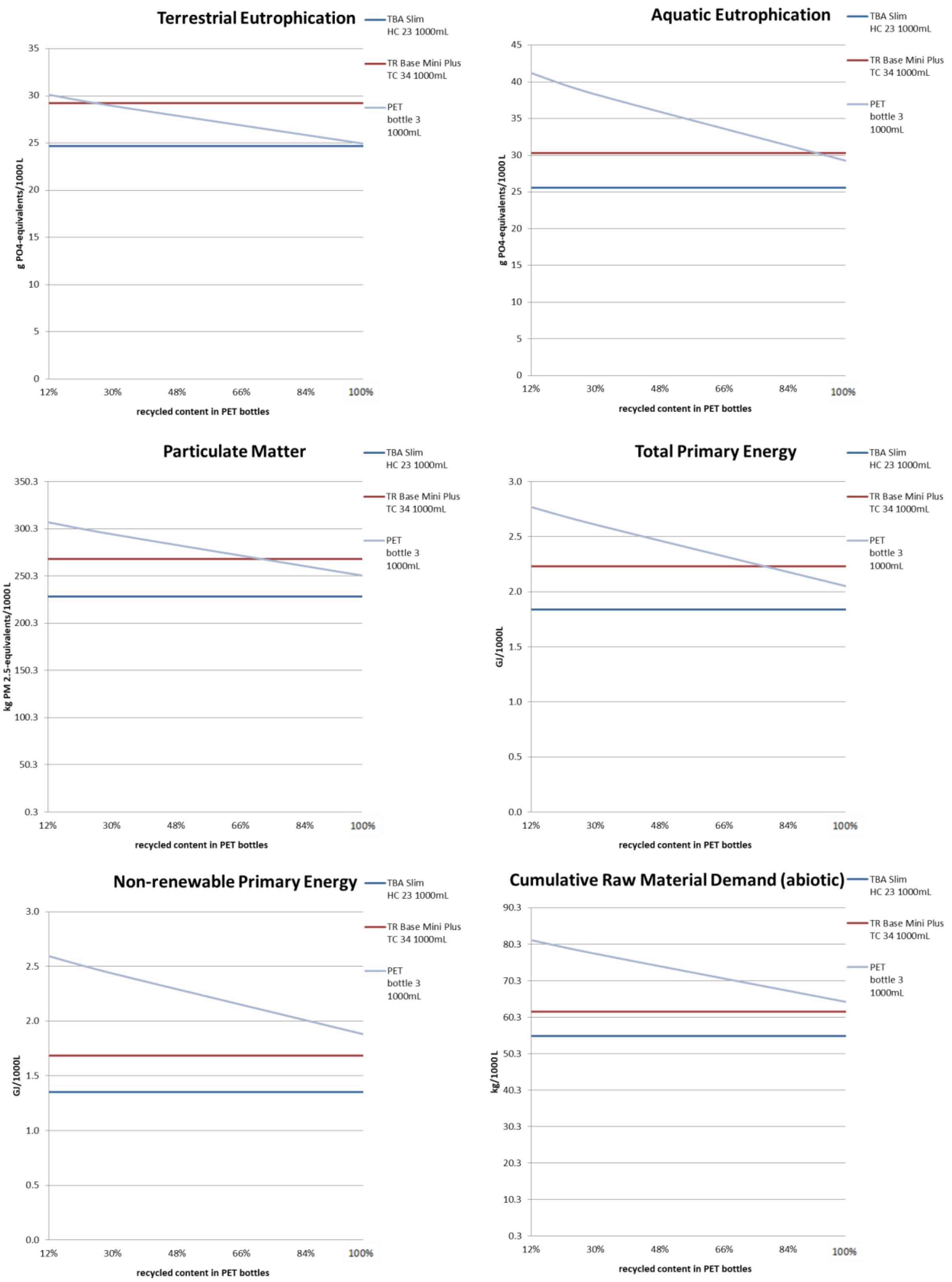


Figure 99: Indicator results for scenario variants recycled PET of **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

In the cases of 'Climate Change', 'Ozone Depletion Potential', 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)' the PET bottle shows higher impacts than the compared beverage carton systems also with the regarded increase of recycled content.

In most of the other categories, the PET bottle breaks even with some beverage cartons when increasing its recycled content.

5.4.2 Scenario variants regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, scenario variants with reduced bottle weight are performed for the packaging systems listed in Table 31. In these analyses the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

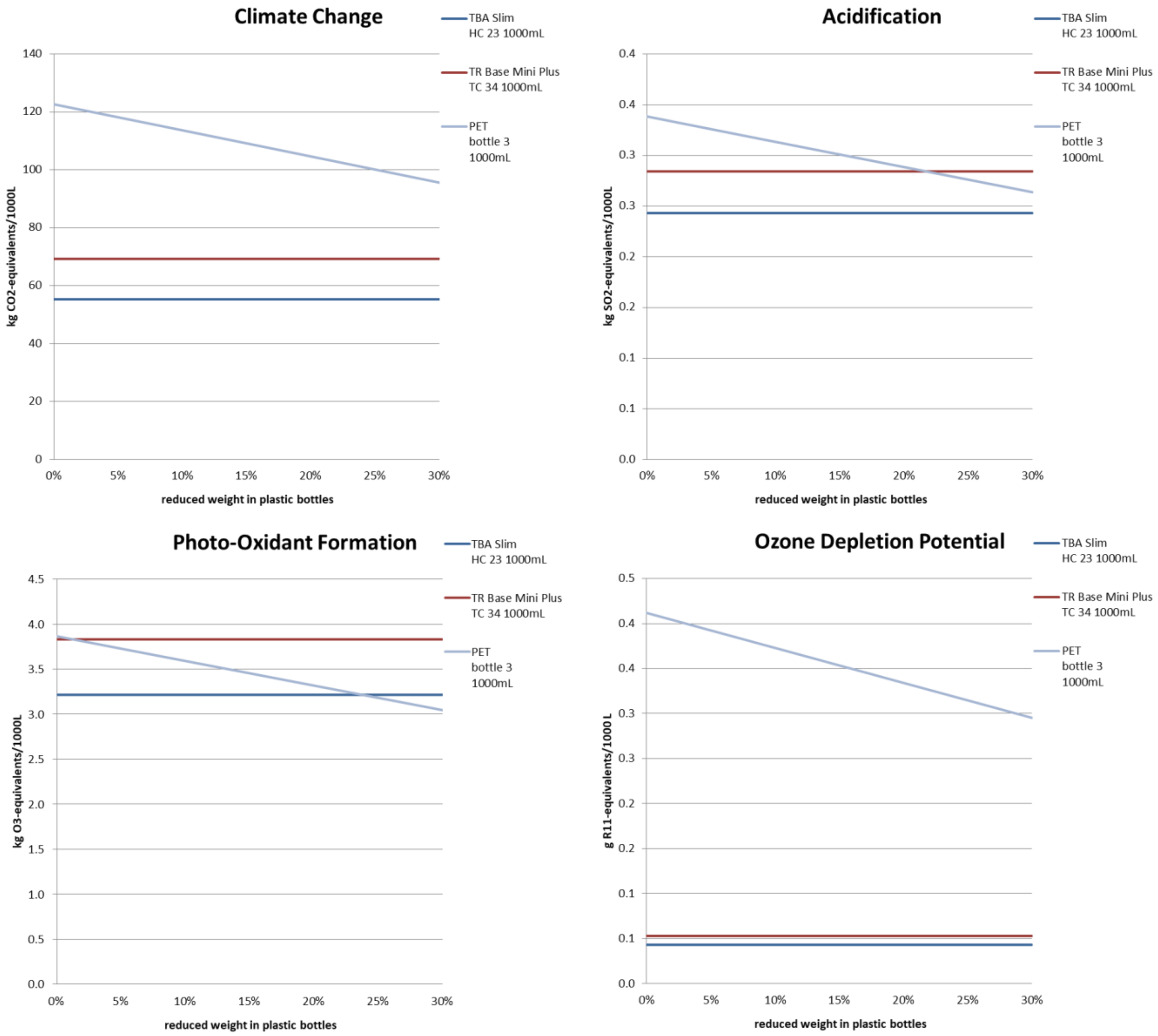


Figure 100: Indicator results for scenario variants on plastic bottle weight of **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 1)

