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

Final Report

commissioned by Tetra Pak North West Europe

Heidelberg, October 2018

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# Abbreviations

| | |
|---|---|
| **ACE** | Alliance for Beverage Cartons and the Environment |
| **BB** | Bio-based |
| **BC** | Beverage carton |
| **BEL** | Belgium |
| **Bio-PE** | Bio-based polyethylene |
| **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) |
| **FR** | France |
| **GE** | Germany |
| **GWP** | Global Warming Potential |
| **HBEFA** | Handbuch für Emissionsfaktoren (Handbook for Emission Factors) |
| **LDPE** | Low density polyethylene |
| **ifeu** | Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research) |
| **IPCC** | Intergovernmental Panel on Climate Change |
| **IRL** | Ireland |
| **ISO** | International Organization for Standardization |
| **JNSD** | Juice, Nectars, 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 |
| **NMVOC** | Non-methane volatile organic compounds |
| **NEL** | Netherlands |
| **$NO_X$** | Nitrogen oxides |
| **ODP** | Ozone Depletion Potential |
| **pc** | Packs |
| **PM2.5** | Particulate matter with an aerodynamic diameter of 2.5 µm or smaller |
| **PA 6** | Polyamide 6 |
| **PE** | Polyethylene |
| **PET** | Polyethylene terephthalate |
| **PP** | Polypropylene |
| **SBM** | Stretch blow moulding |
| **SUP** | Stand up pouch |
| **TB** | Tetra Brik |
| **TBA** | Tetra Brik Aseptic |
| **TiO2** | Titanium dioxide |
| **TPA** | Tetra Prisma Aseptic |
| **TT** | Tetra Top |
| **TWA** | Tetra Wedge Aseptic |
| **UBA** | Umweltbundesamt (German Federal Environment Agency) |
| **UHT** | Ultra-heat treatment |
| **UK** | United Kingdom |
| **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 2013]. 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 a global cooperation agreement with the WWF on issues concerning forestry and climate change.

Tetra Pak has recently finalised LCA studies for several packaging formats including bio-based alternatives in several European markets. As LCA results for a specific market cannot be directly applied in other markets, Tetra Pak North West Europe is looking to undertake a separate LCA study covering its four key markets: Belgium, Ireland, the Netherlands and the United Kingdom. This study shall deliver LCA results for key carton packages as well as key competing packages in different beverage segments. Although combined in one study, the four markets are examined separately. Direct comparisons between specific packaging systems between different markets are not part of the goal of this study.

The goal of the study is to conduct an LCA analysing the environmental performance of beverage carton systems compared to competing alternative beverage packaging systems on four individual markets.
Competing packaging systems include:

- PET bottles
- HDPE bottles
- Glass bottles
- PP cups
- Stand up pouches.

The analysed packaging systems contain the following chilled and ambient beverage and liquid food segments in the following volume ranges:

- Juice, Nectars, & Still Drinks (JNSD)
    - 1000mL
    - 200mL-330mL
- Still water
    - 330mL-500mL
- Dairy products like milk and protein drinks
    - 1000mL-2000mL

    - 189mL-500mL

- Cream
    - 300mL-330mL
- Yoghurt
    - 120mL-250mL

Geographical markets are:

- United Kingdom
- Ireland
- Belgium
- The Netherlands

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 (partly with bio-based material) on four individual markets in the described segments and markets.

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

Further objectives are addressed through sensitivity analyses:

(3) to provide knowledge regarding the environmental performance of ambient carton packages, if the aluminum barrier is replaced with a PE barrier.

(4) to provide knowledge regarding the environmental performance of carton packaging systems compared to PET bottles with reduced weights

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

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

(7) to provide knowledge regarding the environmental performance of carton packaging systems compared to HDPE bottles with 30% and 50% recycled material content.

The sensitivity analyses are conducted for selected packaging systems on selected markets chosen by TetraPak regarding their market relevance. (see Table 28-Table 32)

The results of this study for all scopes shall be used for internal and external communication.

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

## 1.2 Organisation of the study

This study was commissioned by Tetra Pak in 2016. It has been conducted by the Institute for Energy and Environmental Research Heidelberg GmbH (ifeu).

The members of the project panel are:

- **Tetra Pak:** René Hanselmann, Frank Vandewal, Gavin Landeg
- **ifeu:** Frank Wellenreuther, Samuel Schlecht, Stefanie Markwardt

## 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. 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 and preliminary results have been available.

The members of the critical review panel are

- Philippe Osset (chair), Solinnen
- Leigh Holloway, Eco3 Design Ltd
- Will Schreiber, 3Keel

## 1.4 Functional unit

The function examined in this LCA study is the packaging of beverages for retail. The functional unit for this study is the provision of 1000 l packaging volume for chilled or ambient beverage at the point of sale. The packaging of the beverages is provided as protection for the required shelf life of the product.

The maximum shelf life of all regarded ambient packaging systems varies between one month and 12-18 months. In general products stay in stores a maximum of two weeks. Therefore the shelf life is long enough that no beverage losses are to be expected because of discarded filled packages. This means, that the products would be used up, before the lowest shelf life of any packaging is reached.

Regarding chilled 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 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 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 foil, pallets), which are necessary for the packaging, filling and delivery of 1000 L beverage.

## 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 transport 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 (incl. 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 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)

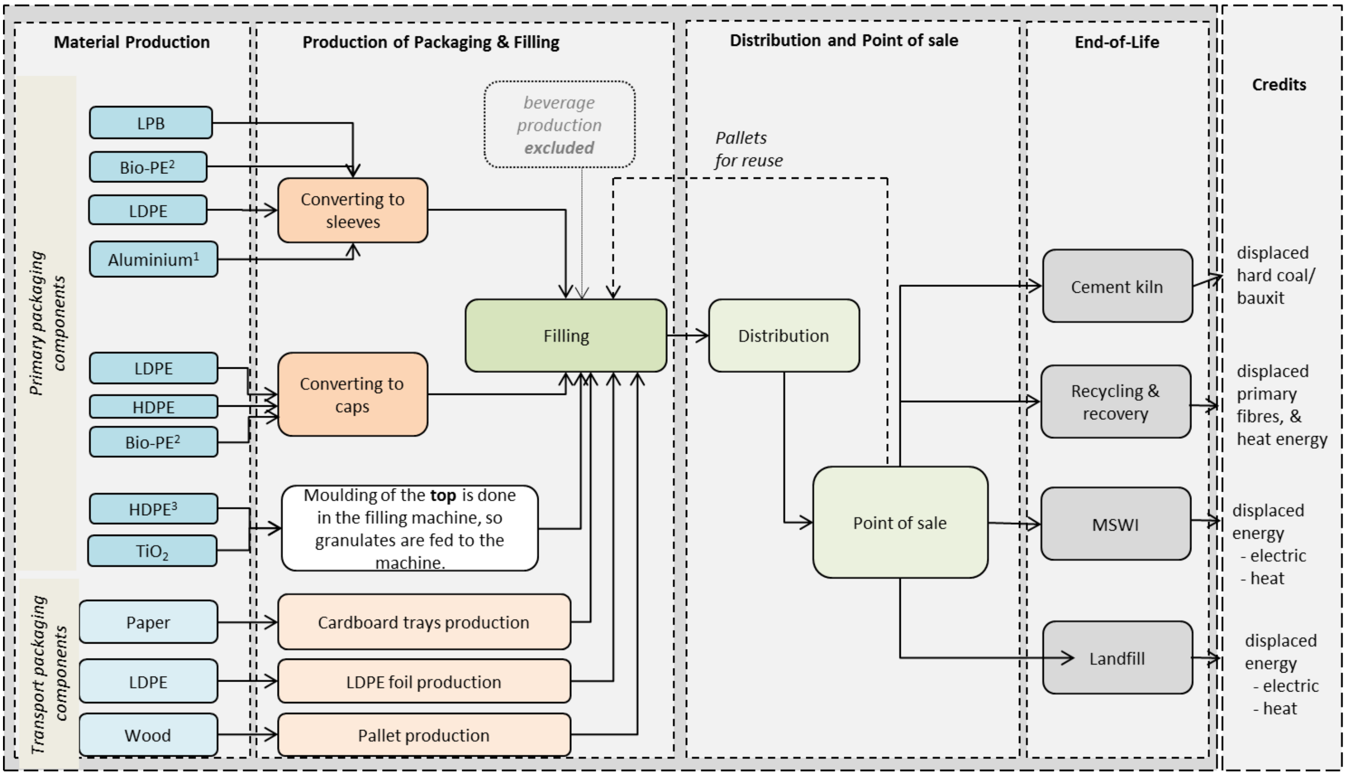
Not included are:

- 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. For some of the plastic bottles roll container are used during the transport from fillers to the point of sale (see section 3). Roll container have a weight of 38kg, mainly consist of steel and are reused between 200 to 500 times (IVL 2009; ERM 2010). As in the Tetra Pak Nordics LCA [ifeu 2017] in this study roll containers are treated as transport media and therefore as part of the infrastructure for the used vehicles. Due to the high reuse rate the container are not a substantial part of the products life cycle and are not identified as environmental hot spot within the supply chain. However, the weight of the roll container itself is considered for retail.
- production of beverage and transport to fillers as no relevant differences between the systems under examination are to be expected

- distribution of beverage from the filler to the point-of-sale (distribution of packages is included).
- environmental effects from accidents like breakage during transportation.
- losses of beverage at different points in the supply and consumption chain which might occur for instance in the filling process, during handling and storage, etc. as they are considered to be roughly the same for all examined packaging systems. Significant differences in the amount of lost beverage between the regarded packaging systems might be conceivable only if non-intended uses or product treatments are considered as for example in regard to different breakability of packages or potentially different amount of residues left in an emptied package due to the design of the package/closure.
  Further possible losses are directly related to the handling of the consumer in the use phase, which is not part of this study as handling behaviours are very different and difficult to assess. Some data about beverage losses in houshoulds is available, these losses though cannot be allocated to the different beverage packaging systems. Further no data is available for losses at the points of sail. Therefore these possible beverage loss differences are not quantifiable. In consequence a sensitivity analysis regarding beverage losses would be highly speculative and is not part of this study. This is indeed not only true for the availability of reliable data, but also uncertainties in inventory modelling methodology of regular and accidental processes and the allocation of potential beverage waste treatment aspects.
- transport of filled packages from the point of sale to the consumer as no relevant differences between the systems under examination are to be expected and the implementation would be highly speculative as no reliable data is available.
- use phase of packages at the consumers as no relevant differences between the systems under examination are to be expected (for example in regard to cleaning before disposal) and the implementation would be highly speculative as no reliable data is available.

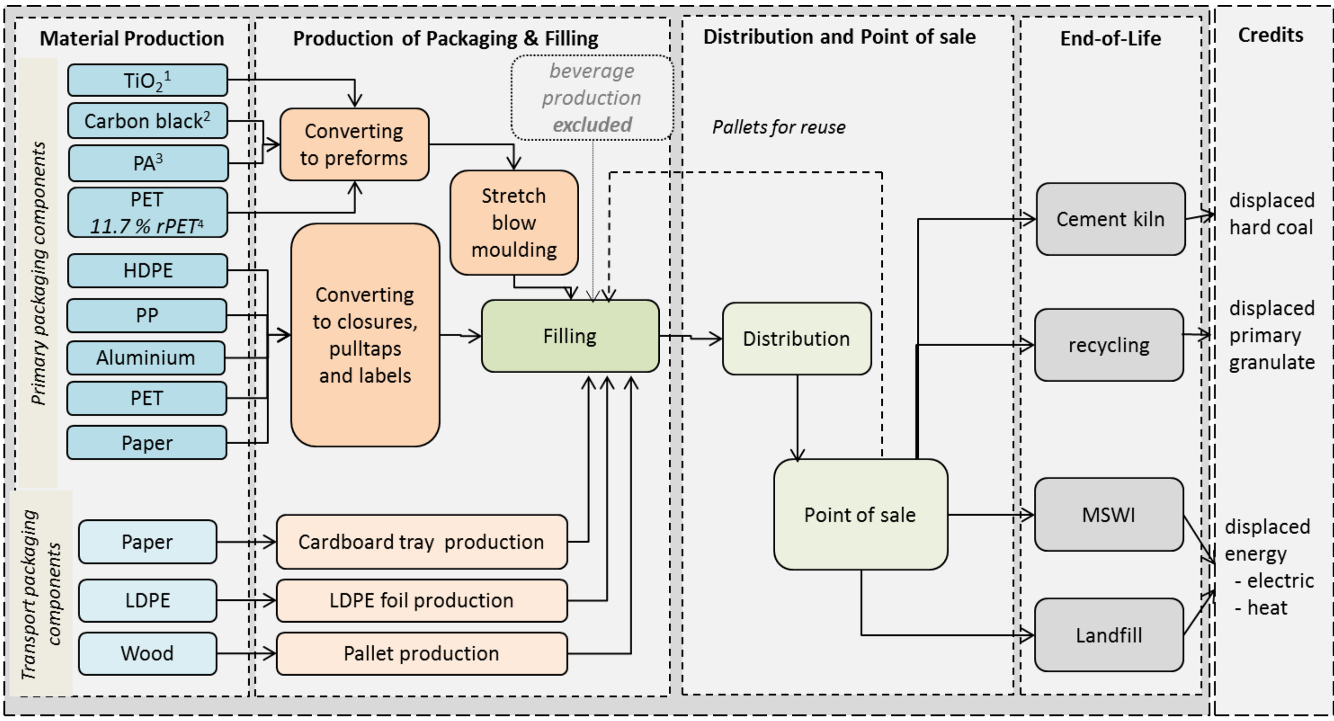
These exclusions do not effect the comparisons between packaging systems.

The following simplified flow charts shall illustrate the system boundaries considered for the packaging systems beverage carton (Figure 1), PET bottle (Figure 2), HDPE bottle (Figure 3), PP cup (Figure 4), glass bottle (Figure 5) and stand up pouch (Figure 6). The application of credits in this study is further illustrated in the section 1.7 about allocation.



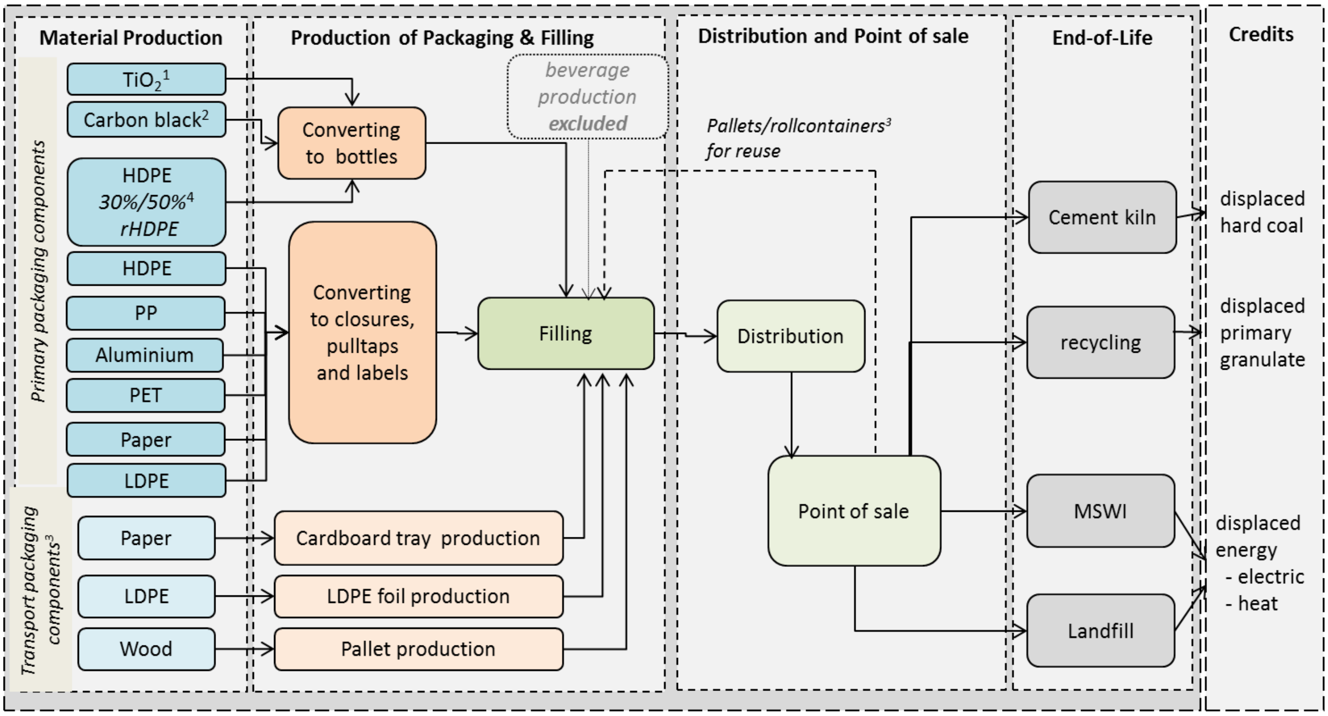

¹ Aluminium does not apply for beverage cartons filled with chilled milk
² for selected beverage cartons
³ for selected Tetra Top beverage cartons

**Figure 1: System boundaries of beverage cartons**



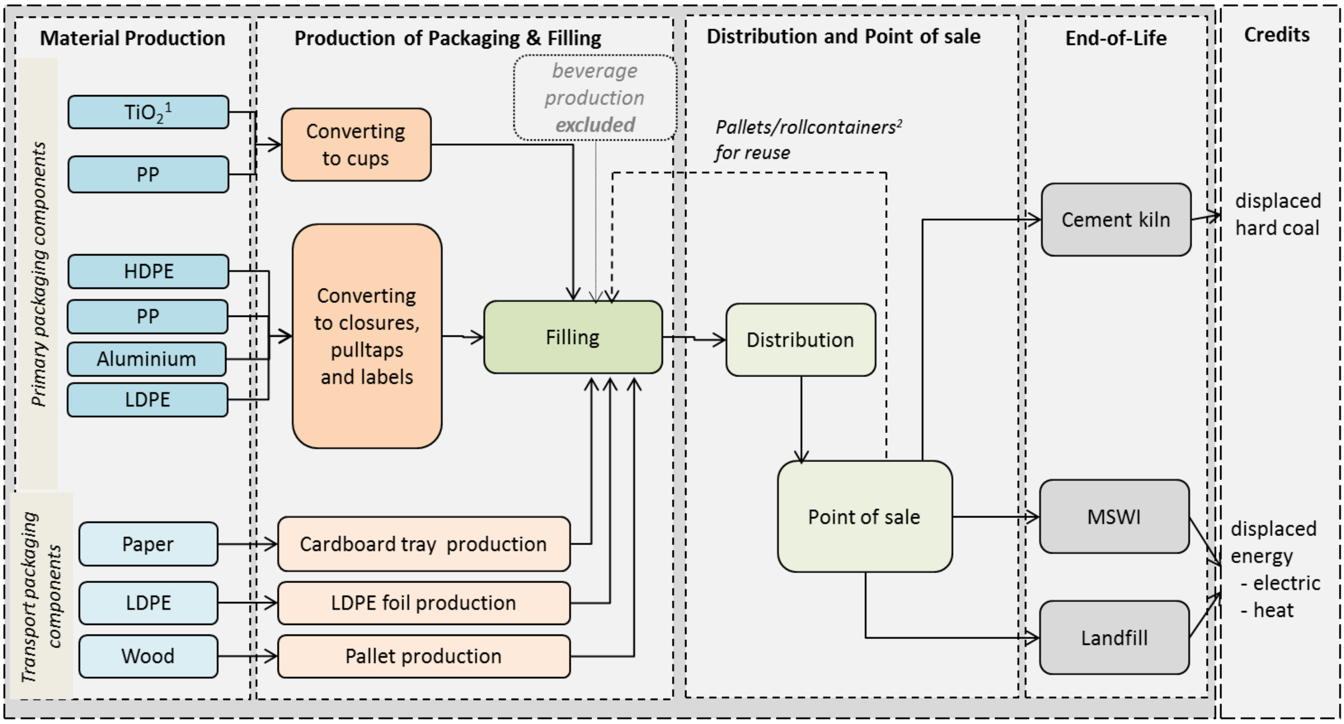

¹ applies only for opaque bottles
² applies for ambient dairy bottles
³ applies for ambient JNSD bottles and ambient dairy bottles without carbon black layer
⁴ PET bottle 5: 50% rPET

**Figure 2: System boundaries of PET bottles**




[1] applies only for opaque bottles
[2] applies for ambient dairy bottles
[3] weight of rollcontainers is considered for retail, production of rollcontainers is excluded
[4] applies for sensitivity analysis

**Figure 3: System boundaries of HDPE bottles**




[1] applies only for opaque cups
[2] weight of rollcontainers is considered for retail, production of rollcontainers is excluded

**Figure 4: System boundaries of PP cups**

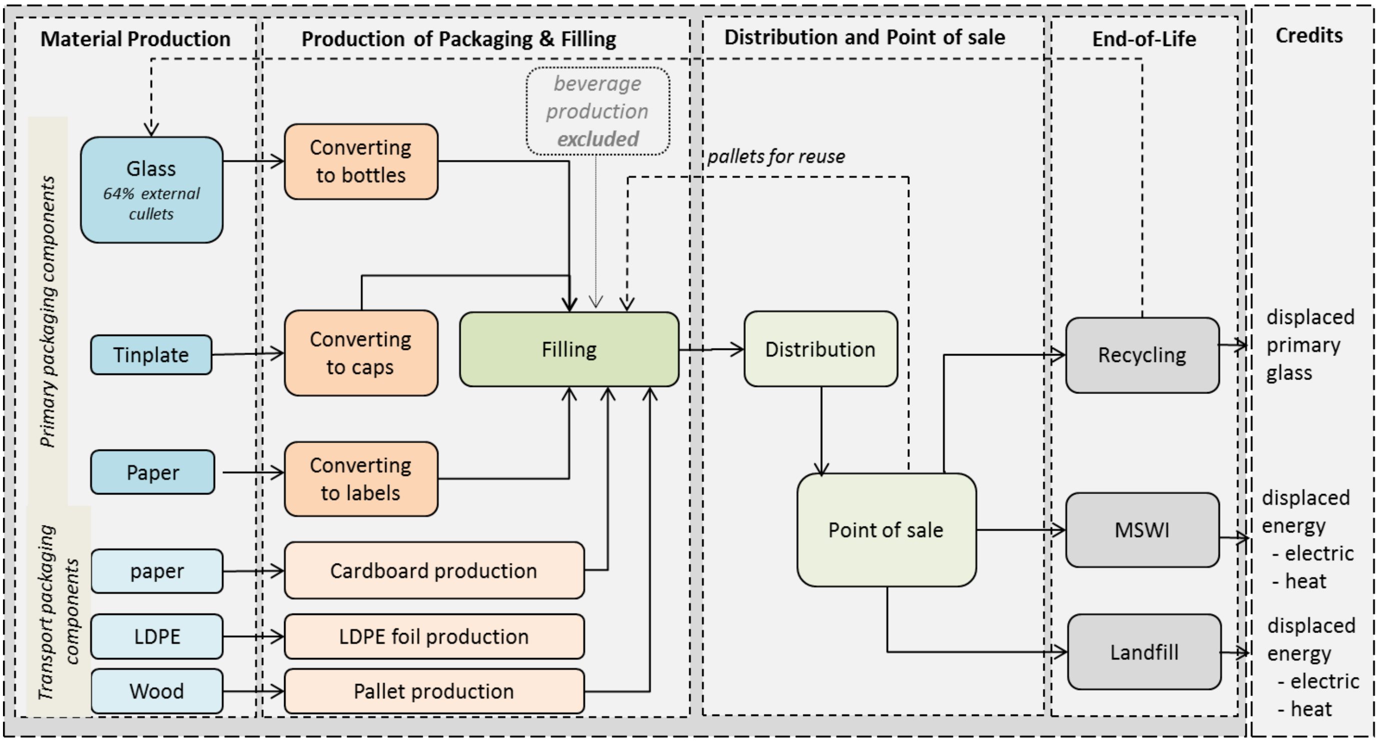



**Figure 5: System boundaries of glass bottles**

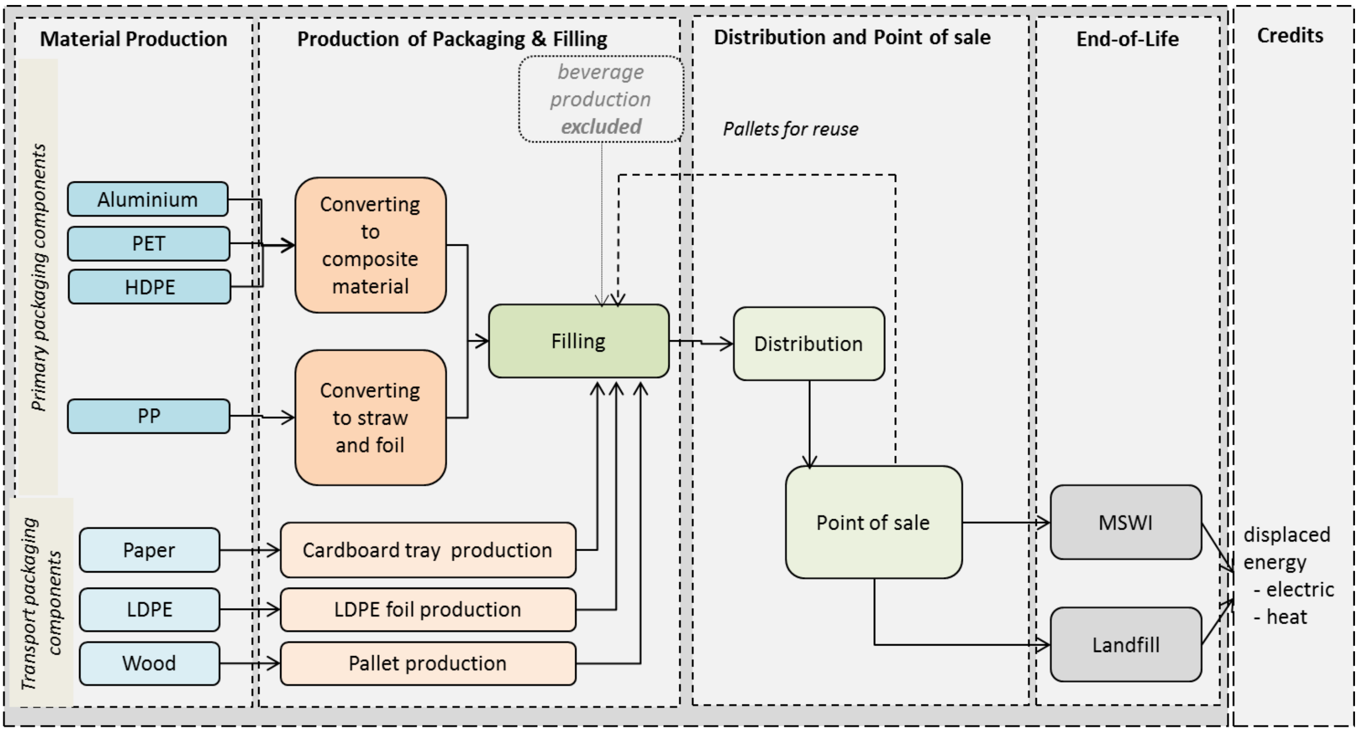



**Figure 6: System boundaries of stand up pouch**

**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 preceding systems with an input material share of less than 1% of the total mass input of a considered process were excluded from the present study. However, total cut-off is not to surpass 5% of input materials as referred to the functional unit. 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 material is applied. This is not the case in this study. Based on the mass-related cut-off the amount of printing ink used for the surface of beverage 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 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 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 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 the UK, Ireland, Belgium and the Netherlands. 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 an European average).

**Time scope**

The reference time period for the comparison of packaging systems is 2017, as the packaging specifications listed in section 2 as well as the market situation for the choice of beverage systems refer to 2017. Thus, the reference time period for the comparison is

2017. Where no figures are available for these years, the used data shall be as up-to-date as possible. This applies for example for the data for the converting of beverage cartons, which refers to 2013. 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 refer to the period between 2002 and 2017 (see Table 33). The datasets for transportation, energy generation and waste treatment processes (except recycling process for beverage 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 and representativeness check according to [ISO 14044]**

| Life cycle steps | Beverage cartons | HDPE bottles | PET bottles | Glass bottle | PP cups | SUP | Complete? | Repre-sentative? |
|---|---|---|---|---|---|---|---|---|
| x: inventory data for all processes available | | | | | | | | |
| **Base material production** | x | x | x | x | x | x | yes | yes |
| **Production of packaging (converting)** | x | x | x | x | x | x | yes | yes |
| **Filling** | x | x | x | x | x | x | yes | yes |
| **Distribution** | x | x | x | x | x | x | yes | yes |
| **End of life** | | | | | | | | |
| Recycling processes | x | x | x | x | x | x | yes | yes |
| MSWI | x | x | x | x | x | x | yes | yes |
| Landfill | x | x | x | x | x | x | yes | yes |
| **Credits** | x | x | x | x | x | x | yes | yes |
| **Transportation of materials to the single production steps** | x | x | x | x | x | x | yes | yes |

**Consistency**

All data used are considered to consistent for the described goal and scope regarding: applied data, data accuracy, technology coverage, time-related coverage and geographical coverage.

**Sources of data**

Process data for base material production and converting were either collected in cooperation with the industry or taken from literature and the ifeu database. Ifeu's internal database includes data either collected in cooperation with industry or is based on literature. The database is continuously updated. Background processes such as energy generation, transportation, MSWI and landfill were taken from the most recent version of it. All data sources are summarised in Table 33 and described in Chapter 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 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 is excluded. The allocation between package and filling goods is based on mass criterion. This allocation is applied as the functional unit of the study defines a fixed amount of beverage through all scenarios. Impacts related to transporting the beverage itself would be the same in all scenarios. There they don’t need to be included in this comparative study of beverage packaging systems.

### System-related allocation

The approach chosen for system-related allocation is illustrated in Figure 5 and 6. 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 Figure 7 (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 of via MSWI. 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 7. Here product A is recovered after use and supplied as a raw material to ‘system B’ avoiding thus the environmental loads related to the production (‘MP-B’) of the virgin materials, e.g. polymer and the disposal of product A (‘MSWI-A’). Note: Avoided processes are indicated by dashed lines in the graphs.

Now, if the system boundaries of the LCA are such that only ‘product system A’ is examined it is necessary to decide how the possible environmental benefits and loads of the polymer material recovery and recycling shall be allocated (i.e. accounted) to ‘system A’. In LCA practice, several allocation methods are found.

**General notes regarding Figure 7 to Figure 9**

The following 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 the 50%:50% allocation method and the 100% allocation method
- to show which processes are allocated:
  - primary material production
  - recovery processes

– waste treatment of final residues (here represented by MSWI)

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 11 - Figure 14) as well as the actual substituted material including different substitution factors(section 3.14).

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 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'.
- The final waste treatment for the materials from both 'systems A and B' is represented in the graphs only as municipal solid waste incineration (MSWI). However, the LCA model implemented comprehends a final waste management 'mix' made up of both landfilling and MSWI processes.

Figure 7 illustrates the general allocation approach used for uncoupled systems and systems which are coupled through recycling. In order to do the allocation consistently, besides the virgin material production ('MP-A') already mentioned above and the disposal of product B ('MSWI-B'), also the recovery process 'Rec' has to be taken into consideration.

Furthermore, there is one important premise to be complied with by any allocation method chosen: the mass balance of all inputs and outputs of 'system A' and 'system B' after allocation must be the same as the inputs and outputs calculated for the sum of 'systems A and B' before allocation is performed.

**Allocation with the 50% method (Figure 8)**

In this method, benefits and loads of 'MP-A', 'Rec' and 'MSWI-B' are equally shared between 'system A and 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 (MSWI-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 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).

***The 50% allocation method was chosen as base scenario in the present study.***

**Allocation with the 100% method (Figure 9)**

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 loads for producing the secondary raw material via 'Rec-A' are assigned to 'system A'. In addition, also the loads that are generated by waste treatment of 'product B' in 'MSWI-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'.

One should be aware that in such a case any LCA focusing on 'system B' would then have to assign the loads associated with the production process 'MP-B' to the 'system B' (otherwise the mass balance rule would be violated). However, 'system B' would not be charged with loads related to 'Rec' as the loads are already accounted for in 'system A'. At the same time, 'MSWI-B' is not charged to 'system B' (again a requirement of the mass balance rule), as it is already assigned to 'system A'.

***The 100% allocation method was chosen as sensitivity analysis in the present study to verify the influence of the chosen allocation method in the base scenarios.*** This choice is considered as conservative approach from the view of the beverage carton.

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

**Application of allocation rules**

The allocation factors have been applied on a mass basis (i.e. the environmental loads of the recycling process are charged with the total loads 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. In the case of PET bottles containing PA a reduced substitution factor of 0.9 is applied.

- 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): 0.9
- HDPE from bottles: 1.0
- HDPE from closures : 0.9
- Glass from bottles: 1

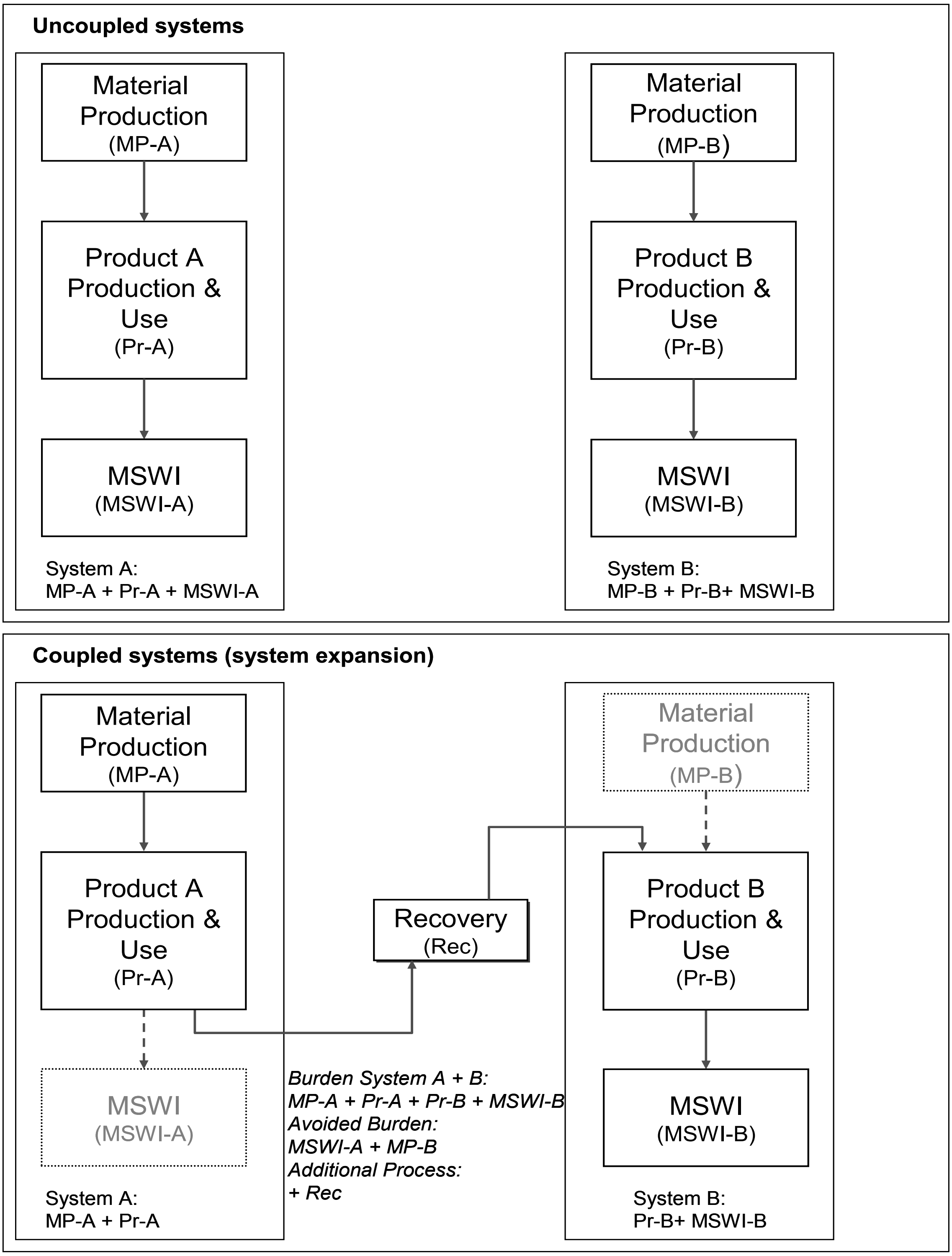



**Figure 7: Additional system benefit/burden through recycling (schematic flow chart)**

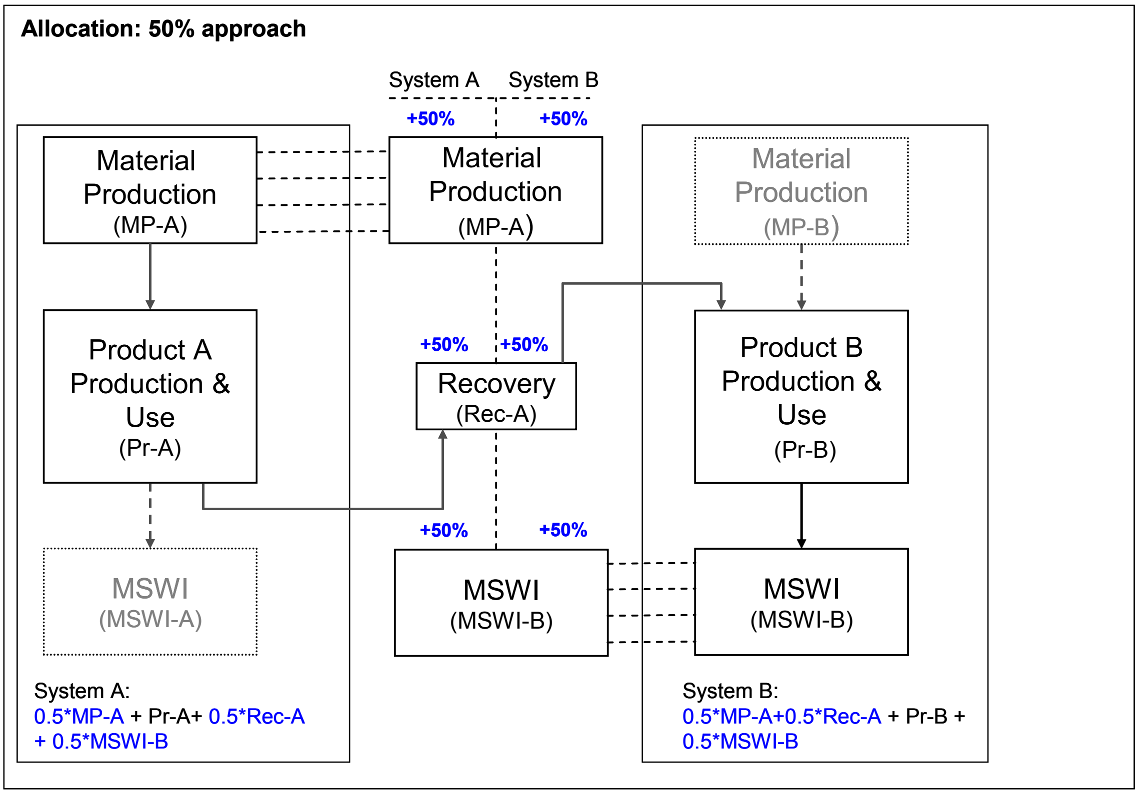



**Figure 8: Principles of 50% allocation (schematic flow chart)**

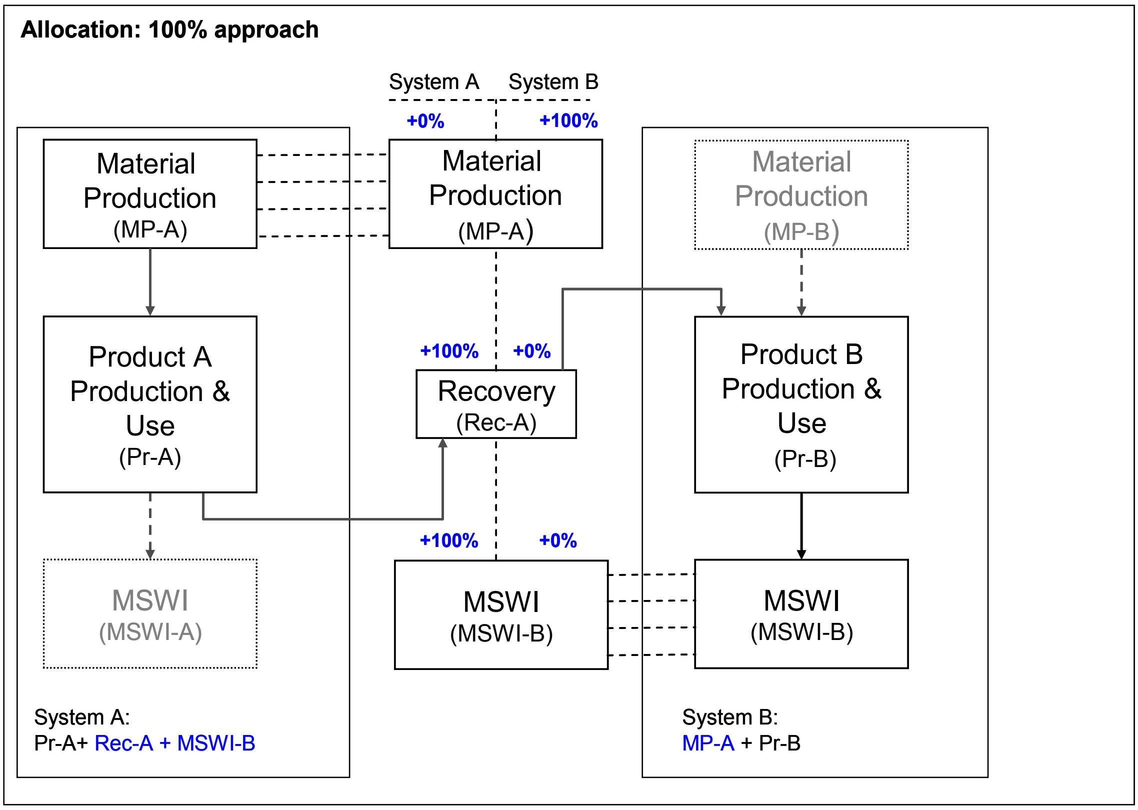



**Figure 9: Principles of 100% allocation (schematic flow chart)**

## 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 the present study, midpoint categories are applied. Midpoint indicators represent potential primary environmental impacts and are located between emission and potential harmful effect. This means that the potential damage caused by the substances is not taken into account.

The selection of the impact categories is based both on the current practice in LCA and the applicability of as less as uncertain characterisation models also with regard to the completeness and availability of the inventory data. 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. Further, the choice of characterisation methods follows earlier studies for Tetra Pak in order to be consistent with these. 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.

### Stratospheric Ozone Depletion

In the 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. 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 concept seem 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:

- ***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.

Note on human toxicity: 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 ($GSD^2$):

| Characterisation factor | $GSD^2$ |
|---|---|
| Human health, emission to rural air | 77 |
| Human health, emission to freshwater | 215 |
| Human health, emission to agricultural soil | 2,189 |
| Freshwater ecotoxicity, emission to rural air | 176 |
| Freshwater ecotoxicity, emission to freshwater | 18 |
| Freshwater ecotoxicity, emission to agricultural soil | 103 |

**Figure 10:** Model uncertainty estimates for USEtox characterisation factors (reference: [Rosenbaum et al. 2008])

To capture the 95 % confidence interval, the mean value of each substance would have to be divided and multiplied by the $GSD^2$. 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 asfor individual agricultural productions in North- and South America (Kauertz et al. (2011), [Fehrenbach et al. 2016]). However data quality for its apllication in this study is considered to be not sufficient enough to deliver robust results. Due to the data uncertainties connected to forestry data and sugar cane cultivation the results of this category in this study cannot be used without hesitation. Results for the base scenarios are included in this report for transparency, but they are not further interpreted for comparisons between systems and not considered for the final conclusions.

The used inventory data for paper production have been determined by Tiedemann 2000. Inventory data for the bio-PE dataset compiled by ifeu are based on [Fehrenbachet.al.2016], where sugar cane is classified in equal shares to class 5 and 6. As a conservative assumption, the land use for sugar cane cultivation is classified to class 6 in the bio-PE dataset compiled by ifeu.

To adress land use by a methodology without losing crutial 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 elementary flows and their classification into impact categories

| Impact category | Elementary flows | | | | | | Unit |
|---|---|---|---|---|---|---|---|
| **Use of Nature** | class 2 | class 3 | class 4 | class 5 | class 6 | class 7 | $m^2$-e*a |

## Raw materials

The published approaches addressing the impact on primary natural resources are currently limited to abiotic raw materials and energy. 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 could be included on the inventory level only. A simple list of resources without an assessment will not add much value to this study, though. In fact, in the view of the authors, such inventory level results might even be misleading to readers. Inventory level information is not part of an environmental assessment and would not be used for the drawing of conclusions anyway.

Therefore, 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. The consequence of this methodological decision of course is, that there is an imbalance regarding the information on raw materials. While materials with an energy content like oil for plastics or wood for paperboard are inventoried in the CED, raw materials without energy content like silica and sodium carbonate for glass bottles are not considered. This has no influence on the final outcome of this study, though, as the CED, as an inventory level indicator, is not 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. For this reason results of these inventory categories are only included in the section results and description and interpretations, but are not used for comparative assertions and conclusions.

### 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 mjdpoint 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 technosphere. 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 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. The unit is $m^3$. The use of freshwater applied in this study refers to water inputs in the life cycle of the product. Not applied in this study is water consumption which would imply the difference between water inputs and water outputs.

## 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) based on lower heating values. This category is described in [VDI 1997] and has not been changed considerably since then.

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

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. Main function of the examined primary packaging is the packaging and protection of beverages. 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 focus of this study lies on the beverage cartons produced by Tetra Pak for which this study aims to provide knowledge of its strengths and weaknesses regarding environmental aspects.

The choice of beverage cartons has been made by Tetra Pak. Cartons of different volumes for the packaging of dairy (chilled and ambient) and JNSD (Juice, Nectars & Still Drinks) (ambient and chilled) have been chosen for examination. For each of these beverage categories, competing packaging systems have been selected. This selection was also done by Tetra Pak. The selection of these competing packaging systems was based on market relevance in each of the four analysed countries. All competing packaging systems are one-way system like the beverage carton systems. Refillable packaging systems are not included in the study as they have no important shares in the applied markets.

The following - show which beverage cartons are compared with the selected competing systems. The comparison is conducted as follows:

- Only packaging systems in the same segment are compared to each other
- Chilled and ambient beverage packaging systems are not compared to each other. In a few cases ambient beverage cartons are compared to chilled bottles as these ambient cartons are sold in chilled shelfs in the stores. As ambient packaging has higher barrier demand, these exceptions are from the perspective of the beverage carton a conservative approach.

**Table 6:** List of beverage cartons in segment **DAIRY 1000ml-2000ml** 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 1500 ml** | C | IRL | HDPE bottle 11 2000 ml | C | IRL |
| **Tetra Rex (TR) OSO 34 Bio-based 1500 ml** | C | IRL | HDPE bottle 11 2000 ml | C | IRL |
| **Tetra Rex (TR) OSO 34 1000 ml** | C | UK, IRL, NLD | HDPE bottle 1 1136 ml | C | UK |
| | | | HDPE bottle 2 1000 ml | C | IRL |
| | | | PET bottle 1 1000 ml | C | NLD |
| | | | HDPE bottle 2 1000 ml | C | NLD |
| **Tetra Rex (TR) OSO 34 Bio-based 1000 ml** | C | UK, IRL, NLD | HDPE bottle 1 1136 ml | C | UK |
| | | | HDPE bottle 2 1000 ml | C | IRL |
| | | | PET bottle 1 1000 ml | C | NLD |
| | | | HDPE bottle 2 1000 ml | C | NLD |
| **Tetra Brik Aseptic (TBA) Slim HeliCap 23 1000 ml** | A | BEL, NLD | PET bottle 2 1000 ml | A | NLD |
| | | | HDPE bottle 3 1000 ml | A | NLD |
| | | | PET bottle 2 1000 ml | A | BEL |
| | | | HDPE bottle 4 1000 ml | A | BEL |
| **Tetra Brik Aseptic (TBA ) Edge LightCap 1000 ml** | A | BEL, NLD | PET bottle 2 1000 ml | A | BEL, NLD |
| | | | HDPE bottle 3 1000 ml | A | NLD |
| | | | HDPE bottle 4 1000 ml | A | BEL |
| **Tetra Brik Aseptic (TBA ) Edge LightCap Bio-based 1000 ml** | A | BEL, NLD | PET bottle 2 1000 ml | A | BEL, NLD |
| | | | HDPE bottle 3 1000 ml | A | NLD |
| | | | HDPE bottle 4 1000 ml | A | BEL |

**Table 7:** List of beverage cartons in segment **JNSD 1000ml** 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) Edge LightCap 1000 ml** | A | UK, IRL, BEL, NLD | PET bottle 3 1000 ml | A | UK, IRL, BEL, NLD |
| | | | Glass bottle 1 1000 ml | A | BEL, NLD |
| **Tetra Brik Aseptic (TBA) Edge LightCap Bio-based 1000 ml** | A | UK, IRL, BEL, NLD | PET bottle 3 1000 ml | A | UK, IRL, BEL, NLD |
| | | | Glass bottle 1 1000 ml | A | BEL, NLD |
| **Tetra Prisma Aseptic (TPA) Square HeliCap 27 1000 ml** | A | UK, IRL, BEL, NLD | PET bottle 3 1000 ml | A | UK, IRL, BEL, NLD |
| | | | Glass bottle 1 1000 ml | A | BEL, NLD |

**Table 8:** List of beverage cartons in segment **Dairy 189ml-500ml** 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) 200 B 189 ml** | C | UK | HDPE bottle 10 189 ml | C | UK |
| **Tetra Prisma Aseptic (TPA) Edge DreamCap 250 ml** | A | UK, IRL, BEL, NLD | PP cup 3 220 ml | C | UK |
| | | | Glass bottle 3 250 ml | A | UK |
| | | | HDPE bottle 5 250 ml | A | UK, IRL |
| | | | HDPE bottle 6 250 ml | A | UK, IRL |
| | | | HDPE bottle 7 250 ml | A | BEL, NLD |
| | | | PET bottle 12 300 ml | A | BEL, NLD |
| **Tetra Brik Aseptic (TBA) Edge HeliCap23 250 ml** | A | UK, IRL, BEL, NLD | PP cup 3 220 ml | C | UK |
| | | | Glass bottle 3 250 ml | A | UK |
| | | | HDPE bottle 5 250 ml | A | UK, IRL |
| | | | HDPE bottle 6 250 ml | A | UK, IRL |
| | | | HDPE bottle 7 250 ml | A | BEL, NLD |
| | | | PET bottle 12 300 ml | A | BEL, NLD |
| **Tetra Prisma Aseptic (TPA) Square DreamCap 330 ml** | A | UK, IRL, BEL, NLD | PP cup 3 220 ml | C | UK |
| | | | Glass bottle 3 250 ml | A | UK |
| | | | PET bottle 13 330 ml | A | UK, IRL |
| | | | HDPE bottle 8 330 ml | A | UK, IRL |
| | | | PP Cup 1 250 ml | C | BEL, NLD |
| | | | PET bottle 14 330 ml | C | BEL, NLD |

| | | | | | |
|---|---|---|---|---|---|
| **Tetra Prisma Aseptic (TPA) Square DreamCap Bio-based 330 ml** | A | UK, IRL | PP cup 3 220 ml | C | UK |
| | | | Glass bottle 3 250 ml | A | UK |
| | | | PET bottle 13 330 ml | A | UK, IRL |
| | | | HDPE bottle 8 330 ml | A | UK, IRL |
| **Tetra Top (TT) Midi O38 330 ml** | C | BEL, NLD | PP Cup 1 250 ml | C | BEL, NLD |
| | | | PET bottle 14 330 ml | C | BEL, NLD |
| **Tetra Prisma Aseptic (TPA) Square StreamCap 500 ml** | A | UK, IRL | PET bottle 15 475 ml | A | UK |
| | | | HDPE bottle 9 500 ml | A | UK |
| | | | PET bottle 16 500 ml | A | IRL |

**Table 9:** List of beverage cartons in segment **JNSD 200ml-330ml** 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 Wedge Aseptic (TWA) 200 ml** | A | UK, IRL, BEL, NLD | SUP 1 200 ml | A | UK, IRL, BEL, NLD |
| | | | PET bottle 4 200 ml | A | UK, IRL |
| **Tetra Prisma Aseptic (TPA) Edge DreamCap 250 ml** | A | UK, IRL, BEL, NLD | PET bottle 5 250 ml | C | UK, IRL, BEL, NLD |
| | | | PET bottle 6 250 ml | A | BEL, NLD |
| | | | Glass bottle 2 250 ml | A | BEL, NLD |
| **Tetra Brik Aseptic (TBA) Edge HeliCap 23 250 ml** | A | UK, IRL | PET bottle 5 250 ml | C | UK, IRL |
| **Tetra Prisma Aseptic (TPA) Square DreamCap 330 ml** | A | UK, IRL, BEL, NLD | PET bottle 7 330 ml | C | UK, IRL |
| | | | PET bottle 8 330 ml | A | NLD |
| | | | PET bottle 9 330 ml | A | BEL |
| | | | PET bottle 10 330 ml | A | BEL, NLD |
| **Tetra Prisma Aseptic (TPA) Square DreamCap Bio-based 330 ml** | A | UK, IRL, BEL, NLD | PET bottle 7 330 ml | C | UK, IRL |
| | | | PET bottle 8 330 ml | A | NLD |
| | | | PET bottle 9 330 ml | A | BEL |
| | | | PET bottle 10 330 ml | A | BEL, NLD |

**Table 10:** List of beverage cartons in segment **Water 330ml -500ml** 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 Top (TT) Midi O38 330 ml** | A | NLD | PET bottle 11 330 ml | A | NLD |
| **Tetra Prisma Aseptic (TPA) Square DreamCap 330 ml** | A | NLD | PET bottle 11 330 ml | A | NLD |
| **Tetra Prisma Aseptic (TPA) Square DreamCap Bio-based 330 ml** | A | NLD | PET bottle 11 330 ml | A | NLD |
| **Tetra Prisma Aseptic (TPA) Square StreamCap 500 ml** | A | UK | PET bottle 17 500 ml | A | UK |
| | | | PET bottle 18 500 ml | A | UK |
| **Tetra Top (TT) Midi Eifel O38 500 ml** | A | UK | PET bottle 17 500 ml | A | UK |
| | | | PET bottle 18 500 ml | A | UK |
| **Tetra Top (TT) Midi Eifel O38 Bio-based 500 ml** | A | UK | PET bottle 17 500 ml | A | UK |
| | | | PET bottle 18 500 ml | A | UK |

**Table 11:** List of beverage cartons in segment **Cream/Yoghurt 120ml-330ml** 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 Top (TT) Huron O38 250 ml** | C | BEL | PP cup 4 120ml | C | BEL |
| | | | PP cup 5 144ml | C | BEL |
| **Tetra Top (TT) Midi O38 330 ml** | C | UK, IRL | PP cup 2 300 ml | C | UK, IRL |

## 2.2 Packaging specifications

Specifications of beverage carton packaging systems are listed in Table 12 - Table 17

They are provided by Tetra Pak. In Tetra Pak's internal database typical specifications of all primary packages sold are registered.

Data on secondary and tertiary packaging for beverage cartons was also provided by Tetra Pak from its internal packaging system model. The data is periodically updated and the most recent data of 2017 is used in this LCA.

Specifications of the competing packaging systems are listed in Table 18 -

Table 24. They were determined by ifeu in 2017. For each packaging system one or two sample bottles were bought by TetraPak at the point of sale and have been sent to ifeu. Specifications were determined by weighing the individual sample bottles. Even though slight variations in bottle weights are possible regarding different examples of a single packaging solution, these possible differences are considered to be low enough to derive the specifications from only a small amount of samples. Weight was determined for each material included in each system. Bottle and cap material of plastic bottles and cups were identified by its resin identification codes. The material of plastic labels was identified by floating experiments in water and vegetable oil. The barrier material included in the bottle bodies was identified as described in the following: All opaque bottles are assumed to contain a share of 1.6% $TiO_2$ as a colour medium [Robertson 2016]. Additionally all opaque bottles were cut open and checked for a black layer. If there was a black layer a 5% content of carbon black as barrier material was assumed. Ambient bottles, except for water (clear and opaque) without a black layer are assumed to contain 8% of PA as barrier material (average of communicated PA content of three bottle plastic producers[1]).

Besides one exception, for all PET bottles the content of recycled PET was assumed to be the European average of 11.7 % [EPBP 2017]. The European average is applied as there are no specific information about recycled content in the PET bottles available. An exception in PET bottle 5 for which a recycled content of 30%-50% is known. As a conservative approach from the perspective of beverage cartons 50% recycled content is applied for PET bottle 5.

The weight of the stand up pouch (SUP) was measured. The weight and material composition refers to the producer's publication and was reconfirmed by weighing the actual pack.

Data on secondary packaging for competing packaging systems was determined partially from secondary packaging at hand. In case secondary packaging was not at hand, the type of packaging (corrugated cardboard tray and/or shrink foil) was identified by internet research. The weight of packaging material was interpolated with the weight of actually measured packaging based on packaging surface area. Packaging surface was calculated

[1] http://www.mgc.co.jp/eng/products/nop/nmxd6/bottle.html
http://www.fosterpolymers.com/downloads/docs/mx/MX-Nylon_properties.pdf
http://www51.honeywell.com/sm/aegis/products-n2/aegis-ox.html

approximately with bottles' dimensions and bottles' arrangement in the trays/shrink packs.

Data on tertiary packaging was partially taken from previous studies conducted for Tetra Pak (i.e. weight of pallet).

Pallet configuration of beverage cartons as well as the information of shrink foil around the beverage carton pallets was provided by Tetra Pak.

Pallet configuration of competing packaging systems was calculated with the online tool *www.onpallet.com*. Europallets with a loading height of 1400mm were assumed for the calculation. The weight of shrink foil per pallets refers to the packaging height of 1400mm. Packaging dimension was taken from the earlier described calculation of secondary packaging. Pallet configuration depends on the size of the bottles as well as the amount and arrangement of bottles in each secondary packaging.

### 2.2.1 Specifications of beverage carton systems

**Table 12: Packaging specifications for regarded carton systems for the *packaging of dairy 1000ml-2000ml*:**

| | | DAIRY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Packaging components** | **Unit** | **TR OSO 34** | **TR OSO 34 Bio-based** | **TR OSO 34** | **TR OSO 34 Bio-based** | **TBA Slim HeliCap 23** | **TBA Edge LightCap** | **TBA Edge LightCap Bio-based** |
| **Volume** | ml | 1500 | 1500 | 1000 | 1000 | 1000 | 1000 | 1000 |
| **Geographic Scope** | - | IRL | IRL | UK, IRL, NLD | UK, IRL, NLD | BEL, NLD | BEL, NLD | BEL, NLD |
| **Chilled / ambient** | - | chilled | chilled | chilled | chilled | ambient | ambient | ambient |
| **primary packaging (sum)** | g | **39.39** | **39.39** | **30.39** | **30.39** | **33.06** | **32.60** | **32.60** |
| **composite material (sleeve)** | g | **36.79** | **36.79** | **27.79** | **27.79** | **30.36** | **29.60** | **29.60** |
| **- liquid packaging board** | g | 32.41 | 32.41 | 24.22 | 24.22 | 22.23 | 23.50 | 23.50 |
| **- LDPE** | g | 4.38 | | 3.57 | | 6.73 | 4.70 | 2.00 |
| **- Bio-PE** | g | | 4.38 | | 3.57 | | | 2.70 |
| **- Aluminium** | g | | | | | 1.40 | 1.40 | 1.40 |
| **Closure** | g | **2.60** | **2.60** | **2.60** | **2.60** | **2.70** | **3.00** | **3.00** |
| **- HDPE** | g | | | 1.40 | | 1.31 | 1.40 | |
| **- LDPE** | g | 2.60 | | 1.20 | | | 1.60 | 1.60 |
| **- Bio-PE** | g | | 2.60 | | 2.60 | | | 1.40 |
| **- PP** | g | | | | | 1.39 | | |
| **secondary packaging (sum)** | g | **159.16** | **159.16** | **151.81**[UK, NLD] **17.22**[IRL] | **151.81**[UK, NLD] **17.22**[IRL] | **114.28** | **122.81** | **122.81** |
| **- tray (corr.cardboard)** | g | 159.16 | 159.16 | 151.81 [NLD] | 151.81 [NLD] | 114.28 | 122.81 | 122.81 |
| **- shrink pack (LDPE)** | g | | | 17.22 [UK IRL] | 17.22 [UK IRL] | | | |
| **tertiary packaging (sum)** | g | **25651** | **25651** | **25651** | **25651** | **27551** | **25651** | **25651** |
| **pallet** | g | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 |
| **type of pallet** | - | EURO | EURO | EURO | EURO | EURO | EURO | EURO |
| **number of use cycles** | - | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| **cardboard layer** | g | 475 | 475 | 475 | 475 | 475 | 475 | 475 |
| **number of cardboard layers** | | 1 | 1 | 1 | 1 | 5 | 1 | 1 |
| **stretch foil (per pallet) (LDPE)** | g | 176 | 176 | 176 | 176 | 176 | 176 | 176 |
| **pallet configuration** | | | | | | | | |
| **cartons per tray** | pc | 8 | 8 | 10 | 10 | 12 | 10 | 10 |
| **trays / shrink packs per layer** | pc | 11 | 11 | 15 | 15 | 15 | 15 | 15 |
| **layers per pallet** | pc | 4 | 4 | 4 | 4 | 4 | 5 | 5 |
| **cartons per pallet** | pc | 352 | 352 | 600 | 600 | 720 | 750 | 750 |

**Table 13: Packaging specifications for regarded carton systems for the *packaging of JNSD 1000ml*:**

| | | JNSD | | |
|---|---|---|---|---|
| **Packaging components** | **Unit** | **TBA Edge LightCap** | **TBA Edge LightCap Bio-based** | **TPA Square HeliCap 27** |
| **Volume** | ml | 1000 | 1000 | 1000 |
| **Geographic Scope** | - | UK, IRL, BEL, NLD | UK, IRL, BEL, NLD | UK, IRL, BEL, NLD |
| **Chilled / ambient** | - | ambient | ambient | ambient |
| **primary packaging (sum)** | **g** | **33.50** | **33.50** | **39.44** |
| **composite material (sleeve)** | **g** | **30.50** | **30.50** | **35.56** |
| **- liquid packaging board** | g | 23.50 | 23.50 | 25.69 |
| **- LDPE** | g | 5.60 | 2.50 | 7.94 |
| **- Bio-PE** | g | | 3.10 | |
| **- Aluminium** | g | 1.40 | 1.40 | 1.93 |
| **Closure** | **g** | **3.00** | **3.00** | **3.88** |
| **- HDPE** | g | 1.40 | | 3.26 |
| **- LDPE** | g | 1.60 | 1.60 | |
| **- Bio-PE** | g | | 1.40 | |
| **- PP** | g | | | 0.62 |
| **secondary packaging (sum)** | **g** | **122.81** | **122.81** | **134.74** |
| **- tray (corr.cardboard)** | g | 122.81 | 122.81 | 134.74 |
| **tertiary packaging (sum)** | **g** | **25651** | **25651** | **25651** |
| **pallet** | g | 25000 | 25000 | 25000 |
| **type of pallet** | - | EURO | EURO | EURO |
| **number of use cycles** | - | 25 | 25 | 25 |
| **cardboard layer** | g | 475 | 475 | 475 |
| **number of cardboard layers** | | 1 | 1 | 1 |
| **stretch foil (per pallet) (LDPE)** | g | 176 | 176 | 176 |
| **pallet configuration** | | | | |
| **cartons per tray** | pc | 10 | 10 | 8 |
| **trays / shrink packs per layer** | pc | 15 | 15 | 15 |
| **layers per pallet** | pc | 5 | 5 | 6 |
| **cartons per pallet** | pc | 750 | 750 | 720 |

**Table 14: Packaging specifications for regarded carton systems for the *packaging of dairy 189ml-500ml*:**

| | | DAIRY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Packaging components | Unit | TB 200 B | TPA Edge DreamCap | TBA Edge HeliCap 23 | TPA Square DreamCap | TPA Square DreamCap Bio-based | TT Midi O38 | TPA Square StreamCap |
| Volume | ml | 189 | 250 | 250 | 330 | 330 | 330 | 500 |
| Geographic Scope | - | UK | UK, IRL, BEL, NLD | UK, IRL, BEL, NLD | UK, IRL, BEL, NLD | UK, IRL | BEL, NLD | UK, IRL |
| Chilled / ambient | - | chilled | ambient | ambient | ambient | ambient | chilled | ambient |
| **primary packaging (sum)** | **g** | **7.55** | **13.04** | **12.71** | **16.60** | **16.63** | **17.33** | **21.80** |
| **composite material (sleeve)** | **g** | **7.20** | **9.33** | **10.01** | **12.89** | **12.89** | **10.35** | **18.50** |
| - liquid packaging board | g | 5.60 | 6.39 | 6.89 | 8.79 | 8.79 | 8.67 | 13.48 |
| - LDPE | g | 1.60 | 2.27 | 2.53 | 3.17 | 3.17 | 1.68 | 3.81 |
| - Aluminium | g | | 0.67 | 0.59 | 0.93 | 0.93 | | 1.21 |
| **Top** | **g** | | | | | | **3.68** | |
| - HDPE | g | | | | | | 3.68 | |
| **Straw** | **g** | **0.35** | | | | | **3.68** | |
| - PP | g | 0.35 | | | | | 3.68 | |
| **Closure** | **g** | | **3.71** | **2.70** | **3.71** | **3.74** | **3.30** | **3.30** |
| - HDPE | g | | 1.35 | 1.31 | 1.35 | | 3.30 | 1.50 |
| - LDPE | g | | | | | | | |
| - Bio-PE | g | | | | | 1.37 | | |
| - PP | g | | 2.36 | 1.39 | 2.36 | 2.37 | | 1.80 |
| **secondary packaging (sum)** | **g** | **7.20** | **113.63** | **79.96** | **115.08** | **115.08** | **72.13** | **129.72** |
| - tray (corr.cardboard) | g | | 113.63 | 79.96 | 115.08 | 115.08 | 72.13 | 129.72 |
| - shrink pack (LDPE) | g | 7.20 | | | | | | |
| **tertiary packaging (sum)** | **g** | **26601** | **25651** | **25651** | **25651** | **25651** | **28501** | **25651** |
| pallet | g | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 |
| type of pallet | - | EURO | EURO | EURO | EURO | EURO | EURO | EURO |
| number of use cycles | - | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 | 475 | 475 | 475 | 475 |
| number of cardboard layers | | 3 | 1 | 1 | 1 | 1 | 7 | 1 |
| stretch foil (per pallet) (LDPE) | g | 176 | 176 | 176 | 176 | 176 | 176 | 176 |
| **pallet configuration** | | | | | | | | |
| cartons per tray | pc | 18 | 24 | 24 | 24 | 24 | 24 | 24 |
| trays / shrink packs per layer | pc | 24 | 12 | 15 | 12 | 12 | 12 | 8 |
| layers per pallet | pc | 9 | 8 | 8 | 6 | 6 | 7 | 6 |
| cartons per pallet | pc | 3888 | 2304 | 2880 | 1728 | 1728 | 2016 | 1152 |

**Table 15: Packaging specifications for regarded carton systems for the *packaging of cream and yoghurt 120ml-330ml*:**

| | | CREAM | YOGHURT |
|---|---|---|---|
| **Packaging components** | **Unit** | **TT Midi O38** | **TT Huron** |
| Volume | ml | 330 | 250 |
| Geographic Scope | - | UK, IRL | BEL |
| Chilled / ambient | - | chilled | chilled |
| **primary packaging (sum)** | **g** | **17.33** | **11.70** |
| **composite material (sleeve)** | **g** | **10.35** | **9.00** |
| - liquid packaging board | g | 8.67 | 7.50 |
| - LDPE | g | 1.68 | 1.50 |
| - Aluminium | g | | |
| **Top** | **g** | **3.68** | **2.70** |
| - HDPE | g | 3.68 | 2.70 |
| **Closure** | **g** | **3.30** | |
| - HDPE | g | 3.30 | |
| - LDPE | g | | |
| - Bio-PE | g | | |
| - PP | g | | |
| **secondary packaging (sum)** | **g** | **72.13** | **29.80** |
| tray (corr.cardboard) | g | 72.13 | 29.80 |
| **tertiary packaging (sum)** | **g** | **28501** | **30401** |
| pallet | g | 25000 | 25000 |
| type of pallet | - | EURO | EURO |
| number of use cycles | - | 25 | 25 |
| cardboard layer | g | 475 | 475 |
| number of cardboard layers | | 7 | 11 |
| stretch foil (per pallet) (LDPE) | g | 176 | 176 |
| **pallet configuration** | | | |
| cartons per tray | pc | 24 | 6 |
| trays / shrink packs per layer | pc | 12 | 36 |
| layers per pallet | pc | 7 | 11 |
| cartons per pallet | pc | 2016 | 2376 |

**Table 16: Packaging specifications for regarded carton systems for the *packaging of JNSD 200ml-330ml*:**

| | | JNSD | | | | |
|---|---|---|---|---|---|---|
| **Packaging components** | **Unit** | **TWA** | **TPA Edge DreamCap** | **TBA Edge HeliCap 23** | **TPA Square DreamCap** | **TPA Square DreamCap Bio-based** |
| Volume | ml | 200 | 250 | 250 | 330 | 330 |
| Geographic Scope | - | UK, IRL, BEL, NLD | UK, IRL, BEL, NLD | UK, IRL | UK, IRL, BEL, NLD | UK, IRL, BEL, NLD |
| Chilled / ambient | - | ambient | ambient | ambient | ambient | ambient |
| **primary packaging (sum)** | g | **8.70** | **13.04** | **12.71** | **16.60** | **16.63** |
| **composite material (sleeve)** | g | **8.26** | **9.33** | **10.01** | **12.89** | **12.89** |
| - liquid packaging board | g | 5.97 | 6.39 | 6.89 | 8.79 | 8.79 |
| - LDPE | g | 1.78 | 2.27 | 2.53 | 3.17 | 3.17 |
| - Aluminium | g | 0.51 | 0.67 | 0.59 | 0.93 | 0.93 |
| **Top** | g | | | | | |
| - HDPE | | | | | | |
| **Straw incl. foil** | g | **0.44** | | | | |
| **- PP** | g | 0.44 | | | | |
| **Closure** | g | | **3.71** | **2.70** | **3.71** | **3.74** |
| - HDPE | g | | 1.35 | 1.31 | 1.35 | |
| - Bio-PE | g | | | | | 1.37 |
| - PP | g | | 2.36 | 1.39 | 2.36 | 2.37 |
| **secondary packaging (sum)** | g | **86.24** | **113.63** | **79.96** | **115.08** | **115.08** |
| tray (corr.cardboard) | g | 86.24 | 113.63 | 79.96 | 115.08 | 115.08 |
| **tertiary packaging (sum)** | g | **25651** | **25651** | **25651** | **25651** | **25651** |
| pallet | g | 25000 | 25000 | 25000 | 25000 | 25000 |
| type of pallet | - | EURO | EURO | EURO | EURO | EURO |
| number of use cycles | - | 25 | 25 | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 | 475 | 475 |
| number of cardboard layers | | 1 | 1 | 1 | 1 | 1 |
| stretch foil (per pallet) (LDPE) | g | 176 | 176 | 176 | 176 | 176 |
| **pallet configuration** | | | | | | |
| cartons per tray | pc | 12 | 24 | 24 | 24 | 24 |
| trays / shrink packs per layer | pc | 44 | 12 | 15 | 12 | 12 |
| layers per pallet | pc | 7 | 8 | 8 | 6 | 6 |
| cartons per pallet | pc | 3696 | 2304 | 2880 | 1728 | 1728 |

**Table 17: Packaging specifications for regarded carton systems for the *packaging of water 330ml-500ml*:**

| | | WATER | | | | | |
|---|---|---|---|---|---|---|---|
| Packaging components | Unit | TPA Square DreamCap | TPA Square DreamCap Bio-based | TT Midi O38 | TPA Square StreamCap | TT Midi Eifel O38 | TT Midi Eifel O38 Bio-based |
| Volume | ml | 330 | 330 | 330 | 500 | 500 | 500 |
| Geographic Scope | - | NLD | NLD | NLD | UK | UK | UK |
| Chilled / ambient | - | ambient | ambient | ambient | ambient | ambient | ambient |
| **primary packaging (sum)** | **g** | **16.60** | **16.63** | **17.33** | **21.80** | **21.74** | **21.76** |
| **composite material (sleeve)** | **g** | **12.89** | **12.89** | **10.35** | **18.50** | **14.96** | **14.96** |
| - liquid packaging board | g | 8.79 | 8.79 | 8.67 | 13.48 | 11.56 | 11.56 |
| - LDPE | g | 3.17 | 3.17 | 1.68 | 3.81 | 2.67 | 1.30 |
| - Bio-PE | g | | | | | | 1.37 |
| - Aluminium | g | 0.93 | 0.93 | | 1.21 | 0.73 | 0.73 |
| **Top** | **g** | | | **3.68** | | **3.89** | **3.90** |
| - HDPE | g | | | 3.68 | | 3.89 | 0.47 |
| - Bio-PE | g | | | | | | 3.43 |
| **Straw incl. foil** | **g** | | | | | | |
| - PP | g | | | | | | |
| **Closure** | **g** | **3.71** | **3.74** | **3.30** | **3.30** | **2.90** | **2.90** |
| - HDPE | g | 1.35 | | 3.30 | 1.50 | 2.90 | |
| - Bio-PE | g | | 1.37 | | | | 2.90 |
| - PP | g | 2.36 | 2.37 | | 1.80 | | |
| **secondary packaging (sum)** | **g** | **115.08** | **115.08** | **72.13** | **129.72** | **110.54** | **110.54** |
| - tray (corr.cardboard) | g | 115.08 | 115.08 | 72.13 | 129.72 | 110.54 | 110.54 |
| **tertiary packaging (sum)** | **g** | **25651** | **25651** | **28501** | **25651** | **26920** | **26920** |
| pallet | g | 25000 | 25000 | 25000 | 25000 | 25000 | 25000 |
| type of pallet | - | EURO | EURO | EURO | EURO | EURO | EURO |
| number of use cycles | - | 25 | 25 | 25 | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 | 475 | 350 | 350 |
| number of cardboard layers | | 1 | 1 | 7 | 1 | 5 | 5 |
| stretch foil (per pallet) (LDPE) | g | 176 | 176 | 176 | 176 | 170 | 170 |
| **pallet configuration** | | | | | | | |
| cartons per tray | pc | 24 | 24 | 24 | 24 | 12 | 12 |
| trays / shrink packs per layer | pc | 12 | 12 | 12 | 8 | 19 | 19 |
| layers per pallet | pc | 6 | 6 | 7 | 6 | 5 | 5 |
| cartons per pallet | pc | 1728 | 1728 | 2016 | 1152 | 1140 | 1140 |

### 2.2.2 Specifications of alternative packaging systems

**Table 18: Packaging specifications for regarded alternative systems in the segment *Dairy 1000ml-2000ml*:**

| | | DAIRY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Packing components | Unit | HDPE bottle 11 | HDPE bottle 1 | HDPE bottle 2 | HDPE bottle 3 | HDPE bottle 4 | PET bottle 1 | PET bottle 2 |
| Volume | ml | 2000 | 1136 | 1000 | 1000 | 1000 | 1000 | 1000 |
| Geographic scope | - | IRL | UK | IRL, NLD | NLD | BEL | NLD | BEL, NLD |
| Chilled / ambient | - | chilled | chilled | chilled | ambient | ambient | chilled | ambient |
| Clear / opaque | - | clear | clear | clear | clear | opaque | opaque | opaque |
| **primary packaging (sum)** | g | **32.75** | **24.80** | **34.03** | **37.62** | **37.52** | **30.79** | **28.33** |
| **Bottle (sum)** | g | **28.61** | **22.29** | **29.57** | **31.26** | **33.64** | **27.92** | **24.44** |
| -virgin PET | g | | | | | | | 19.97 |
| - recycled PET (11.7%) | g | | | | | | | 2.86 |
| - HDPE | g | 28.61 | 22.29 | 29.57 | 31.26 | 31.42 | 27.47 | |
| - TiO2 (1.6%) | g | | | | | 0.54 | 0.45 | 0.39 |
| - Carbon black (5%) | g | | | | | 1.68 | | 1.22 |
| **Label** | g | **1.41** | **0.73** | **0.96** | **1.94** | **1.62** | **0.64** | **0.96** |
| - paper | g | | | 0.96 | 1.94 | 1.62 | | |
| - PP | g | | | | | | | 0.96 |
| - HDPE | g | 1.41 | 0.73 | | | | 0.64 | |
| **closure** | g | **2.73** | **1.51** | **3.50** | **4.10** | **2.07** | **2.23** | **2.93** |
| - HDPE | g | 2.73 | 1.51 | | 4.10 | | 2.23 | |
| - LDPE | g | | | 3.50 | | 2.07 | | |
| - PP | g | | | | | | | 2.93 |
| **pull tap** | g | | **0.28** | | **0.32** | **0.20** | | |
| - LDPE | g | | 0.14 | | | | | |
| - Aluminium | g | | 0.14 | | 0.32 | 0.20 | | |
| **secondary packaging (sum)** | g | | | | **13.00** | **12.57** | **57.13** | **13.80** |
| - shrink pack (LDPE) | g | | | | 13.00 | 12.57 | 20.32 | 13.80 |
| - tray (cardboard) | g | | | | | | 36.81 | |
| **tertiary packaging (sum)** | g | **38000** | **38000** | **38000** | **24721** | **24246** | **24246** | **23771** |
| roll container | g | 38000 | 38000 | 38000 | | | | |
| pallet | g | | | | 22000 | 22000 | 22000 | 22000 |
| type of pallet | - | | | | EURO | EURO | EURO | EURO |
| number of use cycles | | 200 | 200 | 200 | 25 | 25 | 25 | 25 |
| cardboard layer | g | | | | 475 | 475 | 475 | 475 |
| number of cardboard layers | | | | | 5 | 4 | 4 | 3 |
| stretch foil (per pallet) (LDPE) | g | | | | 346 | 346 | 346 | 346 |
| **pallet configuration** | | | | | | | | |
| Bottles per pack | pc | | | | 6 | 6 | 12 | 6 |
| packs per layer | pc | | | | 21 | 25 | 13 | 25 |
| layers per pallet | pc | | | | 6 | 5 | 5 | 4 |
| bottles per pallet/roll container | pc | 80 | 140 | 140 | 756 | 750 | 780 | 600 |

**Table 19: Packaging specifications for regarded alternative systems in the segment *JNSD 1000ml*:**

| | | JNSD | |
|---|---|---|---|
| Packing components | Unit | Glass bottle 1 | PET bottle 3 |
| Volume | ml | 1000 | 1000 |
| Geographic scope | - | BEL, NLD | BEL, NLD |
| Chilled / ambient | - | ambient | ambient |
| Clear / opaque | - | clear | clear |
| primary packaging (sum) | g | 375.38 | 32.20 |
| Bottle (sum) | g | 368.19 | 28.04 |
| -virgin PET | g | | 22.52 |
| - recycled PET (11.7%) | g | | 3.28 |
| - HDPE | g | | |
| - Glass | g | 368.19 | |
| - PA (8%) | g | | 2.24 |
| Label | g | 2.10 | 1.02 |
| - paper | g | 2.10 | |
| - PP | g | | 1.02 |
| closure | g | 5.01 | 3.15 |
| - HDPE | g | | 3.15 |
| - Tin plate | g | 5.01 | |
| secondary packaging (sum) | g | 65.72 | 12.10 |
| - shrink pack (LDPE) | g | 13.98 | 12.10 |
| - tray (cardboard) | g | 51.74 | |
| tertiary packaging (sum) | g | 24246 | 24246 |
| pallet | g | 22000 | 22000 |
| type of pallet | - | EURO | EURO |
| number of use cycles | | 25 | 25 |
| cardboard layer | g | 475 | 475 |
| number of cardboard layers | | 4 | 4 |
| stretch foil (per pallet) (LDPE) | g | 346 | 346 |
| pallet configuration | | | |
| Bottles per pack | pc | 6 | 6 |
| packs per layer | pc | 21 | 26 |
| layers per pallet | pc | 5 | 5 |
| bottles per pallet | pc | 630 | 780 |

**Table 20: Packaging specifications for regarded alternative systems in the segment *dairy 189ml-500ml; <330mm*:**

| | | DAIRY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Packing components | Unit | HDPE bottle 10 | PP cup 3 | Glass bottle 3 | HDPE bottle 5 | HDPE bottle 6 | HDPE bottle 7 | PET bottle 12 |
| Volume | ml | 189 | 220 | 250 | 250 | 250 | 250 | 300 |
| Geographic scope | - | UK | UK | UK | UK, IRL | UK, IRL | BEL, NLD | BEL, NLD |
| Chilled / ambient | - | chilled | chilled | ambient | ambient | ambient | ambient | ambient |
| Clear / opaque | - | clear | opaque | clear | opaque | opaque | opaque | clear |
| **primary packaging (sum)** | **g** | **12.87** | **17.56** | **197.56** | **23.75** | **25.64** | **17.41** | **18.26** |
| **Bottle (sum)** | **g** | **10.81** | **12.69** | **192.17** | **19.42** | **21.22** | **13.40** | **13.72** |
| - virgin PET | g | | | | | | | 12.11 |
| - recycled PET (11.7%) | g | | | | | | | 1.61 |
| - HDPE | g | 10.81 | | | 18.14 | 19.82 | 12.52 | |
| - PP | g | | 12.49 | | | | | |
| - TiO2 (1.6%) | g | | 0.20 | | 0.31 | 0.34 | 0.21 | |
| - carbon black (5%) | g | | | | 0.97 | 1.06 | 0.67 | |
| - glass | g | | | 192.17 | | | | |
| **Label** | **g** | **0.30** | | **1.18** | **1.19** | **1.28** | **0.75** | **1.65** |
| - paper | g | | | | | 0.09 | 0.75 | |
| - HDPE | g | | | 0.59 | | 1.19 | | |
| - PET | g | | | 0.59 | 1.19 | | | 1.65 |
| - PP | g | 0.30 | | | | | | |
| - carbon black | g | | | | | | | 0.43 |
| **closure** | **g** | **1.50** | **3.68** | **4.21** | **2.97** | **2.97** | **2.96** | **2.46** |
| - HDPE | g | 1.50 | | | | | | 2.46 |
| - PP | g | | 3.68 | | 2.97 | 2.97 | 2.96 | |
| **pull tap** | **g** | **0.26** | **0.59** | | **0.17** | **0.17** | **0.30** | |
| - LDPE | g | 0.12 | | | | | | |
| - aluminium | g | 0.14 | 0.59 | | 0.17 | 0.17 | 0.30 | |
| - tin plate | g | | | 4.21 | | | | |
| **straw** | **g** | | **0.60** | | | | | |
| - PP | g | | 0.60 | | | | | |
| **secondary packaging (sum)** | **g** | **16.12** | **46.06** | **51.00** | **53.63** | **21.24** | **5.09** | **53.00** |
| - shrink pack (LDPE) | g | 16.12 | | | 15.51 | | 5.09 | |
| - tray (cardboard) | g | | 46.06 | 51.00 | 38.12 | 21.24 | | 53.00 |
| **tertiary packaging (sum)** | **g** | **38000** | **27571** | **24721** | **26146** | **26146** | **26621** | **25671** |
| roll container | g | 38000 | | | | | | |
| pallet | g | | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 |
| type of pallet | - | | EURO | EURO | EURO | EURO | EURO | EURO |
| number of use cycles | | 200 | 25 | 25 | 25 | 25 | 25 | 25 |
| cardboard layer | g | | 475 | 475 | 475 | 475 | 475 | 475 |
| number of cardboard layers | | | 11 | 5 | 8 | 8 | 9 | 7 |
| stretch foil (per pallet) (LDPE) | g | | 346 | 346 | 346 | 346 | 346 | 346 |
| **pallet configuration** | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Bottles per pack** | pc | | 10 | 8 | 16 | 3 | 6 | 12 |
| **packs per layer** | pc | | 15 | 27 | 13 | 72 | 49 | 22 |
| **layers per pallet** | pc | | 12 | 6 | 9 | 9 | 10 | 8 |
| **bottles per pallet/roll container** | pc | 360 | 1800 | 1296 | 1872 | 1944 | 2940 | 2112 |

**Table 21: Packaging specifications for regarded alternative systems in the segment *dairy 189ml-500ml; >=330ml*:**

| | | DAIRY | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Packing components | Unit | HDPE bottle 8 | PET bottle 13 | PET bottle 14 | PP cup 1 | PET bottle 15 | PET bottle 16 | HDPE bottle 9 |
| Volume | ml | 330 | 330 | 330 | 250 | 475 | 500 | 500 |
| Geographic scope | - | UK, IRL | UK, IRL | BEL, NLD | BEL, NLD | UK | IRL | UK |
| Chilled / ambient | - | ambient | ambient | chilled | chilled | ambient | ambient | ambient |
| Clear / opaque | - | opaque | opaque | clear | opaque | opaque | opaque | opaque |
| **primary packaging (sum)** | g | **30.61** | **32.03** | **21.65** | **11.56** | **40.00** | **41.28** | **31.51** |
| **Bottle (sum)** | g | **25.53** | **26.39** | **17.11** | **7.55** | **34.02** | **34.75** | **26.30** |
| - virgin PET | g | | 20.77 | 15.11 | | 26.77 | 27.35 | |
| -recycled PET (11.7%) | g | | 3.09 | 2.00 | | 3.98 | 4.07 | |
| - HDPE | g | 23.85 | | | | | | 24.56 |
| - PP | g | | | | 7.43 | | | |
| - TiO2 (1.6%) | g | 0.41 | 0.42 | | 0.12 | 0.54 | 0.56 | 0.42 |
| - carbon black (5%) | g | 1.28 | | | | | | 1.32 |
| - PA (8%) | g | | 2.11 | | | 2.72 | 2.78 | |
| **Label** | g | **1.94** | **1.90** | **1.58** | **1.37** | **2.10** | **2.55** | **2.03** |
| - paper | g | | | | | 0.09 | | |
| - HDPE | g | | | | 1.37 | | | 2.03 |
| - PET | g | 1.94 | 1.90 | 1.58 | | 2.01 | 2.55 | |
| **closure** | g | **2.98** | **3.74** | **2.97** | **2.14** | **3.88** | **3.98** | **3.01** |
| - HDPE | g | | 3.74 | 2.97 | | 3.88 | 3.98 | |
| - PP | g | 2.98 | | | 2.14 | | | 3.01 |
| **pull tap** | g | **0.16** | | | **0.50** | | | **0.17** |
| - Aluminium | g | 0.16 | | | 0.50 | | | 0.17 |
| **secondary packaging (sum)** | g | **55.13** | **35.30** | **117.25** | **61.42** | **48.50** | **48.50** | **48.50** |
| - shrink pack (LDPE) | g | 17.01 | 17.01 | | 12.86 | 15.48 | 15.48 | 15.48 |
| - tray (cardboard) | g | 38.12 | 18.29 | 117.25 | 48.56 | 33.02 | 33.02 | 33.02 |
| **tertiary packaging (sum)** | g | **25196** | **25196** | **25671** | **26621** | **25196** | **25196** | **25196** |
| pallet | g | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 | 22000 |
| type of pallet | - | EURO | EURO | EURO | EURO | EURO | EURO | EURO |
| number of use cycles | | 25 | 25 | 25 | 25 | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 | 475 | 475 | 475 | 475 |
| number of cardboard layers | | 6 | 6 | 7 | 9 | 6 | 6 | 6 |
| stretch foil (per pallet) (LDPE) | g | 346 | 346 | 346 | 346 | 346 | 346 | 346 |
| **pallet configuration** | | | | | | | | |
| Bottles per pack | pc | 16 | 16 | 20 | 10 | 12 | 12 | 12 |
| packs per layer | pc | 13 | 13 | 10 | 15 | 13 | 13 | 13 |
| layers per pallet | pc | 7 | 7 | 8 | 10 | 7 | 7 | 7 |
| bottles per pallet | pc | 1456 | 1456 | 1600 | 1500 | 1092 | 1092 | 1092 |

**Table 22: Packaging specifications for regarded alternative systems in the segment *cream and yoghurt 120ml-330ml*:**

| | | YOGHURT | | CREAM |
|---|---|---|---|---|
| Packing components | Unit | PP cup 4 | PP cup 5 | PP cup 2 |
| Volume | ml | 120 | 144 | 300 |
| Geographic scope | - | BEL | BEL | UK, IRL |
| Chilled / ambient | - | chilled | chilled | chilled |
| Clear / opaque | - | opaque | opaque | clear |
| primary packaging (sum) | g | **8.43** | **9.20** | **12.83** |
| Bottle (sum) | g | **5.13** | **8.33** | **9.54** |
| - PP | g | 5.05 | 8.20 | 9.54 |
| - TiO2 (1.6%) | g | 0.08 | 0.13 | |
| Label | g | **2.44** | | - |
| - paper | g | 2.44 | | |
| closure | g | | | **2.72** |
| - PP | g | | | 2.72 |
| pull tap | g | 0.86 | 0.87 | 0.57 |
| - LDPE | g | | | 0.57 |
| - Aluminium | g | 0.86 | 0.87 | |
| secondary packaging (sum) | g | **48.14** | **49.65** | **35.79** |
| - shrink pack (LDPE) | g | | | 8.83 |
| - tray (cardboard) | g | 48.14 | 49.65 | 26.96 |
| tertiary packaging (sum) | g | **31371** | **31371** | **38000** |
| roll container | g | | | 38000 |
| pallet | g | 22000 | 22000 | |
| type of pallet | - | EURO | EURO | |
| number of use cycles | | 25 | 25 | 200 |
| cardboard layer | g | 475 | 475 | |
| number of cardboard layers | | 19 | 19 | |
| stretch foil (per pallet) (LDPE) | g | 346 | 346 | |
| pallet configuration | | | | |
| Bottles per pack | pc | 6 | 6 | |
| crates per layer | pc | 16 | 16 | |
| layers per pallet | pc | 20 | 20 | |
| bottles per pallet/roll container | pc | 1920 | 1920 | 192 |

**Table 23: Packaging specifications for regarded alternative systems in the segment *JNSD 200ml-330ml; <330mm*:**

| | | JNSD | | | | |
|---|---|---|---|---|---|---|
| Packing components | Unit | SUP 1 | PET bottle 4 | PET bottle 5 | PET bottle 6 | Glass bottle 2 |
| Volume | ml | 200 | 200 | 250 | 250 | 250 |
| Geographic scope | - | UK, IRL, BEL, NLD | UK, IRL | UK, IRL, BEL, NLD | BEL, NLD | BEL, NLD |
| Chilled / ambient | - | ambient | ambient | chilled | ambient | ambient |
| Clear / opaque | - | - | opaque | clear | clear | clear |
| primary packaging (sum) | g | 4.09 | 19.16 | 20.85 | 24.66 | 156.48 |
| Bottle (sum) | g | 3.79 | 13.87 | 17.42 | 16.09 | 151.86 |
| - virgin PET | g | 0.59 | 10.92 | 8.71 | 12.92 | |
| -recycled PET ([1]11.7% / [2]50%) | g | | 1.62[1] | 8.71[2] | 1.88[1] | |
| - HDPE | g | 2.44 | | | | |
| - glass | g | | | | | 151.86 |
| - Aluminium | g | 0.76 | | | | |
| - TiO2 (1.6%) | g | | 0.22 | | | |
| - PA (8%) | g | | 1.11 | | 1.29 | |
| Label | g | | 0.18 | 0.81 | 0.32 | 0.51 |
| - paper | g | | | 0.15 | | 0.51 |
| - PP | g | | 0.18 | | | |
| - HDPE | g | | | 0.66 | 0.32 | |
| closure | g | | 5.11 | 2.62 | 8.25 | 4.12 |
| - HDPE | g | | 4.19 | 2.62 | 6.17 | |
| - PP | g | | 0.92 | | 2.09 | |
| - Tin plate | g | | | | | 4.12 |
| straw incl. foil | | | | | | |
| - PP | g | 0.3 | | | | |
| secondary packaging (sum) | g | 88.00 | 26.94 | 23.04 | 5.98 | 34.46 |
| - shrink pack (LDPE) | g | | | 6.94 | 5.98 | 9.98 |
| - tray (cardboard) | g | 88.00 | 26.94 | 16.13 | | 24.48 |
| tertiary packaging (sum) | g | 26146 | 26146 | 26146 | 25671 | 26146 |
| pallet | g | 22000 | 22000 | 22000 | 22000 | 22000 |
| type of pallet | - | EURO | EURO | EURO | EURO | EURO |
| number of use cycles | | 25 | 25 | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 | 475 | 475 |
| number of cardboard layers | | 8 | 8 | 8 | 7 | 8 |
| stretch foil (per pallet) (LDPE) | g | 346 | 346 | 346 | 346 | 346 |
| pallet configuration | | | | | | |
| Bottles per pack | pc | 10 | 8 | 8 | 6 | 12 |
| crates per layer | pc | 27 | 44 | 35 | 49 | 21 |
| layers per pallet | pc | 9 | 9 | 9 | 8 | 9 |
| bottles per pallet | pc | 2430 | 3168 | 2520 | 2352 | 2268 |

**Table 24: Packaging specifications for regarded alternative systems in the segment *JNSD 200ml-330ml; >=330mm)*:**

| | | JNSD | | | |
|---|---|---|---|---|---|
| Packing components | Unit | PET bottle 7 | PET bottle 8 | PET bottle 9 | PET bottle 10 |
| Volume | ml | 330 | 330 | 330 | 330 |
| Geographic scope | - | UK, IRL | NLD | BEL | BEL, NLD |
| Chilled / ambient | - | chilled | ambient | ambient | ambient |
| Clear / opaque | - | clear | clear | clear | clear |
| **primary packaging (sum)** | g | **23.94** | **23.52** | **23.52** | **22.18** |
| **Bottle (sum)** | g | **20.56** | **18.57** | **18.57** | **18.16** |
| - virgin PET | g | 18.15 | 14.91 | 14.91 | 14.58 |
| -recycled PET (11.7%) | | 2.41 | 2.17 | 2.17 | 2.12 |
| - PA (8%) | % | | 1.49 | 1.49 | 1.45 |
| **Label** | g | **0.65** | **1.03** | **1.03** | **0.81** |
| - paper | g | | 1.03 | 1.03 | |
| - PP | g | | | | |
| - HDPE | g | 0.65 | | | 0.81 |
| **closure** | g | **2.73** | **3.93** | **3.93** | **3.21** |
| - HDPE | g | 2.73 | 3.93 | 3.93 | 3.21 |
| **secondary packaging (sum)** | g | **24.13** | **7.07** | **7.07** | **5.30** |
| - shrink pack (LDPE) | g | 8.01 | 7.07 | 7.07 | 5.30 |
| - tray (cardboard) | g | 16.13 | | | |
| **tertiary packaging (sum)** | g | **25196** | **25671** | **25671** | **25196** |
| pallet | g | 22000 | 22000 | 22000 | 22000 |
| type of pallet | - | EURO | EURO | EURO | EURO |
| number of use cycles | | 25 | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 | 475 |
| number of cardboard layers | | 6 | 7 | 7 | 6 |
| stretch foil (per pallet) (LDPE) | g | 346 | 346 | 346 | 346 |
| **pallet configuration** | | | | | |
| Bottles per pack | pc | 8 | 6 | 6 | 4 |
| crates per layer | pc | 35 | 36 | 36 | 60 |
| layers per pallet | pc | 7 | 8 | 8 | 7 |
| bottles per pallet | pc | 1960 | 1728 | 1728 | 1680 |

**Table 25: Packaging specifications for regarded alternative systems in the segment *JNSD and water (330mL-500mL)*:**

| | | WATER | | |
|---|---|---|---|---|
| Packing components | Unit | PET bottle 11 | PET bottle 17 | PET bottle 18 |
| Volume | ml | 330 | 500 | 500 |
| Geographic scope | - | NLD | UK | UK |
| Chilled / ambient | - | ambient | ambient | ambient |
| Clear / opaque | - | clear | clear | clear |
| primary packaging (sum) | g | 18.53 | 11.21 | 18.21 |
| Bottle (sum) | g | 12.58 | 9.63 | 15.74 |
| - virgin PET | g | 11.11 | 8.50 | 13.90 |
| -recycled PET (11.7%) | | 1.47 | 1.13 | 1.84 |
| Label | g | 0.57 | 0.20 | 0.38 |
| - paper | g | 0.57 | | |
| - PP | g | | 0.20 | |
| - HDPE | g | | | 0.38 |
| closure | g | 5.39 | 1.38 | 2.09 |
| - HDPE | g | 5.39 | 1.38 | 2.09 |
| secondary packaging (sum) | g | 11.53 | 8.84 | 7.93 |
| - shrink pack (LDPE) | g | 11.53 | 8.84 | 7.93 |
| - tray (cardboard) | g | | | |
| tertiary packaging (sum) | g | 25196 | 25196 | 24721 |
| pallet | g | 22000 | 22000 | 22000 |
| type of pallet | - | EURO | EURO | EURO |
| number of use cycles | | 25 | 25 | 25 |
| cardboard layer | g | 475 | 475 | 475 |
| number of cardboard layers | | 6 | 6 | 5 |
| stretch foil (per pallet) (LDPE) | g | 346 | 346 | 346 |
| pallet configuration | | | | |
| Bottles per pack | pc | 12 | 6 | 6 |
| crates per layer | pc | 21 | 31 | 43 |
| layers per pallet | pc | 7 | 7 | 6 |
| bottles per pallet | pc | 1764 | 1302 | 1548 |

## 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 markets UK, Ireland, Belgium and Netherlands. The applied recycling quotas are either based on published quotas or on quotas provided by Tetra Pak. The most up-to-date data at the time of modelling and calculation is used. The recycling quota represents the actual amount of material undergoing a recycling process after sorting took place. The applied quotas and the related references are given in Table 26. In case of the beverage cartons in the UK the recycling quota communicated by ACE has been corrected to a lower value by

Tetra Pak. In case of beverage cartons in Belgium, the recycling quota communicated by ACA for 2016 is extremely high due to the inclusion of pilot projects for separate collection of beverage cartons [FOST 2017]. It is assumed by Tetra Pak that these quotas will not stay that high in the next years. Therefore following a conservative approach from the view of the beverage cartons, a slightly lower quota is applied in this study. It is based on the recycling quotas of 2014 and 2015 as well.

**Table 26: Applied recycling quotas for beverage cartons, plastic and glass bottles in UK, Ireland, Belgium and Netherlands:**

| Country | Packaging system | Recycling quota | Reference year | Source |
|---|---|---|---|---|
| UK | Beverage carton | confidential[3] | 2016 | [Tetra Pak 2018] |
| | Plastic bottles | 57% | 2016 | [RECOUP 2017] |
| | Glass bottles | 67%[1] | 2014 | [Eurostat 2017] |
| | Stand Up Pouch | 0% | 2011 | [WRAP 2011] |
| Ireland | Beverage carton | confidential[3] | 2016 | [ACE 2018] |
| | Plastic bottles | 40%[2] | 2013 | [epa 2016] |
| | Glass bottles | 80%[1] | 2013 | [Eurostat 2017] |
| | Stand Up Pouch | 0% | 2011 | [WRAP 2011] |
| Belgium | Beverage carton | 90% | 2014-16 | [ACE 2018, Tetra Pak 2018] |
| | Plastic bottles | 75% | 2016 | [Fost 2017] |
| | Glass bottles | 100%[1] | 2016 | [Fost 2017] |
| | Stand Up Pouch | 0% | 2011 | [WRAP 2011] |
| Netherlands | Beverage carton | 37% | 2016 | [ACE 2018] |
| | Plastic bottles | 51%[2] | 2015 | [afvalfonds verpakkingen 2016] |
| | Glass bottles | 83%[1] | 2012 | [afvalfonds verpakkingen 2016] |
| | Stand Up Pouch | 0% | 2011 | [WRAP 2011] |

[1] all glass packaging [2] all plastic packaging cartons [3] country specific recycling rate for beverage cartons in the UK and Ireland has been classified as confidential by Tetra Pak. The actual rate used in the model has been disclosed to the review panel.

The remaining part of the post-consumer packaging waste is modelled and calculated according to the average rates for landfilling and incineration in each of the markets analysed. The applied quotas and the related references are given in Table 27.

**Table 27: Applied average rates for landfilling and incineration in in UK, Ireland, Belgium and Netherlands**

| Country | MSWI/Landfill | Quota | Reference year | Source |
|---|---|---|---|---|
| **UK** | MSWI | 58.17% | 2015 | calculated based on [Eurostat 2017] |
| | Landfill | 41.83% | | |
| **Ireland** | MSWI | 29.35% | 2012 | |
| | Landfill | 70.65% | | |
| **Belgium** | MSWI | 97.94% | 2015 | |
| | Landfill | 2.06% | | |
| **Netherlands** | MSWI | 97.08% | 2015 | |
| | Landfill | 2.92% | | |

The following simplified flow charts Figure 11 - Figure 14 illustrate the applied end-of-life model of beverage cartons, PET and HDPE bottles, glass bottles as well as SUPs separated by country. The percentage going into the recycling path in each flowchart corresponds to the recycling quotas in Table 26.