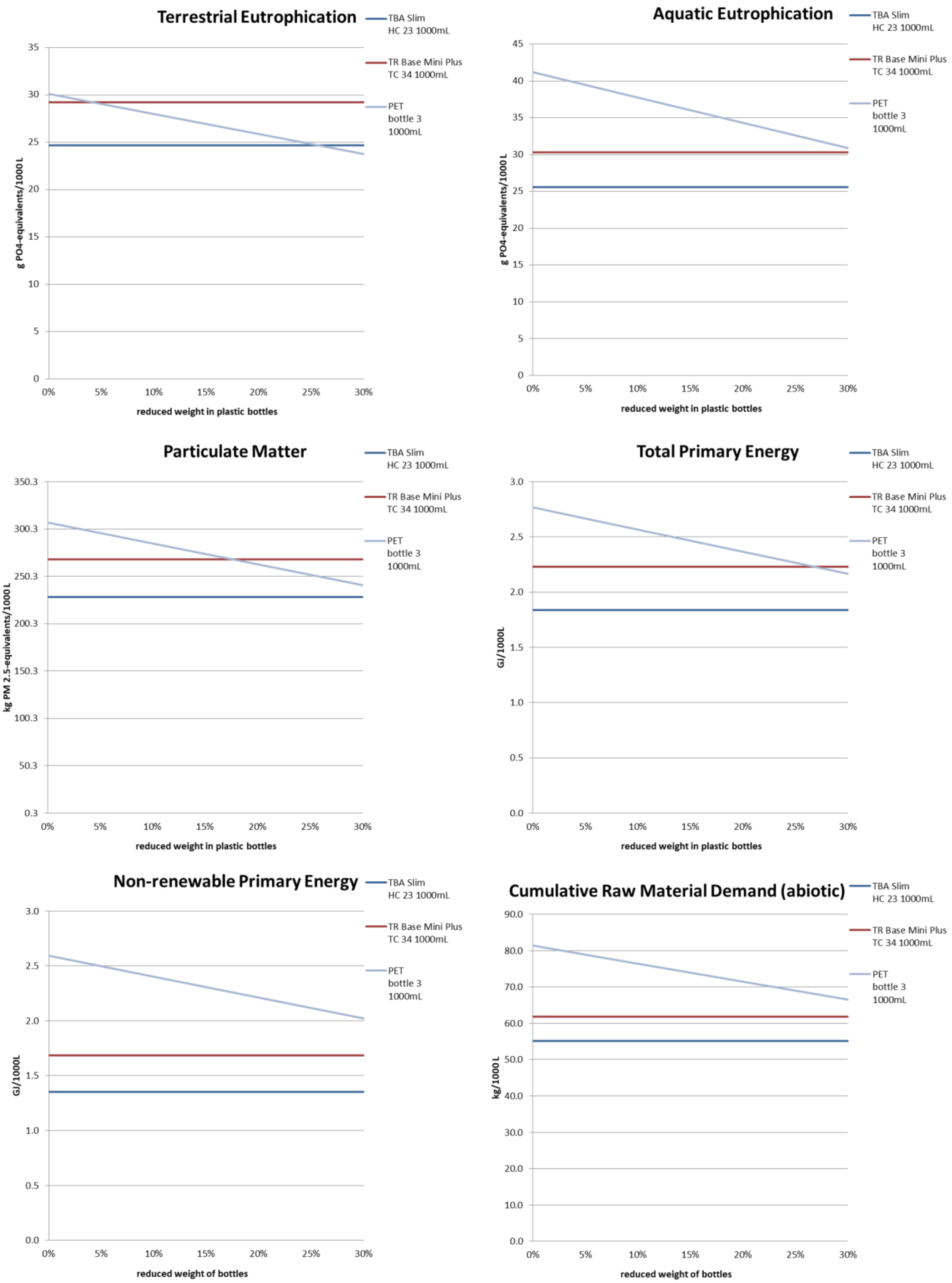


Figure 101: Indicator results for scenario variants on plastic bottle weight of **segment JNSD FAMILY PACK (ambient), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

In the cases of 'Climate Change', 'Ozone Depletion Potential', 'Non-renewable Primary Energy' and 'Cumulative Raw material Demand (abiotic)' the PET bottle shows higher impacts than the compared beverage carton systems also with the regarded decrease of bottle weight.

In most of the other categories, the PET bottle breaks even with some beverage cartons when decreasing its bottle weight.

5.5 WATER PORTION PACK AMBIENT

5.5.1 Scenario variants regarding recycled PET in PET bottles

PET bottles in the base scenarios are modelled with their specific share of recycled PET (rPET). As PET bottles could be produced with 100% recycled content scenario variants are calculated for the packaging systems listed in Table 30. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

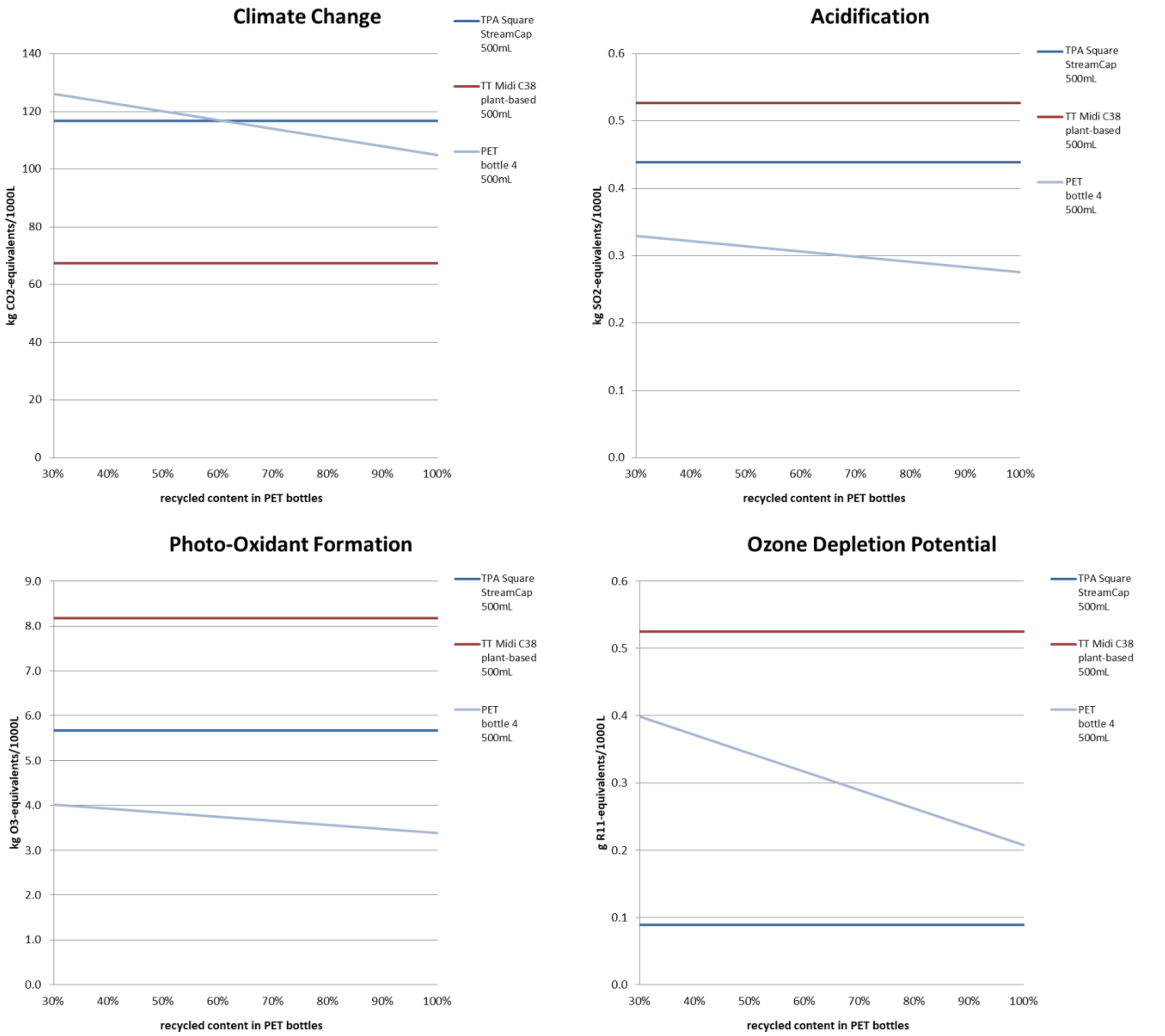


Figure 102: Indicator results for scenario variants recycled PET of **segment WATER PORTION PACK (ambient), Europe**, allocation factor 50% (Part 1)