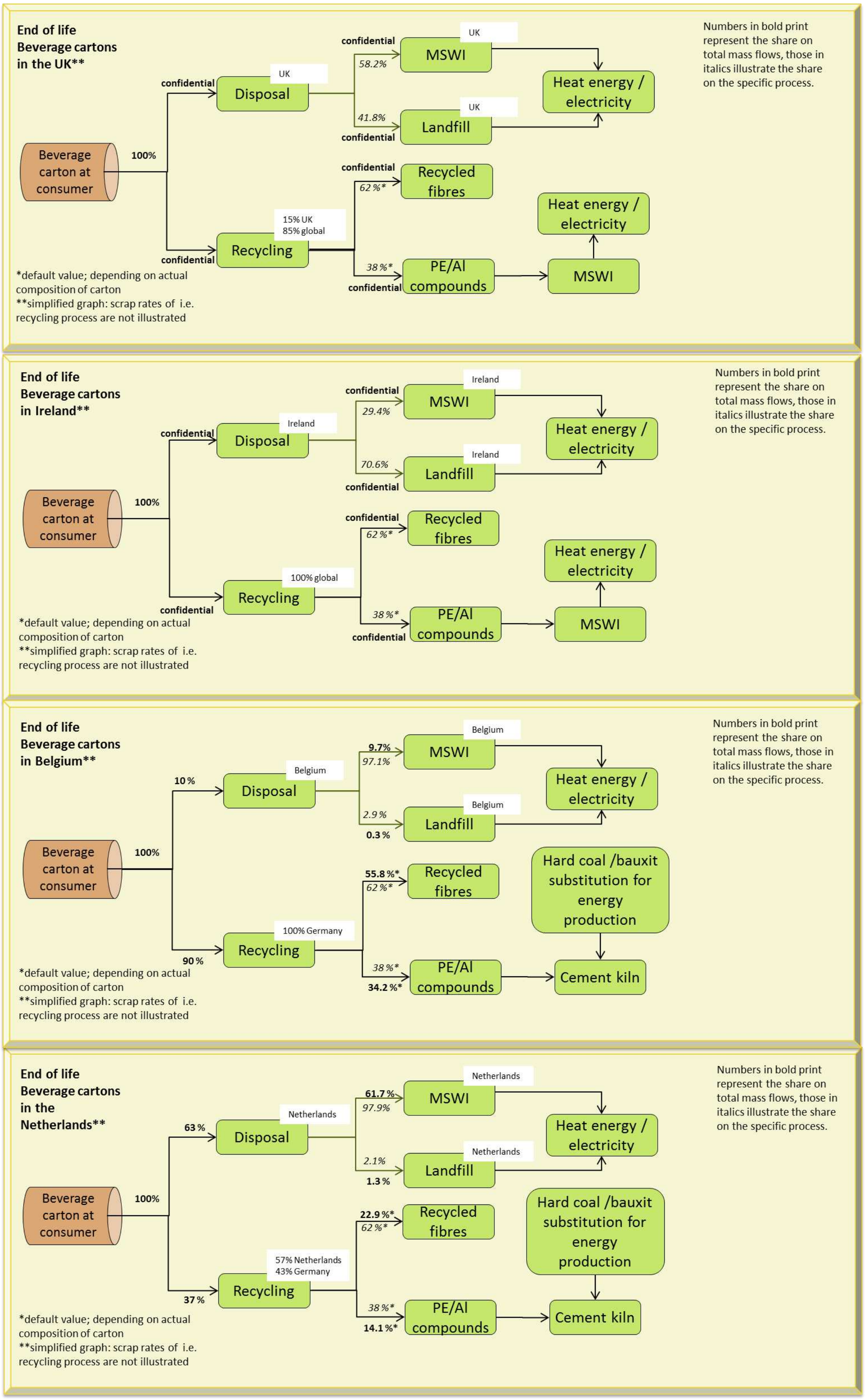



**Figure 11:** Applied average end-of-life quotas for beverage cartons in the UK, Ireland, Belgium and the Netherlands. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

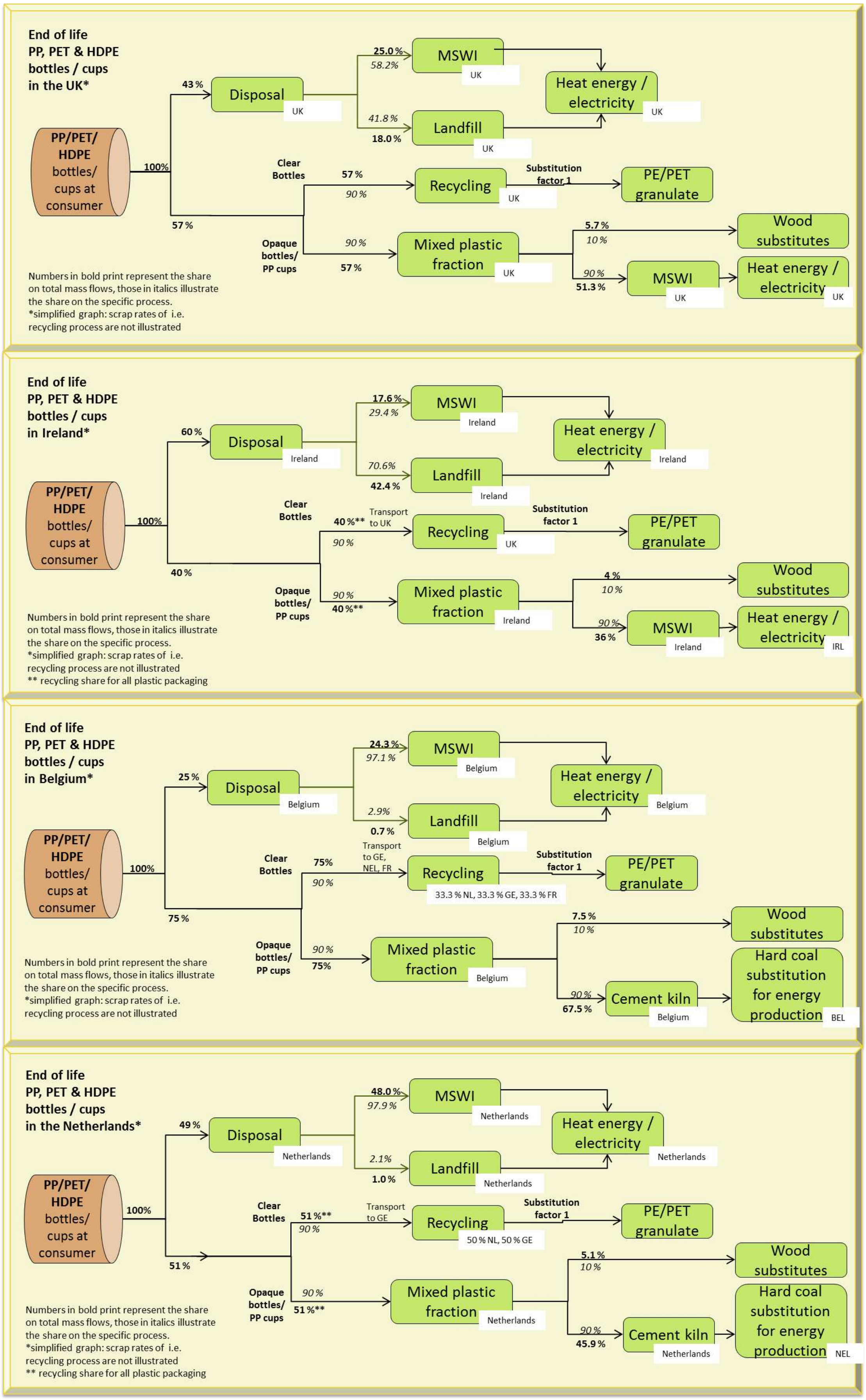



**Figure 12:** Applied average end-of-life quotas for PP, PET and HDPE bottles/cups in the UK, Ireland, Belgium and the Netherlands. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

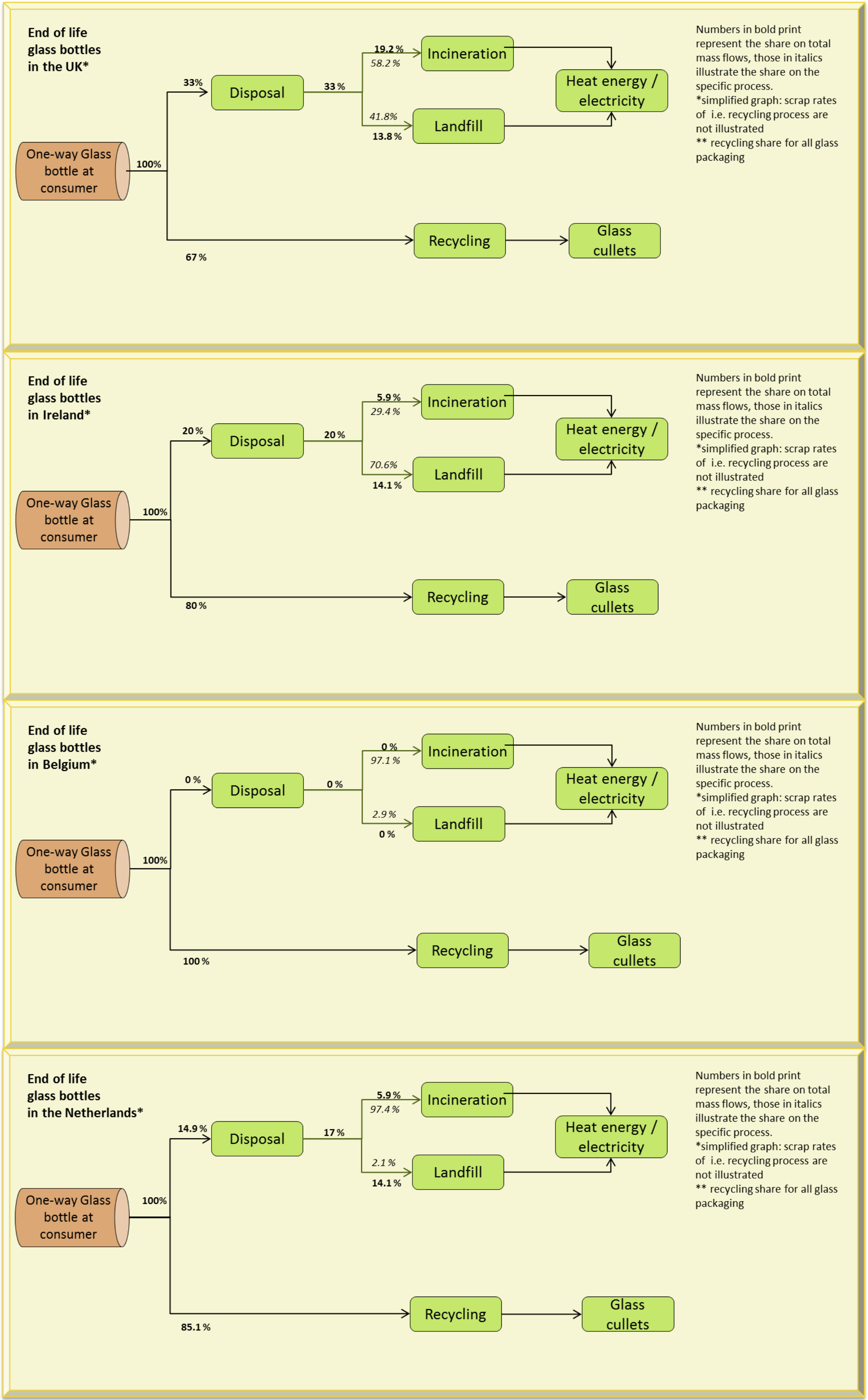



**Figure 13:** Applied average end-of-life quotas for glass bottles in the UK, Ireland, Belgium and the Netherlands. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

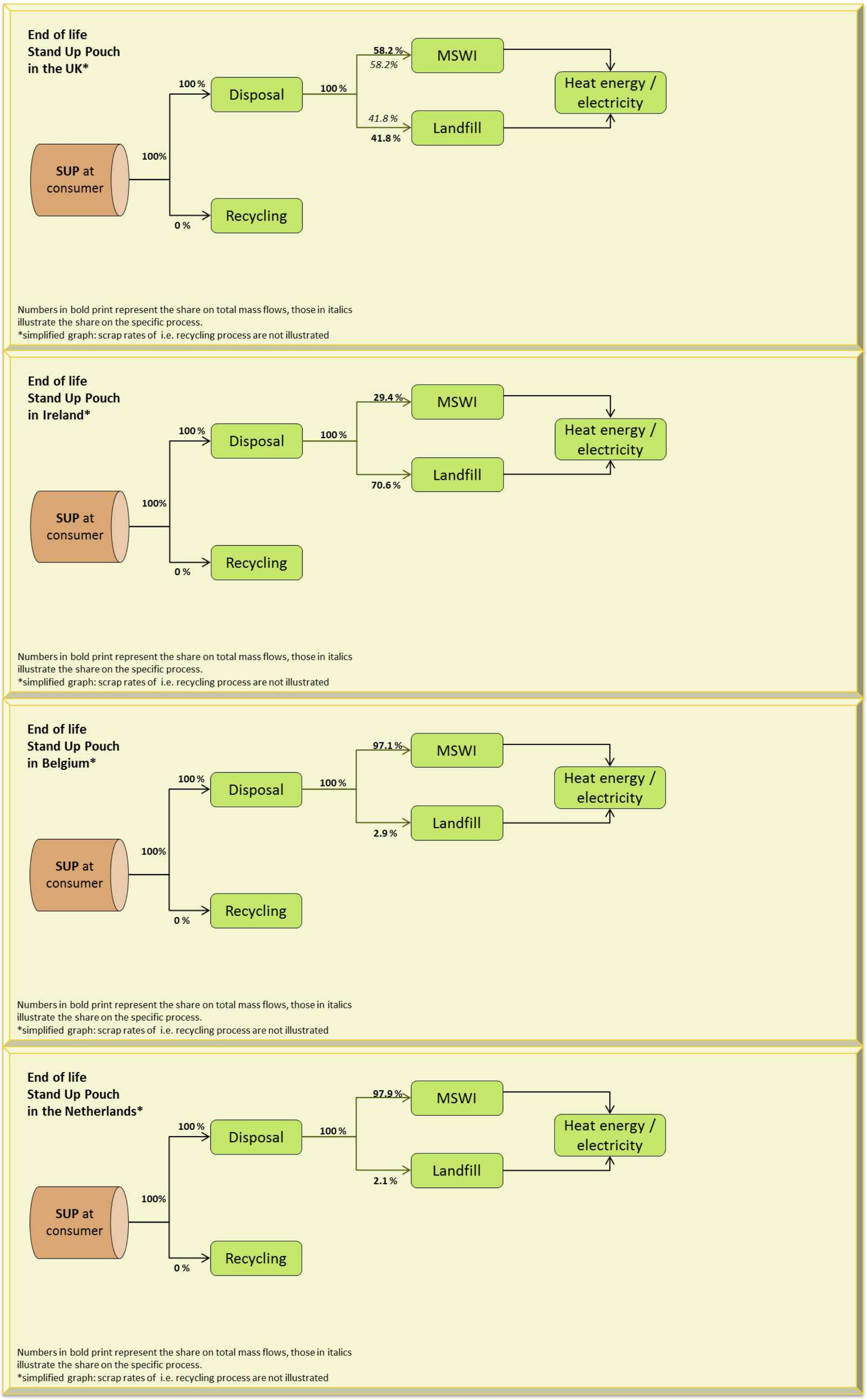



**Figure 14:** Applied average end-of-life quotas for stand up pouches the UK, Ireland, Belgium and the Netherlands. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

## 2.4 Scenarios

### 2.4.1 Base scenarios

For each of the studied packaging systems a base scenario for the British, Irish, Belgian and Dutch market is defined, which is intended to reflect the most realistic situation under the described scope. These base scenarios are clustered into groups within the same beverage segment and volume group. In these base scenarios, the allocation factor applied for open-loop-recycling is 50%.

### 2.4.2 Sensitivity analysis with focus on the allocation factor

In the base scenarios of this study, open-loop allocation is performed with an allocation factor of 50%. Following the ISO norm's recommendation on value choices, one sensitivity analysis is conducted in this study to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied in a 'sensitivity analysis 100'.

### 2.4.3 Sensitivity analysis regarding bio-based plastics in HDPE bottles

The study includes beverage cartons containing bio-based plastic materials. In order to take also bio-based material in plastic bottles into account a sensitivity analysis is performed for the packaging systems listed in Table 28. In these analyses, the allocation factor applied for open-loop-recycling is 50%.

**Table 28: Sensitivity scenarios: bio-based PE in HDPE bottles**

| Base packaging system | Sensitivity | Comparing packaging systems | Geographic scope | Beverage segment |
|---|---|---|---|---|
| **HDPE bottle 4 1000mL** | 100% bio-based PE | TBA Edge 1000 Light Cap<br>TBA Edge 1000 Light Cap Bio-based<br>TBA Edge 1000 Light Cap fully Bio-based[1] | BEL | Dairy 1000mL-2000mL |
| **HDPE bottle 8 330mL** | 100% bio-based PE | Dairy TPA Square 330<br>Dairy TPA Square 330 bio based | UK | Dairy 189mL-500mL |

[1] **TBA Edge 1000 Light Cap fully Bio-based is a theoretical carton for which all** amounts of **fossil PE and aluminium** are **replaced by bio-based PE.** The barrier functionality of PE is not the same as of aluminium. Due to confidentiality of different barrier materials under study, the application of bio-based PE as alternative barrier is only a proxy for possible non-aluminium barriers

### 2.4.4 Sensitivity analysis regarding recycled content in PET bottles

All PET bottles in the base scenarios are assumed to contain the European average of 11.7% recycled PET. As PET bottles could be produced with 100% recycled content a sensitivity analysis is performed for the packaging systems listed in Table 29. In these analyses, the allocation factor applied for open-loop-recycling is 50%.

**Table 29: Sensitivity scenarios: recycled content in PET bottles**

| Base packaging system | Sensitivity | Comparing packaging systems | Geographic scope | Beverage segment |
|---|---|---|---|---|
| **PET bottle 2 1000 mL** | 100% recycled PET | TBA Edge 1000 Light Cap<br>TBA Edge 1000 Light Cap Bio-based | BEL | Dairy 1000mL-2000mL |
| **PET bottle 5 250mL** | 100% recycled PET | TPA Edge 250 Dreamcap<br>TBA Edge 250 Helicap | UK | JNSD 200mL-330mL |

### 2.4.5 Sensitivity analysis regarding recycled content in HDPE bottles

All HDPE bottles in the base scenarios are modelled with 100% primary HDPE. In case of the UK, in 2009 the Dairy Roadmap (formerly known as Milk Roadmap) was introduced [Dairy Roadmap 2015]. This roadmap set goals for raising the content of recycled HDPE in fresh milk bottles to 30% by 2015 and 50% by 2020. The 30% mark had been reached in 2014. Nevertheless the current recycled HDPE content is substantially lower due to capacity reduction for recycled HDPE in the UK [WRAP 2018]. As it is unclear if there is still a certain share of rHDPE contained in UK HDPE bottles the base scenarios are modelled without rHDPE. In order to take the formerly reached mark of 30% rHDPE and the still valid goal of 50% rHDPE in 2020 of the Dairy Roadmap into account, sensitivity analyses are conducted for the chilled dairy bottles containing fresh milk on the UK market as described in Table 30 In these analyses. The allocation factor applied for open-loop-recycling is 50%.

**Table 30: Sensitivity scenarios: recycled content in HDPE bottles**

| Base packaging system | Sensitivity | Comparing packaging systems | Geographic scope | Beverage segment |
|---|---|---|---|---|
| **HDPE bottle 1 1136 mL** | 30% recycled HDPE | TR 1000 OSO 34<br>TR 1000 OSO 34 Bio-based | UK | Dairy 1000mL-2000mL |
| **HDPE bottle 1 1136 mL** | 50% recycled HDPE | TR 1000 OSO 34<br>TR 1000 OSO 34 Bio-based | UK | Dairy 1000mL-2000mL |

### 2.4.6 Sensitivity analysis regarding plastic bottle weight

To consider potential future developments in terms of weight of the plastic bottles, a sensitivity analysis with reduced bottle weight is performed for the packaging systems listed in Table 31. In these analyses the allocation factor applied for open-loop-recycling is 50%.

**Table 31: Sensitivity scenarios: reduced weight of PET bottles**

| Base packaging system | Sensitivity | Comparing packaging systems | Geographic scope | Beverage segment |
|---|---|---|---|---|
| **PET bottle 7 330mL** | 10% reduced bottle weight | TPA Square 330 Dreamcap | UK | JNSD 200mL-330mL |
| **PET bottle 16 500mL** | 10 % reduced bottle weight | TPA Square 500 Streamcap | IRL | Dairy 189mL-500mL |
| **PET bottle 2 1000mL** | 10 % reduced bottle weight | TBA Edge 1000 Light Cap | BEL | Dairy 1000mL-2000mL |
| **PET bottle 11 330mL** | 10% reduced bottle weight | TPA Square 330 Dreamcap | NLD | Water 330mL-500mL |

### 2.4.7 Sensitivity analysis regarding alternative barrier material in beverage cartons

To consider alternative barrier materials instead of aluminium in beverage cartons, a sensitivity analysis with fossil PE instead of aluminium is performed for the packaging systems listed in Table 32. The barrier functionality of PE is not the same as of aluminium. Due to confidentiality of different barrier materials under study, the application of fossil PE as alternative barrier is only a proxy for possible non-aluminium barriers. In these analyses, the allocation factor applied for open-loop-recycling is 50%.

**Table 32: Sensitivity scenarios: alternative barrier materials in beverage cartons**

| Base packaging system | Sensitivity | Comparing packaging systems | Geographic scope | Beverage segment |
|---|---|---|---|---|
| **TPA Square bio-based 330ml** | PE instead of aluminium | PET bottle 7 | UK | JNSD 200mL-330mL |
| **TPA Square bio-based 330ml** | PE instead of aluminium | HDPE bottle 8 | IRL | Dairy 189mL-500mL |
| **TBA Edge bio-based 1000ml** | PE instead of aluminium | PET bottle 2 | BEL | Dairy 1000mL-2000mL |
| **TBA Edge bio-based 1000ml** | PE instead of aluminium | HDPE bottle 2 | NEL | Dairy 1000mL-2000mL |

# 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 33 gives an overview of important datasets applied in the current study.

**Table 33: Overview on inventory/process datasets used in the current study**

| Material / Process step | Source | Reference period |
|---|---|---|
| **Intermediate goods** | | |
| **PP** | Plastics Europe, published online April 2014 | 2011 |
| **HDPE** | Plastics Europe, published April 2014 | 2011 |
| **LDPE** | Plastics Europe, published April 2014 | 2011 |
| **BioPE** | ifeu database based on different sources e.g. [MACEDO 2008] and [Chalmers 2009] | 2005-2011 |
| **PET** | Plastics Europe, published online June 2017 | 2015 |
| **PA6** | Plastics Europe, last online retrieval in 2005 | 1999 |
| **Titanium dioxide** | Ecoinvent V.3.4 | 2017 |
| **Carbon Black** | Ecoinvent V.3.4 | 2011-2015 |
| **Tinplate** | [APEAL 2015] | 2012/2013 |
| **Aluminium** | EAA Environmental Profile report 2013 [EAA 2013] | 2010 |
| **Corrugated cardboard** | [FEFCO 2015] | 2014 |
| **Liquid packaging board** | ifeu data, obtained from ACE [ACE 2012] | 2009 |
| **Production** | | |
| **BC converting** | Tetra Pak | 2009 |
| **Glass bottle converting including glass production** | UBA 2000 (bottle glass); energy prechains 2012 | 2000/2012 |
| **Preform production** | Data provided by Tetra Pak, gathered in 2009, updated in 2016 | 2016 |
| **HDPE bottle production** | Data provided by Tetra Pak, gathered in 2009, updated in 2016 | 2016 |
| **Filling** | | |
| **Filling of beverage cartons** | Data provided by Tetra Pak | 2017 |
| **Filling plastic bottles** | Data provided by Tetra Pak, gathered in 2009, updated in | 2016 |

| Material / Process step | Source | Reference period |
|---|---|---|
| | 2016 for LCA Tetra Pak Nordics<br>SBM is included in data for PET bottles | |
| **Filling glass bottles** | ifeu data obtained from various fillers | 2012 |
| **Recovery** | | |
| **Beverage carton recycling** | Ifeu database, based on data from various European recycling plants | 2004 |
| **PET bottle** | ifeu database, data collected from different recycles in Germany and Europe | 2009 |
| **HDPE bottle** | ifeu database, data collected from different recyclers in Germany and Europe | 2008 |
| **Glass bottle** | ifeu database, [FEVE 2006] | 2004/2005 |
| **Background data** | | |
| **electricity production, UK & Ireland, Belgium, Netherlands, Europe** | ifeu database, based on statistics and power plant models | 2015 |
| **Municipal waste incineration** | ifeu database, based on statistics and incineration plant models | 2008 |
| **Landfill** | ifeu database, based on statistics and incineration plant models | 2008 |
| **lorry transport** | ifeu database, based on statistics and transport models, emission factors based on HBEFA 3.3 [INFRAS 2017]. | 2009 |
| **rail transport** | [EcoTransIT 2016] | 2016 |
| **sea ship transport** | [EcoTransIT 2016] | 2016 |

## 3.1 Plastics

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

- Polypropylene (PP)
- High density polyethylene (HDPE)
- Low density polyethylene (LDPE)
- BioPE
- Polyethylentherephthalat (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 ecoprofile 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 ecoprofile 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 Bio-based Polyethylene (Bio-PE)

All packaging systems analyzed in this study, which contain bio-based Polyethylene (PE) are beverage carton systems. The only exceptions are the two sensitivity analyses with 100% bio-based HDPE bottles. The bio-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. This study uses two LCA datasets provided by Braskem, one for bio-based HDPE and one for bio-based LDPE [Braskem 2018]. In order to address co-products in the bio-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 is 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 2012]. 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. Therefore impacts of caprolactam production are allocated between caprocaltam and ammonium sulphate. . To the view of the authors, this approach is not consistent as other datasets of plastics are used alongside in this study, which 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 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 2010. Respectively, this represented 84% to 93% of the single production steps alumina production, past and anode production, as well as electrolysis and casthouse of the primary aluminium production in Europe [EAA 2013].

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 2012 and are published by APEAL [APEAL 2015]. 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 APEAL the dataset represent about 95% of the annual European supply or production volume.

## 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 of food container glass 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. This substitution follows a consequential LCA approach, whereas this LCA is conducted as an attributional LCA. As the credits of the substitution are aggregated in the FEVE dataset, these credits could not be reported separately in this study. Further the FEVE dataset includes also non-food container glass leading to a different cullet rate.

## 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.

Both data 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 3.4), 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.

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated card-board 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 oxidised with chlorine. After distillation of the resulting tetrachloride it is re-oxidised 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 is 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 mosty 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 cartons

The manufacture of composite board was modelled using European average converting data from Tetra Pak that refer to the year 2013. More recent data are currently not available. Process data have been collected from all European sites. The converting process covers the lamination of LPB with LDPE and aluminium including required additives, printing, 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 was 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. Data was gathered in 2009 from production plants, which are producing competing PET bottle systems, and was updated in 2016 for the Tetra Pak Nordics LCA study [ifeu 2017]. This data is also used in this study.

### 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 database2016 for the Tetra Pak Nordics LCA study [ifeu 2017]. The data was also gathered from production plants, which are producing competing HDPE bottle systems. This data is also applied in this study.

## 3.10 Closure production

The closures made of fossil and bio-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 cartons and alternative packaging systems regarding material and energy flows. The respective data for beverage cartons were provided by Tetra Pak in 2017, 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 collected by Tetra Pak in 2009 and updated in 2016 for the Tetra Pak Nordics LCA [Tetra Pak 2017a. This data is also used in this study. 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 2017, as filling machines and technologies have not changed since then. Filling data for PP cups has been collected by [Tetra Pak 2017] for a competing PP cup filling line Electricity demands are supplied by the grid electricity of the country of filling.

## 3.12 Transport settings

Table 34 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 34:** Transport distances and means: Transport defined by distance and mode [km/mode]

| Packaging element | Material producer to converter | Converter to filler |
|---|---|---|
| HDPE, LDPE, PP, PET granulate for all packages | 200 / road* | |
| Bio PE | 10800 / sea*<br>500 / road* | |
| Aluminium | 250 / road* | |
| Paper board for composite board | 200 / road***<br>1300 / sea***<br>400 / rail*** | |
| Cardboard for trays | primary fibres:<br>500 / sea, 400 / rail, 250 / road***<br>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 | | UK: 1390 / road**<br>IRL: 1990 / road**<br>BEL: 1090 / road**<br>NEL: 1180 / road** |

*Assumption/Calculation; **average distances from three European converting plants in Spain, Hungary and Germany; ***taken from published LCI reports

## 3.13 Distribution of filled packs from filler to point of sale

Table 35 shows the applied distribution distances. Distribution centers are the places where the products are temporarily stored and then distributed to the different point of sales (i.e. supermarkets). Distances have been calculated as average distances from representative filling plants to one representative distribution center in each country. The applied distances from distribution centers to point of sales are educated estimates. For each country the same distribution model is applied for all packages.
It is assumed that not the full return distance is driven with an empty load, as lorries 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 First hand data is available on average empty return distances. For this reason an estimation of 33% based on expert judgement 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. This is only valid for

the distribution step from filler to warehouse. 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 35:** Distribution distances in km for the examined packaging systems in the UK, Ireland, Belgium and the Netherlands based

| | Distribution distance [km] as applied in this study | | | |
|---|---|---|---|---|
| | Distribution Step 1 | | Distribution step 2 | |
| country | **filler > distribution center** (delivery) | **distribution center > filler** (return trip) | **distribution center > POS** (delivery) | **POS > distribution center** (return trip) |
| UK | 300 | 99 | 70 | 70 |
| Ireland | 225 | 74 | 70 | 70 |
| Belgium | 100 | 60 | 50 | 50 |
| Netherlands | 200 | 66 | 60 | 60 |

## 3.14 Recovery and recycling

**Beverage cartons**

Food cartons are typically positively sorted into a beverage and food carton fraction, which subsequently is sent to a paper recycling facility for fibre recovery. The secondary fibre material is used e.g. as a raw material for cardboard. A substitution factor 0.9 is applied.

By the best knowledge of Tetra Pak inthe UK and Ireland plastics and aluminium compounds are assumed to undergo thermal treatment with energy recovery. In the scope of Belgium and the Netherlands, plastics and aluminium compounds are assumed to be thermally treated in cement kiln for energy production as a substitution of bauxite. 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**

A considerable share of plastic bottles is collected and sorted, 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.

According to Tetra Pak the recycling of clear plastic bottles taking place in the following countries:

- Clear plastic bottles sold in the UK are recycled in the UK
- Clear plastic bottles sold in Ireland are recycled in the UK
- Clear plastic bottles sold in Belgium are sent for recycling to the Netherlands, Germany and France. An even distribution between the three countries is assumed.
- Clear plastic bottles sold in the Netherlands are recycled besides in the Netherlands itself also in Germany. Also here an even distribution between the Netherlands and Germany is assumed.

The white opaque 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. Therefor opaque bottles are removed from the recycling stream of a large amount of recycling plants [EPBP 2018]. Therefore in the model of this studythey end up in a mixed plastic fraction and undergo thermal treatment (MSWI or cement kiln) instead of regranulation. A share of 10% is assumed to be used as wood substitutes.

**Glass bottles**

The glass of collected glass bottles is shredded and the ground glass serves as an input in the glass production, the share of external cullet is modelled as 64%. 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.

## 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. 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 a utilisation of capacity by 70%. Energy use is based on an average fleet composition of this ship category with data taken from [EcoTransIT World 2016]. The Ecological Transport Information Tool (EcoTransIT) calculates environmental impacts of any freight transport. Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on [EcoTransIT World 2016]. For the consideration of well-to-tank emissions data were taken from IFEU’s internal database.

Rail transport

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. For all processes using external electricity ,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]. It is based on national electricity mix data by the International Energy Agency (IEA)[2]. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2015 for the production of paperboard and the market related mix of energy suppliers in the year 2015 for all other processes depending on their location (e.g. energy for filling process: either UK, Ireland, Belgium, Netherlands; energy for corrugated cardboard production: European). The applied shares of energy sources to the related market are given in Table 36.

[1] Twenty-foot Equivalent Unit
[2] http://www.iea.org/statistics/

**Table 36:** Share of energy source to specific energy mix, reference year 2015 based on [IEA 2017]

| country<br>Energy source | EU 28 | UK | Ireland | Belgium | Nether-lands |
|---|---|---|---|---|---|
| **Hard coal** | 14.11% | 22.23% | 17.06% | 3.18% | 35.93% |
| **Brown coal** | 10.32% | 0.00% | 0.00% | 0.00% | 0.00% |
| **Fuel oil** | 1.65% | 0.30% | 1.24% | 0.07% | 0.07% |
| **Natural gas** | 16.51% | 30.05% | 52.28% | 35.71% | 45.93% |
| **Nuclear energy** | 26.70% | 20.90% | 0.00% | 37.88% | 3.73% |
| **Hydropower/Wind/Solar /Geothermal** | 24.50% | 16.83% | 27.50% | 13.45% | 8.39% |
| ***Hydropower*** | 45.74% | 11.70% | 10.93% | 3.61% | 1.07% |
| ***Windpower*** | 40.42% | 74.95% | 89.04% | 63.33% | 86.70% |
| ***Solar energy*** | 13.01% | 13.35% | 0.03% | 33.06% | 12.23% |
| ***Geothermal energy*** | 0.83% | 0.00% | 0.00% | 0.00% | 0.00% |
| **Biomass energy** | 4.84% | 7.82% | 1.40% | 6.66% | 2.66% |
| **Waste** | 1.35% | 1.87% | 0.60% | 3.05% | 3.29% |

### 3.15.3 Municipal waste incineration

The electrical and thermal efficiencies of the municipal solid waste incineration plants (MSWI) are based on statistics for the four Northwest European markets published by the CEWEP.

**Table 37**: Electrical and thermal efficiencies of the incineration plants in the four studied markets.

| Country | Electrical efficiency | Thermal efficiency | Reference period | Source |
|---|---|---|---|---|
| **UK** | 17% | 3% | 2015 | [Tolvik 2016] |
| **Ireland** | 18% | - | 2015 | [CEWEP 2016a] |
| **Belgium** | 14% | 4% | 2014 | [CEWEP 2016b] |
| **Netherlands** | 16% | 8% | 2012 | [CEWEP 2013] |

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 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. Emissions of methane from biogenic materials (e.g. during landfill) are always accounted at the inventory level AND in form of GWP.

# 4 Results Belgium

In this section, the results of the examined packaging systems for Belgium 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/PP for bottles/cups/SUP including additives, e.g. carbon black (**'PET/HDPE/PP for bottles/cups/SUP'**)
- production and transport of liquid packaging board **('LPB')**
- production and transport of plastics and additives for beverage carton **('plastics for sleeve')**
- production and transport of aluminium & converting to foil **('aluminium foil')**
- converting processes of cartons **('converting')**
- production and transport of base materials for closures, top and label **('top, closure & label')**
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays **('transport packaging')**
- filling process including packaging handling **('filling')**
- retail of the packages from filler to the point-of-sale including cooling during transport if relevant **('distribution')**
- $CO_2$ emissions from incineration of bio-based and renewable materials **('CO2 reg. (recycling & disposal)')**; in the following also the term regenerative CO2 emissions is used
- sorting, recycling and disposal processes **('recycling & disposal')**

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. These secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental loads of the substituted material. The so-called 50% allocation method has been used for the crediting procedure (see section1.7) in the base scenarios.

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')**
- Uptake of athmospheric $CO_2$ during the plant growth phase ('**$CO_2$-uptake**')

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
Each impact category graph includes three bars per packaging system under investigation, which illustrate (from left to right):

- sectoral results of the packaging system itself (stacked bar 'environmental burdens')
- credits given for secondary products leaving the system (negative stacked bar 'credits')
- net results as a results of the substraction of credits from overall environmental loads (grey bar 'net results')

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

A note on significance: 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 is common practice for LCA studies comparing different product systems. This means differences ≤ 10% are considered as insignificant.

# 4.1 Results base scenarios DAIRY 1000mL-2000mL BELGIUM

## 4.1.1 Presentation of results

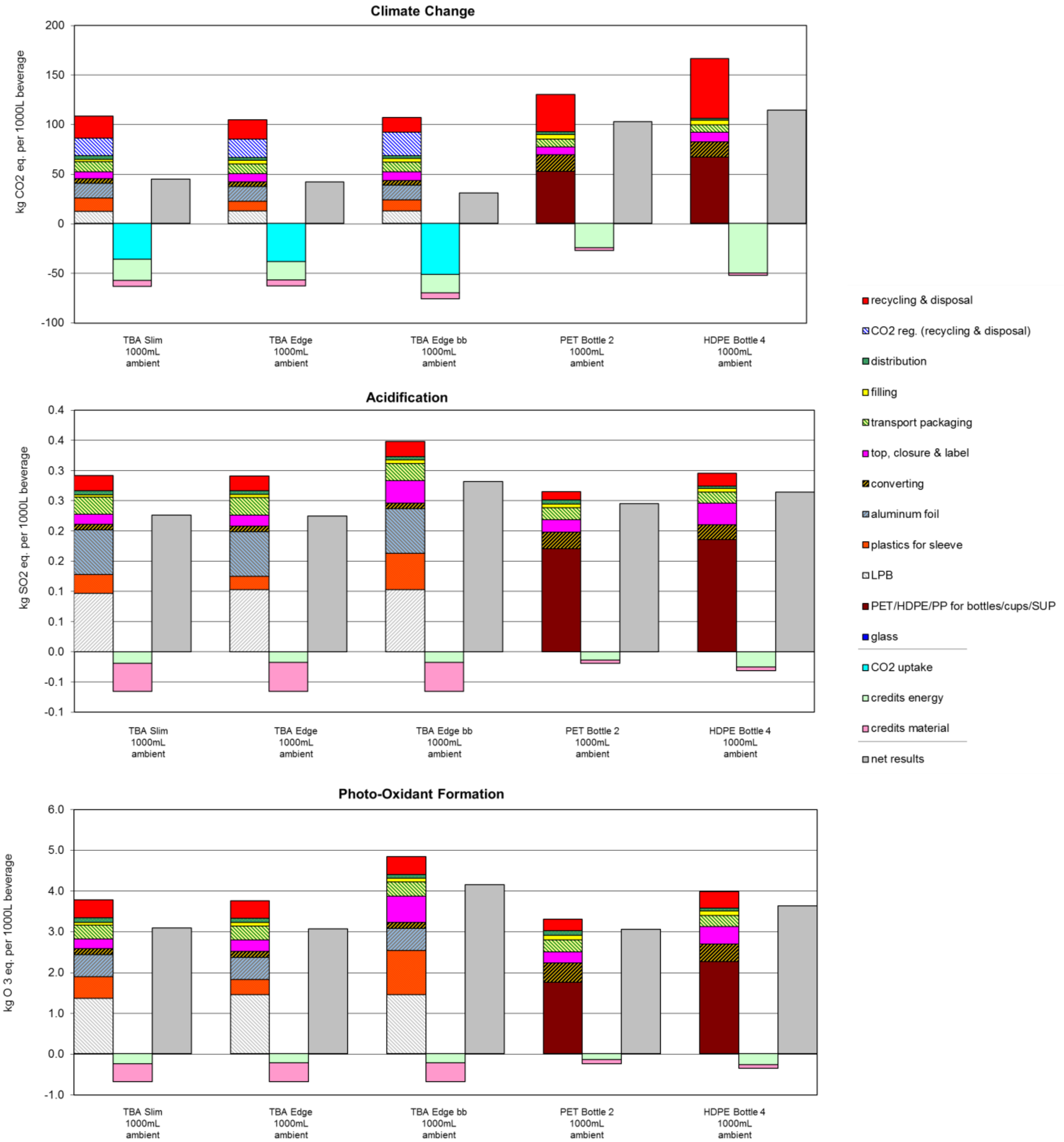



**Figure 15:** Indicator results for base scenarios of **segment Dairy 1000mL-2000mL, Belgium**, allocation factor 50% (Part 1)

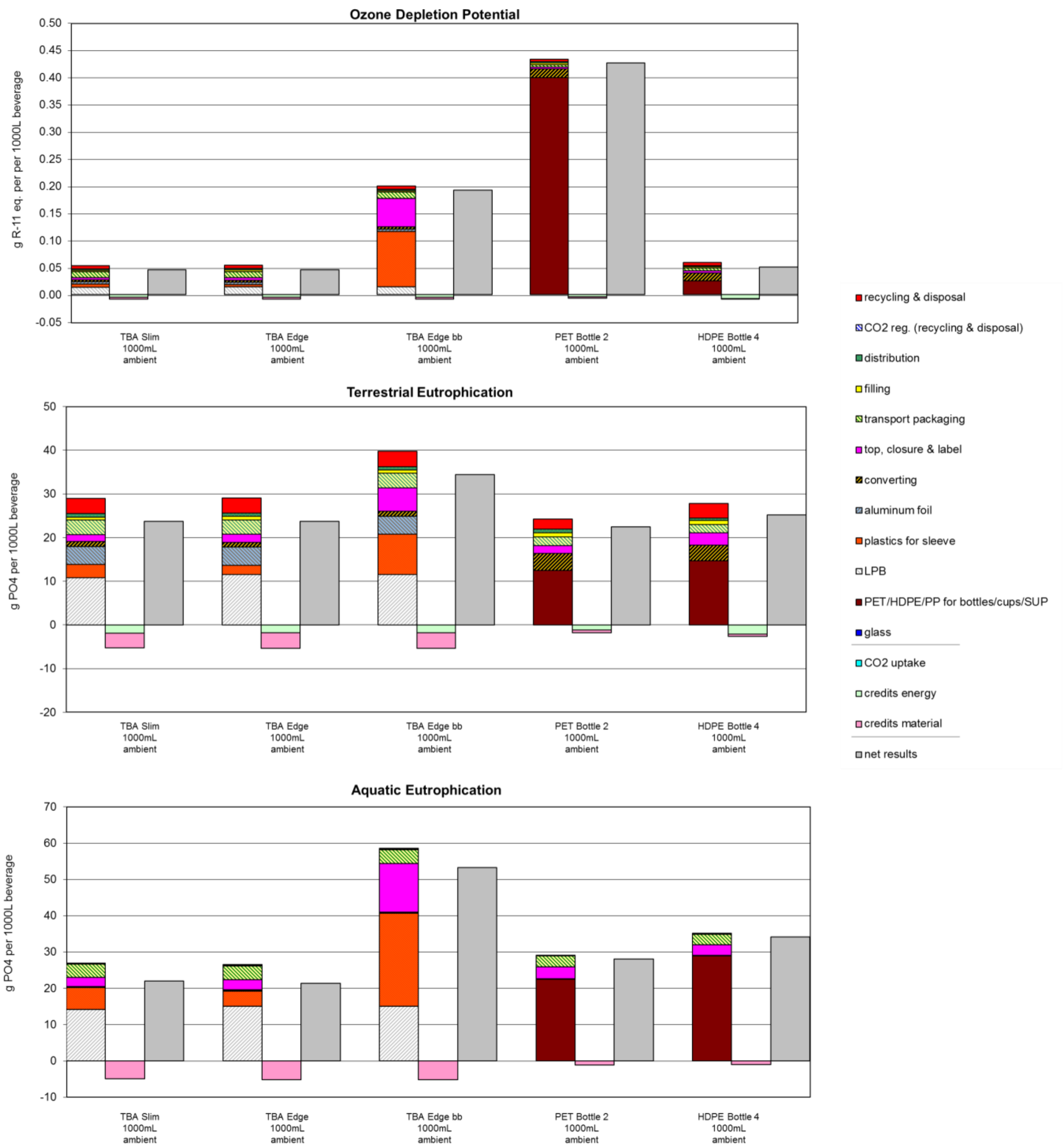



**Figure 16** Indicator results for base scenarios of **segment Dairy 1000mL-2000mL, Belgium**, allocation factor 50% (Part 2)

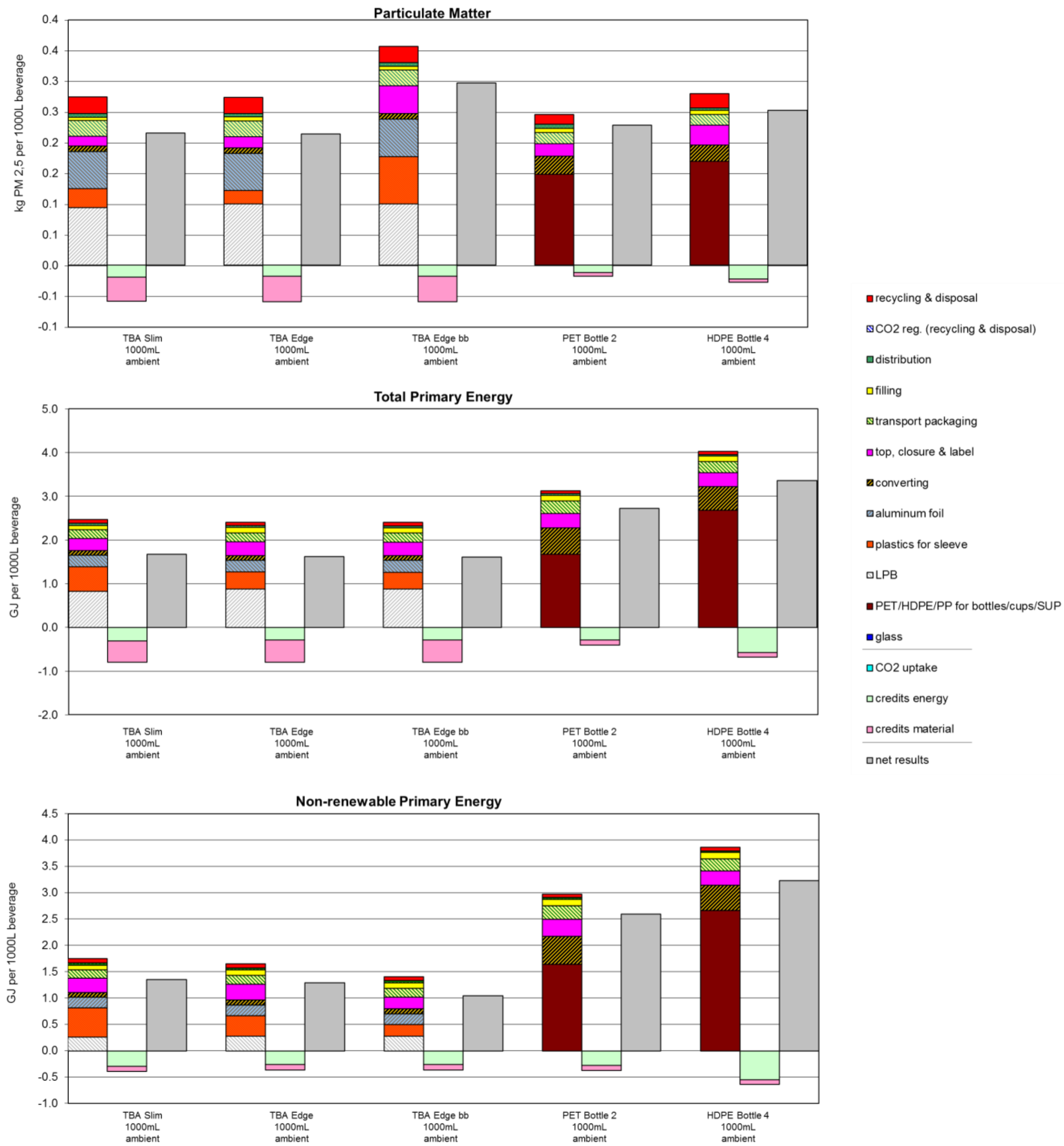



**Figure 17:** Indicator results for base scenarios of **segment Dairy 1000mL-2000mL, Belgium**, allocation factor 50% (Part 3)

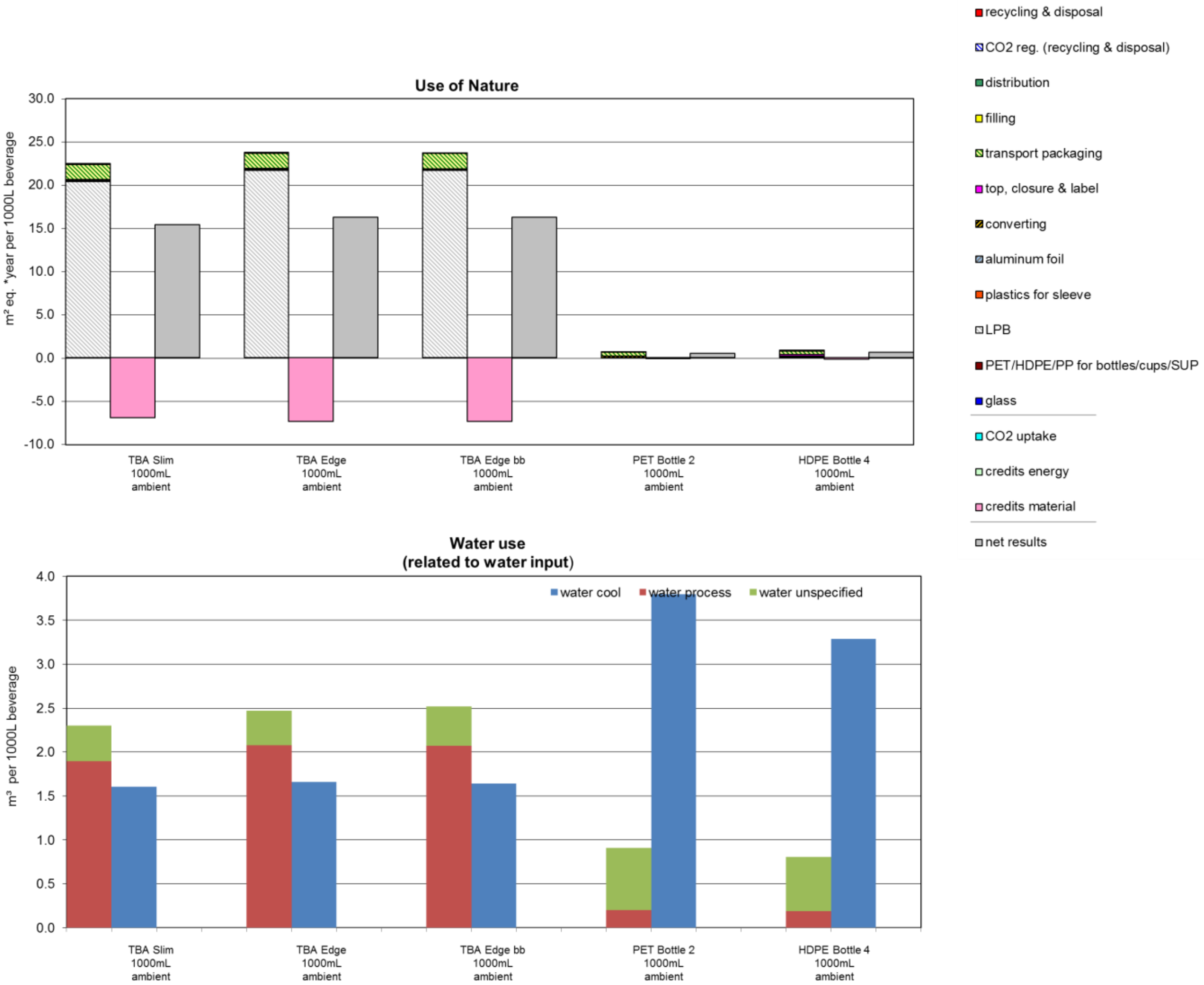



**Figure 18:** Indicator results for base scenarios of **segment Dairy 1000mL-2000mL, Belgium**, allocation factor 50% (Part 4)

**Table 38:** Category indicator results per impact category for base scenarios of **segment DAIRY 1000mL-2000mL, Belgium**- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TBA Slim 1000mL ambient | TBA Edge 1000mL ambient | TBA Edge bb 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 90.39 | 85.95 | 82.93 | 129.82 | 166.29 |
| | CO2 (reg) | 17.62 | 18.68 | 23.63 | 0.00 | 0.00 |
| | Credits* | -27.19 | -24.52 | -24.52 | -27.14 | -52.24 |
| | $CO_2$ uptake | -36.26 | -38.54 | -51.57 | 0.00 | 0.00 |
| | Net results (∑) | 44.57 | 41.57 | 30.47 | 102.69 | 114.05 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.29 | 0.29 | 0.35 | 0.27 | 0.30 |
| | Credits* | -0.07 | -0.07 | -0.07 | -0.02 | -0.03 |
| | Net results (∑) | 0.23 | 0.22 | 0.28 | 0.25 | 0.26 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 3.77 | 3.76 | 4.83 | 3.30 | 3.98 |
| | Credits* | -0.68 | -0.69 | -0.69 | -0.24 | -0.36 |
| | Net results (∑) | 3.09 | 3.07 | 4.15 | 3.06 | 3.63 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.05 | 0.05 | 0.20 | 0.43 | 0.06 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.01 | -0.01 |
| | Net results (∑) | 0.05 | 0.05 | 0.19 | 0.43 | 0.05 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 29.04 | 29.12 | 39.78 | 24.25 | 27.84 |
| | Credits* | -5.27 | -5.33 | -5.33 | -1.72 | -2.64 |
| | Net results (∑) | 23.76 | 23.79 | 34.46 | 22.53 | 25.20 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 26.91 | 26.52 | 58.41 | 29.14 | 35.09 |
| | Credits* | -4.88 | -5.18 | -5.18 | -1.10 | -1.00 |
| | Net results (∑) | 22.02 | 21.34 | 53.23 | 28.04 | 34.09 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.27 | 0.27 | 0.36 | 0.25 | 0.28 |
| | Credits* | -0.06 | -0.06 | -0.06 | -0.02 | -0.03 |
| | Net results (∑) | 0.22 | 0.21 | 0.30 | 0.23 | 0.25 |
| Total Primary Energy [GJ] | Burdens | 2.47 | 2.42 | 2.41 | 3.13 | 4.04 |
| | Credits* | -0.79 | -0.79 | -0.79 | -0.40 | -0.67 |
| | Net results (∑) | 1.68 | 1.63 | 1.62 | 2.73 | 3.36 |
| Non-renewable primary energy [GJ] | Burdens | 1.74 | 1.65 | 1.41 | 2.97 | 3.86 |
| | Credits* | -0.39 | -0.36 | -0.36 | -0.37 | -0.64 |
| | Net results (∑) | 1.35 | 1.29 | 1.04 | 2.59 | 3.22 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 22.36 | 23.66 | 23.65 | 0.63 | 0.80 |
| | Credits* | -6.99 | -7.42 | -7.42 | -0.16 | -0.21 |
| | Net results (∑) | 15.38 | 16.24 | 16.23 | 0.47 | 0.59 |
| Water use [$m^3$] | Water cool | 1.60 | 1.66 | 1.64 | 3.79 | 3.29 |
| | Water process | 1.90 | 2.08 | 2.07 | 0.20 | 0.19 |
| | Water unspec | 0.40 | 0.39 | 0.45 | 0.71 | 0.61 |

*material and energy credits

### 4.1.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the DAIRY 1000mL-2000mL 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’ (53%-26%) and ‘Use of Nature’ (91%). It is also relevant regarding ‘Photo-Oxidant Formation’ (30%-38%) ‘Acidification’ (29%-35%), ‘Terrestrial Eutrophication’ (29%-40%), ‘Particulate Matter’ (28%-36%) and also the consumption of ‘Total Primary Energy’ (34%-37%).

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 SO2, thus contributing considerably to the acidifying potential.

The required energy for paper production mainly originates from 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 shows burdens in most impact categories. Substantial shares of burdens can be seen for the categories ‘Acidification’ (21%-25%) and ‘Particulate Matter’ (17%-22%). These result from SO2 and NOx emissions from the aluminium production.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable burdens in most impact categories (7%-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 two exceptions are climate change, where plastics (9%-13%) and LPB (11%-12%) contribute about the same and the inventory category ‘Non-renewable Primary Energy’, where the plastics make up 32% (TBA Slim), 24% (TBA Edge) of the total burdens. If ‘plastics for sleeve' contains bio-based plastics (i.e. for TBA Edge bio-based 1000mL), this life cycle step plays a major role (22%-51%) for the overall burdens in all categories apart from 'Climate Change' (12%), 'Acidification' (17%), 'Total Primary Energy' (16%) and 'Non-renewable Primary Energy' (16%).

The life cycle step 'top, closure & label' contributes to a small amount in almost all impact categories (6%-10%). In case the plastics used for 'top, closure & label' are bio-based (i.e. TBA Edge bio-based 1000mL), the results are considerably higher (11%-27%) in all categories except 'Climate Change', 'Total Primary Energy Demand' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (2%-8%). It generates emissions, which contribute to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories 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%-14%). The exception is 'Ozone Depletion Potential' for the cartons with fossil based plastics. In these cases 'transport packaging' has a higher share of 21% of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle steps 'filling' and 'distribution' show only small burdens for all beverage carton systems in all impact categories (max. 8%). Therefore none of these steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact category 'Climate Change' (36%-37%). 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.

'CO2 reg. (recycling & disposal)' describes separately all regenerative CO2 emissions from recycling and disposal processes. In case of beverage cartons in Belgium these derive mainly from the incineration of bio-based plastics and paper. They play an important role for the results of all beverage carton systems in the impact category 'Climate Change'. Together with the fossil-based CO2 emissions of the life cycle step 'recycling & disposal'. They represent the total CO2 emissions from the packaging's end-of-life.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits from material recycling are higher than energy credits in all impact categories except 'Climate Change' as in Belgium 90% of the beverage cartons are recycled. Material credits for 'Climate Change' are low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart of 'Ozone Depletion Potential'

The uptake of CO2 by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative CO2.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY 1000mL-2000mL 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.

Even though this is true for all bottles, differences can be observed depending on the kind of plastic used. For most impact categories the burdens from plastic production (life cycle step 'PET/HDPE/PP for bottles/cups/SUP' in the graphs) are higher for the HDPE bottle than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows a comparatively low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

The 'converting' process shows for all bottles in this a considerable share of burdens (4%-24%) 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 minor impacts shares (6%-12%) in most categories mainly attributed to the different plastics used for the closures. Even though the closure of the HDPE 4 Bottle is lighter than the one of PET Bottle 2, it shows higher impacts in most categories. This is due to the additional aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems show minor impact shares (1%-11%) in all categories. For most categories the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 6%) for all bottle systems in all impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the fossil-based plastic bottles' 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (29%-26%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the white opaque plastic bottles do not undergo a material recycling and there is almost no landfilling in Belgium, almost all bottles are incinerated in MSWI plants.

The influence of credits on the net result is very low in most categories. The exception is 'Climate Change', where the credits reduce the overall burdens by around 30%. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the used white plastic bottles are incinerated in MSWIs, the received material credits are negligible compared to the credits for energy.

### 4.1.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 39:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Belgium**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 41.57 | -60% | -64% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -89% | -10% |
| Acidification [kg $SO_2$ eq.] | 0.22 | -8% | -15% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 23.79 | 6% | -6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 21.34 | -24% | -37% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.07 | 0% | -15% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.21 | -6% | -15% |

**Table 40:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Belgium**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 30.47 | -70% | -73% |
| Ozone depletion potential [g R-11 eq.] | 0.19 | -55% | 275% |
| Acidification [kg $SO_2$ eq.] | 0.28 | 15% | 7% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 34.46 | 53% | 37% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 53.23 | 90% | 56% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.15 | 36% | 14% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.30 | 30% | 18% |

**Table 41:** Comparison of net results: **TBA Slim 1000 mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Belgium**

| The net results of **TBA Slim 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Slim 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 44.57 | -57% | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -89% | -11% |
| Acidification [kg $SO_2$ eq.] | 0.23 | -8% | -14% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 23.76 | 5% | -6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 22.02 | -21% | -35% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.09 | 1% | -15% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.22 | -6% | -15% |

# *4.2* Results base scenarios JNSD 1000mL BELGIUM

## 4.2.1 Presentation of results

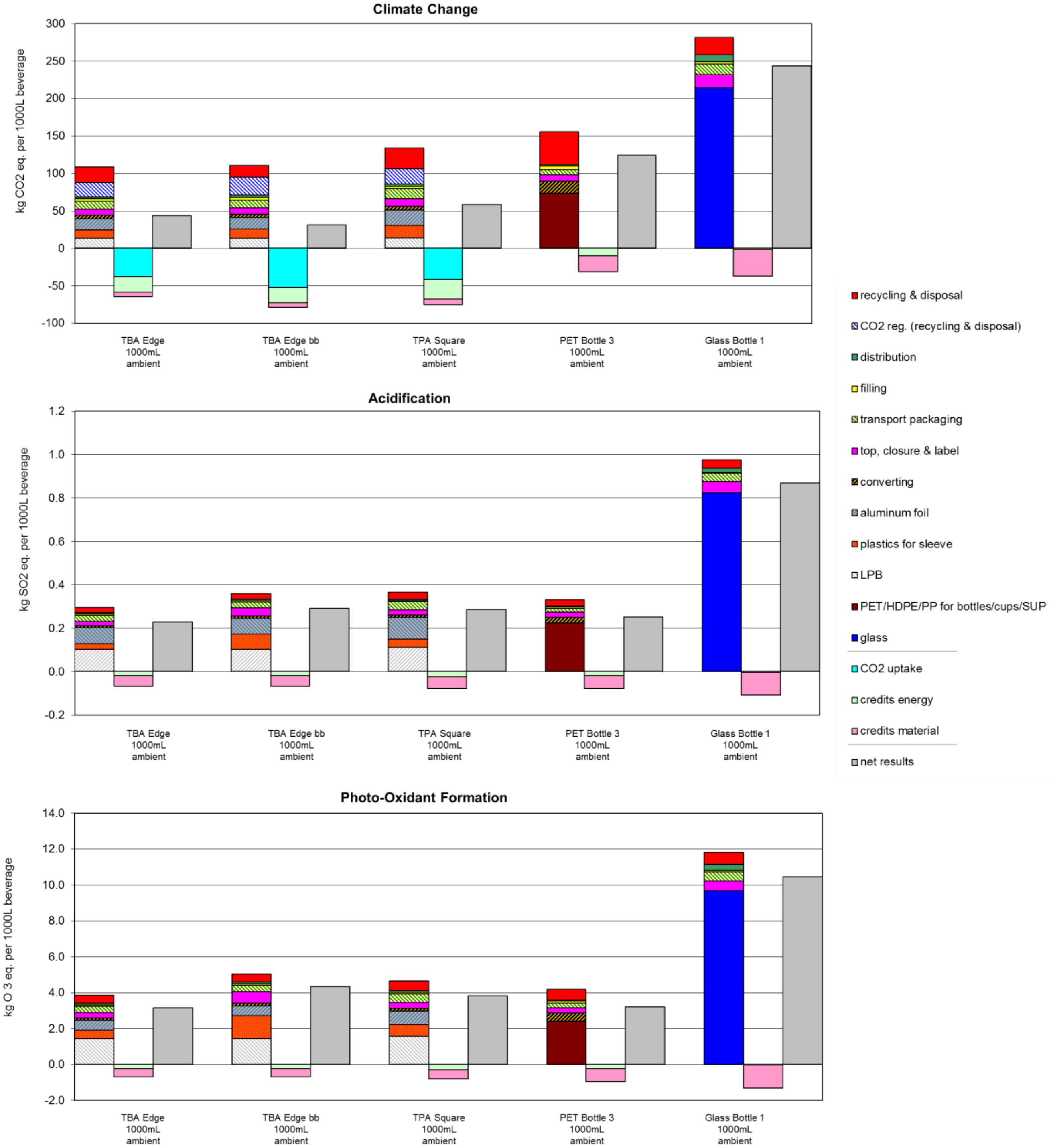



**Figure 19:** Indicator results for base scenarios of **segment JNSD 1000mL, Belgium**, allocation factor 50% (Part 1)

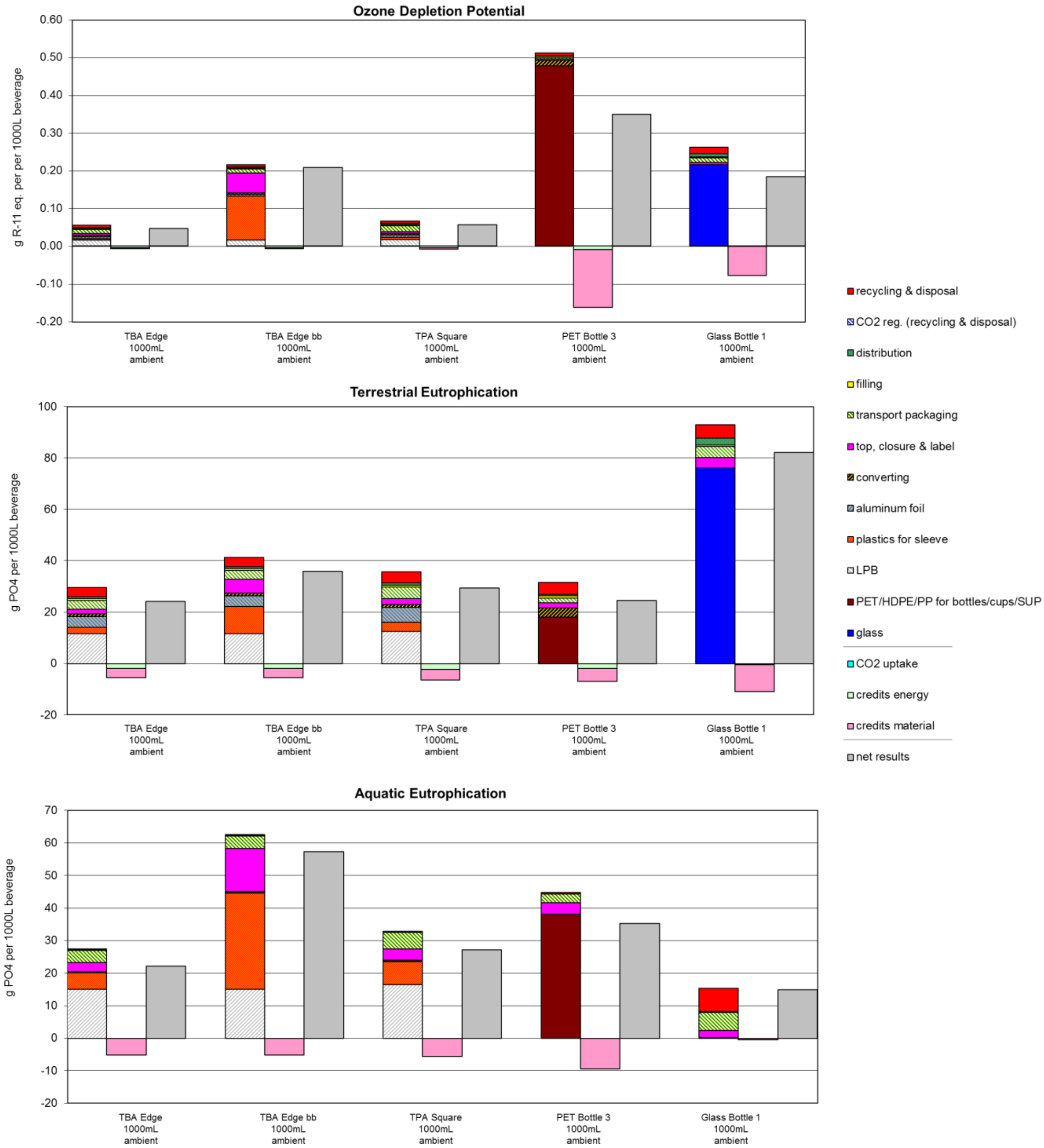



**Figure 20:** Indicator results for base scenarios of **segment JNSD 1000mL, Belgium**, allocation factor 50% (Part 2)

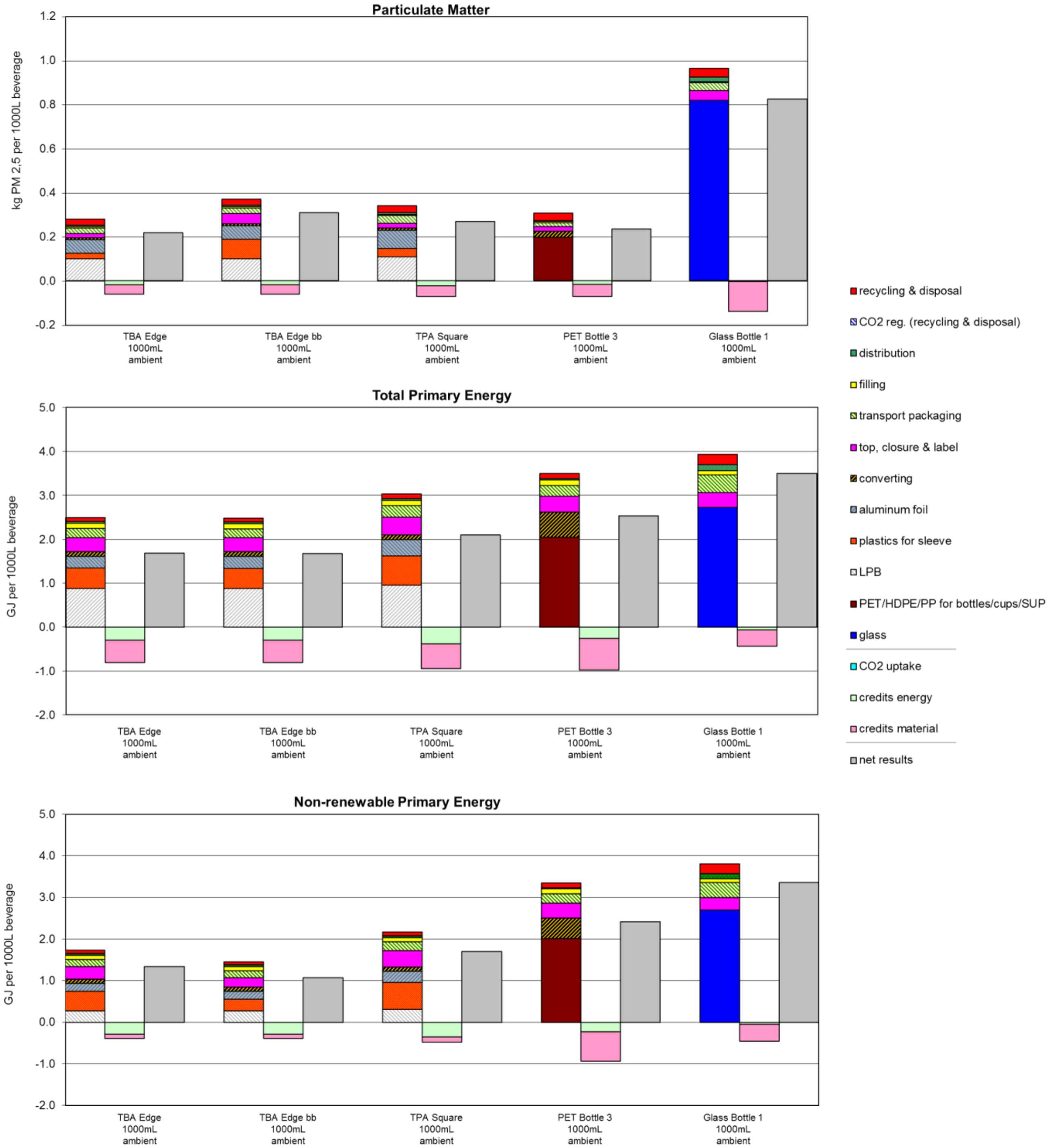



**Figure 21:** Indicator results for base scenarios of **segment JNSD 1000mL, Belgium**, allocation factor 50% (Part 3)

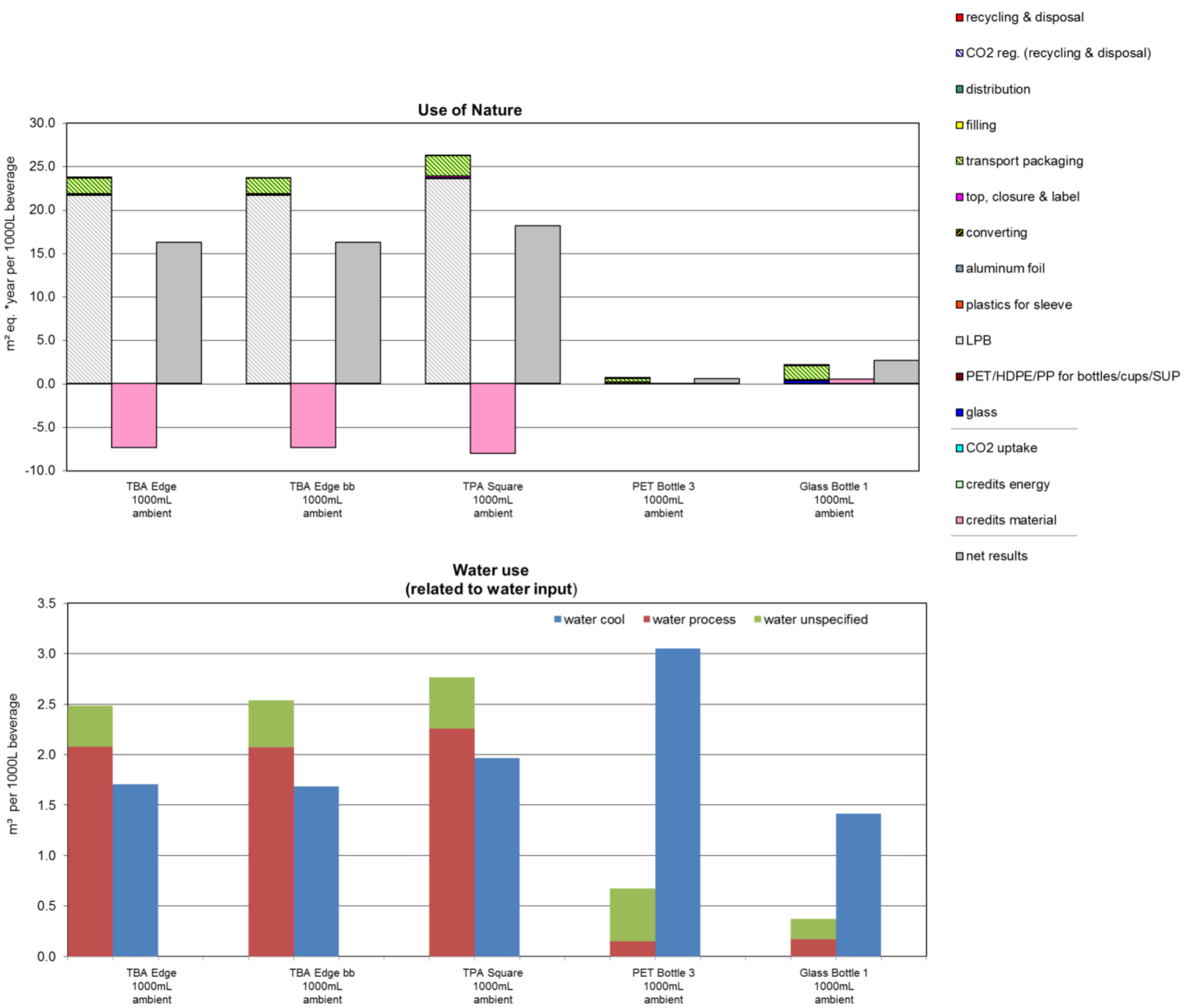



**Figure 22:** Indicator results for base scenarios of **segment JNSD 1000mL, Belgium**, allocation factor 50% (Part 4)

**Table 42:** Category indicator results per impact category for base scenarios of segment JNSD 1000mL, Belgium- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TBA Edge 1000mL ambient | TBA Edge bb 1000mL ambient | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 89.42 | 86.09 | 113.33 | 155.30 | 280.91 |
| | CO2 (reg) | 18.68 | 24.11 | 20.38 | 0.00 | 0.00 |
| | Credits* | -26.13 | -26.13 | -33.38 | -31.58 | -38.01 |
| | $CO_2$ uptake | -38.53 | -52.85 | -41.98 | 0.00 | 0.00 |
| | Net results (∑) | 43.44 | 31.22 | 58.35 | 123.71 | 242.90 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.30 | 0.36 | 0.36 | 0.33 | 0.98 |
| | Credits* | -0.07 | -0.07 | -0.08 | -0.08 | -0.11 |
| | Net results (∑) | 0.23 | 0.29 | 0.29 | 0.25 | 0.87 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 3.84 | 5.02 | 4.62 | 4.16 | 11.78 |
| | Credits* | -0.70 | -0.70 | -0.81 | -0.97 | -1.34 |
| | Net results (∑) | 3.14 | 4.32 | 3.81 | 3.20 | 10.44 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.05 | 0.22 | 0.07 | 0.51 | 0.26 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.16 | -0.08 |
| | Net results (∑) | 0.05 | 0.21 | 0.06 | 0.35 | 0.18 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 29.61 | 41.33 | 35.67 | 31.64 | 93.01 |
| | Credits* | -5.42 | -5.42 | -6.29 | -6.97 | -10.83 |
| | Net results (∑) | 24.19 | 35.91 | 29.38 | 24.66 | 82.18 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 27.32 | 62.37 | 32.70 | 44.65 | 15.34 |
| | Credits* | -5.18 | -5.18 | -5.64 | -9.46 | -0.47 |
| | Net results (∑) | 22.14 | 57.19 | 27.05 | 35.19 | 14.87 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.28 | 0.37 | 0.34 | 0.31 | 0.96 |
| | Credits* | -0.06 | -0.06 | -0.07 | -0.07 | -0.14 |
| | Net results (∑) | 0.22 | 0.31 | 0.27 | 0.24 | 0.82 |
| Total Primary Energy [GJ] | Burdens | 2.49 | 2.48 | 3.04 | 3.51 | 3.94 |
| | Credits* | -0.81 | -0.81 | -0.94 | -0.97 | -0.43 |
| | Net results (∑) | 1.69 | 1.68 | 2.10 | 2.54 | 3.51 |
| Non-renewable primary energy [GJ] | Burdens | 1.73 | 1.46 | 2.17 | 3.35 | 3.80 |
| | Credits* | -0.38 | -0.38 | -0.47 | -0.93 | -0.45 |
| | Net results (∑) | 1.34 | 1.08 | 1.70 | 2.41 | 3.35 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 23.66 | 23.65 | 26.23 | 0.61 | 2.14 |
| | Credits* | -7.42 | -7.42 | -8.09 | -0.05 | 0.48 |
| | Net results (∑) | 16.24 | 16.23 | 18.14 | 0.56 | 2.62 |
| Water use [$m^3$] | Water cool | 1.71 | 1.68 | 1.96 | 3.05 | 1.41 |
| | Water process | 2.08 | 2.07 | 2.26 | 0.15 | 0.17 |
| | Water unspec | 0.41 | 0.47 | 0.51 | 0.52 | 0.20 |

*material and energy credits

### 4.2.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 1000mL 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%-55%) and 'Use of Nature' (90%-91%). It is also relevant regarding 'Photo-Oxidant Formation' (33%-41%) 'Acidification' (29%-35%), 'Terrestrial Eutrophication' (28%-39%), 'Particulate Matter' (27%-36%) and also the consumption of 'Total Primary Energy' (32%-35%).

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 SO2, thus contributing considerably to the acidifying potential.

The required energy for paper production mainly originates from 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 shows burdens in most impact categories. Substantial shares of burdens can be seen for the categories 'Acidification' (21%-28%) and 'Particulate Matter' (16%-25%). These result from SO2 and NOx emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (8%-22%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil based plastics (11%-12%) and LPB (10%-12%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about a third of the total burdens. If the 'plastics for sleeves' contain bio-based plastics (i.e. TBA Edge bio-based 1000mL ambient) this life cycle step plays a major role (20%-54%) for the overall burdens in all categories apart from 'Climate Change' (12%), 'Total Primary Energy' (19%) and 'Non-renewable Primary Energy' (19%).

The life cycle step 'top, closure & label' contributes to a small amount (8%-10%) in all impact categories. In case the plastics used for 'top, closure & label' are bio-based (i.e. TBA Edge bio-based 1000mL), the results are considerably higher (10%-24%) in all categories except 'Climate Change', 'Total Primary Energy Demand' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (max. 7%). It generates emissions, which contribute to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories 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 (5%-14%). The exception is 'Ozone Depletion Potential' for the cartons with fossil based plastics. In these cases 'transport packaging' has a higher share of 20%-23% of the burdens due to the low share of the categories 'top, closure & label' and 'plastics for sleeve'.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 7%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (14%-21%), 'Photo-Oxidant Formation' (10%-14%), 'Terrestrial Eutrophication' (9%-12%), 'Acidification' (7%-9%) and 'Particulate Matter' (7%-10%). 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. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO2 emissions from incineration plants and cement kilns.

'CO2 reg. (recycling & disposal)' describes separately all regenerative CO2 emissions from recycling and disposal processes. In case of beverage cartons in Belgium these derive mainly from the incineration of bio-based plastics and paper. They play an important role for the results of all beverage carton systems in the impact category 'Climate Change'.

Together with the fossil-based CO2 emissions of the life cycle step ‘recycling & disposal’. They represent the total CO2 emissions from the packaging’s end-of-life.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits from material recycling are higher than energy credits in all impact categories except ‘Climate Change’ as in Belgium 90% of the beverage cartons are recycled. Material credits for ‘Climate Change’ are low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of CO2 by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative CO2.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 1000mL 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. The burdens mainly derive from PET production, nevertheless a considerable share of burdens derives from the production of the PA additive. The high results of ‘Ozone Depletion Potential’ are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The ‘converting’ process shows for all bottles in this a 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 minor impacts (6%-10%) in all categories mainly attributed to the plastics used for the closure.

The production and provision of ‘transport packaging’ for the bottle system shows minor shares of impact (1%-8%) in most categories. For most categories the relevant emissions derive from shrink foil production. The exception is ‘Aquatic Eutrophication’, where the emissions result from the production of paper for slipsheets.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 4%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (28%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is high in most categories. With a recycling rate of 75% for the clear plastic bottle, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

**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 (69%-92%) 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' (37%) and 'Use of Nature' (75%) transport packaging also plays an important role.

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 though have an important impact on the overall net results apart from 'Aquatic Eutrophication' and 'Use of Nature'.

### 4.2.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 43:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Belgium**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 43.44 | -65% | -82% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -87% | -75% |
| Acidification [kg $SO_2$ eq.] | 0.23 | -10% | -74% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 24.19 | -2% | -71% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 22.14 | -37% | 49% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.14 | -2% | -70% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.22 | -7% | -74% |

**Table 44:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Belgium**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 31.22 | -75% | -87% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -41% | 13% |
| Acidification [kg $SO_2$ eq.] | 0.29 | 15% | -66% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.91 | 46% | -56% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 57.19 | 63% | 285% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.32 | 35% | -59% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | 31% | -63% |

**Table 45:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Belgium**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 58.35 | -53% | -76% |
| Ozone depletion potential [g R-11 eq.] | 0.06 | -84% | -69% |
| Acidification [kg $SO_2$ eq.] | 0.29 | 13% | -67% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 29.38 | 19% | -64% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 27.05 | -23% | 82% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.07 | 0% | -15% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.27 | 15% | -67% |

# 4.3 Results base scenarios DAIRY *189mL-500mL BELGIUM*

## 4.3.1 Presentation of results

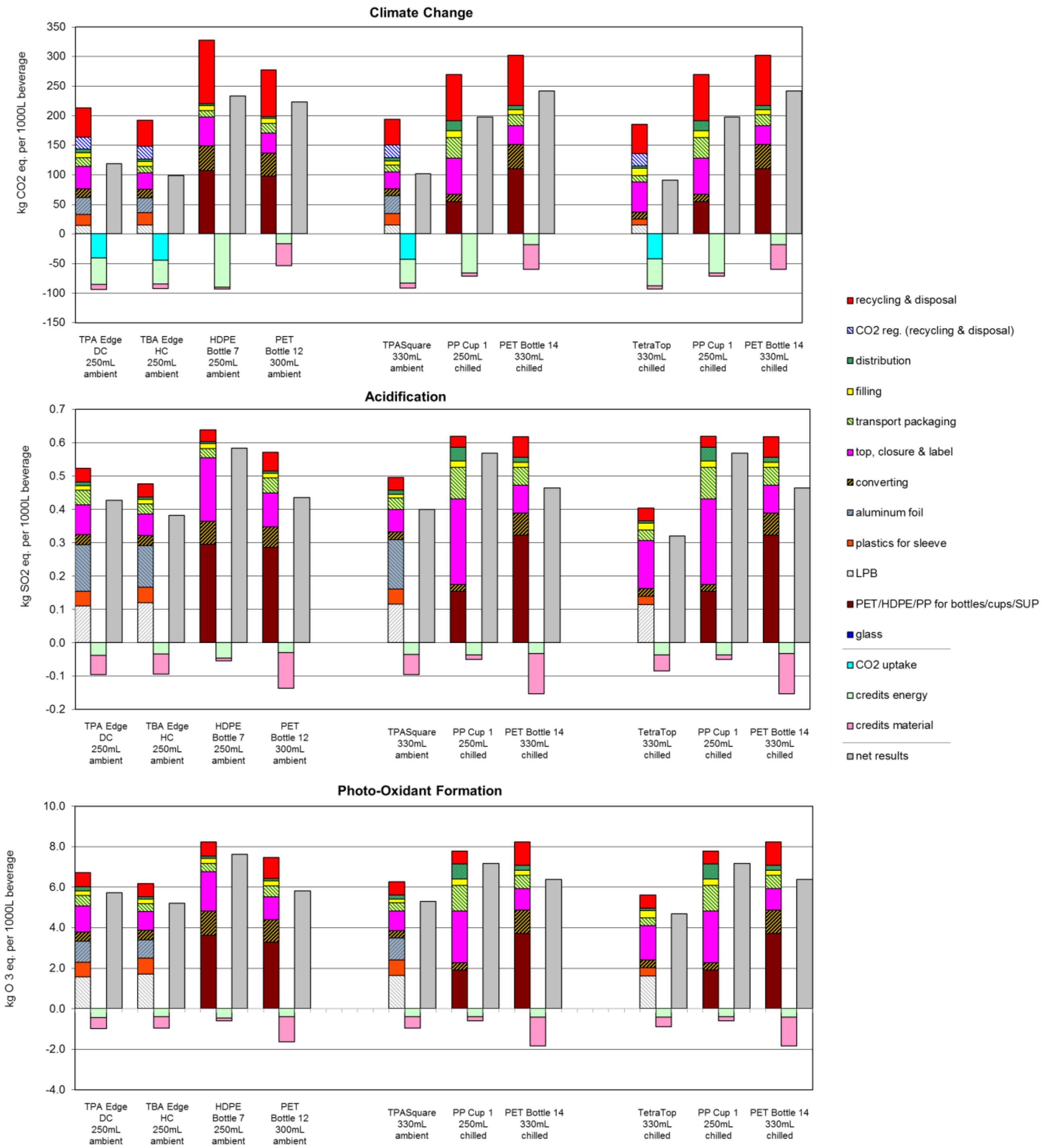



**Figure 23:** Indicator results for base scenarios of segment DAIRY 189mL-500mL BELGIUM, allocation factor 50% (Part 1)

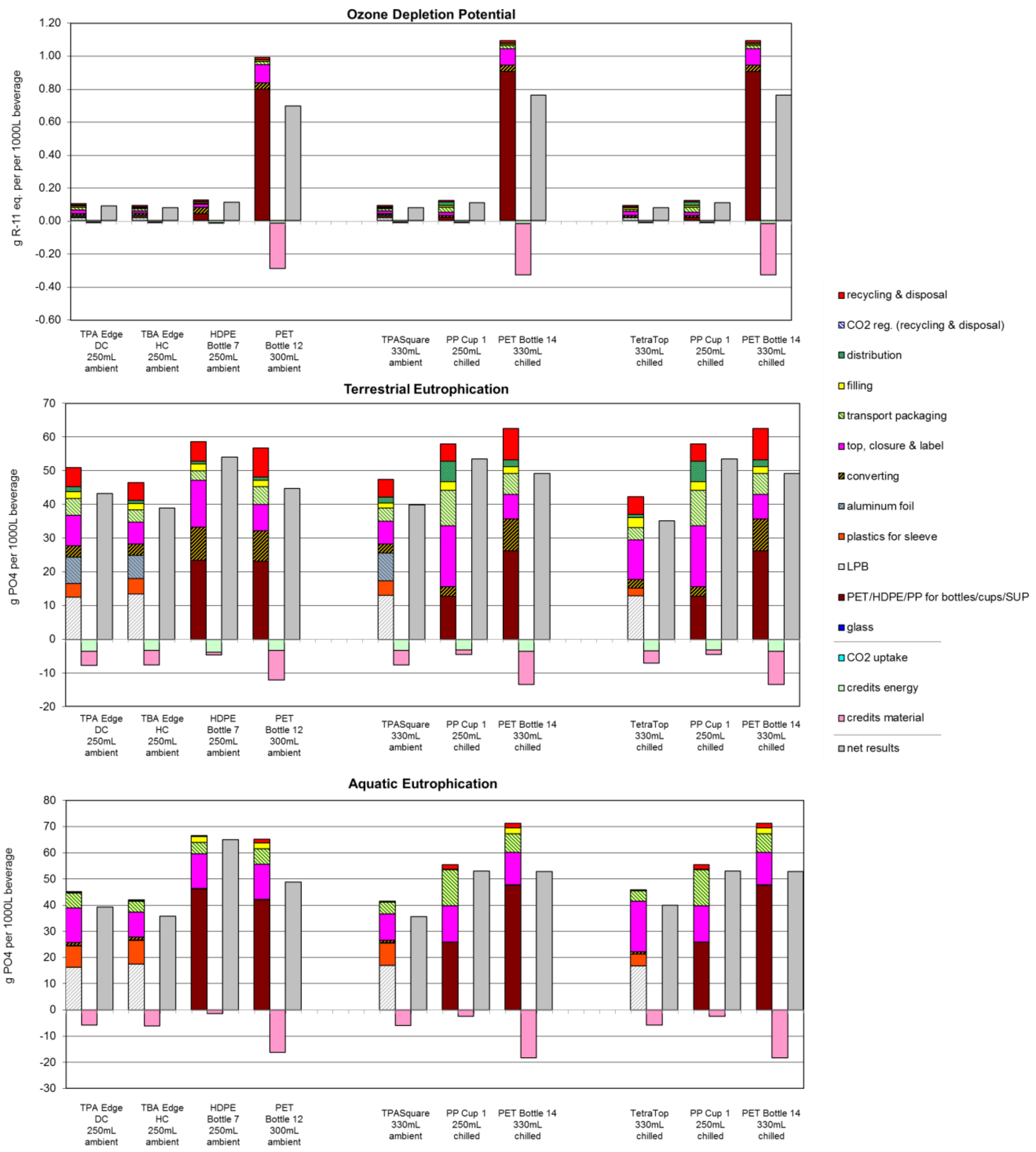



**Figure 24:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL BELGIUM**,, allocation factor 50% (Part 2)

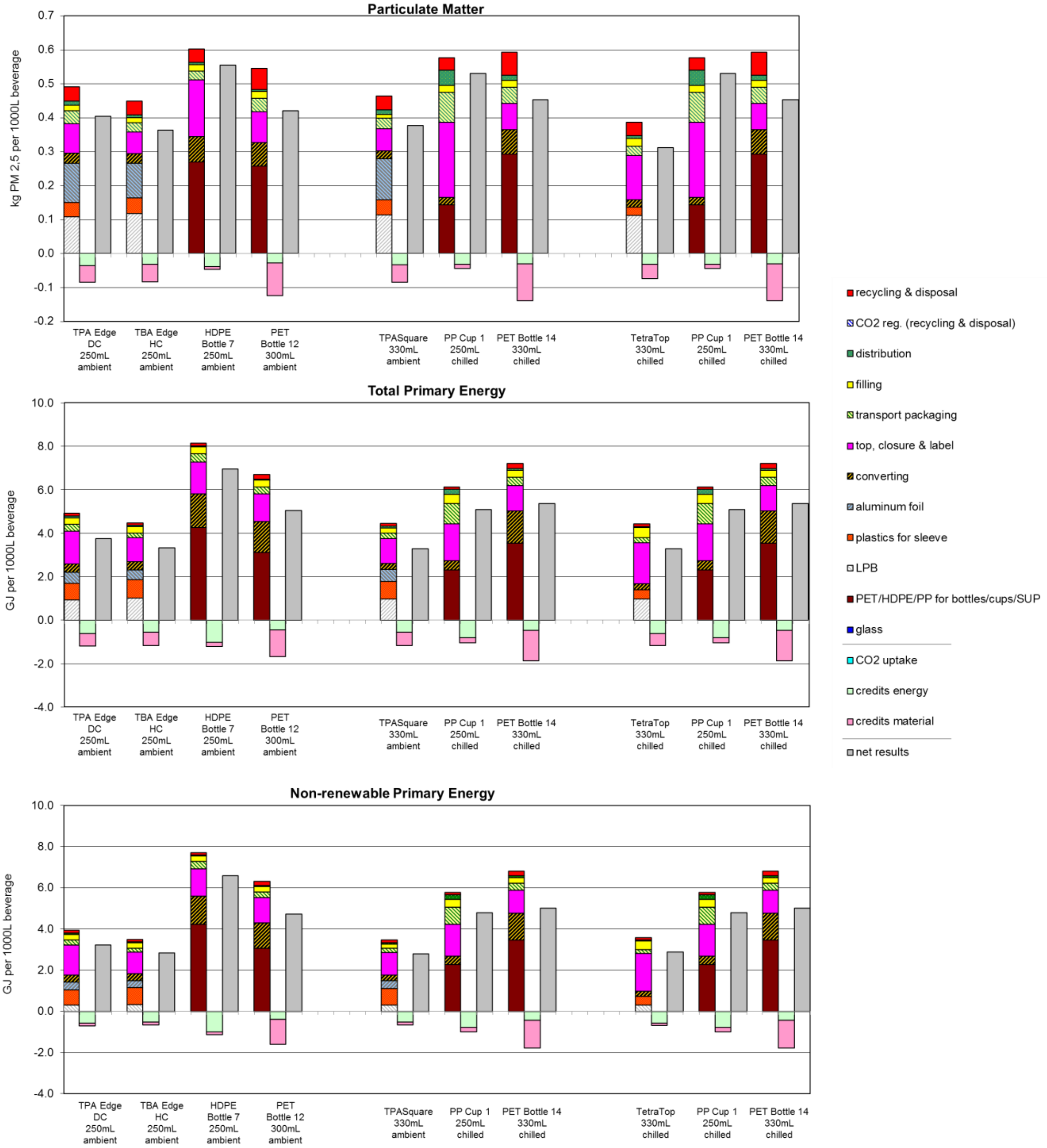



**Figure 25:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL BELGIUM**,, allocation factor 50% (Part 3)

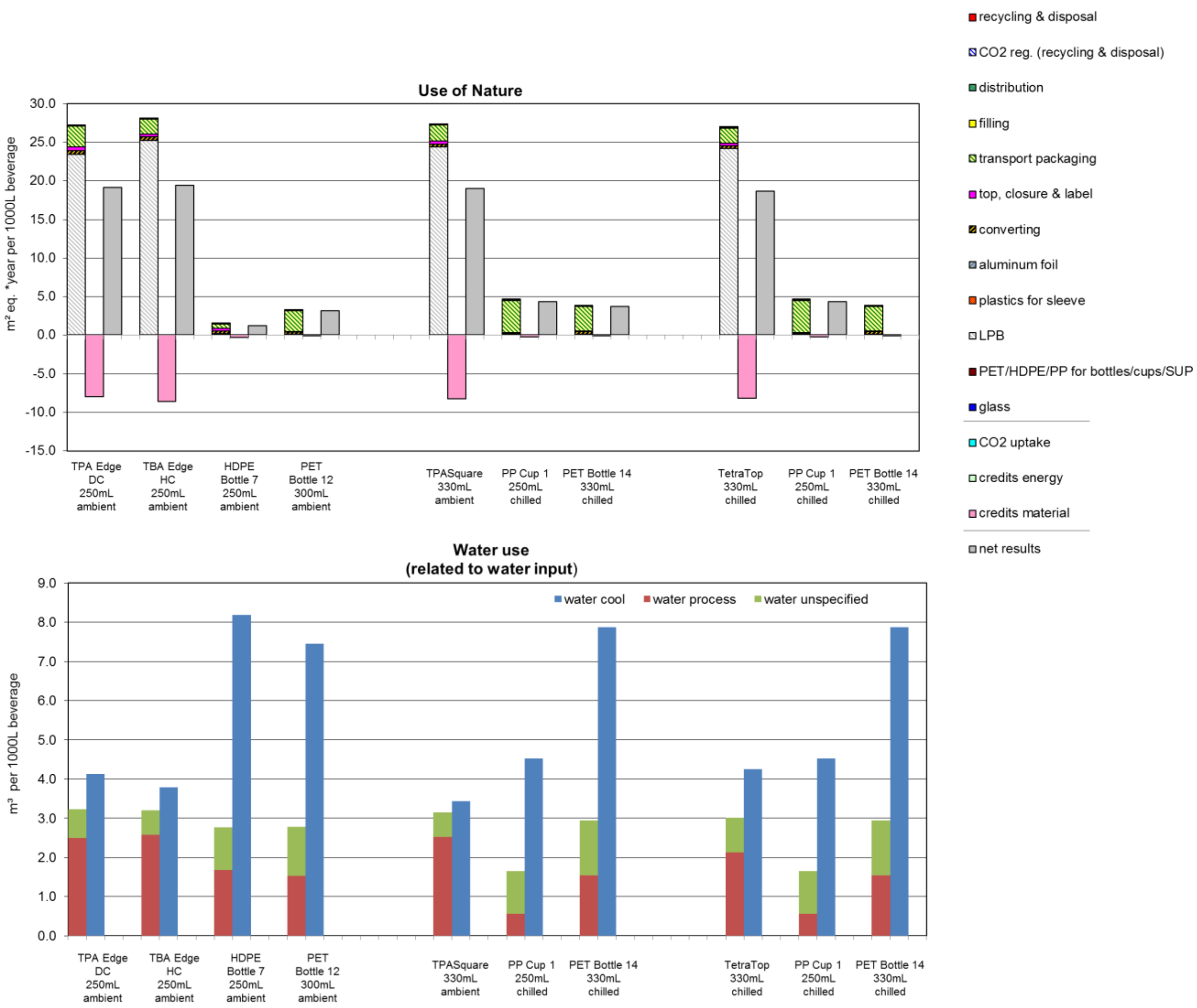



**Figure 26:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL BELGIUM**,, allocation factor 50% (Part 4)

**Table 46:** Category indicator results per impact category for base scenarios of **segment DAIRY 189mL-500mL BELGIUM (250-300mL)**-burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | TBA Edge HC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 191.66 | 169.41 | 326.48 | 276.64 |
| | CO2 (reg) | 20.38 | 21.74 | 0.00 | 0.00 |
| | Credits* | -52.62 | -48.53 | -94.07 | -54.09 |
| | $CO_2$ uptake | -41.61 | -44.82 | 0.00 | 0.00 |
| | Net results (∑) | 117.81 | 97.80 | 232.41 | 222.55 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.52 | 0.48 | 0.64 | 0.57 |
| | Credits* | -0.10 | -0.09 | -0.05 | -0.14 |
| | Net results (∑) | 0.43 | 0.38 | 0.58 | 0.43 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.70 | 6.17 | 8.22 | 7.46 |
| | Credits* | -1.00 | -0.98 | -0.62 | -1.65 |
| | Net results (∑) | 5.70 | 5.18 | 7.60 | 5.81 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.09 | 0.13 | 0.99 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.29 |
| | Net results (∑) | 0.09 | 0.08 | 0.11 | 0.70 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 50.93 | 46.56 | 58.66 | 56.71 |
| | Credits* | -7.72 | -7.61 | -4.61 | -12.02 |
| | Net results (∑) | 43.22 | 38.95 | 54.05 | 44.69 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 44.97 | 41.85 | 66.37 | 65.05 |
| | Credits* | -5.72 | -6.10 | -1.52 | -16.24 |
| | Net results (∑) | 39.25 | 35.75 | 64.85 | 48.81 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.49 | 0.45 | 0.60 | 0.54 |
| | Credits* | -0.09 | -0.09 | -0.05 | -0.12 |
| | Net results (∑) | 0.40 | 0.36 | 0.55 | 0.42 |
| Total Primary Energy [GJ] | Burdens | 4.93 | 4.49 | 8.15 | 6.71 |
| | Credits* | -1.18 | -1.16 | -1.19 | -1.66 |
| | Net results (∑) | 3.75 | 3.34 | 6.96 | 5.05 |
| Non-renewable primary energy [GJ] | Burdens | 3.92 | 3.49 | 7.69 | 6.31 |
| | Credits* | -0.70 | -0.66 | -1.13 | -1.60 |
| | Net results (∑) | 3.22 | 2.83 | 6.57 | 4.72 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.11 | 28.00 | 1.48 | 3.17 |
| | Credits* | -8.04 | -8.65 | -0.37 | -0.09 |
| | Net results (∑) | 19.07 | 19.35 | 1.11 | 3.09 |
| Water use [$m^3$] | Water cool | 4.13 | 3.79 | 8.18 | 7.46 |
| | Water process | 2.49 | 2.57 | 1.67 | 1.52 |
| | Water unspec | 0.73 | 0.63 | 1.10 | 1.26 |

*material and energy credits

**Table 47:** Category indicator results per impact category for base scenarios of **segment DAIRY 189mL-500mL BELGIUM (330mL)**-burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 171.97 | 269.04 | 301.24 |
| | CO2 (reg) | 21.14 | 0.00 | 0.00 |
| | Credits* | -48.95 | -72.47 | -60.46 |
| | $CO_2$ uptake | -43.35 | 0.00 | 0.00 |
| | Net results (∑) | 100.81 | 196.57 | 240.78 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.50 | 0.62 | 0.62 |
| | Credits* | -0.10 | -0.05 | -0.15 |
| | Net results (∑) | 0.40 | 0.57 | 0.46 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.26 | 7.77 | 8.21 |
| | Credits* | -0.98 | -0.62 | -1.85 |
| | Net results (∑) | 5.27 | 7.15 | 6.37 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.09 | 0.12 | 1.09 |
| | Credits* | -0.01 | -0.01 | -0.33 |
| | Net results (∑) | 0.08 | 0.11 | 0.76 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 47.47 | 58.01 | 62.63 |
| | Credits* | -7.63 | -4.46 | -13.45 |
| | Net results (∑) | 39.85 | 53.55 | 49.18 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 41.38 | 55.30 | 71.08 |
| | Credits* | -5.92 | -2.46 | -18.37 |
| | Net results (∑) | 35.46 | 52.83 | 52.71 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.46 | 0.57 | 0.59 |
| | Credits* | -0.09 | -0.05 | -0.14 |
| | Net results (∑) | 0.38 | 0.53 | 0.45 |
| Total Primary Energy [GJ] | Burdens | 4.45 | 6.14 | 7.23 |
| | Credits* | -1.15 | -1.04 | -1.86 |
| | Net results (∑) | 3.30 | 5.10 | 5.37 |
| Non-renewable primary energy [GJ] | Burdens | 3.45 | 5.76 | 6.80 |
| | Credits* | -0.66 | -0.98 | -1.78 |
| | Net results (∑) | 2.79 | 4.78 | 5.01 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.28 | 4.55 | 3.75 |
| | Credits* | -8.37 | -0.28 | -0.09 |
| | Net results (∑) | 18.91 | 4.28 | 3.66 |
| Water use [$m^3$] | Water cool | 3.44 | 4.52 | 7.87 |
| | Water process | 2.53 | 0.56 | 1.54 |
| | Water unspec | 0.62 | 1.08 | 1.40 |

*material and energy credits

**Table 48:** Category indicator results per impact category for base scenarios of **segment DAIRY 189mL-500mL BELGIUM (330mL chilled)**, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TetraTop 330mL chilled | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 163.62 | 269.04 | 301.24 |
| | CO2 (reg) | 20.65 | 0.00 | 0.00 |
| | Credits* | -50.92 | -72.47 | -60.46 |
| | $CO_2$ uptake | -42.96 | 0.00 | 0.00 |
| | Net results (∑) | 90.38 | 196.57 | 240.78 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.40 | 0.62 | 0.62 |
| | Credits* | -0.08 | -0.05 | -0.15 |
| | Net results (∑) | 0.32 | 0.57 | 0.46 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 5.60 | 7.77 | 8.21 |
| | Credits* | -0.92 | -0.62 | -1.85 |
| | Net results (∑) | 4.68 | 7.15 | 6.37 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.09 | 0.12 | 1.09 |
| | Credits* | -0.01 | -0.01 | -0.33 |
| | Net results (∑) | 0.08 | 0.11 | 0.76 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 42.33 | 58.01 | 62.63 |
| | Credits* | -7.10 | -4.46 | -13.45 |
| | Net results (∑) | 35.23 | 53.55 | 49.18 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.75 | 55.30 | 71.08 |
| | Credits* | -5.83 | -2.46 | -18.37 |
| | Net results (∑) | 39.91 | 52.83 | 52.71 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.39 | 0.57 | 0.59 |
| | Credits* | -0.07 | -0.05 | -0.14 |
| | Net results (∑) | 0.31 | 0.53 | 0.45 |
| Total Primary Energy [GJ] | Burdens | 4.44 | 6.14 | 7.23 |
| | Credits* | -1.15 | -1.04 | -1.86 |
| | Net results (∑) | 3.29 | 5.10 | 5.37 |
| Non-renewable primary energy [GJ] | Burdens | 3.57 | 5.76 | 6.80 |
| | Credits* | -0.68 | -0.98 | -1.78 |
| | Net results (∑) | 2.89 | 4.78 | 5.01 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.90 | 4.55 | 3.75 |
| | Credits* | -8.29 | -0.28 | -0.09 |
| | Net results (∑) | 18.61 | 4.28 | 3.66 |
| Water use [$m^3$] | Water cool | 4.25 | 4.52 | 7.87 |
| | Water process | 2.13 | 0.56 | 1.54 |
| | Water unspec | 0.88 | 1.08 | 1.40 |

*material and energy credits

### 4.3.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the DAIRY 189mL-500mL 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’ (36%-42%) and ‘Use of Nature’ (86%-90%). It is also relevant regarding ‘Photo-Oxidant Formation’ (23%-29%), ‘Acidification’ (21%-28%), ‘Terrestrial Eutrophication’ (25%-30%), ‘Particulate Matter’ (22%-29%) and also the consumption of ‘Total Primary Energy’ (19%-23%).

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 SO2, thus contributing considerably to the acidifying potential.

The required energy for paper production mainly originates from 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 ambient beverage cartons systems shows burdens in most impact categories. Substantial burdens can be seen for the categories ‘Acidification’ (26%-30%) and ‘Particulate Matter’ (24%-26%). These result from SO2 and NOx emissions from the aluminium production. In case of chilled beverage cartons no aluminium layer is needed, and therefore no burdens are shown.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable (4%-22%) burdens in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the plastics (6%-11%) and LPB (6%-8%)

contribute about the same and the inventory category ‘Non-renewable Primary Energy’, where the plastics make up about a 12% - 24% of the total burdens.

The life cycle step ‘top, closure & label’ contributes considerably (14%-51%) to almost all impact categories due to the heavy closures in comparison to the weight of the sleeve materials. For the Tetra Top beverage carton system the step ‘top, closure & label’ contributes even the highest share of burdens in most categories because of its heavy top and cap made out of plastics.

The converting process generally plays a minor role (max. 13%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems shows minor impact shares (5%-17%) in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max 13%) for all beverage carton systems in all categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (33%-28%), ‘Photo-Oxidant Formation’ (10%-12%), ‘Terrestrial Eutrophication‘ (11%-12%), ‘Acidification’ (8%-10%) and ‘Particulate Matter’ (9%-10%). 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. The contributions to the impact categories ‘Acidification’, and ‘Terrestrial eutrophication’ are mainly caused by NO2 emissions from incineration plants and cement kilns.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative CO2 emissions from recycling and disposal processes. In case of beverage cartons in Belgium in this segment these derive mainly from the incineration of paper. They play an important role for the results of all beverage carton systems in the impact category ‘Climate Change’. Together with the fossil-based CO2 emissions of the life cycle step ‘recycling & disposal’. They represent the total CO2 emissions from the packaging’s end-of-life.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits from material recycling are higher than energy credits in all impact categories except ‘Climate Change’ as in Belgium 90% of the beverage cartons are recycled. Material credits for ‘Climate Change’ are low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of CO2 by trees harvested for the production of paperboard 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. 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative CO2.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY 189mL-500mL 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. This is true for PET and HDPE bottles as well as for bottles in both sub-segments: chilled and ambient.

Differences can be observed depending on the kind of plastic used, though. For most impact categories the burdens from plastic production (life cycle step 'PET/HDPE/PP for bottles/cups/SUP' in the graphs) are higher for the HDPE bottle than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows a comparatively low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

The 'converting' process of all regarded bottles shows considerable shares of impacts (3%-31%) in all categories apart from 'Aquatic Eutrophication'. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows relevant impact shares (9%-30% in most categories mainly attributed to the different plastics used for the closures. High shares of impact (15%-30%) are seen for the HDPE Bottle 7 due to the additional aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems show a high share of impact (up to 85%) for 'Use of Nature' and minor shares of impacts (2%-10%) in the other categories. In case of HDPE Bottle 7 for most categories the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets. In the cases of PET Bottle 12 and PET Bottle 14 all relevant emissions derive from production of paper for trays and slipsheets as well as stretch foil production.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 7%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the fossil-based plastic bottles' 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (28%-33%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is high in most categories. With a recycling rate of 75% for the clear plastic bottles PET Bottle 12 and PET Bottle 14, the received material credits are higher than the credits for energy. For the white opaque HDPE Bottle 7 no primary granulate is credited as they are incinerated in MSWIs. The received material credits for this bottle are negligible compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

**PP cups** (specifications see section 2.2.2)

In the regarded PP Cup 1 system in the DAIRY 189mL-500mL segment, the biggest part of the environmental burdens (16%-47%) are caused by the production of the base materials of the cups in most impact and inventory categories (next to the production of closures and labels with shares of burden from 16% until 42%).

The 'converting' process of the regarded PP Cup 1 shows  minor shares of impacts (max. 10%) in all categories apart from 'Aquatic Eutrophication'. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows high impacts (16%-42%) in most categories attributed to the different plastics and especially aluminium used for the closures.

The production and provision of 'transport packaging' for the PP Cup 1 show a high share of impact (91%) for 'Use of Nature' and considerable shares (13%-26%) of impacts in all other categories. The relevant emissions derive from shrink foil production and from the production of paper for trays and slipsheets.

The life cycle step 'filling' shows only small shares of burdens (max 9%) for the PP cup 1 in most impact categories. Therefore this step plays not an important role for the overall results in any category.