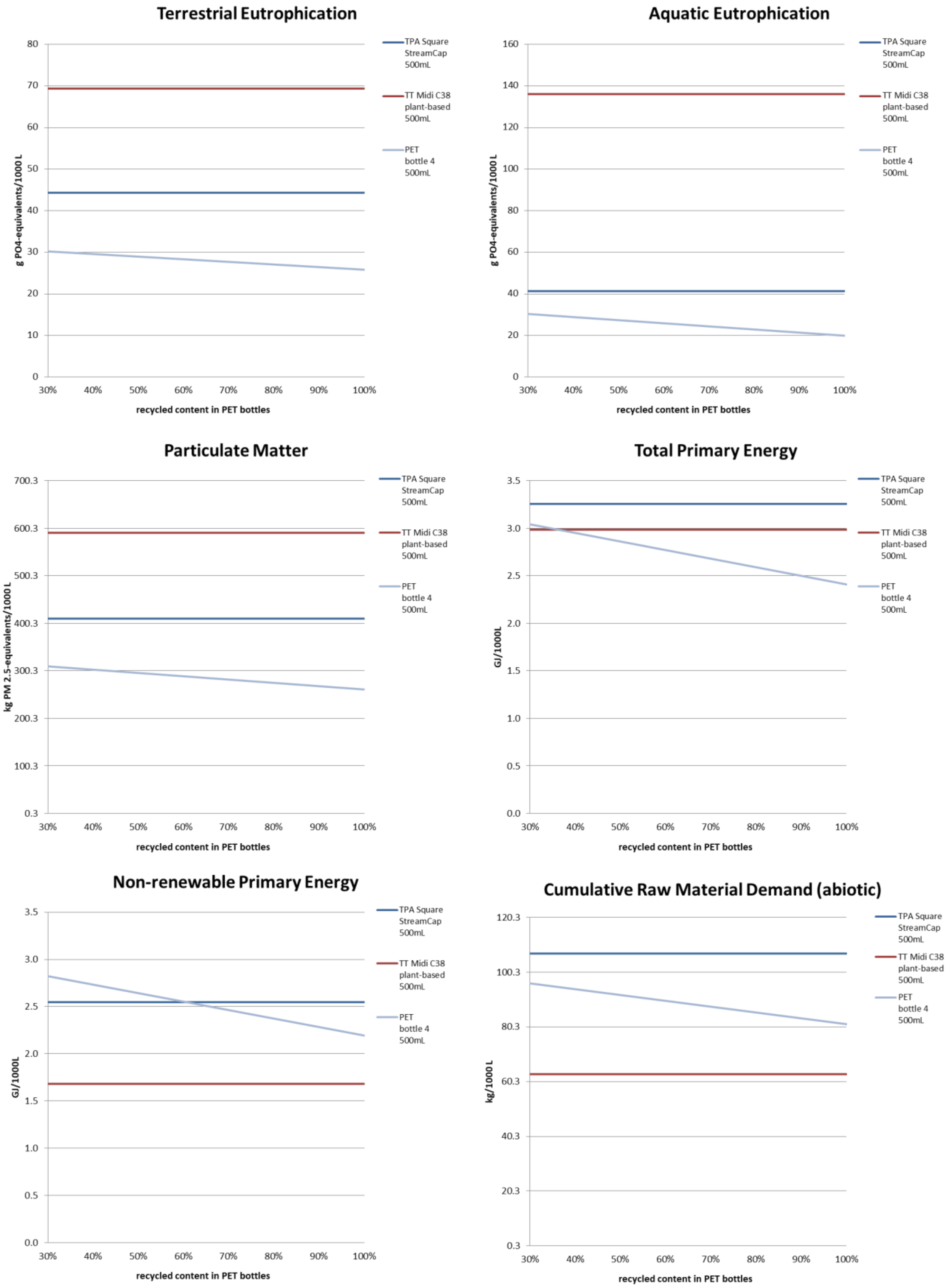


Figure 103: Indicator results for scenario variants recycled PET of **segment WATER PORTION PACK (ambient), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

In the cases of 'Climate Change', 'Non-renewable Primary Energy' and 'Total primary Energy' the PET bottle breaks even with some beverage cartons when increasing its recycled content.

In the other categories, the ranking of the beverage cartons and the PET bottle stays the same when increasing the PET bottle's recycled content.

5.5.2 Scenario variants regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, scenario variants with reduced bottle weight are performed for the packaging systems listed in and Table 31. In these analyses the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following break-even graphs.

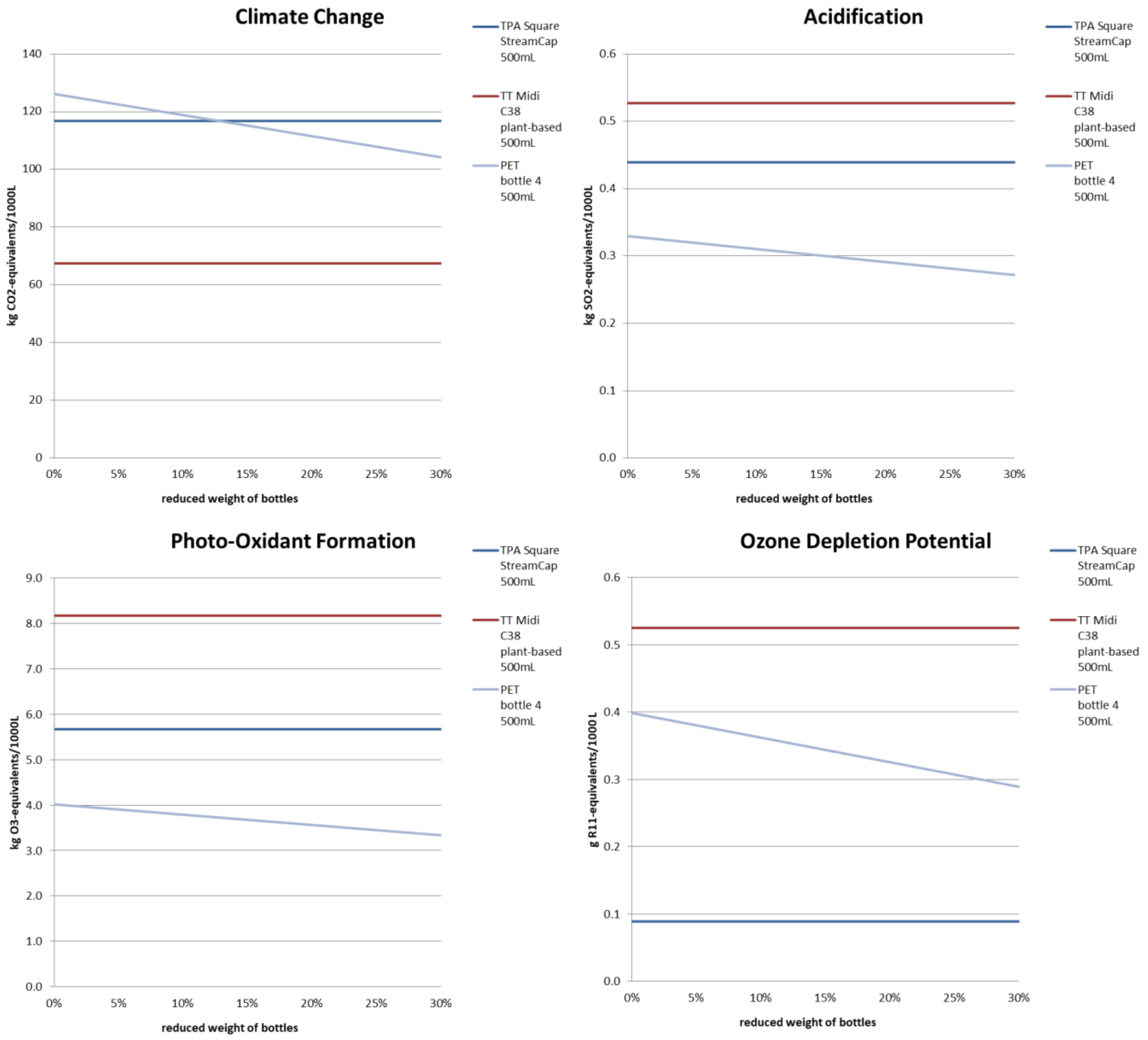


Figure 104: Indicator results for scenario variants on plastic bottle weight of **segment WATER PORTION PACK (ambient), Europe**, allocation factor 50% (Part 1)

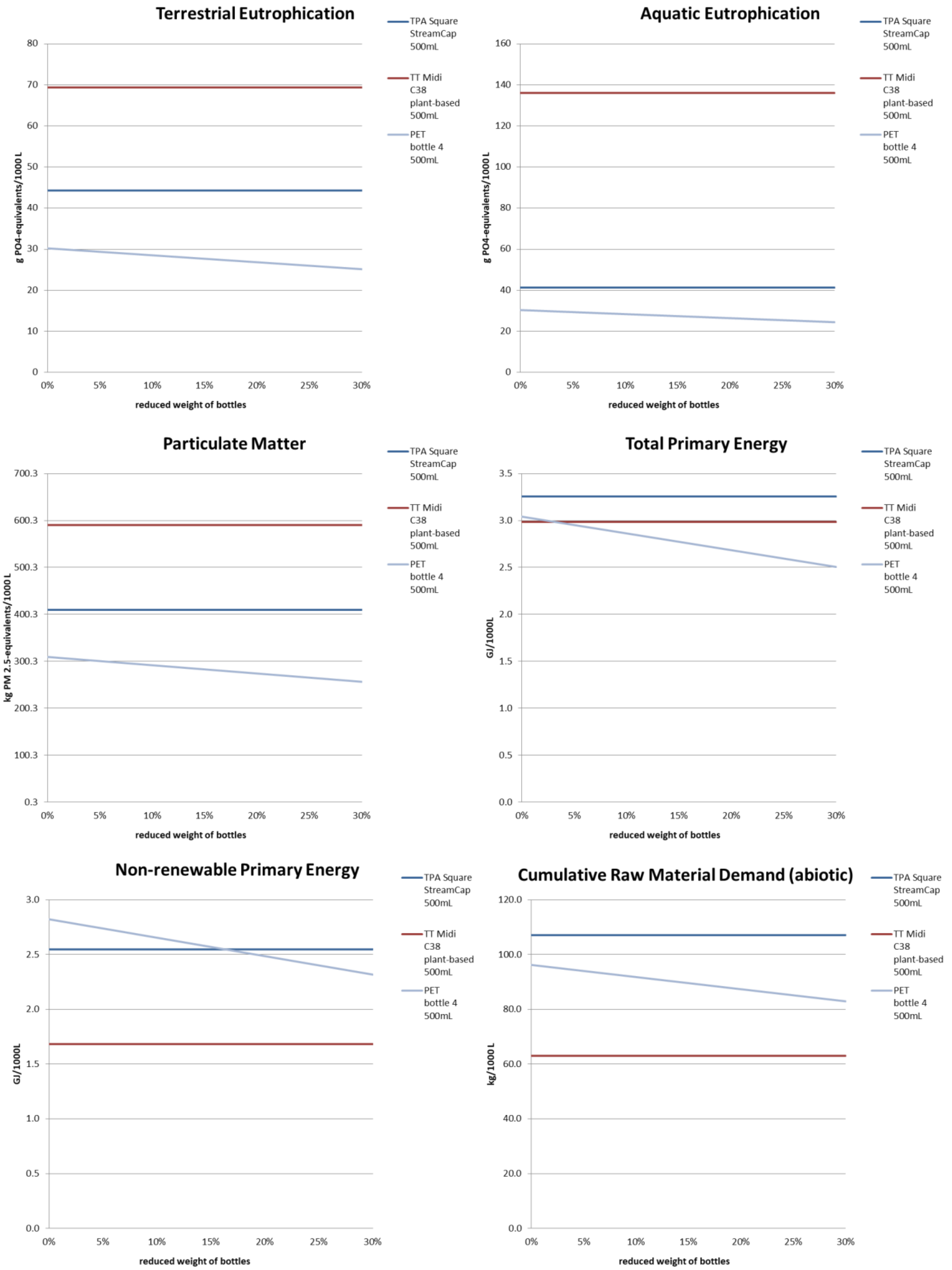


Figure 105: Indicator results for scenario variants on plastic bottle weight of **segment WATER PORTION PACK (ambient), Europe**, allocation factor 50% (Part 2)

Description and Interpretation

In the cases of ‘Climate Change’, ‘Non-renewable Primary Energy’ and ‘Total primary Energy’ the PET bottle breaks even with some beverage cartons when decreasing its bottle weight.

In the other categories, the ranking of the beverage cartons and the PET bottle stays the same when decreasing the PET bottle’s bottle weight.

6 Conclusions

In the following sections results are summarised and conclusions are drawn regarding the environmental impact assessment of the packaging systems in the different segments on the European market. This section addresses all sensitivity analyses. In doing so, results of the 50% allocation (base) scenarios and the 100% allocation sensitivity analysis are taken into account to the same degree.

6.1 DAIRY FAMILY PACK CHILLED

In case of 'Climate Change' all beverage cartons in this segment show lower impacts than the compared HDPE, PET and single use glass bottles regardless the allocation factor.

For the other categories except 'Use of nature', the comparison of the examined beverage carton systems with fossil based plastics to the PET bottles in this segment shows lower impacts for the beverage cartons in all other impact categories regardless of the allocation factor. Compared to the single use glass bottle beverage carton systems with fossil based plastics show lower impacts in all other impact categories regardless of the allocation factor except for 'Aquatic Eutrophication' for which the beverage cartons show higher impacts. For the comparison of beverage carton systems with fossil based plastics with the HDPE bottle no clear result can be observed.

In case of the beverage carton containing plant-based plastics, environmental impacts in the category 'Climate Change' are lower than those of cartons with fossil based plastics. However, the use of plant-based plastics also leads to higher environmental impacts in all other impact categories examined. This leads to the beverage carton showing higher impacts in most categories than the compared plastic bottles. Compared to the single use glass bottle, the beverage carton containing plant-based plastics shows lower impacts except for 'Aquatic Eutrophication' and 'Ozone Depletion Potential'.

In case of 'Use of Nature' beverage cartons show substantial higher results than the fossil-based competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

The scenario variant regarding plant-based HDPE bottles shows that a substitution of fossil plastics by plant-based plastics leads to lower environmental impacts in the category 'Climate Change' but to substantial higher impacts in all other impact categories.

Regarding the scenario variant regarding increased recycled content of the PET bottle, the ranking between the PET bottle with increased recycled content and the compared beverage cartons stays the same in most cases.

Regarding the scenario variants with decreased bottle weight, the plastic bottles show higher impacts for 'Climate Change' also with decreased bottle weight. In case of the other impact categories the ranking between the beverage cartons and the PET bottle stays the same, whereas the HDPE bottle breaks even with some beverage cartons when decreasing its weight.

6.2 DAIRY FAMILY PACK AMBIENT

In case of 'Climate Change' all beverage cartons in this segment show lower impacts than the compared HDPE and PET bottles regardless the allocation factor.

For the other categories except 'Use of Nature', the comparison of the examined beverage carton system with fossil based plastics to the PET bottles in this segment shows lower or similar impacts for the beverage cartons in all other impact categories depending on the allocation factor. For the comparison of beverage carton system with fossil based plastics with the HDPE bottle lower or similar impacts are shown for the beverage carton depending on the allocation factor.

In case of the beverage carton containing plant-based plastics, environmental impacts in the category 'Climate Change' are lower than those of cartons with fossil based plastics. However, the use of plant-based plastics also leads to higher environmental impacts in all other impact categories examined. This leads to the beverage carton showing higher impacts in most categories than the compared plastic bottles.

In case of 'Use of Nature' beverage cartons show substantial higher results than the fossil-based competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

The scenario variant regarding plant-based HDPE bottles shows that a substitution of fossil plastics by plant-based plastics leads to lower environmental impacts in the categories 'Climate Change' but to substantial higher impacts in all other impact categories.

Regarding the scenario variant regarding increased recycled content of the PET bottle, in the cases of 'Climate Change' and 'Ozone Depletion Potential' the PET bottle shows higher impacts than the compared beverage carton systems also with the regarded increase of recycled content. In most of the other impact categories, the PET bottle breaks even with some beverage cartons when increasing its recycled content.

Regarding the scenario variants with decreased bottle weight, the plastic bottles show higher impacts for 'Climate Change' also with decreased bottle weight. In case of the other impact categories the plastic bottles break even with the compared beverage cartons in several categories.

6.3 DAIRY PORTION PACK CHILLED

In case of 'Climate Change' and all other impact categories except 'Use of Nature' the beverage carton in this segment shows lower impacts than the compared HDPE bottle regardless the allocation factor.

In case of 'Use of Nature' beverage cartons show substantial higher results than the fossil-based competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

The scenario variant regarding plant-based HDPE bottle shows that a substitution of fossil plastics by plant-based plastics leads to lower environmental impacts in the categories 'Climate Change' but to substantial higher impacts in all other impact categories.

The scenario variant of the HDPE bottle with reduced weight shows that the impacts in all impact categories are lower if less material is used. In all categories the HDPE bottle shows higher impacts than the compared beverage carton system also with the regarded decrease of bottle weight

6.4 JNSD FAMILY PACK AMBIENT

In case of 'Climate Change' all beverage cartons in this segment show lower impacts than the compared PET and single use glass bottles regardless the allocation factor.

For the other categories except 'Use of Nature', the comparison of the examined TBA Slim HC23 1000mL beverage carton system to the PET bottle in this segment shows lower impacts for the beverage carton in all other impact categories regardless of the allocation factor. For the comparison of the TR Base Mini Plus TC34 1000mL beverage carton system with the PET bottle no clear result can be observed in the other impact categories.

Compared to the single use glass bottle all beverage carton systems show lower impacts in all other impact categories except 'Use of Nature' regardless of the allocation factor except for 'Aquatic Eutrophication' for which the beverage cartons show higher impacts.

In case of 'Use of Nature' beverage cartons show substantial higher results than the competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

Regarding the scenario variant regarding increased recycled content of the PET bottle, in the cases of 'Climate Change' and 'Ozone Depletion Potential' the PET bottle shows higher impacts than the compared beverage carton systems also with the regarded increase of recycled content. In most of the other impact categories, the PET bottle breaks even with some beverage cartons when increasing its recycled content.

Regarding the scenario variants with decreased bottle weight, the plastic bottles show higher impacts for 'Climate Change' and 'Ozone Depletion Potential' also with decreased bottle weight. In case of the other impact categories the PET bottle breaks even with some beverage cartons when decreasing its weight.

6.5 JNSD PORTION PACK AMBIENT

In case of 'Climate Change' all beverage cartons in this segment show lower impacts than the compared glass bottle and stand up pouch regardless the allocation factor.

For the other categories except 'Use of Nature', the comparison of the examined beverage carton systems to the glass bottle in this segment shows lower impacts for the beverage carton in all other impact categories regardless the allocation factor except for 'Aquatic Eutrophication' for which the beverage cartons show similar or higher impacts.

Compared to the SUP the beverage carton systems show lower impacts in all other impact categories except 'Use of Nature' regardless of the allocation factor except for 'Aquatic Eutrophication' and 'Terrestrial Eutrophication' for which the beverage cartons show similar or higher impacts depending on the allocation factor.

In case of 'Use of Nature' beverage cartons show substantial higher results than the competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

6.6 WATER PORTION PACK AMBIENT

In case of 'Climate Change' TT Midi C38 plant-based 500mL shows lower impacts than the compared PET bottle, single use glass bottle and aluminium can regardless the allocation factor. The TPA Edge StreamCap 500mL shows also lower impacts for 'Climate Change' compared to the glass bottle and aluminium can but similar impact compared to the PET bottle regardless the allocation factor.

For the other categories except 'Use of Nature', the comparison of the TT Midi C38 plant-based 500mL to the PET bottle and aluminium can in this segment shows higher impacts for the beverage carton in most other impact categories regardless of the allocation factor. Compared to the single use glass bottle, the TT Midi C38 plant-based 500mL shows lower impacts in all other impact categories regardless of the allocation factor except for 'Aquatic Eutrophication' and 'Ozone Depletion Potential'.

The comparison of the TPA Edge StreamCap 500mL to the PET bottle in this segment shows higher impacts for the beverage carton in most other impact categories regardless of the allocation factor. Compared to the single use glass bottle, the TPA Edge StreamCap 500mL shows lower impacts in all other impact categories regardless of the allocation factor except for 'Aquatic Eutrophication'. Compared to the aluminium can no clear result can be observed.

In case of 'Use of Nature' beverage cartons show substantial higher results than the competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

Regarding the scenario variant regarding increased recycled content of the PET bottle, in the cases of 'Climate Change' and 'Total primary Energy' the PET bottle breaks even with some beverage cartons when increasing its recycled content. In the other impact categories, the ranking of the beverage cartons and the PET bottle stays the same when increasing the PET bottle's recycled content.