The life cycle step 'distribution' shows considerable shares burdens (max 17%) in most impact categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The impact of the PP Cup's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (29%). The incineration of cups in MSWIs causes high greenhouse gas emissions. As the white opaque PP Cup 1 does not undergo a material recycling and there is almost no landfilling in Belgium, almost all of these cups are incinerated in MSWI plants.

The influence of credits on the net result is high in most categories. For the white opaque PP Cup 1 no primary granulate is credited as they are incinerated in MSWIs, the received material credits for this bottle are negligible compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

### 4.3.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 49:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of **TPA Edge DC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 117.81 | -49% | -47% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -20% | -87% |
| Acidification [kg $SO_2$ eq.] | 0.43 | -27% | -2% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.22 | -20% | -3% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.25 | -39% | -20% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.70 | -25% | -2% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | -27% | -4% |

**Table 50:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of **TBA Edge HC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TBA Edge HC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 97.80 | -58% | -56% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -30% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.38 | -35% | -12% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 38.95 | -28% | -13% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 35.75 | -45% | -27% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.18 | -32% | -11% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.36 | -35% | -14% |

**Table 51:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of **TPA Square DC 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 100.81 | -49% | -58% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -26% | -90% |
| Acidification [kg $SO_2$ eq.] | 0.40 | -30% | -14% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 39.85 | -26% | -19% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 35.46 | -33% | -33% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.27 | -26% | -17% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.38 | -29% | -17% |

**Table 52:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of **TT 330mL chilled …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TT 330mL chilled | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 90.38 | -54% | -62% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -27% | -90% |
| Acidification [kg $SO_2$ eq.] | 0.32 | -44% | -31% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.23 | -34% | -28% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.91 | -24% | -24% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.68 | -35% | -26% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | -41% | -31% |

# *4.4* Results base scenarios DAIRY (YOGHURT) *120mL-250mL BELGIUM*

## 4.4.1 Presentation of results

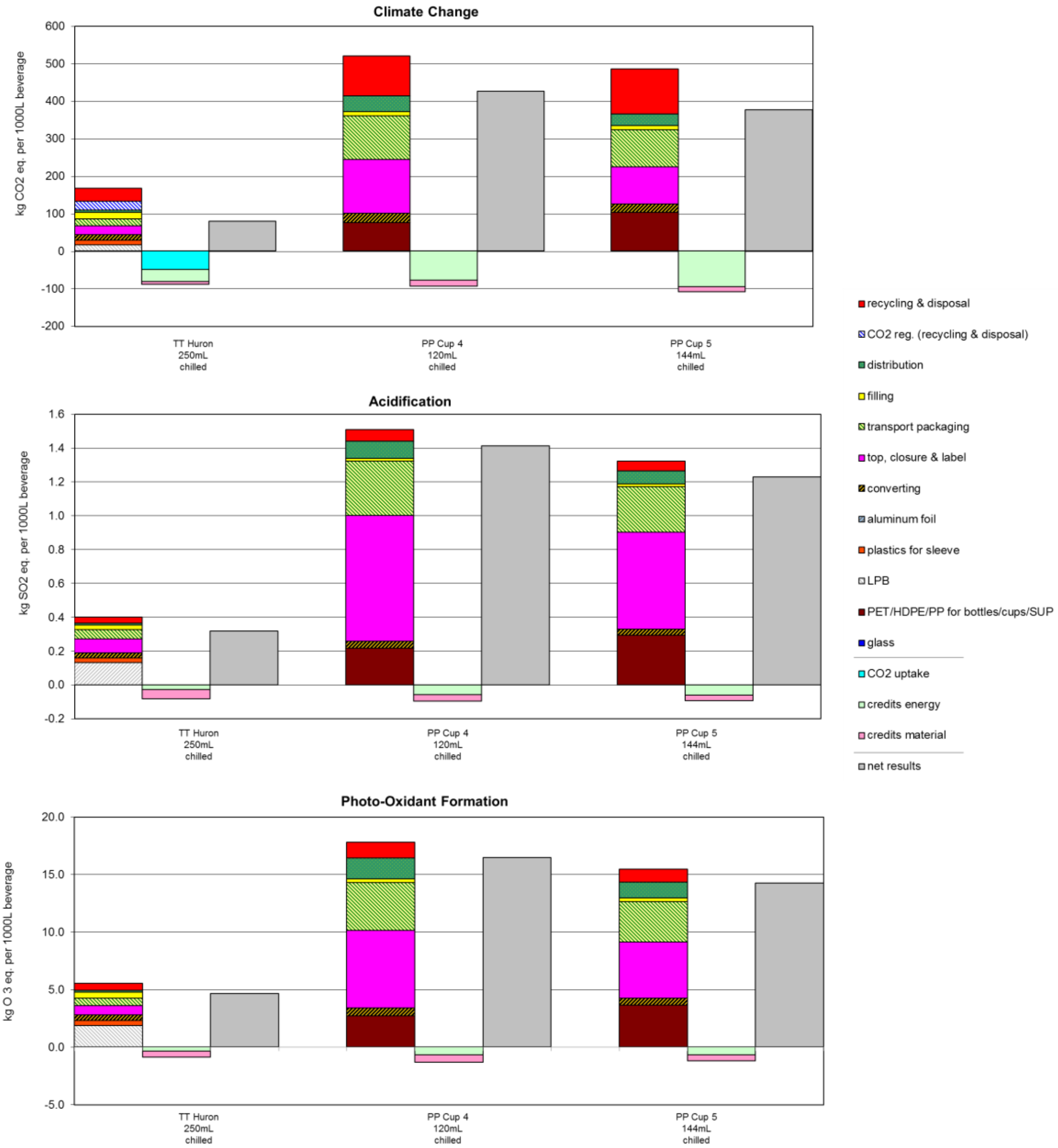



**Figure 27:** Indicator results for base scenarios of **DAIRY (YOGHURT) 120mL-250mL BELGIUM**, allocation factor 50% (Part 1)

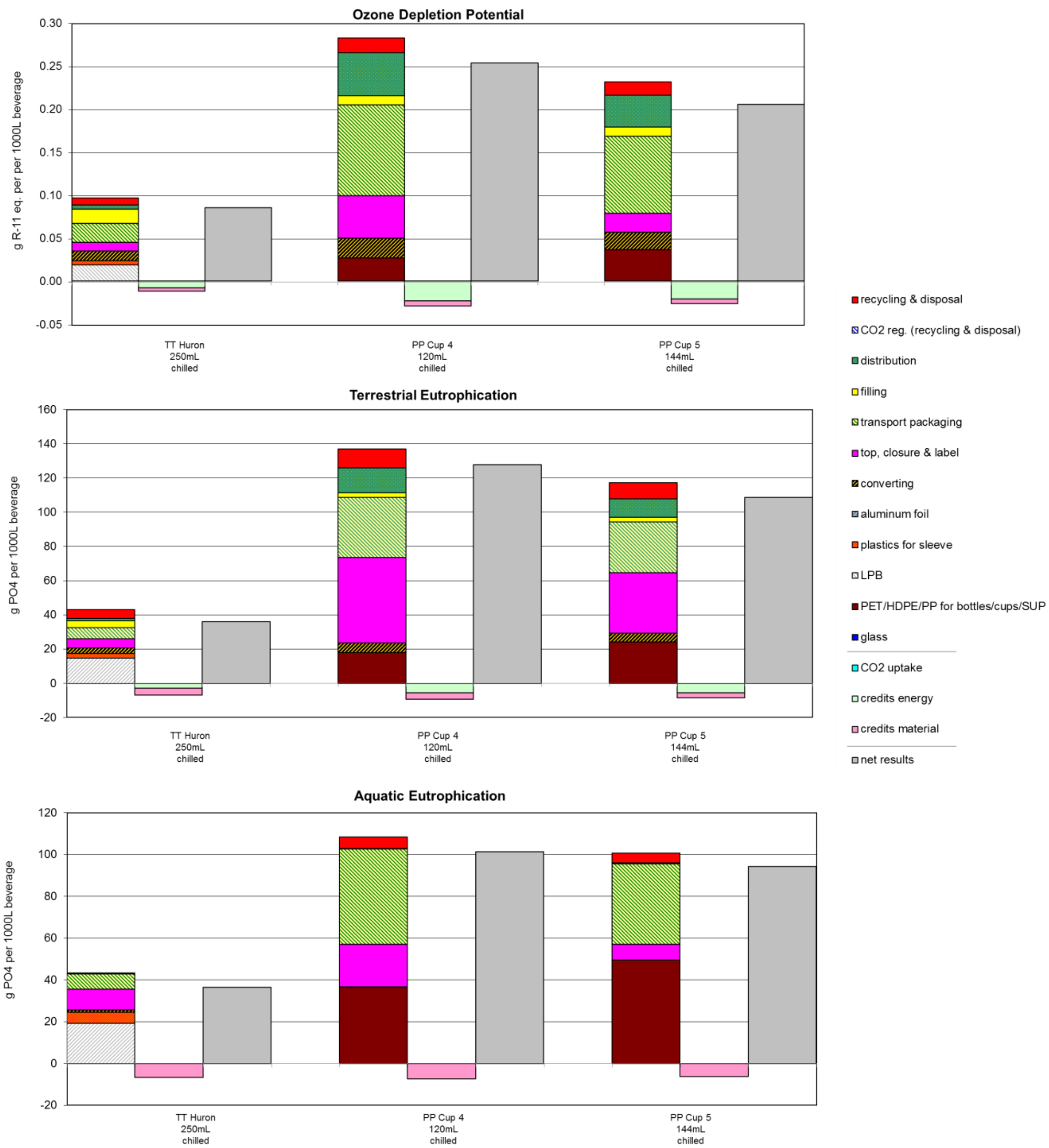



**Figure 28:** Indicator results for base scenarios of **DAIRY (YOGHURT) 120mL-250mL BELGIUM**, allocation factor 50% (Part 2)

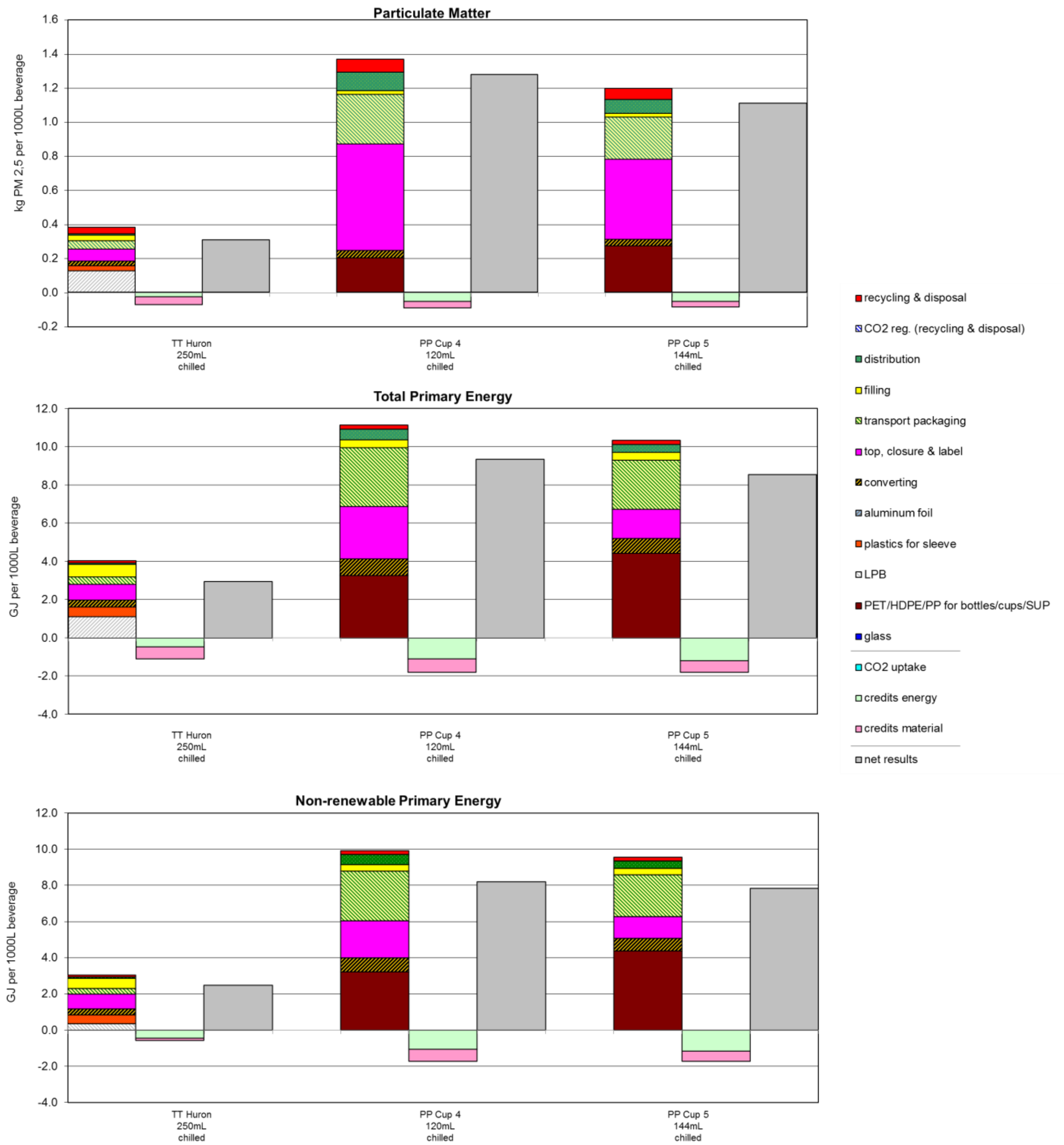



**Figure 29:** Indicator results for base scenarios of DAIRY (YOGHURT) 120mL-250mL BELGIUM, allocation factor 50% (Part 3)

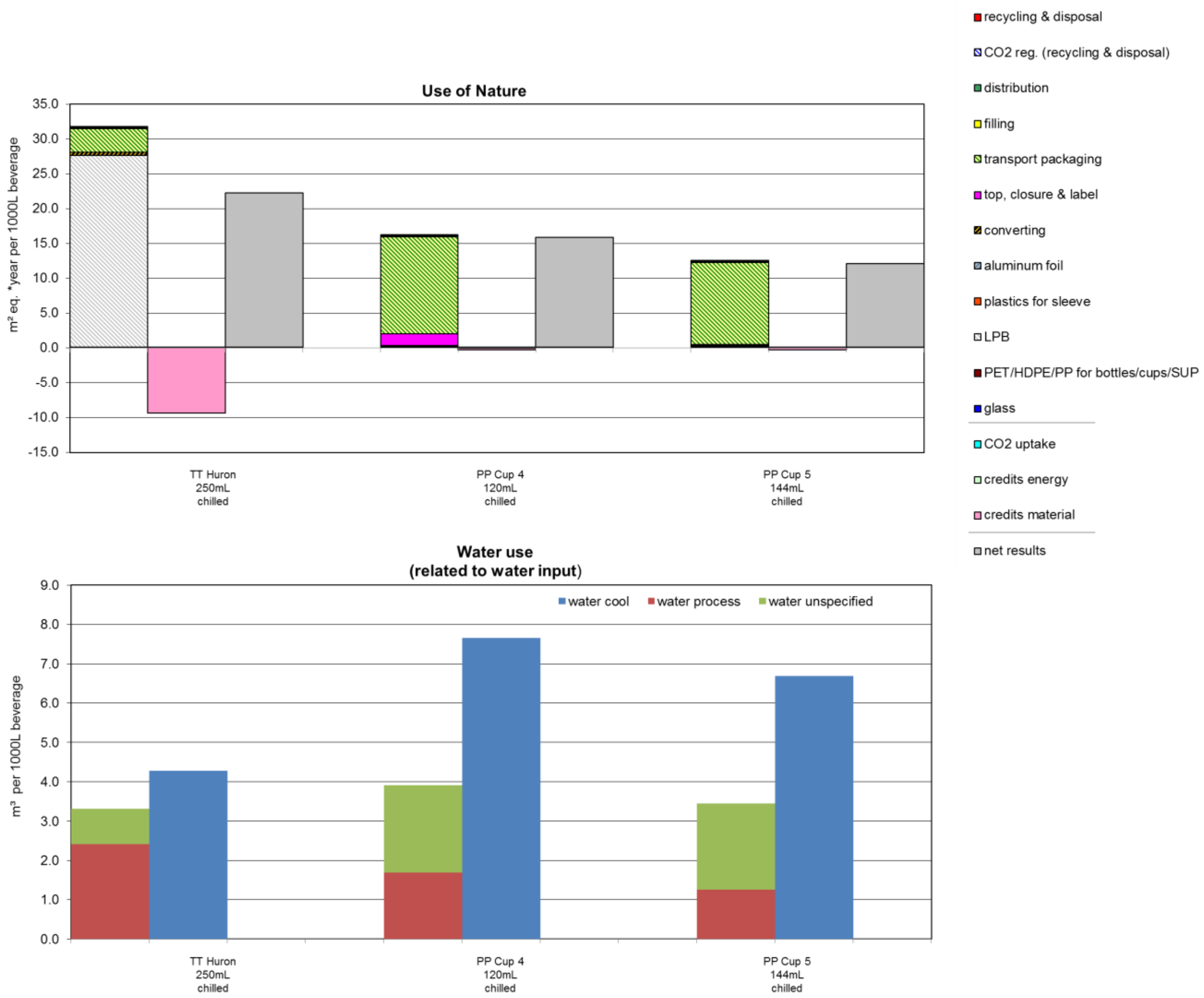



**Figure 30:** Indicator results for base scenarios of **DAIRY (YOGHURT) 120mL-250mL BELGIUM**, allocation factor 50% (Part 4)

**Table 53:** Category indicator results per impact category for base scenarios of **DAIRY (YOGHURT) 120mL-250mL BELGIUM**- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TT Huron 250mL chilled | PP Cup 4 120mL chilled | PP Cup 5 144mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 143.97 | 519.63 | 485.44 |
| | CO2 (reg) | 23.64 | 0.00 | 0.00 |
| | Credits* | -39.54 | -94.45 | -109.07 |
| | $CO_2$ uptake | -49.06 | 0.00 | 0.00 |
| | Net results (∑) | 79.01 | 425.18 | 376.37 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.40 | 1.51 | 1.32 |
| | Credits* | -0.08 | -0.10 | -0.09 |
| | Net results (∑) | 0.32 | 1.41 | 1.23 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 5.53 | 17.78 | 15.45 |
| | Credits* | -0.89 | -1.33 | -1.22 |
| | Net results (∑) | 4.64 | 16.45 | 14.22 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.28 | 0.23 |
| | Credits* | -0.01 | -0.03 | -0.03 |
| | Net results (∑) | 0.09 | 0.25 | 0.21 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 43.05 | 137.09 | 117.37 |
| | Credits* | -6.92 | -9.22 | -8.59 |
| | Net results (∑) | 36.12 | 127.87 | 108.77 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 43.11 | 108.38 | 100.47 |
| | Credits* | -6.61 | -7.22 | -6.26 |
| | Net results (∑) | 36.50 | 101.16 | 94.21 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.38 | 1.37 | 1.19 |
| | Credits* | -0.07 | -0.09 | -0.09 |
| | Net results (∑) | 0.31 | 1.28 | 1.11 |
| Total Primary Energy [GJ] | Burdens | 4.04 | 11.15 | 10.36 |
| | Credits* | -1.09 | -1.79 | -1.81 |
| | Net results (∑) | 2.95 | 9.35 | 8.55 |
| Non-renewable primary energy [GJ] | Burdens | 3.05 | 9.90 | 9.55 |
| | Credits* | -0.56 | -1.70 | -1.72 |
| | Net results (∑) | 2.49 | 8.20 | 7.84 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 31.61 | 16.13 | 12.42 |
| | Credits* | -9.45 | -0.36 | -0.40 |
| | Net results (∑) | 22.17 | 15.77 | 12.01 |
| Water use [$m^3$] | Water cool | 4.27 | 7.66 | 6.68 |
| | Water process | 2.41 | 1.69 | 1.26 |
| | Water unspec | 0.90 | 2.23 | 2.19 |

*material and energy credits

### 4.4.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton system regarded in the YOGHURT 120mL-250mL 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' (44%) and 'Use of Nature' (87%). It is also relevant regarding 'Photo-Oxidant Formation' (33%), 'Acidification' (33%), 'Terrestrial Eutrophication' (34%), 'Particulate Matter' (33%) and also the consumption of 'Total Primary Energy' (28%).

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 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 step production of 'aluminium foil' for the sleeves shows no results as the beverage carton in this segment is chilled and therefore doesn't have an aluminium layer.

The production of 'plastics for sleeve' of the beverage cartons shows minor shares of burdens (max. 16%) in all categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are 'Climate Change' and the inventory category 'Non-renewable Primary Energy', where the plastics and LPB contribute about the same.

The life cycle step ‘top, closure & label’ contributes considerably (13%-26%) to almost all impact categories due to the relatively heavy top in comparison to the weight of the sleeve materials.

The converting process generally plays a minor role (max 12%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems shows considerable (9%-23%) impacts in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max 17%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact category ‘Climate Change’ (35%). 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.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in Belgium in this segment these derive mainly from the incineration of paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits from material recycling are higher than energy credits in all impact categories except ‘Climate Change’ as in Belgium 90% of the beverage cartons are recycled. Material credits for ‘Climate Change’ are low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard 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. 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**PP cups** (specifications see section 2.2.2)

In the regarded PP cup  systems in the YOGHURT 120mL-250mL segment, the major shares of the environmental burdens are caused by the production of the base materials of the cups (1%-34%), the life cycle step ‘top, closure & label’ (1%-49%) and ‘Transport Packaging’ (20%-86%).

The ‘converting’ process of the regarded PP Cup 1 shows a small shares of impacts (max 9%) in all categories apart from ‘Aquatic Eutrophication’ with less than 1% share of burdens. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows high impacts (1%-49%) in most categories attributed to the aluminium used for the pull taps. In the case of PP Cup 4 additionally burdens derive from the thick paper label.

The production and provision of ‘transport packaging’ for the PP cups shows high shares of impacts (20%-86%) in all categories. The relevant emissions derive from the production of paper for trays and slipsheets as well as stretch foil production.

The life cycle step ‘filling’ shows only small shares of burdens (max. 5%) for the PP cups in all categories. Therefore this step plays not an important role for the overall results in any category.

The life cycle step ‘distribution’ shows considerable shares of burdens (1%-18%) in most impact categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of yoghurt.

The impact of the PP Cup’s ‘recycling & disposal’ life cycle step is most noticeable regarding ‘Climate Change’ (21%-25%). The incineration of cups in MSWIs causes high greenhouse gas emissions. As the white opaque PP cups do not undergo a material recycling and there is almost no landfilling in Belgium, almost all of these cups are incinerated in MSWI plants.

The influence of credits on the net result is high in most categories. For the white opaque PP Cup 1 no primary granulate is credited as they are incinerated in MSWIs, the received material credits for cup material are negligible compared to the credits for energy. The larger amount of material credits derives from the recycling of the large amount of LDPE foil from tertiary packaging. The energy credits of all cups mainly originate from the incineration plants.

### 4.4.3 Comparison between packaging systems

The following table shows the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 54:** Comparison of net results: **TT Huron 250mL** versus its competing alternative packaging systems **DAIRY (YOGHURT) 120mL-250mL BELGIUM**

| The net results of **TT Huron 250mL chilled …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TT Huron 250mL chilled | PP Cup 4 120mL chilled | PP Cup 5 144mL chilled |
| Climate Change [kg $CO_2$eq] | 79.01 | -81% | -79% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -66% | -58% |
| Acidification [kg $SO_2$ eq.] | 0.32 | -77% | -74% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.12 | -72% | -67% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 36.50 | -64% | -61% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.64 | -72% | -67% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | -76% | -72% |

# 4.5 Results base scenarios JNSD 200ml-330ml BELGIUM

## 4.5.1 Presentation of results

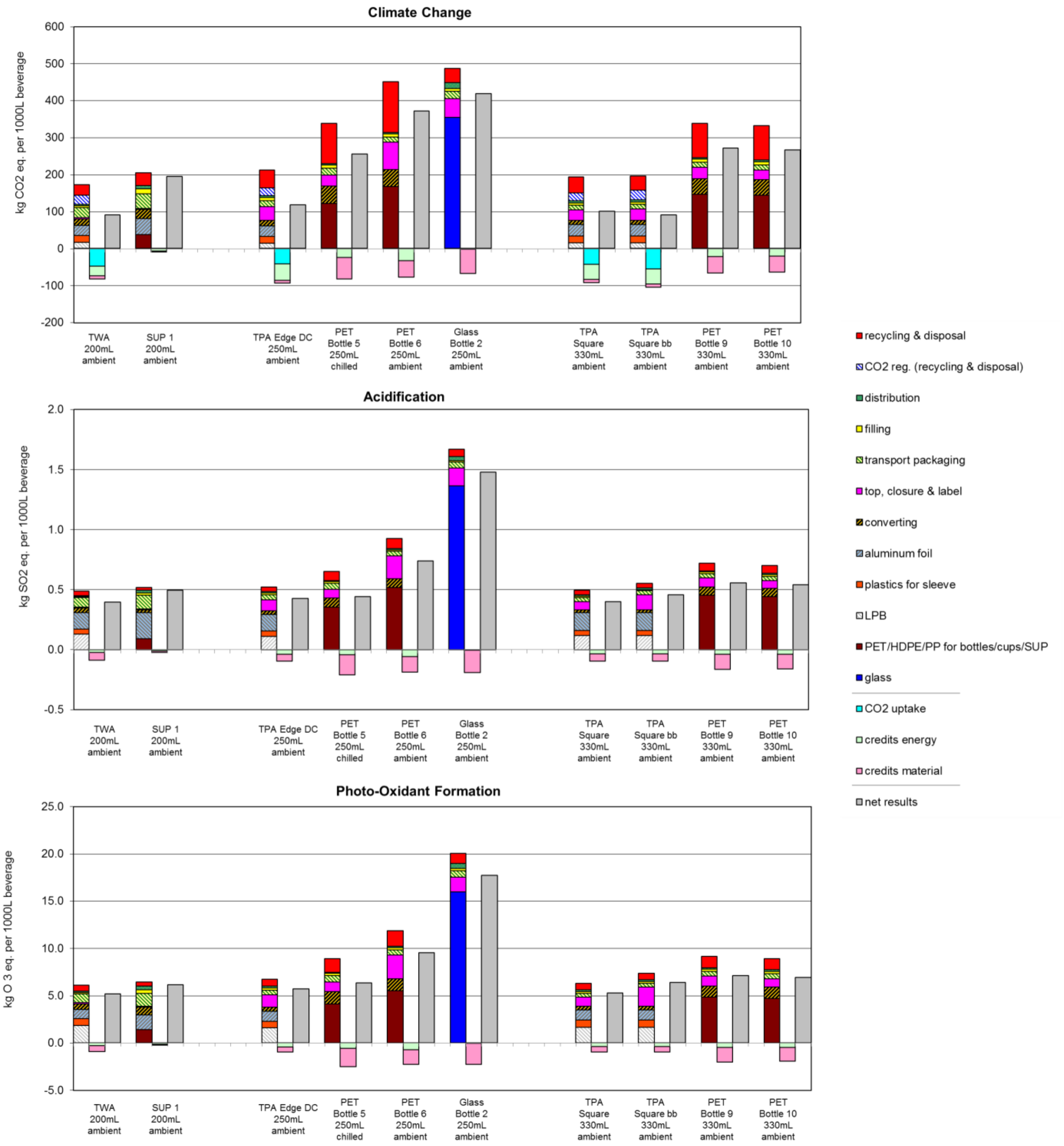



**Figure 31:** Indicator results for base scenarios of **segment JNSD 200ml-330ml BELGIUM**, allocation factor 50% (Part 1)

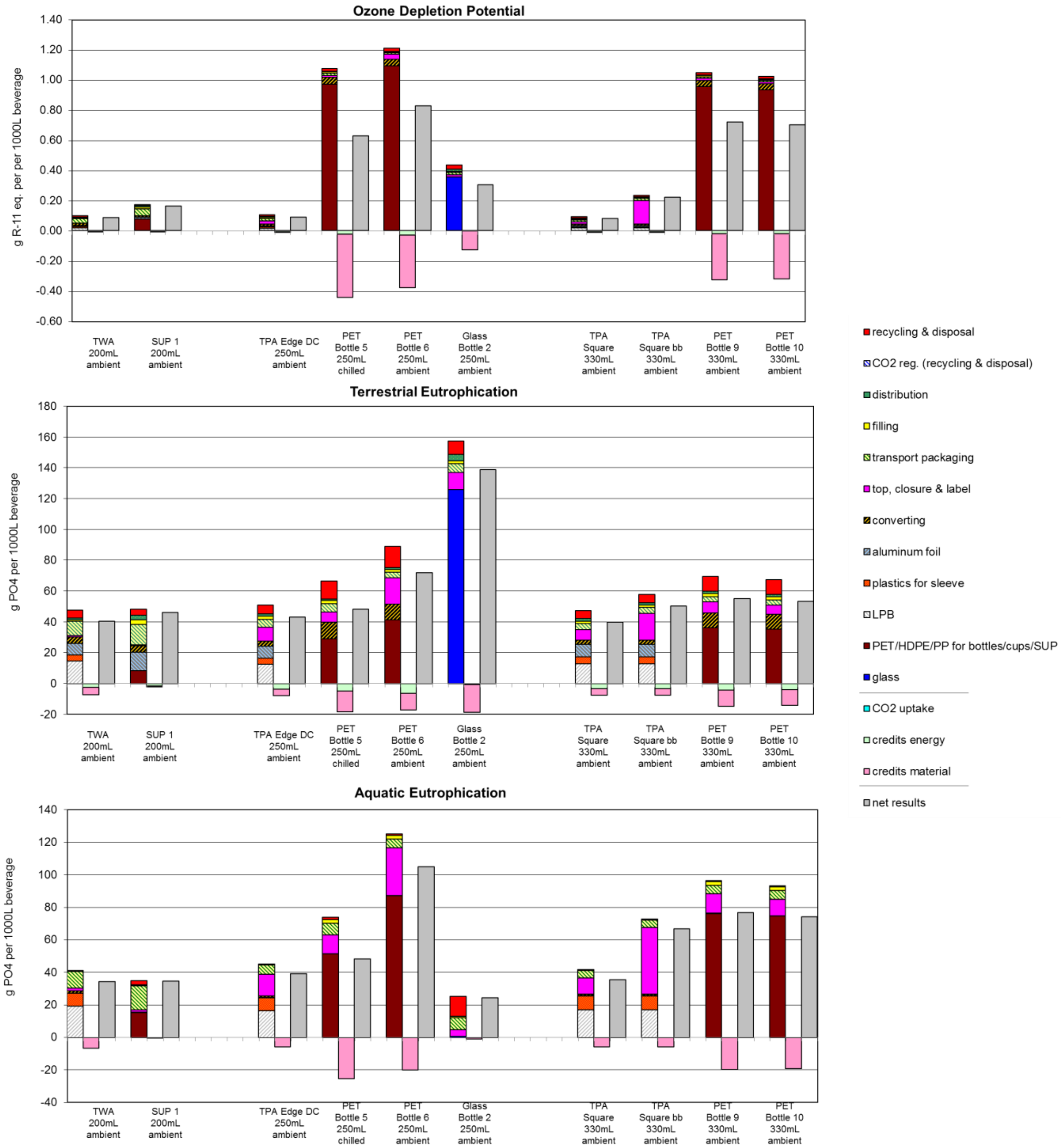



**Figure 32:** Indicator results for base scenarios of **segment JNSD 200ml-330ml BELGIUM**, allocation factor 50% (Part 2)

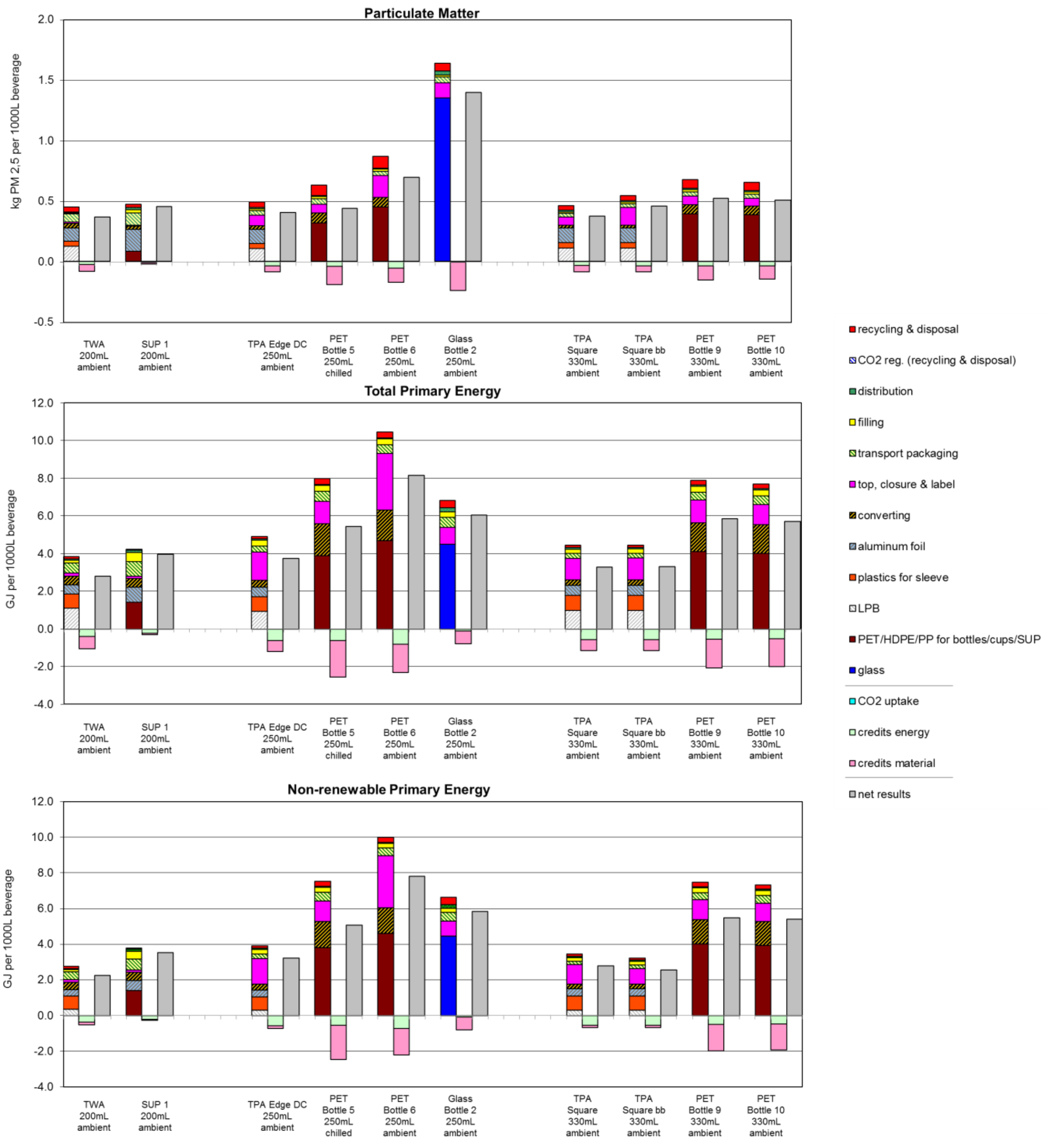



**Figure 33:** Indicator results for base scenarios of **segment JNSD 200ml-330ml BELGIUM**, allocation factor 50% (Part 3)

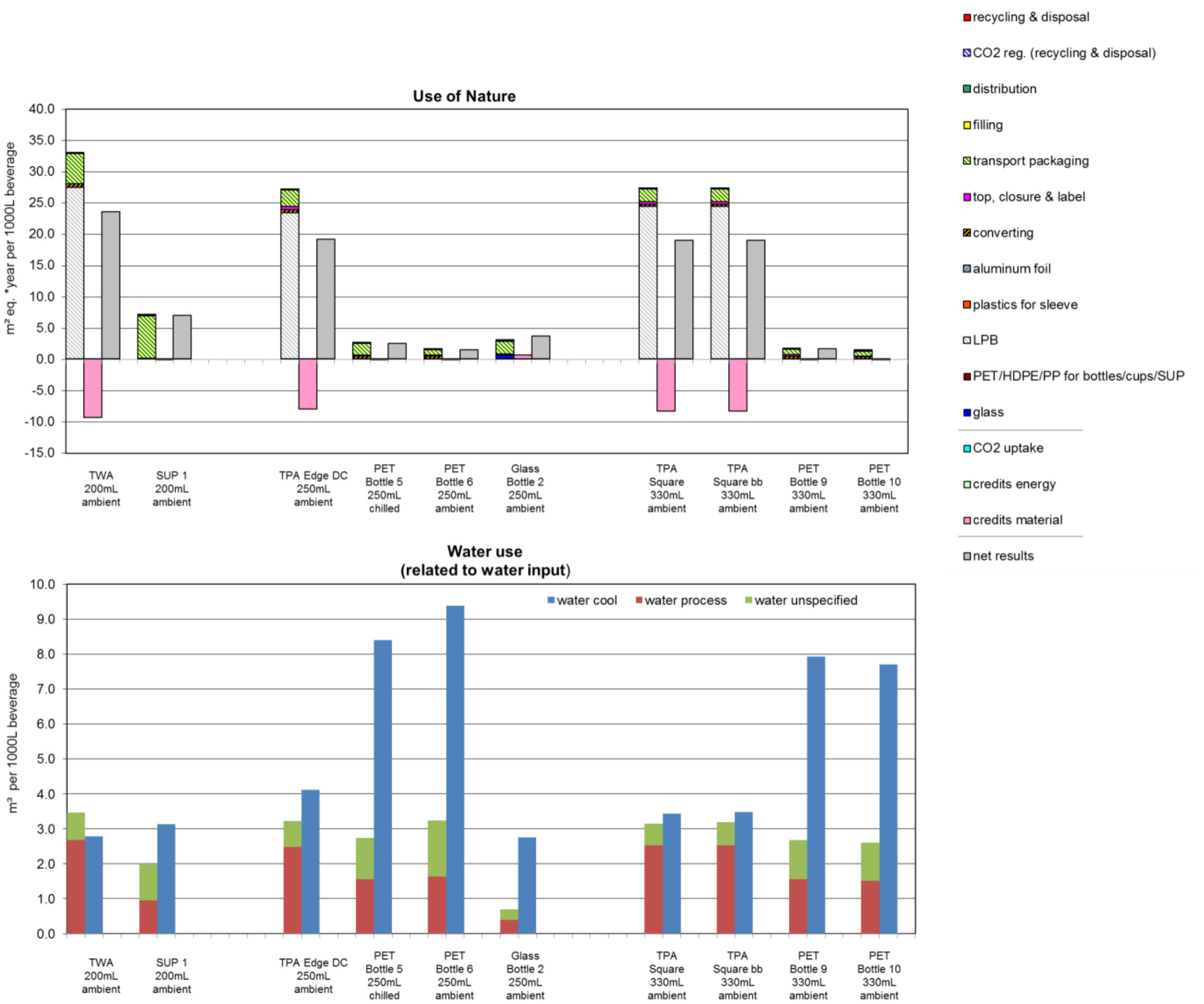



**Figure 34:** Indicator results for base scenarios of **segment JNSD 200ml-330ml BELGIUM**, allocation factor 50% (Part 4)

**Table 55:** Category indicator results per impact category for base scenarios of **segment JNSD 200ml-330ml BELGIUM (200mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TWA 200mL ambient | SUP 1 200mL ambient |
|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 148.62 | 203.50 |
| | CO2 (reg) | 23.85 | 0.00 |
| | Credits* | -33.55 | -9.70 |
| | $CO_2$ uptake | -48.86 | 0.00 |
| | Net results (∑) | 90.05 | 193.80 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.48 | 0.52 |
| | Credits* | -0.09 | -0.02 |
| | Net results (∑) | 0.40 | 0.49 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.07 | 6.43 |
| | Credits* | -0.93 | -0.28 |
| | Net results (∑) | 5.15 | 6.15 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.17 |
| | Credits* | -0.01 | -0.01 |
| | Net results (∑) | 0.09 | 0.16 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 47.69 | 48.23 |
| | Credits* | -7.19 | -2.16 |
| | Net results (∑) | 40.50 | 46.07 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 40.87 | 34.89 |
| | Credits* | -6.59 | -0.34 |
| | Net results (∑) | 34.28 | 34.55 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.45 | 0.47 |
| | Credits* | -0.08 | -0.02 |
| | Net results (∑) | 0.37 | 0.45 |
| Total Primary Energy [GJ] | Burdens | 3.85 | 4.25 |
| | Credits* | -1.05 | -0.28 |
| | Net results (∑) | 2.80 | 3.97 |
| Non-renewable primary energy [GJ] | Burdens | 2.76 | 3.78 |
| | Credits* | -0.50 | -0.24 |
| | Net results (∑) | 2.26 | 3.54 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 32.89 | 7.01 |
| | Credits* | -9.41 | -0.06 |
| | Net results (∑) | 23.47 | 6.95 |
| Water use [$m^3$] | Water cool | 2.79 | 3.14 |
| | Water process | 2.68 | 0.95 |
| | Water unspec | 0.79 | 1.03 |

*material and energy credits

**Table 56:** Category indicator results per impact category for base scenarios of **segment JNSD 200ml-330ml BELGIUM (250mL)** burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | PET Bottle 5 250mL chilled | PET Bottle 6 250mL ambient | Glass Bottle 2 250mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 191.53 | 337.77 | 449.79 | 485.99 |
| | CO2 (reg) | 20.37 | 0.00 | 0.00 | 0.00 |
| | Credits* | -52.61 | -82.64 | -78.10 | -68.14 |
| | $CO_2$ uptake | -41.60 | 0.00 | 0.00 | 0.00 |
| | Net results (∑) | 117.69 | 255.13 | 371.69 | 417.85 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.52 | 0.65 | 0.93 | 1.67 |
| | Credits* | -0.10 | -0.21 | -0.19 | -0.19 |
| | Net results (∑) | 0.43 | 0.44 | 0.74 | 1.48 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.69 | 8.89 | 11.84 | 19.99 |
| | Credits* | -1.00 | -2.54 | -2.30 | -2.31 |
| | Net results (∑) | 5.70 | 6.34 | 9.54 | 17.68 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 1.07 | 1.21 | 0.43 |
| | Credits* | -0.01 | -0.45 | -0.38 | -0.13 |
| | Net results (∑) | 0.09 | 0.63 | 0.83 | 0.30 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 50.90 | 66.62 | 88.98 | 157.46 |
| | Credits* | -7.72 | -18.35 | -16.96 | -18.67 |
| | Net results (∑) | 43.19 | 48.27 | 72.02 | 138.79 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 44.96 | 73.71 | 124.81 | 25.18 |
| | Credits* | -5.72 | -25.51 | -20.00 | -0.93 |
| | Net results (∑) | 39.24 | 48.20 | 104.81 | 24.26 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.49 | 0.63 | 0.87 | 1.64 |
| | Credits* | -0.09 | -0.19 | -0.17 | -0.24 |
| | Net results (∑) | 0.40 | 0.44 | 0.70 | 1.40 |
| Total Primary Energy [GJ] | Burdens | 4.93 | 7.99 | 10.46 | 6.84 |
| | Credits* | -1.18 | -2.55 | -2.30 | -0.77 |
| | Net results (∑) | 3.75 | 5.45 | 8.16 | 6.07 |
| Non-renewable primary energy [GJ] | Burdens | 3.92 | 7.53 | 9.99 | 6.62 |
| | Credits* | -0.70 | -2.45 | -2.19 | -0.79 |
| | Net results (∑) | 3.22 | 5.08 | 7.79 | 5.83 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.10 | 2.60 | 1.55 | 3.00 |
| | Credits* | -8.04 | -0.12 | -0.15 | 0.61 |
| | Net results (∑) | 19.07 | 2.48 | 1.40 | 3.61 |
| Water use [$m^3$] | Water cool | 4.12 | 8.41 | 9.38 | 2.75 |
| | Water process | 2.49 | 1.57 | 1.63 | 0.39 |
| | Water unspec | 0.73 | 1.18 | 1.61 | 0.30 |

*material and energy credits

**Table 57:** Category indicator results per impact category for base scenarios of **segment JNSD 200ml-330ml BELGIUM (330mL)** burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | PET Bottle 9 330mL ambient | PET Bottle 10 330mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 171.97 | 169.42 | 337.93 | 330.94 |
| | CO2 (reg) | 21.14 | 26.16 | 0.00 | 0.00 |
| | Credits* | -48.95 | -49.08 | -66.52 | -64.62 |
| | $CO_2$ uptake | -43.35 | -55.98 | 0.00 | 0.00 |
| | Net results (∑) | 100.81 | 90.53 | 271.41 | 266.33 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.50 | 0.55 | 0.72 | 0.70 |
| | Credits* | -0.10 | -0.10 | -0.17 | -0.16 |
| | Net results (∑) | 0.40 | 0.46 | 0.55 | 0.54 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.26 | 7.34 | 9.14 | 8.89 |
| | Credits* | -0.98 | -0.99 | -2.03 | -1.97 |
| | Net results (∑) | 5.27 | 6.36 | 7.11 | 6.92 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.09 | 0.23 | 1.05 | 1.02 |
| | Credits* | -0.01 | -0.01 | -0.33 | -0.32 |
| | Net results (∑) | 0.08 | 0.22 | 0.72 | 0.70 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 47.47 | 57.92 | 69.71 | 67.61 |
| | Credits* | -7.63 | -7.63 | -14.64 | -14.23 |
| | Net results (∑) | 39.85 | 50.29 | 55.08 | 53.38 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 41.38 | 72.46 | 96.33 | 93.17 |
| | Credits* | -5.92 | -5.92 | -19.76 | -19.16 |
| | Net results (∑) | 35.46 | 66.54 | 76.57 | 74.01 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.46 | 0.54 | 0.67 | 0.66 |
| | Credits* | -0.09 | -0.09 | -0.15 | -0.15 |
| | Net results (∑) | 0.38 | 0.46 | 0.52 | 0.51 |
| Total Primary Energy [GJ] | Burdens | 4.45 | 4.46 | 7.91 | 7.70 |
| | Credits* | -1.15 | -1.15 | -2.05 | -1.99 |
| | Net results (∑) | 3.30 | 3.31 | 5.86 | 5.71 |
| Non-renewable primary energy [GJ] | Burdens | 3.45 | 3.23 | 7.46 | 7.31 |
| | Credits* | -0.66 | -0.66 | -1.97 | -1.91 |
| | Net results (∑) | 2.79 | 2.57 | 5.49 | 5.39 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.28 | 27.27 | 1.68 | 1.35 |
| | Credits* | -8.37 | -8.37 | -0.11 | -0.10 |
| | Net results (∑) | 18.91 | 18.91 | 1.58 | 1.25 |
| Water use [$m^3$] | Water cool | 3.44 | 3.49 | 7.94 | 7.70 |
| | Water process | 2.53 | 2.52 | 1.57 | 1.51 |
| | Water unspec | 0.62 | 0.67 | 1.11 | 1.09 |

*material and energy credits

### 4.5.2 Description and interpretation (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 220mL-330mL 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 category 'Use of Nature' (83%-89%). It is also relevant regarding 'Aquatic Eutrophication' (23%-47%), 'Photo-Oxidant Formation' (22%-30%) 'Acidification', (21%-27%) 'Terrestrial

Eutrophication' (22%-31%), 'Particulate Matter' (21%-28%) and also the consumption of 'Total Primary Energy' (19%-29%).

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 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 shows burdens in most impact categories. Substantial burdens can be seen for the categories 'Acidification' (27%-30%) and 'Particulate Matter' (22%-26%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (3%-27%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil based plastics (6%-9%) and LPB (9%-11%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about 20% - 25% of the total burdens.

The life cycle step 'top, closure & label' contributes to a considerable amount (14%-68%) in almost all impact categories with the exception of the TWA with only minor burdens (max. 6%) in this step as this carton has no closure and only a straw~~.~~ In case the plastics used for 'top, closure & label' are bio-based (i.e. TPA Square bio-based 330mL), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (1%-15%). It generates emissions, which contribute mostly to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems shows considerable shares (6%-17%) of impacts in all categories. One exception is the TWA 200 with higher shares of burdens (14%-32%) from transport packaging in all categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 7%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (31%-34%). 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.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in Belgium these derive mainly from the incineration of bio-based plastics and paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits from material recycling are higher than energy credits in all impact categories except ‘Climate Change’ as in Belgium 90% of the beverage cartons are recycled. Material credits for ‘Climate Change’ are low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 200mL-330mL 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. The shares of burdens in most categories mainly derive from PET production, nevertheless in the case of ambient PET bottles a considerable share of burdens derives from the production of the PA additive. The high results of 'Ozone Depletion Potential' are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The 'converting' process of all regarded bottles shows considerable shares of impacts (3%-27%) in all categories apart from 'Aquatic Eutrophication' with a share of impacts of less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows minor shares of impacts (1%-18%) in most categories mainly attributed to the plastics used for the closure. One exception is the PET Bottle 6 with higher shares of impacts (3%-29%) in this step because if it's heavy closure.

The production and provision of 'transport packaging' for the bottle system shows low shares of impacts (1%-10%) in all categories except of 'Use of Nature' in which the paper production contributes to 52%-74% of the burdens. In the cases of PET Bottle 6, 9 and 10 for most categories except of 'Use of Nature' the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets. In the case of PET Bottle 5 all relevant emissions derive from production of paper for trays and slipsheets as well as from stretch foil production.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max 5%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (27%-32%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is high in most categories. With a recycling rate of 75% for the clear plastic bottle, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

**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 in all categories (66%-83%) 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' (67%) transport packaging also plays a visible role.

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 though have an important impact on the overall net results apart from 'Aquatic Eutrophication' and 'Use of Nature'.

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

In the regarded SUP in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens is caused by the production of the base materials of the pouch in most impact and inventory categories. The burdens mainly derive from aluminium (up to 42%) and plastics (up to 44%) production with a higher share of burdens from aluminium in the impact categories 'Acidification' and 'Particulate Matter' due to $SO_2$ and $NO_x$ emissions from the aluminium production

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

The production and provision of 'transport packaging' for the SUP show considerable shares of impacts (17%-43%) in most categories. In case of 'Use of Nature' the production of paper contributes to 96% of the burdens. All relevant emissions derive from production of paper for trays and slipsheets as well as from the production of stretch foil.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 12%) for the SUP in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the SUP's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (17%). The incineration of plastic bottles 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 almost all SUPs are incinerated. The energy credits mainly originate from the incineration plants.

### 4.5.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than

10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 58:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TWA 200mL ambient | SUP 1 200mL ambient |
| Climate Change [kg $CO_2$eq] | 90.06 | -54% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -47% |
| Acidification [kg $SO_2$ eq.] | 0.40 | -20% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 40.50 | -12% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 34.28 | -1% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.15 | -16% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.37 | -19% |

**Table 59:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled | PET Bottle 6 250ml ambient | Glass Bottle 2 250ml ambient |
| Climate Change [kg $CO_2$eq] | 117.69 | -54% | -68% | -72% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -86% | -89% | -70% |
| Acidification [kg $SO_2$ eq.] | 0.43 | -4% | -42% | -71% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.19 | -11% | -40% | -69% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.24 | -19% | -63% | 62% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.70 | -10% | -40% | -68% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | -8% | -42% | -71% |

**Table 60:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PET Bottle 9 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 100.81 | -63% | -62% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -89% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.40 | -28% | -26% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 39.85 | -28% | -25% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 35.46 | -54% | -52% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.27 | -26% | -24% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.38 | -28% | -26% |

**Table 61:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 9 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 90.53 | -67% | -66% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -69% | -68% |
| Acidification [kg $SO_2$ eq.] | 0.46 | -18% | -15% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 50.29 | -9% | -6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 66.54 | -13% | -10% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.36 | -11% | -8% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.46 | -13% | -10% |

# 5 Sensitivity Analyses Belgium

## 5.1 Sensitivity Analyses DAIRY 1000mL-2000mL BELGIUM

### 5.1.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

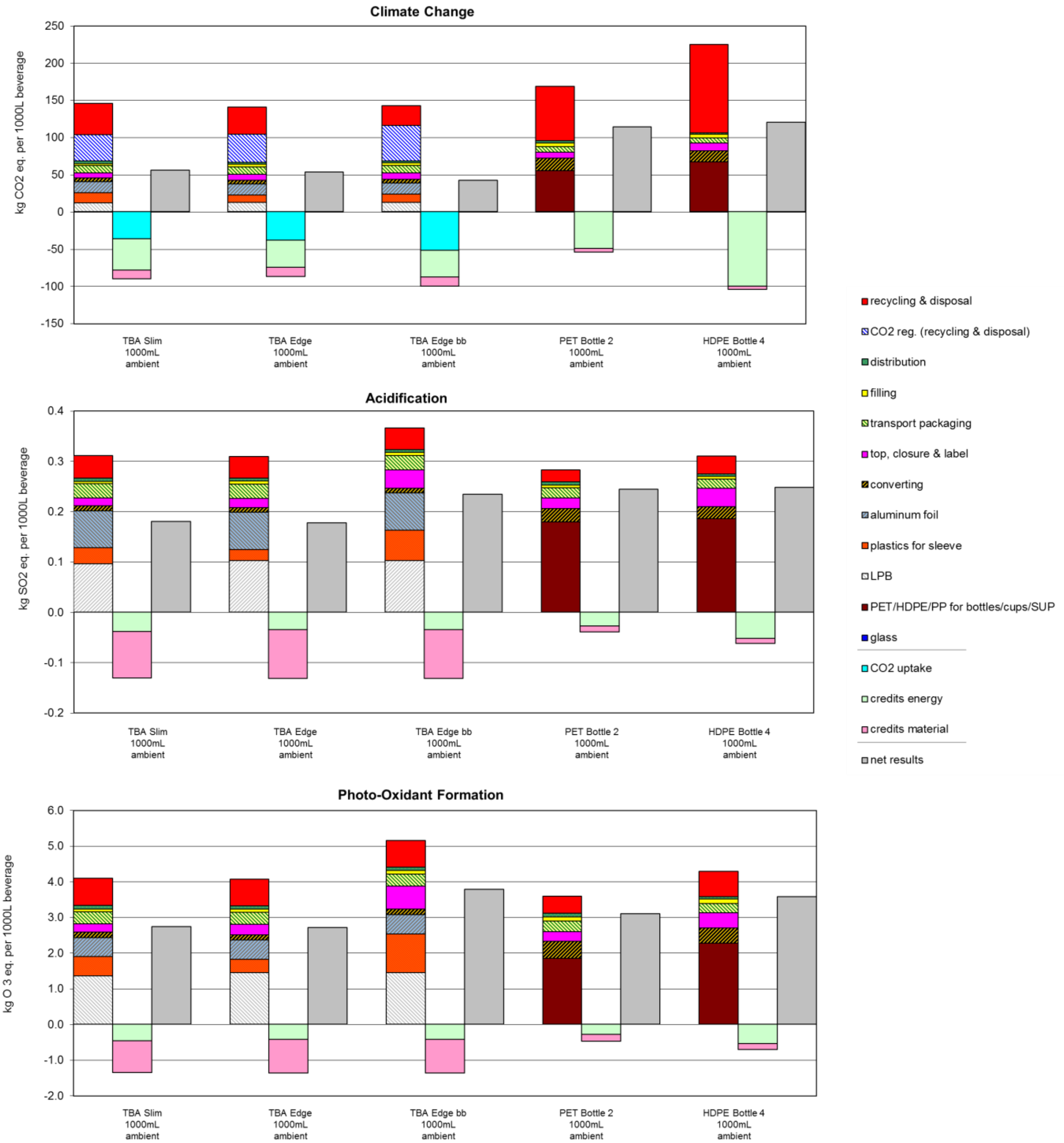



**Figure 35:** Indicator results for sensitivity analysis on system allocation of segment DAIRY 1000mL-2000mL BELGIUM, allocation factor 100% (Part 1)

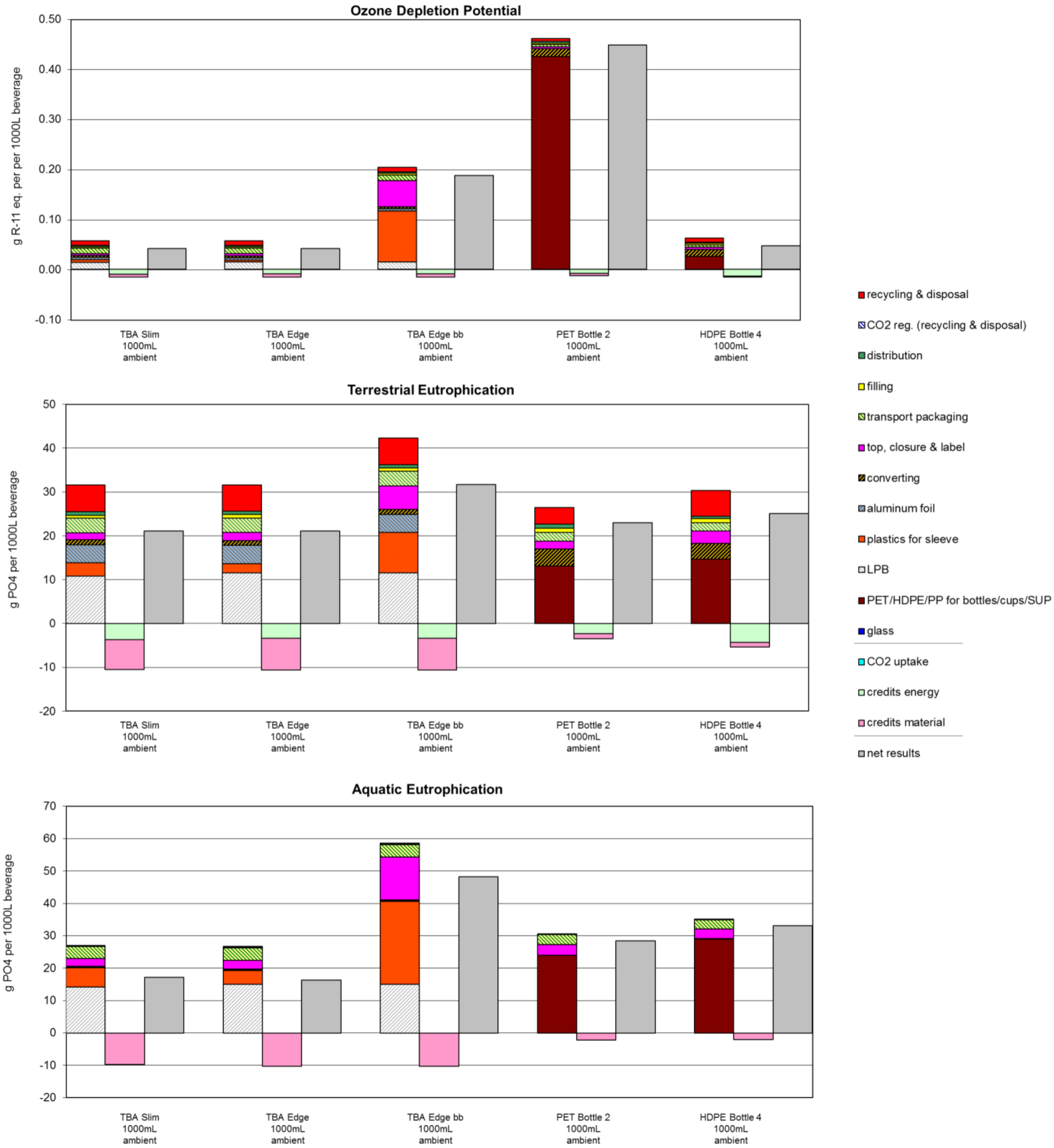



**Figure 36:** Indicator results for sensitivity analysis on system allocation of segment DAIRY 1000mL-2000mL BELGIUM, allocation factor 100% (Part 2)

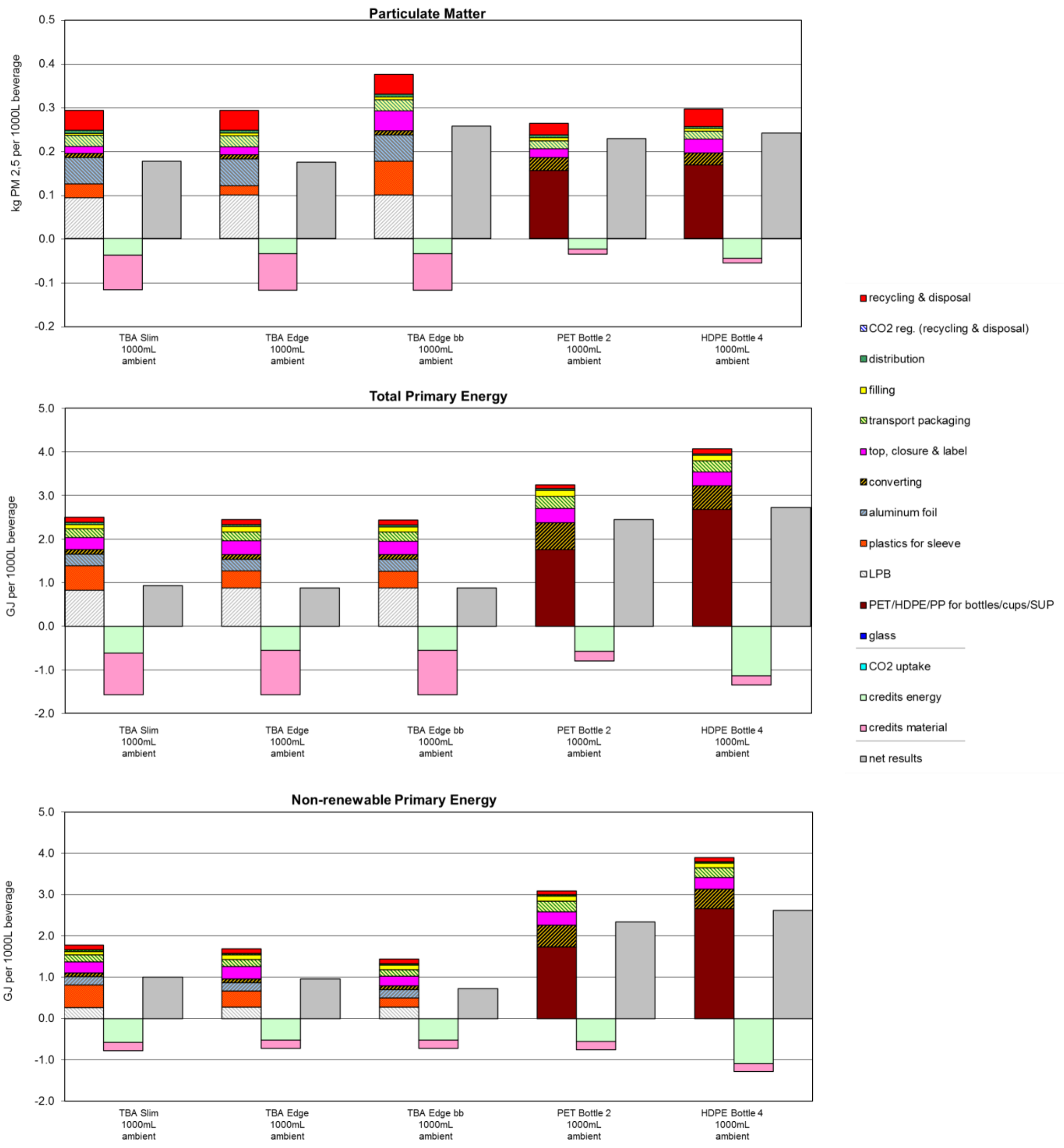



**Figure 37:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 100% (Part 3)

### 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 Belgium 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles the net results stay about the same in most impact categories as the additionally allocated credits and burdens show similar absolute values. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 62:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Belgium**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TBA Edge 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 53.40 | -53% | -56% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -91% | -11% |
| Acidification [kg $SO_2$ eq.] | 0.18 | -27% | -28% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 21.11 | -8% | -16% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 16.22 | -43% | -51% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.71 | -13% | -24% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.17 | -24% | -28% |

**Table 63:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Belgium**

| The net results of<br>**TBA Edge bb 1000mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 42.29 | -63% | -65% |
| Ozone depletion potential [g R-11 eq.] | 0.19 | -58% | 303% |
| Acidification [kg $SO_2$ eq.] | 0.23 | -4% | -5% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 31.77 | 38% | 27% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 48.11 | 70% | 45% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.78 | 22% | 6% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.26 | 13% | 7% |

**Table 64:** Comparison of net results: **TBA Slim 1000 mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Belgium**

| The net results of<br>**TBA Slim 1000mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Slim 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 4 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 55.47 | -51% | -54% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -91% | -12% |
| Acidification [kg $SO_2$ eq.] | 0.18 | -26% | -27% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 21.14 | -8% | -16% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 17.19 | -39% | -48% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.74 | -12% | -23% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.18 | -23% | -27% |

### 5.1.2 Sensitivity analysis regarding bio-based plastics in HDPE bottles

To consider potential future developments in terms of bio-based material in plastic bottles a sensitivity analysis is performed for the packaging systems listed in Table 28. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

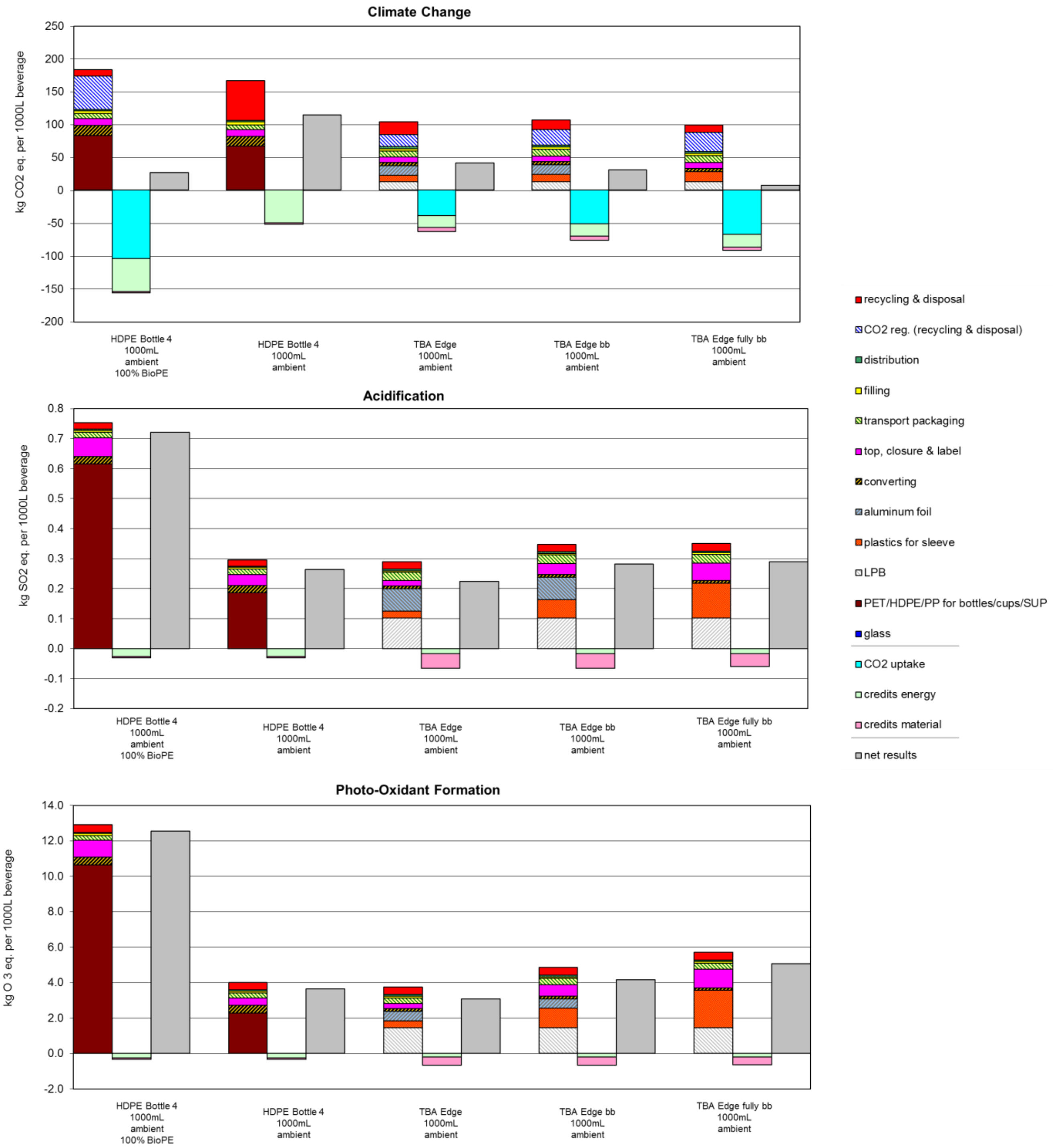



**Figure 38:** Indicator results for sensitivity analysis on bio-based plastics in HDPE bottles of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 1)

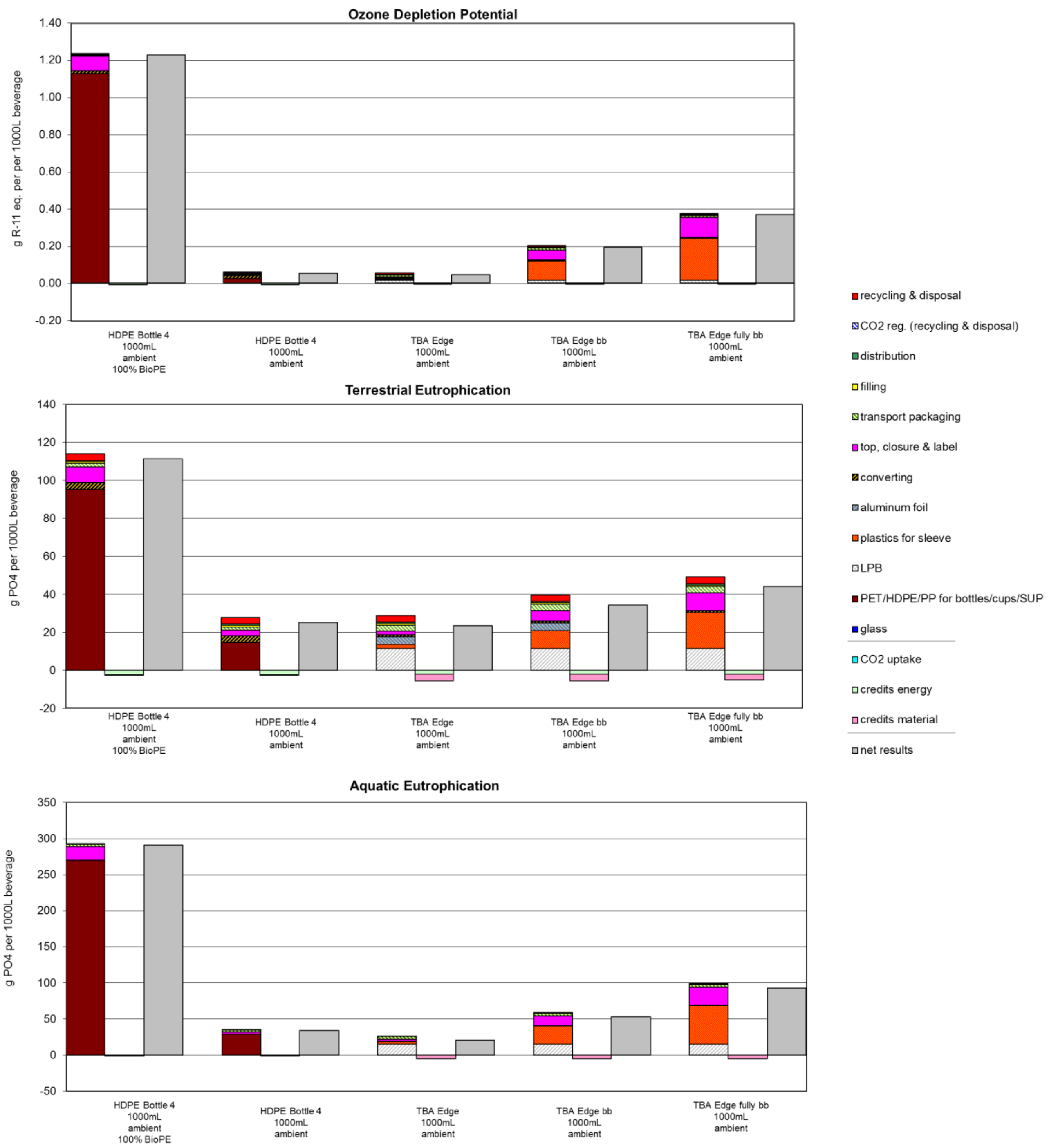



**Figure 39:** Indicator results for sensitivity analysis on bio-based plastics in HDPE bottles of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 2)

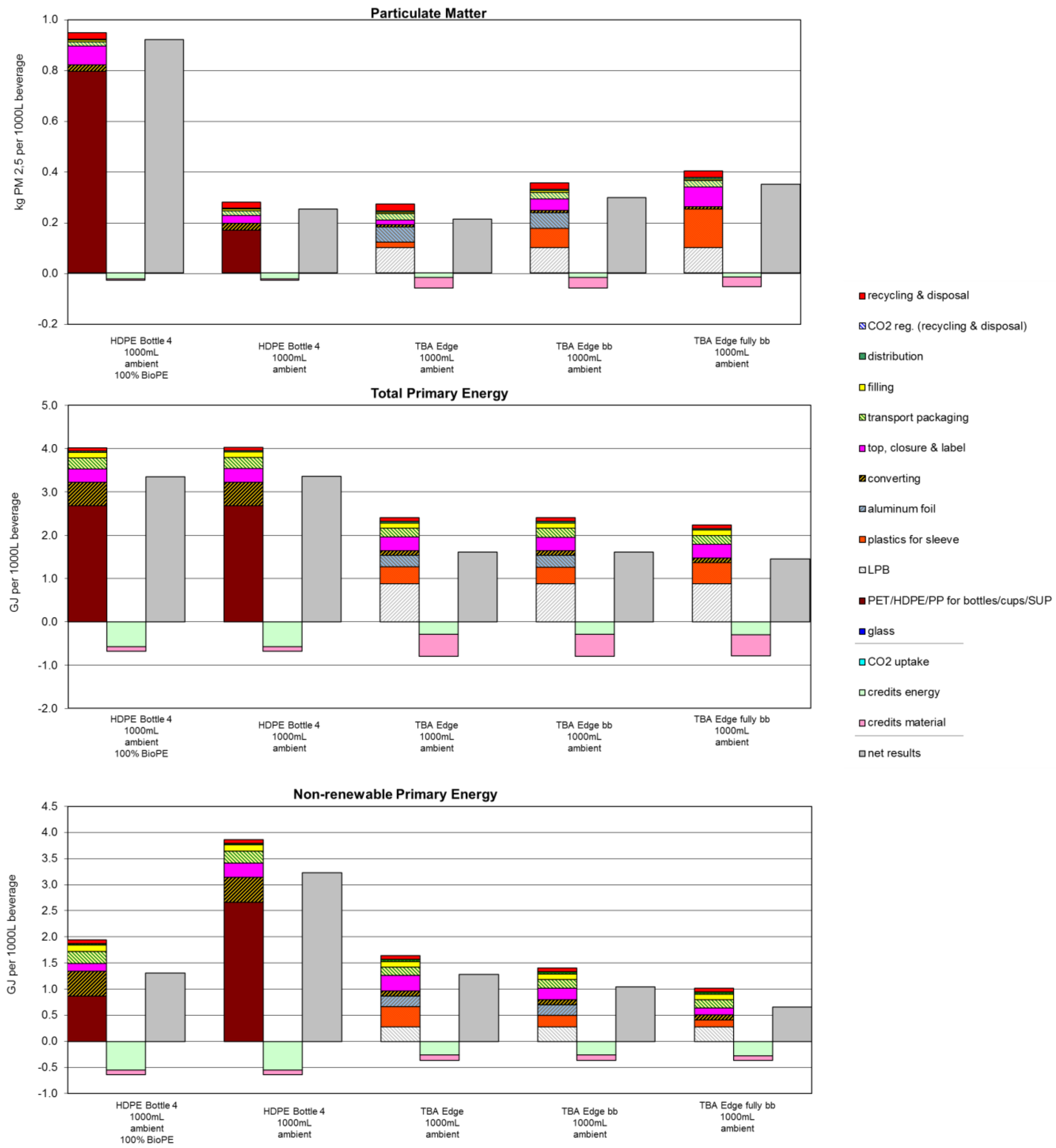



**Figure 40:** Indicator results for sensitivity analysis on bio-based plastics in HDPE bottles of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 3)

### Description and Interpretation

Replacing fossil HDPE with bio-based HDPE reduces the impacts of the step plastic production in the impact category 'Climate Change'. The reason for the impact reduction for 'Climate Change' is the high CO2 uptake of the bio-based HDPE.

In all other impact categories the use of bio-based HDPE leads to much higher impacts. The reasons are 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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the impact categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’ and ‘Acidification’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

Regarding the primary energy inventory categories, net results are higher for ‘Total Primary Energy’ and lower for ‘Non-renewable Primary Energy’ compared with the HDPE Bottle 4 of the base scenario.

This is due to the higher energy demand of the production of thick juice for Bio PE. The energy used for this process is mainly renewable, though.

When applying the 100% bio-based HDPE sensitivity analysis to HDPE Bottle 4, the TBA Edge 1000 with fossil based plastics shows now 20% higher net results than the 100% bio-based HDPE Bottle 4  for ‘Climate Change’. The TBA Edge 1000 with bio-based based plastics shows no significant difference in net results for ‘Climate Change’ anymore.  The fully bio-based TBA Edge 1000 shows 75% lower net results than the 100% bio-based HDPE Bottle 4  for ‘Climate Change’. In all other impact categories the 100% bio-based HDPE bottle leads to much higher results than the compared beverage carton systems including those where the HDPE Bottle 4 shows lower net results in the base scenario.

Regarding both, primary energy inventory categories, the net results of the 100% bio-based HDPE Bottle 4 stay higher than those of both compared beverage carton systems.

### 5.1.3 Sensitivity analysis regarding recycled content in PET bottles

All PET bottles in the base scenarios are assumed to contain the European average of 11.7% recycled PET. As PET bottles could be produced with 100% recycled content a sensitivity analysis is performed 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.

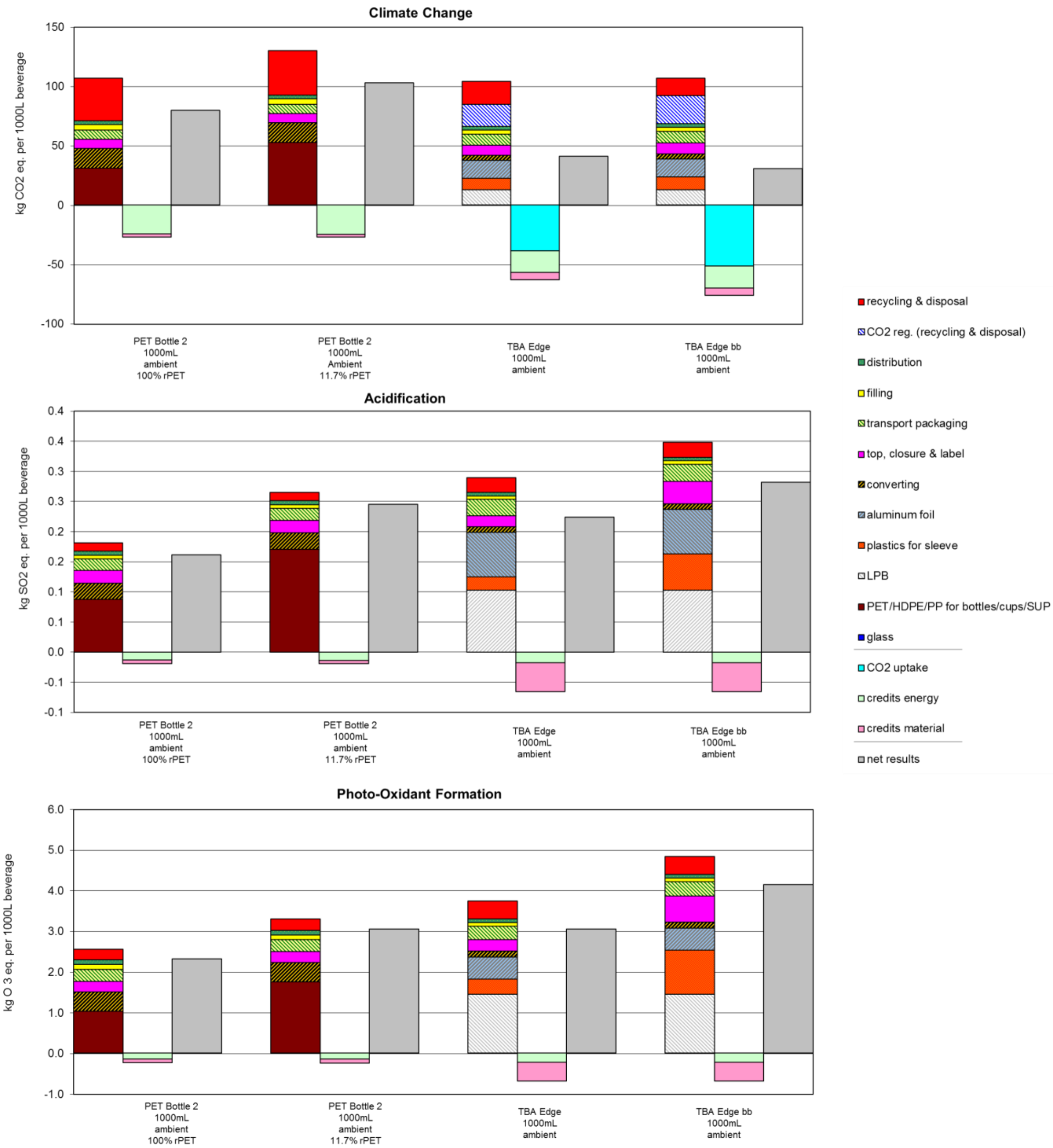



**Figure 41:** Indicator results for sensitivity analysis on recycled content in PET bottles of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 1)

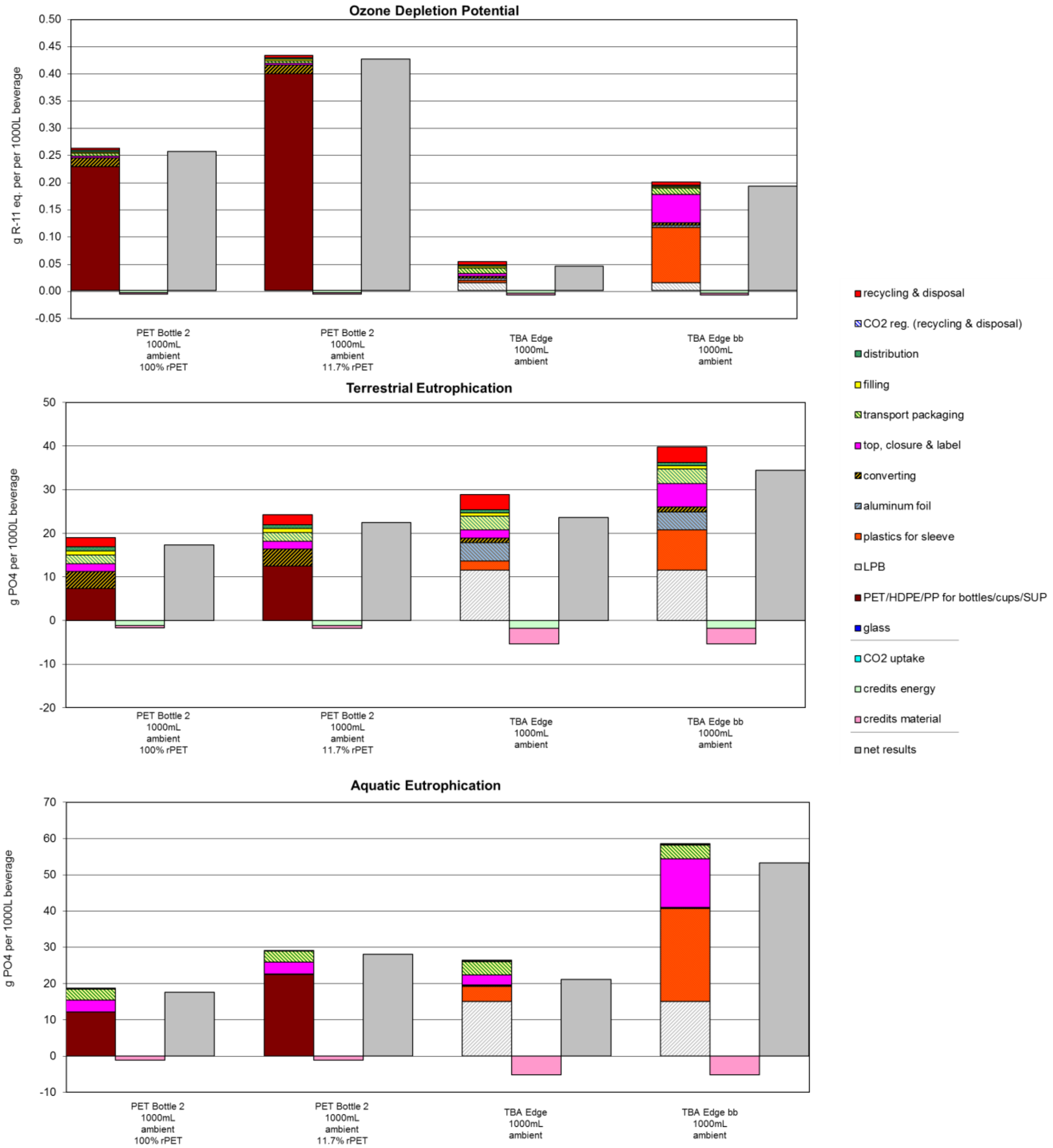



**Figure 42:** Indicator results for sensitivity analysis on recycled content in PET bottles of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 2)

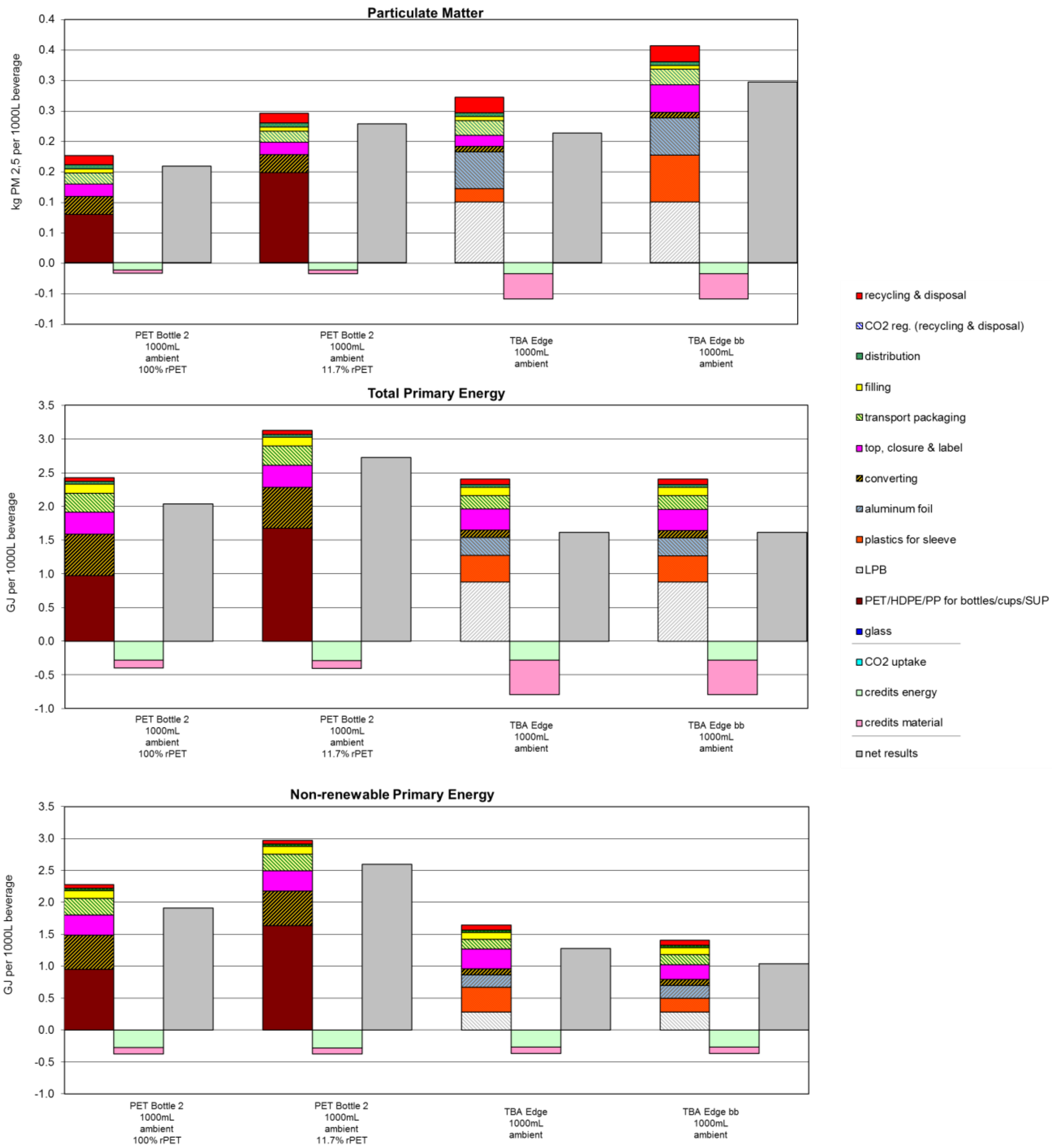



**Figure 43:** Indicator results for sensitivity analysis on recycled content in PET bottles of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 3)

## Description and Interpretation

Increasing the share of recycled PET from the European average of 11.7% to 100% reduced the impact of the production of PET. This leads to lower net results in all examined categories with the highest reduction (40%) in ‘Ozone Depletion Potential’ and smallest reduction (22%) in ‘Climate Change’.

For the impact categories ‘Climate Change’ and ‘Ozone Depletion Potential’, as well as the inventory category ‘Non-renewable Primary Energy’ net results of the compared beverage carton systems stay lower than those of the 100% rPET bottle. For the other impact categories ‘Acidification’, ‘Photo-Oxidant Formation’, ‘Terrestrial Eutrophication’, ‘Aquatic Eutrophication’ and ‘Particulate Matter’ the 100% rPET bottle shows lower net results than the compared beverage carton systems. In the inventory category ‘Total Primary Energy’ the TBA Edge bio-based 1000 shows no significant differences in net results to the 100% rPET Bottle 2 anymore, while the TBA Edge 1000 with fossil based plastics still shows lower net results.

### 5.1.4 Sensitivity analysis regarding plastic bottle weight

To consider potential future developments in terms of weight of the plastic bottles, a sensitivity analysis with reduced bottle weight is 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 graphs.

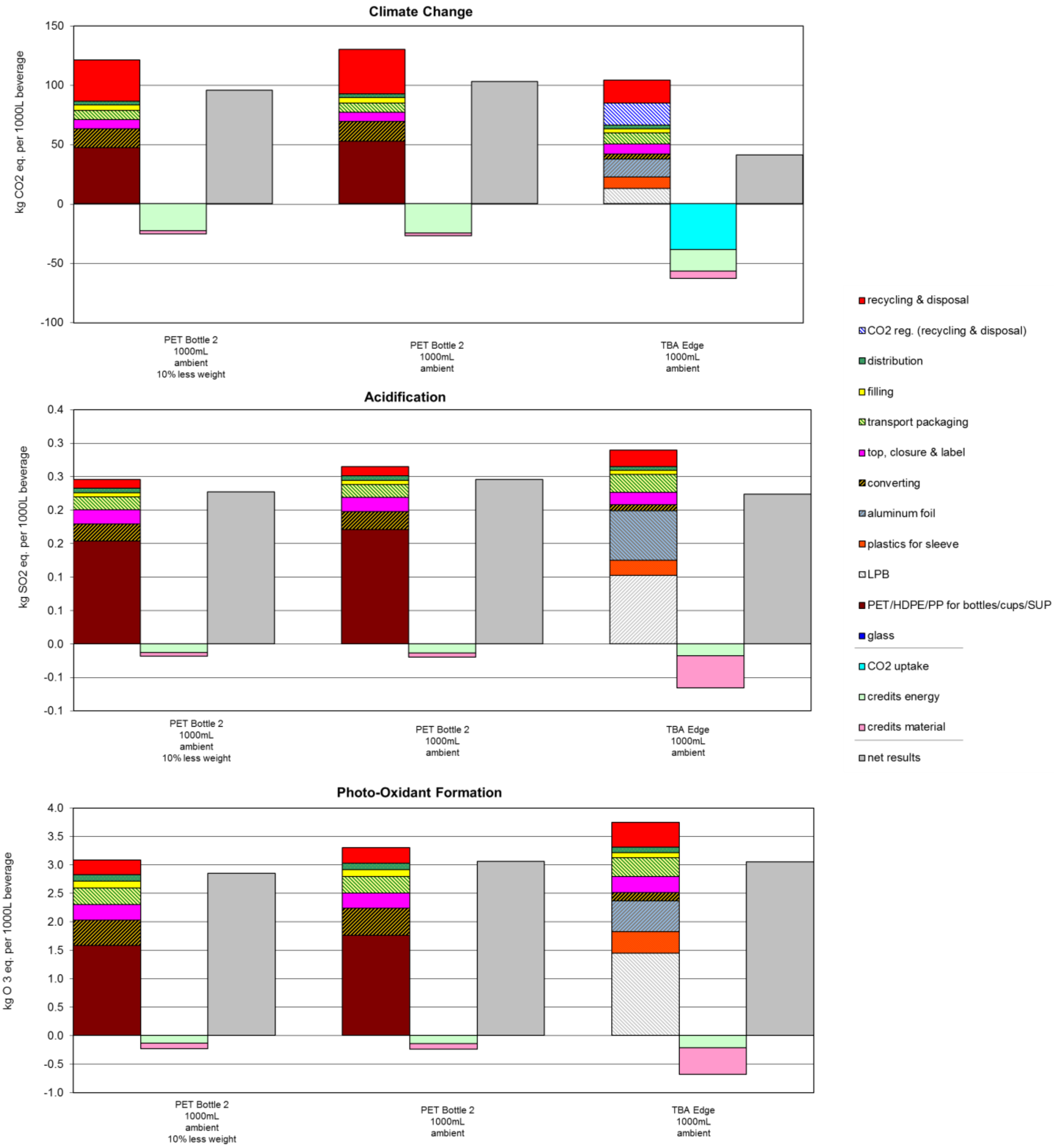



**Figure 44:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 1)

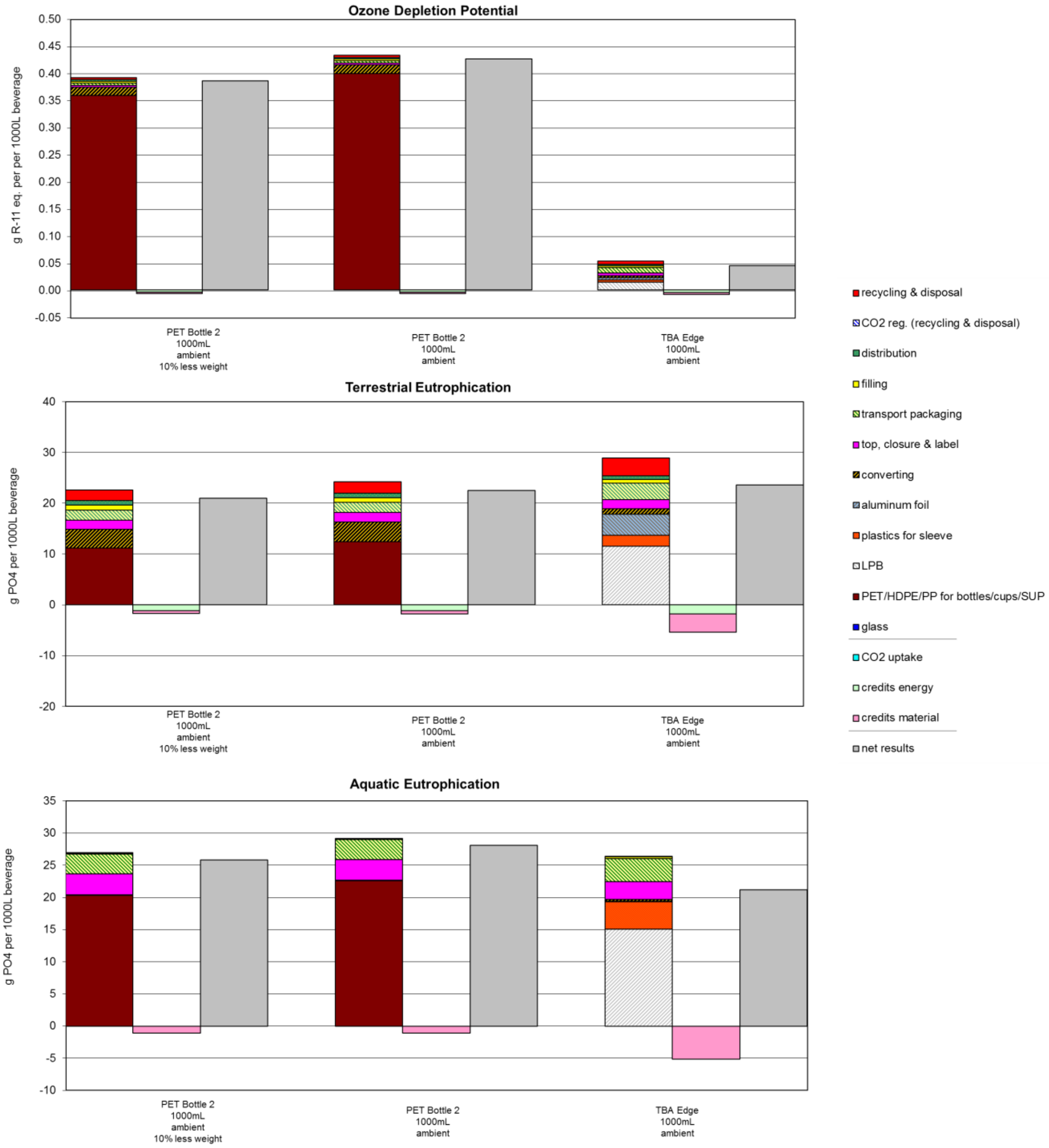



**Figure 45:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 2)

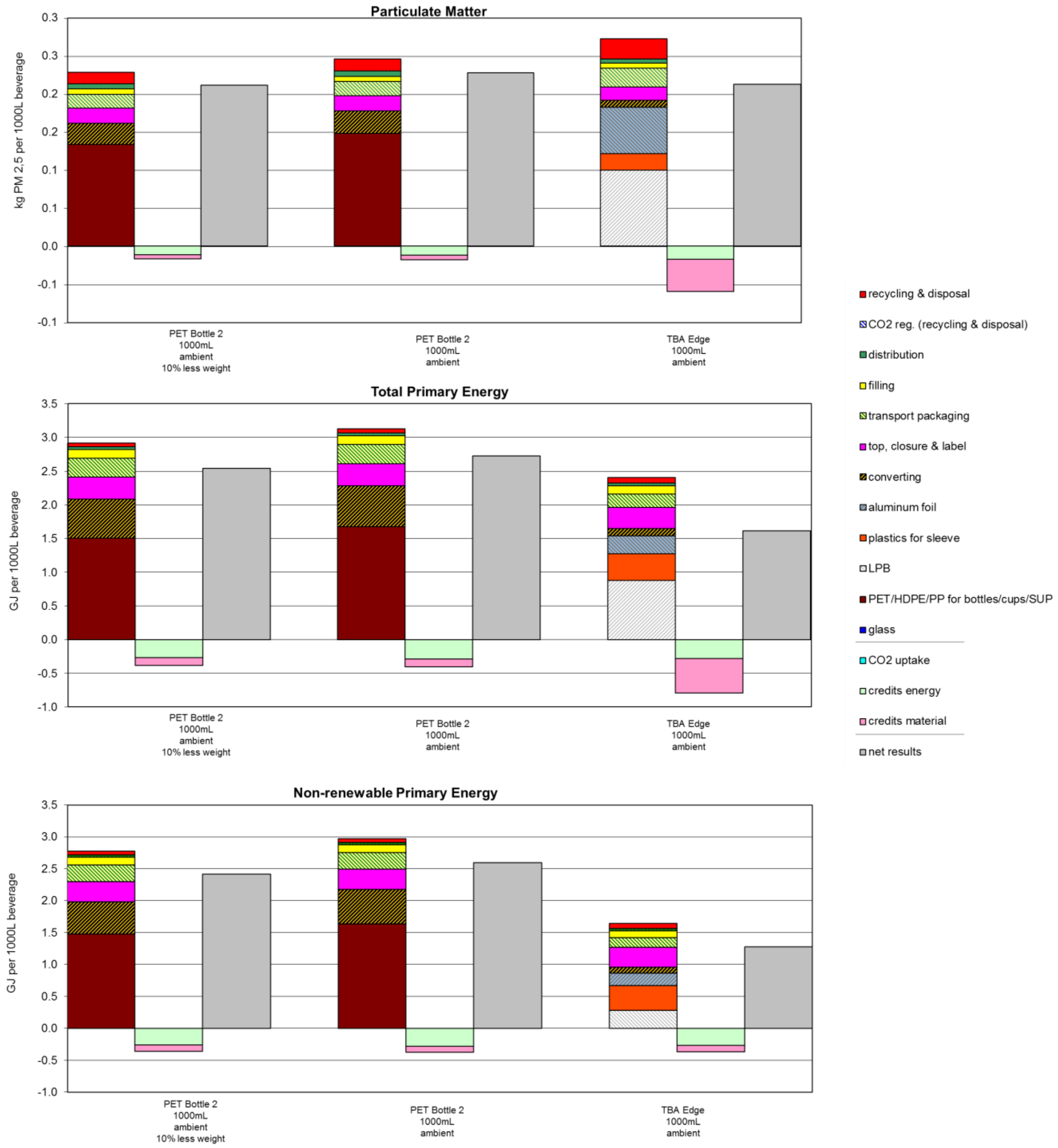



**Figure 46:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 3)

### Description and Interpretation

The reduction of PET bottle weight by 10% reduces the impacts in most lifecycle steps and also the credits. The reduction of net results ranges only from 7% - 10%.

The described changes in net results do not change the net results' ranking of the compared packaging systems.