Regarding the scenario variants with decreased bottle weight, the PET bottle breaks even with some beverage cartons when decreasing its bottle weight. In the other categories, the ranking of the beverage cartons and the PET bottle stays the same when decreasing the PET bottle's weight.

6.7 LIQUID FOOD PORTION PACK AMBIENT

In case of 'Climate Change' the liquid food carton in this segment shows lower impacts than the compared steel can and single use glass jar regardless the allocation factor.

For the other categories except 'Use of Nature', the comparison of the examined liquid food carton system to the steel can and glass jar in this segment shows lower impacts for the liquid food carton in all other impact categories except for 'Aquatic Eutrophication' regardless of the allocation factor.

In case of 'Use of Nature' liquid food cartons show substantial higher results than the competing packaging systems regardless the allocation factor.

The choice of allocation factor has only a small influence on the assessment of the environmental impacts in this segment.

7 Limitations

The results of the base scenarios and analysed packaging systems and the respective comparisons between packaging systems are valid within the framework conditions described in sections 1 and 2. The following limitations must be taken into account however.

Limitations arising from the selection of **market segments**:
The results are valid only for the filling products Dairy, JNSD, Water and liquid food. Even though carton packaging systems, plastic bottles, SUP, cans and glass bottles are common in other market segments, other filling products create different requirements towards their packaging and thus certain characteristics may differ strongly, e.g. barrier functions.

Limitations concerning **selection of packaging systems:**
The results are valid only for the exact packaging systems, which have been chosen by Tetra Pak. Even though this selection is based on market data it does not represent the whole European market.

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.

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

Each packaging system is defined by multiple system parameters, which may potentially alter the overall environmental profile. All packaging specifications of the carton packaging systems were provided by Tetra Pak® and are to represent the typical packaging systems used in the analysed market segment. These data have been cross-checked by ifeu.

To some extent, there may be a certain variation of design (i.e. specifications) within a specific packaging system. Packaging specifications different from the ones used in this study cannot be compared directly with the results of this study.

Limitations concerning the chosen **environmental impact potentials** and applied **assessment methods**:
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 impact **categories**:
The results are valid only for the environmental impact categories, which were examined. They are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. This means that the potential damage caused by the substances is not taken into account.

Limitation concerning the assessment of **raw materials**:
Raw materials are not assessed on impact category level. The abiotic Cumulated Resource Demand (CRD) is included as inventory category. Biotic raw materials are not included in this category. Additionally the Cumulative Energy Demand (CED) is included in the inventory categories as indication for the loss potential of energy resources. The consequence of this methodological decision is that there is an imbalance regarding the information on raw materials. While materials with energy content are inventoried in the CED, raw materials without energy content are not considered.

Limitation concerning the assessment of **Use of Nature**:
Data quality for the application of the impact category 'Use of Nature' in this study is considered to be sufficient enough to deliver robust results in this study. Due to the data uncertainties connected to forestry data and sugar cane cultivation, the results of this category in this study though cannot be used without hesitation. Nevertheless the results of this impact category are included to the comparisons and final conclusions of the study as the mentioned data uncertainties do not change the large difference in land use between materials from forests or other plant-based materials and materials from fossil sources.

Limitation concerning the assessment of **water use**:
Due to the lack of mandatory information to assess the potential environmental impact, water scarcity cannot be assessed on LCIA level within this study. However, the use of water will be included as an inventory category. However, it includes neither any reference to the origin of this water, nor to its quality at the time of output/release. The respective results in this category are therefore of mere indicative nature and are not suited for conclusive quantitative statements related to either of the analysed packaging systems.

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.

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.

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 **allocation**:
The results are only valid for the applied allocation approaches in this study. Allocation approaches other than those used in this study can lead to different results.

Limitations concerning **data**:
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 and data from ifeu's internal database.

For all packaging systems, the same methodological choices were applied concerning allocation rules, system boundaries and calculation of environmental categories.

8 Overall conclusion and recommendations

The following overall conclusions summarise the findings of the analysed packaging comparisons. These overall conclusions should not be used for statements of specific packaging systems in specific segments. Regarding conclusions of specific packaging systems in specific segments, the detailed conclusion section of each segment should be consulted.

The beverage and liquid food carton systems analysed in this study show different environmental performances depending on different segments as well as their packaging specifications.

Alternative packaging systems examined in this study show high burdens from the production of their base materials, like plastics, glass, aluminium or steel. For beverage and liquid food cartons on the other hand the production of liquid packaging board (LPB) does not contribute as much to the environmental impact, as its production utilises mainly renewable energy leading to lower environmental impacts.

Beverage and liquid food cartons show lower environmental impacts than their compared packaging systems in almost all segments regarding 'Climate Change'. Only in the segment WATER one of the examined beverage cartons shows similar impacts for 'Climate Change' as one of the competing packaging systems (PET bottle).

The results of the comparisons with competing packaging systems for the other categories are more diverse between the different segments and packaging systems. Therefore, for conclusions regarding the comparative performances of beverage and liquid food cartons beyond climate change, the detailed conclusion section of each segment and market should be consulted. In case of 'Use of Nature' the beverage and liquid food cartons show substantial higher results than the fossil based competing packaging systems.

The utilisation of plant-based polyethylene instead of fossil-based polyethylene does not deliver clear results. While it leads to lower results in 'Climate Change', the emissions from the production of this plant-based polyethylene, including its agricultural background system, increase the environmental impacts in all the other impact categories considered.

In general the conclusions are limited concerning the categories related of resources. The only assessed impact category is 'Use of Nature'. The categories 'Water use', 'Cumulative Raw material Demand (abiotic)', 'Total Primary Energy' and 'Non-renewable Energy' are inventory categories only and therefore not fully considered for the conclusions.

From the findings of this study the authors develop the following recommendations:

- The results of this European baseline study shall be used as reference for additional local supplementary studies. As the local supplements focus only on 'Climate Change', this study shall be used as a reference especially regarding the other categories adressed in this Europen baseline study.
- From an environmental viewpoint no general recommendation for one type of packaging can be given that is valid for all segments.
- If there is a strong focus on climate change mitigation in Tetra Pak's environmental policy, the utilisation of plant-based polyethylene can be an applicable path to follow as the 'Climate Change' impacts of plant-based plastics are lower than those of fossil based plastics. Because of the additional impacts in all categories except 'Climate Change' resulting from the production of plant-based plastics, the use of plant-based plastics, though, cannot be endorsed unreservedly. In any case the consequences for the environmental performance in other impact categories should never be disregarded completely.
- It is shown in this study that the closures can contribute a considerable amount to the overall life cycle impacts of beverage cartons with smaller volumes To improve the overall environmental performance it is recommended to assess the possibilities of using smaller and lighter closures for beverage cartons, especially for the ones with a filling volume below 500mL.
- It is recommended to the industries and related associations in general to provide more comprehensive process inventory data, especially for production processes to reduce the level of data asymmetries that could lead to misinterpreted results (f.e. regarding water use: regionalised data and water output flows). This is required to allow recently developed methods such as assessment methods for water consumption and UseTox to be successfully applicable. Further data improvement is also recommended for the application of the impact category Use of Nature.

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Appendix A: Impact categories

The impact categories used in this study are introduced below and the corresponding characterisation factors are quantified. In each case, references are given for the origin of the methods that were used. The procedure for calculating the indicator result is given at the end of each sub-section.

A.1 Climate change

Climate Change is the impact of anthropogenic emissions on the radiative forcing of the atmosphere causing a temperature rise at the earth's surface. This could lead to adverse environmental effects on ecosystems and human health. This mechanism is described in detail in the relative references [IPCC 1995]. The category most used in life cycle assessments up to now is the radiative forcing [CML 2002, Klöpffer 1995] and is given as CO_2 equivalents. The characterisation method is a generally recognised method.

The Intergovernmental Panel on Climate Change (IPCC) is an international body of experts that computes and extrapolates methods and relevant parameters for all substances that influence climate change. The latest IPCC reports available at the time of LCA calculations commonly represent the scientific basis for quantifying climate change.

All carbon dioxide emissions, whether they are of regenerative or fossil origin, are accounted for with a characterisation factor of 1 CO_2 equivalent.

When calculating CO_2 equivalents, the gases' residence times in the troposphere is taken into account and the question arises as to what period of time should be used for the climate model calculations for the purposes of the product life cycle. Calculation models for 20, 50 and 100 years have been developed over the years, leading to different global warming potentials (GWPs). The models for 20 years are based on the most reliable prognosis; for longer time spans (500-year GWPs have been used at times), the uncertainties increase [CML 2002]. The Centre of Environmental Science – Leiden University (CML) as well as the German Environmental Agency both recommend modelling on a 100-year basis because it allows to better reflect the long-term impact of Climate Change. According to this recommendation, the 'characterisation factor' applied in the current study for assessing the impact on climate change is the *Global Warming Potential* for a 100-year time period based on IPCC 2013.

An excerpt of the most important substances taken into account when calculating the Climate Change are listed below along with the respective CO_2-equivalent factors – expressed as Global Warming Potential (GWP).

Greenhouse gas	CO_2 equivalents (GWP_i)[1]
Carbon dioxide (CO_2). fossil	1
Methane (CH_4)[2] fossil	30
Methane (CH_4) regenerative	28
Nitrous oxide (N_2O)	265
Tetrafluoromethane	6630
Hexafluoroethane	11100
Halon 1301	6290
R22	1810
Tetrachlormethane	1760
Trichlorethane	160
• Source: [IPCC 2013]	

Table A-1: Global warming potential for the most important substances taken into account in this study; CO_2 equivalent values for the 100-year perspective

Numerous other gases likely have an impact on GWP by IPCC. Those greenhouse gases are not represented in Table A-1 as they are not part of the inventory of this LCA study.

The contribution to the Climate Change is obtained by summing the products of the amount of each emitted harmful material (m_i) of relevance for Climate Change and the respective GWP (GWP_i) using the following equation:

$$GWP = \sum_i (m_i \times GWP_i)$$

Note on biogenic carbon:

At the impact assessment level, it must be decided how to model and calculate CO_2-based GWP. In this context, biogenic carbon (the carbon content of renewable biomass resources) plays a special role: as they grow, plants absorb carbon from the air, thus reducing the amounts of carbon dioxide in the atmosphere. The question is how this uptake should be valued in relation to the (re-)emission of CO_2 at the material's end of life, for example CO_2 fixation in biogenic materials such as growing trees versus the greenhouse gas's release from thermal treatment of cardboard waste.

In the life cycle community two approaches are common. CO_2 may be included at two points in the model, its uptake during the plant growth phase attributed with negative GWP values and the corresponding re-emissions at end of life with positive ones.

[1] The values reported by [IPCC 2013] in Appendix 8.A were rounded off to whole numbers.

[2] According to [IPCC 2013], the indirect effect from oxidation of CH_4 to CO_2 is considered in the GWP value for fossil methane (based on Boucher et al., 2009). The calculation for the additional effect on GWP is based on the assumption, that 50% of the carbon is lost due to deposition as formaldehyde to the surface (IPCC 2013). The GWP reported for unspecified methane does not include the CO_2 oxidation effect from fossil methane and is thus appropriate methane emissions from biogenic sources and fossil sources for which the carbon has been accounted for in the LCI.

Alternatively, neither the uptake of non-fossil CO_2 by the plant during its growth nor the corresponding CO_2 emissions are taken into account in the GWP calculation.

In the present study, the first approach has been applied for the impact assessment.

Methane emissions originating from any life cycle step of biogenic materials (e.g. their landfilling at end of life) are always accounted for both at the inventory level and in the impact assessment (in form of GWP).

A.2 Photo-oxidant formation

Due to the complex reactions during the formation of near-ground ozone (photo smog or summer smog), the modelling of the relationships between the emissions of unsaturated hydrocarbons and nitrogen oxides is extremely difficult.

The method to be applied for the impact category Photo-oxidant formation, should be the „Maximum Incremental Reactivity“ of VOC und Nitrogen-MIR (Nitrogen-MIR) based on the publication of [Carter 2010]. The MIR concept is the most appropriate characterisation model for LCIA based on generic spatial independent global inventory data and combines a consistent modelling of potential impacts for VOC and NOx and the precautionary principle. The MIR and NMIR are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NOx inputs. The unit for the category indicator MIR is kg O_3-e.
The related characterisation factors applied in this study are based on [Carter 2010]. Examples of the factors for more than 1100 substances are listed in Table A-2.

Harmful gas (examples)	Characterisation factors (MIR/NMIRs$_i$) [Carter 2010] [g O_3-e/g-emission]
1-Butene	9.73
1-Propanol	2.50
2-Propanol	0.61
Acetaldehyde	6.54
Acetic acid	0.68
Acetone	0.36
Benzene	0.72
Carbon monoxide, fossil	0.056
Ethane	0.28
Ethanol	1.53
Ethene	9.00
Formaldehyde	9.46
Methane, fossil	0.014
Methanol	0.67
NMVOC, unspecified	3.60
Styrene	1.73
Nitrogen dioxide	16.85
Nitrogen monoxide	24.79
Toluene	4,00

Source: [Carter 2010]

Table A-2: Maximum Incremental Reactivity (MIR) of substances considered in this project (excerpt)

The contribution to the Maximum Incremental Reactivity is calculated by summing the products of the amounts of the individual harmful substances and the respective MIR values using the following equation:

$$MIR = \sum_i (m_i \times MIR_i)$$

A.3 Stratospheric ozone depletion

Stratospheric ozone depletion refers to the thinning of the stratospheric ozone layer as a result of anthropogenic emissions. This causes a greater fraction of solar UV-B radiation to reach the earth's surface, with potentially harmful impacts on human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials [UNEP 1998].
The ozone depletion potential category indicator that was selected and described in [CML 1992, CML 2002] uses a list of 'best estimates' for ODPs that has been compiled by the World Meteorological Organisation (WMO). These ODPs are steady-state ODPs based on a model. They describe the integrated impact of an emission or of a substance on the ozone layer compared with CFC-11 [CML 2002]. The following table shows the list of harmful substances considered in this study, along with their respective ozone depletion potential (ODP) expressed as CFC-11 equivalents based on the latest publication of the WMO [WMO 2011].

Harmful substance	CFC-11 equivalent (ODP_i)
CFC-11	1
CFC-12	0.82
CFC-113	0.85
CFC-114	0.58
CFC-115	0.57
Halon-1301	15.9
Halon-1211	7.9
Halon-2402	13
CCl_4	0.82
CH3CCl3	0.16
HCFC-22	0.04
HCFC-123	0.01
HCFC-141b	0.12
HCFC-142b	0.06
CH_3Br	0.66
N_20	0.017
• Source: [WMO 2011]	

Table A-4: Ozone depletion potential of substances considered in this study

The contribution to the ozone depletion potential is calculated by summing the products of the amounts of the individual harmful substances and the respective ODP values using the following equation:

$$ODP = \sum_i (m_i \times ODP_i)$$

A.4 Eutrophication and oxygen-depletion

Eutrophication means the excessive supply of nutrients and can apply to both surface waters and soils. With respect to the different environmental mechanisms and the different safeguard subjects, the impact category eutrophication is split up into the terrestrial eutrophication and aquatic eutrophication.

The safeguard subject for freshwater aquatic ecosystems is defined as preservation of aerobic conditions and the conservation of site-specific biodiversity, whereas the safeguard subject for terrestrial ecosystems addresses the preservation of the natural balance of the specific ecosystem, the preservation of nutrient-poor ecosystems as high moors and the conservation of site-specific biodiversity.

It is assumed here for simplification that all nutrients emitted via the air cause enrichment of the terrestrial ecosystems and that all nutrients emitted via water cause enrichment of the aquatic ecosystems. Oligotrophy freshwater systems in pristine areas of alpine or boreal regions are often not affected by effluent releases, but due to their nitrogen limitation sensitive regarding atmospheric nitrogen deposition. Therefore, the potential impacts of atmospheric nitrogen deposition on oligotrophic waters are included in the impact category terrestrial eutrophication.

The eutrophication of surface waters also causes oxygen-depletion as secondary effect. If there is an over-abundance of oxygen-consuming reactions taking place, this can lead to oxygen shortage in the water. The possible perturbation of the oxygen levels could be measured by the Bio-chemical Oxygen Demand (BOD) or the Chemical Oxygen Demand (COD). As the BOD is often not available in the inventory data and the COD essentially represents all the available potential for oxygen-depletion, the COD is used as a conservative estimate[1].

In order to quantify the magnitude of this undesired supply of nutrients and oxygen depletion substances, the eutrophication potential category was chosen. This category is expressed as phosphate equivalents [Heijungs et al. 1992]. The table below shows the harmful substances and nutrients that were considered in this study, along with their respective characterisation factors:

[1] The COD is (depending on the degree of degradation) higher than the BOD, which is why the equivalence factor is deemed relatively unreliable and too high.

Harmful substance	PO_4^{3-} equivalents (EP_i) in kg PO_4^{3-} equiv./kg
Eutrophication potential (terrestrial)	
Nitrogen oxides (NO_X as NO_2)	• 0.13
Ammonia (NH_3)	• 0.35
Dinitrogen oxide (N_2O)	• 0.27
Eutrophication potential (aquatic) (+ oxygen depletion)	
Phosphate ($PO4^{3-}$)	• 1
Total phosphorus	• 3.06
Chemical Oxygen Demand (COD)	• 0.022
Ammonium (NH_4^+)	• 0.33
Nitrate (NO_3^{2-})	• 0.1
N-compounds. unspec.	• 0.42
P as P_2O_5	• 1.34
P-compounds unspec.	• 3.06
• Source: [Heijungs et al 1992]	

Table A-3: Eutrophication potential of substances considered in this study

The eutrophication potential (EP) is calculated separately for terrestrial and aquatic systems. In a rough simplification the oligotrophic aquatic systems are covered by the terrestrial eutrophication potential. In each case, that contribution is obtained by summing the products of the amounts of harmful substances that are emitted and the respective EP values.

The following equations are used for terrestrial or aquatic eutrophication:

$$EP(aquatic) = \sum_i (m_i \times EP(aquatic)_i)$$

$$EP(terrestrial) = \sum_i (m_i \times EP(terrestrial)_i)$$

A.4 Acidification

Acidification can occur in both terrestrial and aquatic systems. The emission of acid-forming substances is responsible for this.

The acidification potential impact category that was selected and described in [CML 1992, CML 2002, Klöpffer 1995] is deemed adequate for this purpose. No specific characteristics of the affected soil or water systems are hence necessary. The acidification potential is usually expressed as SO_2 equivalents. The table below shows the harmful substances considered in this study, along with their respective acidification potential (AP) expressed as SO_2 equivalents.