### 5.1.5 Sensitivity analysis regarding alternative barrier material in beverage cartons

To consider alternative barrier materials instead of aluminium in beverage cartons, a sensitivity analysis with fossil PE instead of aluminium is performed for the packaging systems listed in Table 32. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

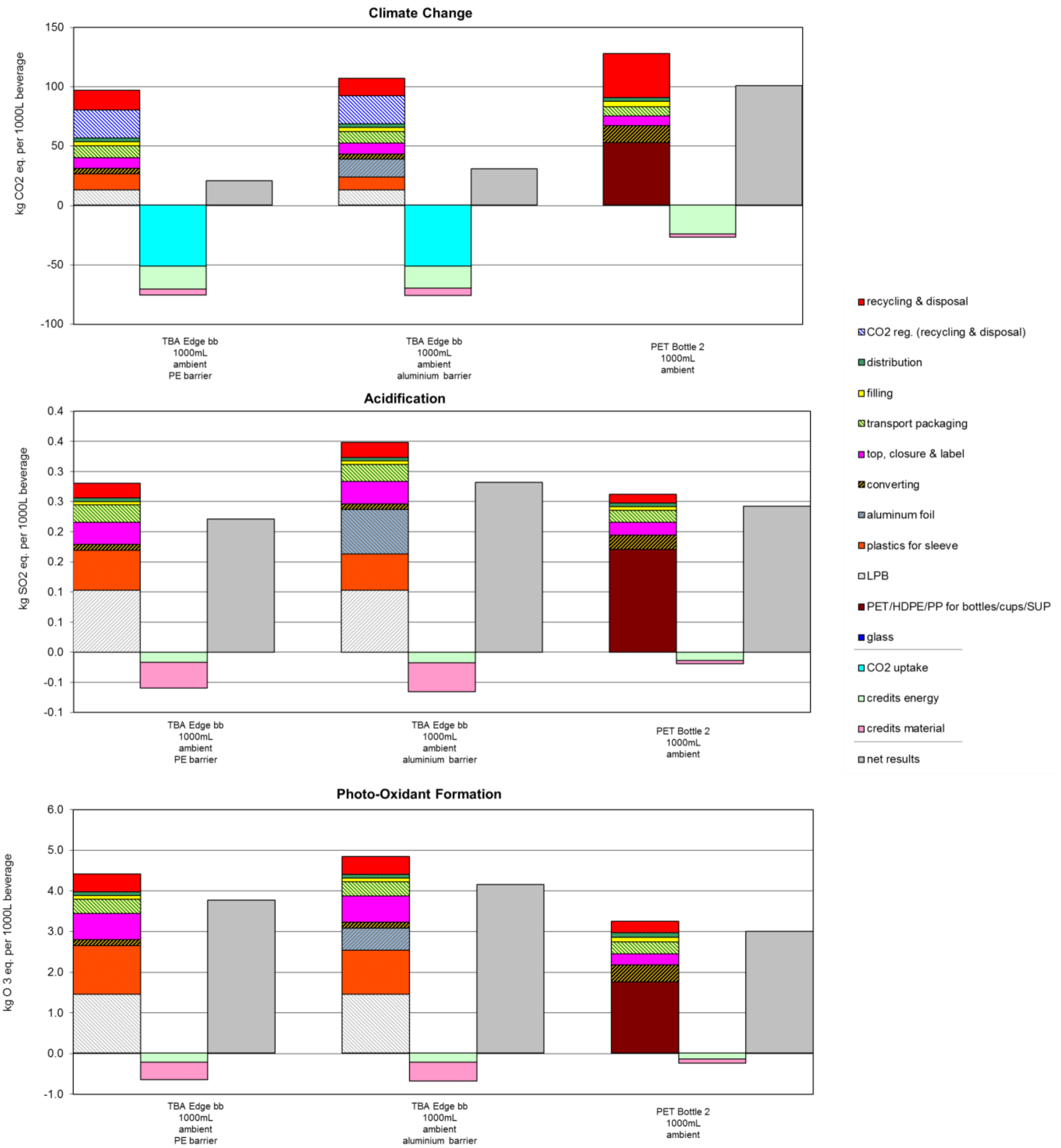



**Figure 47:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 1)

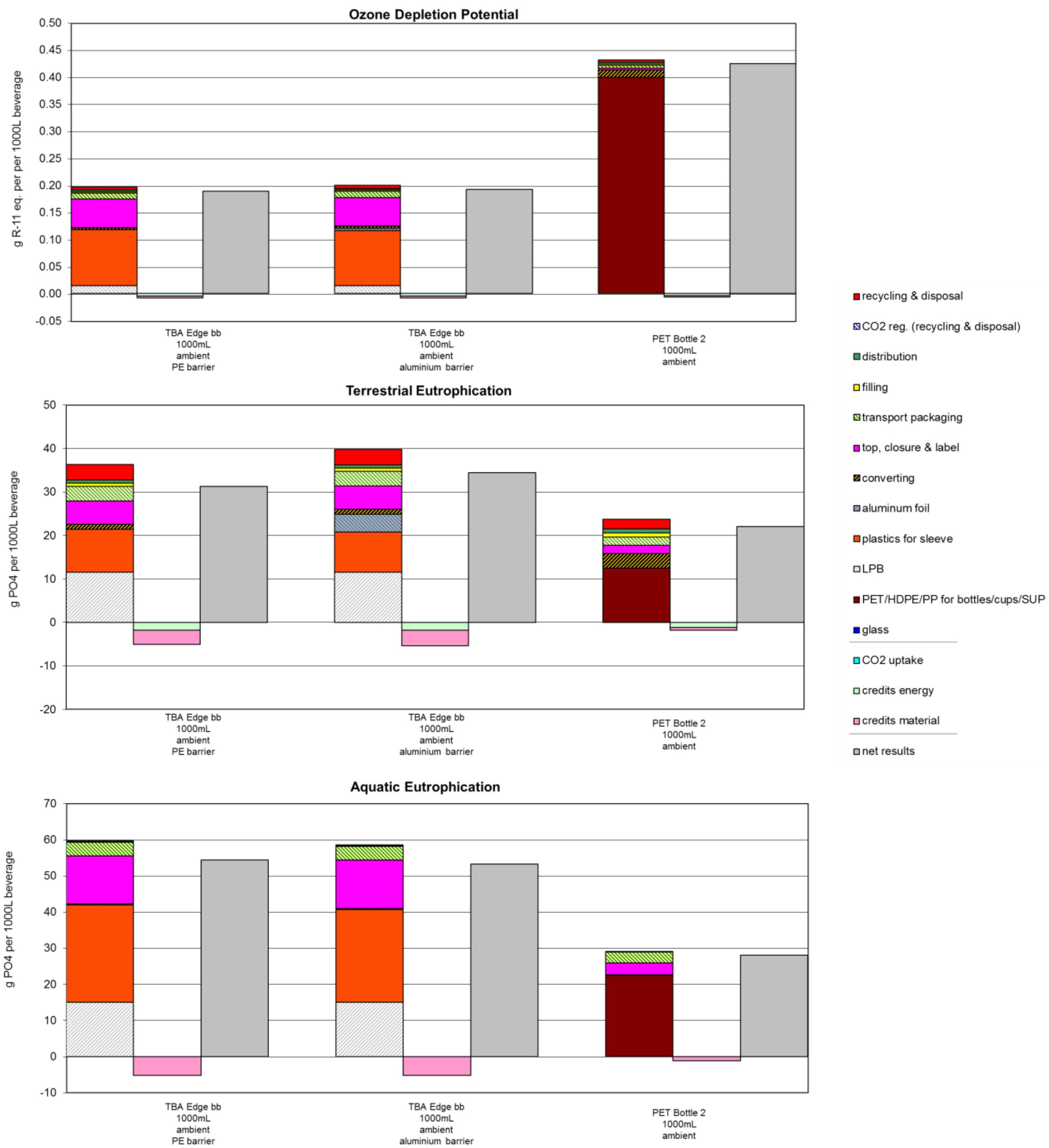



**Figure 48:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 2)

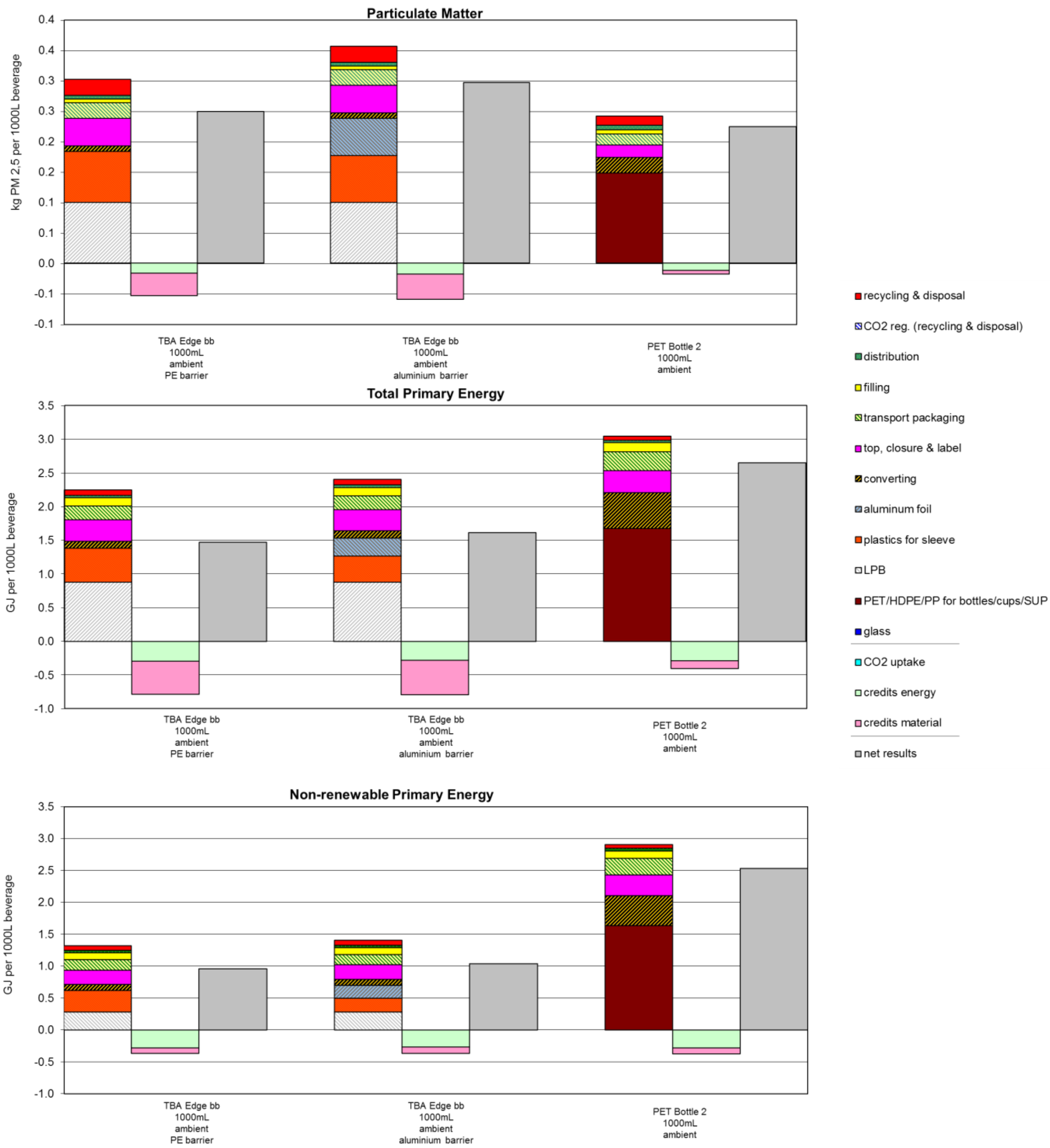



**Figure 49:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 1000mL-2000mL BELGIUM**, allocation factor 50% (Part 3)

### Description and Interpretation

Replacing the aluminium layer in the sleeves by a PE layer leads to reductions of net results of 12% - 30% in the impact categories ‘Particulate Matter’, ‘Acidification’ and ‘Climate Change’. Lower reductions of 7% - 9% can be seen in the categories ‘Total Primary Energy’, ‘Non-renewable Primary Energy’, ‘Terrestrial Eutrophication’ and ‘Photo-Oxidant Formation’. On the other hand 5% higher net results can be seen for ‘Aquatic Eutrophication’. Almost no changes of net results can be seen for ‘Ozone Depletion’.

The described changes in net results do not change the net results' ranking of the compared packaging systems. The exception is 'Acidification' where no significant difference in net results can be regarded in contrast to the base scenario where the beverage carton shows higher net results.

## 5.2 Sensitivity Analyses JNSD 1000mL BELGIUM

### 5.2.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

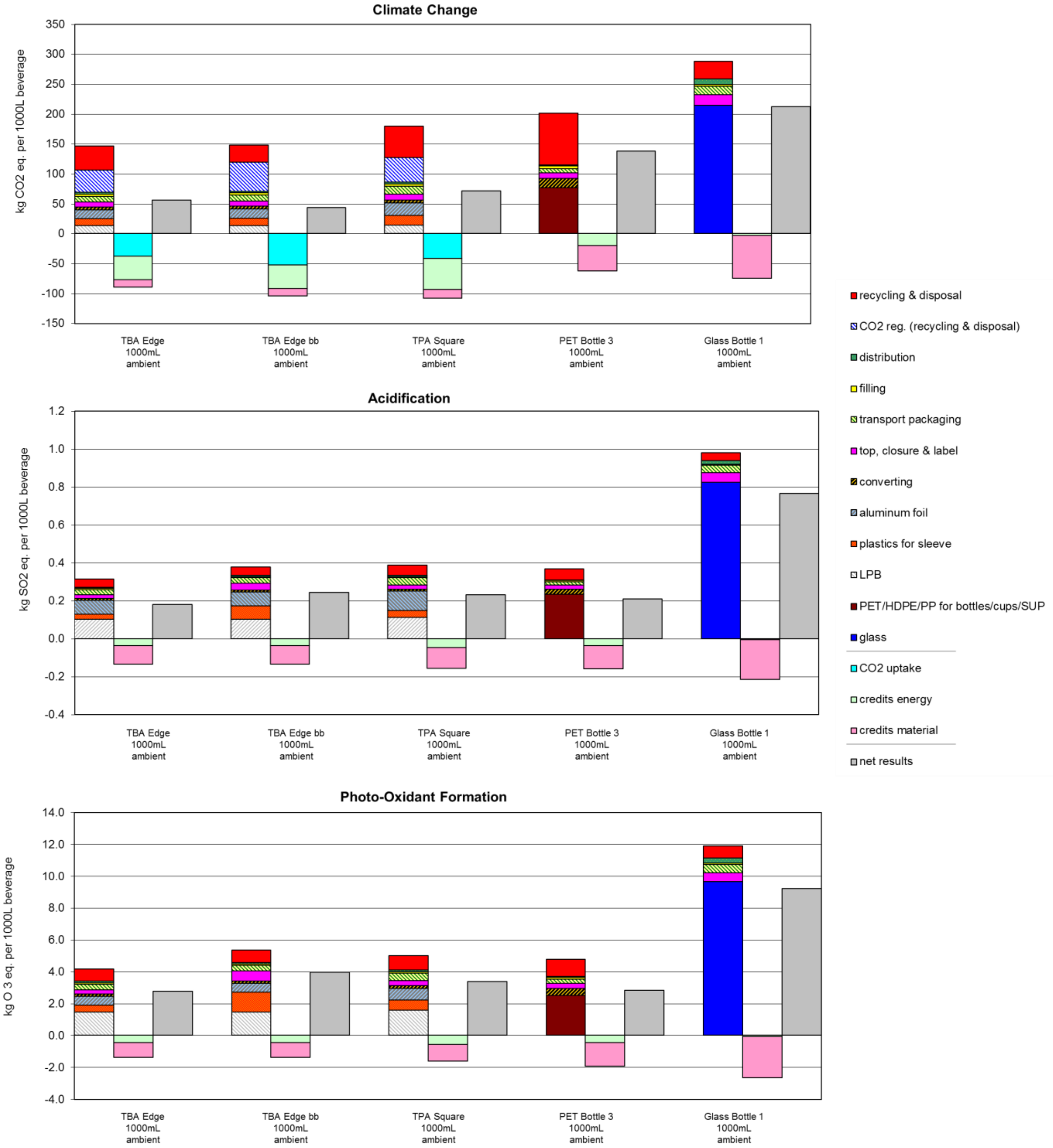



**Figure 50:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL BELGIUM**, allocation factor 100% (Part 1)

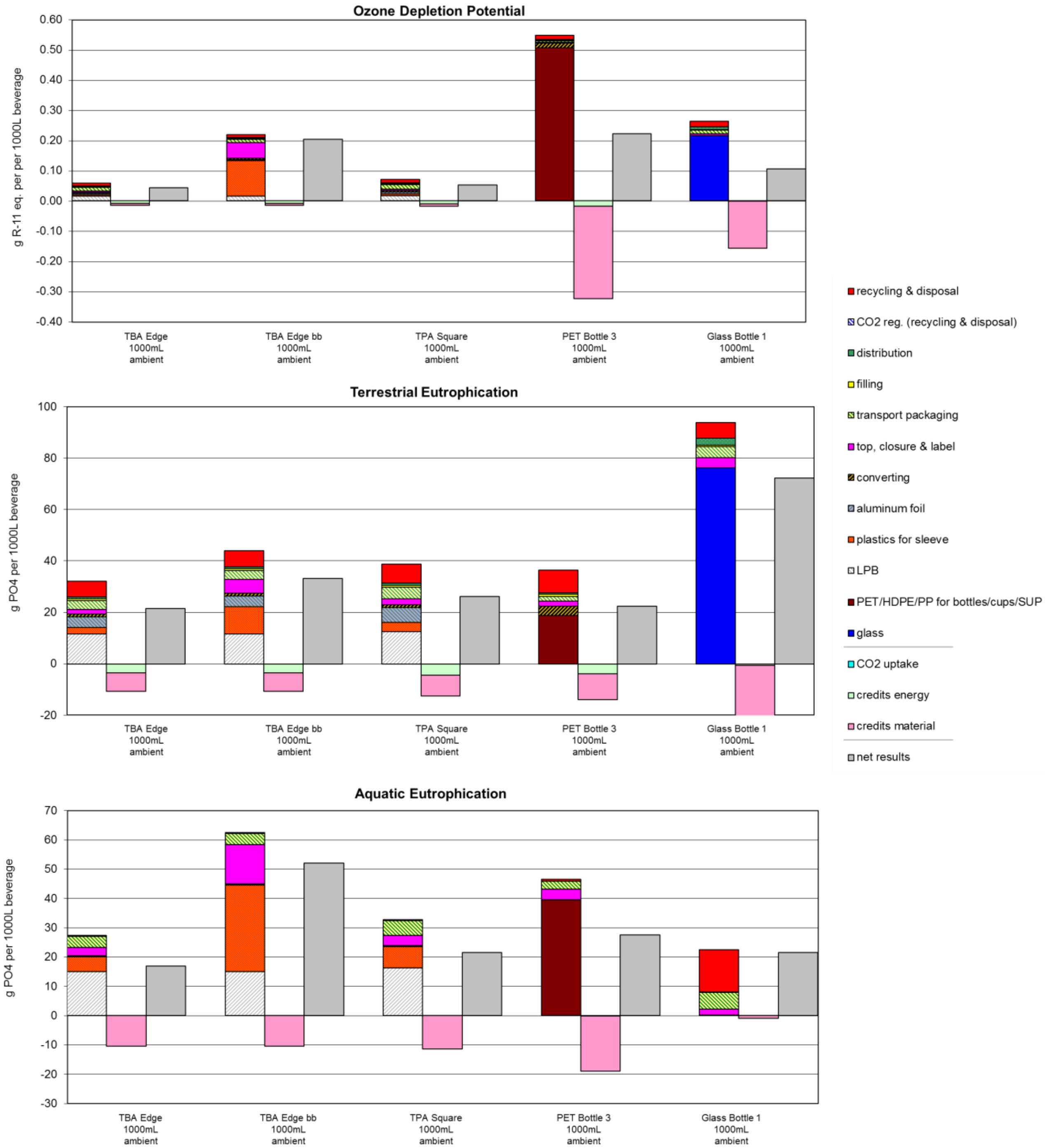



**Figure 51:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL BELGIUM**, allocation factor 100% (Part 2)

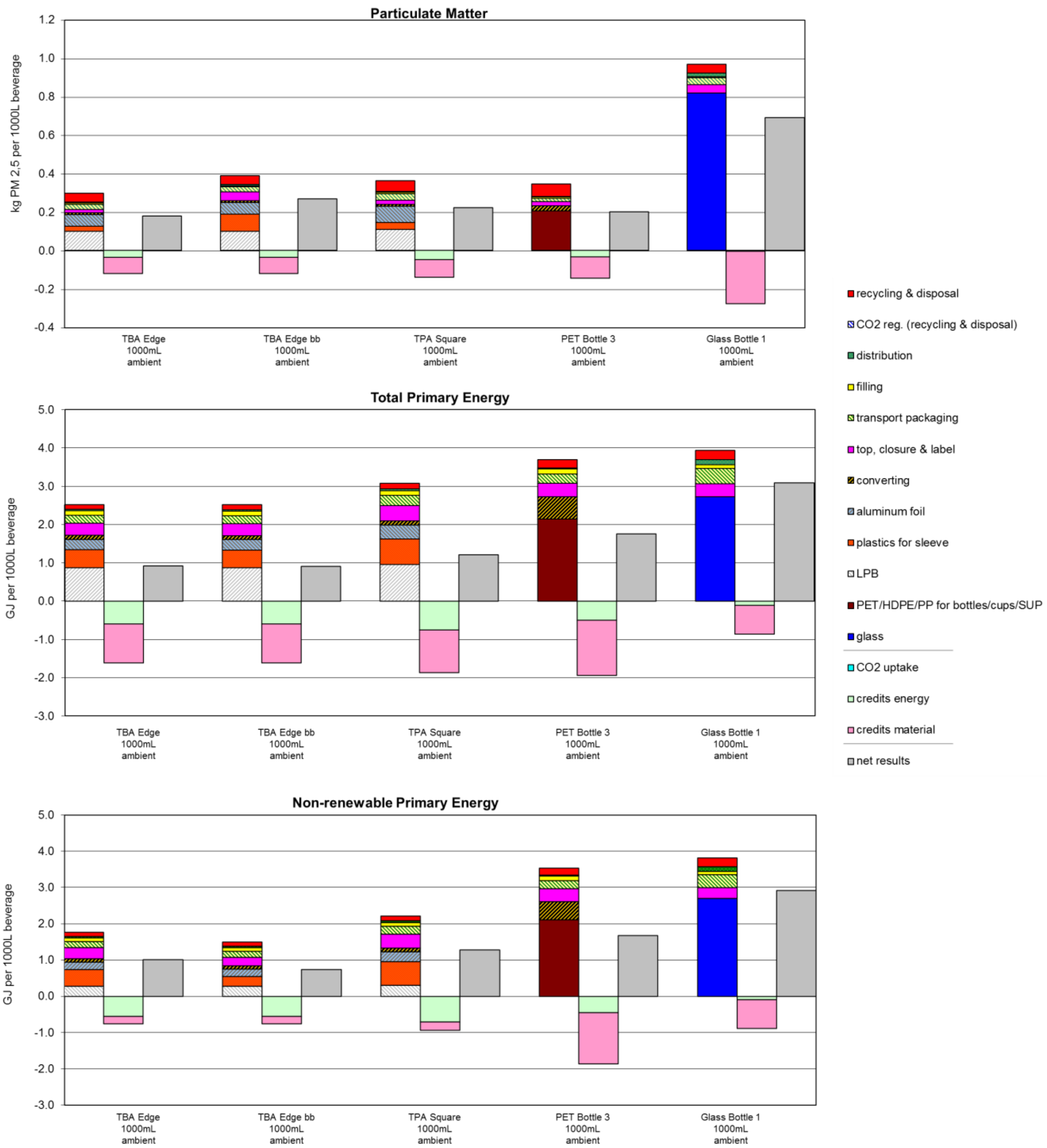



**Figure 52:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL BELGIUM**, allocation factor 100% (Part 3)

## 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 Belgium 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

In the case of the glass bottle the net results of all impact categories decrease when applying the 100% allocation factor due to the high material credits compared to the burdens for recycling.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for all packaging due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 65:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Belgium**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 55.22 | -60% | -74% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -81% | -60% |
| Acidification [kg $SO_2$ eq.] | 0.18 | -14% | -76% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 21.48 | -4% | -70% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 17.02 | -38% | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.77 | -2% | -70% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.18 | -11% | -74% |

**Table 66:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Belgium**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 43.01 | -69% | -80% |
| Ozone depletion potential [g R-11 eq.] | 0.20 | -8% | 94% |
| Acidification [kg $SO_2$ eq.] | 0.24 | 16% | -68% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 33.19 | 48% | -54% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 52.07 | 89% | 142% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.95 | 40% | -57% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.27 | 34% | -61% |

**Table 67:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Belgium**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 70.69 | -49% | -67% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -77% | -51% |
| Acidification [kg $SO_2$ eq.] | 0.23 | 10% | -70% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 26.24 | 17% | -64% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 21.47 | -22% | 0% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.39 | 20% | -63% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.22 | 11% | -68% |

## 5.3 Sensitivity Analyses DAIRY 189mL-500mL BELGIUM

### 5.3.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

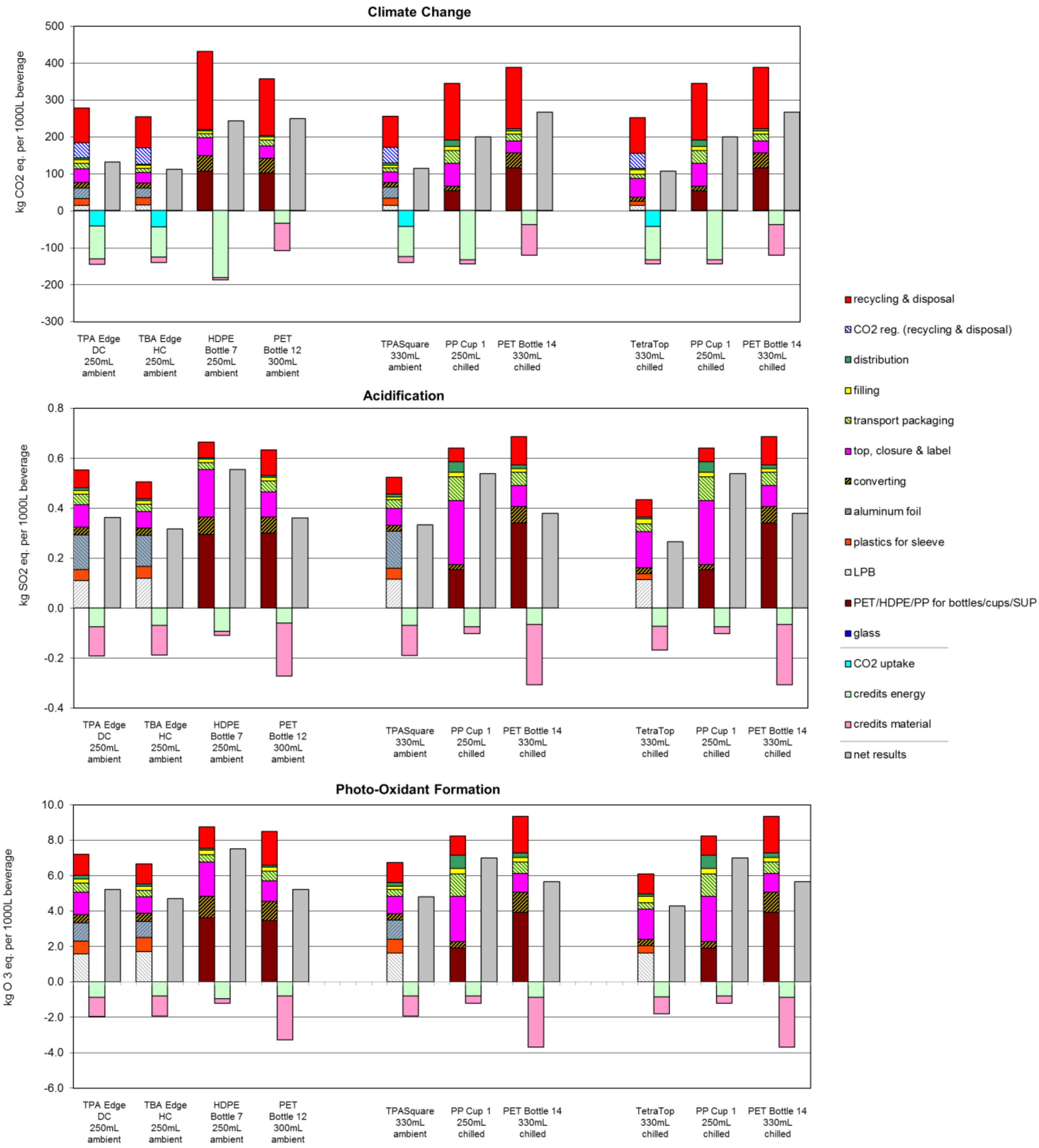



**Figure 53:** Indicator results for sensitivity analysis on system allocation of segment DAIRY 189mL-500mL BELGIUM, allocation factor 100% (Part 1)

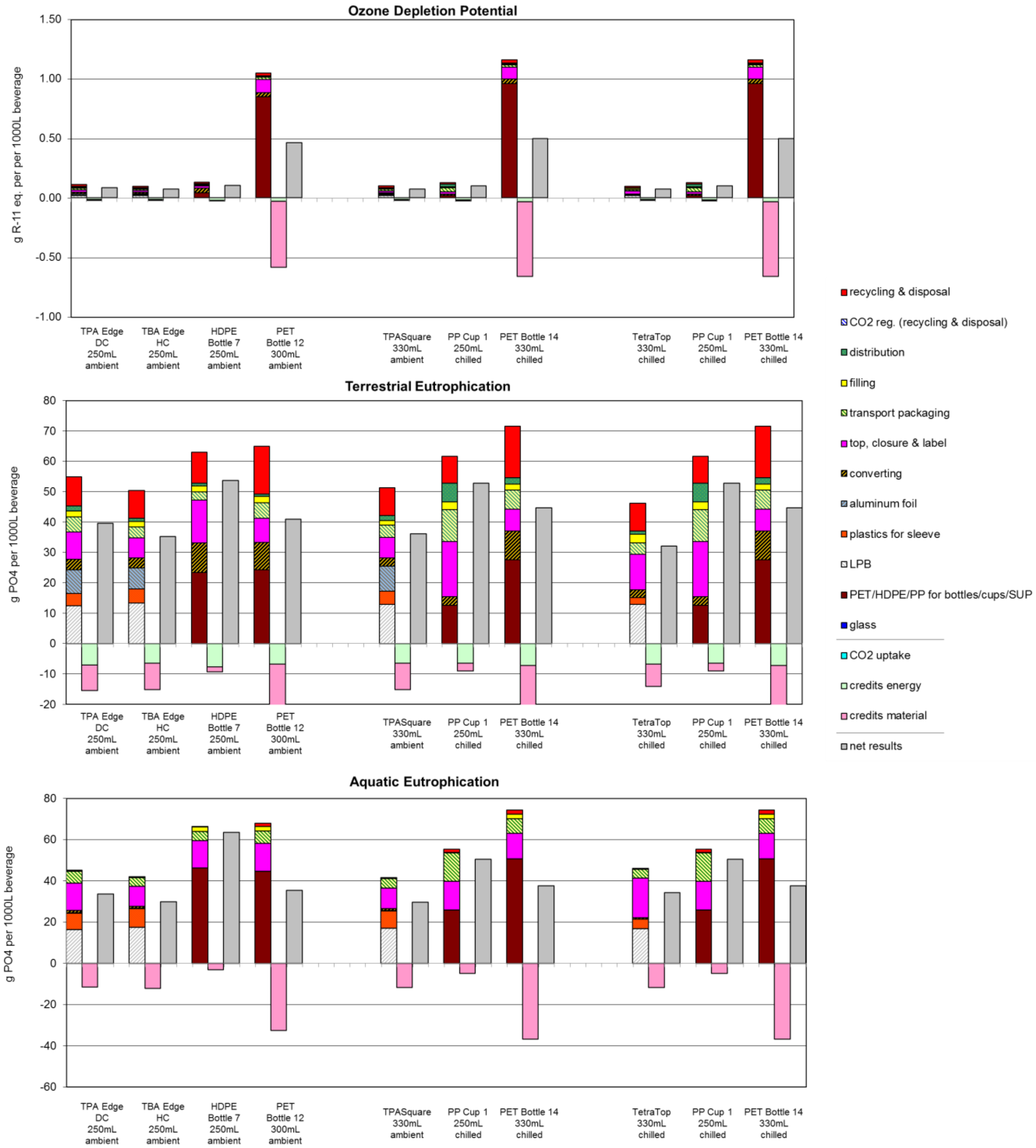



**Figure 54:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL BELGIUM**, allocation factor 100% (Part 2)

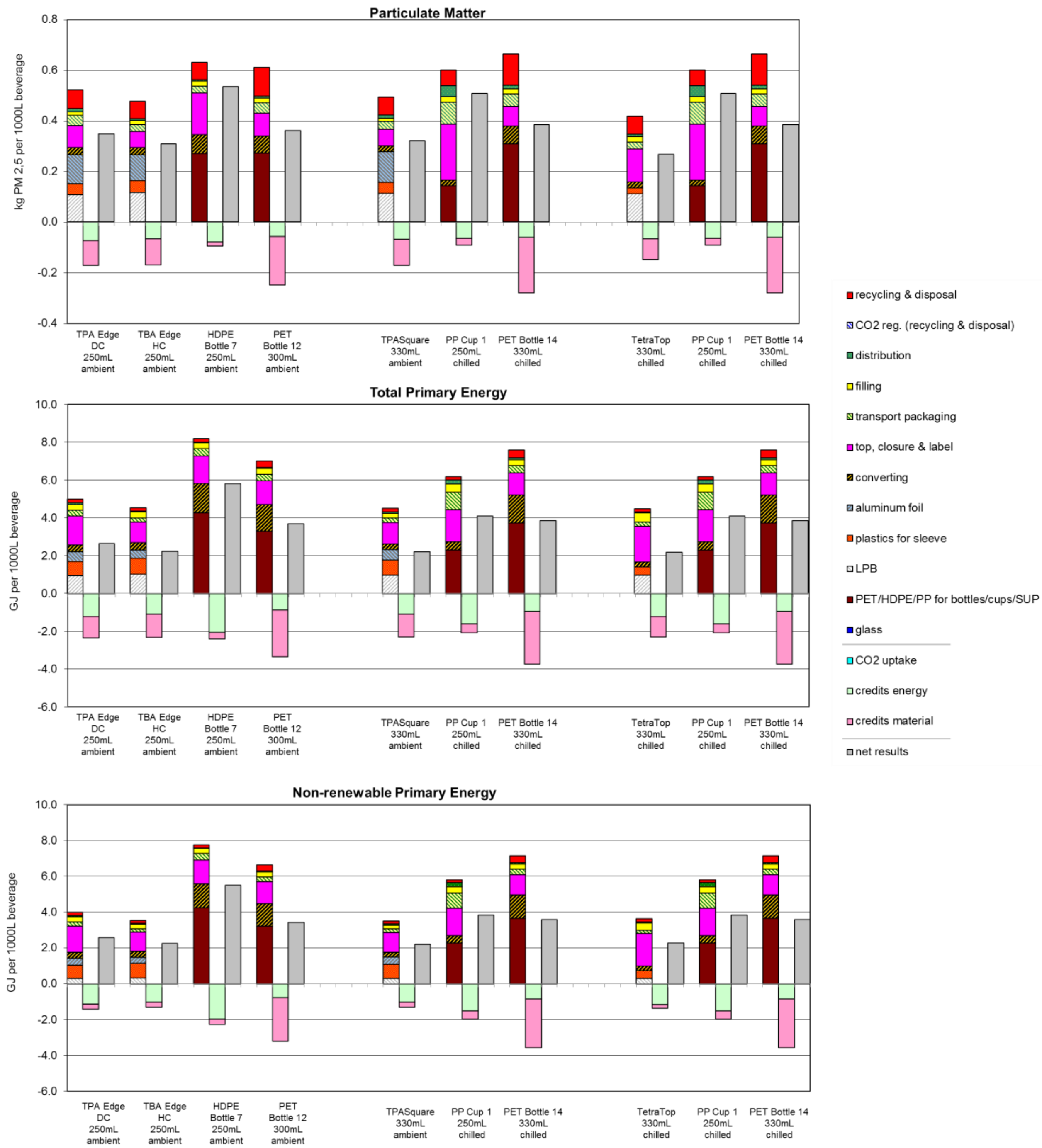



**Figure 55:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL BELGIUM**, allocation factor 100% (Part 3)

## 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 Belgium 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles and PP cups the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for all packaging systems due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 68:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 131.52 | -46% | -47% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -21% | -82% |
| Acidification [kg $SO_2$ eq.] | 0.36 | -35% | 0% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 39.65 | -26% | -3% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 33.59 | -47% | -5% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.21 | -31% | 0% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.35 | -35% | -3% |

**Table 69:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of<br>**TBA Edge HC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Edge HC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 111.97 | -54% | -55% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -31% | -85% |
| Acidification [kg $SO_2$ eq.] | 0.32 | -43% | -12% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.33 | -34% | -14% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 29.71 | -53% | -16% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.69 | -37% | -10% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | -42% | -15% |

**Table 70:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of<br>**TPA Square DC 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 113.87 | -43% | -57% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -27% | -86% |
| Acidification [kg $SO_2$ eq.] | 0.33 | -38% | -12% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.20 | -32% | -19% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 29.60 | -41% | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.78 | -32% | -15% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.32 | -37% | -16% |

**Table 71:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL BELGIUM**

| The net results of<br>**TT 330mL chilled …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TT 330mL chilled | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 107.15 | -46% | -60% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -28% | -86% |
| Acidification [kg $SO_2$ eq.] | 0.26 | -51% | -30% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 32.13 | -39% | -28% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 34.14 | -32% | -9% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.26 | -39% | -25% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.27 | -48% | -30% |

## 5.4 Sensitivity Analyses DAIRY (YOGHURT) 120mL-250mL BELGIUM

### 5.4.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

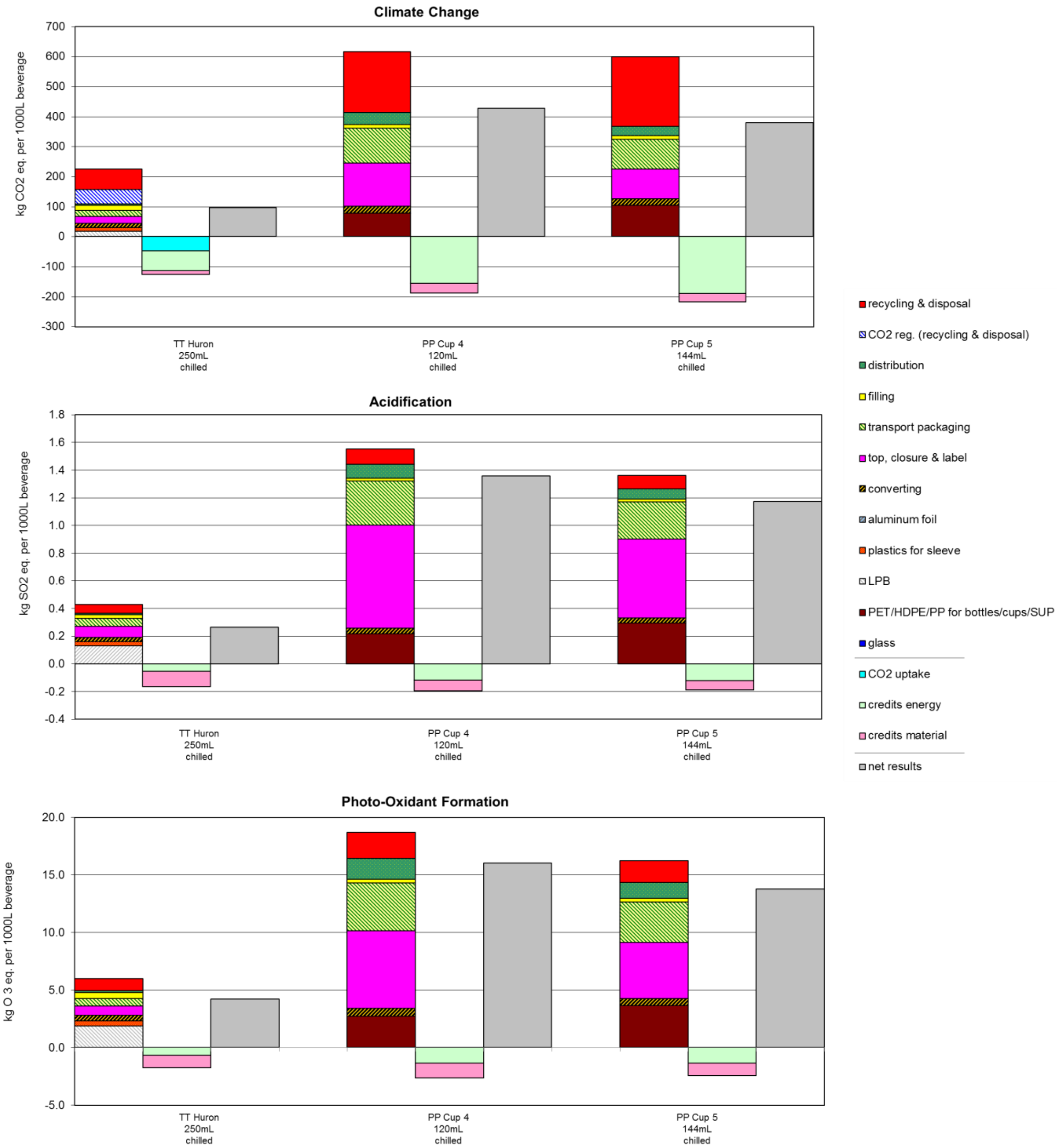



**Figure 56:** Indicator results for sensitivity analysis on system allocation of segment DAIRY (YOGHURT) 120mL-250mL BELGIUM, allocation factor 100% (Part 1)

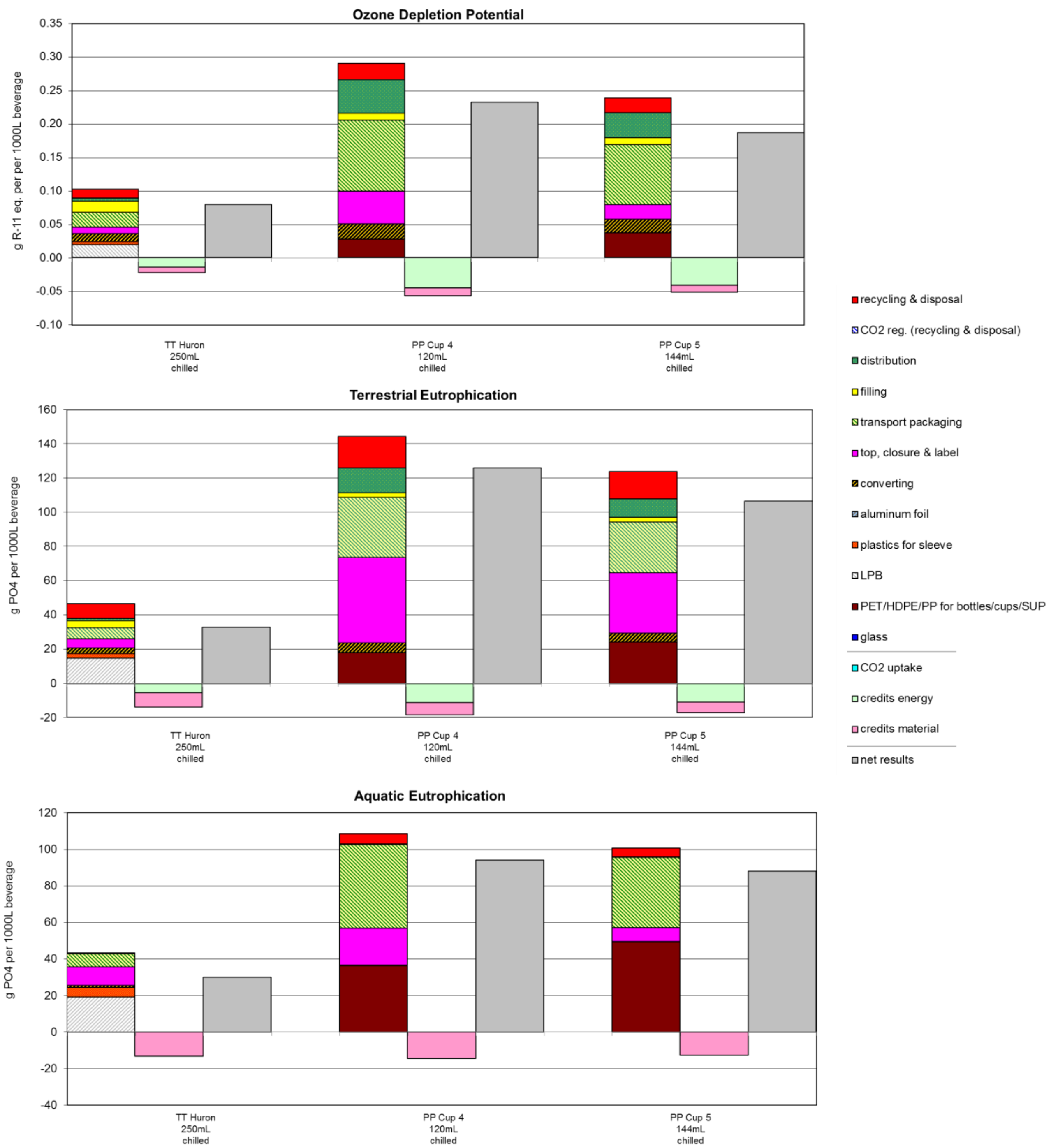



**Figure 57:** Indicator results for sensitivity analysis on system allocation of segment DAIRY (YOGHURT) 120mL-250mL BELGIUM, allocation factor 100% (Part 2)

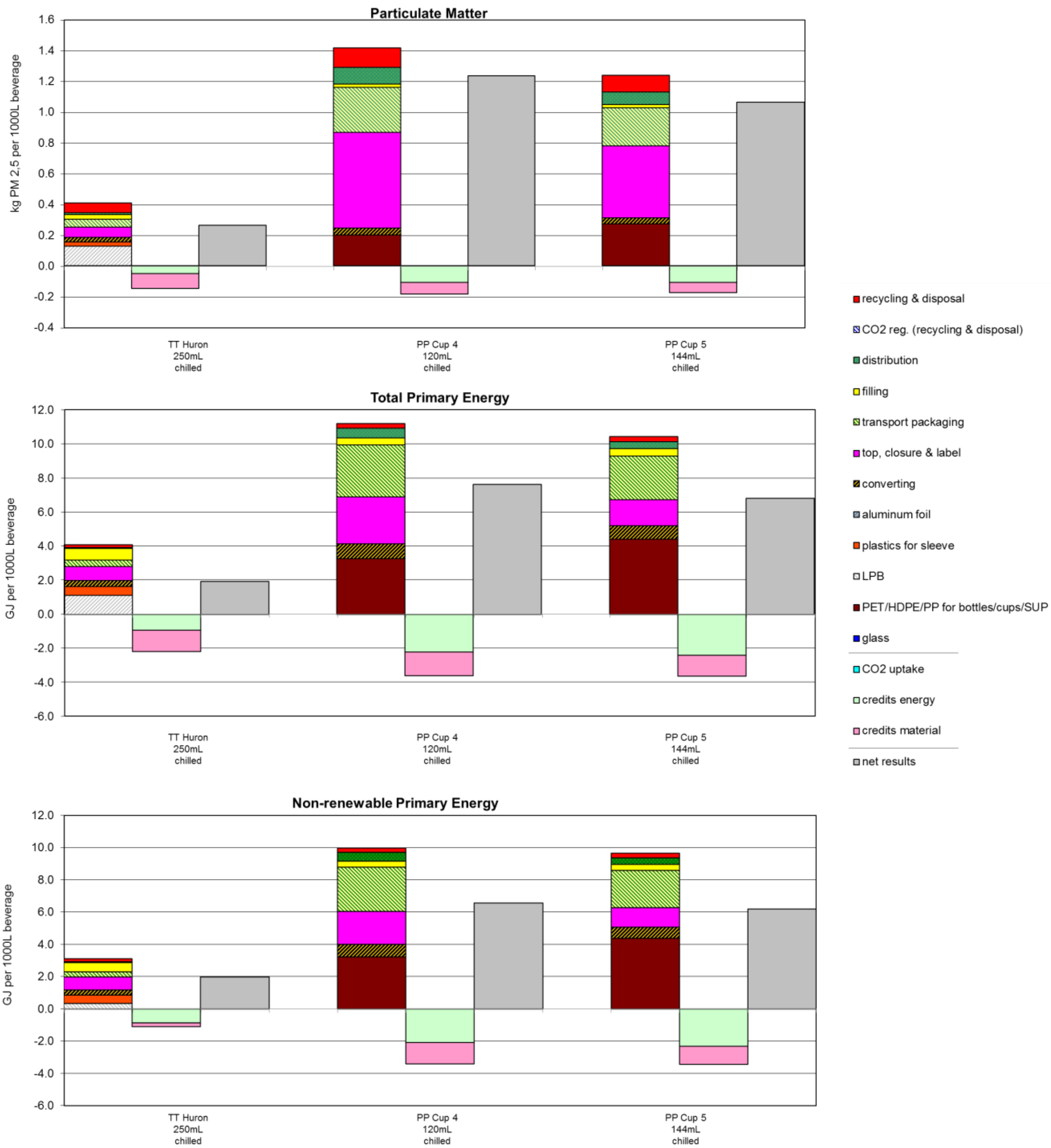



**Figure 58:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (YOGHURT) 120mL-250mL BELGIUM**, allocation factor 100% (Part 3)

## 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 Belgium 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of PP cups the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for both, beverage carton systems and PP cups due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following table shows the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 72:** Comparison of net results: **TT Huron 250mL** versus its competing alternative packaging systems **DAIRY (YOGHURT) 120mL-250mL BELGIUM**

| The net results of **TT Huron 250mL chilled …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TT Huron 250mL chilled | PP Cup 4 120mL chilled | PP Cup 5 144mL chilled |
| Climate Change [kg $CO_2$eq] | 95.73 | -78% | -75% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -66% | -58% |
| Acidification [kg $SO_2$ eq.] | 0.26 | -81% | -78% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 32.84 | -74% | -69% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 29.96 | -68% | -66% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 0.18 | -73% | -69% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.26 | -79% | -75% |

# 5.5 Sensitivity Analyses JNSD 200ml-330ml BELGIUM

### 5.5.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

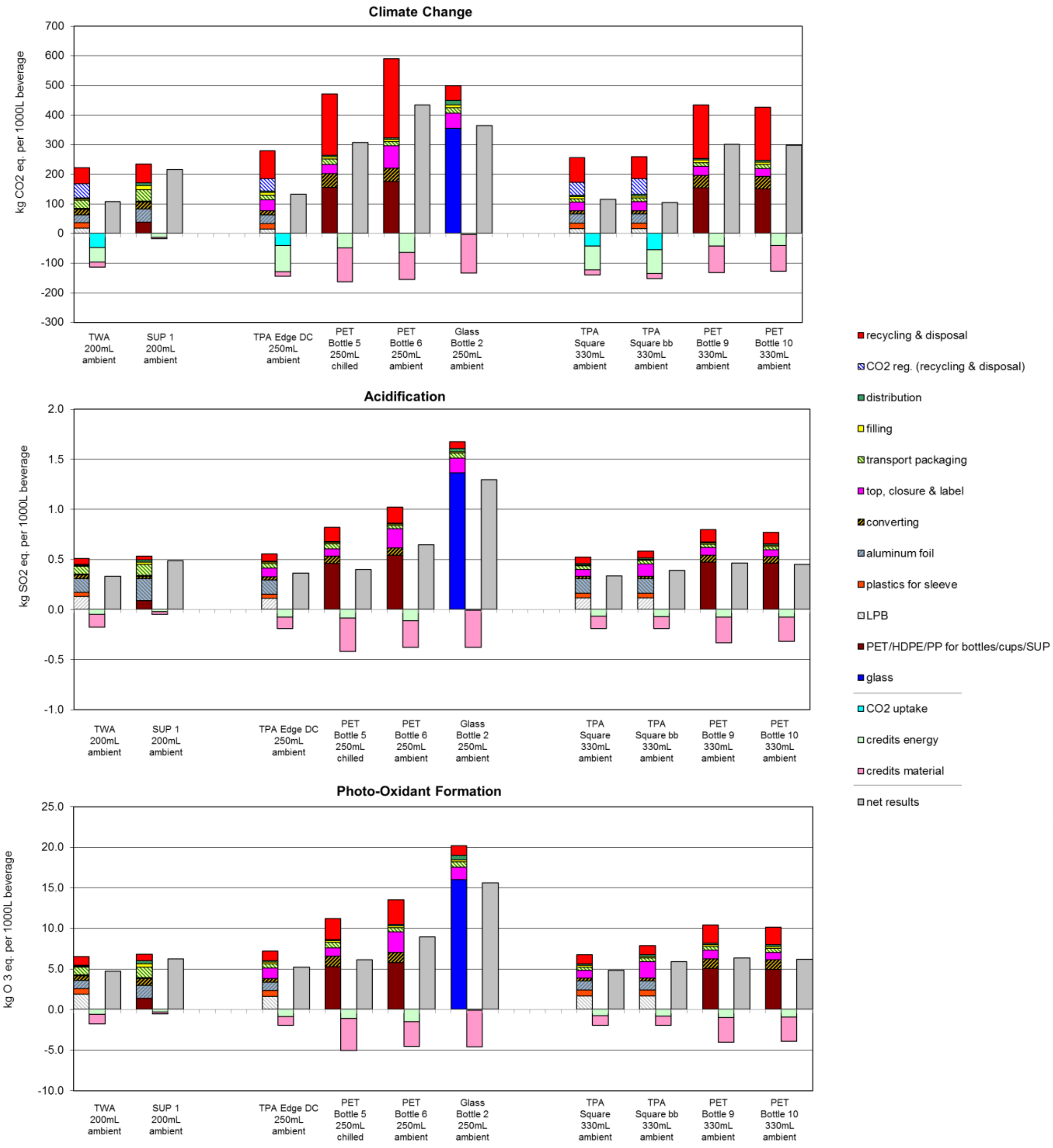



**Figure 59:** Indicator results for sensitivity analysis on system allocation of segment JNSD 200ml-330ml BELGIUM, allocation factor 100% (Part 1)

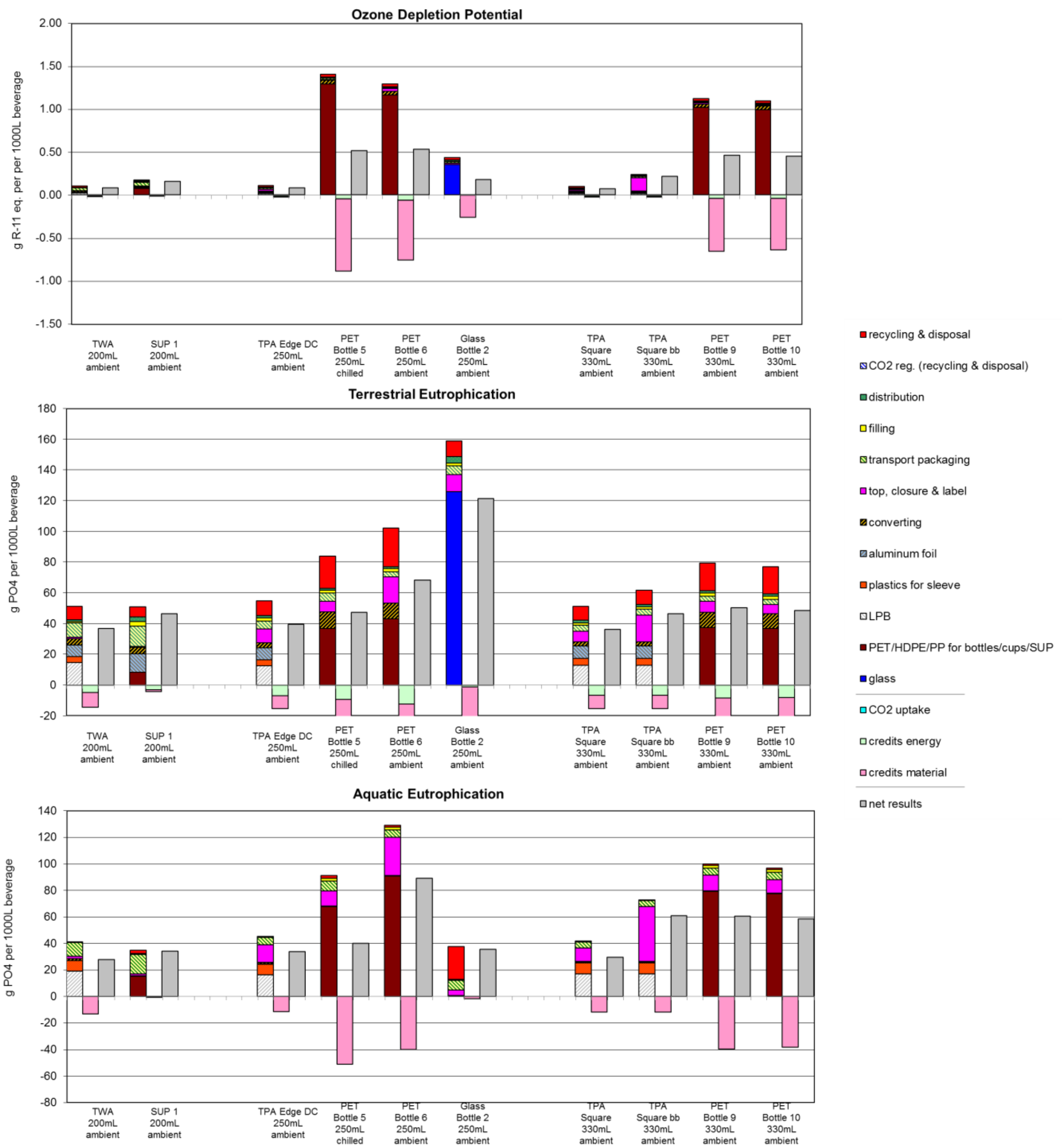



**Figure 60:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml BELGIUM**, allocation factor 100% (Part 2)

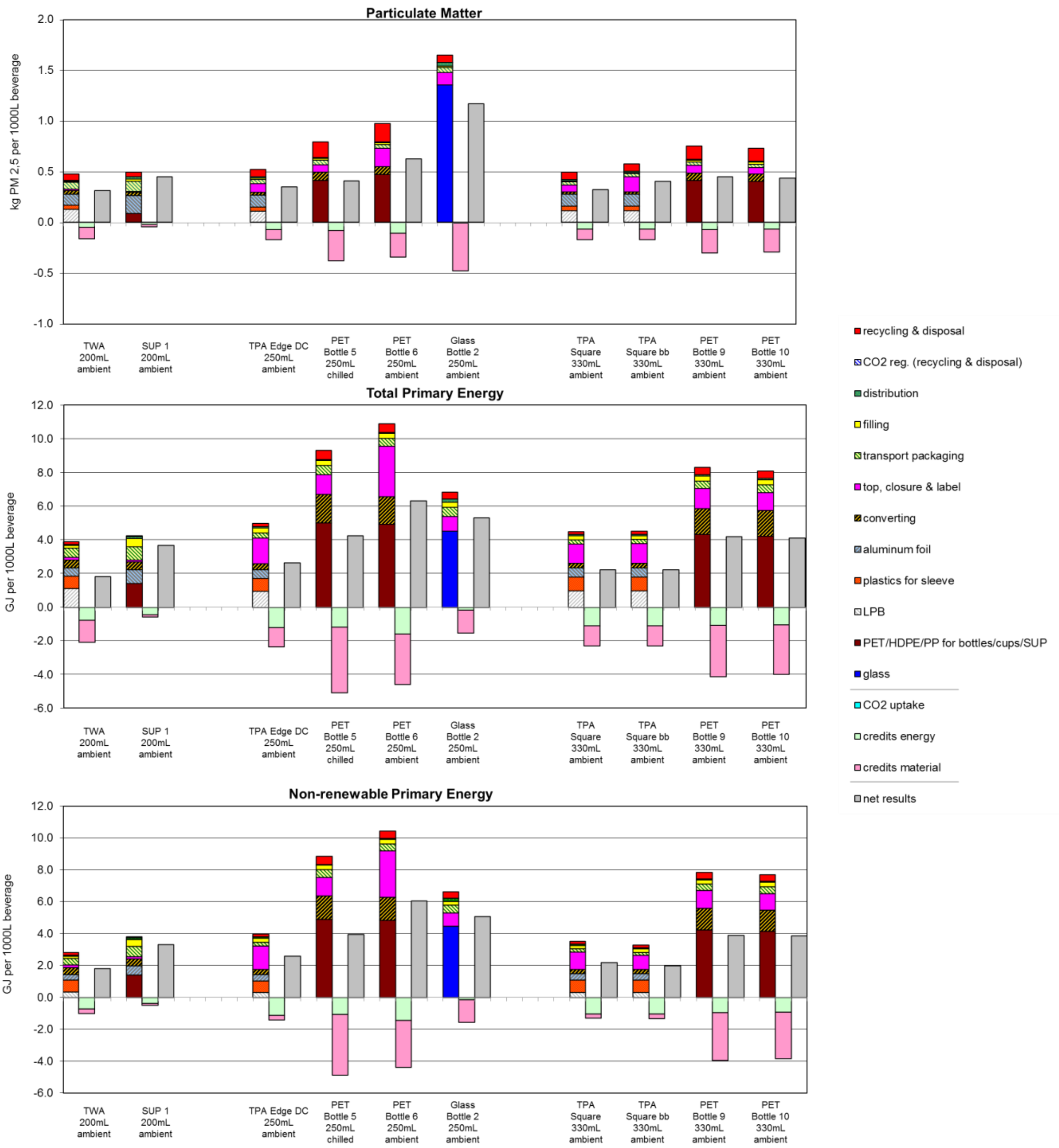



**Figure 61:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml BELGIUM**, allocation factor 100% (Part 3)

## 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 Belgium 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles and SUP the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

In the case of the glass bottle the net results of all impact categories decrease when applying the 100% allocation factor due to the high material credits compared to the burdens for recycling.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for all packaging due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 73:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TWA 200mL ambient | SUP 1 200mL ambient |
| Climate Change [kg $CO_2$eq] | 105.98 | -51% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -49% |
| Acidification [kg $SO_2$ eq.] | 0.33 | -32% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.97 | -21% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 27.76 | -19% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.67 | -25% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | -30% |

**Table 74:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled | PET Bottle 6 250ml ambient | Glass Bottle 2 250ml ambient |
| Climate Change [kg $CO_2$eq] | 131.40 | -57% | -70% | -64% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -84% | -84% | -53% |
| Acidification [kg $SO_2$ eq.] | 0.36 | -10% | -44% | -72% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 39.62 | -16% | -42% | -67% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 33.58 | -16% | -62% | -6% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.21 | -15% | -41% | -67% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.35 | -15% | -44% | -70% |

**Table 75:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PET Bottle 9 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 113.87 | -62% | -62% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -84% | -84% |
| Acidification [kg $SO_2$ eq.] | 0.33 | -28% | -26% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.20 | -28% | -26% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 29.60 | -51% | -49% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.78 | -24% | -22% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.32 | -29% | -27% |

**Table 76:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml BELGIUM**

| The net results of **TPA Square DC bb 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 9 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 103.62 | -65% | -65% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -54% | -53% |
| Acidification [kg $SO_2$ eq.] | 0.39 | -16% | -13% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 46.63 | -7% | -4% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 60.68 | 1% | 4% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.86 | -7% | -5% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | -11% | -8% |

# 6 Conclusions Belgium

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 Belgium 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 1000mL-2000mL BELGIUM

In general, the examined beverage carton systems with fossil based plastics show lower or similar environmental impacts in all of the impact categories than their competing systems. In regard of the different kind of bottles, these beverage carton systems score better in more impact categories compared to the HDPE bottle than to the PET bottle.

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

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a very limited influence on the assessment of the environmental impacts in this segment.

The sensitivity analysis regarding bio-based plastics in HDPE bottles shows, similar as for the beverage cartons with bio-based plastics, higher impacts in all categories except ‘Climate Change’. Regarding this category, considerable lower impacts can be observed. Namely to the extent that the ‘Climate Change’ impacts of the 100% bio-based HDPE bottle are actually lower than those of the beverage carton with fossil based plastics.

The sensitivity analysis regarding recycled content in PET bottles shows, that a higher share of rPET leads to generally favourable results for the bottle. A theoretical share of 100% rPET applied, leads to a better environmental performance than the regarded beverage carton in many environmental impact categories. Regarding ‘Climate Change’, though, even the 100% rPET bottle does not achieve the environmental performance of the compared beverage cartons.

The sensitivity analysis regarding plastic bottle weight shows that a reductions of bottle weight leads to lower environmental impacts of the bottles. A weight reduction of 10% as applied in this sensitivity analysis shows only a minor influence for the comparison with the regarded beverage carton.

The sensitivity analysis regarding alternative barrier material in beverage cartons shows that a substitution of aluminium foil by PE leads to lower environmental impacts in almost all categories.

## 6.2 JNSD 1000mL BELGIUM

In this segment, one examined beverage carton system with fossil based plastics, namely the TBA Edge 1000mL ambient shows lower or similar environmental impacts in all of the impact categories than the compared PET bottle. Compared to the glass bottle the carton shows lower impacts in all categories apart from 'Aquatic Eutrophication'.

A second, heavier beverage carton with fossil based plastics, the TPA Square 1000mL ambient, which also contains a relatively high amount of aluminium, does not show an overall more favourable environmental performance than the compared PET bottle in all impact categories except 'Climate Change' and 'Ozone Depletion Potential'.

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

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a very limited influence on the assessment of the environmental impacts in this segment.

## 6.3 DAIRY *189mL-500mL BELGIUM*

In this segment, all examined beverage carton systems show lower environmental impacts in all of the impact categories than the HDPE bottle and PP cup with which they are compared. Compared to the PET bottle the carton shows mostly lower or in some cases similar impacts.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a limited influence on the assessment of the environmental impacts in this segment

Regarding the comparison with the HDPE bottle and the PP cup the choice of allocation factor has a very limited influence. Results of the comparison of beverage cartons and PET bottles somewhat depend on the choice of allocation factor in some environmental impact categories.

## 6.4 DAIRY (YOGHURT) *120mL-250mL BELGIUM*

In this segment, the examined beverage carton system shows lower environmental impacts in all of the impact categories than both compared PP cups. The examined Tetra

Top Huron 250mL chilled also benefits from its larger volume than that of the compared PP cups.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has almost no influence on the assessment of the environmental impacts in this segment.

## 6.5 JNSD 200ml-330ml BELGIUM

In this segment examined beverage carton systems with fossil based plastics show lower or similar environmental impacts in all of the impact categories than the compared PET bottles and SUP. Compared to the glass bottle the carton shows lower impacts in all categories apart from 'Aquatic Eutrophication'.

In case of the beverage carton containing bio-based plastics (i.e TPA Square DC bb 330mL ambient), environmental impacts in the category 'Climate Change' are lower than those of the respective carton with fossil based plastics (i.e TPA Square DC 330mL ambient). However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. The influence of bio-based plastics is limited, though, as only a small share of plastics is bio-based. Nevertheless it leads to the beverage carton showing only slightly lower impacts only in most categories than the compared bottles.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a limited influence on the assessment of the environmental impacts in this segment.

# 7 Results Netherlands

In this section, the results of the examined packaging systems for the Netherlands 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/PP for bottles/cups/SUP including additives, e.g. carbon black (**'PET/HDPE/PP for bottles/cups/SUP'**)
- production and transport of liquid packaging board **('LPB')**
- production and transport of plastics and additives for beverage carton **('plastics for sleeve')**
- production and transport of aluminium & converting to foil **('aluminium foil')**
- converting processes of cartons **('converting')**
- production and transport of base materials for closures, top and label **('top, closure & label')**
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays **('transport packaging')**
- filling process including packaging handling **('filling')**
- retail of the packages from filler to the point-of-sale including cooling during transport if relevant **('distribution')**
- $CO_2$ emissions from incineration of bio-based and renewable materials **('CO2 reg. (recycling & disposal)')**; in the following also the term regenerative CO2 emissions is used
- sorting, recycling and disposal processes **('recycling & disposal')**

Secondary products (recycled materials and recovered energy) are obtained through recovery processes of used packaging materials, e.g. recycled fibres from cartons may replace primary fibres. It is assumed, that those secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental loads of the substituted material. The so-called 50% allocation method has been used for the crediting procedure (see section1.7) in the base scenarios.

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')**
- Uptake of athmospheric $CO_2$ during the plant growth phase ('**$CO_2$-uptake**')

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
Each impact category graph includes three bars per packaging system under investigation, which illustrate (from left to right):

- sectoral results of the packaging system itself (stacked bar 'environmental burdens')
- credits given for secondary products leaving the system (negative stacked bar 'credits')
- net results as a results of the substraction of credits from overall environmental loads (grey bar 'net results')

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

A note on significance: 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 is common practice for LCA studies comparing different product systems. This means differences ≤ 10% are considered as insignificant.

## 7.1 Results base scenarios DAIRY 1000mL-2000mL NETHERLANDS

### 7.1.1 Presentation of results

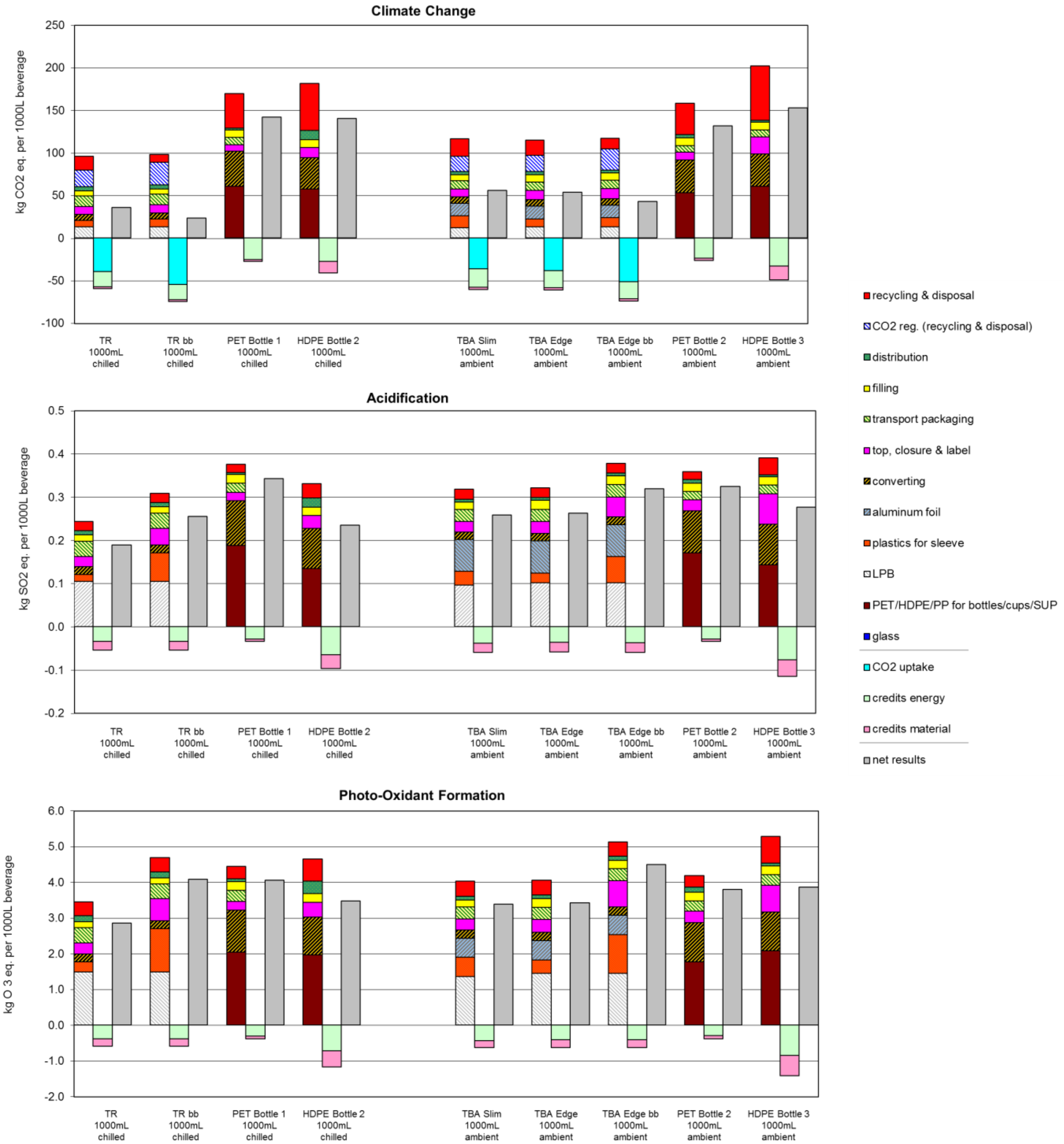



**Figure 62:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 50% (Part 1)

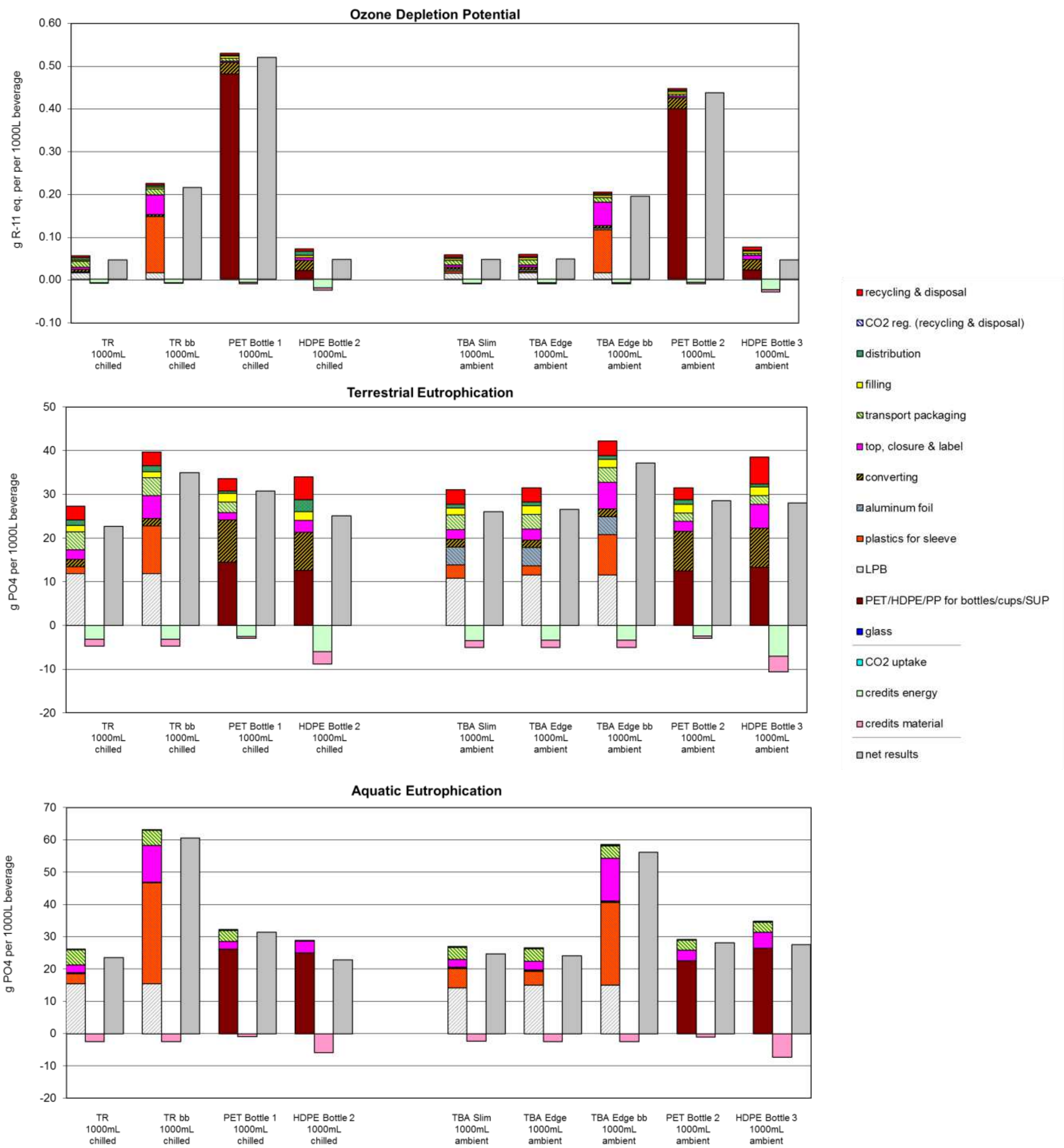



**Figure 63** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 50% (Part 2)

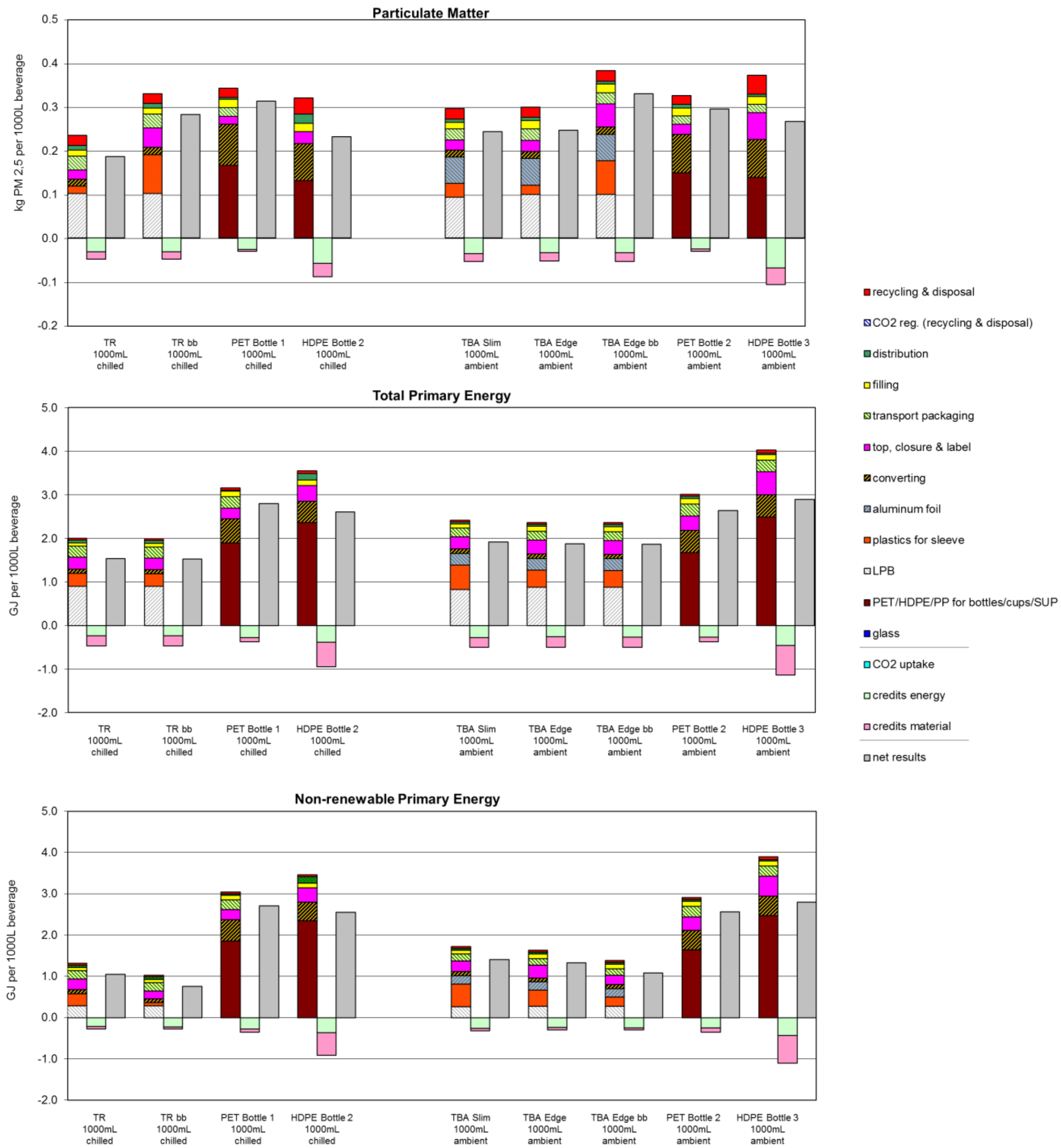



**Figure 64:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 50% (Part 3)

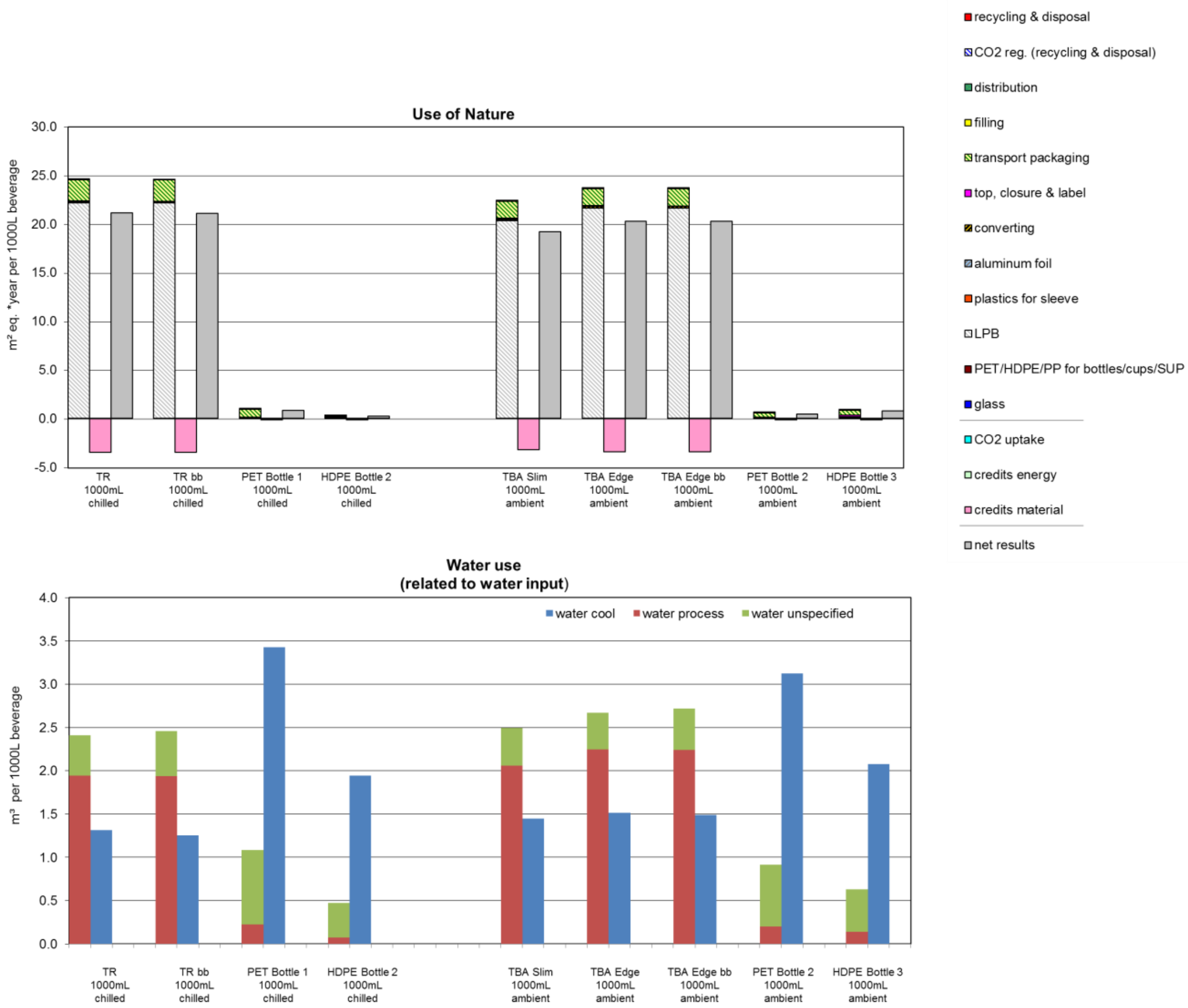



**Figure 65:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 50% (Part 4)

**Table 77:** Category indicator results per impact category for base scenarios of **segment DAIRY 1000mL-2000mL NETHERLANDS (1000mL chilled)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TR 1000mL chilled | TR bb 1000mL chilled | PET Bottle 1 1000mL chilled | HDPE Bottle 2 1000mL chilled |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 75.93 | 71.41 | 169.18 | 181.37 |
| | CO2 (reg) | 19.57 | 26.46 | 0.00 | 0.00 |
| | Credits* | -20.18 | -20.32 | -27.51 | -41.18 |
| | $CO_2$ uptake | -39.44 | -54.57 | 0.00 | 0.00 |
| | Net results (∑) | 35.88 | 22.99 | 141.66 | 140.19 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.24 | 0.31 | 0.38 | 0.33 |
| | Credits* | -0.05 | -0.05 | -0.03 | -0.10 |
| | Net results (∑) | 0.19 | 0.26 | 0.34 | 0.24 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 3.44 | 4.68 | 4.44 | 4.65 |
| | Credits* | -0.59 | -0.60 | -0.38 | -1.18 |
| | Net results (∑) | 2.85 | 4.08 | 4.06 | 3.47 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.05 | 0.22 | 0.53 | 0.07 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.02 |
| | Net results (∑) | 0.05 | 0.22 | 0.52 | 0.05 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 27.36 | 39.73 | 33.65 | 33.99 |
| | Credits* | -4.68 | -4.71 | -2.92 | -8.85 |
| | Net results (∑) | 22.67 | 35.01 | 30.74 | 25.15 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 26.05 | 63.01 | 32.22 | 28.80 |
| | Credits* | -2.46 | -2.46 | -0.85 | -5.93 |
| | Net results (∑) | 23.59 | 60.55 | 31.37 | 22.87 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.23 | 0.33 | 0.34 | 0.32 |
| | Credits* | -0.05 | -0.05 | -0.03 | -0.09 |
| | Net results (∑) | 0.19 | 0.28 | 0.31 | 0.23 |
| Total Primary Energy [GJ] | Burdens | 2.01 | 2.00 | 3.17 | 3.55 |
| | Credits* | -0.46 | -0.47 | -0.36 | -0.94 |
| | Net results (∑) | 1.55 | 1.53 | 2.80 | 2.61 |
| Non-renewable primary energy [GJ] | Burdens | 1.32 | 1.03 | 3.04 | 3.46 |
| | Credits* | -0.27 | -0.27 | -0.34 | -0.91 |
| | Net results (∑) | 1.05 | 0.76 | 2.70 | 2.55 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 24.55 | 24.54 | 0.98 | 0.33 |
| | Credits* | -3.45 | -3.45 | -0.13 | -0.08 |
| | Net results (∑) | 21.10 | 21.09 | 0.85 | 0.25 |
| Water use [$m^3$] | Water cool | 1.31 | 1.25 | 3.43 | 1.95 |
| | Water process | 1.95 | 1.94 | 0.22 | 0.07 |
| | Water unspec | 0.46 | 0.52 | 0.86 | 0.40 |

*material and energy credits

**Table 78:** Category indicator results per impact category for base scenarios of **segment DAIRY 1000mL-2000mL NETHERLANDS (1000mL ambient)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TBA Slim 1000mL | TBA Edge 1000mL | TBA Edge bb 1000mL | PET Bottle 2 1000mL | HDPE Bottle 3 1000mL |
|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 98.54 | 95.93 | 92.15 | 158.01 | 201.86 |
| | CO2 (reg) | 17.94 | 19.02 | 24.96 | 0.00 | 0.00 |
| | Credits* | -24.33 | -22.76 | -22.88 | -26.41 | -49.20 |
| | $CO_2$ uptake | -36.26 | -38.54 | -51.57 | 0.00 | 0.00 |
| | Net results (∑) | 55.89 | 53.65 | 42.66 | 131.60 | 152.66 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.32 | 0.32 | 0.38 | 0.36 | 0.39 |
| | Credits* | -0.06 | -0.06 | -0.06 | -0.03 | -0.11 |
| | Net results (∑) | 0.26 | 0.26 | 0.32 | 0.33 | 0.28 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 4.02 | 4.05 | 5.13 | 4.18 | 5.27 |
| | Credits* | -0.64 | -0.63 | -0.63 | -0.39 | -1.42 |
| | Net results (∑) | 3.38 | 3.42 | 4.49 | 3.79 | 3.85 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.06 | 0.06 | 0.20 | 0.45 | 0.08 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.01 | -0.03 |
| | Net results (∑) | 0.05 | 0.05 | 0.19 | 0.44 | 0.05 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 31.14 | 31.56 | 42.24 | 31.51 | 38.59 |
| | Credits* | -5.04 | -4.99 | -5.01 | -2.96 | -10.57 |
| | Net results (∑) | 26.10 | 26.57 | 37.23 | 28.55 | 28.03 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 26.96 | 26.57 | 58.46 | 29.14 | 34.82 |
| | Credits* | -2.27 | -2.42 | -2.42 | -1.10 | -7.25 |
| | Net results (∑) | 24.69 | 24.15 | 56.04 | 28.04 | 27.58 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.30 | 0.30 | 0.38 | 0.33 | 0.37 |
| | Credits* | -0.05 | -0.05 | -0.05 | -0.03 | -0.11 |
| | Net results (∑) | 0.24 | 0.25 | 0.33 | 0.30 | 0.27 |
| Total Primary Energy [GJ] | Burdens | 2.42 | 2.37 | 2.37 | 3.02 | 4.03 |
| | Credits* | -0.50 | -0.49 | -0.49 | -0.37 | -1.13 |
| | Net results (∑) | 1.93 | 1.88 | 1.87 | 2.65 | 2.90 |
| Non-renewable primary energy [GJ] | Burdens | 1.72 | 1.63 | 1.38 | 2.91 | 3.89 |
| | Credits* | -0.31 | -0.30 | -0.30 | -0.35 | -1.10 |
| | Net results (∑) | 1.40 | 1.33 | 1.09 | 2.56 | 2.79 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 22.35 | 23.65 | 23.64 | 0.60 | 0.89 |
| | Credits* | -3.18 | -3.40 | -3.40 | -0.13 | -0.10 |
| | Net results (∑) | 19.17 | 20.25 | 20.24 | 0.48 | 0.79 |
| Water use [$m^3$] | Water cool | 1.45 | 1.51 | 1.49 | 3.12 | 2.08 |
| | Water process | 2.06 | 2.25 | 2.24 | 0.20 | 0.14 |
| | Water unspec | 0.43 | 0.42 | 0.48 | 0.72 | 0.49 |

*material and energy credits

### 7.1.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For all beverage carton systems regarded in the DAIRY 1000mL-2000mL segment, being chilled or ambient, 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%-59%) and ‘Use of Nature’ (90%-91%). It is also relevant regarding ‘Photo-Oxidant Formation’ (28%-43%), ‘Acidification’ (27%-43%), ‘Terrestrial Eutrophication’ (27%-43%), ‘Particulate Matter’ (26%-43%) and also the consumption of ‘Total Primary Energy’ (34%-45%).

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 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 beverage cartons for ambient milk consist of an additional layer of aluminium foil. The production of ‘aluminium foil’ for the sleeves shows burdens in most impact categories. Substantial burdens can be seen for the categories ‘Acidification’ (20%-23%) and ‘Particulate Matter’ (16%-20%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable shares of burdens (5%-59%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where fossil plastics (8%-12%) and LPB (10%-14%) contribute about the same and the inventory category ‘Non-renewable Primary

Energy', where the plastics contribute up to about a third of the total burdens. If 'plastics for sleeve' contains bio-based plastics (i.e. for TR bb 1000mL chilled and TBA Edge bb 1000mL), this life cycle step plays a major role (14%-59%) for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step 'top, closure & label' contributes to a considerable amount (7%-26%) in almost all impact categories. In case the plastics used for 'top, closure & label' are bio-based (i.e. TR bb 1000mL chilled and TBA Edge bb 1000mL), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (max. 9%). It generates emissions, which contribute mainly to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show considerable shares of impacts (5%-20%) in all categories.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 9%) for all beverage carton systems in all categories. Therefore none of these life cycle steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (32%-37%). 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.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Netherlands these derive mainly from the incineration of bio-based plastics and paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits are given for the substitution of primary material due to recycling. As the Dutch recycling rate for beverage cartons is only 37% the energy credits are higher than the material credits in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'.

Material credits for 'Climate Change' are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart from 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY 1000mL-2000mL segment, the biggest part of the environmental burdens (29%-90%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. This is true for PET and HDPE bottles as well as for bottles in both sub-segments: chilled and ambient.

Differences can be observed depending on the kind of plastic used, though. For most impact categories the burdens from plastic production (life cycle step 'PET/HDPE/PP for bottles/cups/SUP' in the graphs) are higher for the HDPE bottle than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows a comparatively low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

The 'converting' process of all regarded bottles shows considerable shares of impacts (5%-35%) in all categories apart from 'Aquatic Eutrophication' with share of impacts less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable shares of impacts (1%-29%) in most categories mainly attributed to the different closures. 'Top, closure & label' of both HDPE bottles (chilled and ambient) show higher impacts than those of the PET bottles. This can be explained by their higher weight and also by the fact that the HDPE Bottle 3 also includes an aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems show minor shares of impacts (1%-11%) in all categories except of 'Use of Nature' in which the paper production contributes to 55%-81% of the burdens. For most categories the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets. An exception in this life cycle step is the HDPE Bottle 2, which does not use any shrink foil or paperboard trays, but instead is transported in reusable roll containers (see section 1.5 for more detail about roll containers). Therefore it does not show any impacts in this life cycle step.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 13%) for all bottle systems in all categories. Therefore none of these sectors play an important role for the overall results in any category.

The impact of the fossil-based plastic bottles’ ‘recycling & disposal’ life cycle step is most noticeable regarding ‘Climate Change’ (23%-32%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is different for the different bottles. Credits of the white opaque PET bottles, which are not materially recycled, show a high impact in the environmental impact category ‘Climate Change’ and lower impacts in the remaining categories. For ‘Ozone Depletion Potential`, Aquatic Eutrophication’ and ‘Use of Nature’ the credits play almost no role for the overall results. The credits of the partially recycled clear HDPE Bottle 3 (Dutch recycling rate for plastic packaging is 51%) show generally higher impacts than those of the PET bottles, as they also receive material credits. This leads to a considerable influence on the net results even in the categories ‘Aquatic Eutrophication” and ‘Ozone Depletion Potential’.

### 7.1.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 79:** Comparison of net results: **TR 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TR 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TR 1000mL chilled | PET Bottle 1 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 35.88 | -75% | -74% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -91% | -3% |
| Acidification [kg $SO_2$ eq.] | 0.19 | -45% | -19% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 22.67 | -26% | -10% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 23.59 | -25% | 3% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.85 | -30% | -18% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.19 | -40% | -20% |

**Table 80:** Comparison of net results: **TR bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TR bb 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TR bb 1000mL chilled | PET Bottle 1 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 22.99 | -84% | -84% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -59% | 359% |
| Acidification [kg $SO_2$ eq.] | 0.26 | -26% | 8% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.01 | 14% | 39% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 60.55 | 93% | 165% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.08 | 1% | 18% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.28 | -10% | 22% |

**Table 81:** Comparison of net results: **TBA Edge 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 53.65 | -59% | -65% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -89% | 5% |
| Acidification [kg $SO_2$ eq.] | 0.26 | -19% | -5% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 26.57 | -7% | -5% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 24.15 | -14% | -12% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.42 | -10% | -11% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.25 | -16% | -7% |

**Table 82:** Comparison of net results: **TBA Edge bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of<br>**TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 42.66 | -68% | -72% |
| Ozone depletion potential [g R-11 eq.] | 0.19 | -55% | 323% |
| Acidification [kg $SO_2$ eq.] | 0.32 | -2% | 16% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 37.23 | 30% | 33% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 56.04 | 100% | 103% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.49 | 19% | 17% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.33 | 12% | 24% |

**Table 83:** Comparison of net results: **TBA Slim 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of<br>**TBA Slim 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Slim 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 55.89 | -58% | -63% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -89% | 1% |
| Acidification [kg $SO_2$ eq.] | 0.26 | -20% | -6% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 26.10 | -9% | -7% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 24.69 | -12% | -10% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.38 | -11% | -12% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.24 | -18% | -9% |

# 7.2 Results base scenarios JNSD 1000mL NETHERLANDS

## 7.2.1 Presentation of results

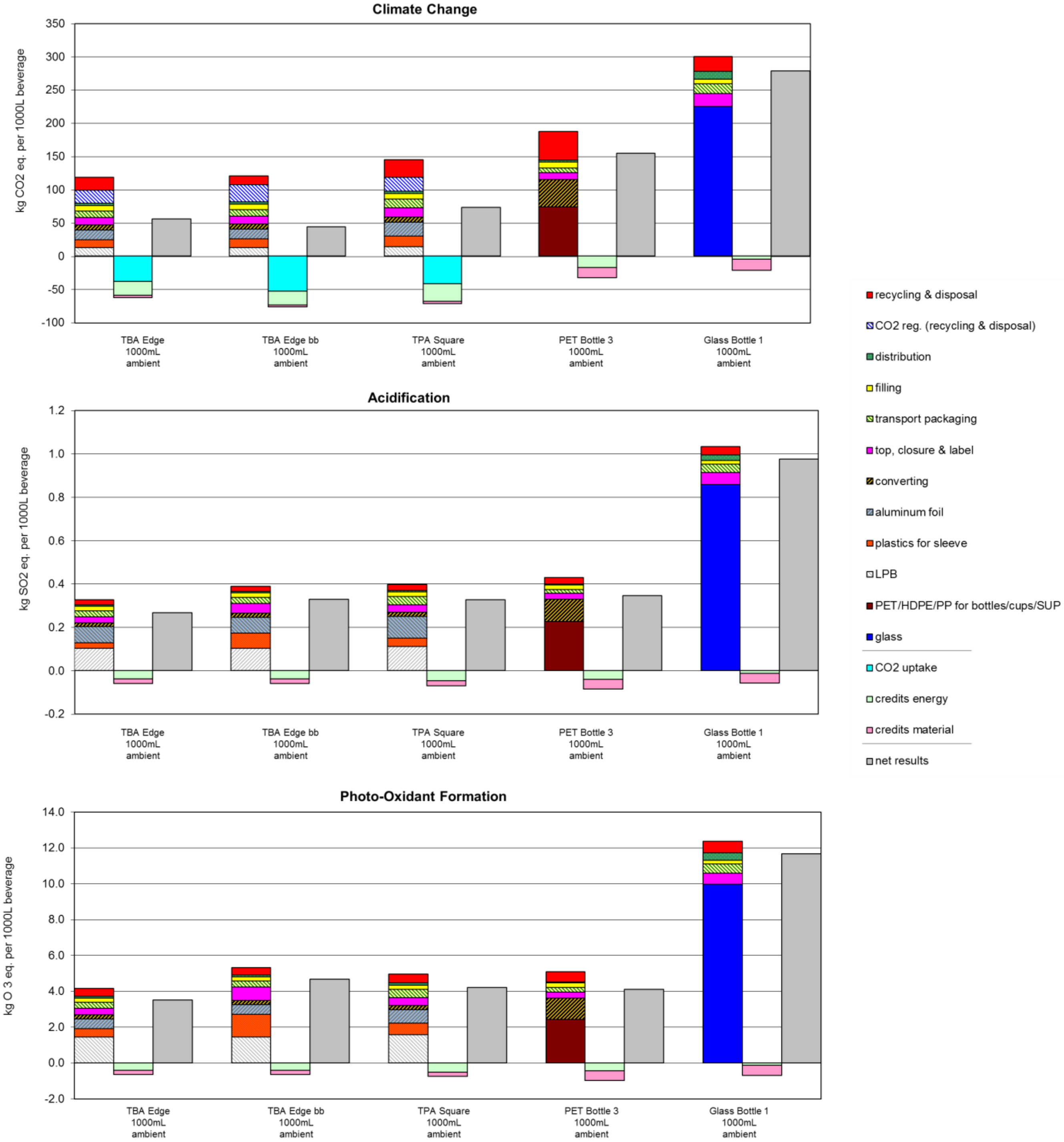



**Figure 66:** Indicator results for base scenarios of **segment JNSD 1000mL, NETHERLANDS**, allocation factor 50% (Part 1)

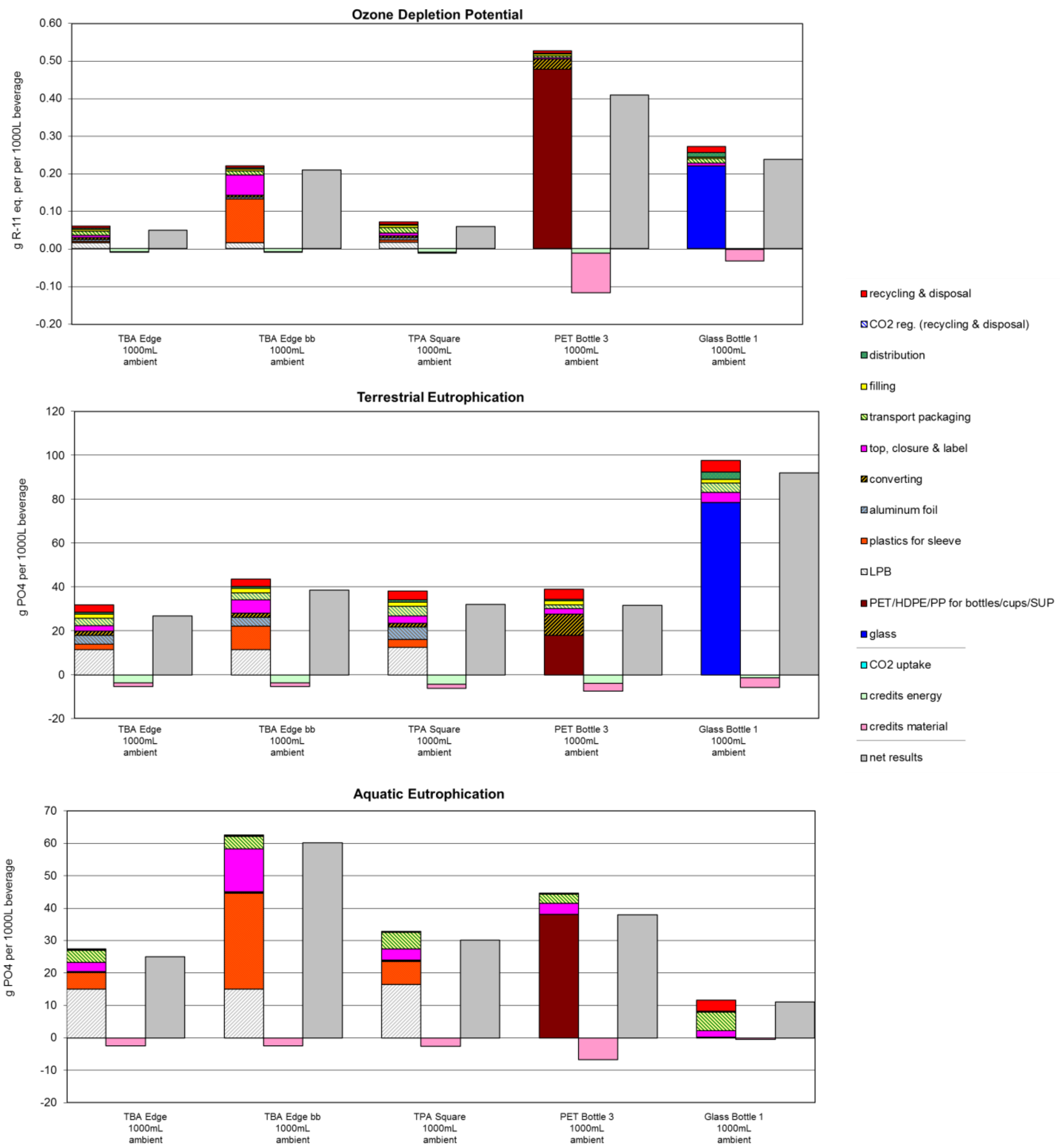



**Figure 67:** Indicator results for base scenarios of **segment JNSD 1000mL, NETHERLANDS**, allocation factor 50% (Part 2)

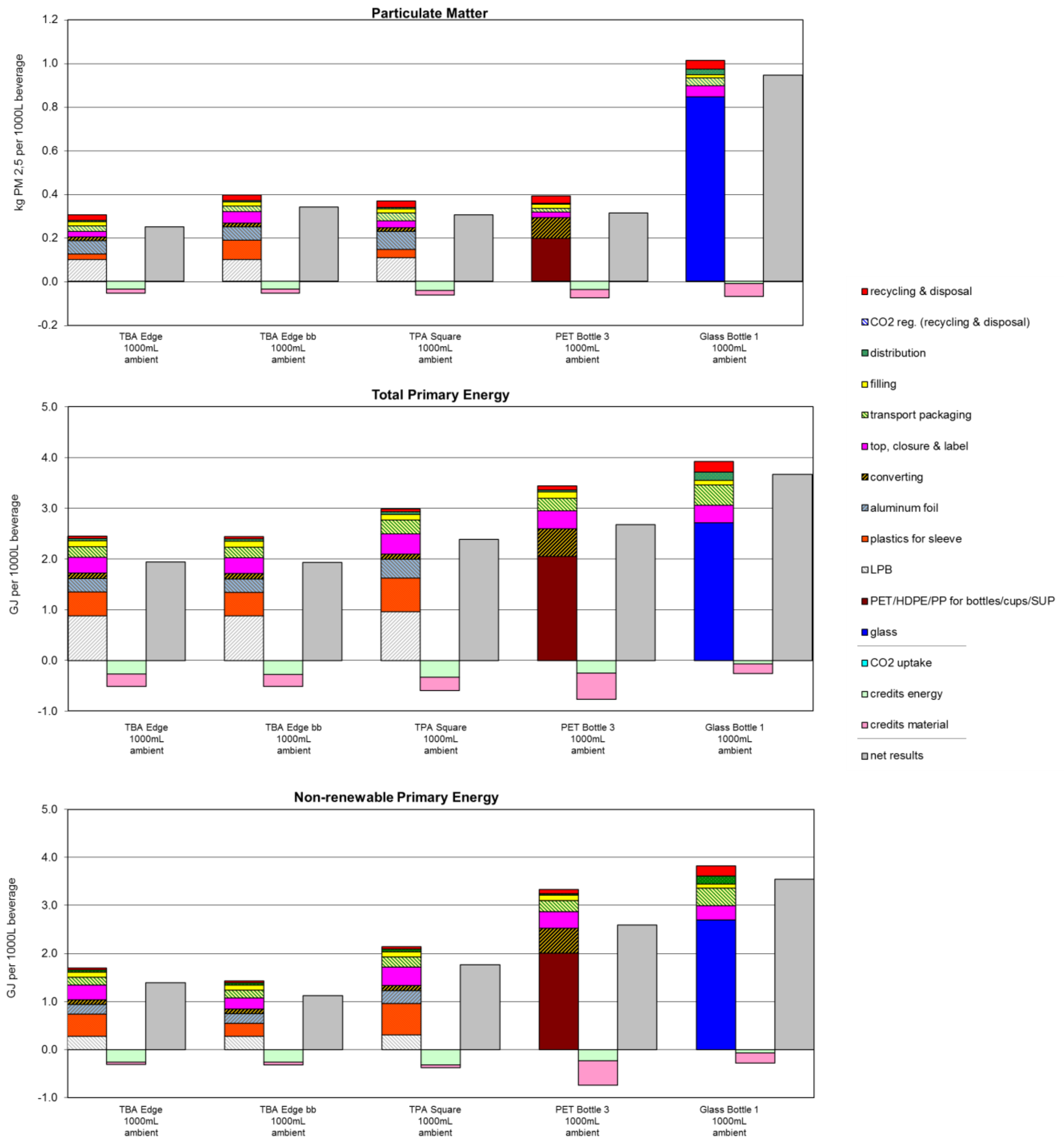



**Figure 68:** Indicator results for base scenarios of **segment JNSD 1000mL, NETHERLANDS**, allocation factor 50% (Part 3)

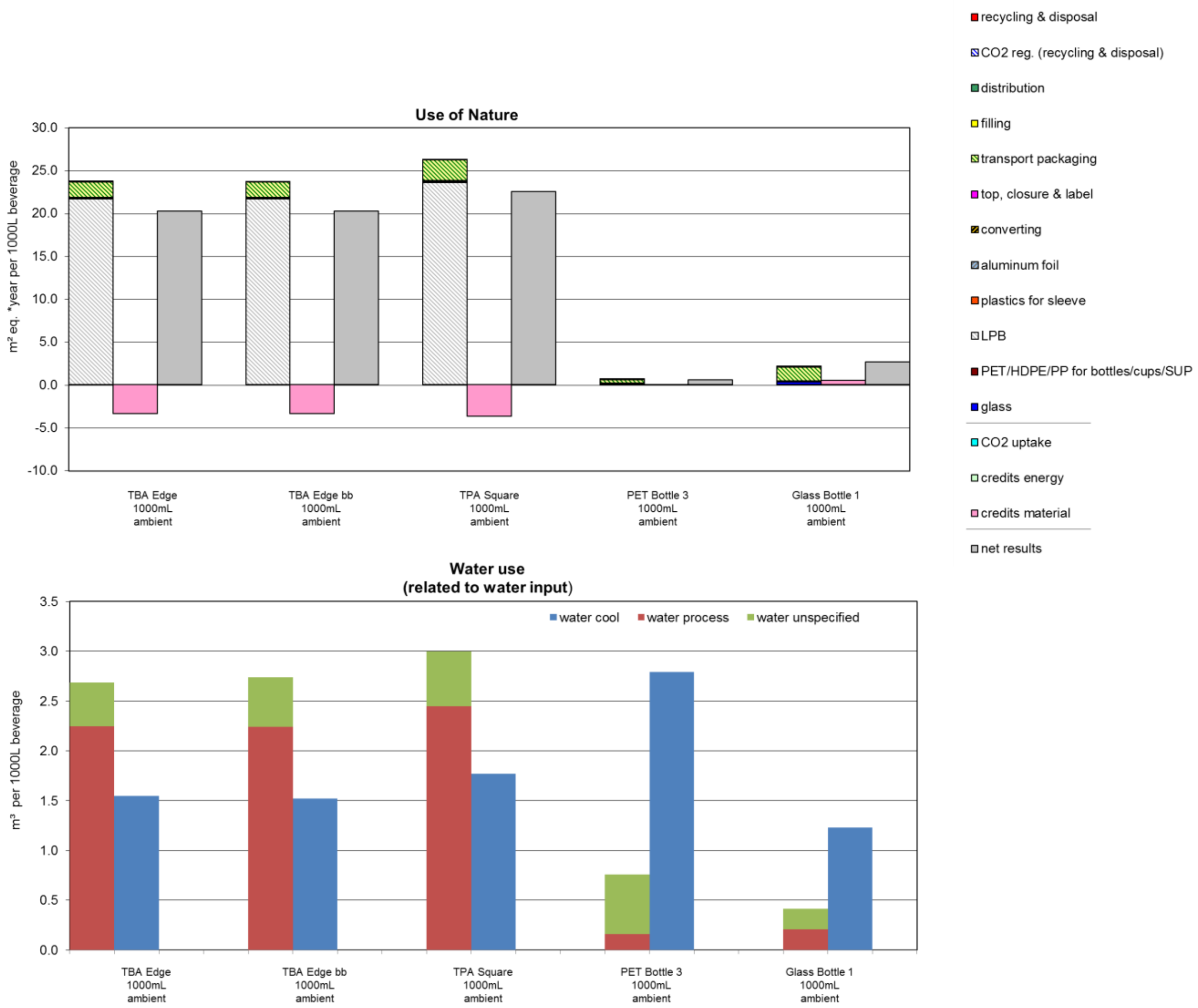



**Figure 69:** Indicator results for base scenarios of **segment JNSD 1000mL, NETHERLANDS**, allocation factor 50% (Part 4)

**Table 84:** Category indicator results per impact category for base scenarios of segment JNSD 1000mL, Netherlands- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TBA Edge 1000mL ambient | TBA Edge bb 1000mL ambient | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 99.26 | 95.10 | 123.66 | 187.02 | 299.94 |
| | CO2 (reg) | 19.02 | 25.54 | 20.75 | 0.00 | 0.00 |
| | Credits* | -23.91 | -24.04 | -29.51 | -32.87 | -21.88 |
| | $CO_2$ uptake | -38.53 | -52.85 | -41.98 | 0.00 | 0.00 |
| | Net results (∑) | 55.84 | 43.74 | 72.92 | 154.15 | 278.06 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.33 | 0.39 | 0.40 | 0.43 | 1.03 |
| | Credits* | -0.06 | -0.06 | -0.07 | -0.08 | -0.06 |
| | Net results (∑) | 0.27 | 0.33 | 0.33 | 0.35 | 0.98 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 4.13 | 5.32 | 4.94 | 5.07 | 12.34 |
| | Credits* | -0.65 | -0.65 | -0.76 | -0.98 | -0.70 |
| | Net results (∑) | 3.49 | 4.67 | 4.18 | 4.08 | 11.65 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.06 | 0.22 | 0.07 | 0.53 | 0.27 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.12 | -0.03 |
| | Net results (∑) | 0.05 | 0.21 | 0.06 | 0.41 | 0.24 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 32.06 | 43.80 | 38.36 | 39.08 | 97.65 |
| | Credits* | -5.12 | -5.15 | -6.03 | -7.34 | -5.57 |
| | Net results (∑) | 26.94 | 38.65 | 32.33 | 31.74 | 92.08 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 27.37 | 62.42 | 32.76 | 44.61 | 11.53 |
| | Credits* | -2.41 | -2.41 | -2.62 | -6.74 | -0.44 |
| | Net results (∑) | 24.96 | 60.00 | 30.14 | 37.88 | 11.08 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.30 | 0.40 | 0.37 | 0.39 | 1.01 |
| | Credits* | -0.05 | -0.05 | -0.06 | -0.08 | -0.07 |
| | Net results (∑) | 0.25 | 0.34 | 0.30 | 0.31 | 0.94 |
| Total Primary Energy [GJ] | Burdens | 2.45 | 2.44 | 2.99 | 3.45 | 3.93 |
| | Credits* | -0.51 | -0.51 | -0.59 | -0.76 | -0.25 |
| | Net results (∑) | 1.94 | 1.93 | 2.39 | 2.68 | 3.67 |
| Non-renewable primary energy [GJ] | Burdens | 1.70 | 1.43 | 2.14 | 3.33 | 3.82 |
| | Credits* | -0.31 | -0.31 | -0.38 | -0.74 | -0.27 |
| | Net results (∑) | 1.40 | 1.12 | 1.77 | 2.59 | 3.54 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 23.65 | 23.64 | 26.21 | 0.60 | 2.13 |
| | Credits* | -3.40 | -3.40 | -3.69 | -0.05 | 0.48 |
| | Net results (∑) | 20.25 | 20.24 | 22.52 | 0.55 | 2.62 |
| Water use [$m^3$] | Water cool | 1.55 | 1.52 | 1.77 | 2.79 | 1.23 |
| | Water process | 2.25 | 2.24 | 2.45 | 0.16 | 0.20 |
| | Water unspec | 0.44 | 0.50 | 0.55 | 0.60 | 0.21 |

*material and energy credits

### 7.2.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 1000mL 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%-55%) and 'Use of Nature' (90%-21%). It is also relevant regarding 'Photo-Oxidant Formation' (27%-35%), 'Acidification' 26%-31%), 'Terrestrial Eutrophication' (26%-33%), 'Particulate Matter' (25%-33%) and also the consumption of 'Total Primary Energy' (26%-31%).