Harmful substance	SO_2 equivalents (AP_i)
Sulphur dioxide (SO_2)	• 1
Nitrogen oxides (NO_X)	• 0.7
Hydrochloric acid (HCl)	• 0.88
Hydrogen sulphide (H_2S)	• 1.88
Hydrogen fluoride (HF)	• 1.6
Hydrogen cyanide (HCN)	• 1.6
Ammonia (NH_3)	• 1.88
Nitric acid (HNO_3)	• 0.51
Nitrogen oxide (NO)	• 1.07
Phosphoric acid (H_3PO_4)	• 0.98
Sulphur trioxide (SO_3)	• 0.8
Sulphuric acid (H_2SO_4)	• 0.65
• Source: [Hauschild und Wenzel 1998] taken from [CML 2010]	

Table A-4: Acidification potential of substances considered in this study

The contribution to the acidification potential is calculated by summing the products of the amounts of the individual harmful substances and the respective AP values using the following equation:

$$AP = \sum_i (m_i \times AP_i)$$

A.5 Particulate matter

The category chosen for this assessment examines the potential threat to human health and natural environment due to the emission of fine particulates (primary particulates as well as precursors). 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. Relevant are small particles with a diameter of less than 10 and especially less than 2.5 µm (in short referred to as PM10 and PM2.5).These particles cannot be absorbed by protection mechanisms and thus deeply penetrate into the lung and cause damage.

Particulate matter is subsuming primary particulates and precursors of secondary particulates. Fine particulate matter can be formed from emissions by different mechanisms: On the one hand particulate matter is emitted directly during the combustion process (primary particles), on the other hand particles are formed by chemical processes from nitrogen oxide and sulphur-dioxide (secondary particles).

They are characterised according to an approach by [De Leeuw 2002].

In accordance with the guidelines of [WHO 2005], PM2.5 is mostly relevant for the toxic effect on human health. Thus, the category indicator aerosol formation potential (AFP) referring to PM2.5-equivalents is applied. The substances assigned to this category are primary particles and secondary particles formed by SO_2, NOx, NH_3 and NMVOCs ([WHO 2005]). The non-organic substances are characterised according to an approach by [De Leeuw 2002]. This characterisation factors were used for reporting by the European Environmental Agency until 2011 and are based on dispersion model results by [Van Jaarsveld 1995]. [ReCiPe 2008] and [JRC 2011] are also using the same base dispersion model results for the calculation of particulate formation. The model by [De Leeuw 2002] covers European emissions and conditions, but is the best available approach for quantifying population density independent factors and is therefore applied for all emissions.

Regarding NMVOC emissions, only the knowledge of exact organic compounds would allow quantification as secondary particles. Therefore, an average value for unspecified NMVOCs calculated by [Heldstab et al. 2003] is applied.

Harmful substance	PM2.5 equivalents (PFP_i) (Air) [kg PM2.5 equivalents/kg]
PM2.5	1
PM10	0.5
NH_3	0.64
SO_2	0.54
SO_x	0.54
NO	0.88
NO_x	0.88
NO_2	0.88
NMVOC[1)]	0.012
Source: [De Leeuw 2002]; [1)] [Heldstab et al. 2003]	

Table A-5: PM2.5 equivalents of substances considered in this study

The contribution to the Aerosol Formation Potential (AFP) is calculated by summing the products of the amounts of the individual harmful substances and the respective AFP equivalent values using the following equation:

$$PFP = \sum_i (m_i \times AFP_i)$$

A.6 Use of Nature

Traditionally, LCAs carried out by the German Federal Environment Agency (UBA) include the impact category land use based on the metric 'Degree of naturalness of areas'. Despite the recent developments on land use in LCAs, the fundamental idea to characterise 'naturalness' as an overarching conservation goal (desired state) forming the basic concept to address selected conservation assets is still appropriate. The idea central to the concept follows the logic that intact ecosystems are not prone to higher levels of disturbance and negative impacts.

Recently the so called hemeroby concept in order to provide an applicable and meaningful impact category indicator for the integration of land use and biodiversity into the Life Cycle (Impact) Assessment has been developped by [Fehrenbach et al. 2015]. This approach is operationalized by a multi-criteria assessment linking the use of land to different subjects of protection: Structure and functionality of ecosystems, biological diversity and different ecosystem services contributing to human wellbeing. In this sense hemeroby is understood as a mid-point indicator giving explicite information on naturalness and providing implicite information, at least partly, on biodiversity (number of species, number of rare or threathened species, diversity of structures), and soil quality (low impact.)

The system of hemeroby is subdivided in to seven classes (see Table 1). This system is appropriate to be applied on any type of land-use type accountable in LCA. Particularly production systems for biomass (wood from forests, all kinds of biomass from agriculture) are assessed in a differentiated way:

> To describe forest systems three criteria are defined: (1) natural character of the soil, (2) natural character of the forest vegetation, (3) natural character of the development conditions. The degree of performance is figured out by applying by 7 metrics for each criterion.
>
> Agricultural systems are assessed by four criteria: (1) diversity of weeds, (2) Diversity of structures, (3) Soil conservation, (4) Material input. Three metrics are used for each criterion to calculate the grade of hemeroby.

The approach includes the derivation of inventory results (x m^2 of area classified as class y) as well as the aggregation to the category indicator 'Distance-to-Nature-Potential' (DNP) (m^2-e * 1a) by characterization factors.

Class	Class name	Land-use type
I	• Natural	undisturbed ecosystem, pristine forest
II	• close-to-nature	close-to-nature forest management
III	• partially close to nature	intermedium forest management, Highly diversified structured agroforestry systems
IV	• semi-natural	half-natural forest management, Extensive grassland, mixed orchards
V	• partially distant to nature	mono-cultural forest, Intensified grassland (pastures); Agriculture with medium large cuts
VI	• distant-to-nature	Highly intensified agricultural land, large areas cleared landscape
VII	• non-natural, artificial	long-term sealed, degraded or devastated area
Source: Fehrenbach et al. 2015		

Table A-6.1: The classification system of hemeroby classes

Class VII as the category most distant from nature is characterized by factor 1. Each class ascending towards naturalness will be characterized by a factor half from the precedent. Therefore the maximum span from class VII to class II is 1 : 32, an span which corresponds with share of class VII area of entire area.[1] Table A-6.2 lists the characterisation factors for each class.

Class	Characterisation factor (DNP_i)
I	0
II	0.0313
III	0.0625
IV	0.125
V	0.25
VI	0.5
VII	1

Table A-6.2: The characterisation factors of hemeroby classes

The ‘Distance-to-Nature-Potential’ (DNP) is calculated by summing the products of the square meters of area classified as land use class 2 to 7 and the respective characterization factor using the following equation:

$$DNP = \sum_i ((m^2 * a)_i \times DNP_i)$$

[1] The global share of area classified as class VII amounts to approximately 3 % of total land area. In consequence, the ratio between class VII land and the sum of other areas is 1:33. (see [Fehrenbach et al. 2015])

A.8 References (for Appendix A)

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Appendix B:

Critical Review Report

Critical Review Statement according to ISO 14040 and 14044

of the study

"Comparative Life Cycle Assessment of Tetra Pak® carton packages and alternative packaging systems for beverages and liquid food on the European market"

to the Commissioner:
Tetra Pak®

Conducted by
IFEU - Institut für Energie- und Umweltforschung Heidelberg GmbH (the "Practitioner")

Performed for
Tetra Pak® Moscow, Russia (the "Commissioner")

by

Birgit Grahl (chair)
Alessandra Zamagni
Leigh Holloway

10.3. 2020

Content

1. Procedural Aspects of the Critical Review

This Critical Review was commissioned by Tetra Pak® Moscow, Russia (commissioner) via Dina Epifanova in August 2019 as a two-stage process. The LCA study was conducted by IFEU-Institut, Heidelberg, Germany (practitioner).

The reviewers received the First Draft Report of the European study 30th September 2019, and the Final Draft Report 23rd December 2019. In both stages of the review process the reviewers sent a list of detailed comments to the practitioner in order to prepare for the respective telephone conferences on 10th October 2019 and 21st January 2020. During the conference calls the comments were elaborated by the panel members and discussed with the practitioner and the commissioner in detail.

The review panel received the second version of the Final Draft of the study 27th February 2020, this Version was transferred into the Final Report 9th March 2020. The statements and comments below are based on this final version.

Formally this critical review is a review by "interested parties" (panel method) according to ISO 14040 section 7.3.3 [2] and ISO 14044 section 4.2.3.7 and 6.3 [3] because the study includes comparative assertions of competing packaging systems and is intended to be disclosed to third parties.

Despite this title, however, the inclusion of further representatives of "interested parties" is optional and was not explicitly intended in this study. The review panel is neutral with regard to and independent from particular commercial interests. The panel 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 organisations or other interested parties, e.g. competitors or consumers.

The reviewers emphasise the open and constructive atmosphere of the project. All necessary data were presented to the reviewers and all issues were discussed openly. All comments of the panel have been treated by the practitioner with sufficient detail in the final report. The resulting critical review (CR) statement represents the consensus between the reviewers.

Note: The present CR statement is delivered to Tetra Pak® Moscow, Russia. The CR panel cannot be held responsible of the use of its work by any third party and also not for a potential misuse in communication done by the Commissioner itself. The conclusions of the CR panel cover the full report from the studies "Comparative Life Cycle Assessment of Tetra Pak® carton packages and alternative packaging systems for beverages and liquid food on the European market – Final Report – 9th March 2020" and no other report, extract or publication which may eventually be undertaken. The CR panel conclusions are given regarding the current state of the art and the information which has been received. The conclusions expressed by the CR panel are specific to the context and content of the present study only and shall not be generalised any further.