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 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 shows burdens in most impact categories. Substantial burdens can be seen for the categories 'Acidification' (19%-26%) and 'Particulate Matter' (15%-23%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (8%-53%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil based plastics (10%-11%) and LPB (10%-11%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about 20% until 30% of the total burdens. If the ‘plastics for sleeves’ contain bio-based plastics (i.e. TBA Edge bio-based 1000mL ambient) this life cycle step plays a major role for the overall burdens in all categories apart from ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The life cycle step ‘top, closure & label’ contributes to a considerable amount (8%-25%) in almost all impact categories. In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TBA Edge bb 1000mL ambient), the results are considerably higher than for cartons with fossil based cartons in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (max. 8%). It generates emissions, which contribute mainly to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems show considerable impacts (5%-21%) in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 8%) for all beverage carton systems in most impact categories. Therefore none of these sectors play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (32%-33%). 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.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Netherlands these derive mainly from the incineration of bio-based plastics and paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits are given for the substitution of primary material due to recycling. As the Dutch recycling rate for beverage cartons is only 37% the energy credits are higher than the material credits in all categories apart from ‘Aquatic Eutrophication‘ and ‘Use of Nature’. Material credits for ‘Climate Change’ are especially low because the production of

substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart from 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 1000mL segment, the biggest part of the environmental burdens (up to 91%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production, nevertheless a considerable share of burdens derives from the production of the PA additive. The high results of 'Ozone Depletion Potential' are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The 'converting' process of the regarded bottle shows considerable shares of impacts (5%-25%) in all categories apart from 'Aquatic Eutrophication' with less than 1% shares of impacts . Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows minor shares of impacts (max 18%) in most categories mainly attributed to the plastics used for the closure.

The production and provision of 'transport packaging' for the bottle system shows small shares of impacts (1%-7%) in all categories except of 'Use of Nature' in which the paper production contributes to 67% of the burdens. For most categories the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 5%) for all bottle systems in most impact categories. Therefore none of these sectors play an important role for the overall results in any category.

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

The influence of credits on the net result is high in most categories. With a recycling rate of 51% for the clear PET bottle, the received material credits are higher than the credits for energy in most categories. The energy credits mainly originate from the incineration plants.

**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 (71%-84%) 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' (49%) and 'Use of Nature' (75%) transport packaging also plays a visible role.

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 though have an important impact on the overall net results apart from 'Aquatic Eutrophication' and 'Use of Nature'.

### 7.2.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 85:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Netherlands**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 55.84 | -64% | -80% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -88% | -79% |
| Acidification [kg $SO_2$ eq.] | 0.27 | -23% | -73% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 26.94 | -15% | -71% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 24.96 | -34% | 125% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.49 | -15% | -70% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.25 | -20% | -73% |

**Table 86:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Netherlands**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 43.75 | -72% | -84% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -49% | -12% |
| Acidification [kg $SO_2$ eq.] | 0.33 | -5% | -66% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 38.65 | 22% | -58% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 60.00 | 58% | 441% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.67 | 14% | -60% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.34 | 9% | -64% |

**Table 87:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Netherlands**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 72.92 | -53% | -74% |
| Ozone depletion potential [g R-11 eq.] | 0.06 | -86% | -75% |
| Acidification [kg $SO_2$ eq.] | 0.33 | -5% | -67% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 32.33 | 2% | -65% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 30.14 | -20% | 172% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.18 | 2% | -64% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.30 | -3% | -68% |

# 7.3 Results base scenarios DAIRY *189mL-500mL NETHERLANDS*

## 7.3.1 Presentation of results

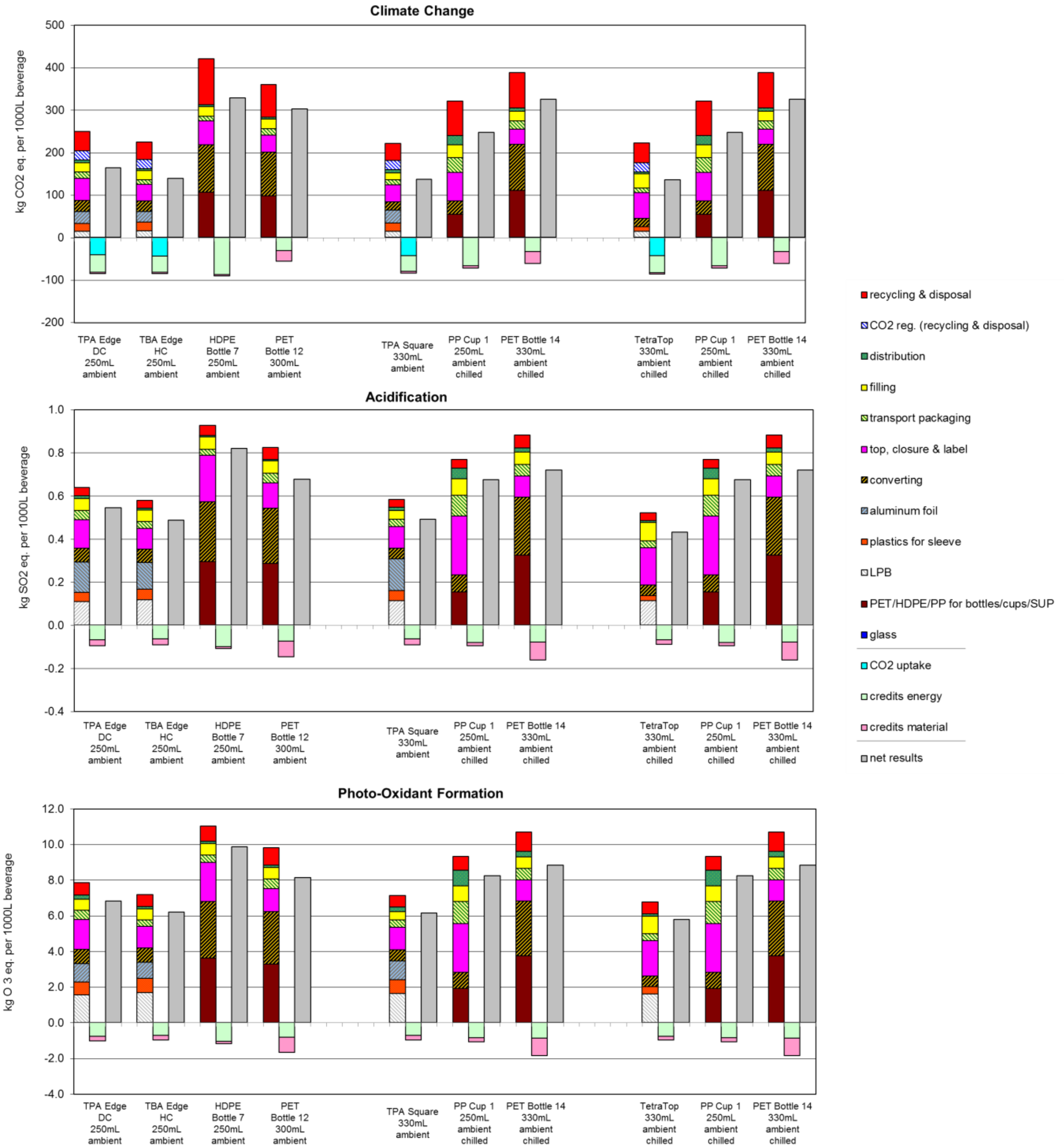



**Figure 70:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 50% (Part 1)

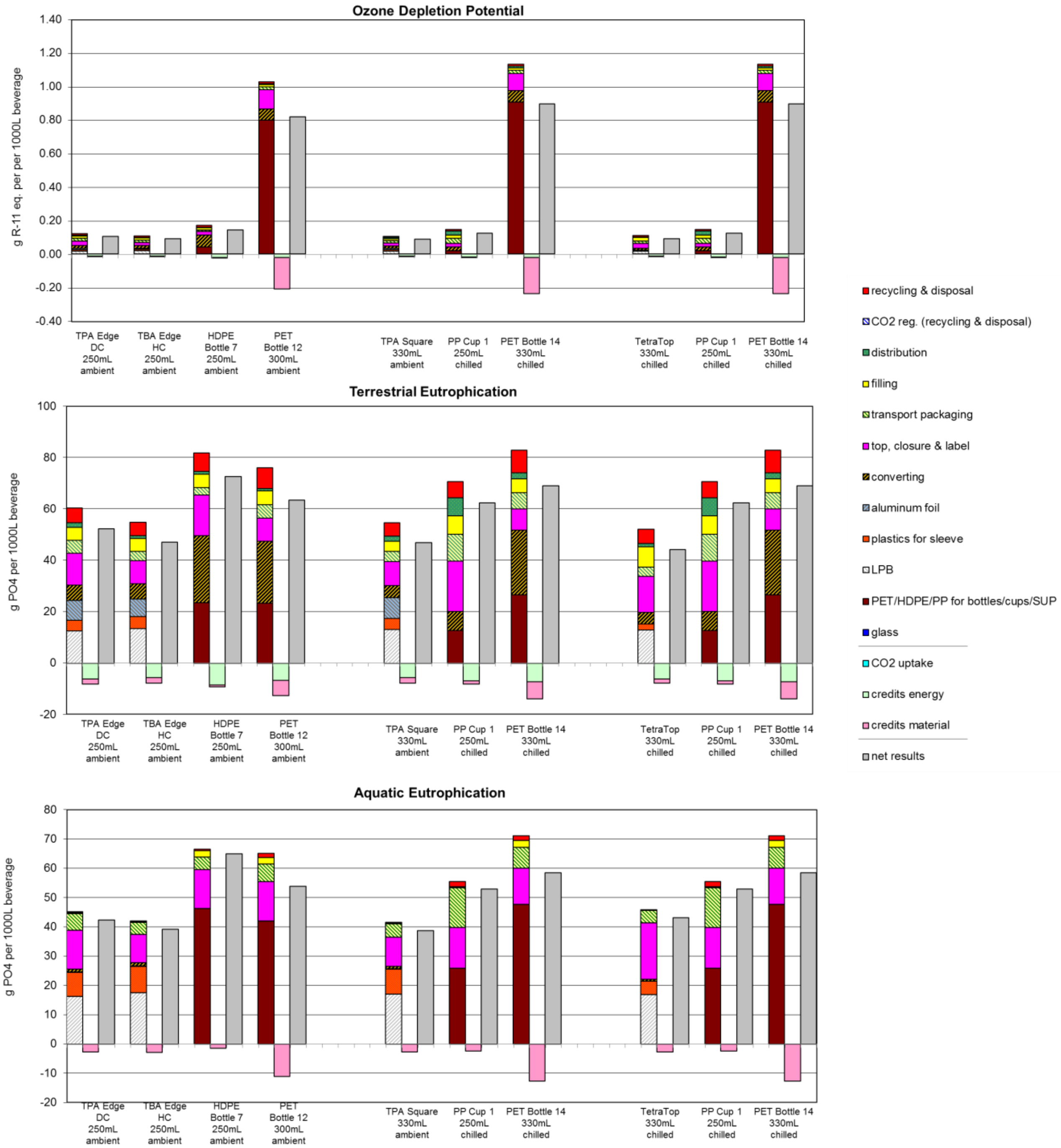



**Figure 71:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 50% (Part 2)

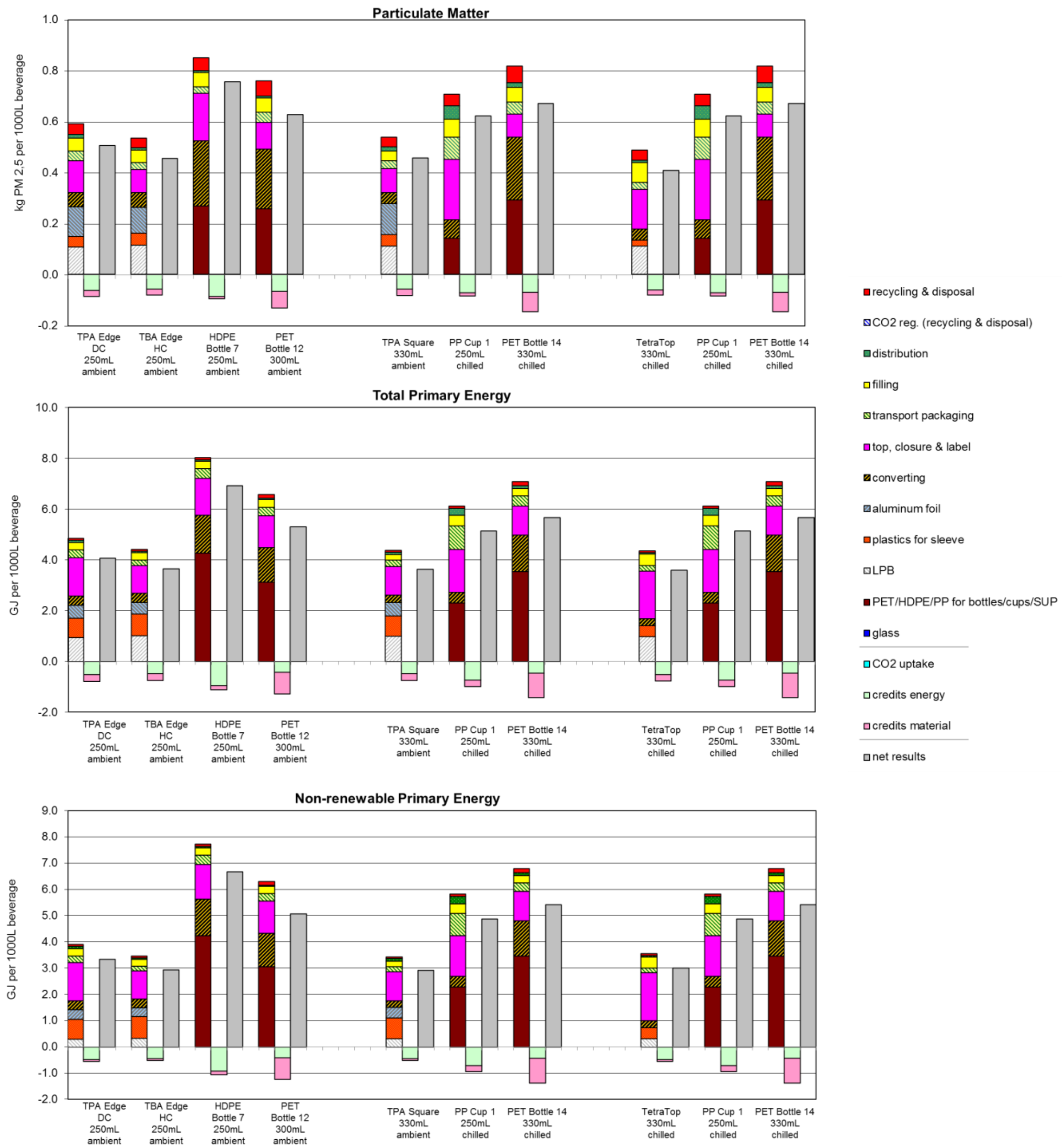
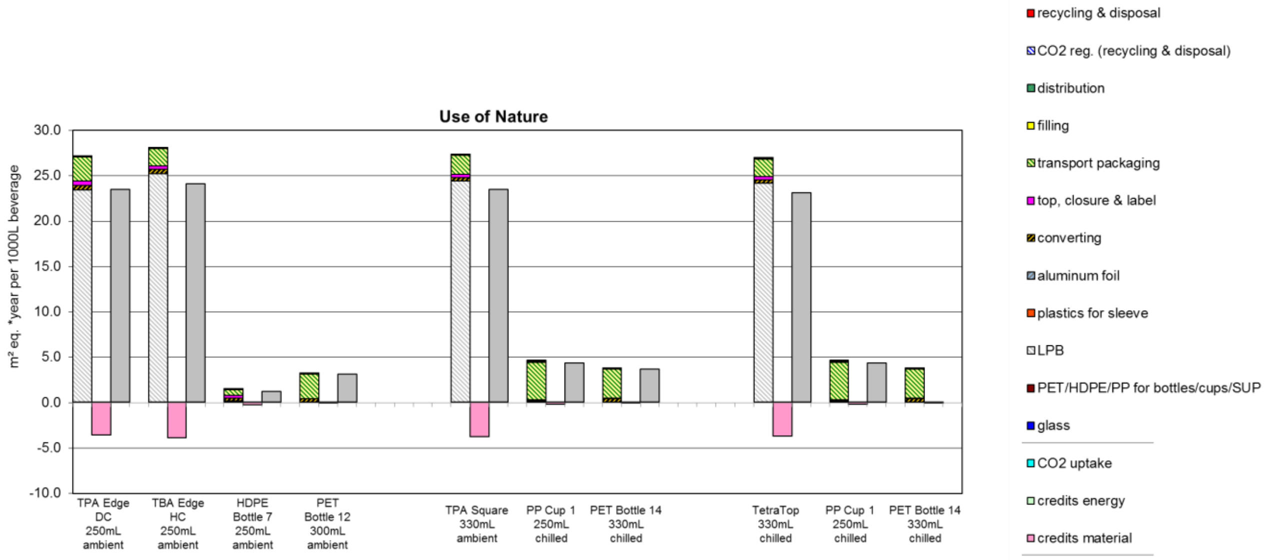



**Figure 72:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 50% (Part 3)



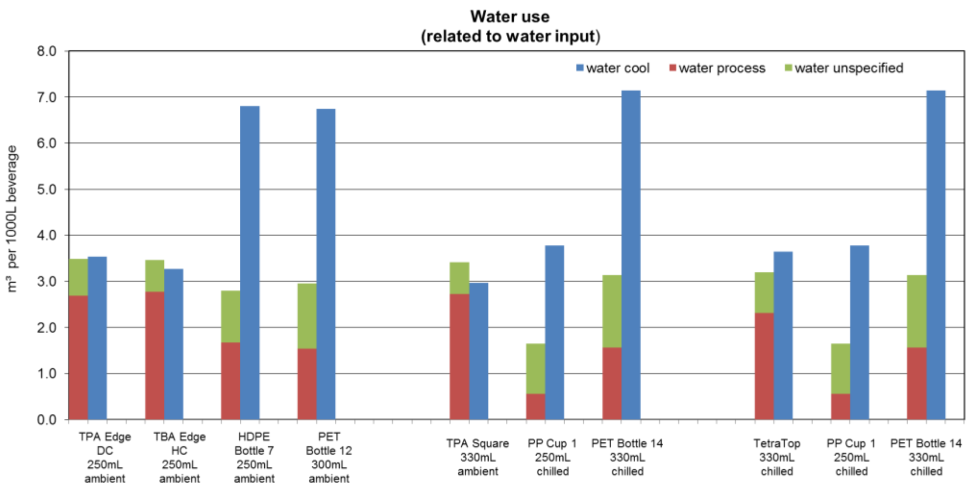




**Figure 73:** Indicator results for base scenarios of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 50% (Part 4)

**Table 88:** Category indicator results per impact category for base scenarios of segment DAIRY 189mL-500mL NETHERLANDS (250mL-300mL) - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | TBA Edge HC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 228.65 | 201.95 | 419.68 | 358.89 |
| | CO2 (reg) | 20.73 | 22.12 | 0.00 | 0.00 |
| | Credits* | -44.33 | -41.16 | -91.46 | -56.56 |
| | $CO_2$ uptake | -41.61 | -44.82 | 0.00 | 0.00 |
| | Net results (∑) | 163.44 | 138.09 | 328.21 | 302.33 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.64 | 0.58 | 0.93 | 0.82 |
| | Credits* | -0.09 | -0.09 | -0.11 | -0.15 |
| | Net results (∑) | 0.55 | 0.49 | 0.82 | 0.68 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.85 | 7.17 | 11.03 | 9.81 |
| | Credits* | -1.02 | -0.98 | -1.18 | -1.67 |
| | Net results (∑) | 6.82 | 6.19 | 9.85 | 8.14 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.12 | 0.11 | 0.17 | 1.03 |
| | Credits* | -0.02 | -0.02 | -0.03 | -0.21 |
| | Net results (∑) | 0.10 | 0.09 | 0.14 | 0.82 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 60.46 | 54.89 | 81.80 | 76.11 |
| | Credits* | -8.12 | -7.75 | -9.25 | -12.69 |
| | Net results (∑) | 52.34 | 47.14 | 72.55 | 63.43 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.03 | 41.91 | 66.37 | 64.97 |
| | Credits* | -2.71 | -2.86 | -1.51 | -11.15 |
| | Net results (∑) | 42.32 | 39.05 | 64.86 | 53.82 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.59 | 0.54 | 0.85 | 0.76 |
| | Credits* | -0.09 | -0.08 | -0.10 | -0.13 |
| | Net results (∑) | 0.51 | 0.45 | 0.76 | 0.63 |
| Total Primary Energy [GJ] | Burdens | 4.85 | 4.41 | 8.04 | 6.58 |
| | Credits* | -0.78 | -0.75 | -1.11 | -1.28 |
| | Net results (∑) | 4.07 | 3.66 | 6.93 | 5.31 |
| Non-renewable primary energy [GJ] | Burdens | 3.90 | 3.46 | 7.72 | 6.30 |
| | Credits* | -0.56 | -0.52 | -1.06 | -1.23 |
| | Net results (∑) | 3.34 | 2.94 | 6.66 | 5.07 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.08 | 27.98 | 1.45 | 3.14 |
| | Credits* | -3.67 | -3.93 | -0.30 | -0.09 |
| | Net results (∑) | 23.42 | 24.04 | 1.14 | 3.05 |
| Water use [$m^3$] | Water cool | 3.54 | 3.27 | 6.81 | 6.75 |
| | Water process | 2.69 | 2.78 | 1.67 | 1.54 |
| | Water unspec | 0.80 | 0.69 | 1.12 | 1.41 |

*material and energy credits

**Table 89:** Category indicator results per impact category for base scenarios of **segment DAIRY 189mL-500mL NETHERLANDS (330mL ambient) -** burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 199.72 | 319.89 | 387.38 |
| | CO2 (reg) | 21.51 | 0.00 | 0.00 |
| | Credits* | -41.24 | -72.67 | -62.26 |
| | $CO_2$ uptake | -43.35 | 0.00 | 0.00 |
| | Net results (∑) | 136.64 | 247.23 | 325.13 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.58 | 0.77 | 0.88 |
| | Credits* | -0.09 | -0.09 | -0.16 |
| | Net results (∑) | 0.49 | 0.68 | 0.72 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.13 | 9.31 | 10.68 |
| | Credits* | -0.98 | -1.08 | -1.85 |
| | Net results (∑) | 6.15 | 8.24 | 8.84 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.15 | 1.13 |
| | Credits* | -0.02 | -0.02 | -0.24 |
| | Net results (∑) | 0.09 | 0.12 | 0.90 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 54.70 | 70.71 | 82.98 |
| | Credits* | -7.73 | -8.24 | -13.97 |
| | Net results (∑) | 46.96 | 62.47 | 69.00 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 41.44 | 55.32 | 70.99 |
| | Credits* | -2.78 | -2.46 | -12.62 |
| | Net results (∑) | 38.66 | 52.87 | 58.38 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.54 | 0.71 | 0.82 |
| | Credits* | -0.08 | -0.08 | -0.15 |
| | Net results (∑) | 0.46 | 0.62 | 0.67 |
| Total Primary Energy [GJ] | Burdens | 4.38 | 6.13 | 7.10 |
| | Credits* | -0.75 | -0.98 | -1.42 |
| | Net results (∑) | 3.63 | 5.15 | 5.68 |
| Non-renewable primary energy [GJ] | Burdens | 3.43 | 5.81 | 6.79 |
| | Credits* | -0.52 | -0.94 | -1.37 |
| | Net results (∑) | 2.91 | 4.87 | 5.42 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.25 | 4.55 | 3.72 |
| | Credits* | -3.81 | -0.23 | -0.10 |
| | Net results (∑) | 23.44 | 4.31 | 3.62 |
| Water use [$m^3$] | Water cool | 2.97 | 3.78 | 7.14 |
| | Water process | 2.73 | 0.56 | 1.56 |
| | Water unspec | 0.68 | 1.09 | 1.57 |

*material and energy credits

**Table 90:** Category indicator results per impact category for base scenarios of **segment** of **segment DAIRY 189mL-500mL NETHERLANDS (330mL chilled)**- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TetraTop 330mL chilled | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 200.84 | 319.89 | 387.38 |
| | CO2 (reg) | 21.01 | 0.00 | 0.00 |
| | Credits* | -43.31 | -72.67 | -62.26 |
| | $CO_2$ uptake | -42.96 | 0.00 | 0.00 |
| | Net results (∑) | 135.57 | 247.23 | 325.13 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.52 | 0.77 | 0.88 |
| | Credits* | -0.09 | -0.09 | -0.16 |
| | Net results (∑) | 0.43 | 0.68 | 0.72 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.77 | 9.31 | 10.68 |
| | Credits* | -0.99 | -1.08 | -1.85 |
| | Net results (∑) | 5.79 | 8.24 | 8.84 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.15 | 1.13 |
| | Credits* | -0.02 | -0.02 | -0.24 |
| | Net results (∑) | 0.09 | 0.12 | 0.90 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 52.08 | 70.71 | 82.98 |
| | Credits* | -7.84 | -8.24 | -13.97 |
| | Net results (∑) | 44.23 | 62.47 | 69.00 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.81 | 55.32 | 70.99 |
| | Credits* | -2.75 | -2.46 | -12.62 |
| | Net results (∑) | 43.06 | 52.87 | 58.38 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.49 | 0.71 | 0.82 |
| | Credits* | -0.08 | -0.08 | -0.15 |
| | Net results (∑) | 0.41 | 0.62 | 0.67 |
| Total Primary Energy [GJ] | Burdens | 4.36 | 6.13 | 7.10 |
| | Credits* | -0.77 | -0.98 | -1.42 |
| | Net results (∑) | 3.59 | 5.15 | 5.68 |
| Non-renewable primary energy [GJ] | Burdens | 3.55 | 5.81 | 6.79 |
| | Credits* | -0.54 | -0.94 | -1.37 |
| | Net results (∑) | 3.00 | 4.87 | 5.42 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.88 | 4.55 | 3.72 |
| | Credits* | -3.80 | -0.23 | -0.10 |
| | Net results (∑) | 23.08 | 4.31 | 3.62 |
| Water use [$m^3$] | Water cool | 3.65 | 3.78 | 7.14 |
| | Water process | 2.31 | 0.56 | 1.56 |
| | Water unspec | 0.89 | 1.09 | 1.57 |

*material and energy credits

### 7.3.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For all beverage carton systems regarded in the DAIRY 189mL-500mL 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' (36%-42%) and 'Use of Nature' (86%-90%). It is also relevant regarding 'Photo-Oxidant Formation' (20%-24%), 'Acidification' (17%-22%), 'Terrestrial Eutrophication' (21%-25%), 'Particulate Matter' (18%-23%) and also the consumption of 'Total Primary Energy' (20%-23%).

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 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 beverage cartons for ambient milk consist of an additional layer of aluminium foil. The production of 'aluminium foil' for the sleeves shows burdens in most impact categories. Substantial burdens can be seen for the categories 'Acidification' (21%-25%) and 'Particulate Matter' (19%-23%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (4%-24%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are 'Climate Change', where the plastics and LPB contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about one quarter of the total burdens.

The life cycle step 'top, closure & label' contributes to a substantial amount (16%-52%) in almost all impact categories. For the Tetra Top beverage carton system the step 'top, closure & label' contributes the highest share of burdens (29%-52%) in most categories because of its heavy top and cap made from plastics.

The converting process generally plays a minor role (max 16%). It generates emissions, which contribute to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems shows minor shares of impacts (5%-14%) in all categories.

The life cycle steps 'filling' and 'distribution' show only minor shares of burdens (max 20%) for all beverage carton systems in most impact categories. Therefore none of these life cycle steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (27%-31%). 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.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Netherlands these derive mainly from the incineration of bio-based plastics and paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits are given for the substitution of primary material due to recycling. As the Dutch recycling rate for beverage cartons is only 37% the energy credits are higher than the material credits in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'. Material credits for 'Climate Change' are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart from 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY 189mL-500mL segment, the biggest part of the environmental burdens (25%-80%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. This is true for PET and HDPE bottles as well as for bottles in both sub-segments: chilled and ambient.

Differences can be observed depending on the kind of plastic used, though. For most impact categories the burdens from plastic production (life cycle step 'PET/HDPE/PP for bottles/cups/SUP' in the graphs) are higher for the HDPE bottle than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows a comparatively low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

The 'converting' process of all regarded bottles shows considerable shares of impacts (6%-43%) in all categories apart from 'Aquatic Eutrophication' with less than 1% share of impact. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable shares of impacts (10%-23%) in most categories mainly attributed to the different closures. 'Top, closure & label' of the HDPE Bottle 7 show higher impacts than those of the PET bottles. This can be explained by the fact that the HDPE Bottle 7 also includes an aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems show minor shares of impacts (2%-10%) in all categories except of 'Use of Nature' in which the paper production contributes to 41%-84% of the burdens. In case of HDPE Bottle 7 for most categories the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets. In the cases of PET Bottle 12 and PET Bottle 14 all relevant emissions derive from production of paper for trays and slipsheets as well as stretch foil production.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 9%) for all bottle systems in most impact categories. Therefore none of these sectors play an important role for the overall results in any category.

The impact of the fossil-based plastic bottles' 'recycling & disposal' life cycle step is most relevant regarding 'Climate Change' (21%-26%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is different for the different bottles. Credits of the white opaque HDPE Bottle 7, which is not materially recycled, show a high impact in the environmental impact category 'Climate Change' and lower impacts in the remaining categories. For 'Ozone Depletion Potential`, Aquatic Eutrophication' and 'Use of Nature' the credits play almost no role for the overall results. The credits of the partially recycled clear PET bottles (Dutch recycling rate for plastic packaging is 51%) show a generally higher influence than those of the HDPE bottle, as they also receive material credits. This leads to a considerable influence on the net results even in the categories ‘Aquatic Eutrophication” and ‘Ozone Depletion Potential’.

**PP cups** (specifications see section 2.2.2)

In the regarded PP Cup 1 system in the DAIRY 189mL-500mL segment, the biggest part of the environmental burdens are caused by the production of the base materials of the cups (13%-47%) in most impact and inventory categories next to ‘top, closure & label’ with 15% until 36%.

The ‘converting’ process of the regarded PP Cup 1 shows minor shares of impacts (2%-14%) in all categories apart from ‘Aquatic Eutrophication’ with less than 1% share of impact. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows high shares of impacts (15%-36%) in most categories attributed to the different plastics and especially aluminium used for the closures.

The production and provision of ‘transport packaging’ for the PP Cup 1 show considerable shares of impacts (11%-25%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 91% of the burdens. The relevant emissions derive from shrink foil production and from the production of paper for trays and slipsheets.

The life cycle step ‘filling’ shows only small shares of burdens (max. 13%) for the PP cup 1 in most impact categories. Therefore this step plays not an important role for the overall results in any category.

The life cycle step ‘distribution’ shows more considerable shares of burdens (max. 17%) in most impact categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The impact of the PP Cup’s ‘recycling & disposal’ life cycle step is most relevant regarding ‘Climate Change’ (25%). The incineration of cups in MSWIs causes high greenhouse gas emissions. As the white opaque PP Cup 1 does not undergo a material recycling and there is almost no landfilling in the Netherlands, almost all of these cups are incinerated in MSWI plants.

The influence of credits on the net result is high in most categories. For the white opaque PP Cup 1 no primary granulate is credited as they are incinerated in MSWIs, the received material credits for this bottle are negligible compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

### 7.3.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 91:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 163.44 | -50% | -46% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -28% | -87% |
| Acidification [kg $SO_2$ eq.] | 0.55 | -34% | -20% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.34 | -28% | -17% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.32 | -35% | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.82 | -31% | -16% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.51 | -33% | -19% |

**Table 92:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TBA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge HC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 138.09 | -58% | -54% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -38% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.49 | -41% | -28% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 47.14 | -35% | -26% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.05 | -40% | -27% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.19 | -37% | -24% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.45 | -40% | -28% |

**Table 93:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TPA Square DC 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 136.64 | -45% | -58% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -28% | -90% |
| Acidification [kg $SO_2$ eq.] | 0.49 | -27% | -32% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 46.96 | -25% | -32% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 38.66 | -27% | -34% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.15 | -25% | -30% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.46 | -27% | -32% |

**Table 94:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TT 330mL chilled …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TT 330mL chilled | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 135.57 | -45% | -58% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -26% | -90% |
| Acidification [kg $SO_2$ eq.] | 0.43 | -36% | -40% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 44.23 | -29% | -36% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 43.06 | -19% | -26% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.79 | -30% | -35% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | -34% | -39% |

# 7.4 Results base scenarios JNSD *200mL-330mL NETHERLANDS*

## 7.4.1 Presentation of results

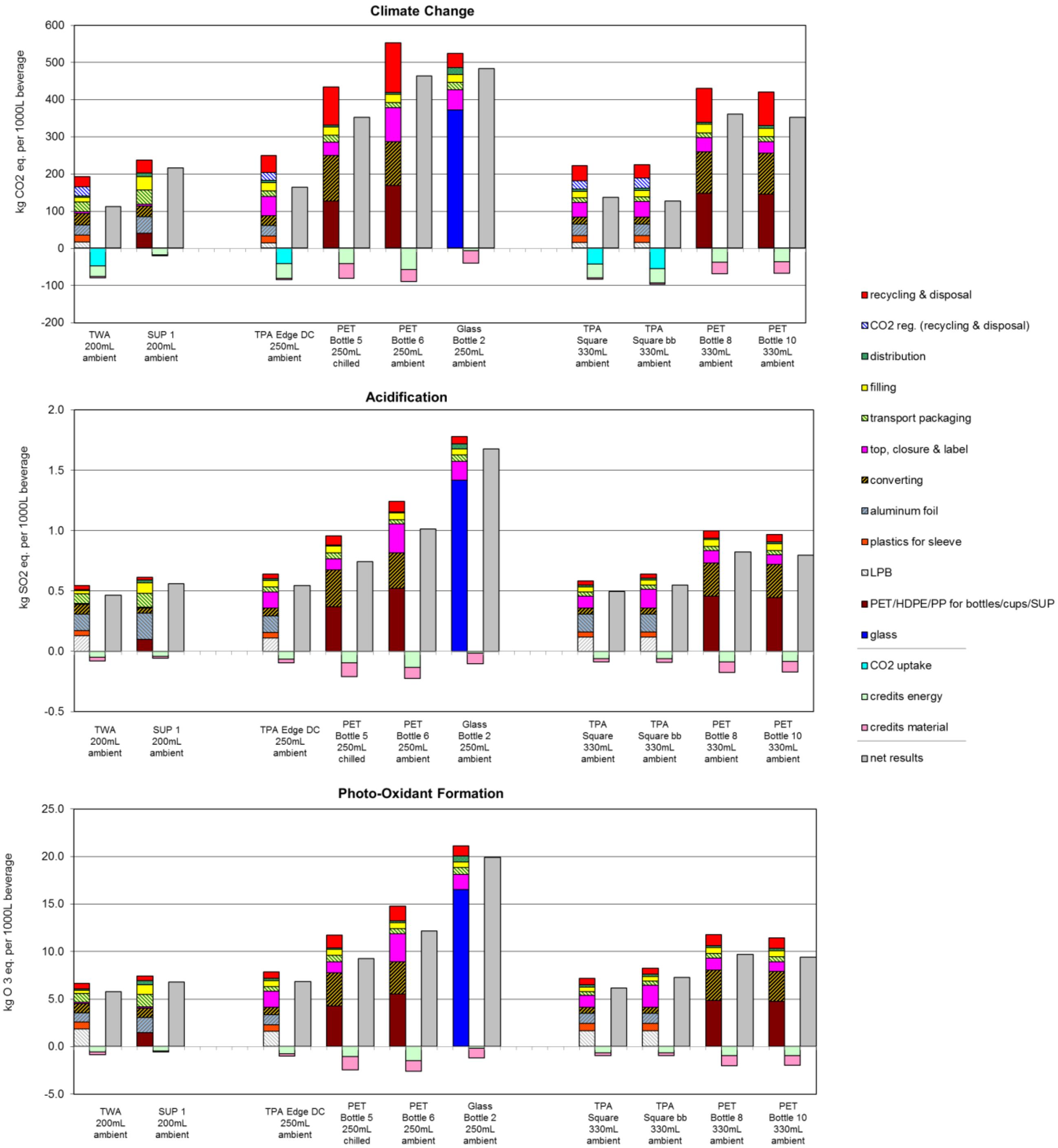



**Figure 74:** Indicator results for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS**, allocation factor 50% (Part 1)

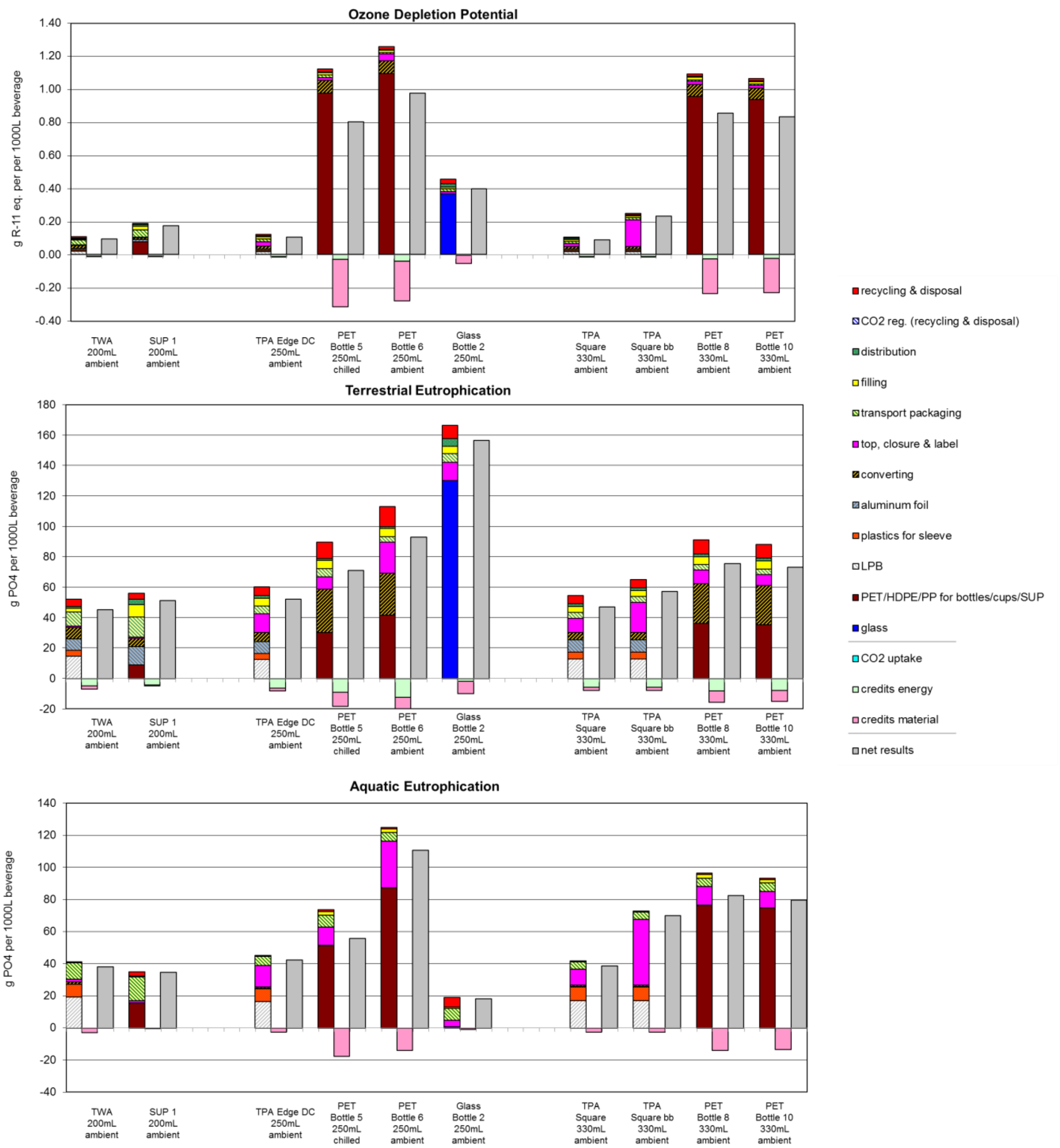



**Figure 75:** Indicator results for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS**, allocation factor 50% (Part 2)

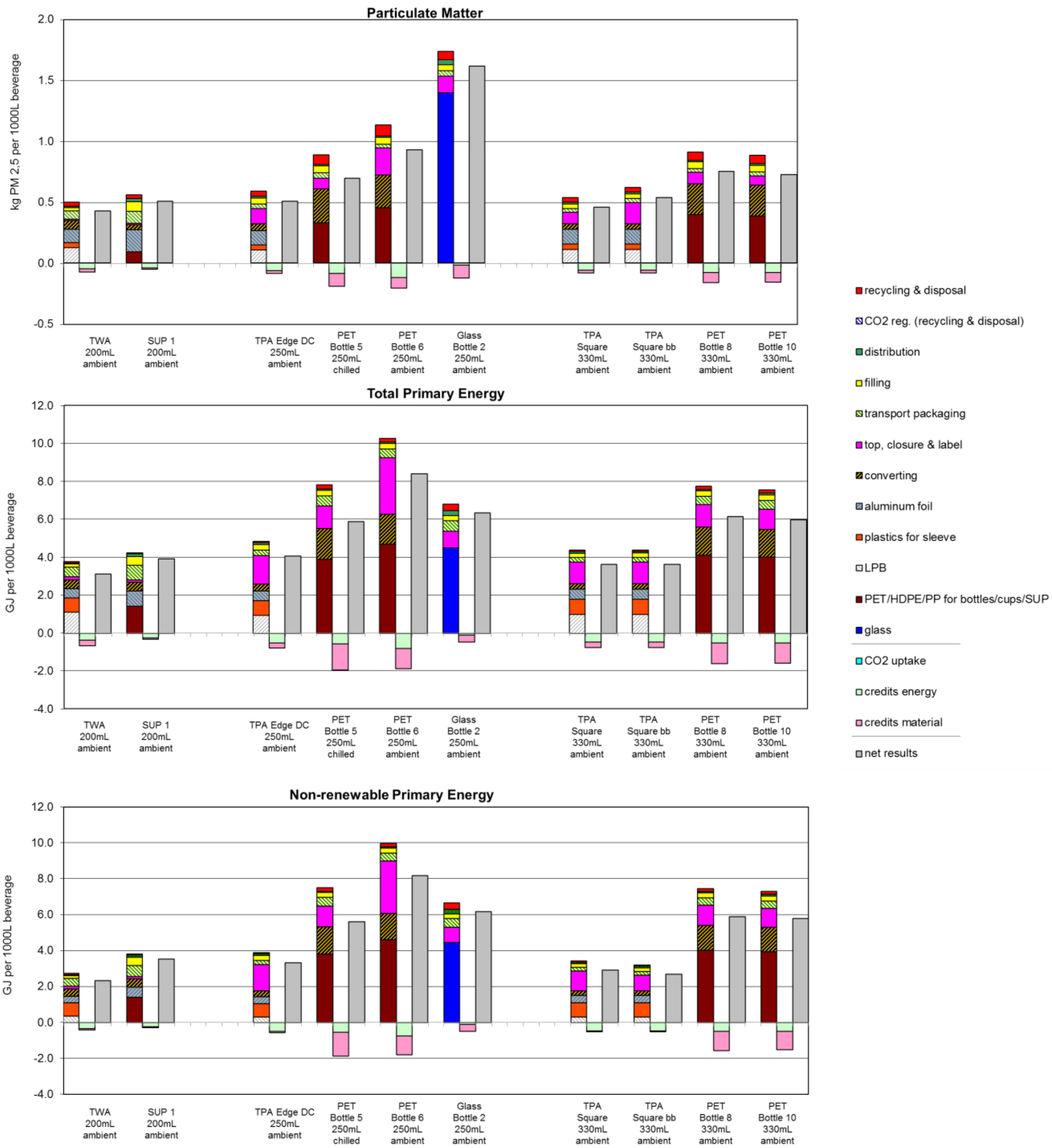



**Figure 76:** Indicator results for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS**, allocation factor 50% (Part 3)

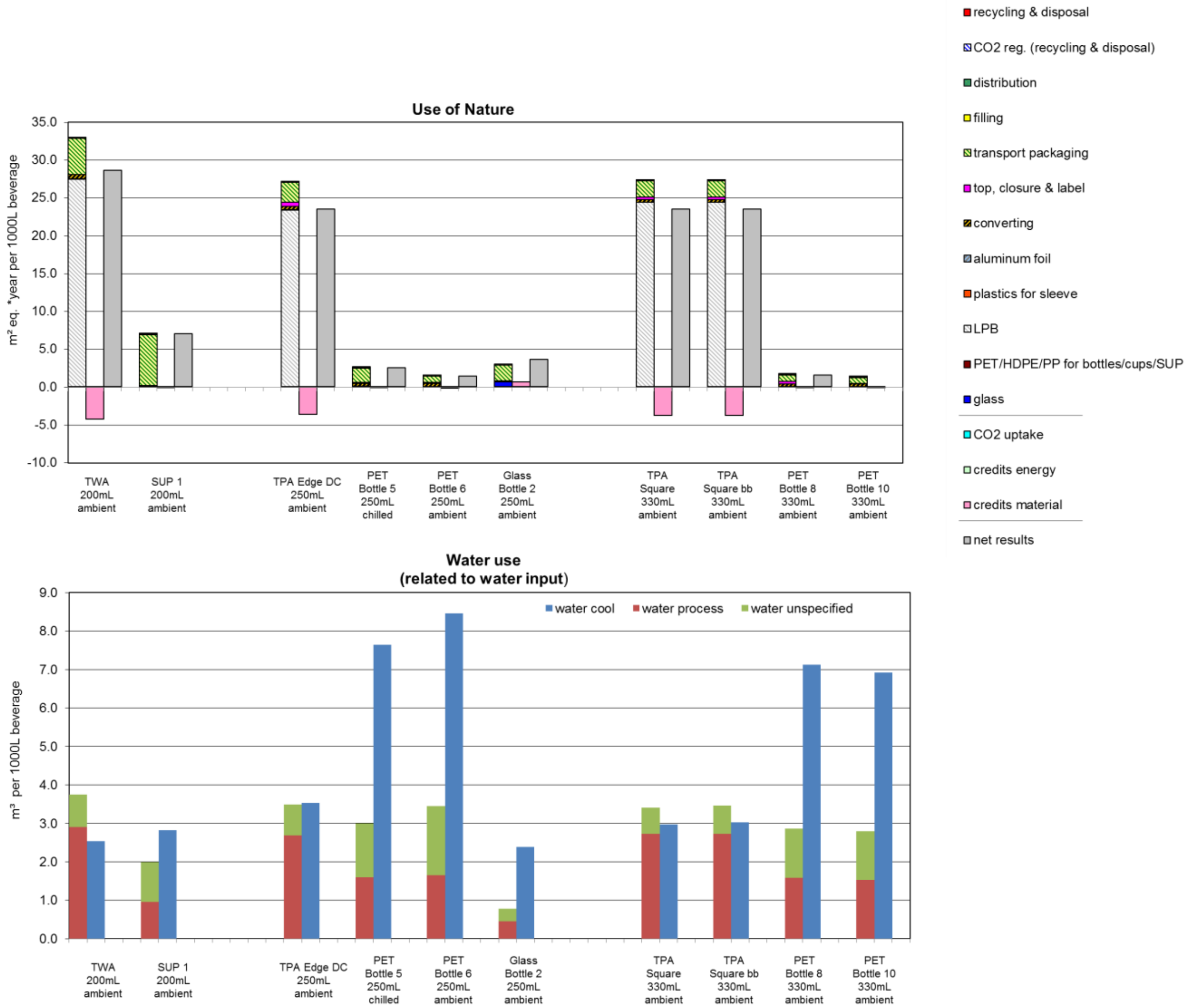



**Figure 77:** Indicator results for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS**, allocation factor 50% (Part 4)

**Table 95:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS (200mL)**_-burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TWA 200mL ambient | SUP 1 200mL ambient |
|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 168.07 | 236.31 |
| | CO2 (reg) | 24.28 | 0.00 |
| | Credits* | -31.91 | -21.32 |
| | $CO_2$ uptake | -48.86 | 0.00 |
| | Net results (∑) | 111.57 | 215.00 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.54 | 0.61 |
| | Credits* | -0.08 | -0.06 |
| | Net results (∑) | 0.46 | 0.56 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.63 | 7.37 |
| | Credits* | -0.87 | -0.59 |
| | Net results (∑) | 5.76 | 6.78 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.19 |
| | Credits* | -0.01 | -0.01 |
| | Net results (∑) | 0.09 | 0.17 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 52.34 | 55.99 |
| | Credits* | -6.92 | -4.78 |
| | Net results (∑) | 45.42 | 51.21 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 40.93 | 34.89 |
| | Credits* | -3.08 | -0.33 |
| | Net results (∑) | 37.86 | 34.56 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.50 | 0.56 |
| | Credits* | -0.07 | -0.05 |
| | Net results (∑) | 0.43 | 0.51 |
| Total Primary Energy [GJ] | Burdens | 3.79 | 4.25 |
| | Credits* | -0.66 | -0.32 |
| | Net results (∑) | 3.12 | 3.93 |
| Non-renewable primary energy [GJ] | Burdens | 2.74 | 3.82 |
| | Credits* | -0.41 | -0.29 |
| | Net results (∑) | 2.32 | 3.53 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 32.87 | 7.00 |
| | Credits* | -4.30 | -0.06 |
| | Net results (∑) | 28.56 | 6.94 |
| Water use [$m^3$] | Water cool | 2.53 | 2.81 |
| | Water process | 2.90 | 0.95 |
| | Water unspec | 0.85 | 1.04 |

*material and energy credits

**Table 96:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS (250mL)**-burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | PET Bottle 5 250mL chilled | PET Bottle 6 250mL ambient | Glass Bottle 2 250mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 228.34 | 433.05 | 552.26 | 523.08 |
| | CO2 (reg) | 20.73 | 0.00 | 0.00 | 0.00 |
| | Credits* | -44.33 | -81.94 | -89.91 | -40.46 |
| | $CO_2$ uptake | -41.60 | 0.00 | 0.00 | 0.00 |
| | Net results (∑) | 163.14 | 351.11 | 462.35 | 482.62 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.64 | 0.95 | 1.24 | 1.78 |
| | Credits* | -0.09 | -0.21 | -0.23 | -0.11 |
| | Net results (∑) | 0.54 | 0.74 | 1.01 | 1.67 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.84 | 11.68 | 14.75 | 21.10 |
| | Credits* | -1.02 | -2.46 | -2.61 | -1.23 |
| | Net results (∑) | 6.81 | 9.22 | 12.15 | 19.87 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.12 | 1.12 | 1.26 | 0.45 |
| | Credits* | -0.02 | -0.32 | -0.28 | -0.06 |
| | Net results (∑) | 0.10 | 0.80 | 0.98 | 0.40 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 60.39 | 89.62 | 112.97 | 166.49 |
| | Credits* | -8.12 | -18.38 | -19.93 | -9.82 |
| | Net results (∑) | 52.27 | 71.24 | 93.04 | 156.67 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.02 | 73.58 | 124.68 | 18.83 |
| | Credits* | -2.71 | -17.87 | -14.17 | -0.86 |
| | Net results (∑) | 42.31 | 55.72 | 110.51 | 17.97 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.59 | 0.89 | 1.13 | 1.73 |
| | Credits* | -0.09 | -0.19 | -0.20 | -0.12 |
| | Net results (∑) | 0.50 | 0.70 | 0.93 | 1.61 |
| Total Primary Energy [GJ] | Burdens | 4.85 | 7.82 | 10.29 | 6.81 |
| | Credits* | -0.78 | -1.94 | -1.87 | -0.46 |
| | Net results (∑) | 4.06 | 5.88 | 8.42 | 6.35 |
| Non-renewable primary energy [GJ] | Burdens | 3.90 | 7.49 | 9.96 | 6.64 |
| | Credits* | -0.56 | -1.88 | -1.80 | -0.49 |
| | Net results (∑) | 3.34 | 5.62 | 8.16 | 6.15 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.08 | 2.56 | 1.51 | 2.99 |
| | Credits* | -3.67 | -0.11 | -0.15 | 0.61 |
| | Net results (∑) | 23.41 | 2.45 | 1.35 | 3.60 |
| Water use [$m^3$] | Water cool | 3.53 | 7.64 | 8.45 | 2.39 |
| | Water process | 2.68 | 1.59 | 1.65 | 0.45 |
| | Water unspec | 0.80 | 1.41 | 1.79 | 0.32 |

*material and energy credits

**Table 97:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL NETHERLANDS (330mL)**- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | PET Bottle 8 330mL ambient | PET Bottle 10 330mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 199.72 | 196.62 | 429.16 | 418.86 |
| | CO2 (reg) | 21.51 | 27.36 | 0.00 | 0.00 |
| | Credits* | -41.24 | -41.44 | -69.37 | -67.82 |
| | $CO_2$ uptake | -43.35 | -55.98 | 0.00 | 0.00 |
| | Net results (∑) | 136.64 | 126.57 | 359.78 | 351.04 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.58 | 0.64 | 1.00 | 0.97 |
| | Credits* | -0.09 | -0.09 | -0.18 | -0.17 |
| | Net results (∑) | 0.49 | 0.55 | 0.82 | 0.79 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.13 | 8.22 | 11.74 | 11.41 |
| | Credits* | -0.98 | -0.98 | -2.07 | -2.02 |
| | Net results (∑) | 6.15 | 7.24 | 9.67 | 9.38 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.25 | 1.09 | 1.06 |
| | Credits* | -0.02 | -0.02 | -0.24 | -0.23 |
| | Net results (∑) | 0.09 | 0.23 | 0.85 | 0.83 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 54.70 | 65.19 | 91.13 | 88.29 |
| | Credits* | -7.73 | -7.77 | -15.47 | -15.12 |
| | Net results (∑) | 46.96 | 57.42 | 75.66 | 73.17 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 41.44 | 72.52 | 96.23 | 93.07 |
| | Credits* | -2.78 | -2.78 | -13.95 | -13.59 |
| | Net results (∑) | 38.66 | 69.74 | 82.28 | 79.48 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.54 | 0.62 | 0.91 | 0.88 |
| | Credits* | -0.08 | -0.08 | -0.16 | -0.16 |
| | Net results (∑) | 0.46 | 0.54 | 0.75 | 0.73 |
| Total Primary Energy [GJ] | Burdens | 4.38 | 4.39 | 7.76 | 7.56 |
| | Credits* | -0.75 | -0.75 | -1.60 | -1.57 |
| | Net results (∑) | 3.63 | 3.64 | 6.16 | 5.99 |
| Non-renewable primary energy [GJ] | Burdens | 3.43 | 3.21 | 7.44 | 7.29 |
| | Credits* | -0.52 | -0.52 | -1.55 | -1.51 |
| | Net results (∑) | 2.91 | 2.68 | 5.89 | 5.78 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.25 | 27.25 | 1.65 | 1.32 |
| | Credits* | -3.81 | -3.81 | -0.11 | -0.11 |
| | Net results (∑) | 23.44 | 23.44 | 1.54 | 1.22 |
| Water use [$m^3$] | Water cool | 2.97 | 3.02 | 7.13 | 6.93 |
| | Water process | 2.73 | 2.73 | 1.59 | 1.53 |
| | Water unspec | 0.68 | 0.74 | 1.28 | 1.25 |

*material and energy credits

### 7.4.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 200mL-330mL 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’ (23%-47%), and ‘Use of Nature’ (83%-89%). It is also relevant regarding ‘Photo-Oxidant Formation’ (20%-28%), ‘Acidification’ (17%-24%), ‘Terrestrial Eutrophication’ (20%-28%), ‘Particulate Matter’ (18%-25%) and also the consumption of ‘Total Primary Energy’ 20%-29%).

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 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 shows burdens in most impact categories. Substantial burdens can be seen for the categories ‘Acidification’ (22%-25%) and ‘Particulate Matter’ (20%-23%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable shares of burdens (3%-27%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil based plastics (7%-9%) and LPB (6%-8%) contribute about the same and the inventory category ‘Non-renewable Primary Energy’, where the plastics make up about 20% - 30% of the total burdens.

The life cycle step ‘top, closure & label’ contributes to a considerable amount (17%-66%) in almost all impact categories with the exception of the TWA with only minor burdens (max. 6%) in this step as this carton has no closure and only a straw~~.~~ In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TPA Square bio-based 330mL), the results are considerably higher than for cartons with fossil based cartons in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a considerable role (up to 20%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems shows considerable shares (5%-14%) of impacts in all categories. One exception is the TWA 200 with higher shares of burdens (14%-29%) from transport packaging in all categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 12%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (27%-28. 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.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Netherlands these derive mainly from the incineration of bio-based plastics and paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits are given for the substitution of primary material due to recycling. As the Dutch recycling rate for beverage cartons is only 37% the energy credits are higher than the material credits in all categories apart from ‘Aquatic Eutrophication‘ and ‘Use of Nature’. Material credits for ‘Climate Change’ are especially low because the production of

substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart from 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens (29%-88%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production and from the production of the PA additive. The high results of 'Ozone Depletion Potential' are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The 'converting' process of all regarded bottles shows considerable shares of impacts (6%-32%) in all categories apart from 'Aquatic Eutrophication' with less than 1% share of impact. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows minor shares of impacts (1%-18&) in most categories mainly attributed to the plastics used for the closure. One exception is the PET Bottle 6 with higher shares of impacts (3%-29%) in this step because if it's heavy closure.

The production and provision of 'transport packaging' for the bottle systems show minor shares of impacts (1%-10%) in all categories except of 'Use of Nature' in which the paper production contributes to 53%-75% of the burdens. In the cases of PET Bottle 6, 8 and 10 for most categories the relevant emissions derive from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets. In the case of PET Bottle 5 all relevant emissions derive from production of paper for trays and slipsheets as well as from stretch foil production.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 6%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (21%-24%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is high in most categories. With a recycling rate of 51% for the PET bottles, the received material credits are higher than the credits for energy in most categories. The energy credits mainly originate from the incineration plants.

**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 (66%-81%) 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’ (39%) and ‘Use of Nature’ (68%) transport packaging also plays a visible role.

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 though have an important impact on the overall net results apart from ‘Aquatic Eutrophication’ and ‘Use of Nature’.

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

In the regarded SUP in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens is caused by the production of the base materials of the pouch in most impact and inventory categories. The burdens mainly derive from aluminium (1%-35%) and plastics (1%-44%) production with a higher share of burdens from aluminium in the impact categories ‘Acidification’ and ‘Particulate Matter’ due to $SO_2$ and $NO_x$ emissions from the aluminium production

The ‘converting’ process of the SUP shows minor shares of impacts (7%-12%) in all categories apart from ‘Aquatic Eutrophication’ and ‘Use of Nature’ with shares of impacts less than 1%. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The production and provision of ‘transport packaging’ for the SUP show considerable shares of impacts (16%-43%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 96% of the burdens. All relevant emissions derive from production of paper for trays and slipsheets as well as from the production of stretch foil.

The life cycle steps ‘filling’ and ‘distribution’ show only minor shares of burdens (max 15%) for the SUP in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the SUP's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (14%). The incineration of plastic bottles 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 almost all SUPs are incinerated. The energy credits mainly originate from the incineration plants.

### 7.4.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 98:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TWA 200mL ambient | SUP 1 200mL ambient |
| Climate Change [kg $CO_2$eq] | 111.57 | -48% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -47% |
| Acidification [kg $SO_2$ eq.] | 0.46 | -17% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 45.42 | -11% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 37.86 | 10% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.76 | -15% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.43 | -16% |

**Table 99:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled | PET Bottle 6 250ml ambient | Glass Bottle 2 250ml ambient |
| Climate Change [kg $CO_2$eq] | 163.14 | -54% | -65% | -66% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -87% | -89% | -74% |
| Acidification [kg $SO_2$ eq.] | 0.54 | -27% | -46% | -68% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.27 | -27% | -44% | -67% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.31 | -24% | -62% | 135% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.81 | -26% | -44% | -66% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.50 | -27% | -46% | -69% |

**Table 100:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PET Bottle 8 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 136.64 | -62% | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -90% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.49 | -40% | -38% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 46.96 | -38% | -36% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 38.66 | -53% | -51% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.15 | -36% | -34% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.46 | -39% | -37% |

**Table 101:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 8 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 126.57 | -65% | -64% |
| Ozone depletion potential [g R-11 eq.] | 0.23 | -73% | -72% |
| Acidification [kg $SO_2$ eq.] | 0.55 | -33% | -31% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 57.42 | -24% | -22% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 69.74 | -15% | -12% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.24 | -25% | -23% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.54 | -28% | -26% |

# *7.5* Results base scenarios JNSD WATER *330mL-500mL NETHERLANDS*

## 7.5.1 Presentation of results

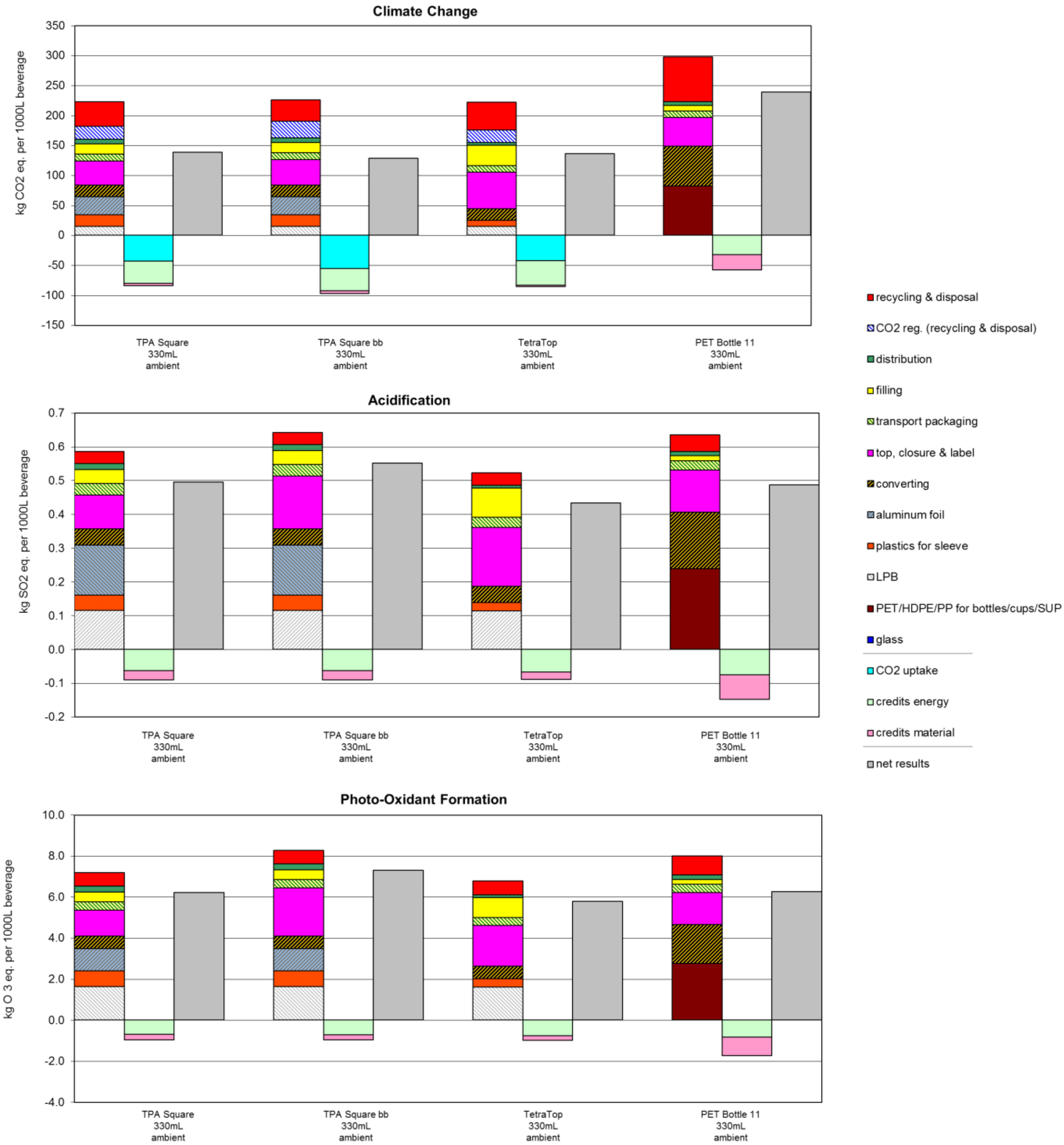



**Figure 78:** Indicator results for base scenarios of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 50% (Part 1)

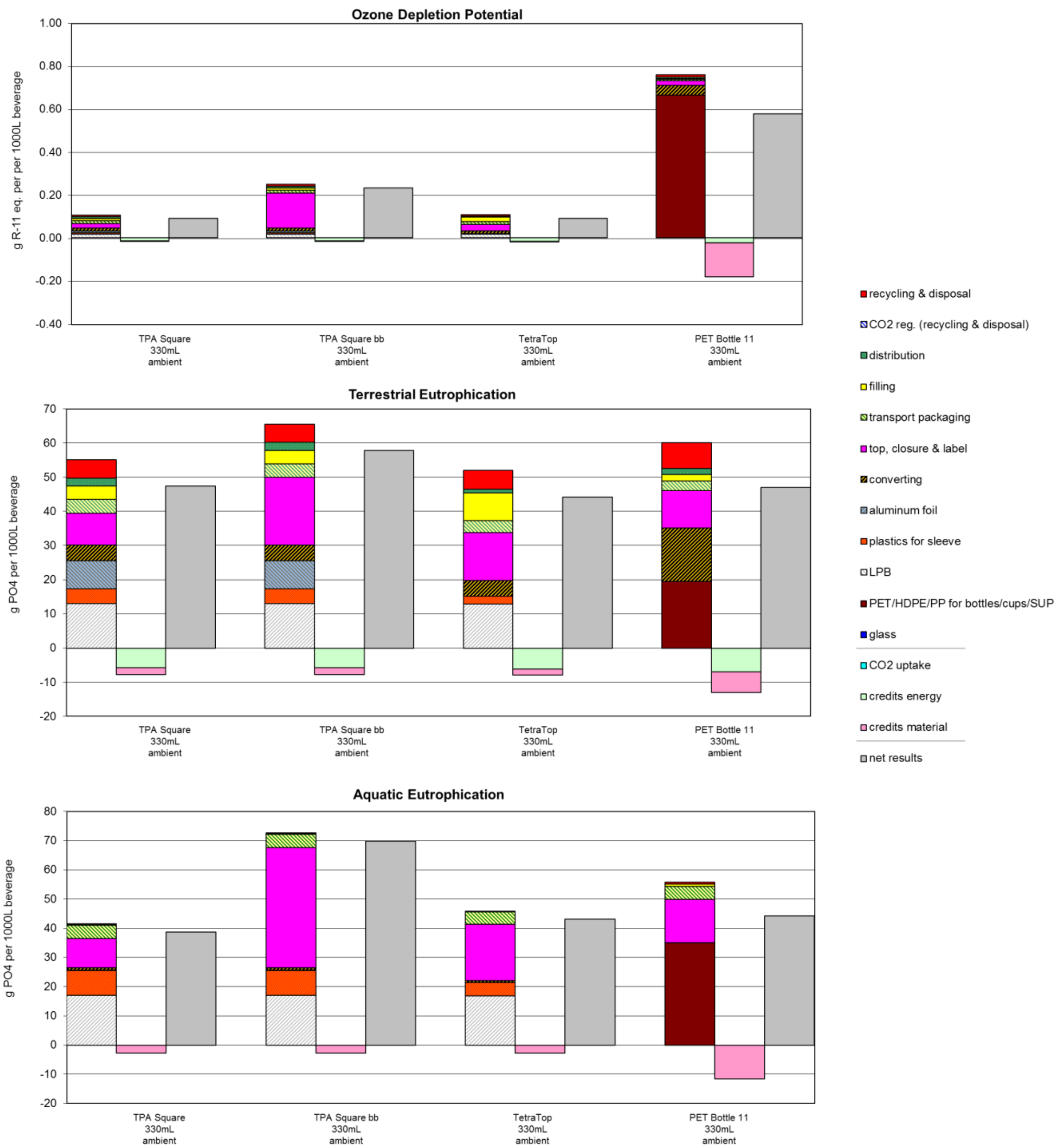



**Figure 79:** Indicator results for base scenarios of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 50% (Part 2)

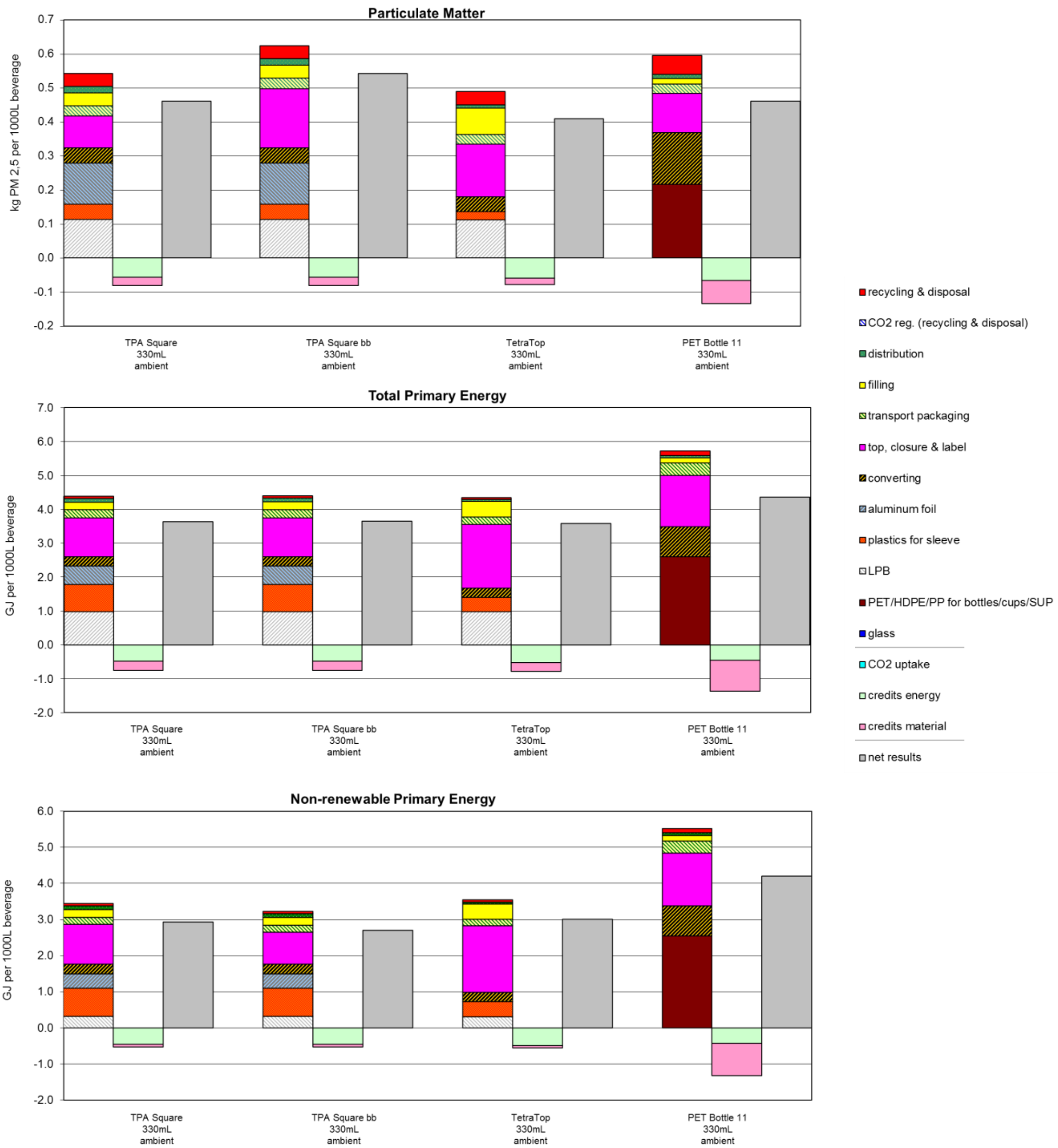



**Figure 80:** Indicator results for base scenarios of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 50% (Part 3)

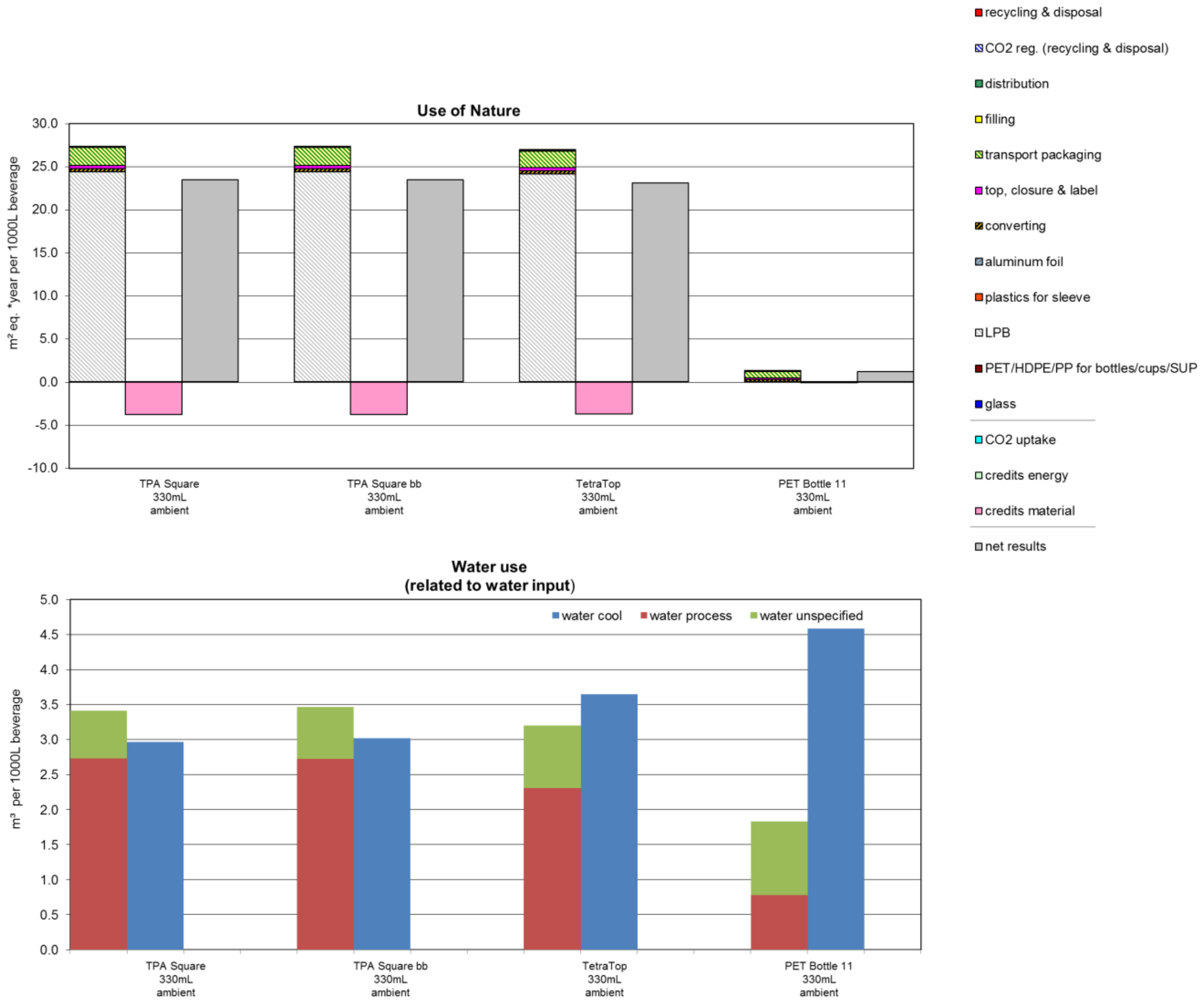



**Figure 81:** Indicator results for base scenarios of segment JNSD WATER 330mL-500mL NETHERLANDS, allocation factor 50% (Part 4)

**Table 102:** Category indicator results per impact category for base scenarios of **segment JNSD WATER 330mL-500mL NETHERLANDS** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | TetraTop 330mL ambient | PET Bottle 11 330mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 200.90 | 197.80 | 200.84 | 297.10 |
| | CO2 (reg) | 21.51 | 27.36 | 21.01 | 0.00 |
| | Credits* | -41.18 | -41.39 | -43.26 | -58.61 |
| | $CO_2$ uptake | -43.35 | -55.98 | -42.96 | 0.00 |
| | Net results (∑) | 137.87 | 127.80 | 135.62 | 238.49 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.59 | 0.64 | 0.52 | 0.64 |
| | Credits* | -0.09 | -0.09 | -0.09 | -0.15 |
| | Net results (∑) | 0.50 | 0.55 | 0.43 | 0.49 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.18 | 8.27 | 6.77 | 7.99 |
| | Credits* | -0.97 | -0.98 | -0.99 | -1.74 |
| | Net results (∑) | 6.21 | 7.29 | 5.79 | 6.24 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.25 | 0.11 | 0.76 |
| | Credits* | -0.02 | -0.02 | -0.02 | -0.18 |
| | Net results (∑) | 0.09 | 0.23 | 0.09 | 0.58 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 55.12 | 65.61 | 52.08 | 60.11 |
| | Credits* | -7.73 | -7.76 | -7.84 | -13.02 |
| | Net results (∑) | 47.39 | 57.84 | 44.24 | 47.08 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 41.44 | 72.52 | 45.81 | 55.69 |
| | Credits* | -2.78 | -2.78 | -2.75 | -11.58 |
| | Net results (∑) | 38.66 | 69.74 | 43.06 | 44.11 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.54 | 0.62 | 0.49 | 0.59 |
| | Credits* | -0.08 | -0.08 | -0.08 | -0.13 |
| | Net results (∑) | 0.46 | 0.54 | 0.41 | 0.46 |
| Total Primary Energy [GJ] | Burdens | 4.40 | 4.41 | 4.36 | 5.72 |
| | Credits* | -0.75 | -0.75 | -0.77 | -1.36 |
| | Net results (∑) | 3.65 | 3.65 | 3.59 | 4.36 |
| Non-renewable primary energy [GJ] | Burdens | 3.44 | 3.22 | 3.55 | 5.51 |
| | Credits* | -0.52 | -0.52 | -0.54 | -1.32 |
| | Net results (∑) | 2.93 | 2.70 | 3.00 | 4.19 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.26 | 27.26 | 26.88 | 1.23 |
| | Credits* | -3.81 | -3.81 | -3.80 | -0.10 |
| | Net results (∑) | 23.45 | 23.44 | 23.08 | 1.13 |
| Water use [$m^3$] | Water cool | 2.97 | 3.02 | 3.65 | 4.59 |
| | Water process | 2.73 | 2.73 | 2.31 | 0.78 |
| | Water unspec | 0.68 | 0.74 | 0.89 | 1.05 |

*material and energy credits

### 7.5.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 330mL-500mL 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' (23%-41%) and 'Use of Nature' (89%-90%). It is also relevant regarding 'Photo-Oxidant Formation' (20%-24%), 'Acidification' (18%-22%), 'Terrestrial Eutrophication' (20%-25%), 'Particulate Matter' (18%-23%) and also the consumption of 'Total Primary Energy' (22%-23%).

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 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 shows burdens for beverage cartons systems containing aluminium foil in most impact categories. Substantial burdens can be seen for the categories 'Acidification' (23%-25%) and 'Particulate Matter' (19%-22%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (4%-24%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil based plastics (5%-9%) and LPB (6%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about 10% - 25% of the total burdens. If the 'plastics for sleeves' contain bio-based plastics (i.e. TPA Square bio-based 330mL ambient) this life cycle step plays a major role for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step 'top, closure & label' contributes to a considerable amount (17%-66%) in almost all impact categories especially for the Tetra Top 330mL ambient with its heavy top. In case the plastics used for 'top, closure & label' are bio-based (i.e. TPA Square bio-based 330mL), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (max. 12%). It generates emissions, which contribute mainly to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems shows minor shares of impacts (5%-13%) in all categories.

The life cycle steps 'filling' and 'distribution' show only minor shares of burdens (max 20%) for all beverage carton systems in most impact categories. Therefore none of these life cycle steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (28%-31%). 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.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Netherlands these derive mainly from the incineration of bio-based plastics and paper. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and cement kilns. Material credits are given for the substitution of primary material due to recycling. As the Dutch recycling rate for beverage cartons is only 37% the energy credits are higher than the material credits in all categories apart from 'Aquatic Eutrophication' and 'Use of Nature'. Material credits for 'Climate Change' are especially low because the production of

substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart from 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottle** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 330mL-500mL segment, the biggest part of the environmental burdens (27%-88%) is also caused by the production of the base materials of the bottle in most impact and inventory categories. The burdens mainly derive from PET production and converting. The high results of 'Ozone Depletion Potential' are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET.

The 'converting' process of the regarded bottle shows considerable shares of impacts (6%-26%) in all categories apart from 'Aquatic Eutrophication' with less than 1% share of impact. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable shares of impacts (3%-27%) in most categories mainly attributed to the plastics used for the relatively heavy closure.

The production and provision of 'transport packaging' for the bottle system show minor shares of impacts (1%-8%) in all categories except of 'Use of Nature' in which the paper production contributes to 61% of the burdens.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max 3%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is most important regarding 'Climate Change' (25%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is high in most categories. With a recycling rate of 51% for the PET bottle, the received material credits are higher than the credits for energy in most categories. The energy credits mainly originate from the incineration plants.

### 7.5.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 103:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL NETHERLANDS**

| The net results of **TPA Square 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square 330mL ambient | PET Bottle 11 330ml ambient |
| Climate Change [kg $CO_2$eq] | 137.87 | -42% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -84% |
| Acidification [kg $SO_2$ eq.] | 0.50 | 2% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 47.39 | 1% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 38.66 | -12% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.21 | -1% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.46 | 0% |

**Table 104:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL NETHERLANDS**

| The net results of **TPA Square bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square bb 330mL ambient | PET Bottle 11 330ml ambient |
| Climate Change [kg $CO_2$eq] | 127.80 | -46% |
| Ozone depletion potential [g R-11 eq.] | 0.23 | -60% |
| Acidification [kg $SO_2$ eq.] | 0.55 | 13% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 57.84 | 23% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 69.74 | 58% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.29 | 17% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.54 | 18% |

**Table 105:** Comparison of net results: **TT 330mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL NETHERLANDS**

| The net results of **TT 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TT 330mL ambient | PET Bottle 11 330ml ambient |
| Climate Change [kg $CO_2$eq] | 135.62 | -43% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -84% |
| Acidification [kg $SO_2$ eq.] | 0.43 | -11% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 44.24 | -6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 43.06 | -2% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.79 | -7% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | -11% |

# 8 Sensitivity Analyses Netherlands

## 8.1 Sensitivity Analyses DAIRY 1000mL-2000mL NETHERLANDS

### 8.1.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

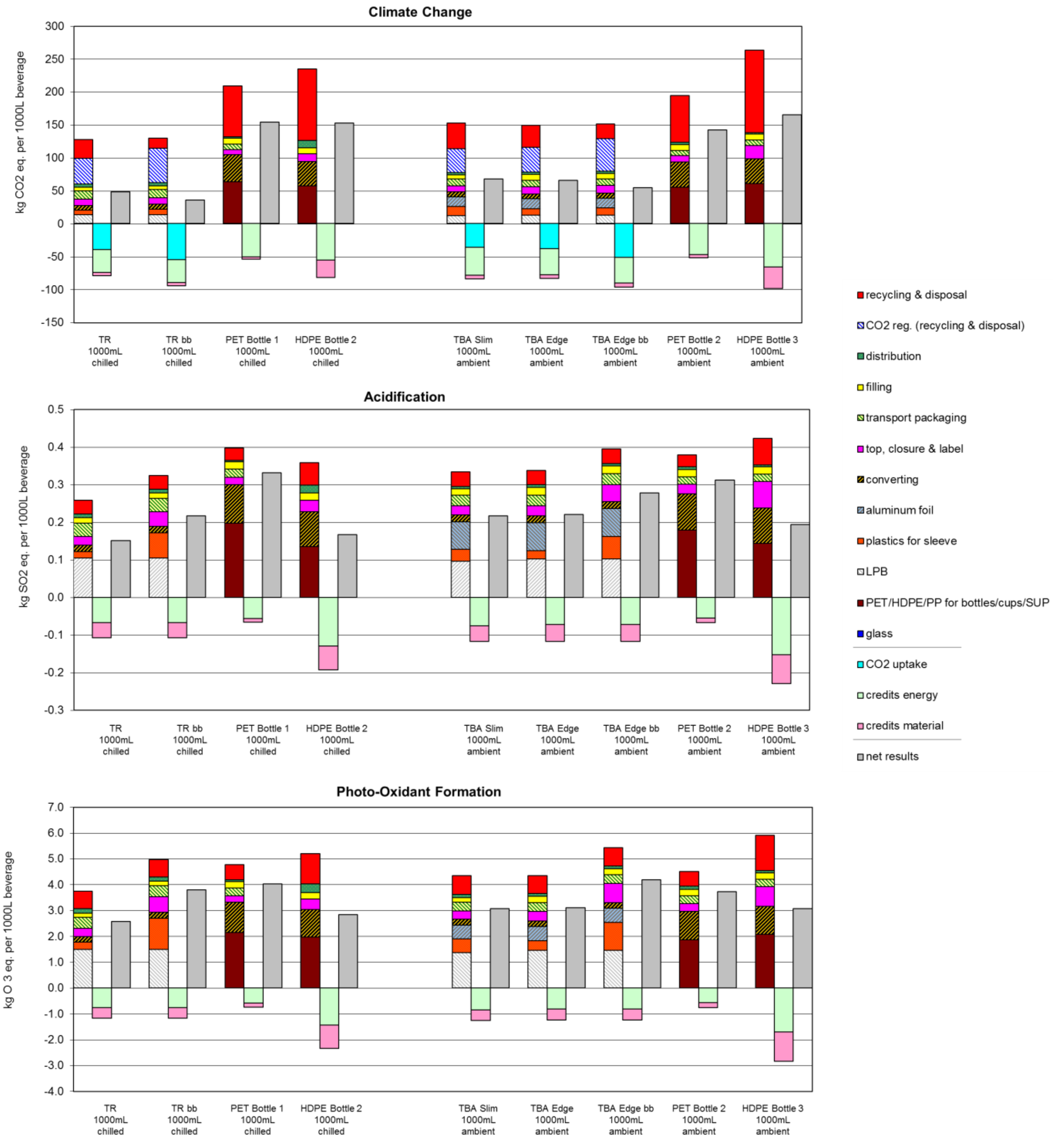



**Figure 82:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 100% (Part 1)

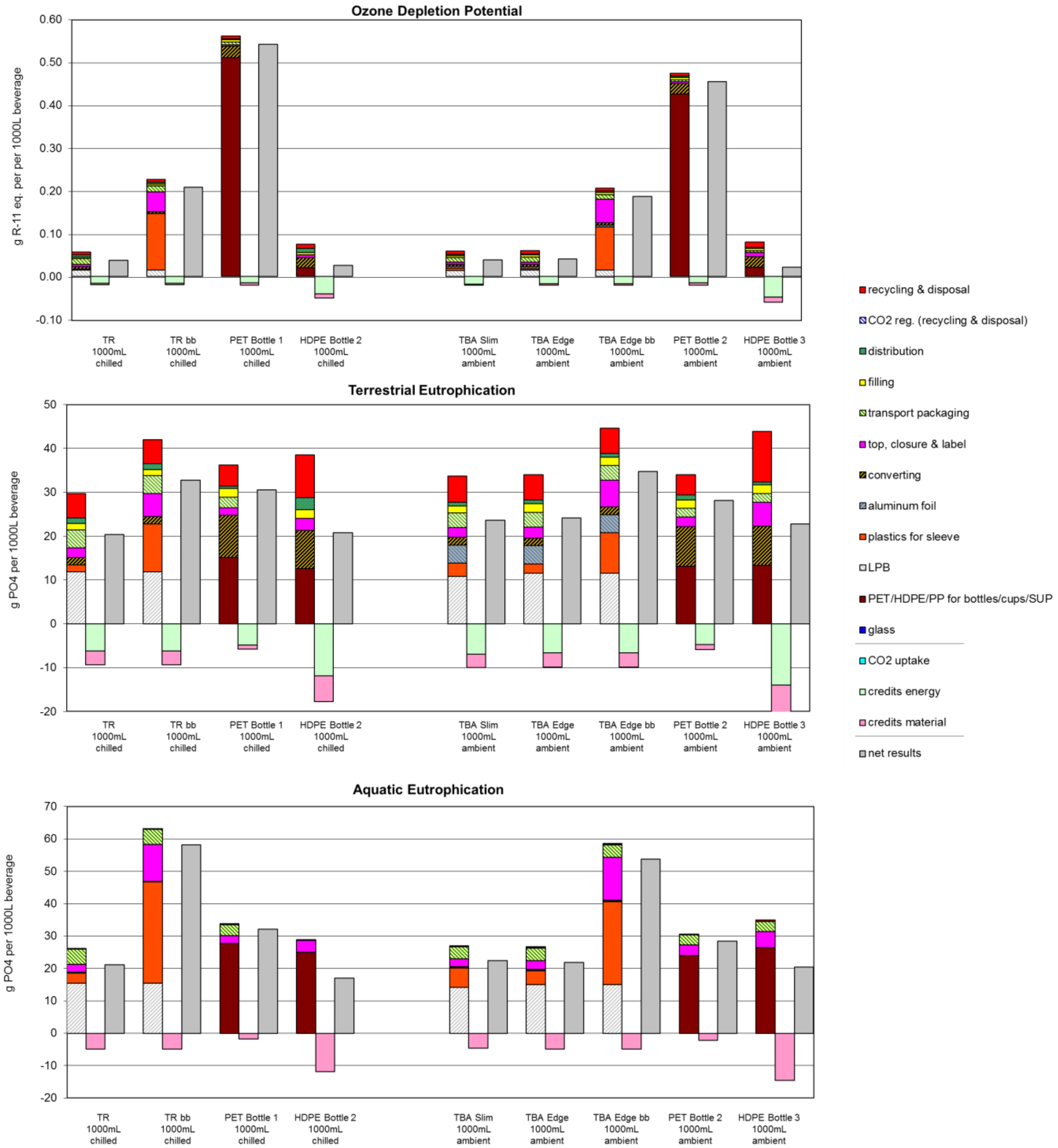



**Figure 83:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 100% (Part 2)

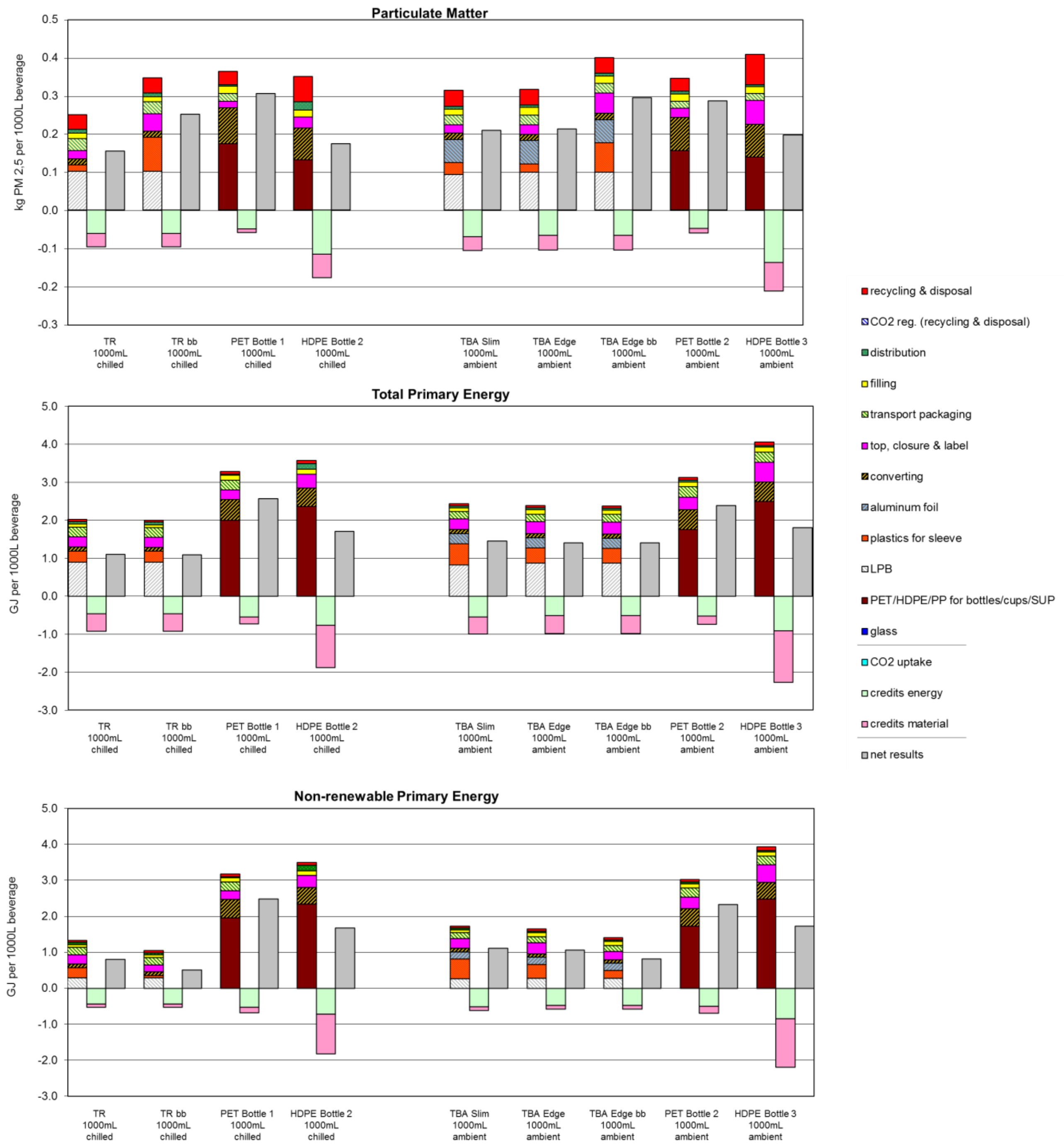



**Figure 84:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 100% (Part 3)

## 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 Netherlands 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. The only exception is 'Climate Change'. For 'Climate Change' applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don't increase when applying the 100% allocation factor.

In the cases of plastic bottles the net result stay about the same in most impact categories as the additionally allocated credits and burdens show similar absolute values. The exception is 'Climate Change'. For 'Climate Change' net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits. In the case of PET bottles also 'Ozone depletion potential' increases when applying the 100% allocation factor.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 106:** Comparison of net results: **TR 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TR 1000mL chilled …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TR 1000mL chilled | PET Bottle 1 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 48.30 | -69% | -68% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -93% | 45% |
| Acidification [kg $SO_2$ eq.] | 0.15 | -54% | -9% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 20.42 | -33% | -2% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 21.15 | -34% | 25% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.56 | -36% | -10% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.16 | -49% | -11% |

**Table 107:** Comparison of net results: **TR bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TR bb 1000mL chilled …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TR bb 1000mL chilled | PET Bottle 1 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 35.28 | -77% | -77% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -62% | 684% |
| Acidification [kg $SO_2$ eq.] | 0.22 | -35% | 30% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 32.77 | 7% | 57% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 58.11 | 81% | 242% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.79 | -6% | 34% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.25 | -18% | 44% |

**Table 108:** Comparison of net results: **TBA Edge 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TBA Edge 1000mLambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Edge 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 65.44 | -54% | -60% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -91% | 89% |
| Acidification [kg $SO_2$ eq.] | 0.22 | -29% | 14% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 24.14 | -14% | 6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 21.77 | -23% | 7% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.10 | -17% | 1% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.21 | -26% | 8% |

**Table 109:** Comparison of net results: **TBA Edge bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 54.34 | -62% | -67% |
| Ozone depletion potential [g R-11 eq.] | 0.19 | -59% | 764% |
| Acidification [kg $SO_2$ eq.] | 0.28 | -11% | 43% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 34.80 | 23% | 53% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 53.66 | 89% | 163% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.17 | 12% | 36% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.30 | 3% | 50% |

**Table 110:** Comparison of net results: **TBA Slim 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, Netherlands**

| The net results of **TBA Slim 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TBA Slim 1000mL ambient | PET Bottle 2 1000mL ambient | HDPE Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 67.73 | -52% | -59% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -91% | 81% |
| Acidification [kg $SO_2$ eq.] | 0.22 | -30% | 12% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 23.69 | -16% | 4% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 22.45 | -21% | 10% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.07 | -18% | 0% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.21 | -27% | 6% |

### 8.1.2 Sensitivity analysis regarding alternative barrier material in beverage cartons

To consider alternative barrier materials instead of aluminium in beverage cartons, a sensitivity analysis with fossil PE instead of aluminium is performed for the packaging systems listed in Table 32. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

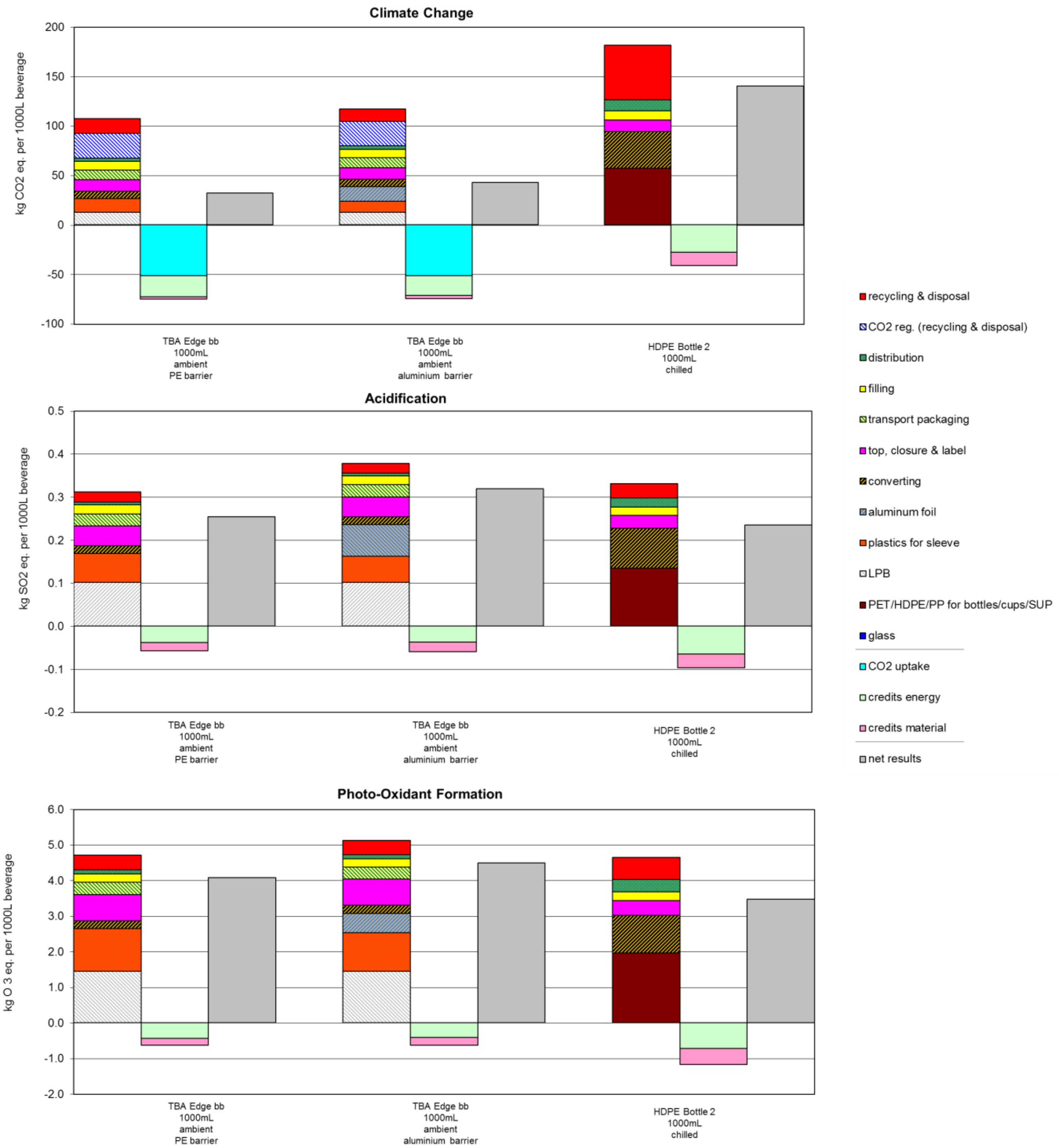



**Figure 85:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of segment DAIRY 1000mL-2000mL NETHERLANDS, allocation factor 50% (Part 1)

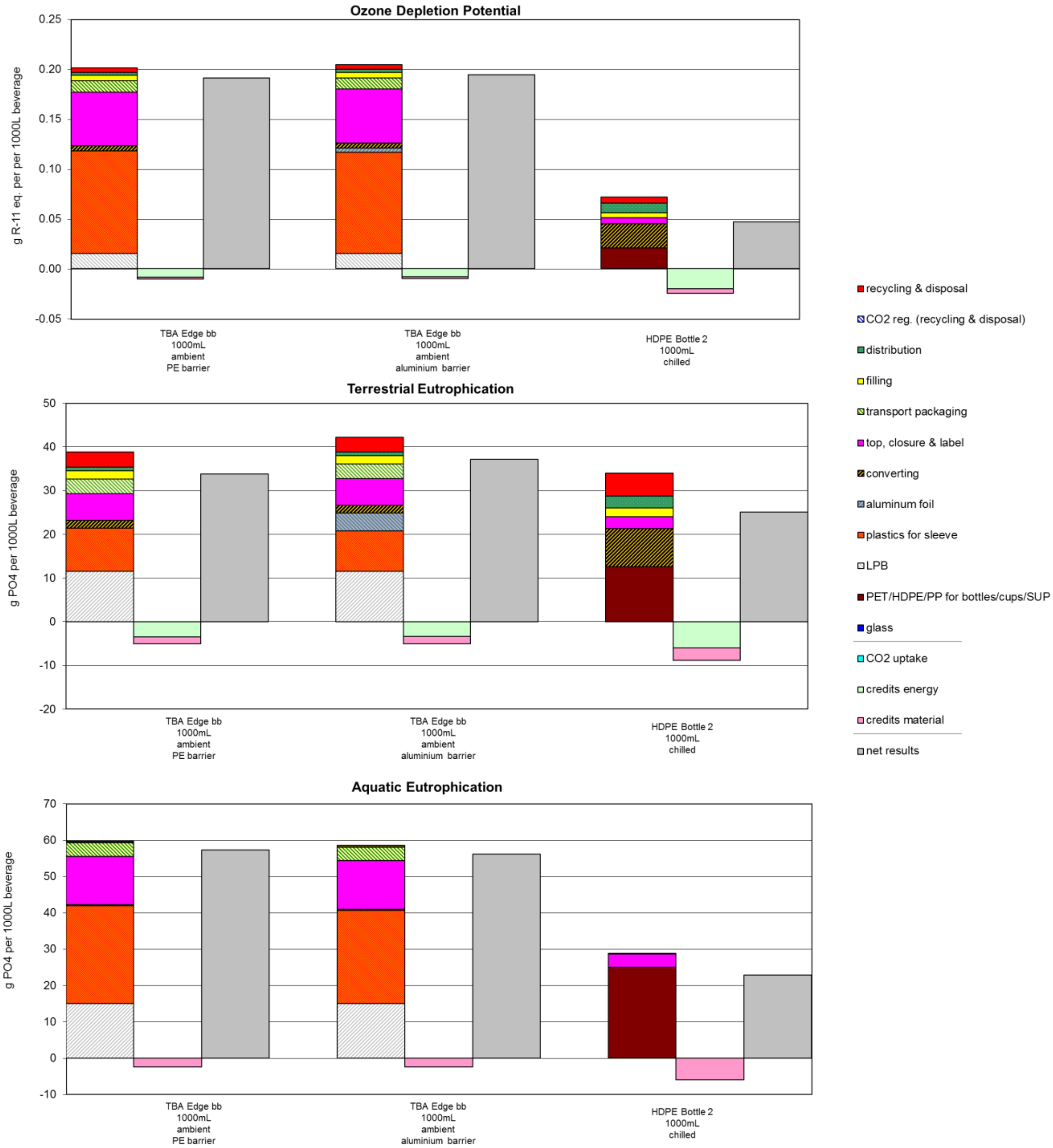



**Figure 86:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 50% (Part 2)

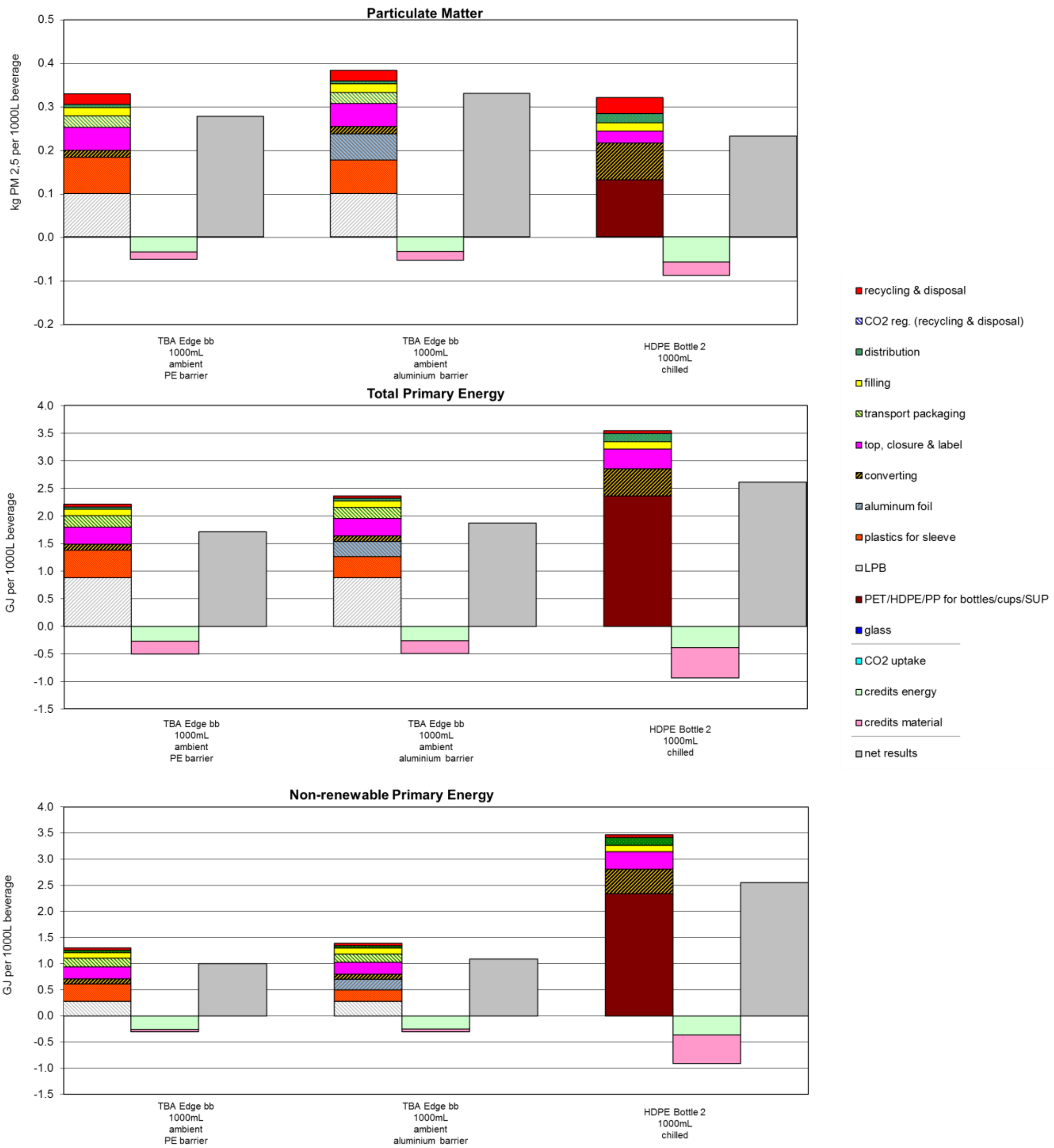



**Figure 87:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 1000mL-2000mL NETHERLANDS**, allocation factor 50% (Part 3)

### Description and Interpretation

Replacing the aluminium layer in the sleeves by a PE layer leads to reductions of net results of 12% - 23% in the impact categories ‘Particulate Matter’, ‘Acidification’ and ‘Climate Change’. Lower reductions of 7% - 9% can be seen in the categories ‘Total Primary Energy’, ‘Non-renewable Primary Energy’, ‘Terrestrial Eutrophication’ and ‘Photo-Oxidant Formation’. On the other hand 4% higher impacts can be seen for ‘Aquatic Eutrophication’. Almost no impacts can be seen for ‘Ozone Depletion’.

The described changes in net results do not upend the net results' ranking of the compared packaging systems.

## 8.2 Sensitivity Analyses JNSD 1000mL NETHERLANDS

### 8.2.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

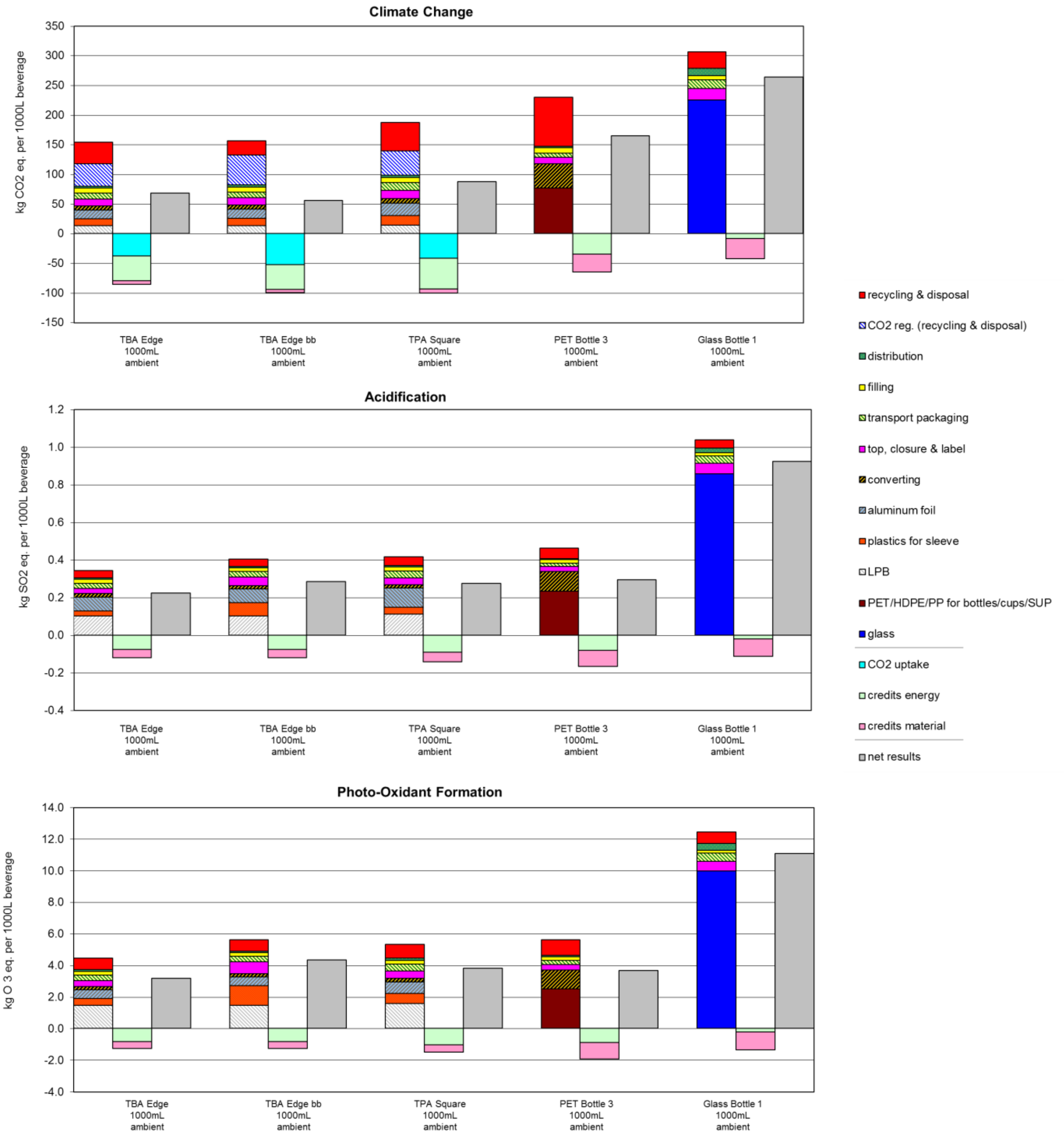



**Figure 88:** Indicator results for sensitivity analysis on system allocation of segment JNSD 1000mL NETHERLANDS, allocation factor 100% (Part 1)

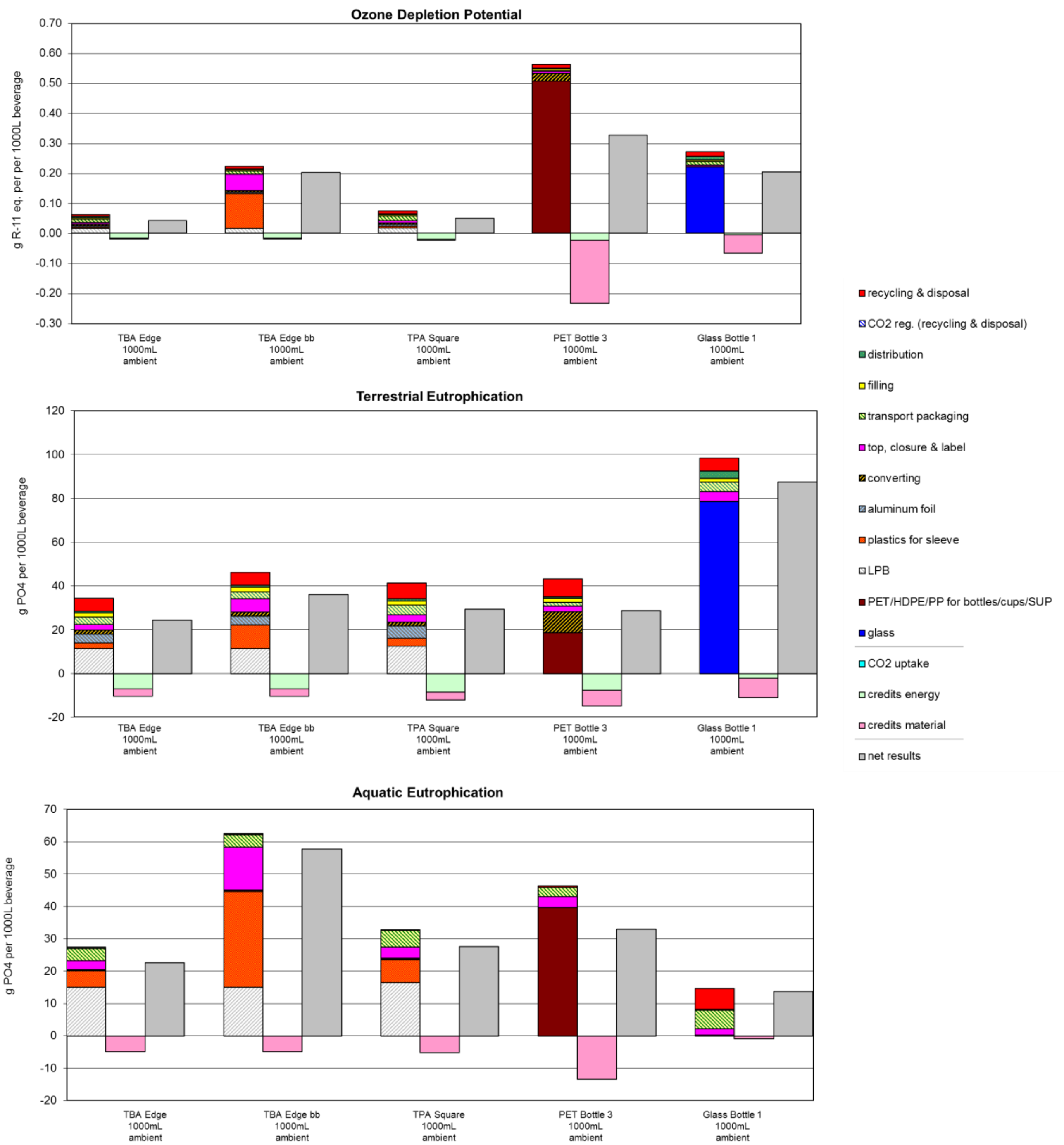



**Figure 89:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL NETHERLANDS**, allocation factor 100% (Part 2)

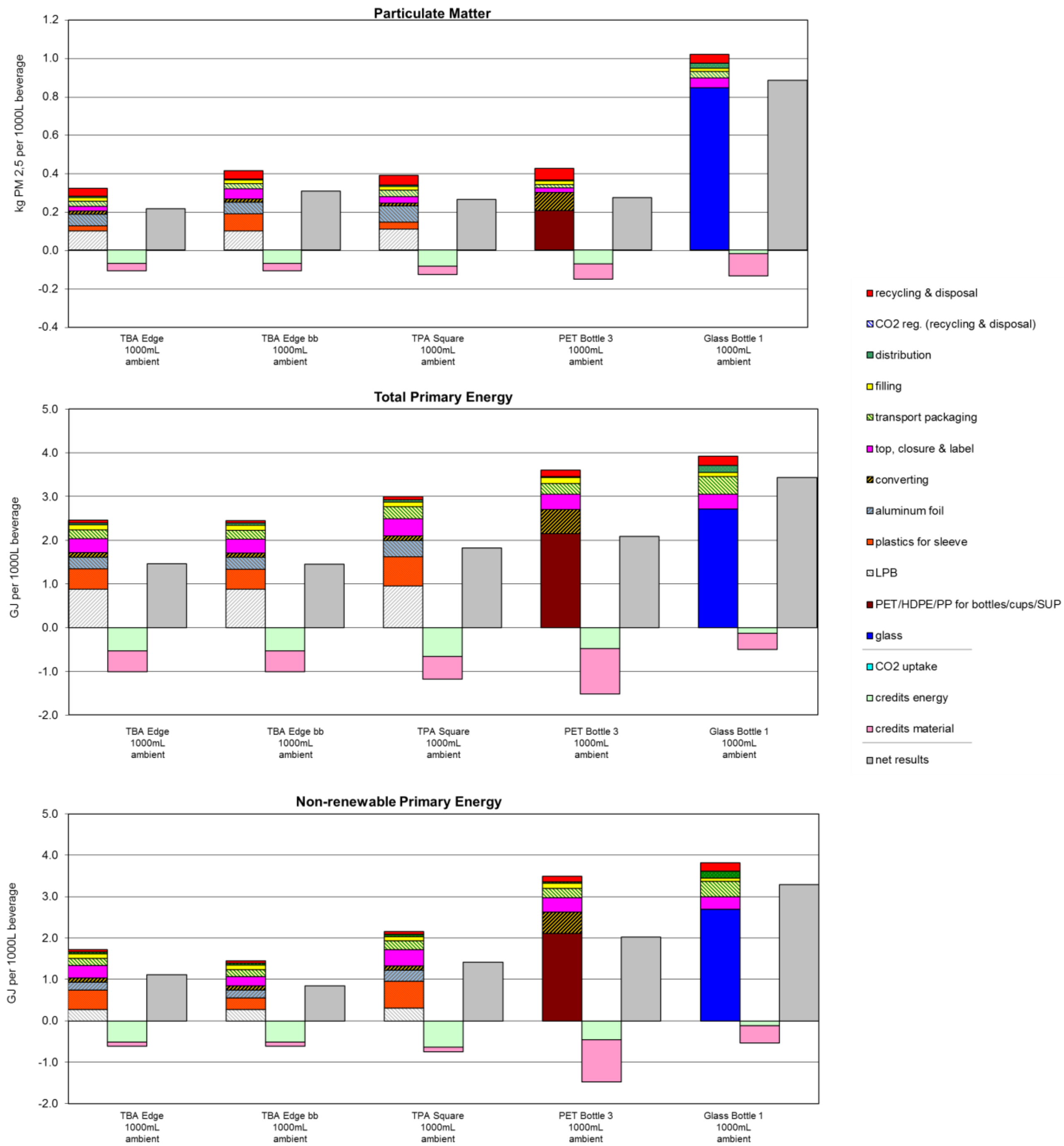



**Figure 90:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL NETHERLANDS**, allocation factor 100% (Part 3)

## 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 Netherlands 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

In the case of the glass bottle the net results of all impact categories decrease when applying the 100% allocation factor due to the high material credits compared to the burdens for recycling.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for all packaging due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 111:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Netherlands**

| The net results of **TBA Edge 1000mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 67.96 | -59% | -74% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -87% | -80% |
| Acidification [kg $SO_2$ eq.] | 0.22 | -24% | -76% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 24.47 | -15% | -72% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 22.58 | -31% | 65% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.16 | -14% | -71% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.22 | -21% | -76% |

**Table 112:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Netherlands**

| The net results of **TBA Edge bb 1000mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 55.74 | -66% | -79% |
| Ozone depletion potential [g R-11 eq.] | 0.20 | -38% | -1% |
| Acidification [kg $SO_2$ eq.] | 0.29 | -3% | -69% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.19 | 25% | -59% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 57.62 | 75% | 321% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.34 | 19% | -61% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | 12% | -65% |

**Table 113:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, Netherlands**

| The net results of **TPA Square 1000mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient | Glass Bottle 1 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 86.78 | -47% | -67% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -85% | -76% |
| Acidification [kg $SO_2$ eq.] | 0.28 | -7% | -70% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 29.45 | 2% | -66% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 27.55 | -16% | 101% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.80 | 4% | -66% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.26 | -4% | -70% |

## 8.3 Sensitivity Analyses DAIRY 189mL-500mL NETHERLANDS

### 8.3.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

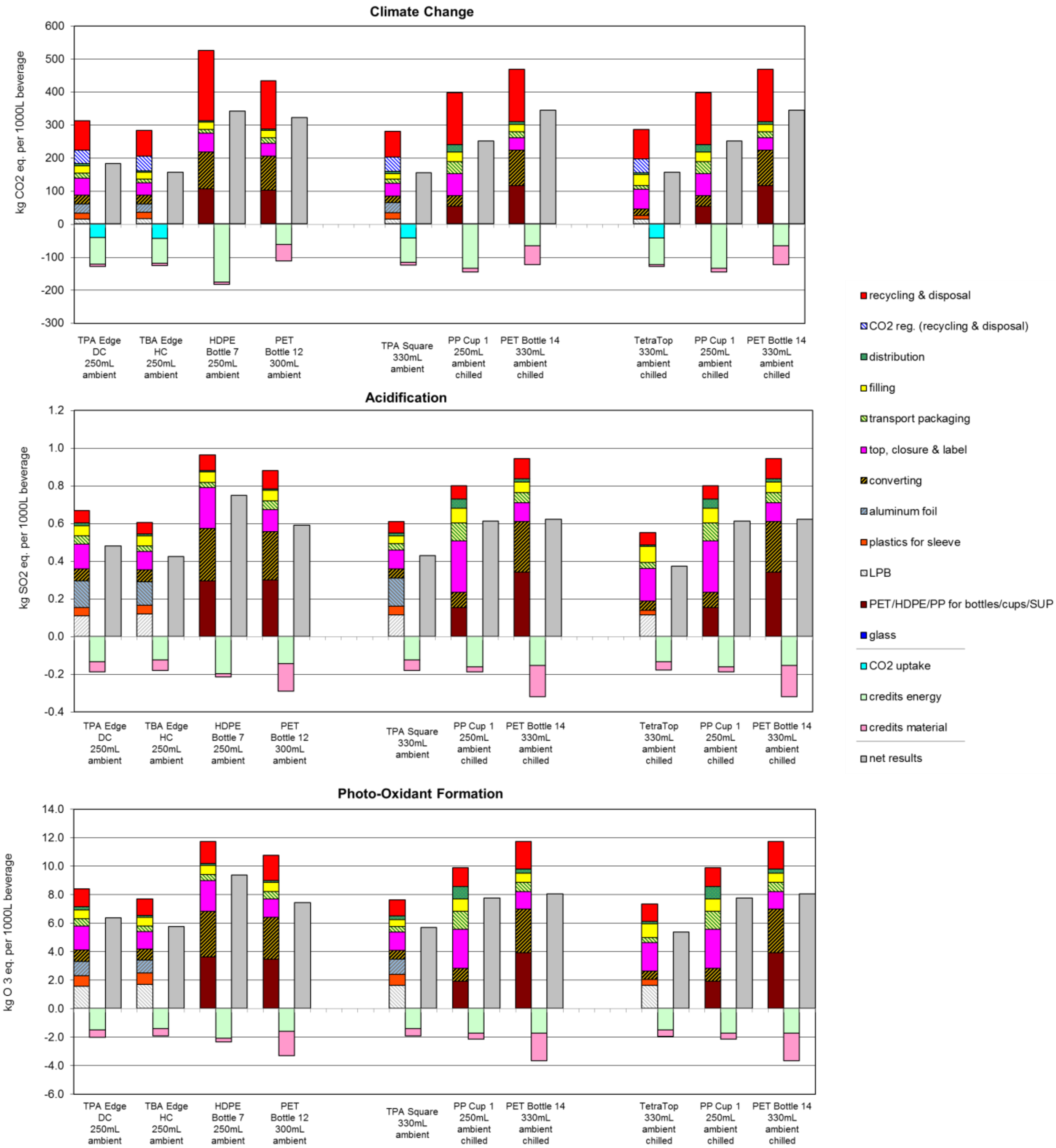


**Figure 91:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 100% (Part 1)

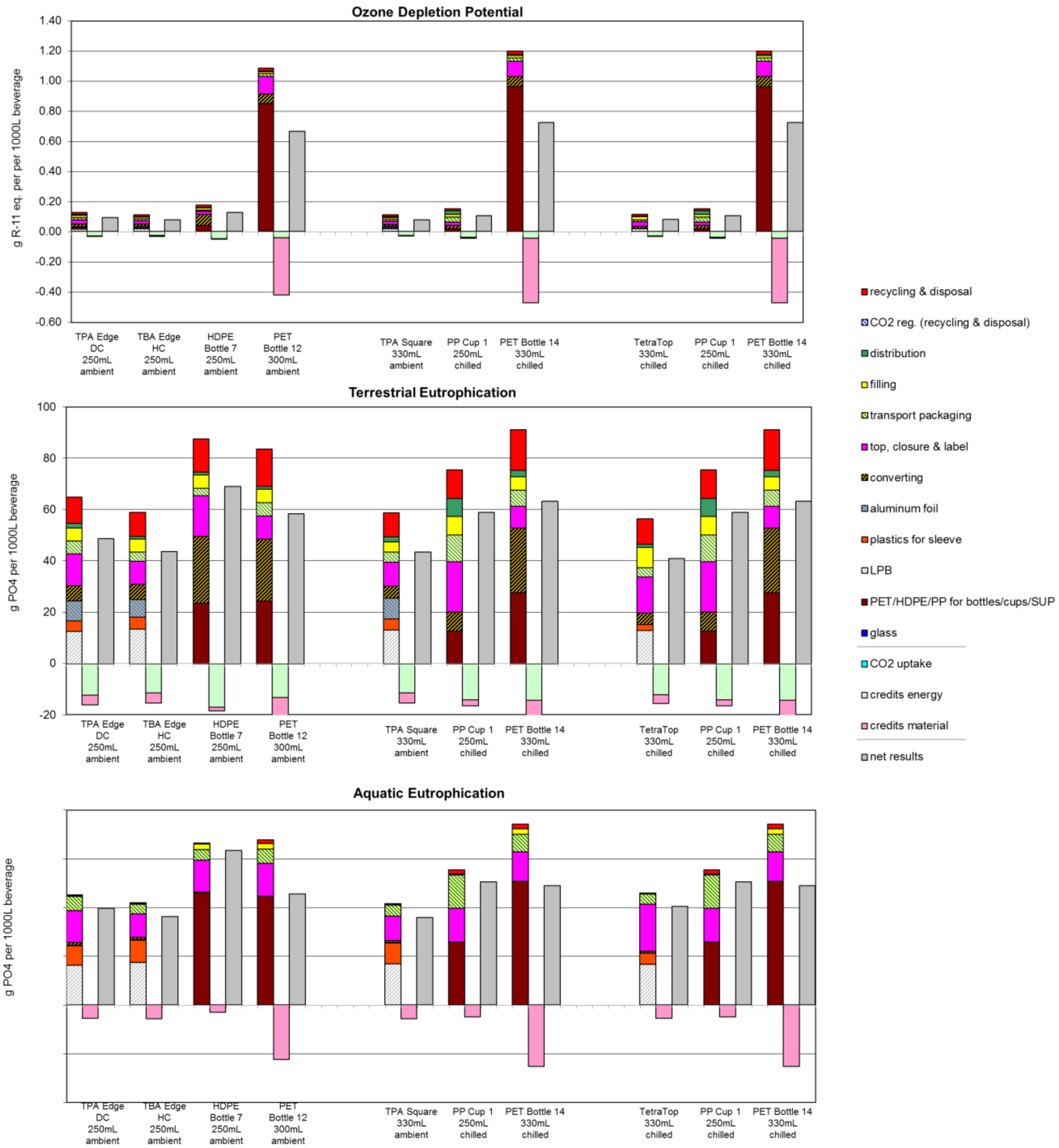



**Figure 92:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 100% (Part 2)

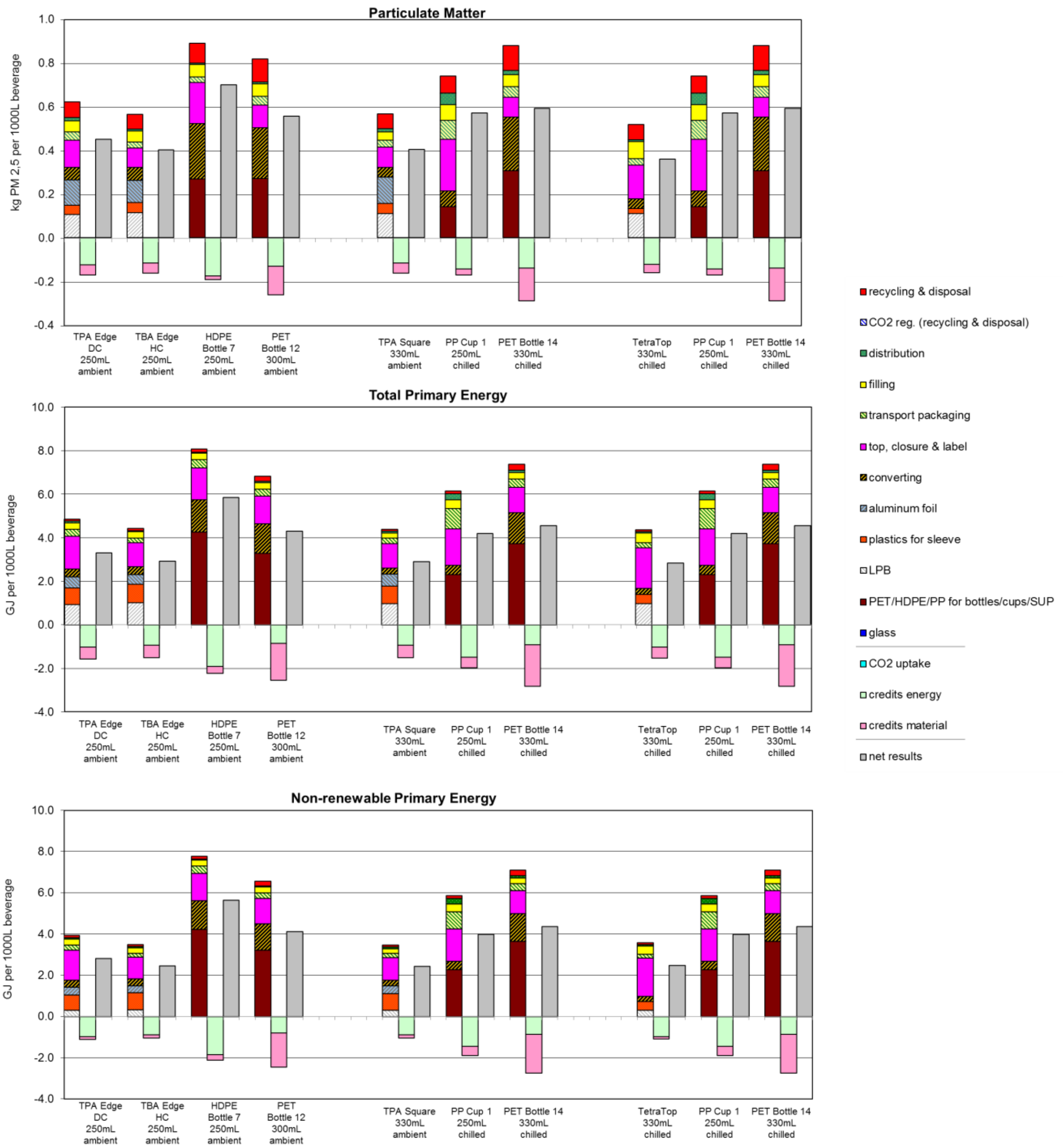



**Figure 93:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL NETHERLANDS**, allocation factor 100% (Part 3)

## 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 Netherlands 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles and PP cups the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for all packaging systems due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 114:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of<br>**TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 182.11 | -47% | -43% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -27% | -86% |
| Acidification [kg $SO_2$ eq.] | 0.48 | -36% | -19% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 48.73 | -29% | -17% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.65 | -37% | -13% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.34 | -32% | -14% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.45 | -35% | -19% |

**Table 115:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TBA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TBA Edge HC 250mL ambient | HDPE Bottle 7 250mL ambient | PET Bottle 12 300mL ambient |
| Climate Change [kg $CO_2$eq] | 156.45 | -54% | -51% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -38% | -88% |
| Acidification [kg $SO_2$ eq.] | 0.42 | -43% | -28% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.64 | -37% | -25% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 36.23 | -43% | -20% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.73 | -39% | -23% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | -42% | -28% |

**Table 116:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 154.23 | -39% | -55% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -28% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.43 | -30% | -31% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.46 | -26% | -31% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 35.91 | -29% | -27% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.69 | -26% | -29% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | -29% | -32% |

**Table 117:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL NETHERLANDS**

| The net results of **TT 330mL chilled …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TT 330mL chilled | PP Cup 1 250mL chilled | PET Bottle 14 330mL chilled |
| Climate Change [kg $CO_2$eq] | 156.55 | -38% | -55% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -26% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.37 | -39% | -40% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 40.91 | -31% | -35% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.35 | -20% | -18% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.35 | -31% | -33% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.36 | -37% | -39% |

## 8.4 Sensitivity Analyses JNSD 200ml-330ml NETHERLANDS

### 8.4.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

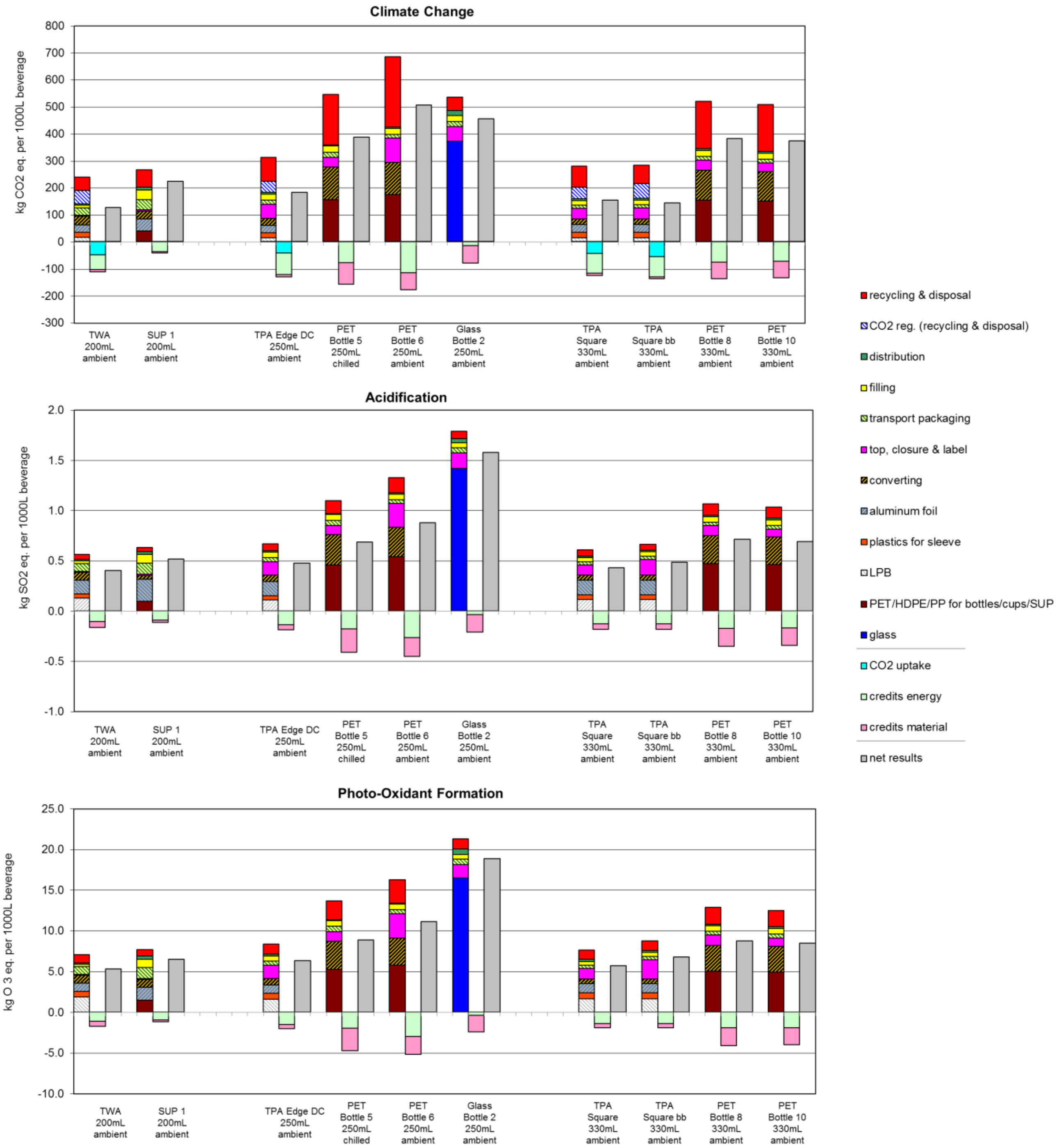



**Figure 94:** Indicator results for sensitivity analysis on system allocation of segment JNSD 200ml-330ml NETHERLANDS, allocation factor 100% (Part 1)

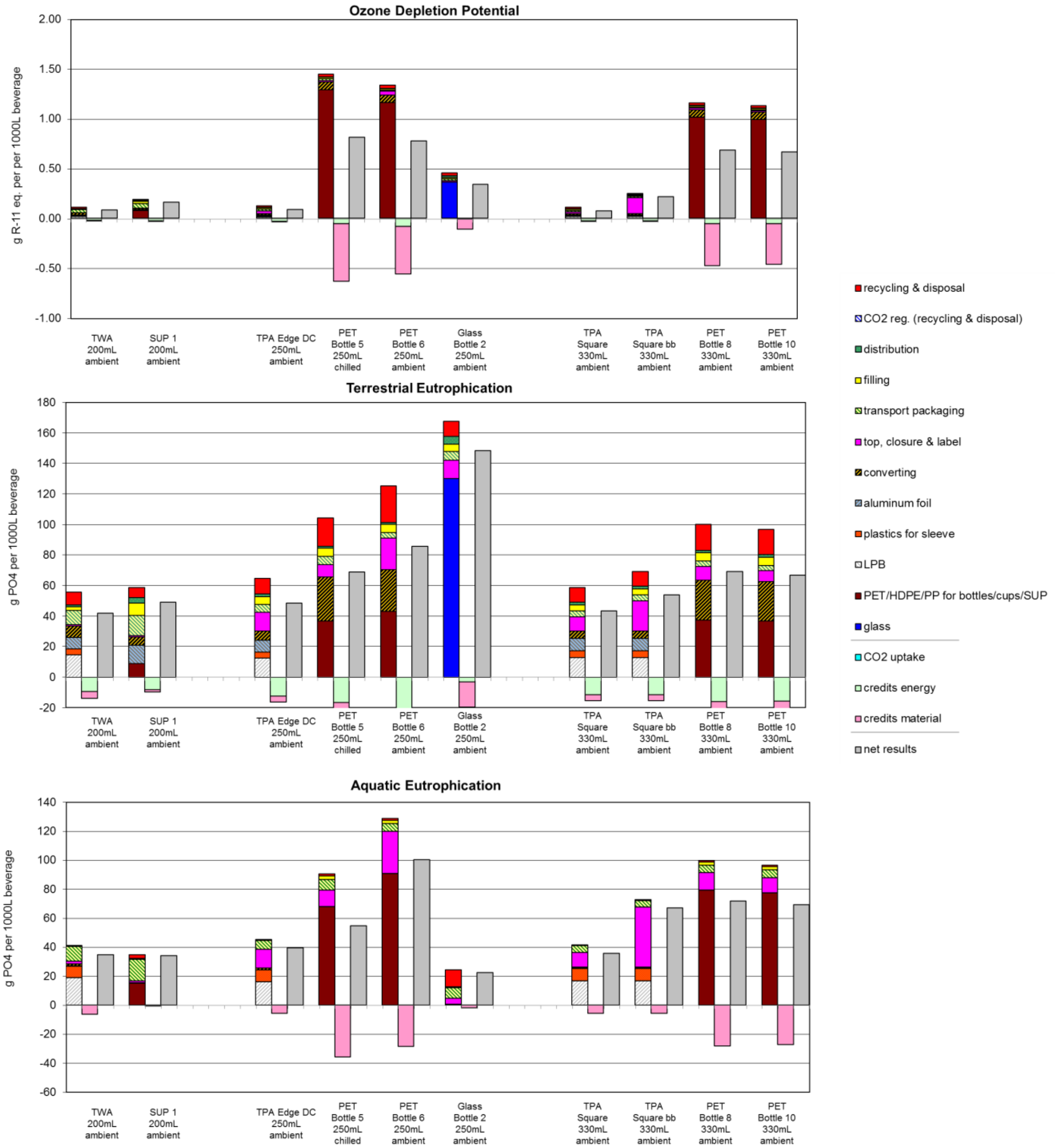



**Figure 95:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml NETHERLANDS**, allocation factor 100% (Part 2)

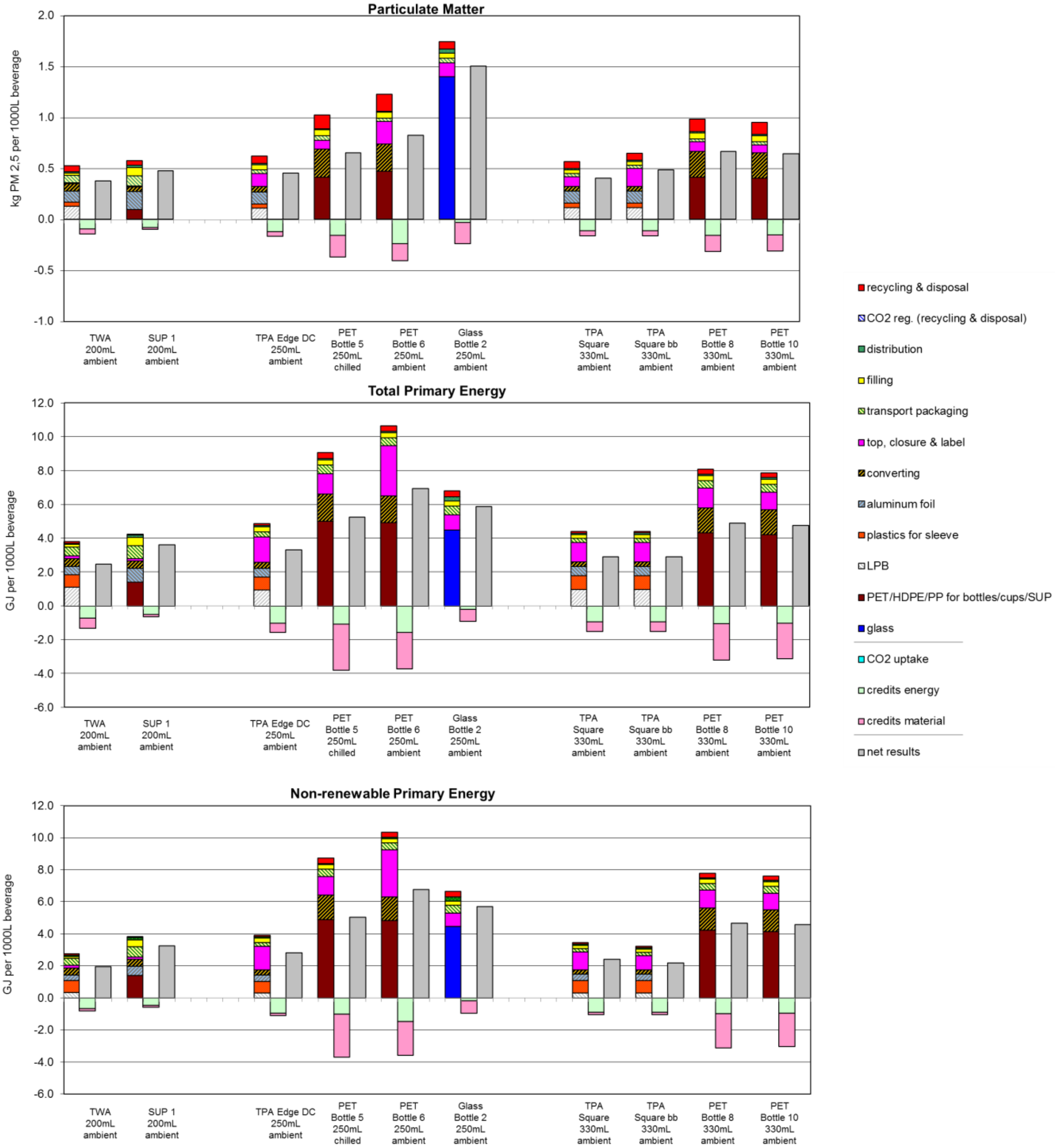



**Figure 96:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml NETHERLANDS**, allocation factor 100% (Part 3)

## 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 Netherlands 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. The only exception is ‘Climate Change’. For ‘Climate Change’ applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don’t increase when applying the 100% allocation factor.

In the cases of plastic bottles and SUP the net results result decrease in most 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. The exception is ‘Climate Change’. For ‘Climate Change’ net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

In the case of the glass bottle the net results of all impact categories decrease when applying the 100% allocation factor due to the high material credits compared to the burdens for recycling.

For the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Energy’ net results decrease when rising the allocation factor to 100% for all packaging due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 118:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TWA 200mL ambient | SUP 1 200mL ambient |
| Climate Change [kg $CO_2$eq] | 126.70 | -43% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -49% |
| Acidification [kg $SO_2$ eq.] | 0.40 | -22% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 42.01 | -15% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 34.82 | 2% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.31 | -18% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.38 | -21% |

**Table 119:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled | PET Bottle 6 250ml ambient | Glass Bottle 2 250ml ambient |
| Climate Change [kg $CO_2$eq] | 181.81 | -53% | -64% | -60% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -89% | -88% | -74% |
| Acidification [kg $SO_2$ eq.] | 0.48 | -30% | -45% | -70% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 48.66 | -29% | -43% | -67% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.64 | -28% | -60% | 76% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.33 | -29% | -43% | -66% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.45 | -31% | -45% | -70% |

**Table 120:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PET Bottle 8 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 154.23 | -59% | -59% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -89% | -89% |
| Acidification [kg $SO_2$ eq.] | 0.43 | -40% | -38% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.46 | -37% | -35% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 35.91 | -50% | -48% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.69 | -35% | -33% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | -39% | -37% |

**Table 121:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml NETHERLANDS**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 8 330mL ambient | PET Bottle 10 330mL ambient |
| Climate Change [kg $CO_2$eq] | 144.11 | -62% | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -68% | -67% |
| Acidification [kg $SO_2$ eq.] | 0.48 | -32% | -30% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 53.91 | -22% | -20% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 66.99 | -7% | -3% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.77 | -23% | -20% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -27% | -24% |

## 8.5 Sensitivity Analyses JNSD WATER 330mL-500mL NETHERLANDS

### 8.5.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

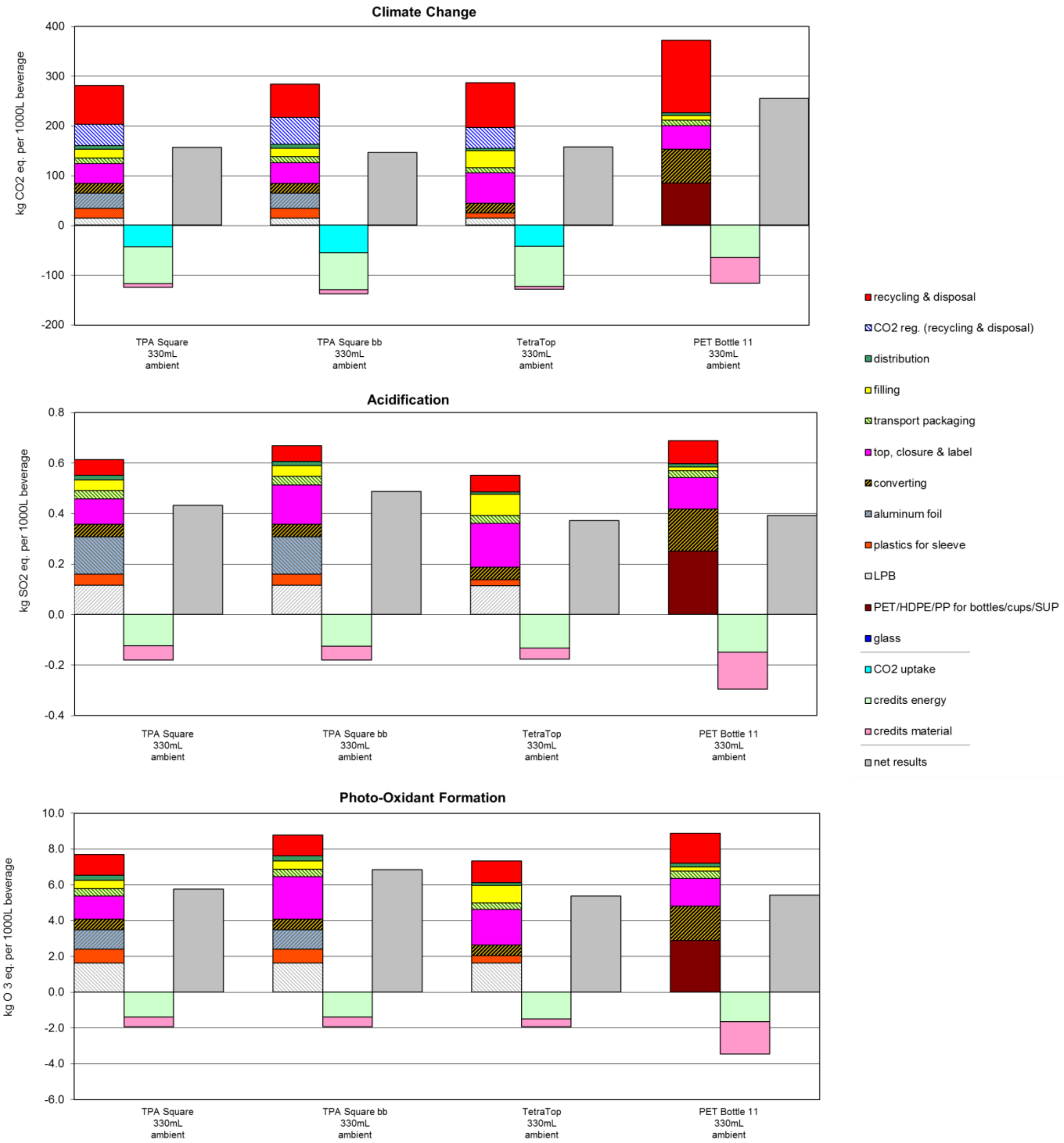



**Figure 97:** Indicator results for sensitivity analysis on system allocation of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 100% (Part 1)

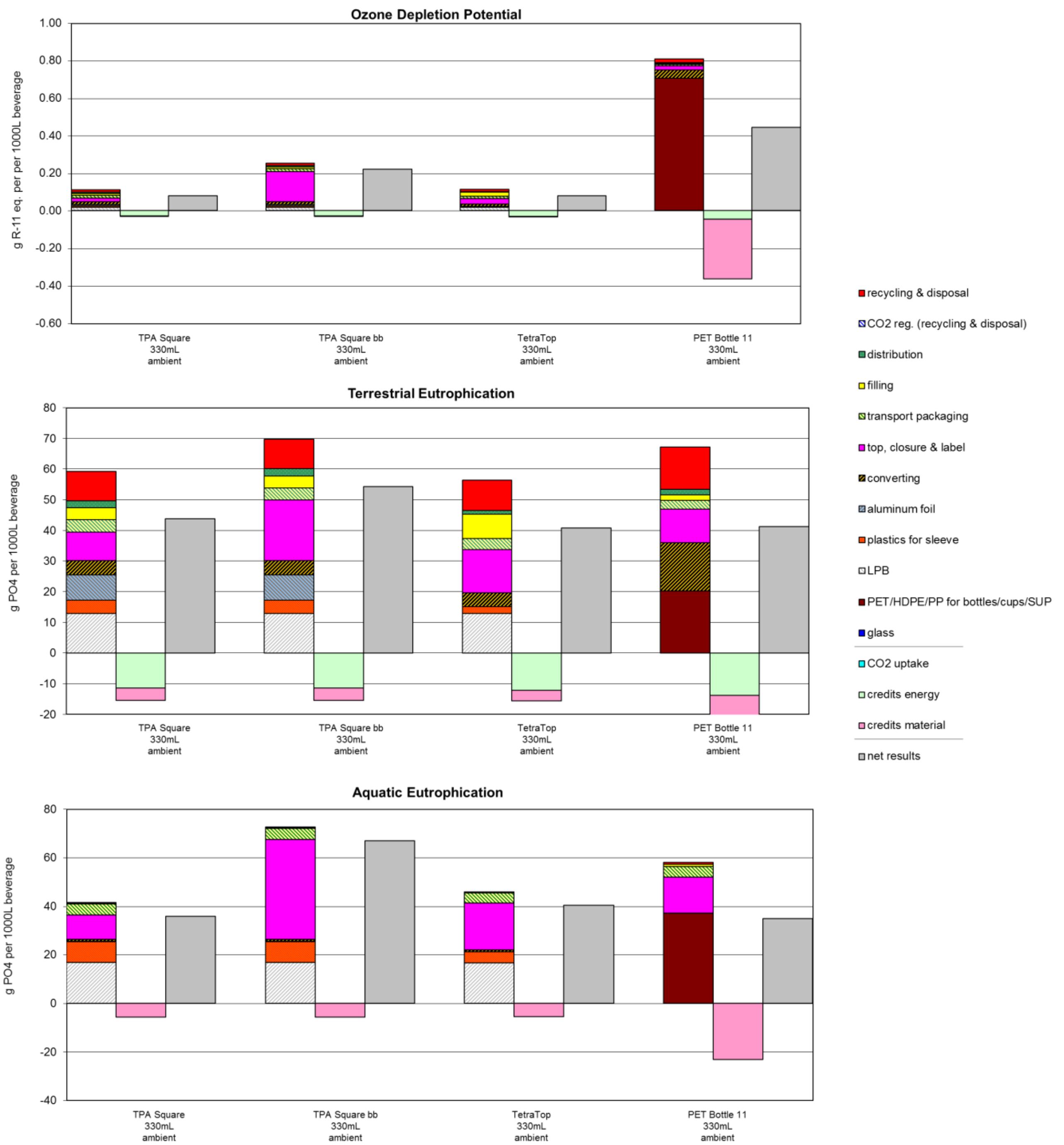



**Figure 98:** Indicator results for sensitivity analysis on system allocation of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 100% (Part 2)

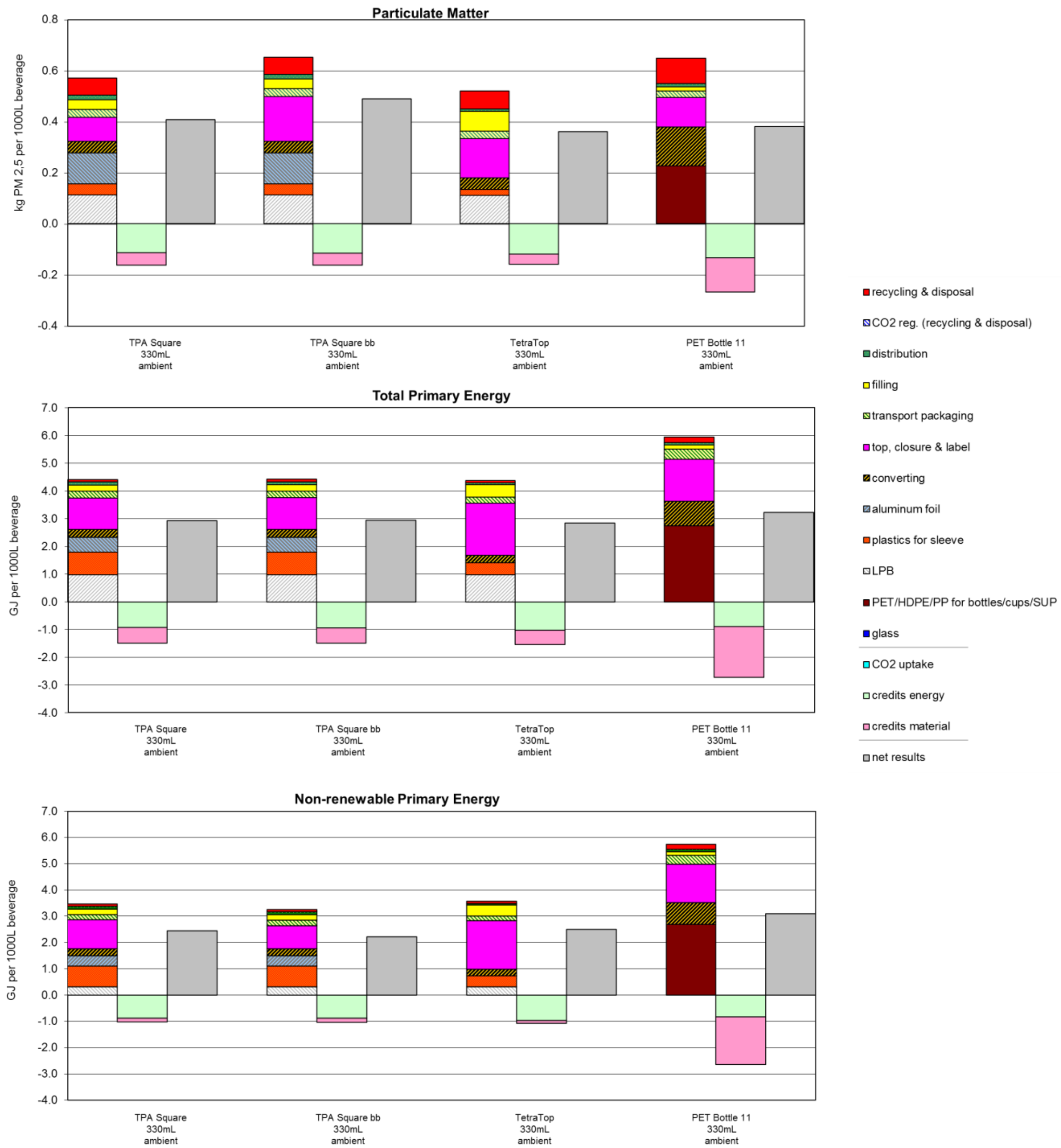



**Figure 99:** Indicator results for sensitivity analysis on system allocation of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 100% (Part 3)

## 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 Netherlands 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. The only exception is 'Climate Change'. For 'Climate Change' applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the allocation factor is not applied for the CO2 uptake, therefore the values for the CO2 uptake don't increase when applying the 100% allocation factor.

In the cases of plastic bottles the net results result decrease in most 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. The exception is 'Climate Change'. For 'Climate Change' net results increase when applying the 100% allocation factor as burdens from incineration are higher than energy and material credits.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for all packaging systems due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 122:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL NETHERLANDS**

| The net results of **TPA Square 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square 330mL ambient | PET Bottle 11 330ml ambient |
| Climate Change [kg $CO_2$eq] | 155.52 | -39% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -82% |
| Acidification [kg $SO_2$ eq.] | 0.43 | 10% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.89 | 6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 35.91 | 3% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.74 | 6% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | 7% |

**Table 123:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL NETHERLANDS**

| The net results of **TPA Square bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square bb 330mL ambient | PET Bottle 11 330ml ambient |
| Climate Change [kg $CO_2$eq] | 145.40 | -43% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -50% |
| Acidification [kg $SO_2$ eq.] | 0.49 | 24% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 54.34 | 31% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 66.99 | 92% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.83 | 26% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | 28% |

**Table 124:** Comparison of net results: **TT 330mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL NETHERLANDS**

| The net results of **TT 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TT 330mL ambient | PET Bottle 11 330ml ambient |
| Climate Change [kg $CO_2$eq] | 156.65 | -38% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -82% |
| Acidification [kg $SO_2$ eq.] | 0.37 | -5% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 40.92 | -1% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.35 | 16% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.35 | -1% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.36 | -5% |

### 8.5.2 Sensitivity analysis regarding plastic bottle weight

To consider potential future developments in terms of weight of the plastic bottles, a sensitivity analysis with reduced bottle weight is 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 graphs.

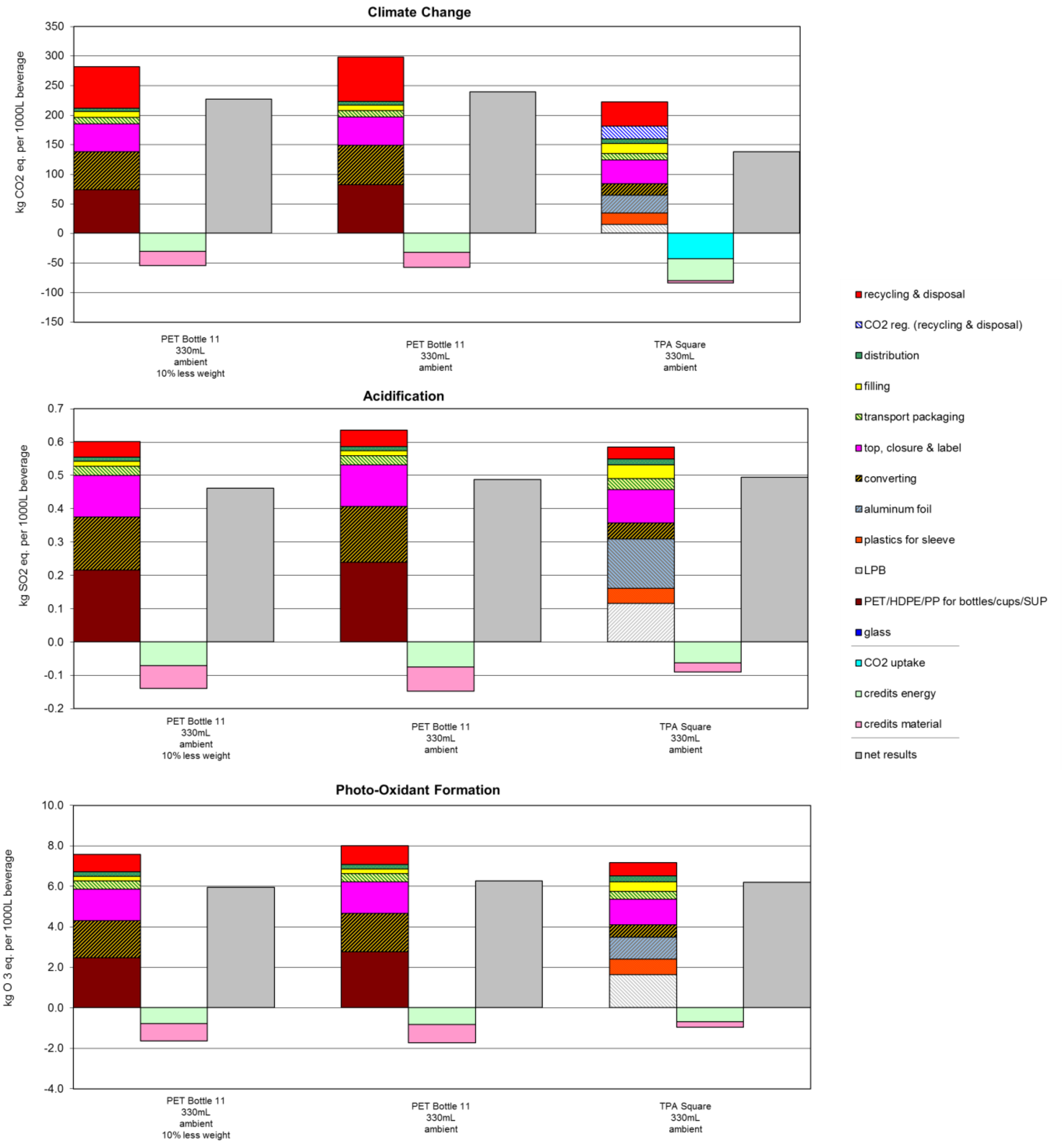



**Figure 100:** Indicator results for sensitivity analysis on plastic bottle weight of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 50% (Part 1)

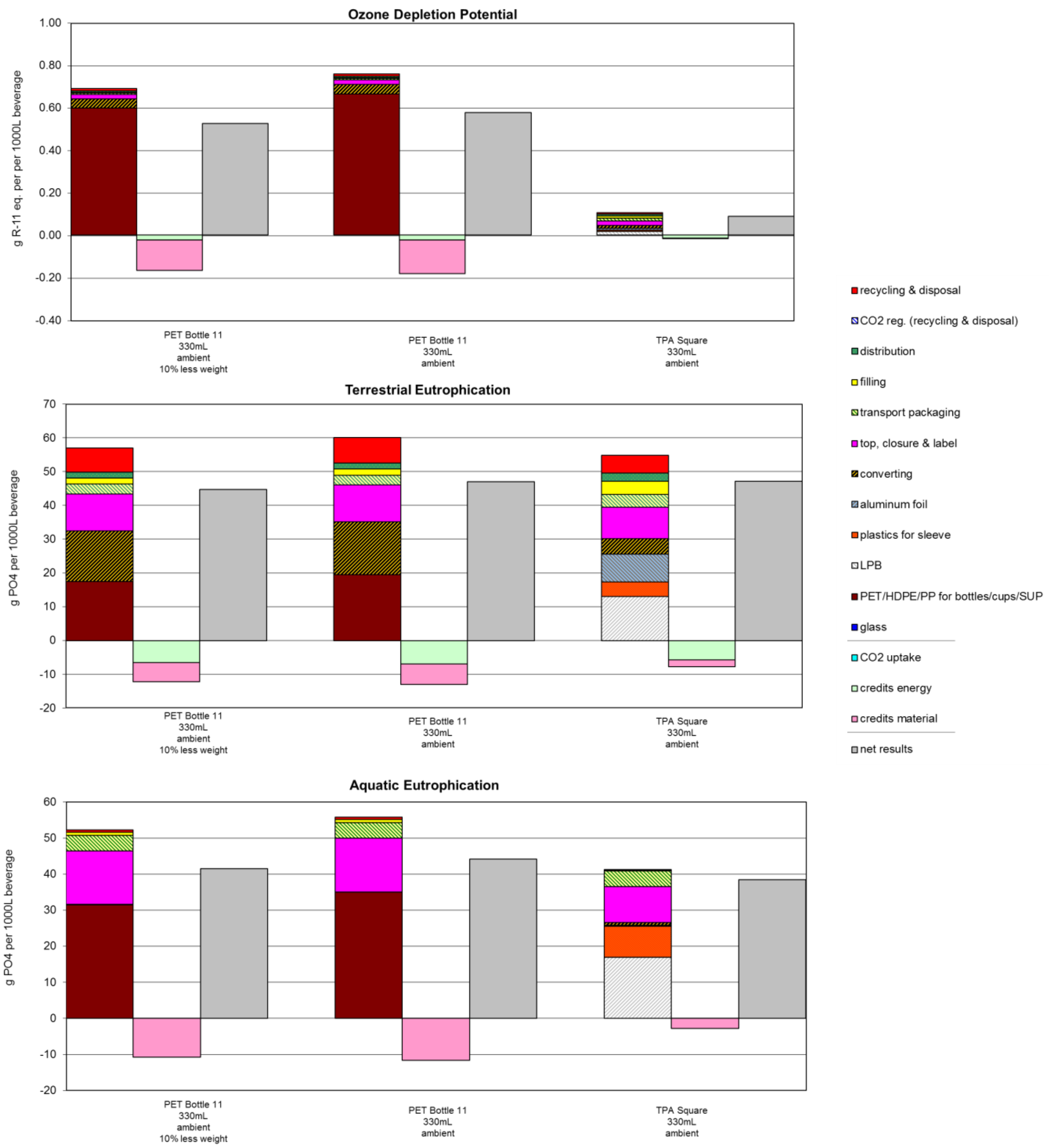



**Figure 101:** Indicator results for sensitivity analysis on plastic bottle weight of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 50% (Part 2)

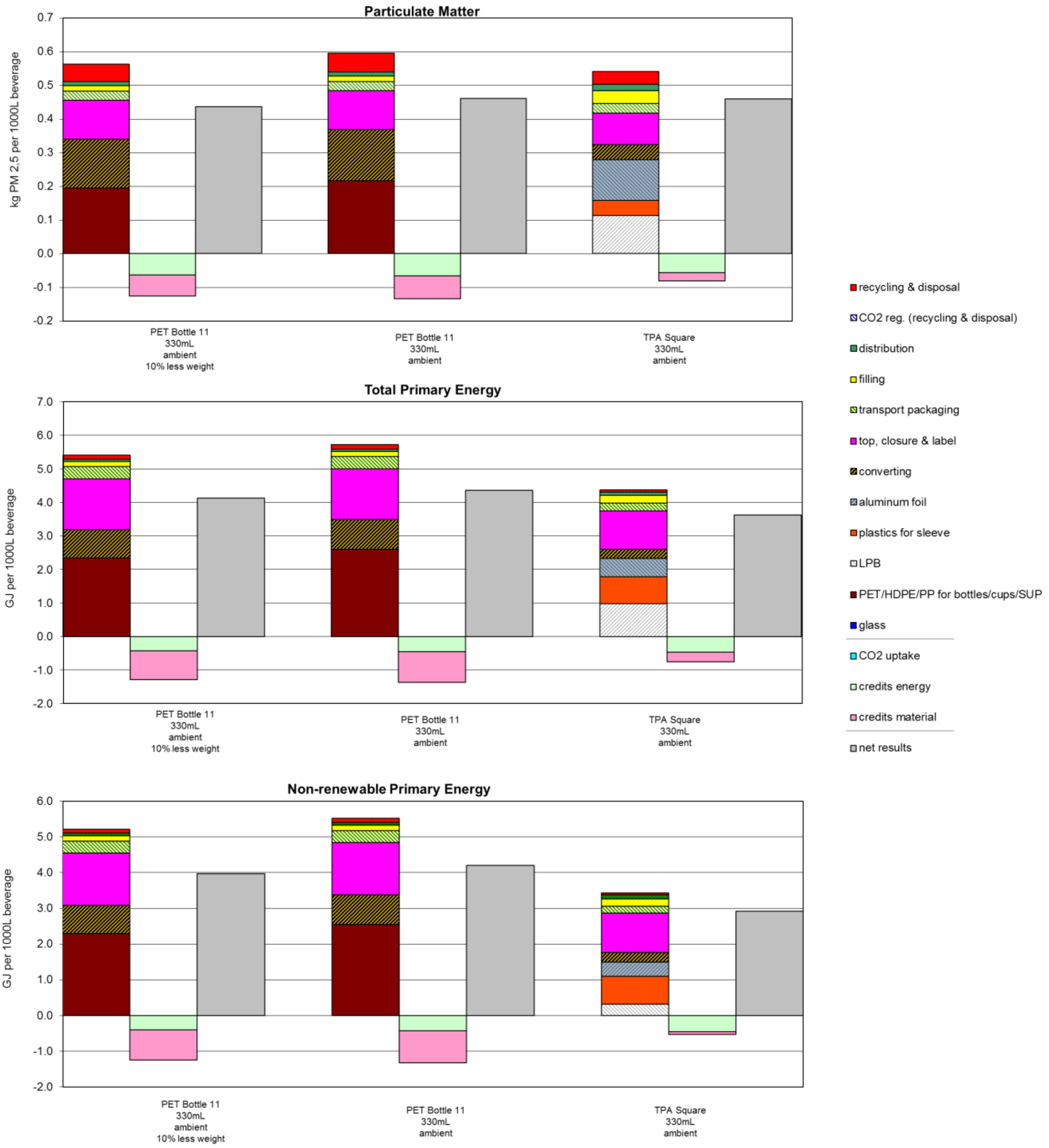



**Figure 102:** Indicator results for sensitivity analysis on plastic bottle weight of **segment JNSD WATER 330mL-500mL NETHERLANDS**, allocation factor 50% (Part 3)

### Description and Interpretation

The reduction PET bottle weight by 10% reduces the impacts of PET production and converting in all impact categories. With no reductions in other life cycle steps the reduction of net results ranges only from 5% - 9%

The described changes in net results lead to small changes of the net results' ranking of the compared packaging systems. In the impact categories 'Acidification', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and 'Particulate Matter' as well as in the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Primary Energy’ the PET Bottle 11 with 10% less weight shows now slightly smaller net results than the TPA Square beverage carton.

# 9 Conclusions Netherlands

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 Dutch 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.

## 9.1 DAIRY 1000mL-2000mL NETHERLANDS

In the comparison of the examined beverage carton systems with fossil based plastics to all bottles in this segment, no unambiguous result can be observed. Compared to the PET bottle the cartons show lower environmental impacts in all of the impact except terrestrial eutrophication for which the results are similar. Compared to the HDPE bottle the beverage carton systems with fossil based plastics show similar or lower environmental impacts in several categories. However impacts in 'Climate Change' are always lower for the beverage cartons.

In case of the beverage carton containing bio-based plastics, environmental impacts in the category 'Climate Change' are lower than those of cartons with fossil based plastics. However, the use of bio-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 bottles.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has a visible influence on the assessment of the environmental impacts in this segment, especially for the comparisons with the HDPE bottle.

The sensitivity analysis regarding alternative barrier material in beverage cartons shows that a substitution of aluminium foil by PE leads to lower environmental impacts in almost all categories.

## 9.2 JNSD 1000mL NETHERLANDS

In this segment, one examined beverage carton system with fossil based plastics, namely the TBA Edge 1000mL ambient shows lower or similar environmental impacts in all of the impact categories than the compared PET bottle. Compared to the glass bottle the carton shows lower impacts in all categories apart from 'Aquatic Eutrophication'.

A second, heavier beverage carton with fossil based plastics, the TPA Square 1000mL ambient, which also contains a relatively high amount of aluminium, does not show an overall favourable environmental performance than the compared PET bottle in all impact categories except ‘Climate Change’ and ‘Ozone Depletion Potential’.

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

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a very limited influence on the assessment of the environmental impacts in this segment.

## 9.3 DAIRY *189mL-500mL NETHERLANDS*

In this segment, all examined beverage carton systems show lower environmental impacts in all of the impact categories than the plastic bottles and the PP cup with which they are compared.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a very limited influence on the assessment of the environmental impacts in this segment

## 9.4 JNSD 200ml-330ml NETHERLANDS

In this segment examined beverage carton systems with fossil based plastics show lower environmental impacts in all of the examined impact categories than the compared PET bottles and lower or similar impacts than the SUP. Compared to the glass bottle the carton shows lower impacts in all categories apart from ‘Aquatic Eutrophication’.

In case of the beverage carton containing bio-based plastics (i.e TPA Square DC bb 330mL ambient), environmental impacts in the category ‘Climate Change’ are lower than those of the respective carton with fossil based plastics (i.e TPA Square DC 330mL ambient). However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. The influence of bio-based plastics is limited, though, as only a small share of plastics is bio-based. That means that also the TPA Square DC bb 330mL ambient shows lower impacts in all categories.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a limited influence on the assessment of the environmental impacts in this segment.

## 9.5 JNSD (WATER) 330ml-500ml NETHERLANDS

In this segment, examined beverage carton systems with fossil based plastics show lower environmental impacts in the category ‘Climate Change’. In the other impact categories results vary depending on the allocation factor and the categories respectively.

In case of the beverage carton containing bio-based plastics (i.e TPA Square DC bb 330mL ambient), environmental impacts in the category 'Climate Change' are lower than those of the respective carton with fossil based plastics (i.e TPA Square DC 330mL ambient), but higher in all other categories. Compared to the relatively light PET bottle, the TPA Square DC bb 330mL ambient shows higher impacts in all categories except 'Climate Change' and 'Ozone depletion potential'.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has a visible influence on many environmental impact categories in this segment.

The sensitivity analysis regarding plastic bottle weight shows that a reductions of bottle weight leads to lower environmental impacts of the bottles. A weight reduction of 10% as applied in this sensitivity analysis shows only a minor influence for the comparison with the regarded beverage carton. The only change in ranking can be seen for the category 'Aquatic Eutrophication' where the beverage carton loses its favourable result.

# 10 Results Ireland

In this section, the results of the examined packaging systems for Ireland 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/PP for bottles/cups/SUP including additives, e.g. carbon black (**'PET/HDPE/PP for bottles/cups/SUP'**)
- production and transport of liquid packaging board **('LPB')**
- production and transport of plastics and additives for beverage carton **('plastics for sleeve')**
- production and transport of aluminium & converting to foil **('aluminium foil')**
- converting processes of cartons **('converting')**
- production and transport of base materials for closures, top and label **('top, closure & label')**
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays **('transport packaging')**
- filling process including packaging handling **('filling')**
- retail of the packages from filler to the point-of-sale including cooling during transport if relevant **('distribution')**
- $CO_2$ emissions from incineration of bio-based and renewable materials **('CO2 reg. (recycling & disposal)')**; in the following also the term regenerative CO2 emissions is used
- sorting, recycling and disposal processes **('recycling & disposal')**

Secondary products (recycled materials and recovered energy) are obtained through recovery processes of used packaging materials, e.g. recycled fibres from cartons may replace primary fibres. It is assumed, that those secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental loads of the substituted material. The so-called 50% allocation method has been used for the crediting procedure (see section1.7) in the base scenarios.

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')**
- Uptake of athmospheric $CO_2$ during the plant growth phase (**'$CO_2$-uptake'**)

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
Each impact category graph includes three bars per packaging system under investigation, which illustrate (from left to right):

- sectoral results of the packaging system itself (stacked bar ‘environmental burdens’)
- credits given for secondary products leaving the system (negative stacked bar ‘credits’)
- net results as a results of the substraction of credits from overall environmental loads (grey bar ‘net results’)

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

A note on significance: 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 is common practice for LCA studies comparing different product systems. This means differences ≤ 10% are considered as insignificant.

# *10.1* Results base scenarios DAIRY 1000mL-2000mL IRELAND

## 10.1.1 Presentation of results DAIRY Ireland

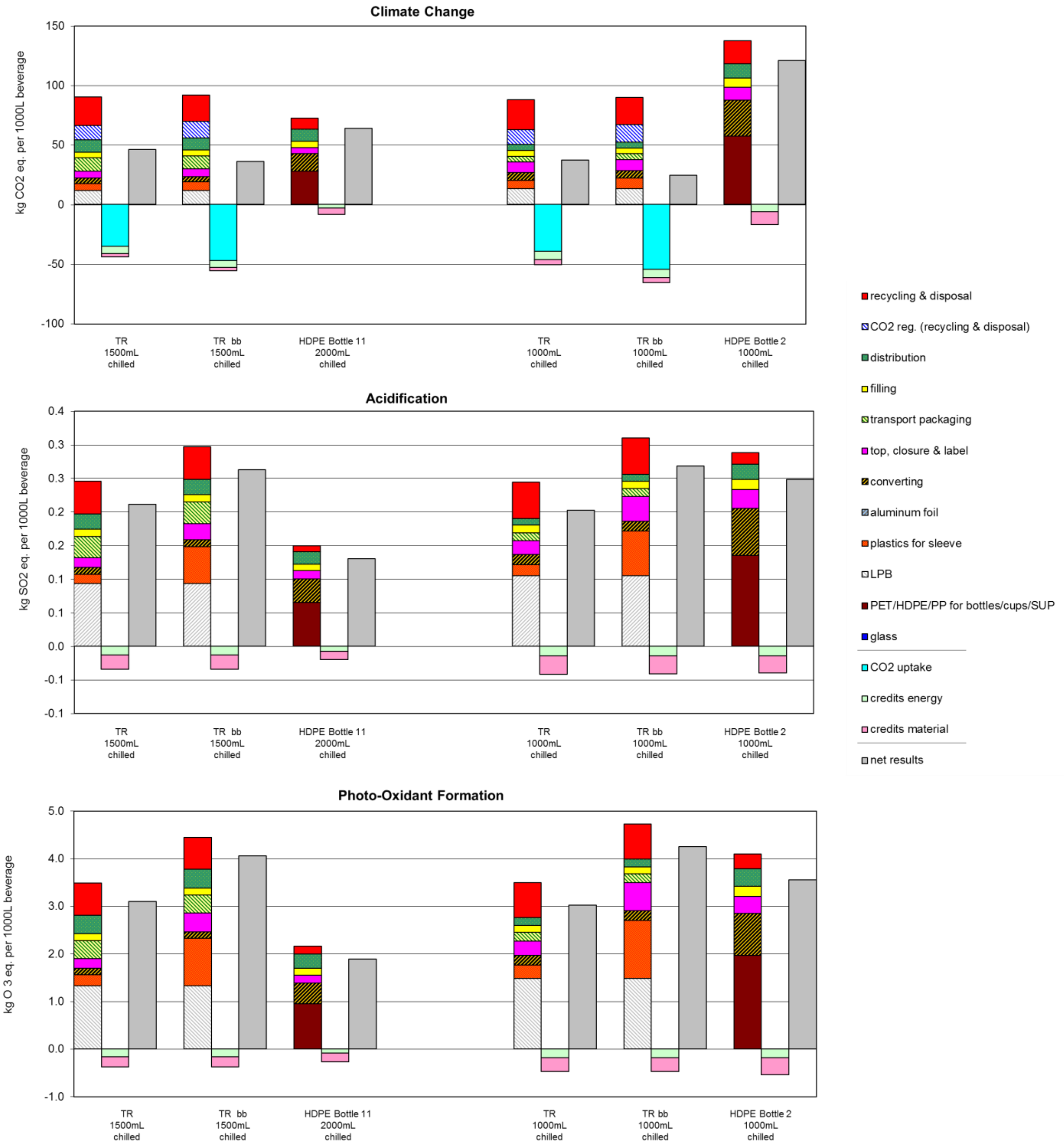



**Figure 103:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 50% (Part 1)

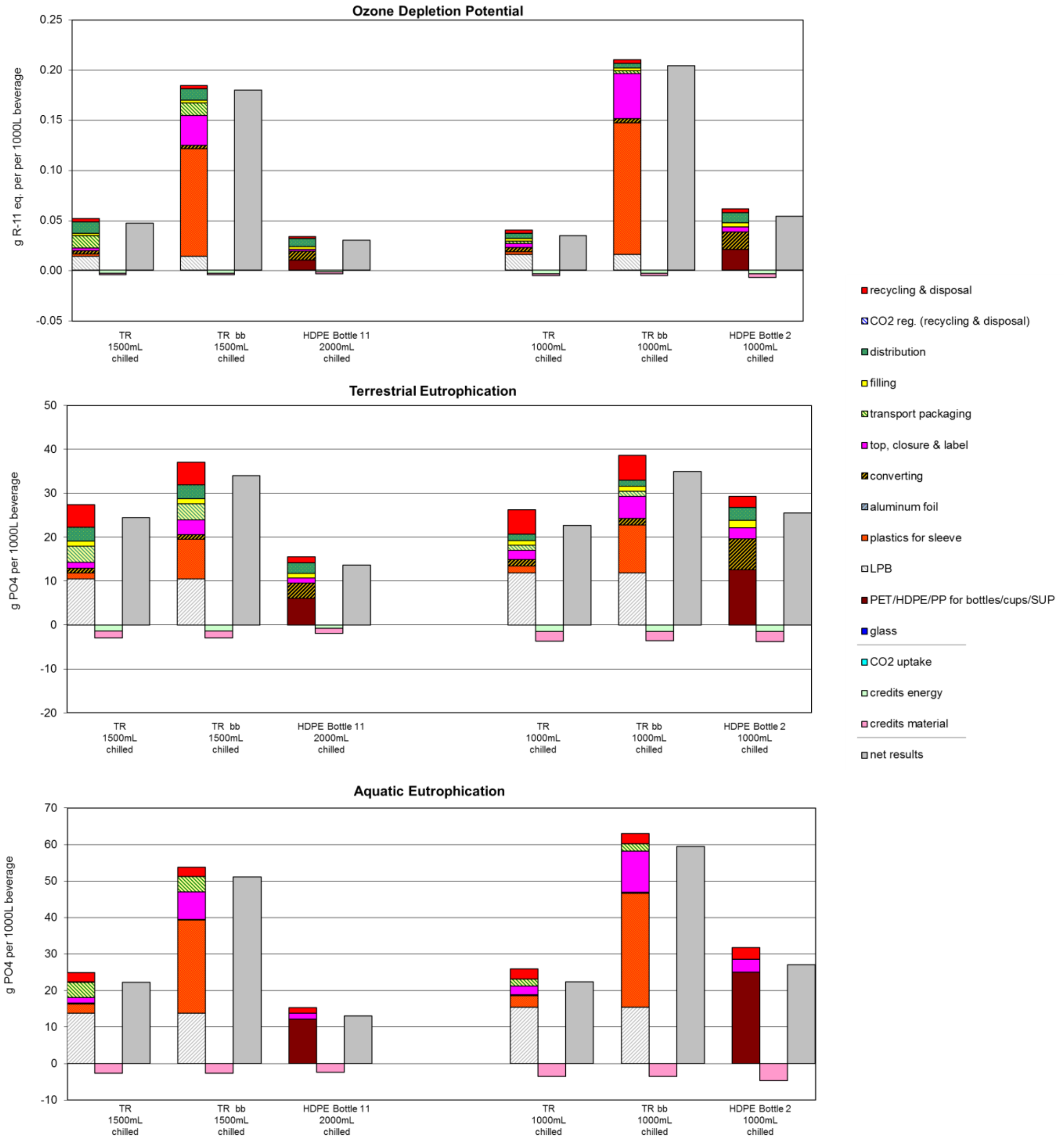



**Figure 104** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 50% (Part 2)

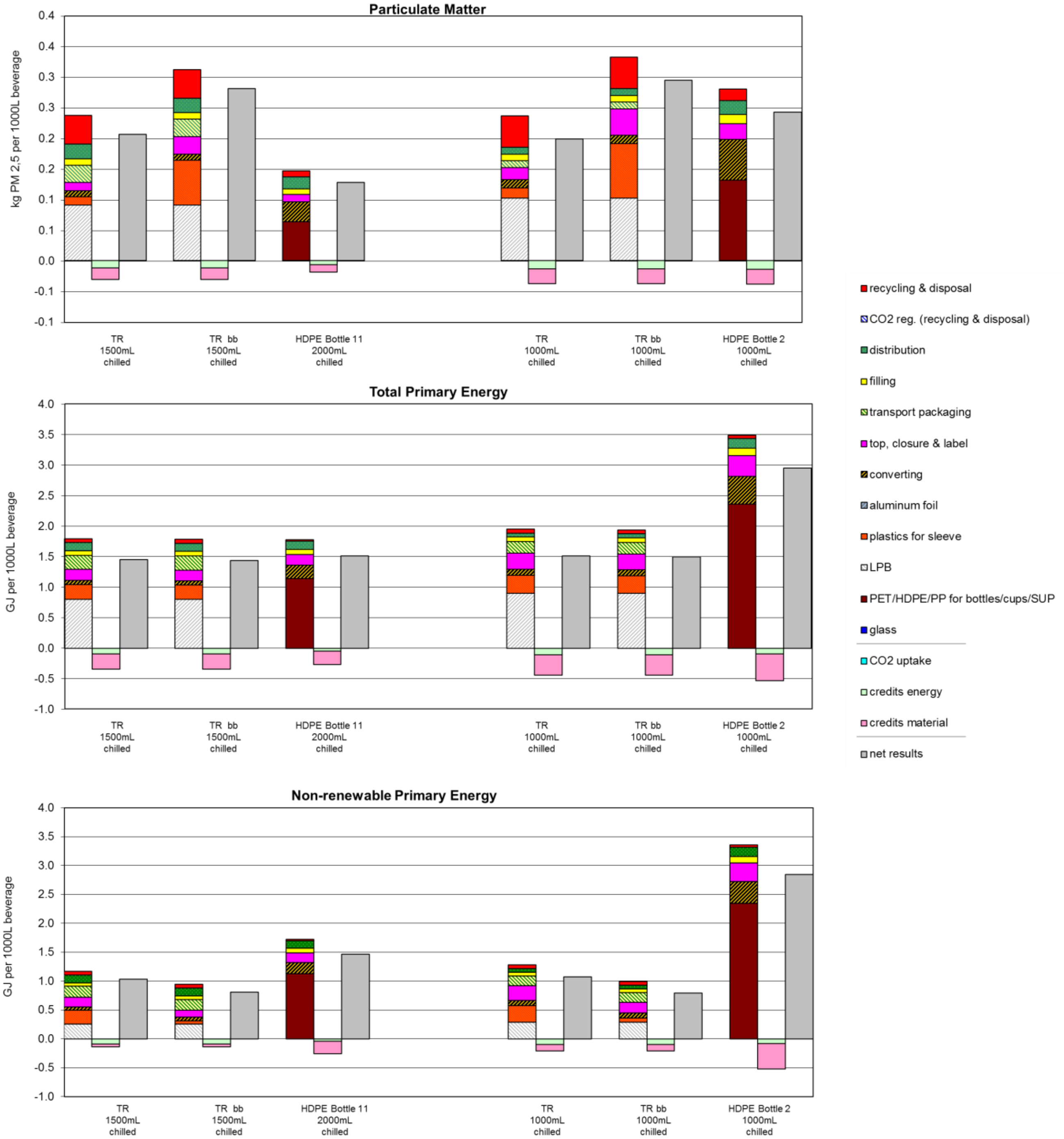



**Figure 105:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 50% (Part 3)

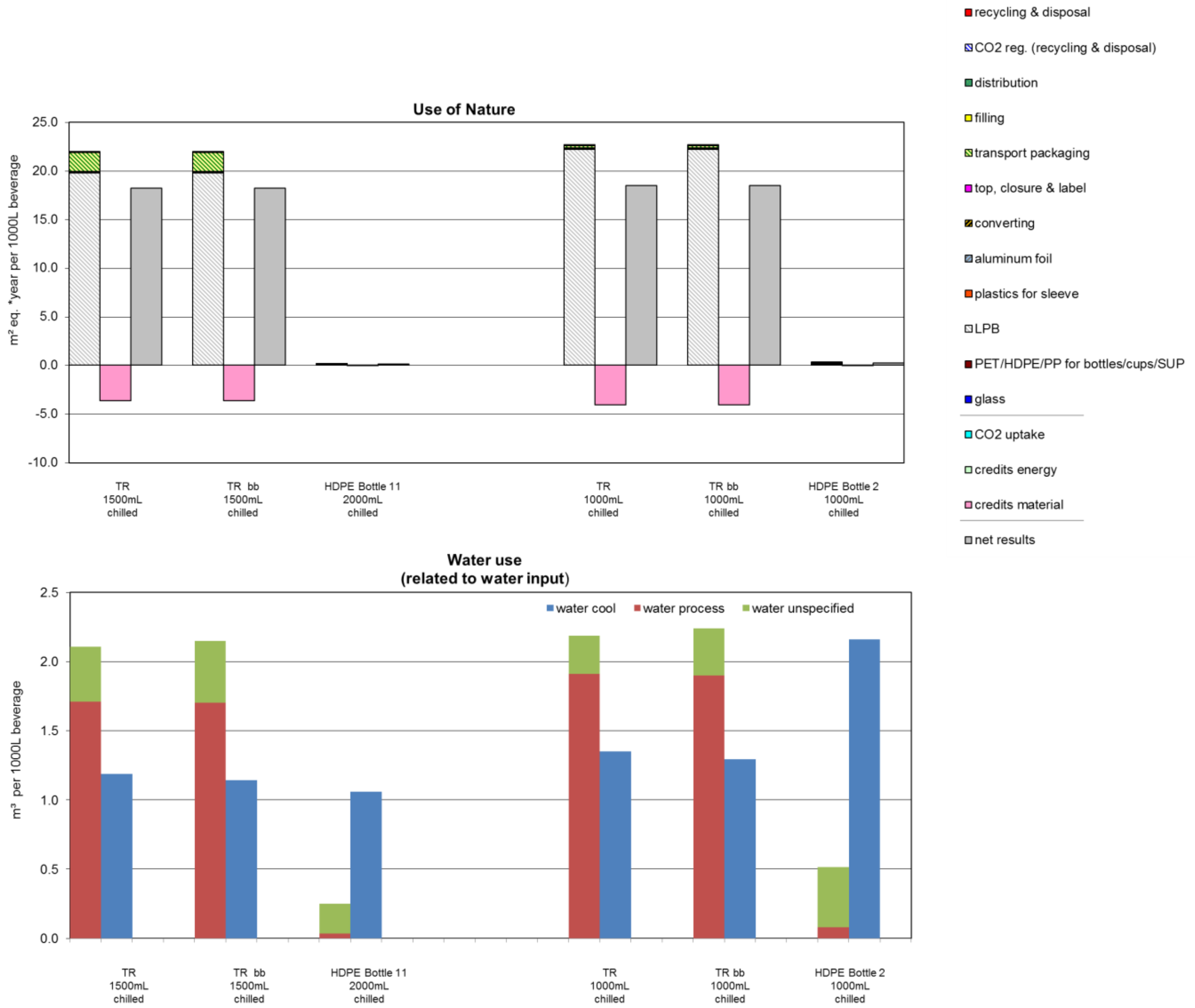



**Figure 106:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 50% (Part 4)

**Table 125:** Category indicator results per impact category for base scenarios of **segment DAIRY 1000mL-2000mL IRELAND (1500mL-2000mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TR 1500mL chilled | TR bb 1500mL chilled | HDPE Bottle 11 2000mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 77.81 | 77.80 | 72.11 |
| | CO2 (reg) | 12.30 | 13.93 | 0.00 |
| | Credits* | -8.76 | -8.75 | -8.36 |
| | $CO_2$ uptake | -35.20 | -47.02 | 0.00 |
| | Net results (∑) | 46.16 | 35.96 | 63.75 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.25 | 0.30 | 0.15 |
| | Credits* | -0.03 | -0.03 | -0.02 |
| | Net results (∑) | 0.21 | 0.26 | 0.13 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 3.48 | 4.44 | 2.15 |
| | Credits* | -0.38 | -0.38 | -0.27 |
| | Net results (∑) | 3.09 | 4.06 | 1.88 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.05 | 0.18 | 0.03 |
| | Credits* | 0.00 | 0.00 | 0.00 |
| | Net results (∑) | 0.05 | 0.18 | 0.03 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 27.40 | 37.05 | 15.55 |
| | Credits* | -2.97 | -2.96 | -1.87 |
| | Net results (∑) | 24.44 | 34.09 | 13.68 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 24.85 | 53.72 | 15.35 |
| | Credits* | -2.65 | -2.65 | -2.32 |
| | Net results (∑) | 22.20 | 51.07 | 13.03 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.24 | 0.31 | 0.15 |
| | Credits* | -0.03 | -0.03 | -0.02 |
| | Net results (∑) | 0.21 | 0.28 | 0.13 |
| Total Primary Energy [GJ] | Burdens | 1.80 | 1.79 | 1.78 |
| | Credits* | -0.35 | -0.34 | -0.26 |
| | Net results (∑) | 1.45 | 1.44 | 1.52 |
| Non-renewable primary energy [GJ] | Burdens | 1.17 | 0.94 | 1.72 |
| | Credits* | -0.13 | -0.13 | -0.26 |
| | Net results (∑) | 1.03 | 0.81 | 1.47 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 21.88 | 21.87 | 0.09 |
| | Credits* | -3.69 | -3.69 | -0.01 |
| | Net results (∑) | 18.19 | 18.18 | 0.08 |
| Water use [$m^3$] | Water cool | 1.19 | 1.14 | 1.06 |
| | Water process | 1.71 | 1.70 | 0.03 |
| | Water unspec | 0.40 | 0.45 | 0.21 |

*material and energy credits

**Table 126:** Category indicator results per impact category for base scenarios of segment **DAIRY 1000mL-2000mL IRELAND (1000mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TR 1000mL chilled | TR bb 1000mL chilled | HDPE Bottle 2 1000mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 75.08 | 75.03 | 137.42 |
| | CO2 (reg) | 12.69 | 14.77 | 0.00 |
| | Credits* | -11.08 | -11.05 | -16.83 |
| | $CO_2$ uptake | -39.44 | -54.57 | 0.00 |
| | Net results (∑) | 37.25 | 24.18 | 120.58 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.24 | 0.31 | 0.29 |
| | Credits* | -0.04 | -0.04 | -0.04 |
| | Net results (∑) | 0.20 | 0.27 | 0.25 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 3.49 | 4.72 | 4.09 |
| | Credits* | -0.48 | -0.48 | -0.54 |
| | Net results (∑) | 3.02 | 4.25 | 3.55 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.04 | 0.21 | 0.06 |
| | Credits* | -0.01 | -0.01 | -0.01 |
| | Net results (∑) | 0.03 | 0.20 | 0.05 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 26.29 | 38.63 | 29.33 |
| | Credits* | -3.60 | -3.60 | -3.77 |
| | Net results (∑) | 22.69 | 35.04 | 25.56 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 25.95 | 62.89 | 31.70 |
| | Credits* | -3.54 | -3.54 | -4.67 |
| | Net results (∑) | 22.41 | 59.35 | 27.03 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.24 | 0.33 | 0.28 |
| | Credits* | -0.04 | -0.04 | -0.04 |
| | Net results (∑) | 0.20 | 0.29 | 0.24 |
| Total Primary Energy [GJ] | Burdens | 1.95 | 1.94 | 3.49 |
| | Credits* | -0.44 | -0.44 | -0.53 |
| | Net results (∑) | 1.51 | 1.50 | 2.96 |
| Non-renewable primary energy [GJ] | Burdens | 1.28 | 0.99 | 3.35 |
| | Credits* | -0.20 | -0.20 | -0.51 |
| | Net results (∑) | 1.08 | 0.79 | 2.84 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 22.58 | 22.57 | 0.23 |
| | Credits* | -4.13 | -4.13 | -0.02 |
| | Net results (∑) | 18.45 | 18.43 | 0.22 |
| Water use [$m^3$] | Water cool | 1.35 | 1.29 | 2.16 |
| | Water process | 1.91 | 1.90 | 0.08 |
| | Water unspec | 0.28 | 0.34 | 0.44 |

*material and energy credits

### 10.1.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the DAIRY 1000mL-2000mL 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%-55%) and ‘Use of Nature’ (90%-98%). It is also relevant regarding ‘Photo-Oxidant Formation’ (30%-39%), ‘Acidification’ (31%-39%), ‘Terrestrial Eutrophication’ (29%-40%), ‘Particulate Matter’ (29%-39%) and also the consumption of ‘Total Primary Energy’ (44%-46%).

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 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 step production of ‘aluminium foil’ for the sleeves shows no results as all beverage cartons in this segment are chilled and therefore don’t contain any aluminium.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable shares of burdens (4%-63%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The exception is the inventory category ‘Non-renewable Primary Energy’, where the plastics and LPB contribute about the same for the cartons with fossil based plastics. If ‘plastics for sleeve’ contains bio-based plastics (i.e. for TR bb 1500mL chilled and TR bb 1000mL chilled), this life cycle step plays a major role for the overall burdens in all categories apart from ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The life cycle step ‘top, closure & label’ contributes to a considerable amount (5%-22%) in almost all impact categories In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TR bio-based 1500mL and TR bio-based 1000mL), the results are considerably higher than for cartons with fossil based cartons in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (max 9%). It generates emissions, which contribute mainly to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems show considerable shares of impacts (1%-27%) in all categories. Impacts are considerably lower for the TR bio-based 1000mL in all impact categories, due to the use of smaller amounts of LDPE shrink-foil as secondary instead of the higher amounts of cardboard for the other cartons in this segment.

The life cycle steps ‘filling’ and ‘distribution’ show only minor shares of burdens (max 12%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (39%-42%), ‘Photo-Oxidant Formation’ (15%-20%), ‘Terrestrial Eutrophication‘ (14%-20%), ‘Acidification’ (16%-21%) and ‘Particulate Matter’ (15%-21%). The majority of the burdens derive from MSWI. Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration and landfilling of packaging materials. The contributions to the impact categories ‘Acidification’, and ‘Terrestrial eutrophication’ are mainly caused by $NO_2$ emissions from incineration plants.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Republic of Ireland these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extent from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the Republic of Ireland the majority of the beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic HDPE bottle systems in the DAIRY 1000mL-2000mL segment, the biggest part (24%-79%) of the environmental burdens is also caused by the production of the base materials of the bottles in most impact and inventory categories.

The ‘converting’ process of all regarded bottles shows considerable shares of impacts (11%-28%) in all categories apart from ‘Aquatic Eutrophication’ with less than 1% share of impact. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows considerable shares of impacts (6%-36%) in all categories mainly attributed to the different plastics used for the closures. For the impact categories ‘Acidification’, ‘Particulate Matter’ as well as the inventory categories ‘Total Primary Energy’ and ‘Non-renewable Primary Energy’ results are higher due to the aluminium pull tab.

The production and provision of ‘transport packaging’ for the bottle systems shows no impacts in all categories due to the transport on roll containers without any other secondary or tertiary packaging material. The burdens from the production of roll containers can be neglected because of their high number of use cycles.

Due to the heavy weight of the roll containers and their smaller capacity the life cycle step ‘distribution’ shows considerable shares of burdens (up to 27%) compared to  lower minor shares of burdens the cartons transported on pallets.

The life cycle step ‘filling’ shows only small shares of burdens (max 7%) in most impact categories. Therefore this step doesn’t play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is highest regarding 'Climate Change' (13%-14%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is noticeable in most categories. With a recycling rate of 40% for plastic packaging, the received material credits are higher than the credits for energy.. The energy credits mainly originate from the incineration plants.