2. General Comments

This particular study for the European market is designed as a complete life cycle assessment according to ISO 14040/44, taking into account European average parameters for production and end-of-life conditions as well as a sufficient number of impact categories and indicators which are discussed in the interpretation.

The study is a baseline study for other, planned, region-specific studies, in which the same LCA model will be used, but only the impact category climate change with the impact indicator GWP will be considered. Due to this limitation in the region-specific studies, the present European study has a special corrective role: The overall view of the results of all impact categories considered is of great importance for understanding an isolated GWP result and shall supplement the country specific reports, as otherwise conclusions on the environmental performance of packaging systems investigated may be shortened.

Due to the special importance of the GWP in the planned region-specific studies and the fact that Tetra Pak's packaging systems use plant-based carton systems, the modelling of biogenic carbon is of outstanding importance. The chosen approach is discussed in detail in a separate chapter of the study. The implications of allocation in the end-of-life and at the beginning of the life cycle are highlighted and it is made clear that, as with any allocation, these are conventions which must be analysed in the interpretation with regard to the chosen boundary conditions (cf. section 3.2).

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."*

In the following sections 3.1 to 3.5, these items are discussed 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 has been performed according to the general structure of LCA described in ISO 14040 and to the requirements stated in ISO 14044. Some aspects are highlighted below:

Although the report does not strictly follow the general structure of LCA reporting (Goal & Scope definition – Life cycle inventory analysis (LCI) – Life cycle impact assessment (LCIA) – Interpretation) all relevant information can easily be identified. The report is written taking into consideration that it will be communicated to third parties. Results are clearly presented; conclusions are deduced from the results in a comprehensible manner and discussed with reference to the underlying conditions and related limitations.

The aim of the study, to investigate the environmental performance of beverages and liquid food cartons compared with competing products, is clearly differentiated into different individual objectives, which are referred to in the interpretation reflecting the results.

The functional unit is meaningfully defined for packaging of beverages and liquid foods and the system boundaries of the examined packaging systems are reasonably defined and presented transparently.

Tetra Pak as the commissioner of the study was responsible for the selection of the packaging systems examined. The criteria are only described in a very general way (cf. section 3.3). Those Tetra Pak packaging were selected which have for beverages or liquid food products a high market relevance in Europe. In addition, Tetra Pak chose at least one typical competitor product for each Tetra Pak package which were analysed in comparison. Regarding the choice of competing products for the EU study, the reviewers did not have access to the data and information regarding the representativeness.

With regard to the selection of competing products, the panel would like to emphasise that no reusable systems were examined, so a one-way variant was also selected for the glass bottle. In the European context, Tetra Pak did not identify the returnable glass bottle as a market-relevant competitor product. Since it is left to the client of a study to define the product systems of the LCA, transparency is satisfied with the tabular qualitative and quantitative presentation of the packaging specifications. The tables clearly define the reference flow of the examined packaging systems. As in any LCA, the results must not be generalised but apply exclusively to the packaging systems defined in the study.

ISO 14040/14044 include no obligation to consider any specific impact categories, but the choice of impact categories must be substantiated, meaningful and support the goal and scope of the study. The choice is reasonable against the backdrop of the goal, well explained and critically discussed (cf. section 3.2).

In order to check the influence of the allocation method on the results, two variants were examined (50:50 and 100:0) and discussed transparently and critically in the interpretation, taking into account the limitations of allocation in general (cf. section 3.2). The two allocation methods examined were not referred to as the "base method" and "sensitivity analysis" to emphasise that no method is "truer" than another. The panel welcomes the equal treatment of the two allocation methods examined, as this approach underlines that any choice of an allocation method can only be interpreted within the given framework.

In addition, further meaningful selected scenarios regarding competing products were examined with different share of plant-based polymers, proportion of recycled material and bottle weights. The results of the scenarios are presented in a transparent manner and are clearly interpreted.

The reviewers conclude that the methods used are consistent with the international standards.

3.2 Scientific and technical validity of the methods used

The methods used represent the scientific and technical state-of-the-art for such analyses. Two aspects are highlighted below:

The selection of the impact categories considered, and the characterisation models used in the European study follow essentially the specifications in [UBA 2016], which are compatible with [ISO 14040, 14044]. Due to data availability and robustness of characterisation models the following data are documented at inventory level and the panel agreed with this:

- Due to methodological uncertainties of the currently available indicator models for mapping the impacts of resource consumption, the study presents the CED (total primary energy, non-renewable

primary energy) and with regard to mineral resources the CRD (Cumulative raw material demand) at inventory level.
- Freshwater Use is presented as another life cycle inventory result. The panel follows the view of the practitioner that the required level of detail is not available for all data sets to include water scarcity as an impact category.

The handling of biogenic carbon in product systems containing plant-based material requires utmost attention to avoid misinterpretations.
- The study treats the CO_2 uptake due to photosynthesis during the growth phase of the plants as negative CO_2 value and if CO_2 is emitted at the end of the life cycle a positive value is assigned. This approach allows for more transparency than the general assumption that biogenic CO_2 is neutral during its life cycle.
- Particular difficulties of interpretation arise when biogenic CO_2 has to be allocated in a cradle-to-grave system considering open-loop-recycling. In the study, two equally applied allocation approaches are analysed: 50:50 allocation and 100:0 allocation. The preconditions and implications of both allocation methods are presented transparently and comprehensibly in a separate chapter.
- It is extremely important that the results of the GWP with consideration of plant-based materials are only communicated in the context of the methodological framework. In order to prevent misinterpretations, the panel expressly points out that readers of the study shall carefully consider the statements in chapter 1.7.2 of the study.

The reviewers conclude that the methods used are scientifically and technically valid.

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

As is normal practice for Critical Reviews, it was not possible to check the correctness of all items of primary and other data, and the background database, but the data used in the study were reviewed for appropriateness and plausibility. The use of the Umberto® 5.5 software facilitates an appropriate modelling of the systems investigated.

Some aspects are highlighted below:
- The data on composition and masses considered in the reference flow are presented transparently and clearly in tabular form for both Tetra Pak packaging systems and those of competitor products.
- With regard to the mass specification of the Tetra Pak carton systems investigated, it is stated that these can vary slightly over different production lines or production sites. A range of errors is not specified. As differences < 10% of the result data are not taken into account in the interpretation, the CR panel expects that the small variations of the packaging composition will not lead to misinterpretations. The polymers marked as confidential in the report have been brought to the knowledge of the CR panel.
- The mass specifications of the competing products are described as "virtual typical packaging systems for Europe" in the corresponding usage segment. Data are generated based on ifeu knowledge and Tetra Pak expert judgment based on specification data from physically analysed samples of actual packaging systems. The measuring methods are not described, however, the underlying masses and materials of the competitor products considered are listed transparently in tabular form and appear plausible in terms of scale.
- The background data sets used are comprehensibly documented in the study and critically analysed with regard to their usability. The panel concludes that the data are appropriately selected and robust against the background of the goal of the study.

The reviewers conclude that the data used are appropriate and reasonable in relation to the goal of the study.

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

The interpretation is integrated into the presentation of the results, which is very useful for traceability due to the large number of packaging systems examined. For each product segment examined, the LCIA and LCI results of the packaging systems considered are carefully and clearly evaluated with reference to the documented result data. This is done for both allocation procedures examined. The panel can follow that in the subsequent comparison of the packaging systems examined, the parameters documented at life cycle inventory level are not included.

The conclusions, which are summarised in a separate chapter, are comprehensibly derived and transparently discussed based on the presented evaluation of the results without any over-interpretation.

The panel appreciates the detailed discussion of the limitations in a separate chapter, which very clearly points out once again that the results of an LCA apply exclusively to the selected framework conditions and cannot be transferred from one framework to another.

The overall conclusions and recommendations are clearly derived.

In order to avoid that LCA results are misinterpreted by the public, it is of central importance that a clear distinction is made between an ecological statement and the significance of a numerical value as a result of the application of a characterisation model in the LCA. The study addresses this aspect and thus integrates the greatest possible transparency.

The reviewers conclude that the interpretations reflect the limitations identified and the goal of the study.

3.5 Transparency and consistency of study report

The study is intended to be communicated to third parties. The report meets the requirements of ISO 14044 (clause 5.2) for third-party reports.

The study is transparently structured. Inconsistencies in the report could not be identified. The line of argument is transparent and comprehensible.

The reviewers conclude that the report is transparent and consistent.

4 Conclusion

The reviewers conclude that the study has been conducted according to and in consistency with the ISO standards 14040 and 14044.

At this point, the reviewers would like to provide some additional notes regarding the communication of the study results:

- Care must be taken to ensure that the implications of the selected impact categories, the limitations and uncertainties, which are clearly presented in the study, are communicated correctly.
- The implications that are generally associated with open-loop end-of-life allocations, which are clearly presented in the study, must be communicated in a comprehensible manner.
- In the public discourse on the relevance of LCA results - in particular the GWP is to be mentioned here at present - fundamental methodological framework conditions of LCA, which are clearly

presented in the study, are often not considered. In communication, care must be taken not to implicitly prejudice the association of a scientific ecological statement.

References:

[ISO 14040] DIN EN ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework

[ISO 14044] DIN EN ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines

[UBA 2016] Detzel, A., Kauertz, B., Grahl, B., Heinisch, J.: Prüfung und Aktualisierung der Ökobilanzen für Getränkeverpackungen. TEXTE 19/2016. Umweltbundesamt, Berlin.

Heidekamp, 10 March 2020	Bologna, 10 March 2020	Ashby de la Zouch, 10 March 2020
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