### 10.1.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 127:** Comparison of net results: **TR 1500mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of<br>**TR 1500mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TR 1500mL chilled | HDPE Bottle 11 2000mL chilled |
| Climate Change [kg $CO_2$eq] | 46.16 | -28% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | 57% |
| Acidification [kg $SO_2$ eq.] | 0.21 | 62% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 24.44 | 79% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 22.20 | 70% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.09 | 64% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.21 | 62% |

**Table 128:** Comparison of net results: **TR bio-based 1500mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR bb 1500mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TR bb 1500mL chilled | HDPE Bottle 11 2000mL chilled |
| Climate Change [kg $CO_2$eq] | 35.96 | -44% |
| Ozone depletion potential [g R-11 eq.] | 0.18 | 502% |
| Acidification [kg $SO_2$ eq.] | 0.26 | 102% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 34.09 | 149% |
| Aquatic Euthrophication [g $PO_4$ eq.] | 51.07 | 292% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.06 | 115% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.28 | 120% |

**Table 129:** Comparison of net results: **TR 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TR 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 37.25 | -69% |
| Ozone depletion potential [g R-11 eq.] | 0.03 | -36% |
| Acidification [kg $SO_2$ eq.] | 0.20 | -18% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 22.69 | -11% |
| Aquatic Euthrophication [g $PO_4$ eq.] | 22.41 | -17% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.02 | -15% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.20 | -18% |

**Table 130:** Comparison of net results: **TR bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR bb 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TR bb 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 24.18 | -80% |
| Ozone depletion potential [g R-11 eq.] | 0.20 | 281% |
| Acidification [kg $SO_2$ eq.] | 0.27 | 8% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.04 | 37% |
| Aquatic Euthrophication [g $PO_4$ eq.] | 59.35 | 120% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.25 | 20% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.29 | 22% |

# *10.2* Results base scenarios JNSD 1000mL IRELAND

## 10.2.1 Presentation of results

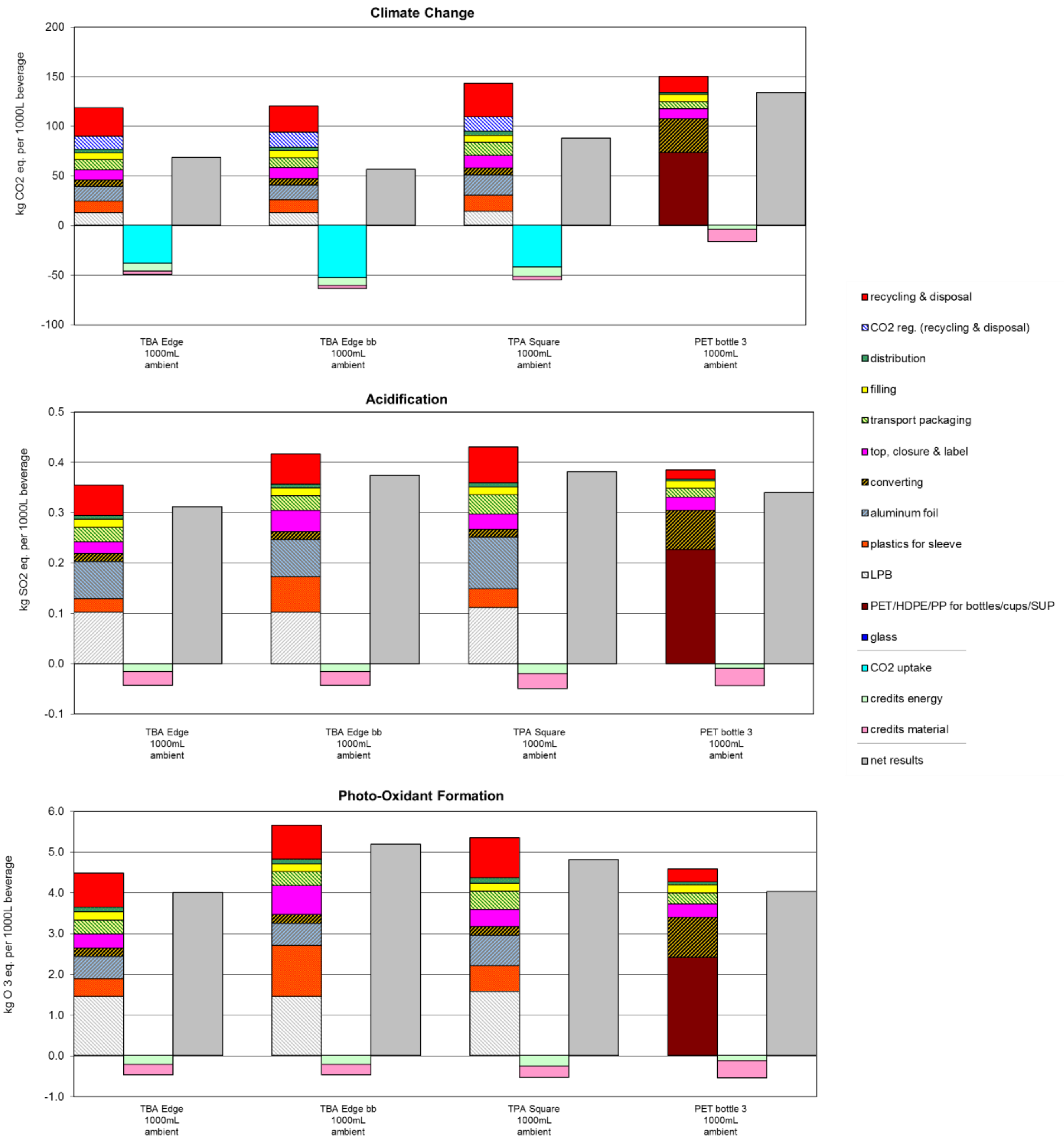



**Figure 107:** Indicator results for base scenarios of **segment JNSD 1000mL, IRELAND**, allocation factor 50% (Part 1)

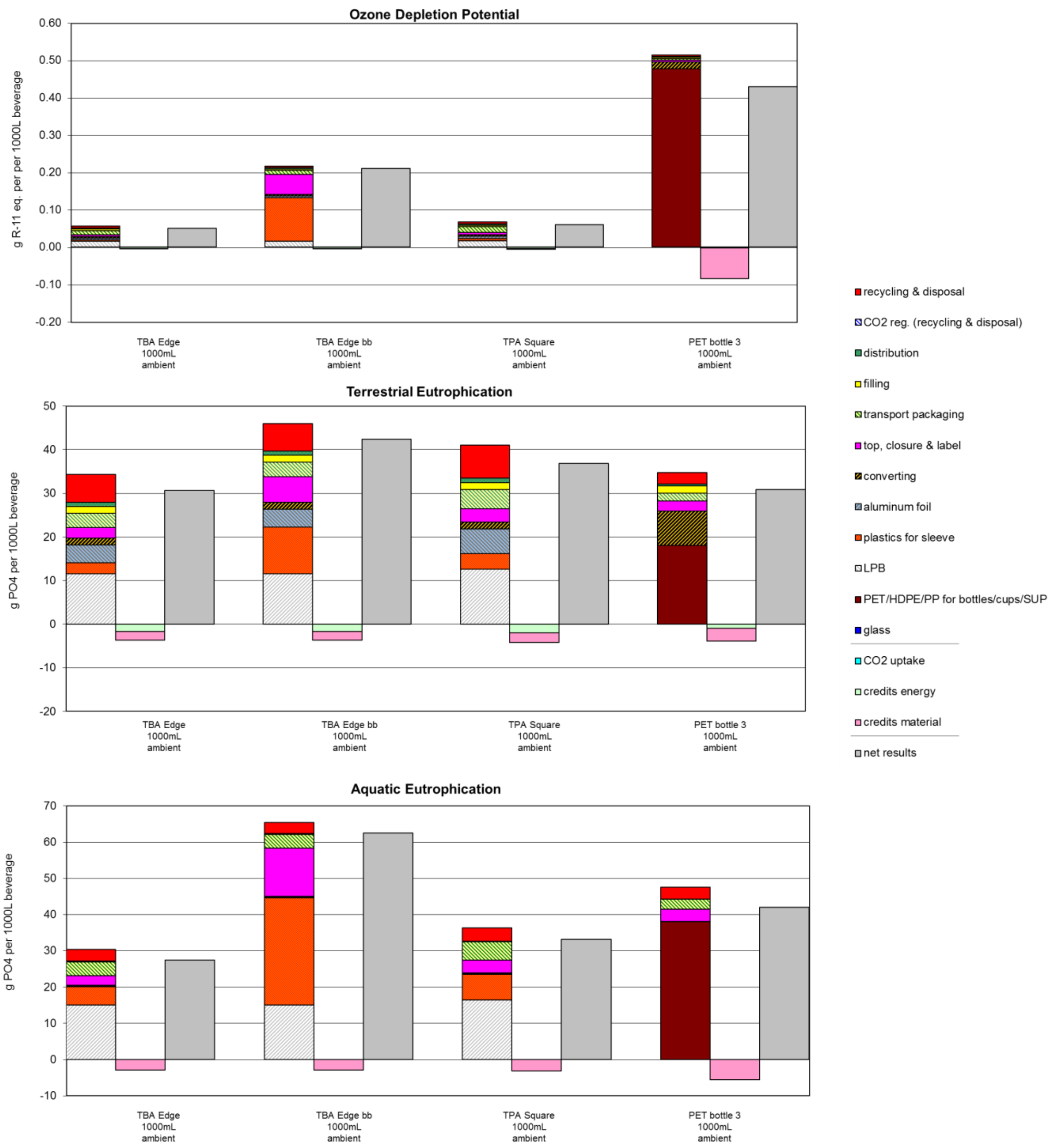



**Figure 108:** Indicator results for base scenarios of **segment JNSD 1000mL, IRELAND**, allocation factor 50% (Part 2)

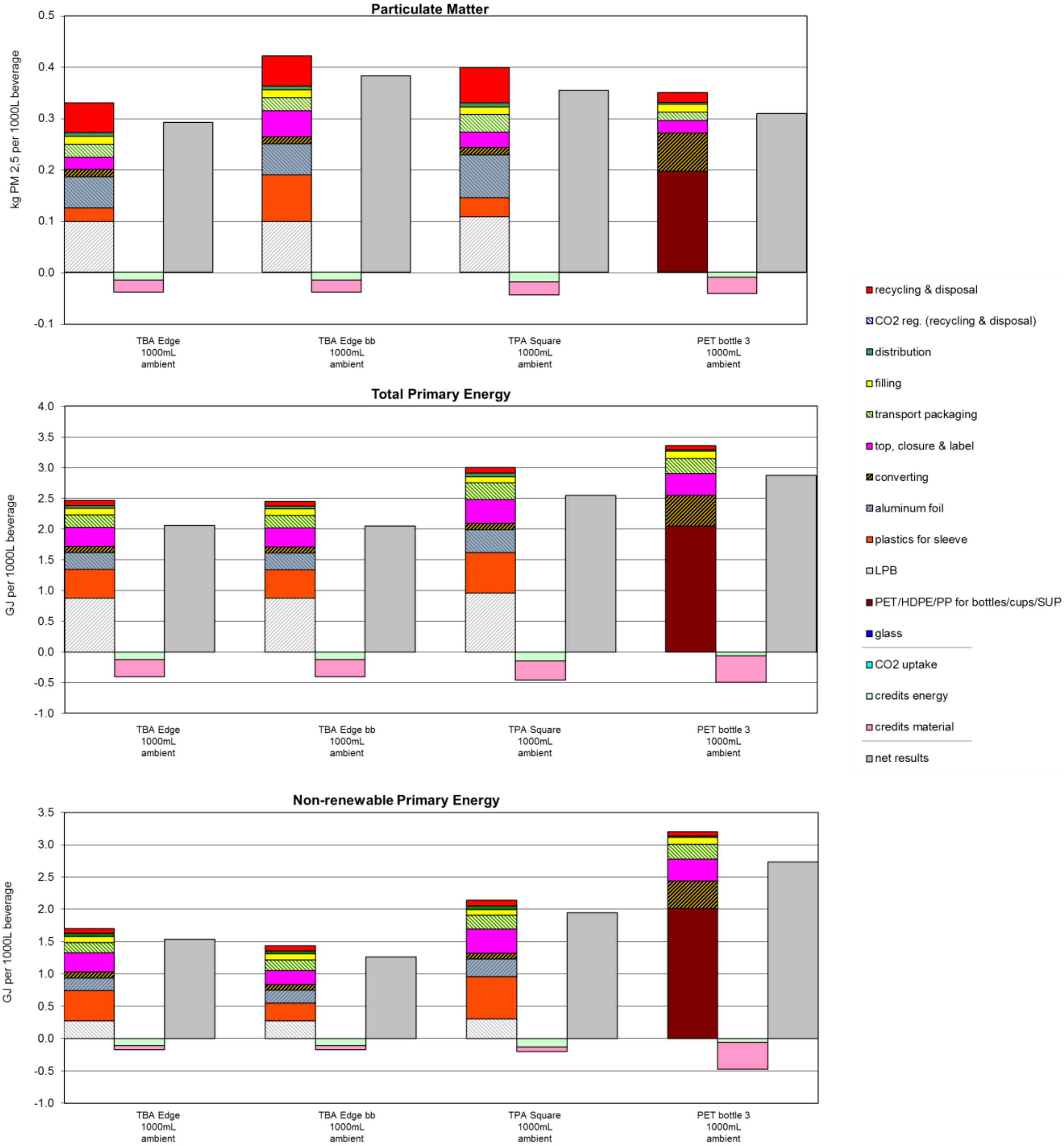
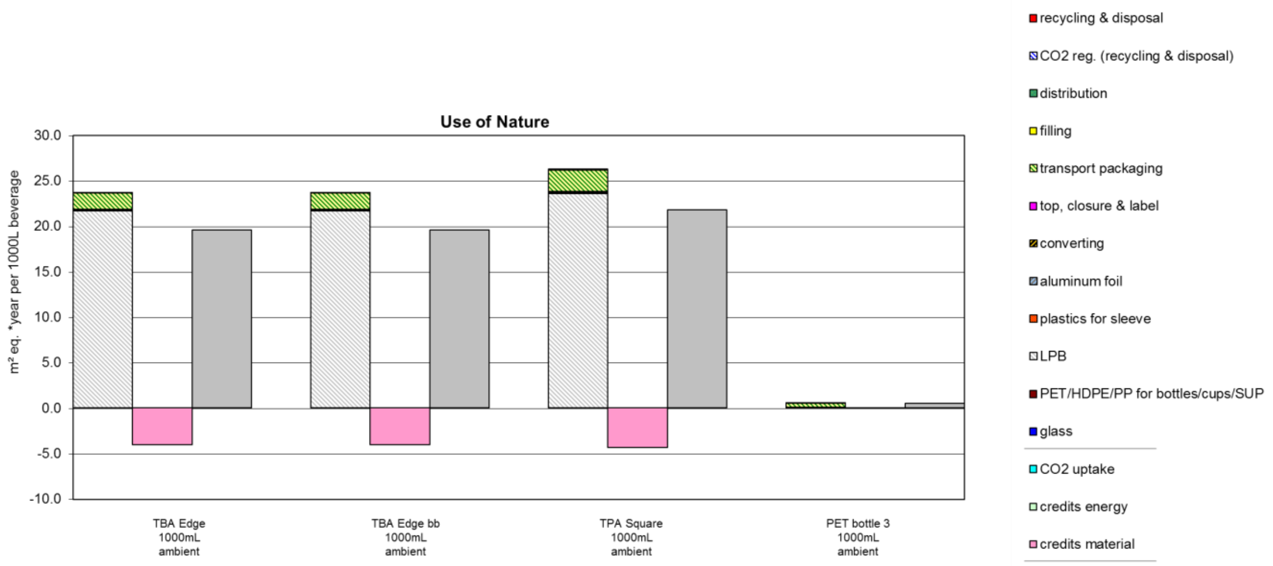



**Figure 109:** Indicator results for base scenarios of **segment JNSD 1000mL, IRELAND**, allocation factor 50% (Part 3)



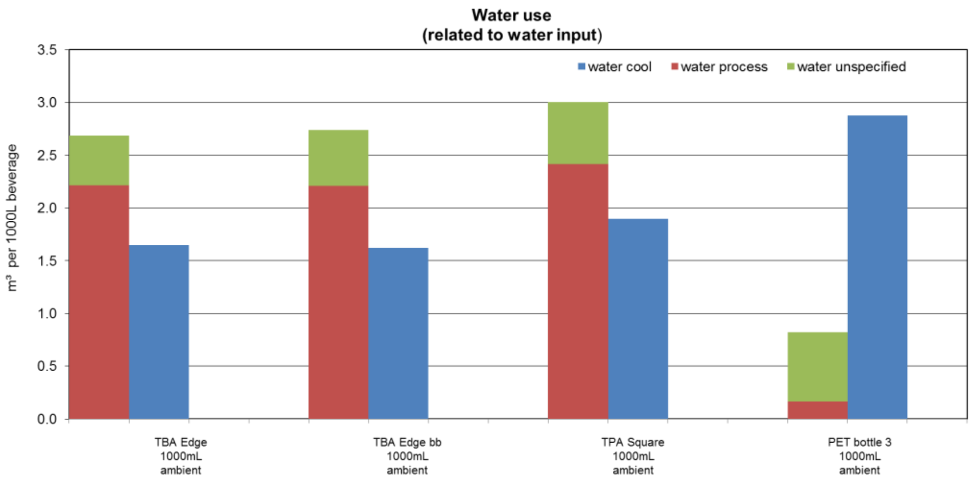




**Figure 110:** Indicator results for base scenarios of **segment JNSD 1000mL, IRELAND**, allocation factor 50% (Part 4)

**Table 131:** Category indicator results per impact category for base scenarios of segment JNSD 1000mL, IRELAND- burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TBA Edge 1000mL ambient | TBA Edge bb 1000mL ambient | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 104.98 | 105.21 | 128.24 | 150.12 |
| | CO2 (reg) | 13.19 | 15.17 | 14.60 | 0.00 |
| | Credits* | -11.16 | -11.20 | -13.29 | -16.59 |
| | $CO_2$ uptake | -38.53 | -52.85 | -41.98 | 0.00 |
| | Net results (∑) | 68.48 | 56.32 | 87.57 | 133.53 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.35 | 0.42 | 0.43 | 0.38 |
| | Credits* | -0.04 | -0.04 | -0.05 | -0.04 |
| | Net results (∑) | 0.31 | 0.37 | 0.38 | 0.34 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 4.47 | 5.65 | 5.34 | 4.58 |
| | Credits* | -0.46 | -0.47 | -0.54 | -0.55 |
| | Net results (∑) | 4.01 | 5.19 | 4.80 | 4.03 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.06 | 0.22 | 0.07 | 0.51 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.09 |
| | Net results (∑) | 0.05 | 0.21 | 0.06 | 0.43 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 34.32 | 46.05 | 41.02 | 34.76 |
| | Credits* | -3.62 | -3.63 | -4.19 | -3.88 |
| | Net results (∑) | 30.70 | 42.42 | 36.84 | 30.88 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 30.32 | 65.36 | 36.23 | 47.49 |
| | Credits* | -2.88 | -2.88 | -3.13 | -5.48 |
| | Net results (∑) | 27.44 | 62.48 | 33.10 | 42.00 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.33 | 0.42 | 0.40 | 0.35 |
| | Credits* | -0.04 | -0.04 | -0.04 | -0.04 |
| | Net results (∑) | 0.29 | 0.38 | 0.35 | 0.31 |
| Total Primary Energy [GJ] | Burdens | 2.47 | 2.46 | 3.01 | 3.37 |
| | Credits* | -0.40 | -0.40 | -0.46 | -0.49 |
| | Net results (∑) | 2.06 | 2.05 | 2.55 | 2.88 |
| Non-renewable primary energy [GJ] | Burdens | 1.70 | 1.43 | 2.14 | 3.20 |
| | Credits* | -0.17 | -0.17 | -0.20 | -0.47 |
| | Net results (∑) | 1.53 | 1.26 | 1.95 | 2.73 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 23.61 | 23.60 | 26.18 | 0.50 |
| | Credits* | -4.06 | -4.06 | -4.41 | -0.02 |
| | Net results (∑) | 19.56 | 19.55 | 21.77 | 0.48 |
| Water use [$m^3$] | Water cool | 1.65 | 1.62 | 1.90 | 2.88 |
| | Water process | 2.22 | 2.21 | 2.41 | 0.16 |
| | Water unspec | 0.47 | 0.53 | 0.59 | 0.66 |

*material and energy credits

### 10.2.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 1000mL 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' (23%-50%) and 'Use of Nature' (90%-92%). It is also relevant regarding 'Photo-Oxidant Formation' (26%-32%), 'Acidification' (25%-29%), 'Terrestrial Eutrophication' (25%-34%), 'Particulate Matter' (24%-30%) and also the consumption of 'Total Primary Energy' (32%-36%).

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 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 shows burdens in most impact categories. Considerable burdens can be seen for the categories 'Acidification' (18%-24%) and 'Particulate Matter' (14%-21%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (7%-54%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil plastics (10%-11%) and LPB (10%-11%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about 20% until 30% of the total burdens. If 'plastics for sleeve' contains bio-based plastics (i.e. for TBA Edge bio-based 1000mL ambient), this life cycle step plays a major role for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step 'top, closure & label' contributes to a considerable amount (7%-25%) in almost all impact categories. In case the plastics used for 'top, closure & label' are bio-based (i.e. TBA Edge bio-based 1000mL ambient), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (max 8%). It generates emissions, which contribute mainly to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show considerable shares of impacts (5%-23%) in all categories.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 7%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (34%-35%), 'Photo-Oxidant Formation' (15%-19%), 'Terrestrial Eutrophication' (14%-19%), 'Acidification' (15%-17%), and 'Particulate Matter' (14%-18%). Greenhouse gases are also generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by $NO_2$ emissions from incineration plants.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Republic of Ireland these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extent from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the Republic of Ireland the majority of beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 1000mL segment, the biggest part of the environmental burdens (49%-93%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production, nevertheless a considerable share of burdens derives from the production of the PA additive. The high results of ‘Ozone Depletion Potential’ are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The ‘converting’ process of all regarded bottles shows considerable shares of impacts (4%-23%) in all categories apart from ‘Aquatic Eutrophication’ with less than 1% share of impact. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows minor shares of impacts (max. 11%) in all categories mainly attributed to the plastics used for the closure.

The production and provision of ‘transport packaging’ for the bottle system shows small shares of impacts (1%-7%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 81% of the burdens. For most categories the relevant emissions derive from shrink foil production. The exception is ‘Aquatic Eutrophication’, where the emissions result from the production of paper for slipsheets.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 5%) for all bottle systems in most impact categories. Therefore none of these sectors play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is most noticeable regarding 'Climate Change' (11%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. With a recycling rate of 40% for plastic packaging, the received material credits are higher than the credits for. The energy credits mainly originate from the incineration plants.

### 10.2.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 132:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, IRELAND**

| The net results of<br>**TBA Edge 1000 JNSD, Gut…** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 68.48 | -49% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -88% |
| Acidification [kg $SO_2$ eq.] | 0.31 | -8% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 30.70 | -1% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 27.44 | -35% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.01 | -1% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.29 | -6% |

**Table 133:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, IRELAND**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 56.32 | -58% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -51% |
| Acidification [kg $SO_2$ eq.] | 0.37 | 10% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 42.42 | 37% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 62.48 | 49% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.19 | 29% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.38 | 24% |

**Table 134:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, IRELAND**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 87.57 | -34% |
| Ozone depletion potential [g R-11 eq.] | 0.06 | -86% |
| Acidification [kg $SO_2$ eq.] | 0.38 | 12% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.84 | 19% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 33.10 | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.80 | 19% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.35 | 15% |

# *10.3* Results base scenarios Dairy *189mL-500mL IRELAND*

## 10.3.1 Presentation of results

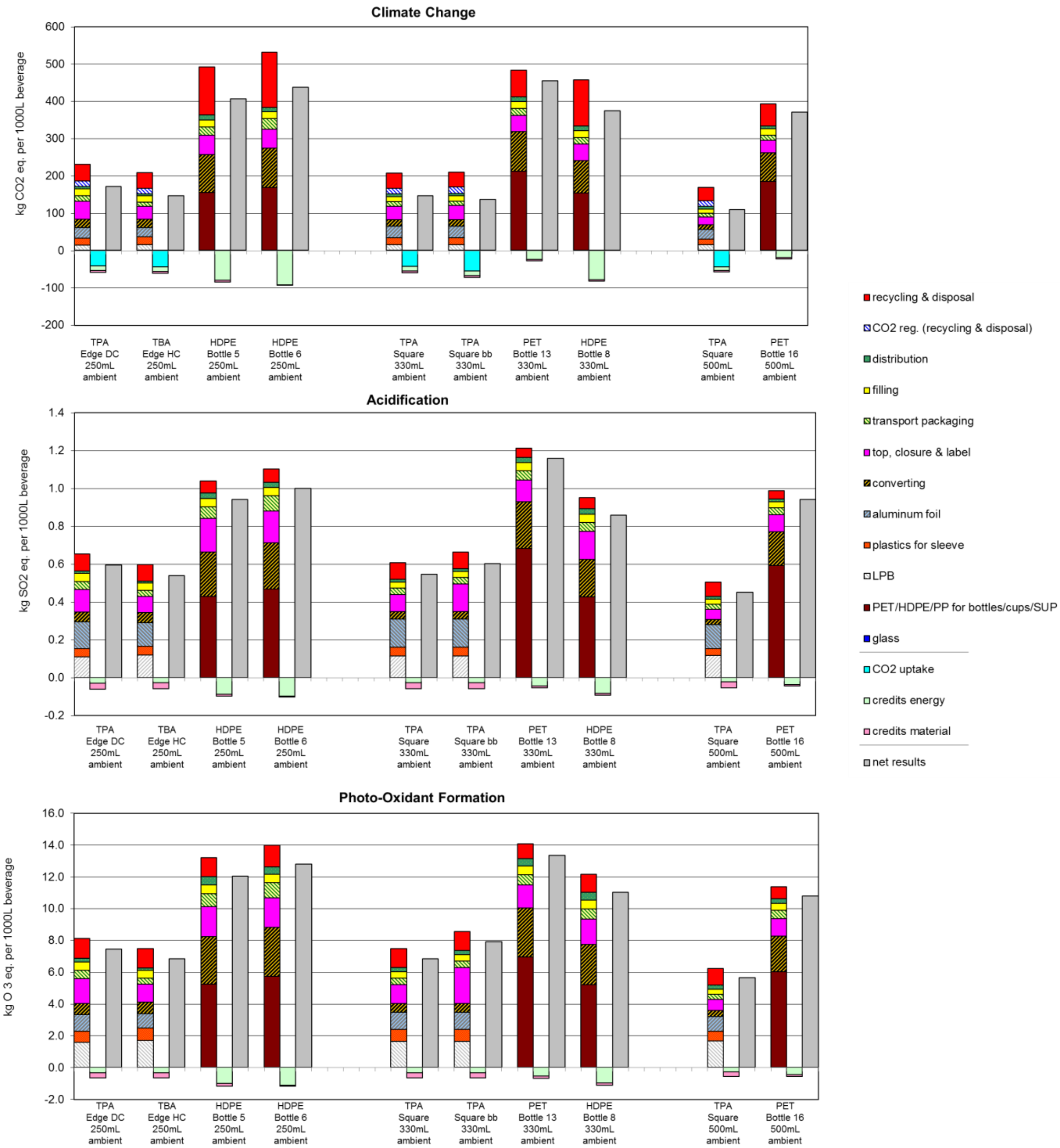



**Figure 111:** Indicator results for base scenarios of **segment Dairy 189mL-500mL IRELAND**, allocation factor 50% (Part 1)

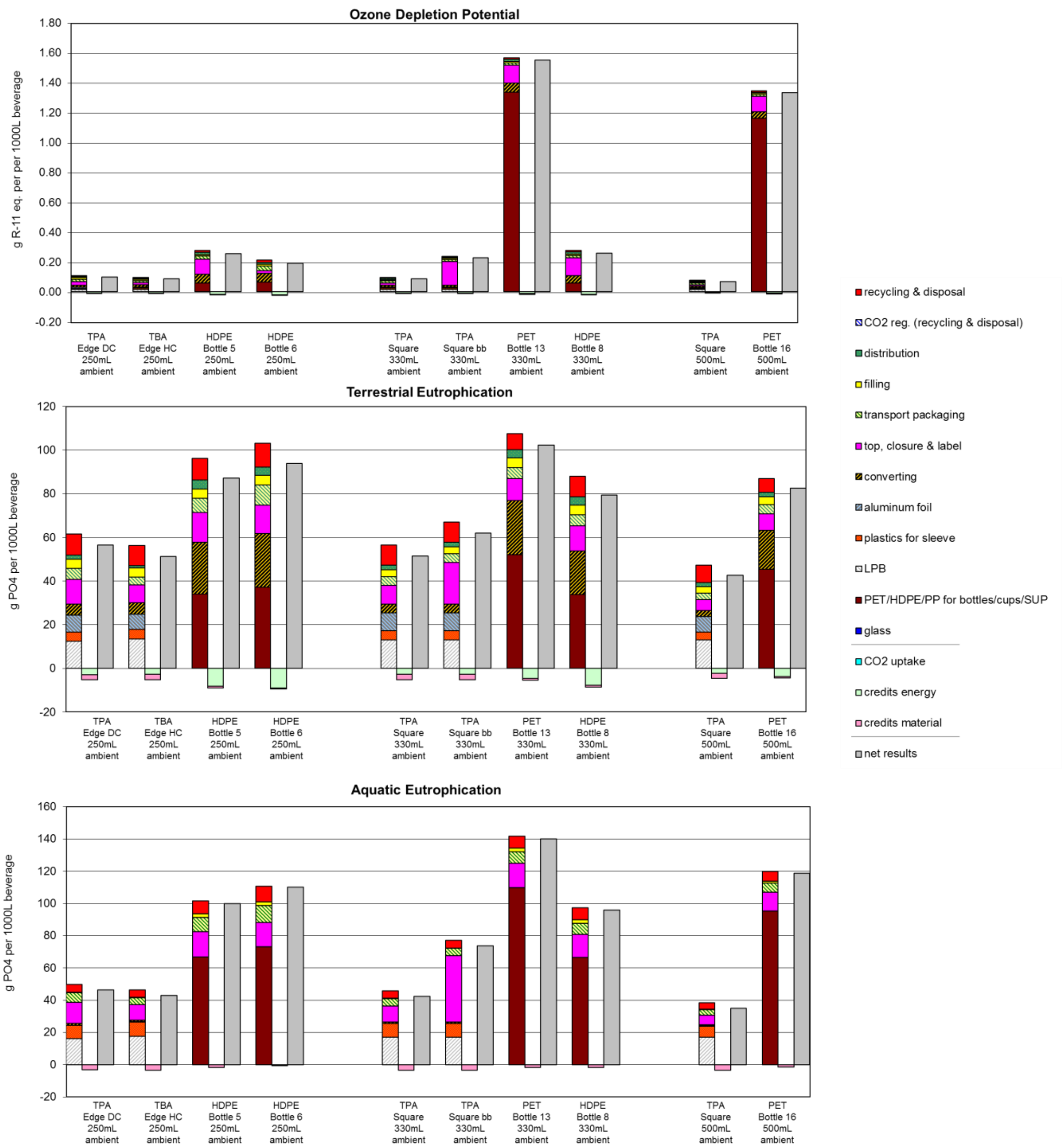



**Figure 112:** Indicator results for base scenarios of **segment Dairy 189mL-500mL IRELAND**, allocation factor 50% (Part 2)

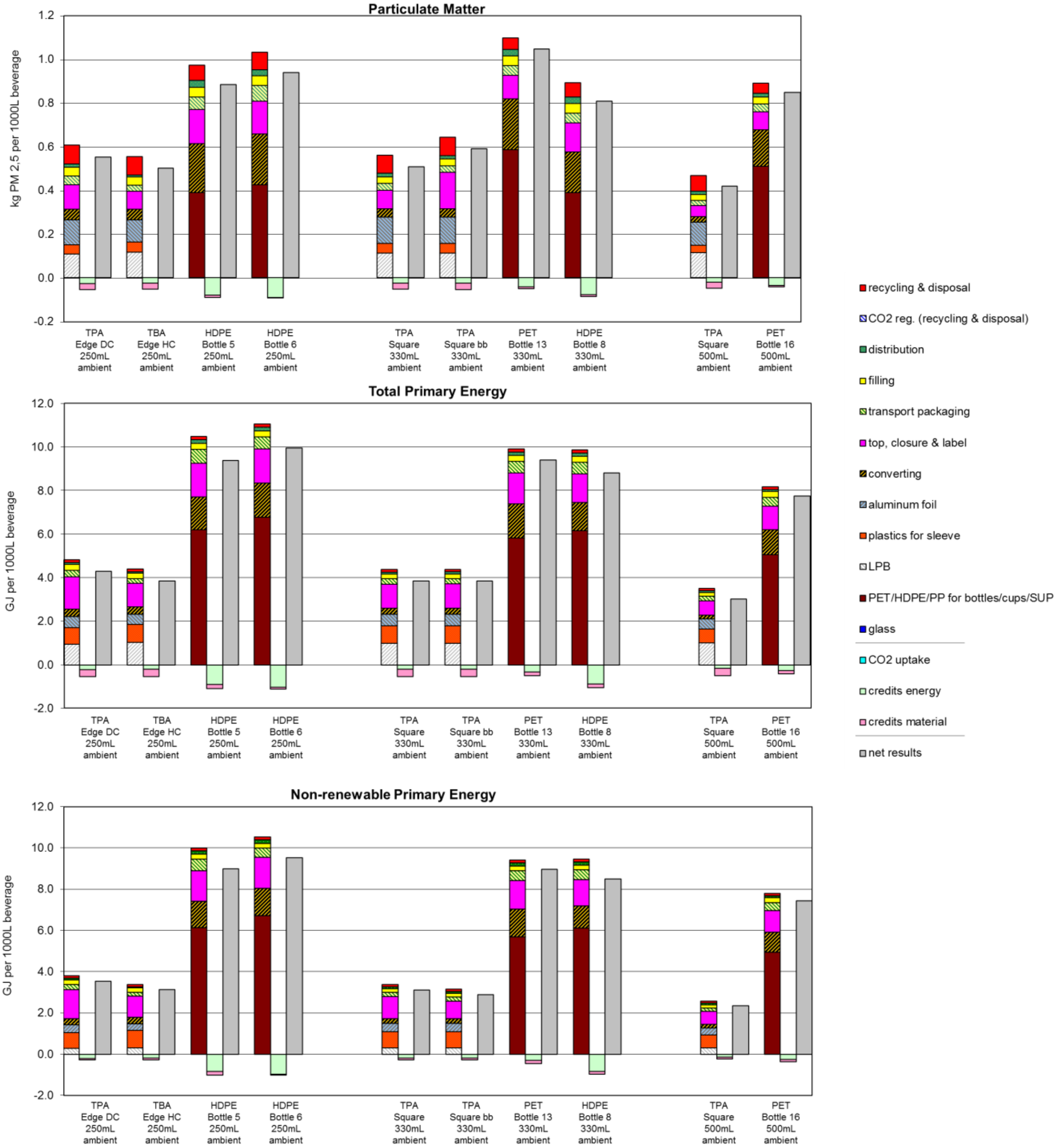
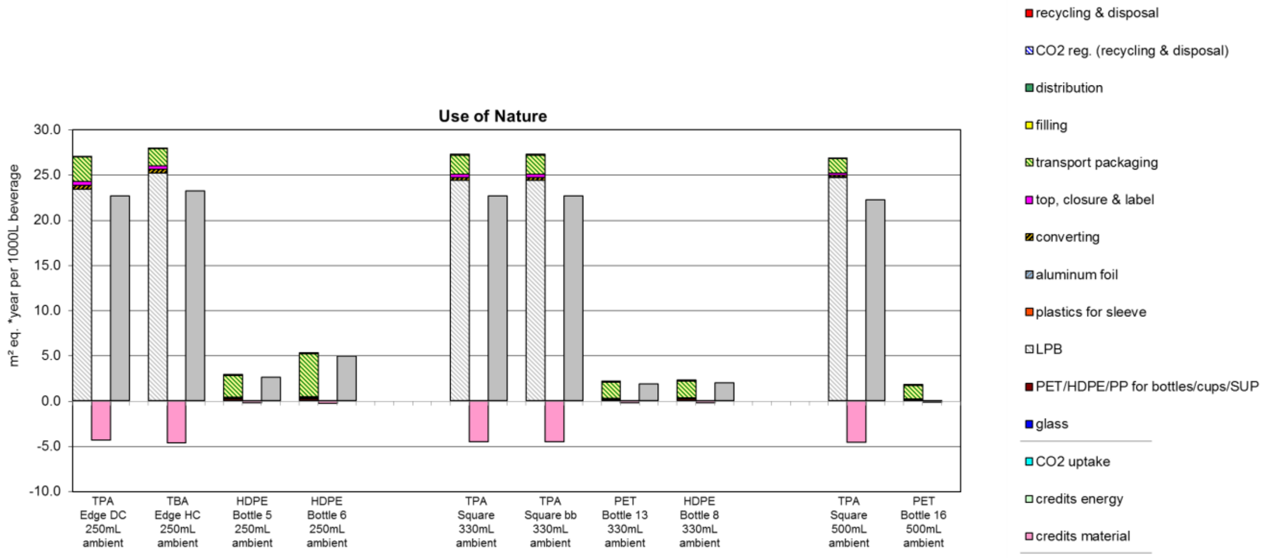



**Figure 113:** Indicator results for base scenarios of **segment Dairy 189mL-500mL IRELAND**, allocation factor 50% (Part 3)



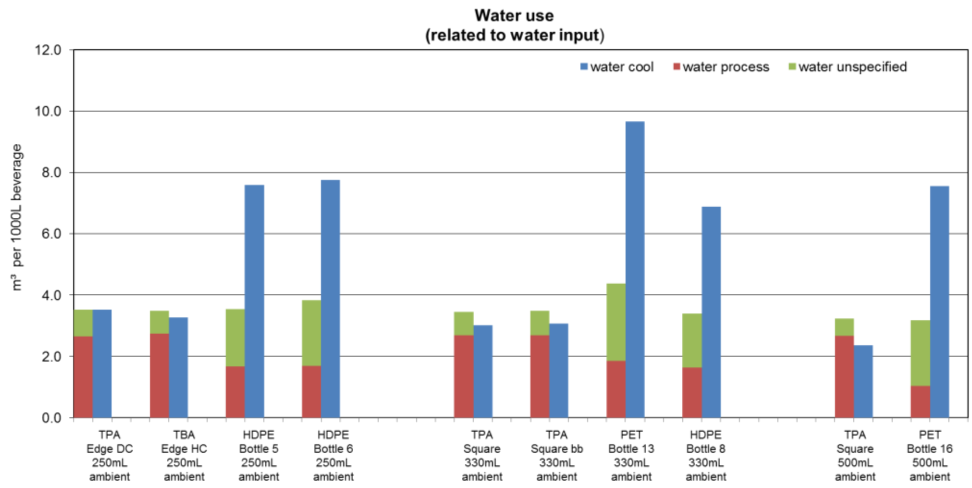




**Figure 114:** Indicator results for base scenarios of **segment Dairy 189mL-500mL IRELAND**, allocation factor 50% (Part 4)

**Table 135:** Category indicator results per impact category for base scenarios of **segment Dairy 189mL-500mL IRELAND (250mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | TBA Edge HC 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 215.00 | 192.51 | 490.54 | 530.19 |
| | CO2 (reg) | 14.92 | 15.42 | 0.00 | 0.00 |
| | Credits* | -17.96 | -17.02 | -85.06 | -93.76 |
| | $CO_2$ uptake | -41.61 | -44.82 | 0.00 | 0.00 |
| | Net results (∑) | 170.35 | 146.08 | 405.47 | 436.43 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.65 | 0.60 | 1.04 | 1.10 |
| | Credits* | -0.06 | -0.06 | -0.10 | -0.10 |
| | Net results (∑) | 0.59 | 0.54 | 0.94 | 1.00 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 8.10 | 7.47 | 13.19 | 13.97 |
| | Credits* | -0.67 | -0.65 | -1.17 | -1.18 |
| | Net results (∑) | 7.44 | 6.82 | 12.01 | 12.79 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.09 | 0.28 | 0.21 |
| | Credits* | -0.01 | -0.01 | -0.02 | -0.02 |
| | Net results (∑) | 0.10 | 0.09 | 0.26 | 0.19 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 61.68 | 56.45 | 96.27 | 103.27 |
| | Credits* | -5.18 | -5.07 | -8.97 | -9.32 |
| | Net results (∑) | 56.50 | 51.38 | 87.31 | 93.95 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 49.59 | 46.27 | 101.49 | 110.46 |
| | Credits* | -3.22 | -3.40 | -1.83 | -0.51 |
| | Net results (∑) | 46.37 | 42.87 | 99.66 | 109.95 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.61 | 0.55 | 0.97 | 1.03 |
| | Credits* | -0.05 | -0.05 | -0.09 | -0.09 |
| | Net results (∑) | 0.55 | 0.50 | 0.88 | 0.94 |
| Total Primary Energy [GJ] | Burdens | 4.83 | 4.40 | 10.48 | 11.07 |
| | Credits* | -0.54 | -0.54 | -1.10 | -1.10 |
| | Net results (∑) | 4.29 | 3.86 | 9.38 | 9.97 |
| Non-renewable primary energy [GJ] | Burdens | 3.82 | 3.39 | 9.99 | 10.52 |
| | Credits* | -0.27 | -0.26 | -1.00 | -1.00 |
| | Net results (∑) | 3.55 | 3.13 | 8.98 | 9.52 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.96 | 27.87 | 2.83 | 5.23 |
| | Credits* | -4.37 | -4.69 | -0.28 | -0.31 |
| | Net results (∑) | 22.60 | 23.17 | 2.56 | 4.92 |
| Water use [$m^3$] | Water cool | 3.52 | 3.27 | 7.59 | 7.75 |
| | Water process | 2.65 | 2.74 | 1.68 | 1.69 |
| | Water unspec | 0.87 | 0.75 | 1.87 | 2.14 |

*material and energy credits

**Table 136:** Category indicator results per impact category for base scenarios of **segment Dairy 189mL-500mL IRELAND (330mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 191.67 | 192.34 | 482.30 | 456.32 |
| | CO2 (reg) | 15.09 | 16.94 | 0.00 | 0.00 |
| | Credits* | -17.14 | -17.19 | -28.80 | -83.12 |
| | $CO_2$ uptake | -43.35 | -55.98 | 0.00 | 0.00 |
| | Net results (∑) | 146.27 | 136.11 | 453.49 | 373.19 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.61 | 0.66 | 1.21 | 0.95 |
| | Credits* | -0.06 | -0.06 | -0.05 | -0.09 |
| | Net results (∑) | 0.55 | 0.60 | 1.16 | 0.86 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.46 | 8.55 | 14.04 | 12.13 |
| | Credits* | -0.65 | -0.65 | -0.70 | -1.12 |
| | Net results (∑) | 6.81 | 7.90 | 13.34 | 11.02 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.24 | 1.57 | 0.28 |
| | Credits* | -0.01 | -0.01 | -0.02 | -0.02 |
| | Net results (∑) | 0.09 | 0.23 | 1.55 | 0.26 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 56.62 | 67.10 | 107.70 | 88.04 |
| | Credits* | -5.06 | -5.07 | -5.30 | -8.56 |
| | Net results (∑) | 51.57 | 62.03 | 102.40 | 79.48 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.78 | 76.87 | 141.40 | 97.30 |
| | Credits* | -3.31 | -3.31 | -1.62 | -1.60 |
| | Net results (∑) | 42.47 | 73.56 | 139.78 | 95.70 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.56 | 0.64 | 1.10 | 0.89 |
| | Credits* | -0.05 | -0.05 | -0.05 | -0.09 |
| | Net results (∑) | 0.51 | 0.59 | 1.05 | 0.81 |
| Total Primary Energy [GJ] | Burdens | 4.38 | 4.39 | 9.92 | 9.87 |
| | Credits* | -0.53 | -0.53 | -0.50 | -1.06 |
| | Net results (∑) | 3.84 | 3.85 | 9.41 | 8.82 |
| Non-renewable primary energy [GJ] | Burdens | 3.38 | 3.16 | 9.40 | 9.44 |
| | Credits* | -0.26 | -0.26 | -0.44 | -0.96 |
| | Net results (∑) | 3.12 | 2.90 | 8.96 | 8.48 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.16 | 27.16 | 2.12 | 2.21 |
| | Credits* | -4.55 | -4.55 | -0.27 | -0.27 |
| | Net results (∑) | 22.62 | 22.61 | 1.85 | 1.94 |
| Water use [$m^3$] | Water cool | 3.02 | 3.07 | 9.67 | 6.89 |
| | Water process | 2.69 | 2.69 | 1.85 | 1.64 |
| | Water unspec | 0.75 | 0.81 | 2.53 | 1.77 |

*material and energy credits

**Table 137:** Category indicator results per impact category for base scenarios of **segment Dairy 189mL-500mL IRELAND (500mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 500mL ambient | PET Bottle 16 500mL ambient |
|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 152.75 | 392.62 |
| | CO2 (reg) | 14.94 | 0.00 |
| | Credits* | -14.65 | -23.10 |
| | $CO_2$ uptake | -43.99 | 0.00 |
| | Net results (∑) | 109.05 | 369.52 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.51 | 0.99 |
| | Credits* | -0.05 | -0.05 |
| | Net results (∑) | 0.45 | 0.94 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.21 | 11.37 |
| | Credits* | -0.58 | -0.58 |
| | Net results (∑) | 5.63 | 10.78 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.08 | 1.35 |
| | Credits* | -0.01 | -0.01 |
| | Net results (∑) | 0.07 | 1.33 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 47.37 | 87.04 |
| | Credits* | -4.55 | -4.40 |
| | Net results (∑) | 42.82 | 82.63 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 38.27 | 119.78 |
| | Credits* | -3.32 | -1.33 |
| | Net results (∑) | 34.95 | 118.45 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.47 | 0.89 |
| | Credits* | -0.05 | -0.04 |
| | Net results (∑) | 0.42 | 0.85 |
| Total Primary Energy [GJ] | Burdens | 3.51 | 8.18 |
| | Credits* | -0.49 | -0.41 |
| | Net results (∑) | 3.02 | 7.77 |
| Non-renewable primary energy [GJ] | Burdens | 2.57 | 7.78 |
| | Credits* | -0.22 | -0.35 |
| | Net results (∑) | 2.35 | 7.43 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.78 | 1.70 |
| | Credits* | -4.62 | -0.23 |
| | Net results (∑) | 22.16 | 1.48 |
| Water use [$m^3$] | Water cool | 2.37 | 7.56 |
| | Water process | 2.66 | 1.03 |
| | Water unspec | 0.58 | 2.14 |

*material and energy credits

**Description and interpretation**

**Beverage carton systems** (specifications see section 2.2.1)

For all beverage carton systems regarded in the DAIRY 189mL-500mL 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’ (22%-45%) and ‘Use of Nature’ (87%-92%). It is also relevant regarding ‘Photo-Oxidant Formation’ (19%-27%), ‘Acidification’ (17%-23%), ‘Terrestrial Eutrophication’ (19%-28%), ‘Particulate Matter’ (17%-24%) and also the consumption of ‘Total Primary Energy’ (20%-29%).

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 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 beverage cartons for ambient milk consist of an additional layer of aluminium foil. The production of ‘aluminium foil’ for the sleeves shows burdens in most impact categories. High burdens can be seen for the categories ‘Acidification’ (21%-25%) and ‘Particulate Matter’ (18%-22%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable shares of burdens (3%-25%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the fossil plastics (8%-10%) and LPB (6%-9%) contribute about the same and the inventory category ‘Non-renewable Primary

Energy’, where the plastics make up about 20% until 25% of the total burdens. If ‘plastics for sleeve’ contains bio-based plastics (i.e. for TPA Square bio-based 330mL ambient), this life cycle step plays a major role for the overall burdens in all categories apart from ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The life cycle step ‘top, closure & label’ contributes for the 250mL-330mL beverage cartons considerably (14%-67%) to almost all impact categories due to the heavy closures in comparison to the weight of the sleeve materials. For the 500mL beverage carton the burdens of ‘top, closure & label’ play a minor role (11%-25%) due to the small weight of the closure compared to the sleeve. In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TPA Square bio-based 330mL ambient), the results are higher in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (1%-14%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems show minor shares of impacts (5%-16%) in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max 10%) for all beverage carton systems in most impact categories. Therefore none of these life cycle steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (26%-30%), ‘Photo-Oxidant Formation’ (14%-17%), ‘Terrestrial Eutrophication‘ (14%-17%), ‘Acidification’ (13%-15%), and ‘Particulate Matter’ (13%-16%). 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. The contributions to the impact categories ‘Acidification’, and ‘Terrestrial eutrophication’ are mainly caused by $NO_2$ emissions from incineration plants.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Republic of Ireland these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in incineration plants and to a minor extent from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the Republic of Ireland the majority of beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Together, energy and material credits play an important role on the net results in all categories apart from ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic bottle systems in the DAIRY 189mL-500mL segment, the biggest part (21%-86%) of the environmental burdens is also caused by the production of the base materials of the bottles in most impact and inventory categories. This is true for PET and HDPE bottles.

Differences can be observed depending on the kind of plastic used, though. For most impact categories the burdens from plastic production (life cycle step ‘PET/HDPE/PP for bottles/cups/SUP’ in the graphs) are higher for the HDPE bottle than for the PET bottle with the exception of ‘Ozone Depletion Potential’ where fossil-based HDPE shows a comparatively low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

The ‘converting’ process of all regarded bottles shows considerable shares of impacts (3%-28%) in all categories apart from ‘Aquatic Eutrophication’ with less than 1% share of impact. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows considerable shares of impacts (8%-43%) in most categories mainly attributed to the different closures. Higher burdens especially in the categories ‘Acidification’ and Particulate Matter’ can be seen the HDPE bottles of this segment due to the additional aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems show minor shares of impacts (1%-15%) in all categories except of 'Use of Nature' in which the paper production contributes to 82%-91% of the burdens.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 6%) for all bottle systems in most impact categories. Therefore none of these sectors play an important role for the overall results in any category.

The impact of the fossil-based plastic bottles' 'recycling & disposal' life cycle step is highest regarding 'Climate Change' (15%-28%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. For the collected white opaque bottles no primary granulate is credited as they are incinerated in MSWIs, the received material credits for this bottle are inconsiderable compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

### 10.3.2 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 138:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 170.36 | -58% | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -61% | -48% |
| Acidification [kg $SO_2$ eq.] | 0.59 | -37% | -41% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 56.50 | -35% | -40% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 46.37 | -53% | -58% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.44 | -38% | -42% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.55 | -37% | -41% |

**Table 139:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TBA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TBA Edge HC 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 146.08 | -64% | -67% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -67% | -55% |
| Acidification [kg $SO_2$ eq.] | 0.54 | -43% | -46% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.38 | -41% | -45% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.87 | -57% | -61% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.82 | -43% | -47% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.50 | -43% | -47% |

**Table 140:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 146.27 | -68% | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -94% | -67% |
| Acidification [kg $SO_2$ eq.] | 0.55 | -53% | -36% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.57 | -50% | -35% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.47 | -70% | -56% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.81 | -49% | -38% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.51 | -51% | -37% |

**Table 141:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 136.11 | -70% | -64% |
| Ozone depletion potential [g R-11 eq.] | 0.23 | -85% | -12% |
| Acidification [kg $SO_2$ eq.] | 0.60 | -48% | -30% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 62.03 | -39% | -22% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 73.56 | -47% | -23% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.90 | -41% | -28% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.59 | -44% | -27% |

**Table 142:** Comparison of net results: **TPA Square 500mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of<br>**TPA Square 500mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square 500mL ambient | PET Bottle 16 500mL ambient |
| Climate Change [kg $CO_2$eq] | 109.05 | -70% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -95% |
| Acidification [kg $SO_2$ eq.] | 0.45 | -52% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 42.82 | -48% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 34.95 | -70% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.63 | -48% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.42 | -50% |

# *10.4* Results base scenarios DAIRY (CREAM) *300mL-330mL IRELAND*

## 10.4.1 Presentation of results

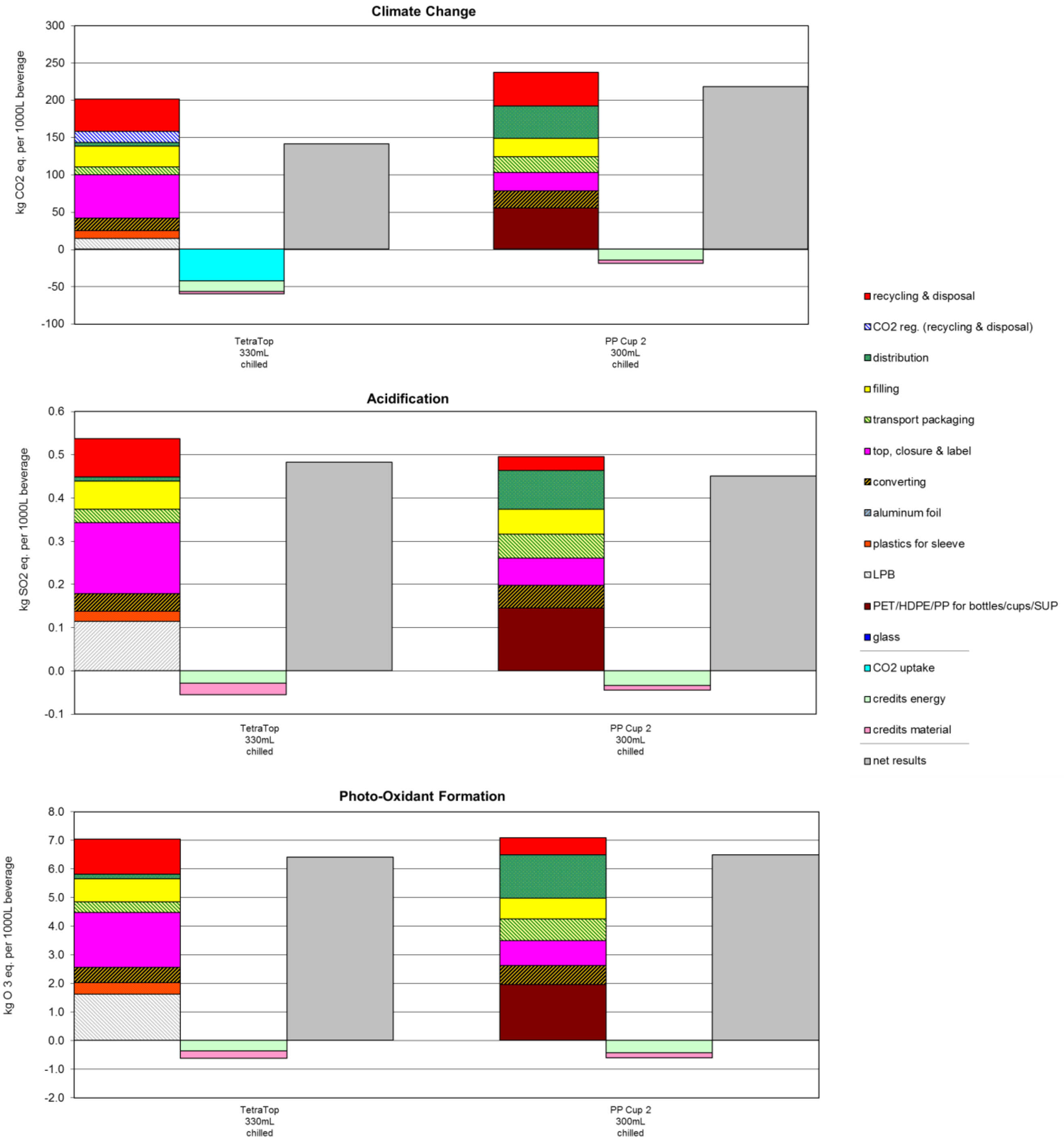



**Figure 115:** Indicator results for base scenarios of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 50% (Part 1)

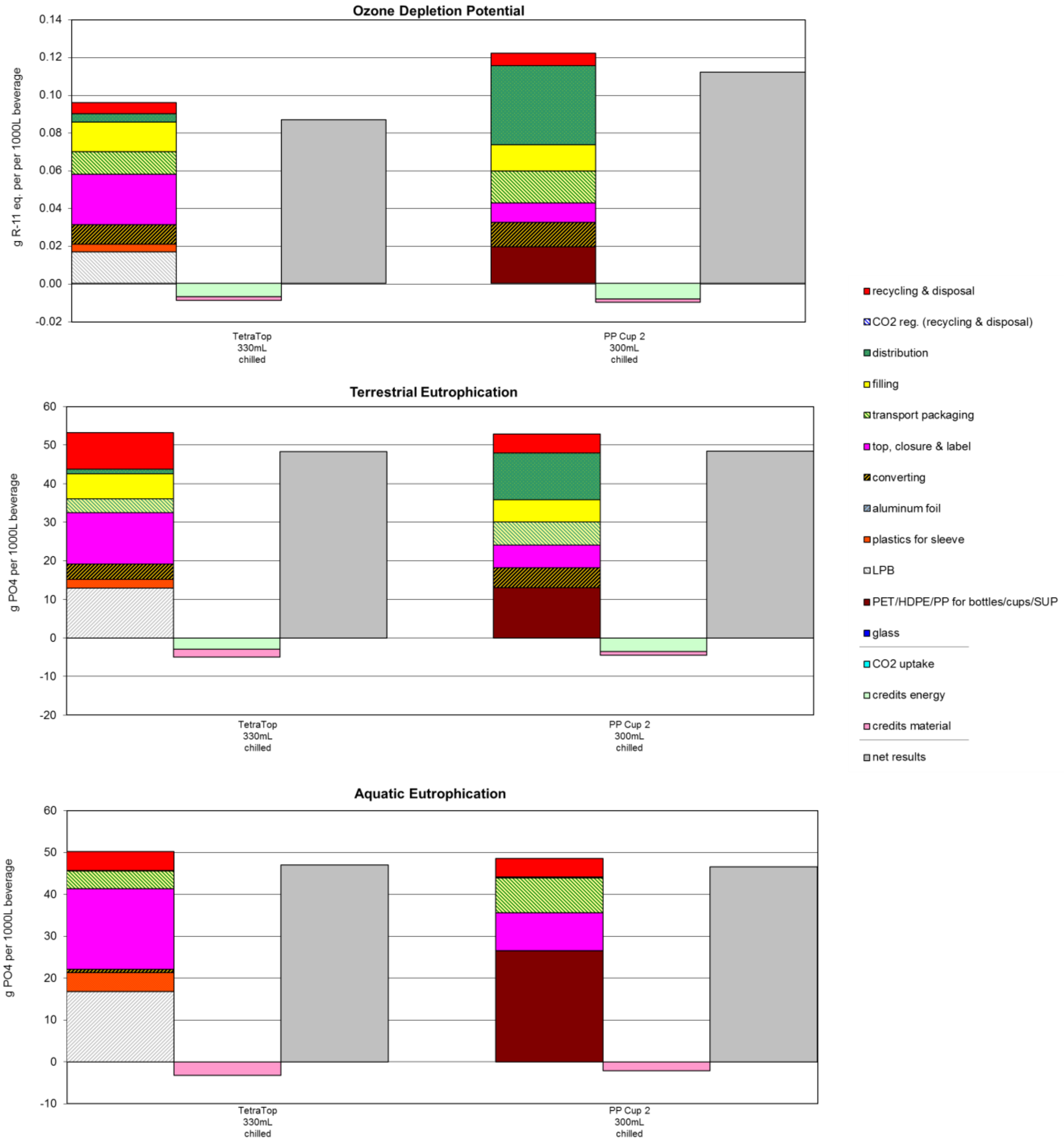



**Figure 116:** Indicator results for base scenarios of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 50% (Part 2)

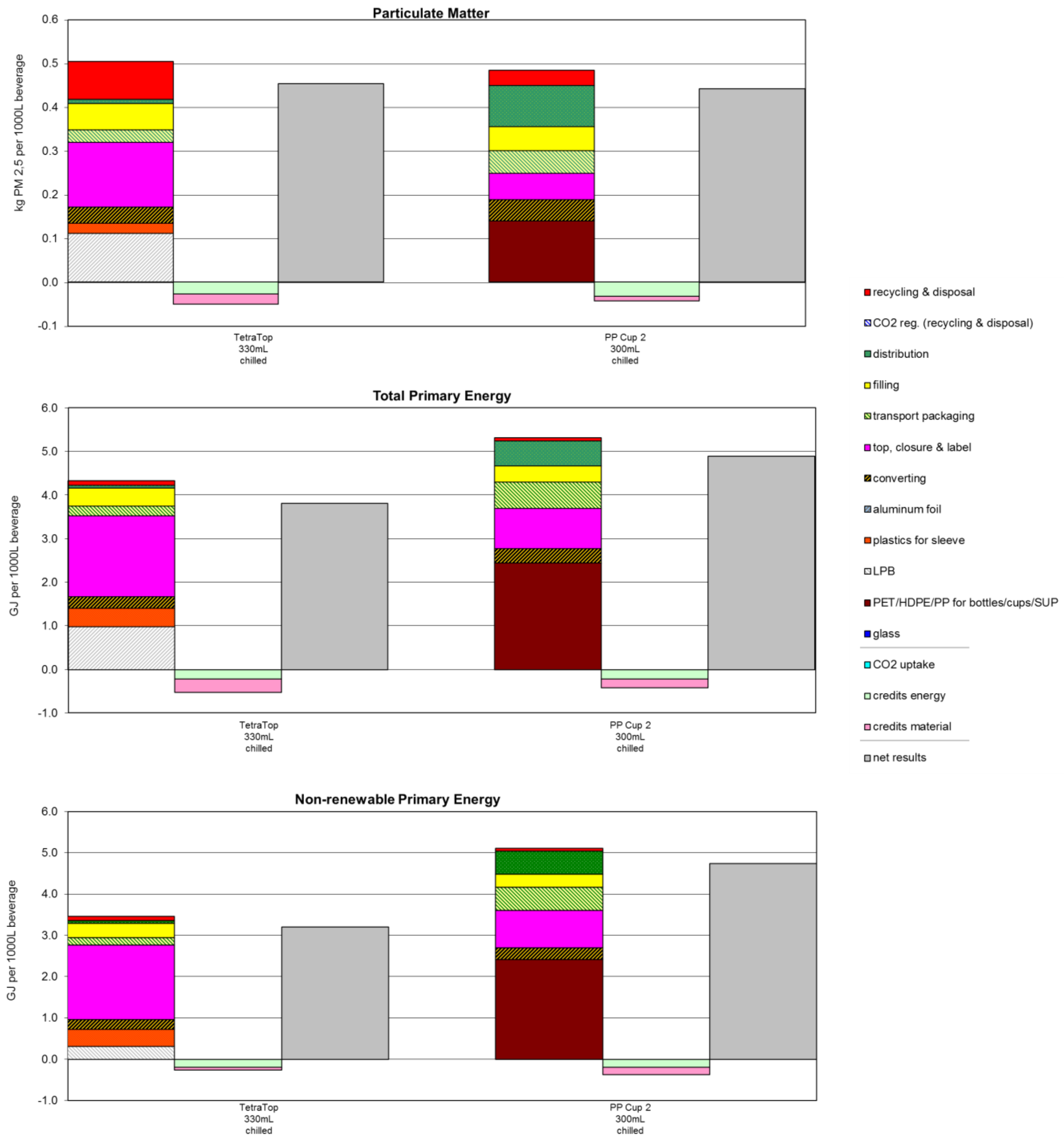



**Figure 117:** Indicator results for base scenarios of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 50% (Part 3)

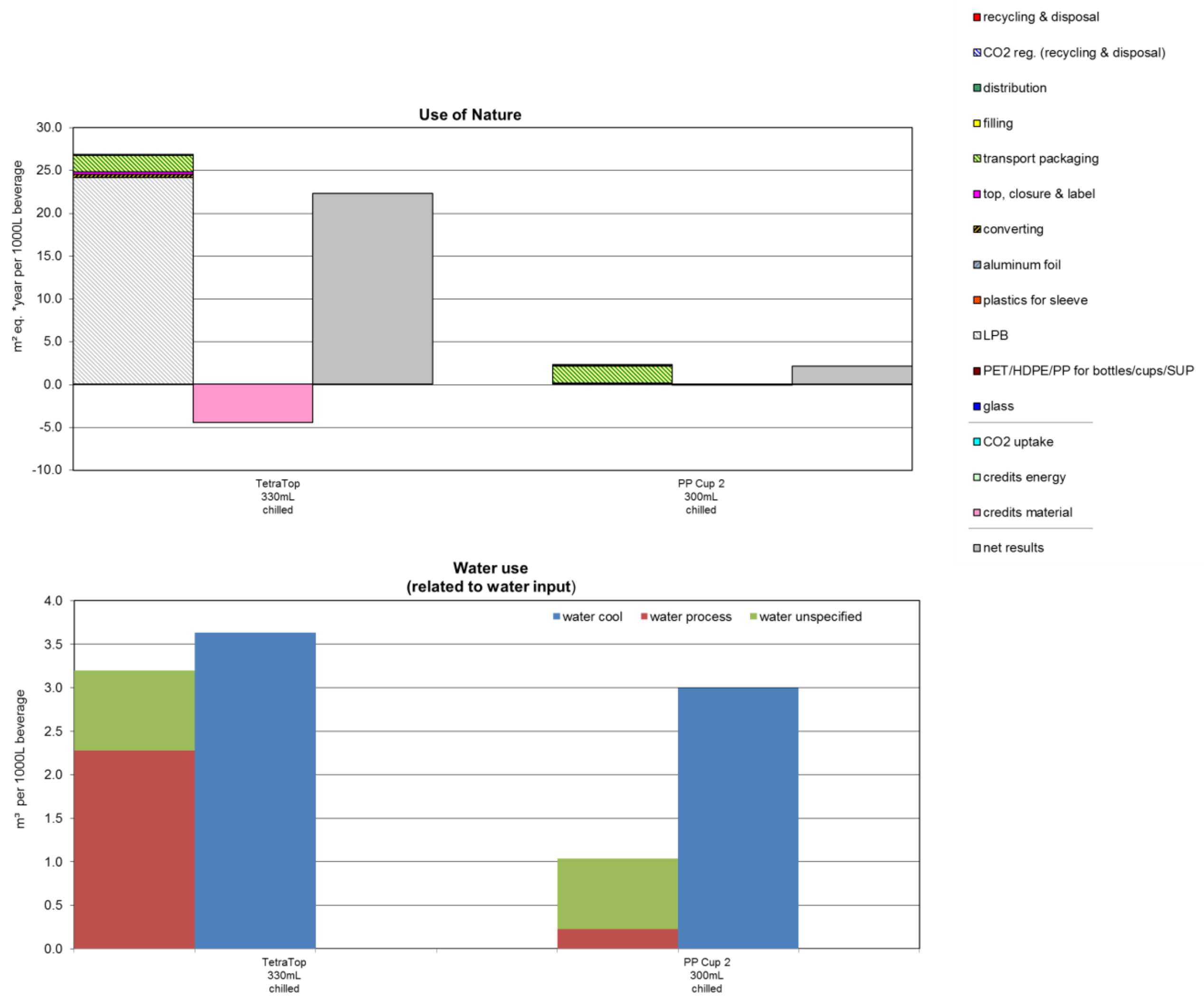



**Figure 118:** Indicator results for base scenarios of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 50% (Part 4)

**Table 143:** Category indicator results per impact category for base scenarios of **segment DAIRY (CREAM) 300mL-330mL IRELAND** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TetraTop 330mL chilled | PP Cup 2 300mL chilled |
|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 185.92 | 236.88 |
| | CO2 (reg) | 14.83 | 0.00 |
| | Credits* | -16.99 | -19.37 |
| | $CO_2$ uptake | -42.96 | 0.00 |
| | Net results (∑) | 140.80 | 217.51 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.54 | 0.50 |
| | Credits* | -0.06 | -0.05 |
| | Net results (∑) | 0.48 | 0.45 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.03 | 7.08 |
| | Credits* | -0.63 | -0.61 |
| | Net results (∑) | 6.40 | 6.48 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.12 |
| | Credits* | -0.01 | -0.01 |
| | Net results (∑) | 0.09 | 0.11 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 53.30 | 52.97 |
| | Credits* | -4.93 | -4.45 |
| | Net results (∑) | 48.37 | 48.51 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 50.19 | 48.54 |
| | Credits* | -3.27 | -2.06 |
| | Net results (∑) | 46.93 | 46.48 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.50 | 0.48 |
| | Credits* | -0.05 | -0.04 |
| | Net results (∑) | 0.45 | 0.44 |
| Total Primary Energy [GJ] | Burdens | 4.34 | 5.32 |
| | Credits* | -0.53 | -0.42 |
| | Net results (∑) | 3.81 | 4.90 |
| Non-renewable primary energy [GJ] | Burdens | 3.46 | 5.11 |
| | Credits* | -0.26 | -0.37 |
| | Net results (∑) | 3.20 | 4.74 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.75 | 2.23 |
| | Credits* | -4.53 | -0.12 |
| | Net results (∑) | 22.23 | 2.10 |
| Water use [$m^3$] | Water cool | 3.63 | 2.99 |
| | Water process | 2.27 | 0.22 |
| | Water unspec | 0.92 | 0.81 |

*material and energy credits

### 10.4.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton system regarded in the DAIRY (CREAM) 300mL-330mL 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’ (33%) and ‘Use of Nature’ (90%). It is also relevant regarding ‘Photo-Oxidant Formation’ (23%), ‘Acidification’ (21%), ‘Terrestrial Eutrophication’ (24%), ‘Particulate Matter’ (22%) and also the consumption of ‘Total Primary Energy’ (23%).

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 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’.

As the beverage carton in this segment is chilled, no aluminium layer is needed, and therefore no results are shown for this step.

The production of ‘plastics for sleeve’ of the beverage cartons shows minor shares of burdens (max. 12%) in all categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are ‘Climate Change’ (5% palstics, 7% LPB) and the inventory category ‘Non-renewable Primary Energy’ (12% palstics, 9% LPB) where the plastics and LPB contribute about the same.

The life cycle step ‘top, closure & label’ contributes for the 300mL-330mL beverage cartons considerably (25%-52%) to all impact categories except ‘Use of Nature’ due to the heavy closure and top in comparison to the weight of the sleeve materials.

The converting process generally plays a minor role (max. 11%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems shows minor shares of impacts (5%-13%) in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only minor shares of burdens (max. 16%) for the beverage carton system in all categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (29%). Greenhouse gases are also generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Republic of Ireland these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extent from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the Republic of Ireland the majority of beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**PP cups** (specifications see section 2.2.2)

In the regarded PP Cup 2 system in the DAIRY (CREAM) 300mL-330mL segment, the biggest part of the environmental burdens are caused by the production of the base materials of the cups (6%-34%) in most impact and inventory categories next to the step distribution with 16% until 55%.

The ‘converting’ process of the regarded PP Cup 3 shows minor shares (1%-11%) of impacts in all categories apart from ‘Aquatic Eutrophication’ with a share of impact less than 1%. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows considerable shares of impacts (2%-19%) in most categories attributed to the different plastics used for the closures.

The production and provision of ‘transport packaging’ for the PP Cup 2 show minor shares of impacts (9%-17%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 87% of the burdens.

The life cycle step ‘filling’ shows only minor shares of burdens (1%-12%) for the PP cup 2 in all categories.

The life cycle step ‘distribution’ shows high shares of burdens (6%-34%) in most impact categories due to the heavy weight of the roll containers and their smaller capacity as well as the large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The impact of the PP Cup’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (19%). The incineration of cups in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. For the white opaque PP Cup 2 no primary granulate is credited as they are incinerated in MSWIs, the received material credits for this bottle are inconsiderable compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

### 10.4.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 144:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **DAIRY (CREAM) 300mL-330mL IRELAND**

| The net results of **TT 330mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TT 330mL chilled | PP Cup 2 300mL chilled |
| Climate Change [kg $CO_2$eq] | 140.80 | -35% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -22% |
| Acidification [kg $SO_2$ eq.] | 0.48 | 7% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 48.37 | 0% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 46.93 | 1% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.40 | -1% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.45 | 3% |

# *10.5* Results base scenarios JNSD *200mL-330mL IRELAND*

## 10.5.1 Presentation of results

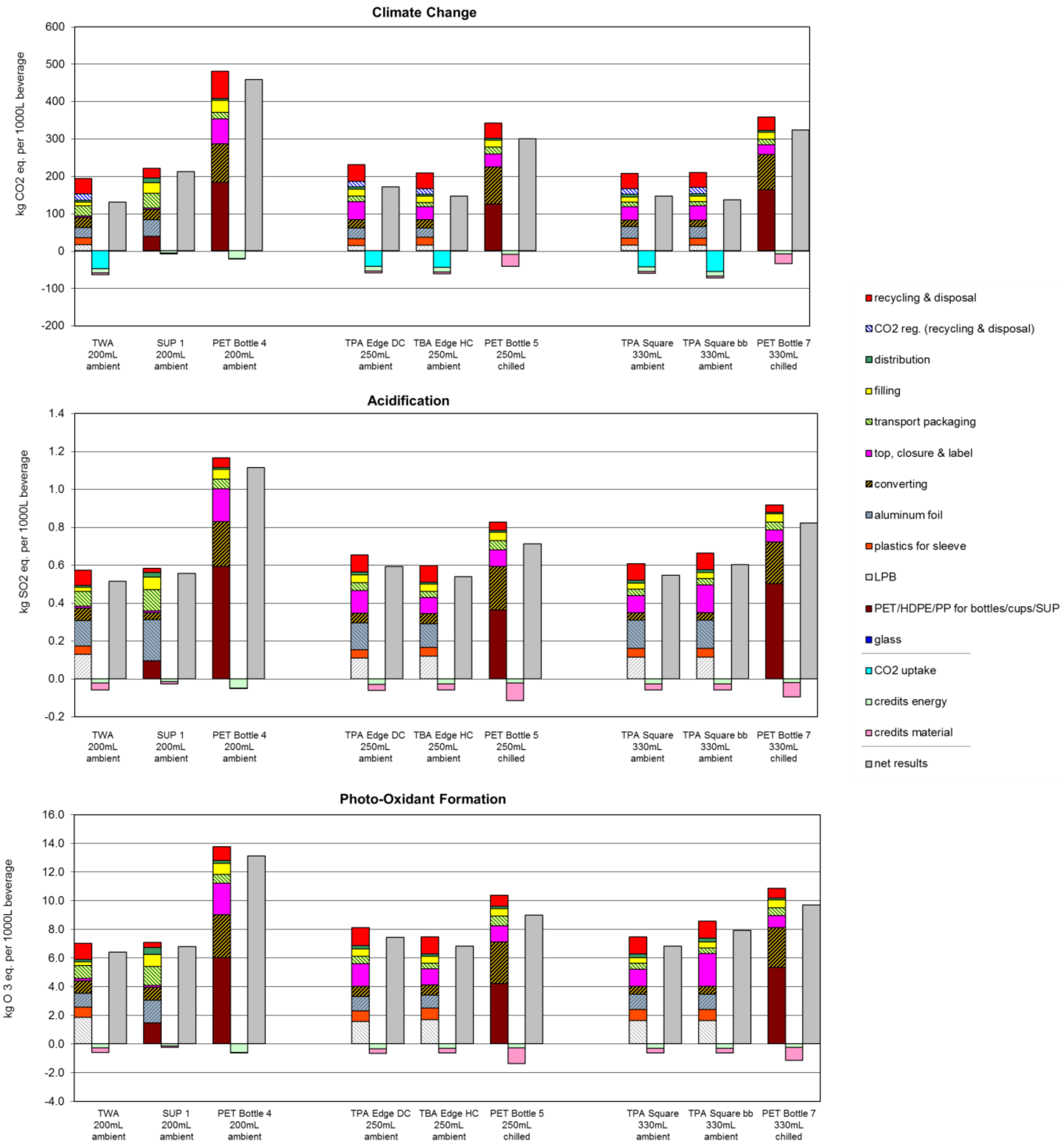



**Figure 119:** Indicator results for base scenarios of **segment JNSD 200mL-330mL IRELAND**, allocation factor 50% (Part 1)

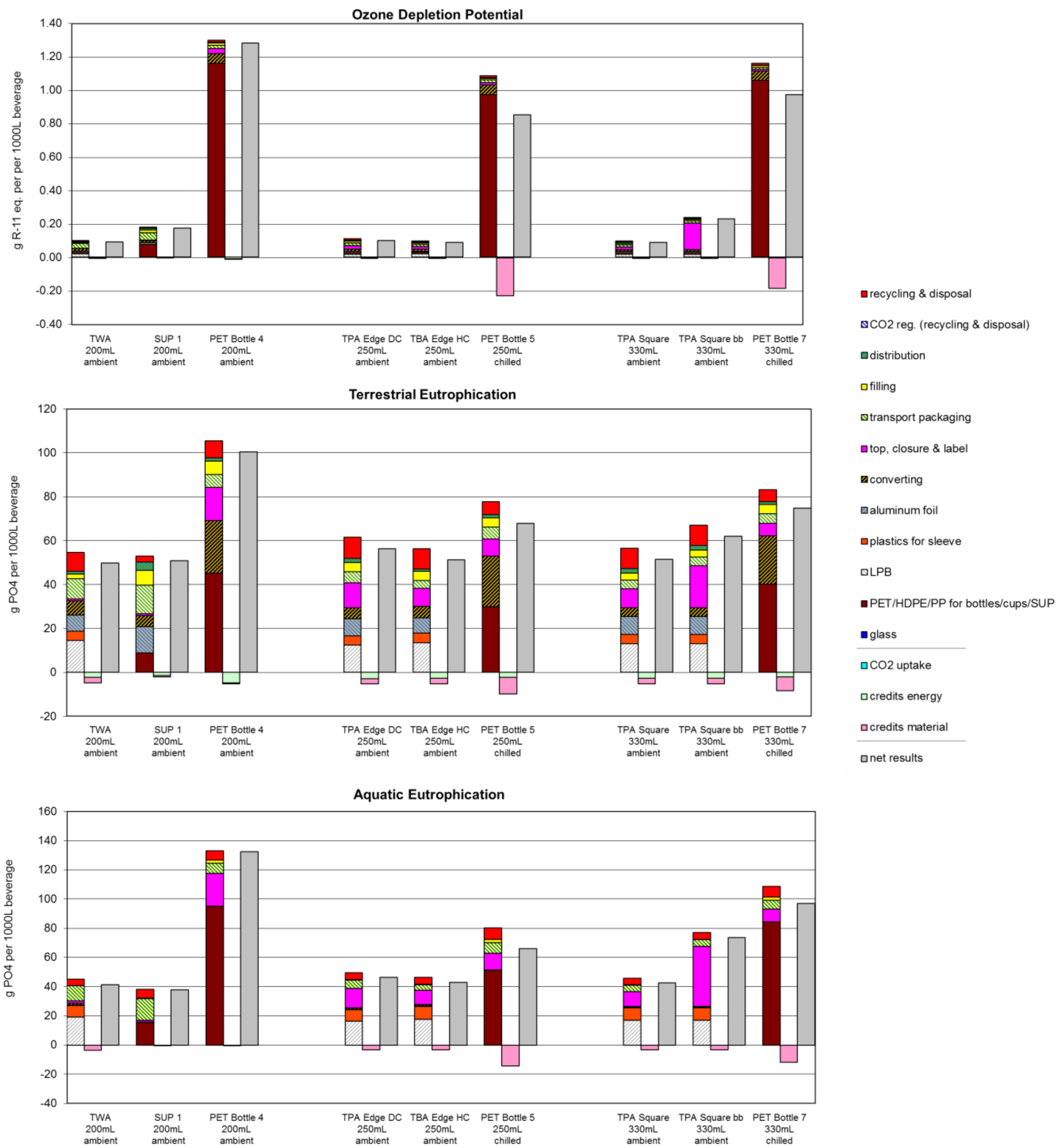



**Figure 120:** Indicator results for base scenarios of **segment JNSD 200mL-330mL IRELAND**, allocation factor 50% (Part 2)

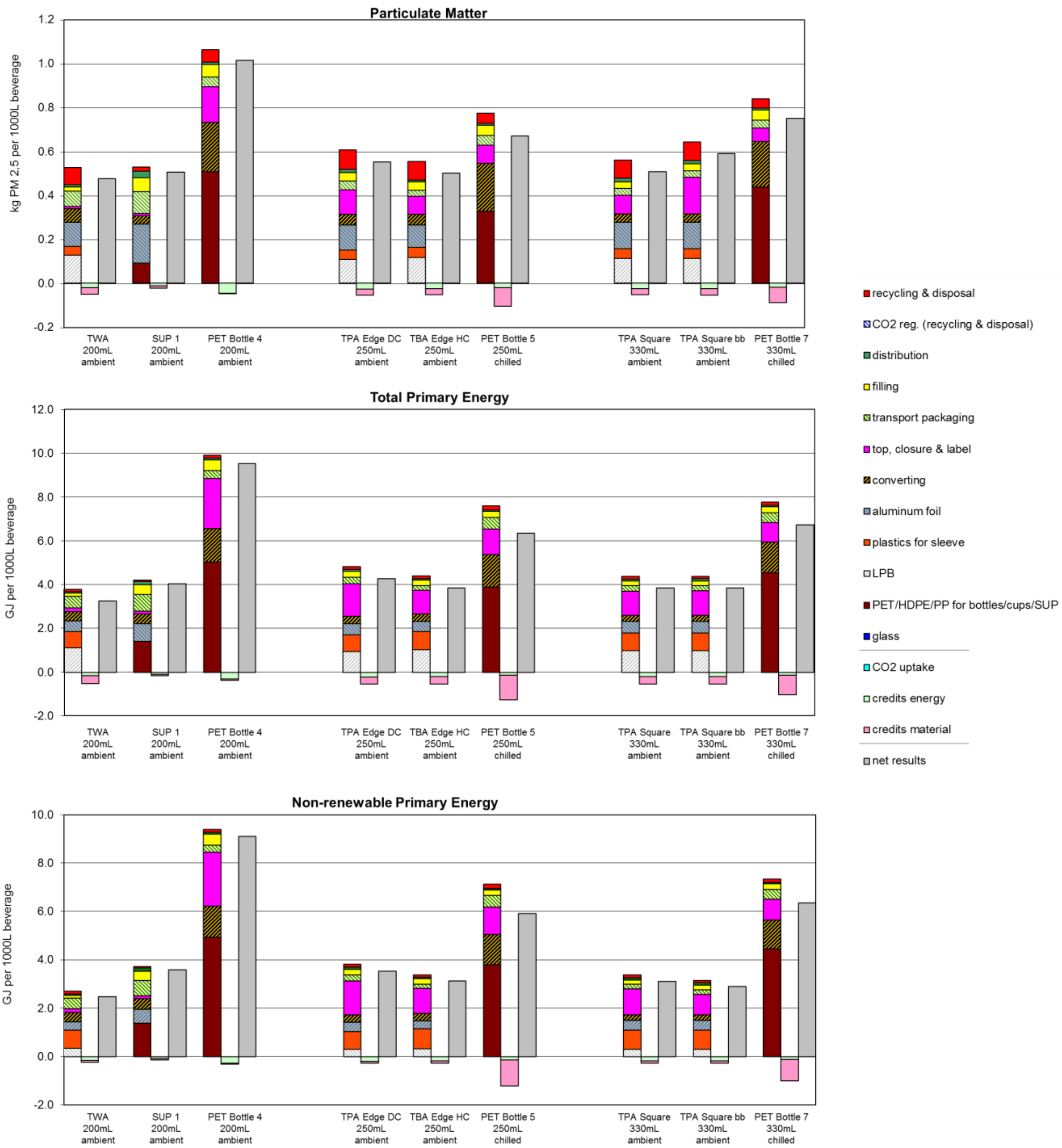



**Figure 121:** Indicator results for base scenarios of **segment JNSD 200mL-330mL IRELAND**, allocation factor 50% (Part 3)

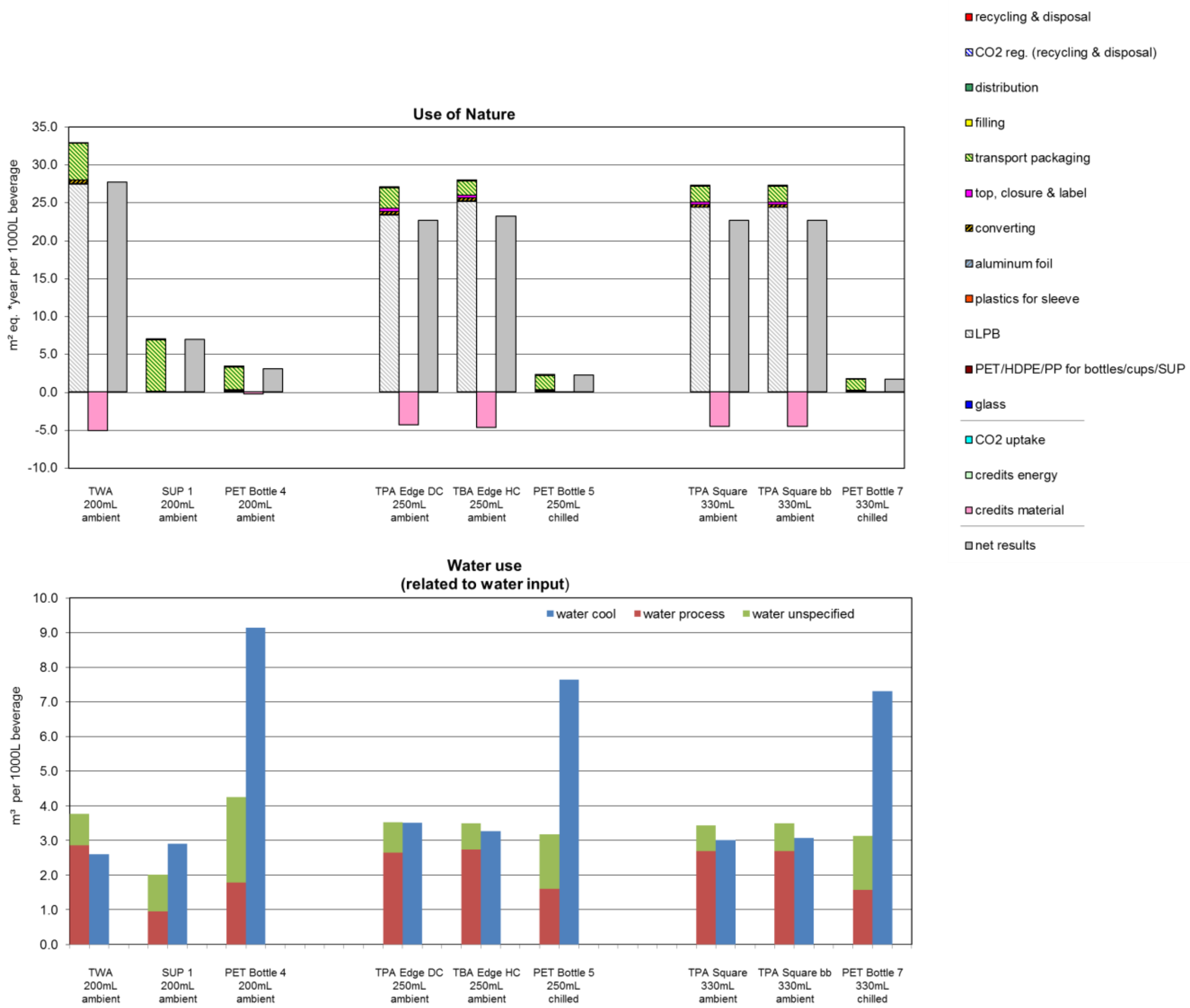



**Figure 122:** Indicator results for base scenarios of **segment JNSD 200mL-330mL IRELAND**, allocation factor 50% (Part 4)

**Table 145:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL IRELAND (200mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TWA 200mL ambient | SUP 1 200mL ambient | PET Bottle 4 200mL ambient |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 175.41 | 220.39 | 479.64 |
| | CO2 (reg) | 18.16 | 0.00 | 0.00 |
| | Credits* | -15.06 | -8.74 | -22.33 |
| | $CO_2$ uptake | -48.86 | 0.00 | 0.00 |
| | Net results (∑) | 129.64 | 211.64 | 457.31 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.57 | 0.58 | 1.17 |
| | Credits* | -0.06 | -0.03 | -0.05 |
| | Net results (∑) | 0.52 | 0.56 | 1.12 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.01 | 7.05 | 13.73 |
| | Credits* | -0.62 | -0.27 | -0.64 |
| | Net results (∑) | 6.39 | 6.78 | 13.09 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.18 | 1.30 |
| | Credits* | -0.01 | -0.01 | -0.02 |
| | Net results (∑) | 0.09 | 0.17 | 1.28 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 54.72 | 52.96 | 105.60 |
| | Credits* | -4.82 | -2.09 | -5.09 |
| | Net results (∑) | 49.90 | 50.88 | 100.51 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.04 | 37.99 | 132.77 |
| | Credits* | -3.67 | -0.33 | -0.43 |
| | Net results (∑) | 41.37 | 37.67 | 132.34 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.53 | 0.53 | 1.06 |
| | Credits* | -0.05 | -0.02 | -0.05 |
| | Net results (∑) | 0.47 | 0.51 | 1.01 |
| Total Primary Energy [GJ] | Burdens | 3.80 | 4.20 | 9.92 |
| | Credits* | -0.53 | -0.15 | -0.37 |
| | Net results (∑) | 3.27 | 4.05 | 9.54 |
| Non-renewable primary energy [GJ] | Burdens | 2.71 | 3.73 | 9.40 |
| | Credits* | -0.22 | -0.13 | -0.30 |
| | Net results (∑) | 2.49 | 3.60 | 9.09 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 32.81 | 6.91 | 3.32 |
| | Credits* | -5.14 | -0.02 | -0.27 |
| | Net results (∑) | 27.67 | 6.89 | 3.05 |
| Water use [$m^3$] | Water cool | 2.61 | 2.90 | 9.15 |
| | Water process | 2.86 | 0.96 | 1.79 |
| | Water unspec | 0.90 | 1.06 | 2.47 |

*material and energy credits

**Table 146:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL IRELAND (250mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | TBA Edge HC 250mL ambient | PET Bottle 5 250mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 214.74 | 192.51 | 341.25 |
| | CO2 (reg) | 14.92 | 15.42 | 0.00 |
| | Credits* | -17.95 | -17.02 | -42.07 |
| | $CO_2$ uptake | -41.60 | -44.82 | 0.00 |
| | Net results (∑) | 170.10 | 146.08 | 299.18 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.65 | 0.60 | 0.83 |
| | Credits* | -0.06 | -0.06 | -0.11 |
| | Net results (∑) | 0.59 | 0.54 | 0.71 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 8.10 | 7.47 | 10.36 |
| | Credits* | -0.67 | -0.65 | -1.39 |
| | Net results (∑) | 7.43 | 6.82 | 8.96 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.09 | 1.09 |
| | Credits* | -0.01 | -0.01 | -0.23 |
| | Net results (∑) | 0.10 | 0.09 | 0.85 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 61.62 | 56.45 | 77.87 |
| | Credits* | -5.18 | -5.07 | -9.87 |
| | Net results (∑) | 56.44 | 51.38 | 68.00 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 49.58 | 46.27 | 80.25 |
| | Credits* | -3.22 | -3.40 | -14.36 |
| | Net results (∑) | 46.36 | 42.87 | 65.89 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.61 | 0.55 | 0.77 |
| | Credits* | -0.05 | -0.05 | -0.11 |
| | Net results (∑) | 0.55 | 0.50 | 0.67 |
| Total Primary Energy [GJ] | Burdens | 4.82 | 4.40 | 7.60 |
| | Credits* | -0.54 | -0.54 | -1.25 |
| | Net results (∑) | 4.29 | 3.86 | 6.35 |
| Non-renewable primary energy [GJ] | Burdens | 3.81 | 3.39 | 7.12 |
| | Credits* | -0.27 | -0.26 | -1.20 |
| | Net results (∑) | 3.54 | 3.13 | 5.91 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.96 | 27.87 | 2.24 |
| | Credits* | -4.37 | -4.69 | -0.03 |
| | Net results (∑) | 22.59 | 23.17 | 2.21 |
| Water use [$m^3$] | Water cool | 3.51 | 3.27 | 7.64 |
| | Water process | 2.65 | 2.74 | 1.61 |
| | Water unspec | 0.87 | 0.75 | 1.56 |

*material and energy credits

**Table 147:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL IRELAND (330mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | PET Bottle 7 330mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 191.67 | 192.34 | 357.64 |
| | CO2 (reg) | 15.09 | 16.94 | 0.00 |
| | Credits* | -17.14 | -17.19 | -35.20 |
| | $CO_2$ uptake | -43.35 | -55.98 | 0.00 |
| | Net results (∑) | 146.27 | 136.11 | 322.44 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.61 | 0.66 | 0.92 |
| | Credits* | -0.06 | -0.06 | -0.10 |
| | Net results (∑) | 0.55 | 0.60 | 0.82 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.46 | 8.55 | 10.85 |
| | Credits* | -0.65 | -0.65 | -1.16 |
| | Net results (∑) | 6.81 | 7.90 | 9.69 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.10 | 0.24 | 1.16 |
| | Credits* | -0.01 | -0.01 | -0.19 |
| | Net results (∑) | 0.09 | 0.23 | 0.97 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 56.62 | 67.10 | 83.16 |
| | Credits* | -5.06 | -5.07 | -8.26 |
| | Net results (∑) | 51.57 | 62.03 | 74.91 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 45.78 | 76.87 | 108.61 |
| | Credits* | -3.31 | -3.31 | -11.63 |
| | Net results (∑) | 42.47 | 73.56 | 96.97 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.56 | 0.64 | 0.84 |
| | Credits* | -0.05 | -0.05 | -0.09 |
| | Net results (∑) | 0.51 | 0.59 | 0.75 |
| Total Primary Energy [GJ] | Burdens | 4.38 | 4.39 | 7.78 |
| | Credits* | -0.53 | -0.53 | -1.03 |
| | Net results (∑) | 3.84 | 3.85 | 6.75 |
| Non-renewable primary energy [GJ] | Burdens | 3.38 | 3.16 | 7.34 |
| | Credits* | -0.26 | -0.26 | -0.99 |
| | Net results (∑) | 3.12 | 2.90 | 6.35 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.16 | 27.16 | 1.70 |
| | Credits* | -4.55 | -4.55 | -0.03 |
| | Net results (∑) | 22.62 | 22.61 | 1.68 |
| Water use [$m^3$] | Water cool | 3.02 | 3.07 | 7.31 |
| | Water process | 2.69 | 2.69 | 1.58 |
| | Water unspec | 0.75 | 0.81 | 1.55 |

*material and energy credits

### 10.5.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 200mL-330mL 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’ (33%-42%) and ‘Use of Nature’ (84%-90%). It is also relevant regarding ‘Photo-Oxidant Formation’ (19%-26%), ‘Acidification’ (17%-23%), ‘Terrestrial Eutrophication’ (20%-27%), ‘Particulate Matter’ (18%-24%) and also the consumption of ‘Total Primary Energy’ (20%-29%).

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 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 shows burdens in most impact categories. High burdens can be seen for the categories ‘Acidification’ (21%-24%) and ‘Particulate Matter’ (18%-22%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable shares of burdens (7%-27%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the plastics (8%-10%) and LPB (6%-8%) contribute about the same and the inventory category ‘Non-renewable Primary Energy’, where the plastics make up about 20% until 30% of the total burdens. If ‘plastics for sleeve' contains bio-based plastics (i.e. for TPA Square 330mL bio-based ambient), this life cycle step plays a major role for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step 'top, closure & label' contributes to a considerable amount (14%-67%) in almost all impact categories with the exception of the TWA with only minor burdens (max. 6%) in this step as this carton has no closure and only a straw~~.~~ In case the plastics used for 'top, closure & label' are bio-based (i.e. TPA Square bio-based 330mL), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (max 17%). It generates emissions, which contribute to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems shows considerable shares (5%-16%) of impacts in all categories. One exception is the TWA 200 with higher shares of burdens (13%-31%) from transport packaging in all categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 10%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (30%). Greenhouse gases are also generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the Republic of Ireland in this segment these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extent from landfills. Material credits from material recycling are lower than energy credits in all impact categories except 'Aquatic Eutrophication' and 'Use of Nature' as in the Republic of Ireland the majority of beverage cartons is not recycled. Material credits for 'Climate Change' are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for 'Aquatic Eutrophication' and 'Use of Nature' result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle systems in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens (37%-91%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production, nevertheless in the case of ambient PET bottles a considerable share of burdens derives from the production of the PA additive. The high results of 'Ozone Depletion Potential' are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The 'converting' process of all regarded bottles shows a considerable shares of impacts (4%-30%) in all categories apart from 'Aquatic Eutrophication' with shares of impact less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable (1%-24%) impacts in most categories mainly attributed to the plastics used for the closure. Especially PET Bottle 4 shows higher shares of impacts in this step because if it's heavy closure.

The production and provision of 'transport packaging' for the bottle system show minor shares of impacts (1%-9%) in all categories except of 'Use of Nature' in which the paper production contributes to 85%-91% of the burdens. All relevant emissions derive from production of paper for trays and slipsheets as well as from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets and trays.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 7%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (15%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is noticeable in most categories. With a recycling rate of 40% for the clear plastic bottle, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

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

In the regarded SUP in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens is caused by the production of the base materials of the pouch in most impact and inventory categories. The burdens mainly derive from aluminium (up to 37%) and plastics (up to 43%) production with a higher share of burdens from aluminium in the impact categories ‘Acidification’ and ‘Particulate Matter’ due to $SO_2$ and $NO_x$ emissions from the aluminium production

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

The production and provision of ‘transport packaging’ for the SUP show considerable shares of impacts (17%-39%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 98% of the burdens. All relevant emissions derive from production of paper for trays and slipsheets as well as from the production of stretch foil.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 13%) for the SUP in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the SUP’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (12%). The incineration of cups 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 almost all SUPs are incinerated. The energy credits mainly originate from the incineration plants.

### 10.5.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 148:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TWA 200mL ambient | SUP 1 200mL ambient | PET Bottle 4 200mL ambient |
| Climate Change [kg $CO_2$eq] | 129.64 | -39% | -72% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -47% | -93% |
| Acidification [kg $SO_2$ eq.] | 0.52 | -7% | -54% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 49.90 | -2% | -50% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 41.37 | 10% | -69% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.39 | -6% | -51% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.47 | -6% | -53% |

**Table 149:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 170.11 | -43% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -88% |
| Acidification [kg $SO_2$ eq.] | 0.59 | -17% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 56.44 | -17% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 46.36 | -30% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.43 | -17% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.55 | -18% |

**Table 150:** Comparison of net results: **TPA Edge HC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Edge HC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 146.08 | -51% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -90% |
| Acidification [kg $SO_2$ eq.] | 0.54 | -24% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.38 | -24% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.87 | -35% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.82 | -24% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.50 | -25% |

**Table 151:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 146.27 | -55% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -91% |
| Acidification [kg $SO_2$ eq.] | 0.55 | -33% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.57 | -31% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.47 | -56% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.81 | -30% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.51 | -32% |

**Table 152:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | T TPA Square DC bb 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 136.11 | -58% |
| Ozone depletion potential [g R-11 eq.] | 0.23 | -76% |
| Acidification [kg $SO_2$ eq.] | 0.60 | -27% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 62.03 | -17% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 73.56 | -24% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.90 | -18% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.59 | -21% |

# 11 Sensitivity Analyses Ireland

## 11.1 Sensitivity Analyses DAIRY 1000mL-2000mL IRELAND

### 11.1.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

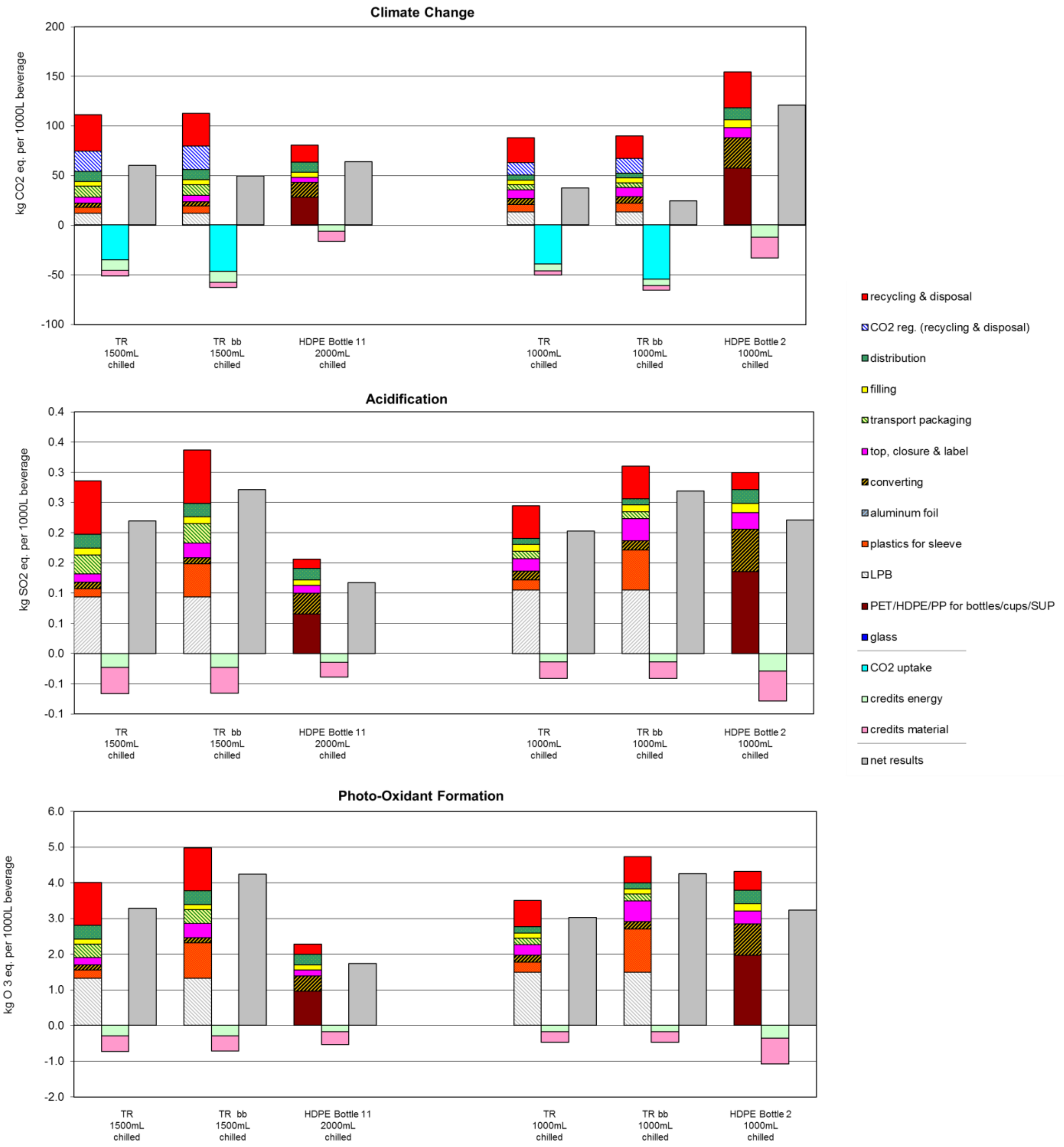



**Figure 123:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 100% (Part 1)

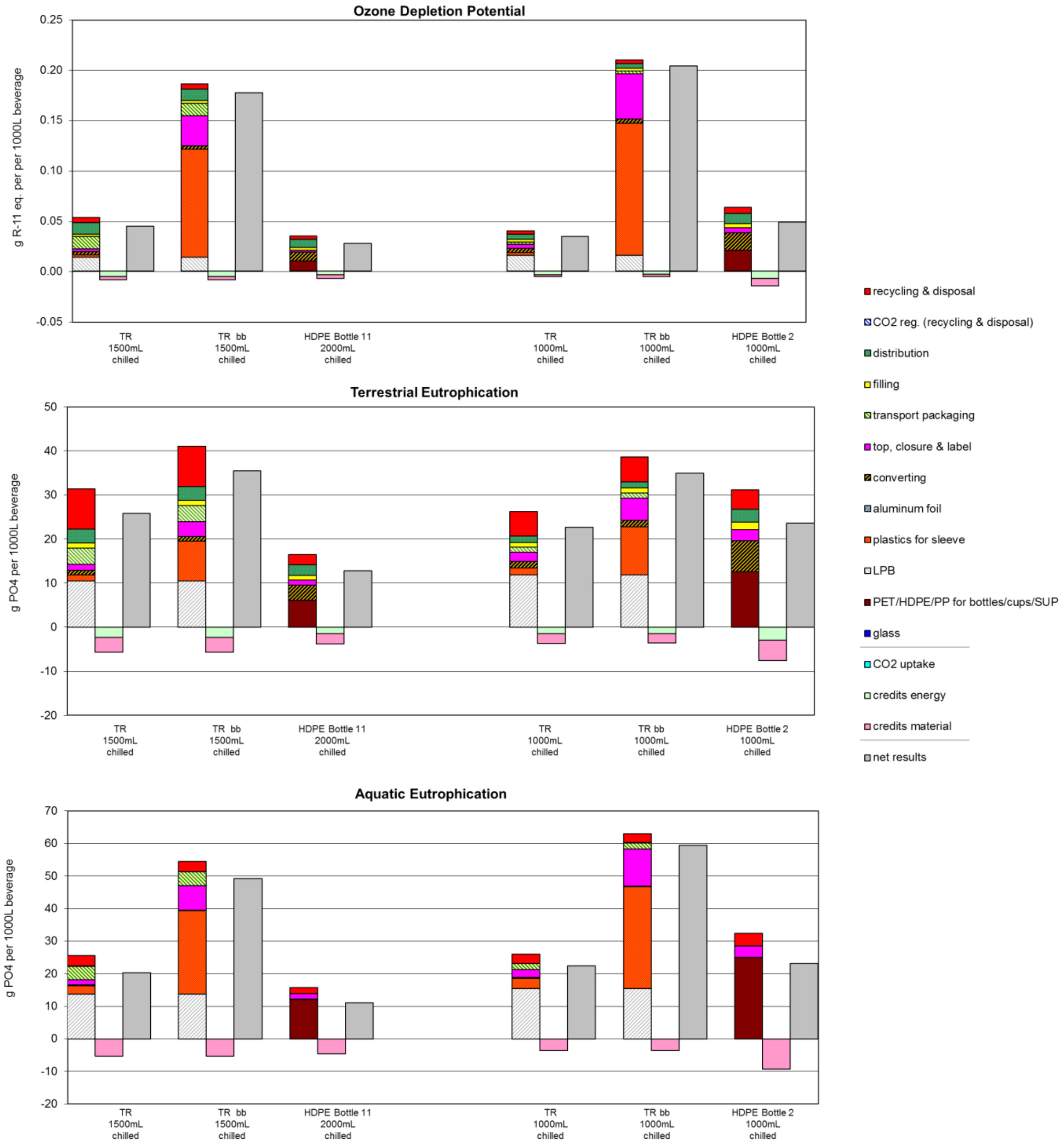



**Figure 124:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 100% (Part 2)

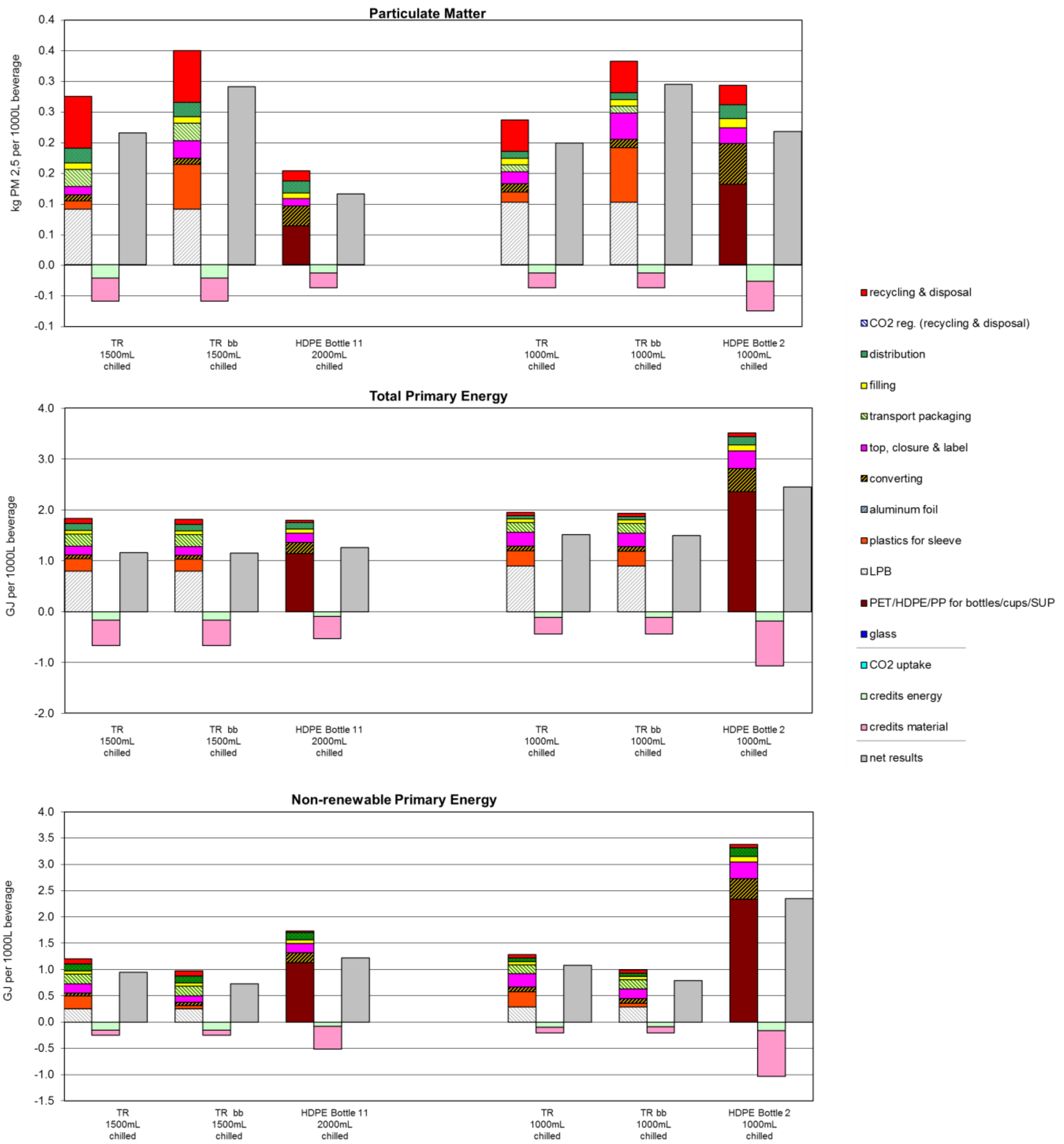



**Figure 125:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL IRELAND**, allocation factor 100% (Part 3)

### 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 Ireland applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor. These are dominated by the credits received for recycled paper board.

In the cases of plastic bottles the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 153:** Comparison of net results: **TR 1500mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR 1500mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TR 1500mL chilled | HDPE Bottle 11 2000mL chilled |
| Climate Change [kg $CO_2$eq] | 59.76 | -6% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | 63% |
| Acidification [kg $SO_2$ eq.] | 0.22 | 88% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 25.81 | 102% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 20.28 | 83% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.27 | 89% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.22 | 86% |

**Table 154:** Comparison of net results: **TR bio-based 1500mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR bb 1500mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TR bb 1500mL chilled | HDPE Bottle 11 2000mL chilled |
| Climate Change [kg $CO_2$eq] | 49.44 | -22% |
| Ozone depletion potential [g R-11 eq.] | 0.18 | 547% |
| Acidification [kg $SO_2$ eq.] | 0.27 | 132% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.46 | 177% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 49.14 | 344% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.24 | 145% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.29 | 151% |

**Table 155:** Comparison of net results: **TR 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TR 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 51.87 | -57% |
| Ozone depletion potential [g R-11 eq.] | 0.03 | -36% |
| Acidification [kg $SO_2$ eq.] | 0.21 | -5% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 24.07 | 2% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 19.78 | -14% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.19 | -1% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.21 | -4% |

**Table 156:** Comparison of net results: **TR bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, IRELAND**

| The net results of **TR bb 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TR bb 1000mL chilled | HDPE Bottle 2 1000mL chilled |
| Climate Change [kg $CO_2$eq] | 38.63 | -68% |
| Ozone depletion potential [g R-11 eq.] | 0.20 | 314% |
| Acidification [kg $SO_2$ eq.] | 0.28 | 25% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.42 | 54% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 56.70 | 146% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.42 | 37% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.30 | 40% |

## 11.2 Sensitivity Analyses JNSD 1000mL IRELAND

### 11.2.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

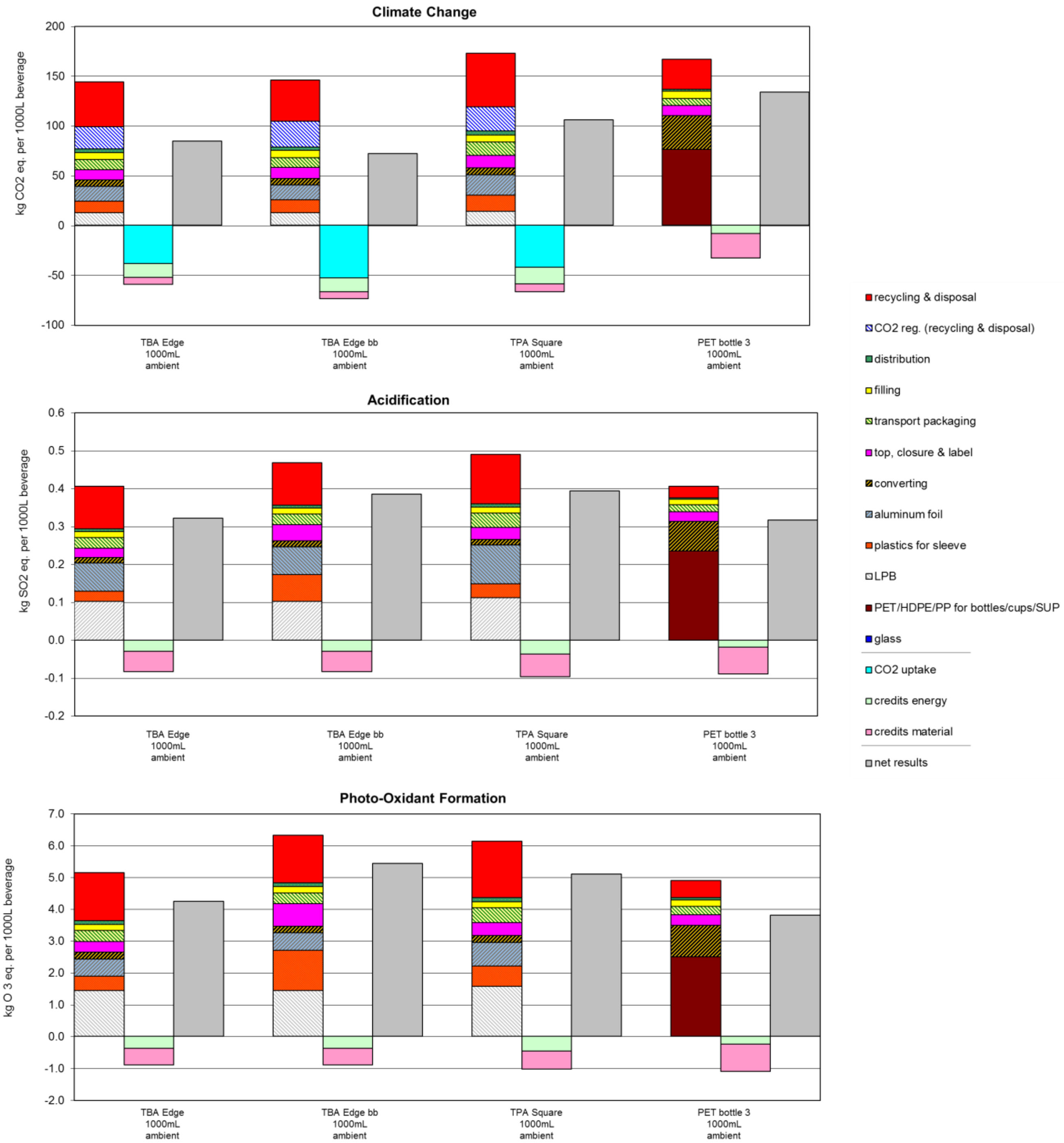



**Figure 126:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL IRELAND**, allocation factor 100% (Part 1)

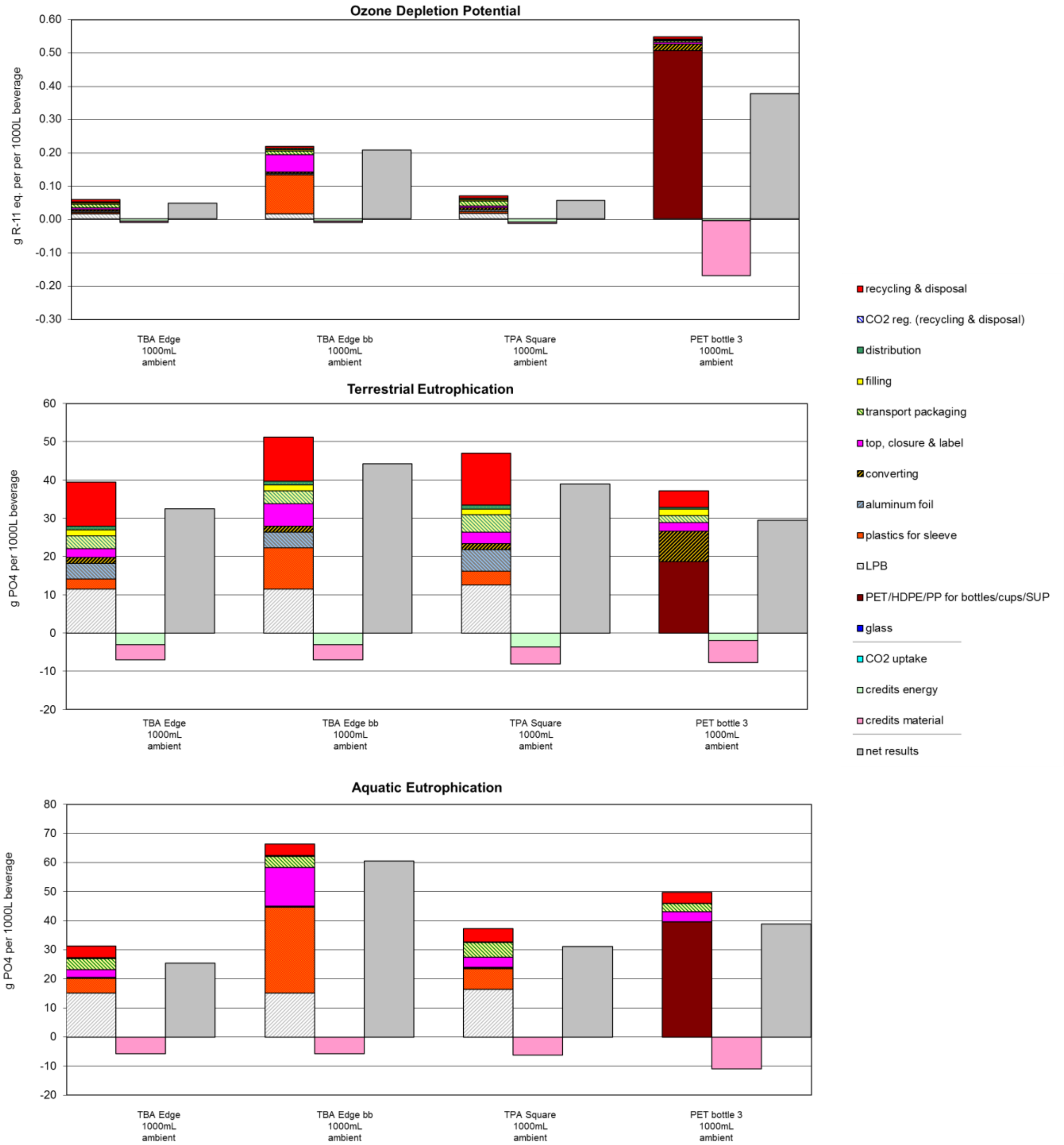



**Figure 127:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL IRELAND**, allocation factor 100% (Part 2)

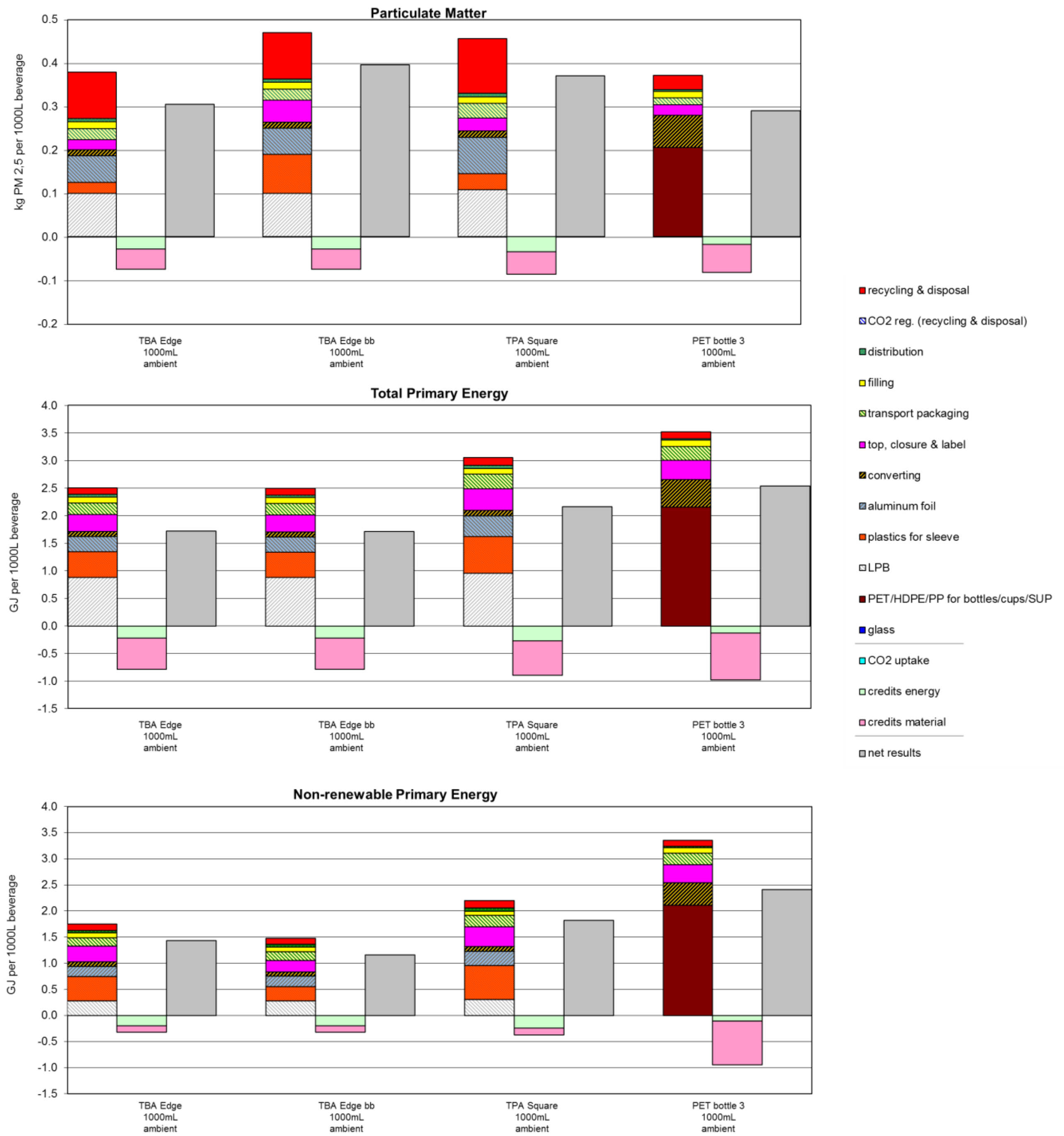



**Figure 128:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL IRELAND**, allocation factor 100% (Part 3)

## 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 Ireland applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor.  These are dominated by the credits received for recycled paper board.

In the cases of plastic bottles the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 157:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, IRELAND**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 84.36 | -37% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -88% |
| Acidification [kg $SO_2$ eq.] | 0.32 | 2% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 32.54 | 10% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 25.45 | -34% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.25 | 12% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.30 | 5% |

**Table 158:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, IRELAND**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 72.14 | -46% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -45% |
| Acidification [kg $SO_2$ eq.] | 0.38 | 21% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 44.26 | 50% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 60.49 | 56% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.43 | 43% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.40 | 36% |

**Table 159:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, IRELAND**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square 1000mL ambient | PET Bottle 3 PA ALLO100, Gut |
| Climate Change [kg $CO_2$eq] | 105.75 | -21% |
| Ozone depletion potential [g R-11 eq.] | 0.06 | -85% |
| Acidification [kg $SO_2$ eq.] | 0.39 | 24% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 39.05 | 32% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 31.00 | -20% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.10 | 34% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.37 | 28% |

## 11.3 Sensitivity Analyses DAIRY 189mL-500mL IRELAND

### 11.3.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

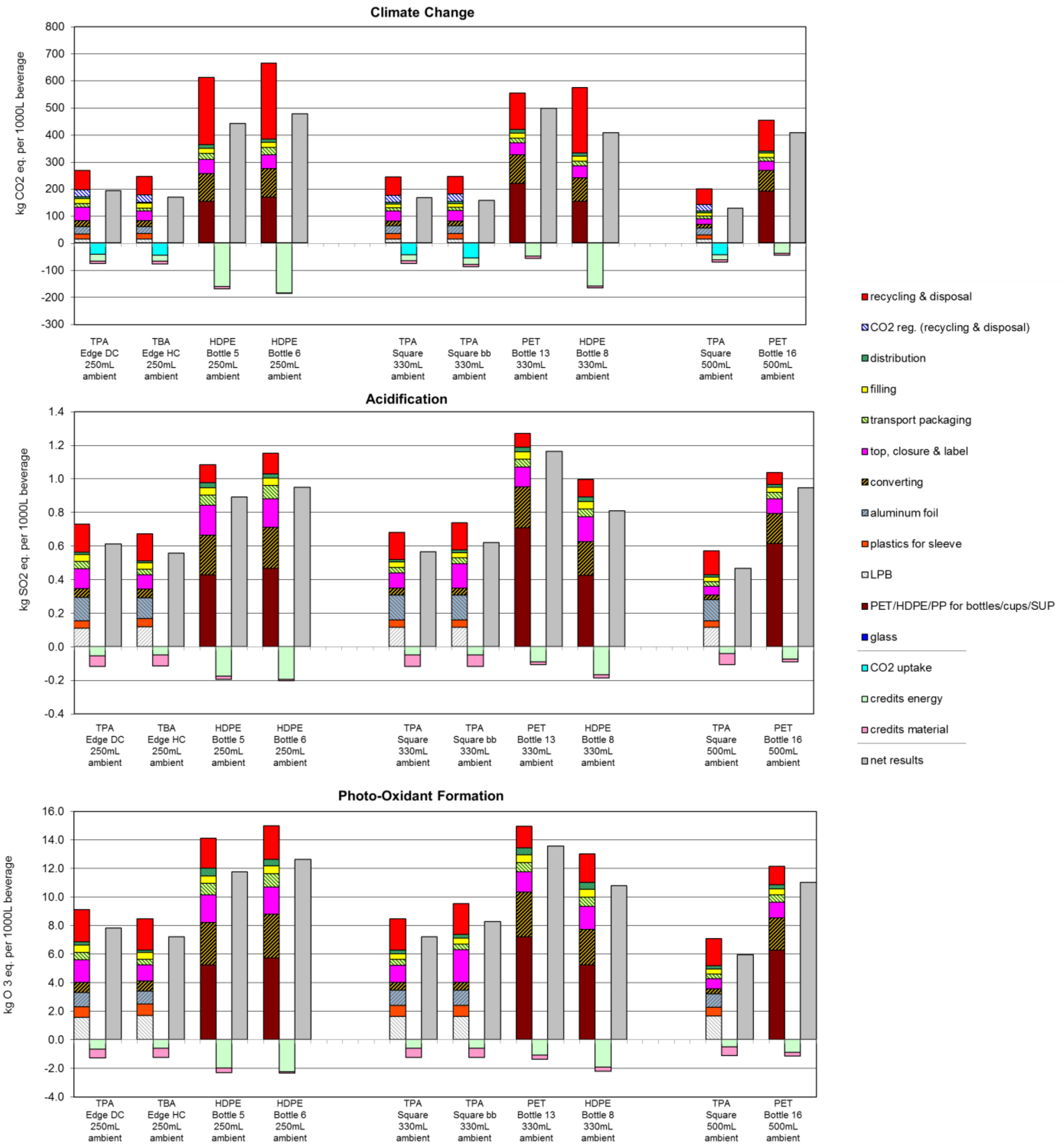



**Figure 129:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL IRELAND**, allocation factor 100% (Part 1)

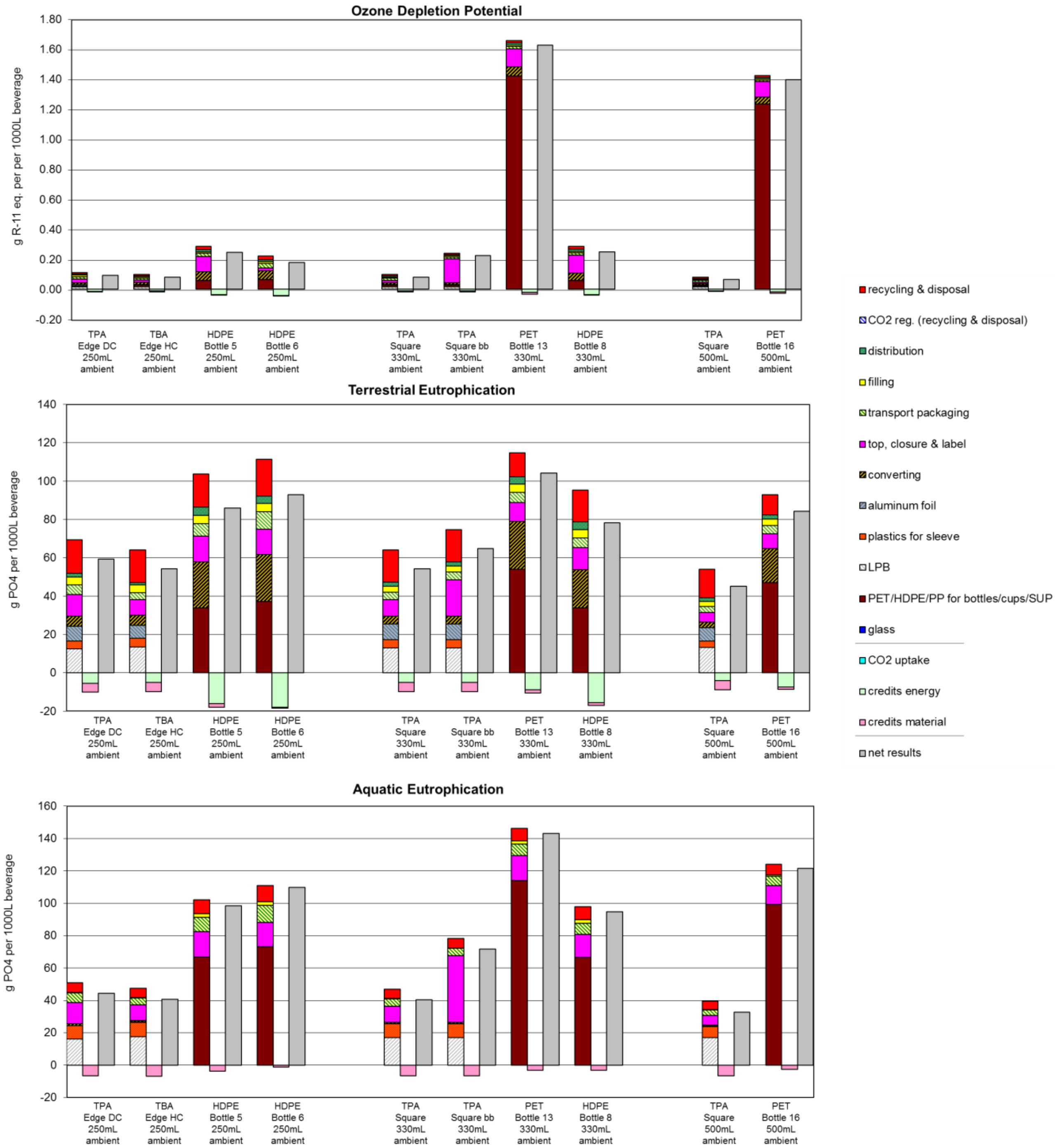



**Figure 130:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL IRELAND**, allocation factor 100% (Part 2)

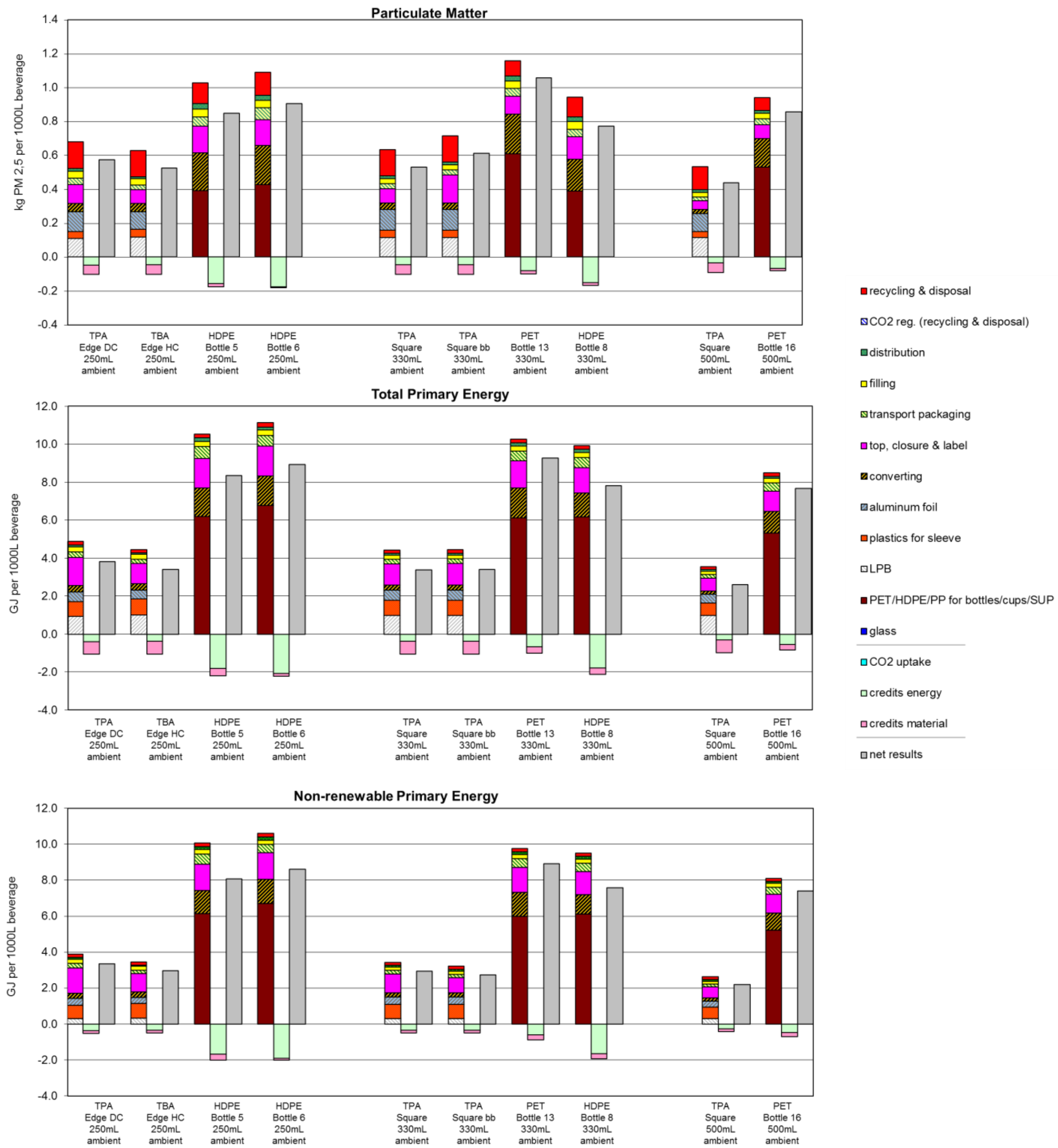



**Figure 131:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL IRELAND**, allocation factor 100% (Part 3)

## 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 Ireland applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor.  These are dominated by the credits received for recycled paper board.

In the cases of HDPE plastic bottles the net result decrease in most impact categories with the exception of 'Climate Change'. For 'Climate Change' net results increase when applying the 100% allocation factor as burdens from recycling and disposal are higher than energy and material credits. In contrast, for PET bottles all impact categories increase due to the lower caloric value of PET than HDPE leading to lower energy credits.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for beverage carton systems, plastic bottles and PP cups due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 160:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TPA Edge DC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 192.37 | -56% | -60% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -62% | -48% |
| Acidification [kg $SO_2$ eq.] | 0.61 | -31% | -36% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 59.41 | -31% | -36% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 44.39 | -55% | -60% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.82 | -34% | -38% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.57 | -32% | -37% |

**Table 161:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TBA Edge HC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TBA Edge HC 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 168.34 | -62% | -65% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -67% | -55% |
| Acidification [kg $SO_2$ eq.] | 0.56 | -38% | -41% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 54.30 | -37% | -42% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.71 | -59% | -63% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.20 | -39% | -43% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.52 | -38% | -42% |

**Table 162:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of **TPA Square DC 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 167.84 | -66% | -59% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -95% | -67% |
| Acidification [kg $SO_2$ eq.] | 0.57 | -51% | -30% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 54.42 | -48% | -30% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.39 | -72% | -57% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.19 | -47% | -33% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.53 | -50% | -32% |

**Table 163:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of<br>**TPA Square DC bb 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 157.68 | -68% | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -86% | -10% |
| Acidification [kg $SO_2$ eq.] | 0.62 | -47% | -23% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 64.89 | -38% | -17% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 71.48 | -50% | -24% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 8.27 | -39% | -23% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.61 | -42% | -21% |

**Table 164:** Comparison of net results: **TPA Square 500mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL IRELAND**

| The net results of<br>**TPA Square 500mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square 500mL ambient | PET Bottle 16 500mL ambient |
| Climate Change [kg $CO_2$eq] | 128.42 | -68% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -95% |
| Acidification [kg $SO_2$ eq.] | 0.47 | -51% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 45.22 | -46% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 32.74 | -73% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.94 | -46% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.44 | -49% |

### 11.3.2 Sensitivity analysis regarding plastic bottle weight

To consider potential future developments in terms of weight of the plastic bottles, a sensitivity analysis with reduced bottle weight is 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 graphs.

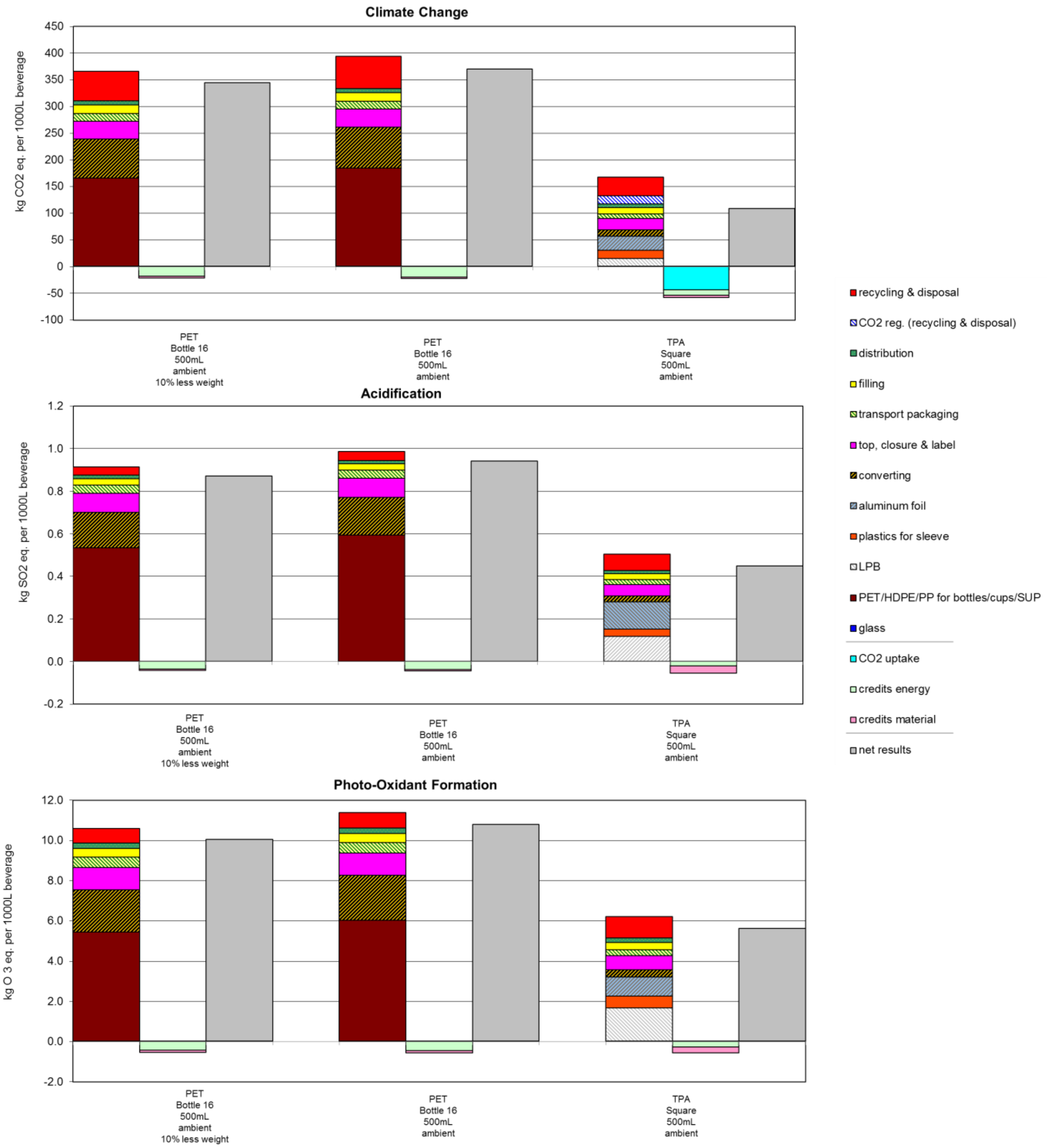



**Figure 132:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 189mL-500mL IRELAND**, allocation factor 50% (Part 1)

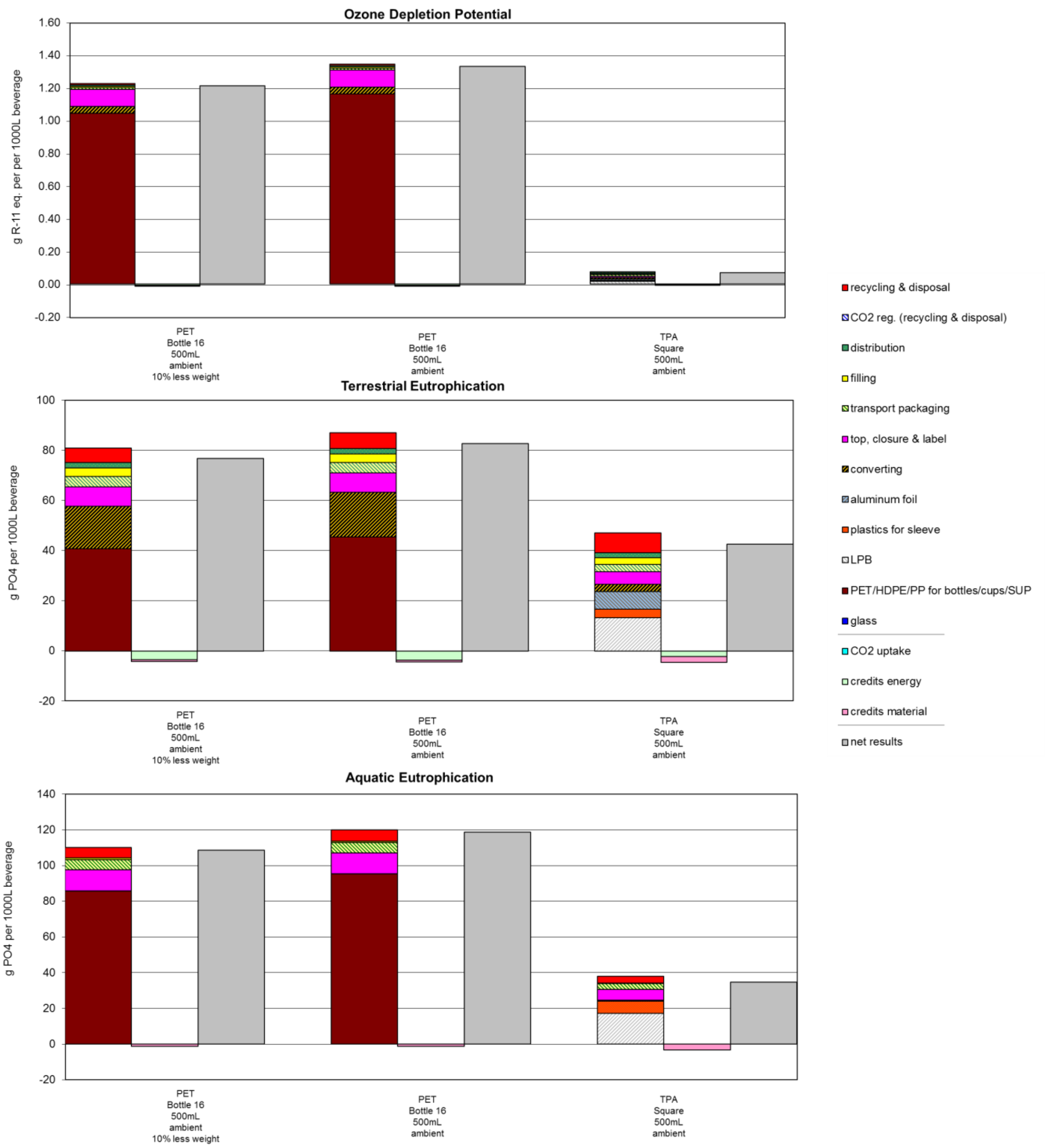



**Figure 133:** Indicator results for sensitivity analysis on plastic bottle weight of segment DAIRY 189mL-500mL IRELAND, allocation factor 50% (Part 2)

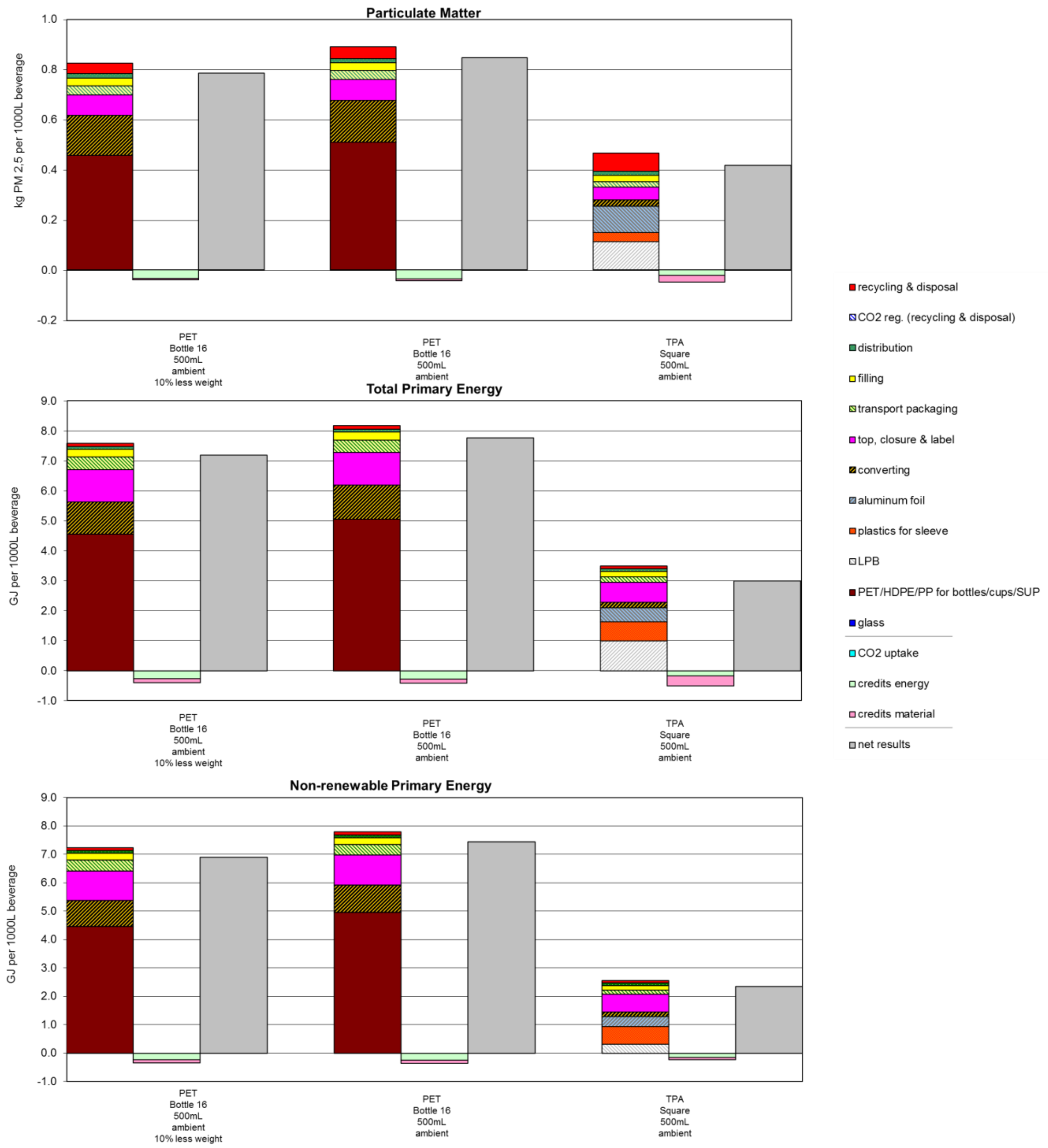



**Figure 134:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 189mL-500mL IRELAND**, allocation factor 50% (Part 3)

## Description and Interpretation

The reduction PET bottle weight by 10% reduces the impacts in most lifecycle steps and also the credits. The reduction of net results range only from results ranges only from 7% - 9%

The described changes in net results do not change the net results' ranking of the compared packaging systems.

### 11.3.3 Sensitivity analysis regarding alternative barrier material in beverage cartons

To consider alternative barrier materials instead of aluminium in beverage cartons, a sensitivity analysis with fossil PE instead of aluminium is performed for the packaging systems listed in Table 32. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

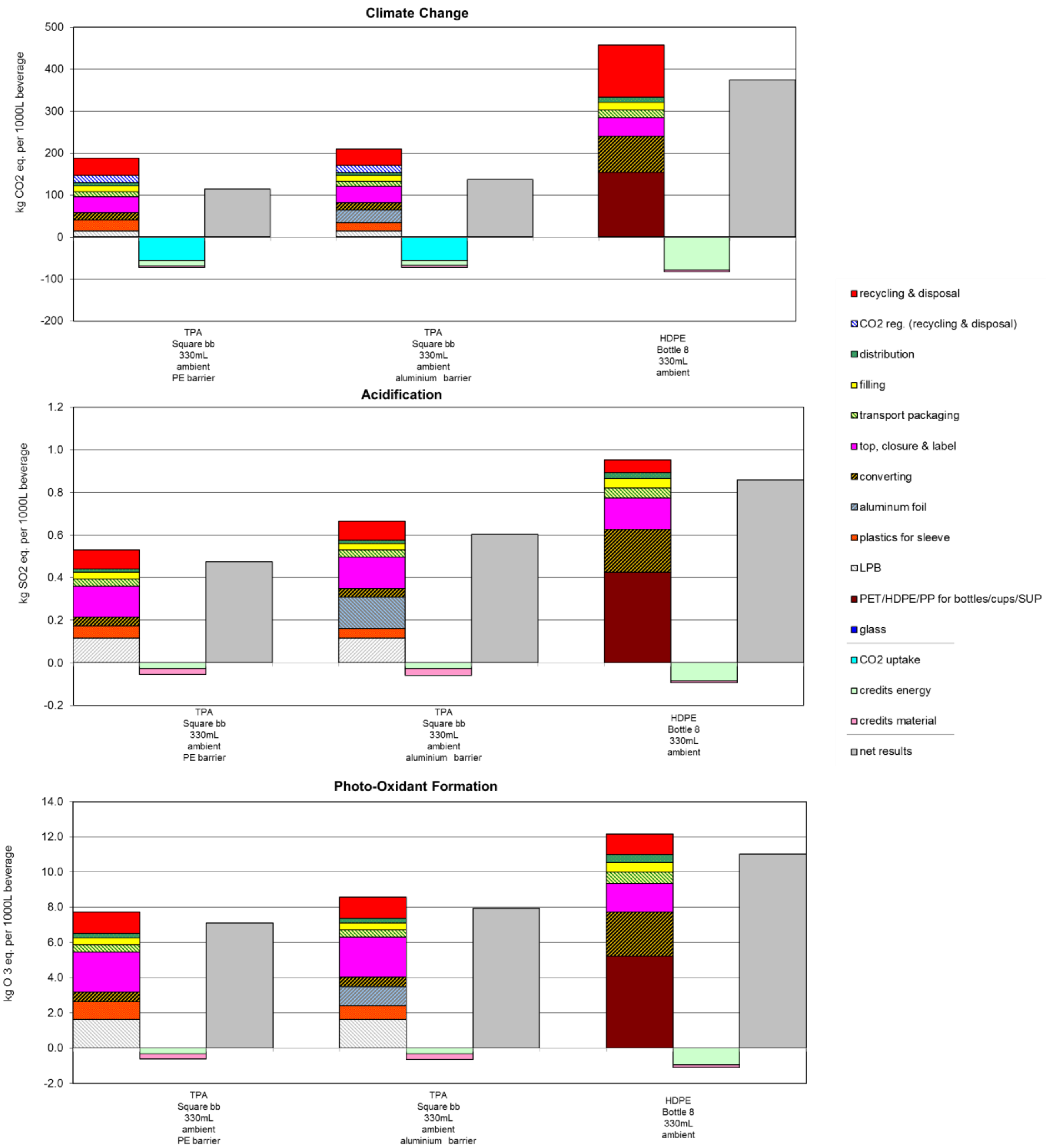



**Figure 135:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of segment DAIRY 189mL-500mL IRELAND, allocation factor 50% (Part 1)

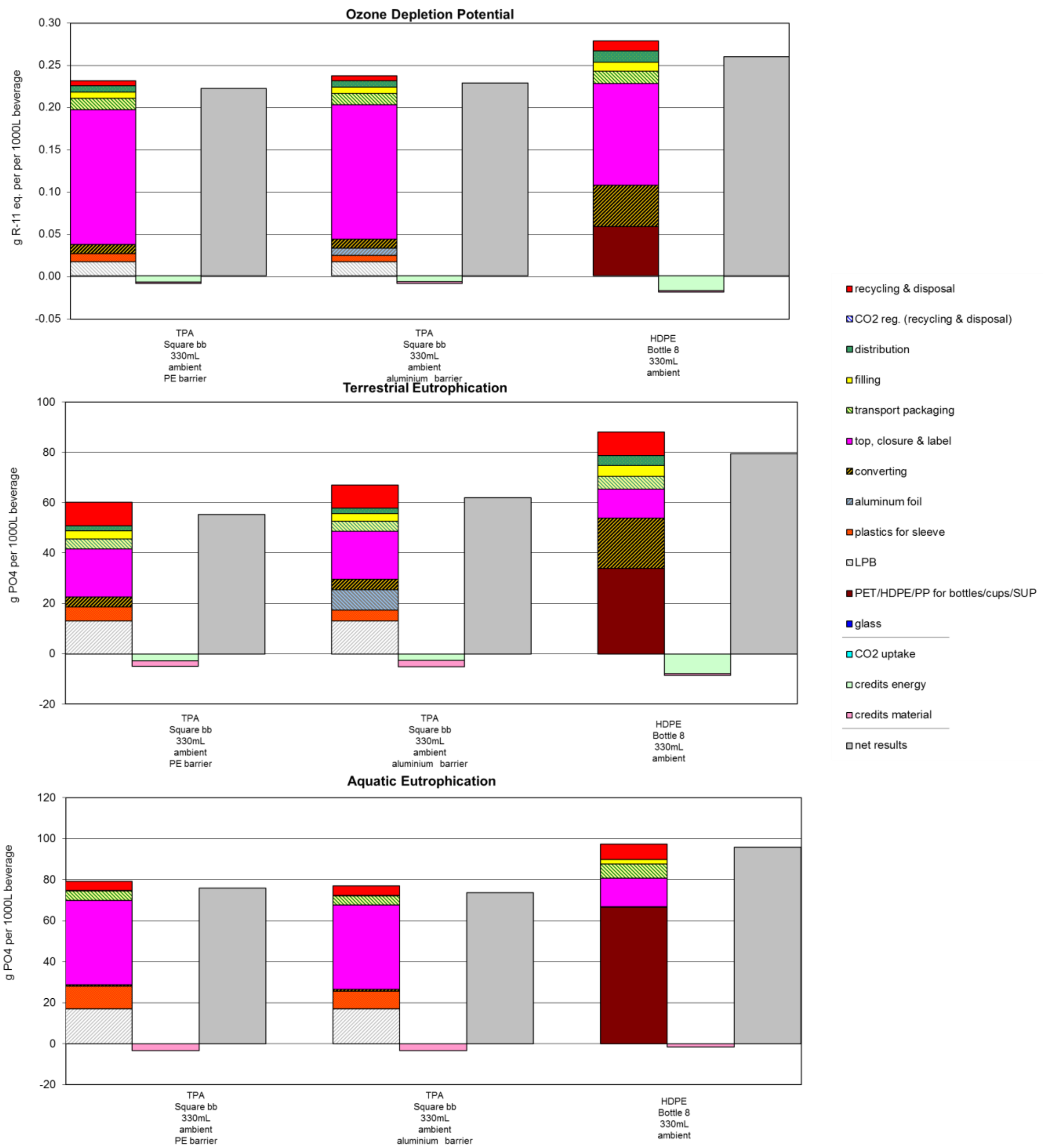



**Figure 136:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of segment DAIRY 189mL-500mL IRELAND, allocation factor 50% (Part 2)

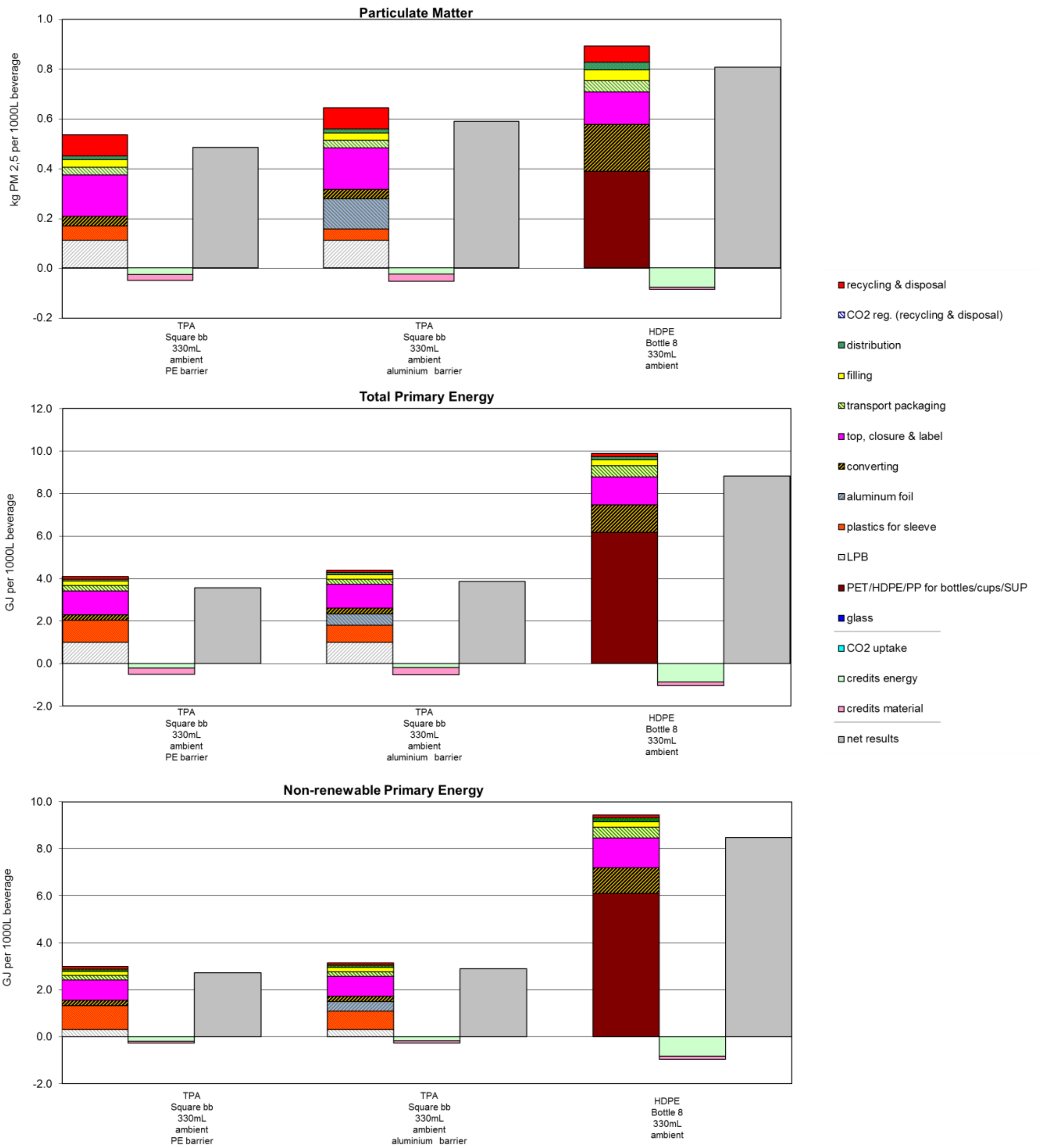



**Figure 137:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 189mL-500mL IRELAND**, allocation factor 50% (Part 3)

## Description and Interpretation

Replacing the aluminium layer in the sleeves by a PE layer leads to reductions of net results of 15% - 20% in the impact categories ‘Particulate Matter’, ‘Acidification’ and ‘Climate Change’. Lower reductions of 5% - 10% can be seen in the categories, ‘Total Primary Energy’, ‘Non-renewable Primary Energy’, ‘Terrestrial Eutrophication’ and ‘Photo-Oxidant Formation’. On the other hand 5% net results can be seen for ‘Aquatic Eutrophication’. Almost no changes can be seen for ‘Ozone Depletion’.

The described changes in net results do not change the net results' ranking of the compared packaging systems.

## 11.4 Sensitivity Analyses DAIRY (CREAM) *300mL-330mL IRELAND*

### 11.4.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

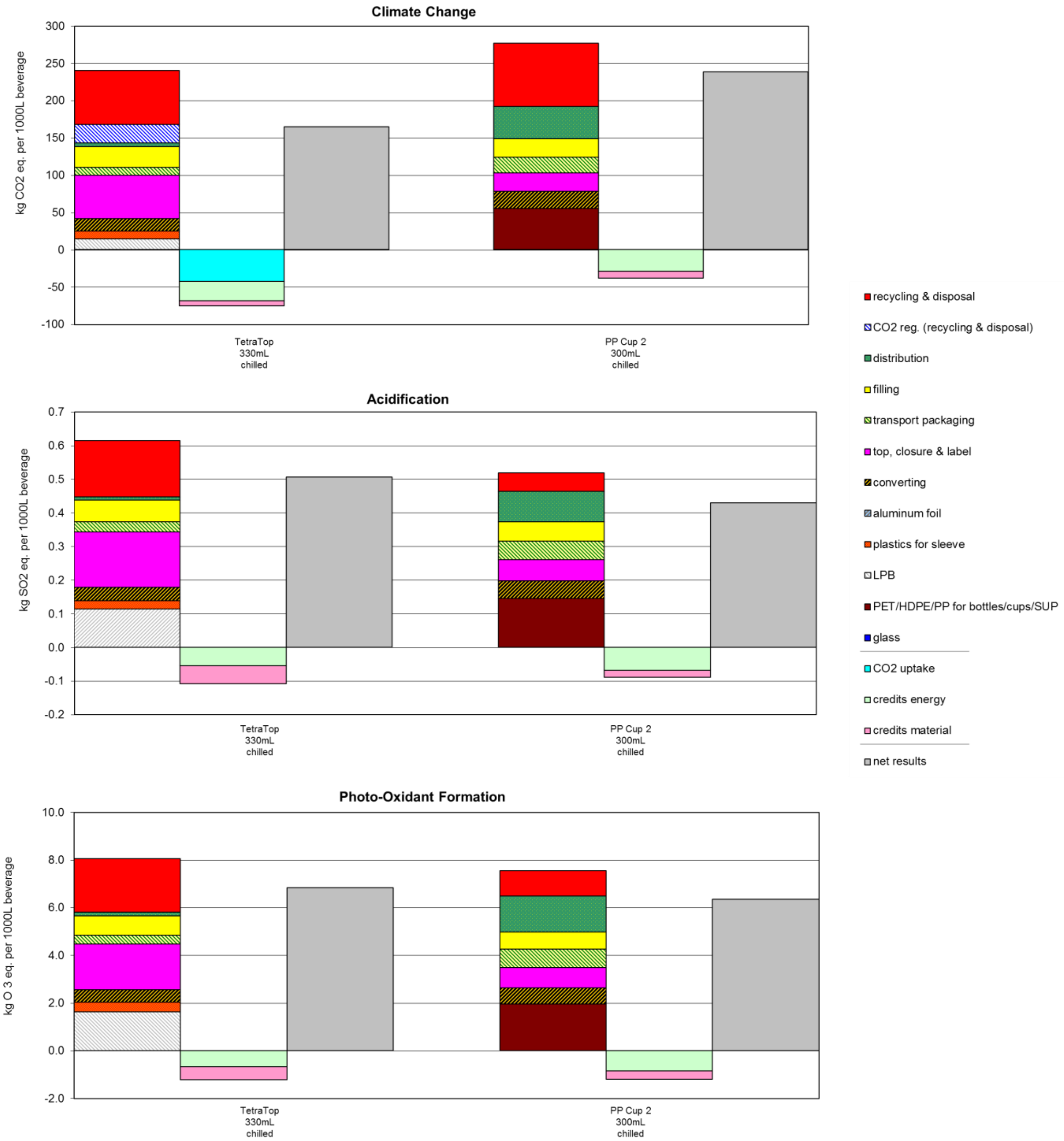



**Figure 138:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 100% (Part 1)

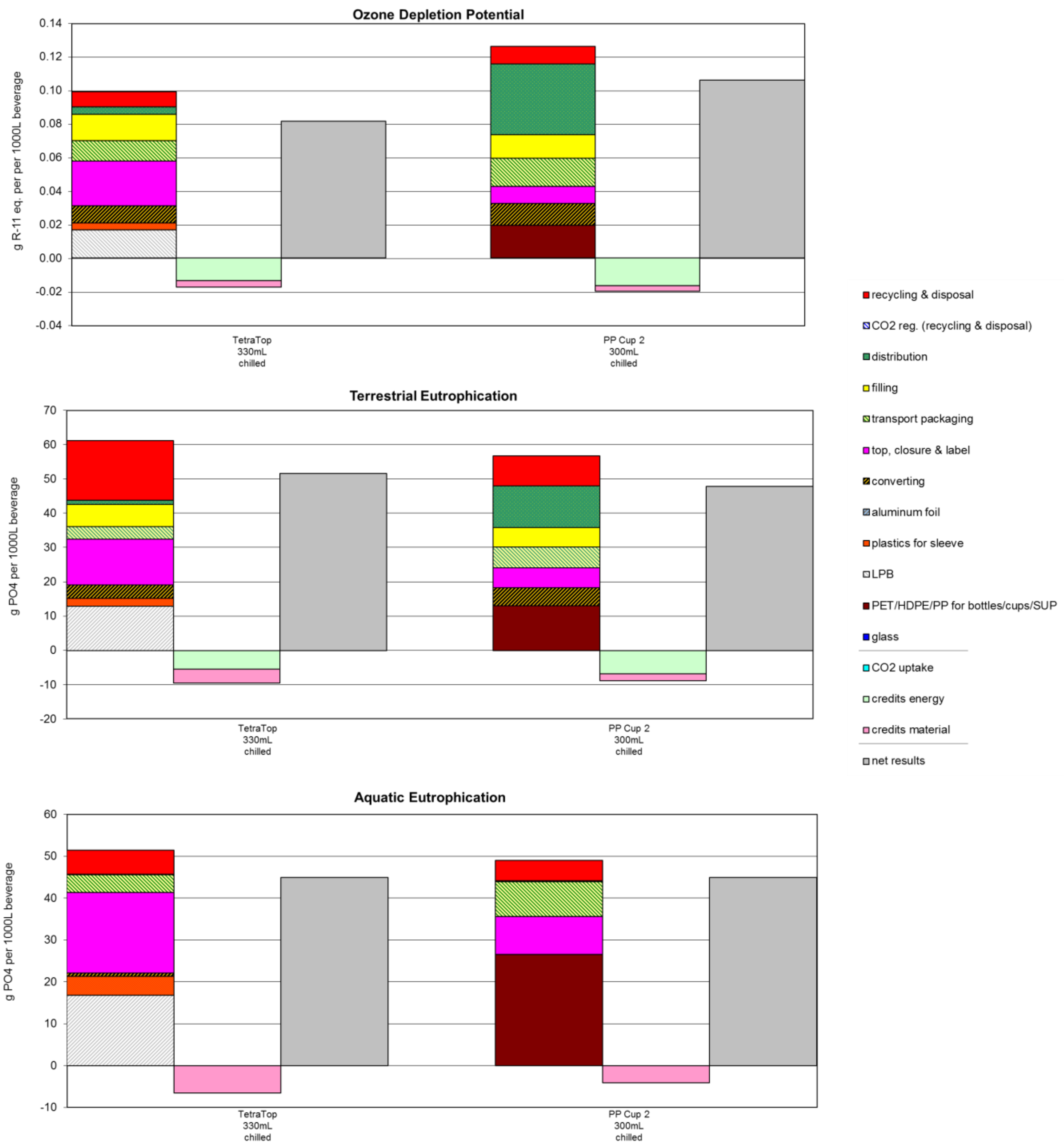



**Figure 139:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 100% (Part 2)

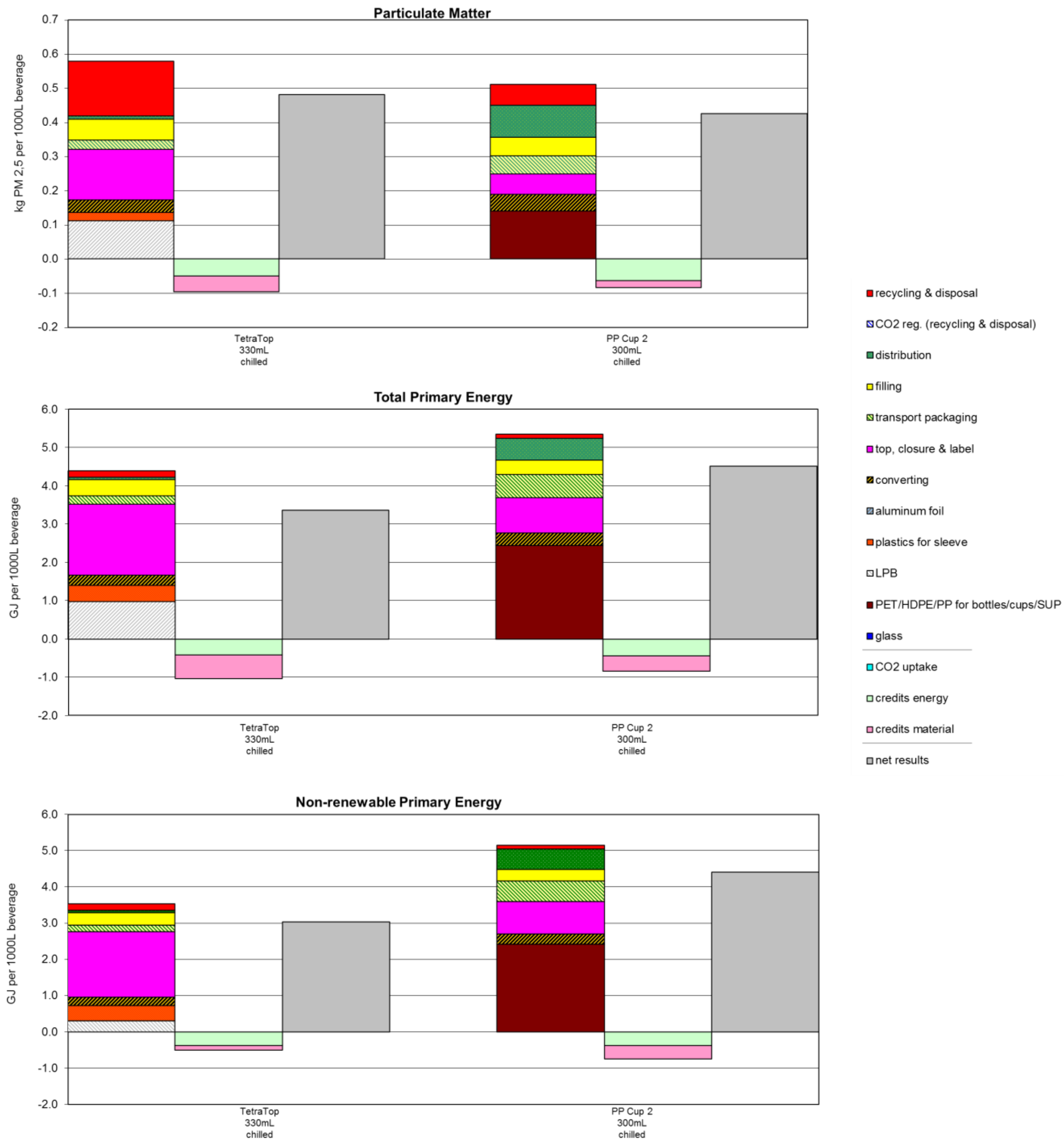



**Figure 140:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (CREAM) 300mL-330mL IRELAND**, allocation factor 100% (Part 3)

## 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 Ireland applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor. These are dominated by the credits received for recycled paper board.

In the case of the PP Cup 2 the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for beverage carton systems, plastic bottles and PP cups due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following table shows the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 165:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **DAIRY (CREAM) 300mL-330mL IRELAND**

| The net results of<br>**TT 330mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TT<br>330mL<br>chilled | PP Cup 2<br>300mL<br>chilled |
| Climate Change [kg $CO_2$eq] | 164.78 | -31% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -23% |
| Acidification [kg $SO_2$ eq.] | 0.51 | 18% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.65 | 8% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 44.90 | 0% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.83 | 8% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.48 | 13% |

## 11.5 Sensitivity Analyses JNSD 200ml-330ml IRELAND

### 11.5.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

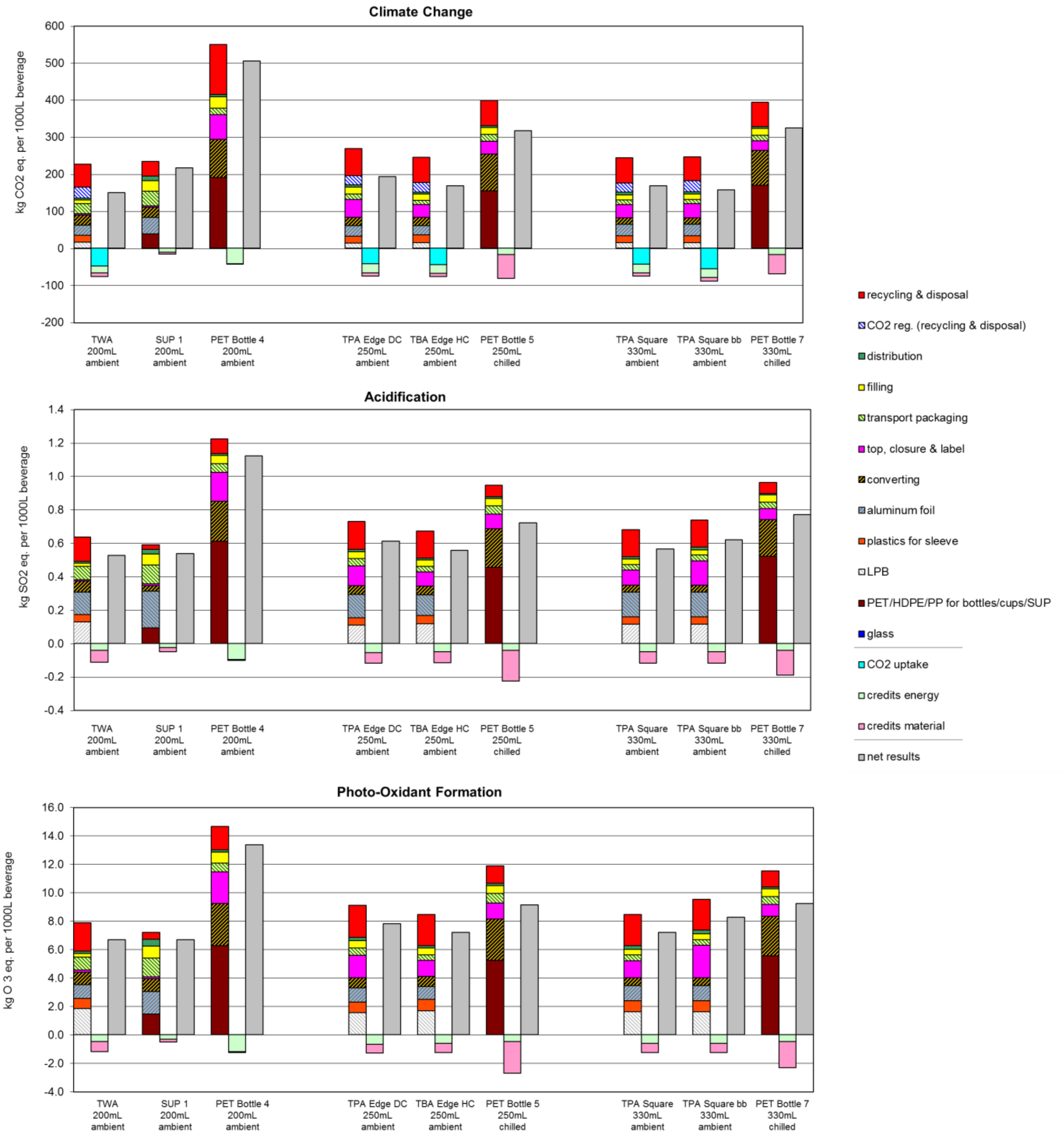



**Figure 141:** Indicator results for sensitivity analysis on system allocation of segment JNSD 200ml-330ml IRELAND, allocation factor 100% (Part 1)

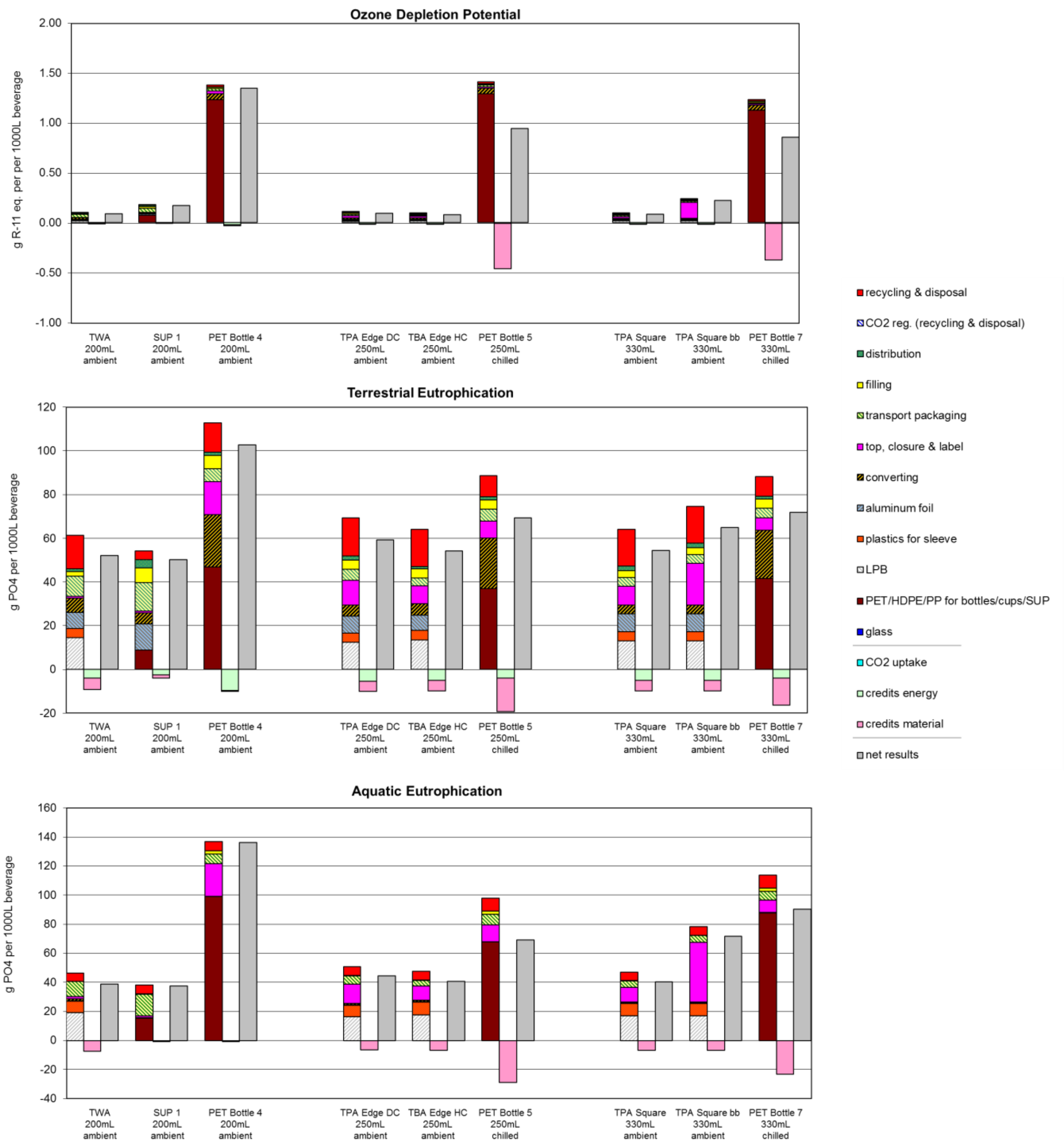



**Figure 142:** Indicator results for sensitivity analysis on system allocation of segment JNSD 200ml-330ml IRELAND, allocation factor 100% (Part 2)

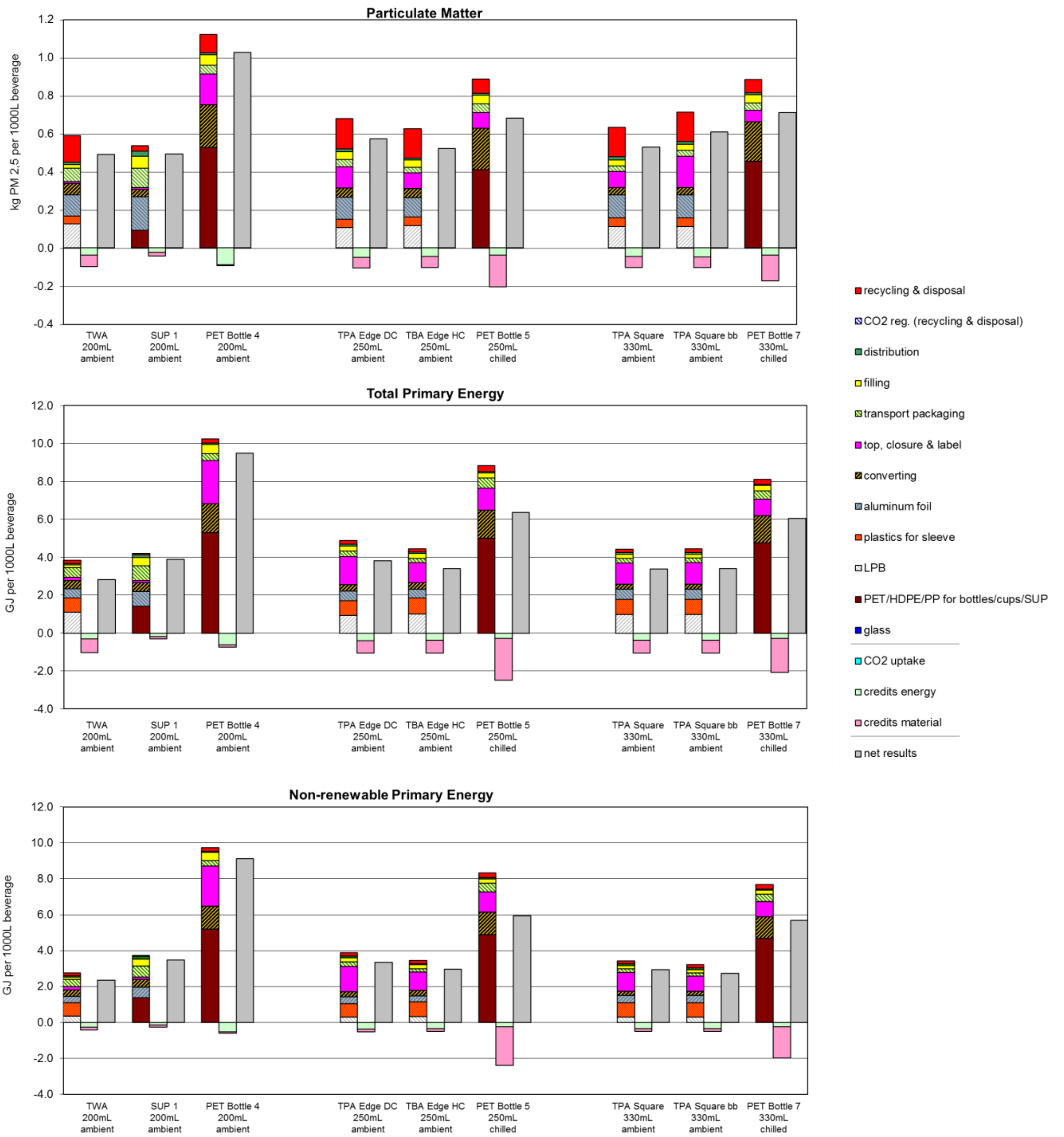



**Figure 143:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml IRELAND**, allocation factor 100% (Part 3)

## 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 Ireland applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor.  These are dominated by the credits received for recycled paper board.

In the cases of most plastic bottles and SUP the net result decrease in most impact categories with the exception of 'Climate Change'. For 'Climate Change' net results increase when applying the 100% allocation factor as burdens from recycling and disposal are higher than energy and material credits. The exception is PET Bottle 4 for which all impact categories increase. Because being an opaque bottle, the PET Bottle 4 is not materially recycled.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 166:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TWA 200mL ambient | SUP 1 200mL ambient | PET Bottle 4 200mL ambient |
| Climate Change [kg $CO_2$eq] | 149.99 | -31% | -70% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -48% | -94% |
| Acidification [kg $SO_2$ eq.] | 0.53 | -2% | -53% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.13 | 4% | -49% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 38.83 | 4% | -71% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.69 | 0% | -50% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -1% | -52% |

**Table 167:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 192.37 | -39% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -90% |
| Acidification [kg $SO_2$ eq.] | 0.61 | -15% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 59.41 | -14% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 44.39 | -36% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.82 | -14% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.57 | -16% |

**Table 168:** Comparison of net results: **TPA Edge HC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Edge HC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 168.34 | -47% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -91% |
| Acidification [kg $SO_2$ eq.] | 0.56 | -23% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 54.30 | -22% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.71 | -41% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.20 | -21% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.52 | -23% |

**Table 169:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 167.84 | -48% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -90% |
| Acidification [kg $SO_2$ eq.] | 0.57 | -27% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 54.42 | -24% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.39 | -55% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.19 | -22% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.53 | -26% |

**Table 170:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml IRELAND**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 157.68 | -51% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -74% |
| Acidification [kg $SO_2$ eq.] | 0.62 | -20% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 64.89 | -10% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 71.48 | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 8.27 | -10% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.61 | -14% |

# 12 Conclusions Ireland

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 Irish 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.

## 12.1 DAIRY 1000mL-2000mL IRELAND

In the comparison of the examined beverage carton TR 1000mL chilled with fossil based plastics to the HDPE bottle, no unambiguous result can be observed. Only in the impact categories ‘Climate Change’, ‘Ozone Depletion Potential’ and ‘Aquatic Eutrophication’ the carton shows lower impacts than the HDPE bottle regardless of the applied allocation factor.

As the TR 1500mL chilled is compared with a HDPE bottle with a higher volume of 2000mL this carton shows higher environmental impacts in all categories apart from ‘Climate Change’.

In case of the beverage cartons containing bio-based plastics, environmental impacts in the category ‘Climate Change’ are lower than those of cartons with fossil based plastics. However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. This leads to the beverage cartons showing higher impacts in all categories except ‘Climate Change’ compared to the HDPE bottles. Especially in the case of the TR bio-based 1500 chilled being compared with the much larger HDPE bottle.

The sensitivity analysis on system allocation shows that while the choice of allocation factor has certain influence on the assessment of the environmental impacts but only for the comparison of the cartons with fossil based plastics it leads to changes in ranking in some categories

## 12.2 JNSD 1000mL IRELAND

In the comparison of the examined beverage carton systems with fossil based plastics to all bottles in this segment, no unambiguous result can be observed. In this segment the examined beverage carton systems with fossil based plastics, show lower environmental impacts in ‘Climate Change’, ‘Ozone depletion potential’ and ‘Aquatic Eutrophication’ than the PET bottle. In the other categories these beverage cartons perform similar or worse than the PET bottle.

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

The sensitivity analysis on system allocation shows that while the choice of allocation factor has certain influence on the assessment of the environmental impacts but only for the comparison of the TBA Edge 1000mL ambient it leads to changes in ranking in some categories

## 12.3 DAIRY *189mL-500mL IRELAND*

In this segment, all examined beverage carton systems show lower environmental impacts in all of the impact categories than the plastic bottles with which they are compared.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a very limited influence on the assessment of the environmental impacts in this segment.

The sensitivity analysis regarding plastic bottle weight shows that a reductions of bottle weight leads to lower environmental impacts of the bottles. A weight reduction of 10% as applied in this sensitivity analysis shows no influence for the comparison with the regarded beverage carton.

The sensitivity analysis regarding alternative barrier material in beverage cartons shows that a substitution of aluminium foil by PE leads to lower environmental impacts in almost all categories. This has no influence for the comparison with the regarded beverage carton.

## 12.4 DAIRY (CREAM) *300mL-330mL IRELAND*

In the comparison of the examined beverage carton systems with fossil based plastics to all bottles in this segment, no unambiguous result can be observed. In this segment the examined beverage carton system with fossil based plastics, show lower environmental impacts in 'Climate Change' and 'Ozone depletion potential' than the PP cup. In the other categories this beverage cartons perform similar or worse than the PET bottle depending on the applied allocation factor.

## 12.5 JNSD 200ml-330ml IRELAND

In this segment examined beverage carton systems with fossil based plastics show lower environmental impacts in all of the examined impact categories than the compared PET bottles and lower or similar impacts than the SUP.

In case of the beverage carton containing bio-based plastics (i.e TPA Square DC bb 330mL ambient), environmental impacts in the category 'Climate Change' are lower than those of the respective carton with fossil based plastics (i.e TPA Square DC 330mL ambient). However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. The influence of bio-based plastics is limited, though, as only a small share of plastics is bio-based. That means that also the TPA Square DC bb 330mL ambient shows lower or similar impacts in all categories.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a limited influence on the assessment of the environmental impacts in this segment.

# 13 Results United Kingdom

In this section, the results of the examined packaging systems for the United Kingdom 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/PP for bottles/cups/SUP including additives, e.g. carbon black (**'PET/HDPE/PP for bottles/cups/SUP'**)
- production and transport of liquid packaging board **('LPB')**
- production and transport of plastics and additives for beverage carton **('plastics for sleeve')**
- production and transport of aluminium & converting to foil **('aluminium foil')**
- converting processes of cartons **('converting')**
- production and transport of base materials for closures, top and label **('top, closure & label')**
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays **('transport packaging')**
- filling process including packaging handling **('filling')**
- retail of the packages from filler to the point-of-sale including cooling during transport if relevant **('distribution')**
- $CO_2$ emissions from incineration of bio-based and renewable materials **('CO2 reg. (recycling & disposal)')**; in the following also the term regenerative CO2 emissions is used
- sorting, recycling and disposal processes **('recycling & disposal')**

Secondary products (recycled materials and recovered energy) are obtained through recovery processes of used packaging materials, e.g. recycled fibres from cartons may replace primary fibres. It is assumed, that those secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental loads of the substituted material. The so-called 50% allocation method has been used for the crediting procedure (see section1.7) in the base scenarios.

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')**
- Uptake of athmospheric $CO_2$ during the plant growth phase ('**$CO_2$-uptake**')

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
Each impact category graph includes three bars per packaging system under investigation, which illustrate (from left to right):

- sectoral results of the packaging system itself (stacked bar ‘environmental burdens’)
- credits given for secondary products leaving the system (negative stacked bar ‘credits’)
- net results as a results of the substraction of credits from overall environmental loads (grey bar ‘net results’)

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

A note on significance: 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 is common practice for LCA studies comparing different product systems. This means differences ≤ 10% are considered as insignificant.

# *13.1* Results base scenarios DAIRY 1000mL-2000mL UNITED KINGDOM

## 13.1.1 Presentation of results

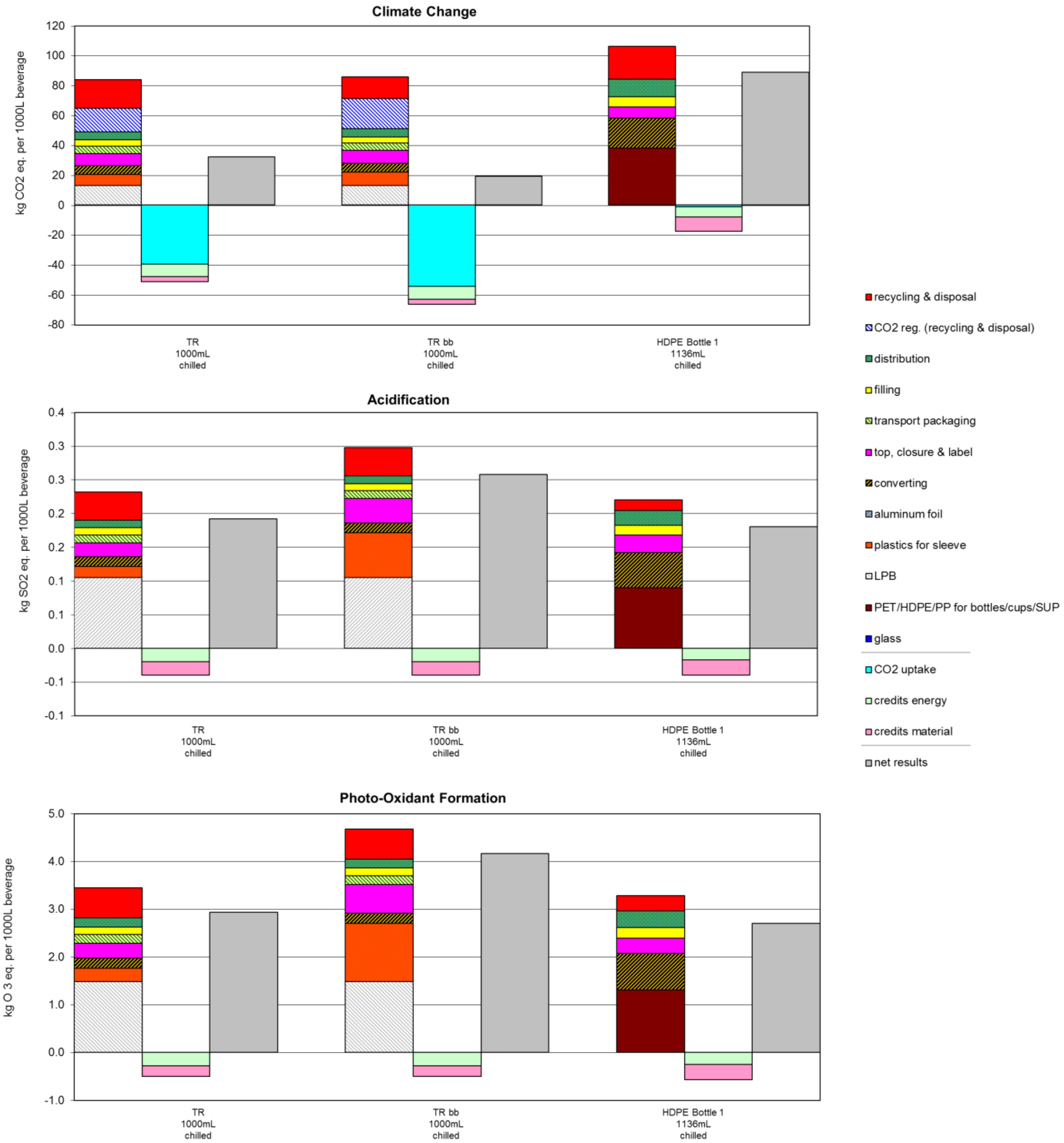



**Figure 144:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 50% (Part 1)

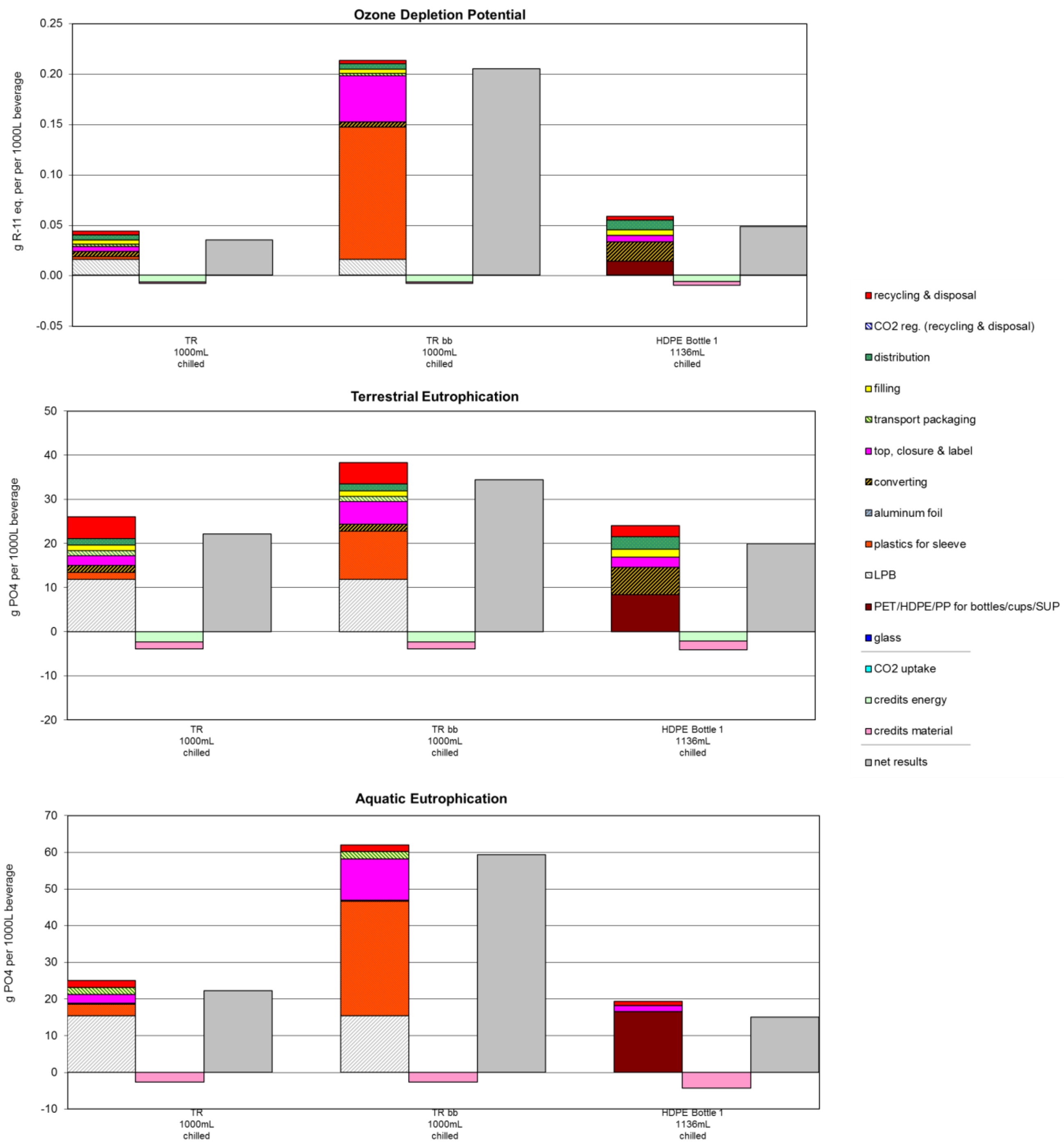



**Figure 145** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 50% (Part 2)

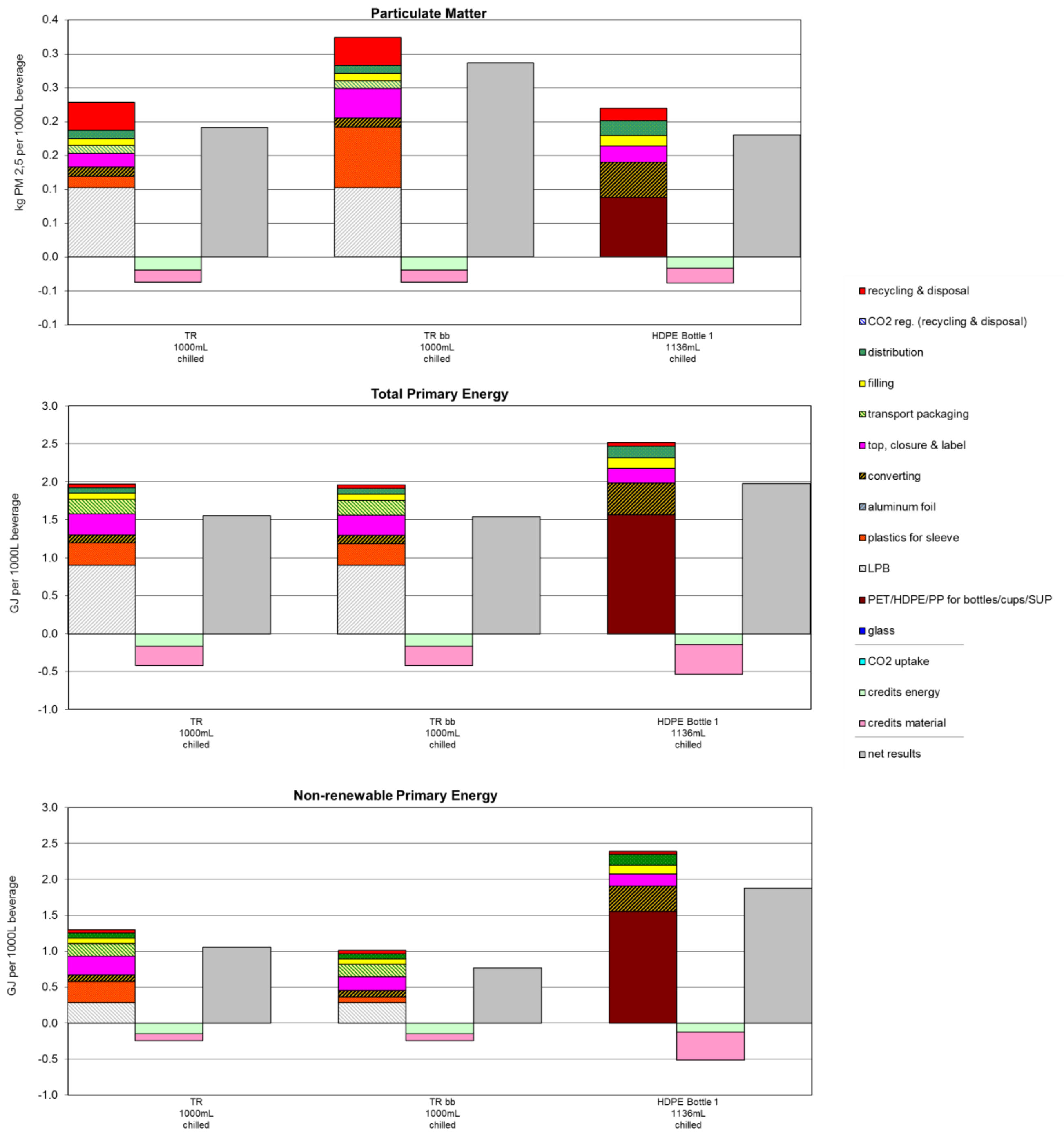



**Figure 146:** Indicator results for base scenarios of segment DAIRY 1000mL-2000mL UNITED KINGDOM, allocation factor 50% (Part 3)

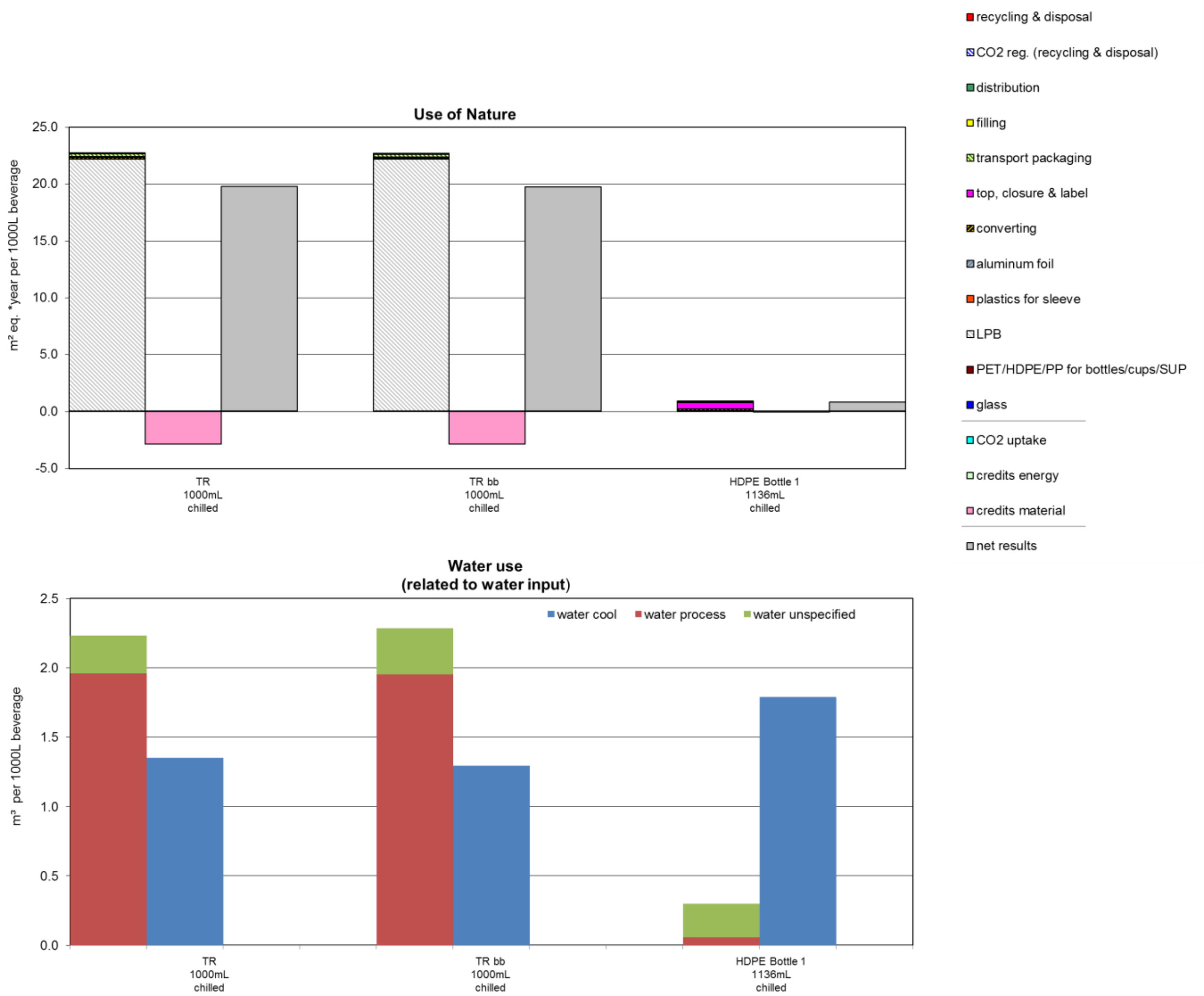



**Figure 147:** Indicator results for base scenarios of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 50% (Part 4)

**Table 171:** Category indicator results per impact category for base scenarios of **segment DAIRY 1000mL-2000mL UNITED KINGDOM** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TR 1000mL chilled | TR bb 1000mL chilled | HDPE Bottle 1 1136mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 67.82 | 65.66 | 105.94 |
| | CO2 (reg) | 15.84 | 20.03 | 0.25 |
| | Credits* | -11.99 | -11.96 | -16.39 |
| | $CO_2$ uptake | -39.44 | -54.57 | -1.18 |
| | Net results (∑) | 32.24 | 19.16 | 88.61 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.23 | 0.30 | 0.22 |
| | Credits* | -0.04 | -0.04 | -0.04 |
| | Net results (∑) | 0.19 | 0.26 | 0.18 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 3.44 | 4.67 | 3.27 |
| | Credits* | -0.51 | -0.51 | -0.58 |
| | Net results (∑) | 2.93 | 4.16 | 2.70 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.04 | 0.21 | 0.06 |
| | Credits* | -0.01 | -0.01 | -0.01 |
| | Net results (∑) | 0.04 | 0.20 | 0.05 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 26.02 | 38.37 | 24.09 |
| | Credits* | -3.90 | -3.89 | -4.11 |
| | Net results (∑) | 22.12 | 34.48 | 19.98 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 24.99 | 61.94 | 19.32 |
| | Credits* | -2.69 | -2.69 | -4.21 |
| | Net results (∑) | 22.30 | 59.26 | 15.10 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.23 | 0.32 | 0.22 |
| | Credits* | -0.04 | -0.04 | -0.04 |
| | Net results (∑) | 0.19 | 0.29 | 0.18 |
| Total Primary Energy [GJ] | Burdens | 1.98 | 1.96 | 2.52 |
| | Credits* | -0.42 | -0.42 | -0.54 |
| | Net results (∑) | 1.56 | 1.54 | 1.98 |
| Non-renewable primary energy [GJ] | Burdens | 1.30 | 1.01 | 2.39 |
| | Credits* | -0.24 | -0.24 | -0.51 |
| | Net results (∑) | 1.06 | 0.77 | 1.88 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 22.64 | 22.63 | 0.82 |
| | Credits* | -2.92 | -2.92 | -0.05 |
| | Net results (∑) | 19.72 | 19.71 | 0.77 |
| Water use [$m^3$] | Water cool | 1.35 | 1.29 | 1.79 |
| | Water process | 1.96 | 1.95 | 0.06 |
| | Water unspec | 0.27 | 0.33 | 0.24 |

*material and energy credits

### 13.1.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the DAIRY 1000mL-2000mL 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%-55%) and 'Use of Nature' (90%). It is also relevant regarding 'Photo-Oxidant Formation' (30%-40%), 'Acidification' (32%-41), 'Terrestrial Eutrophication' (29&-41%), 'Particulate Matter' (29%-41%) and also the consumption of 'Total Primary Energy' (44%).

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 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 step production of 'aluminium foil' for the sleeves shows no results as all beverage cartons in this segment are chilled and therefore don't have an aluminium layer.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (5%-58%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The exception is the inventory category 'Non-renewable Primary Energy', where in case of the carton with fossil based plastics, the plastics (22%) and LPB (21%) contribute about the same. If 'plastics for sleeve' contains bio-based plastics (i.e. for TR bb 1000mL chilled), this life cycle step plays a major role for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step ‘top, closure & label’ contributes to a considerable amount (7%-20%) in almost all impact categories. In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TR bio-based 1000mL), the results are considerably higher than for cartons with fossil based cartons in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (max 9%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems show considerable shares of impacts (6%-25%) in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 10%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (39%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration and landfilling of packaging materials.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the UK these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extend from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the UK the majority of the beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded plastic HDPE bottle system in the DAIRY 1000mL-2000mL segment, the biggest part of the environmental burdens (35%-86%) is also caused by the production of the base materials of the bottles in most impact and inventory categories.

The 'converting' process shows a considerable shares of impacts (15%-33%) in all categories apart from 'Aquatic Eutrophication' with shares less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows minor impacts (7%-12%) in most categories mainly attributed to the different plastics used for the closures. For the impact categories 'Acidification', 'Particulate Matter' as well as the inventory categories 'Total Primary Energy' and 'Non-renewable Primary Energy' shares are in the higher range due to the aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems shows no impacts in all categories due to the transport on roll containers without any other secondary or tertiary packaging material. The burdens from the production of roll containers can be neglected because of their high number of use cycles.

Due to the heavy weight of the roll containers and their smaller capacity the life cycle step 'distribution' shows considerable shares of impacts (up to 17%). These impacts are higher compared to the cartons transported on pallets.

The life cycle step 'filling' shows only small shares of burdens (max 9%) in most impact categories. Therefore this step doesn't play an important role for the overall results in any category.

The impact of the plastic bottle's 'recycling & disposal' life cycle step is highest regarding 'Climate Change' (21%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. With a recycling rate of 57% for the clear plastic bottles, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

### 13.1.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 172:** Comparison of net results: **TR 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, UNITED KINGDOM**

| The net results of<br>**TR 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TR 1000mL chilled | HDPE Bottle 1 1136mL chilled |
| Climate Change [kg $CO_2$eq] | 32.24 | -64% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -27% |
| Acidification [kg $SO_2$ eq.] | 0.19 | 6% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 22.12 | 11% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 22.30 | 48% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.93 | 9% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.19 | 6% |

**Table 173:** Comparison of net results: **TR bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, UNITED KINGDOM**

| The net results of<br>**TR bb 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TR bb 1000mL chilled | HDPE Bottle 1 1136mL chilled |
| Climate Change [kg $CO_2$eq] | 19.16 | -78% |
| Ozone depletion potential [g R-11 eq.] | 0.20 | 324% |
| Acidification [kg $SO_2$ eq.] | 0.26 | 43% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 34.48 | 73% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 59.26 | 292% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.16 | 54% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.29 | 59% |

# 13.2 Results base scenarios JNSD 1000mL UNITED KINGDOM

## 13.2.1 Presentation of results

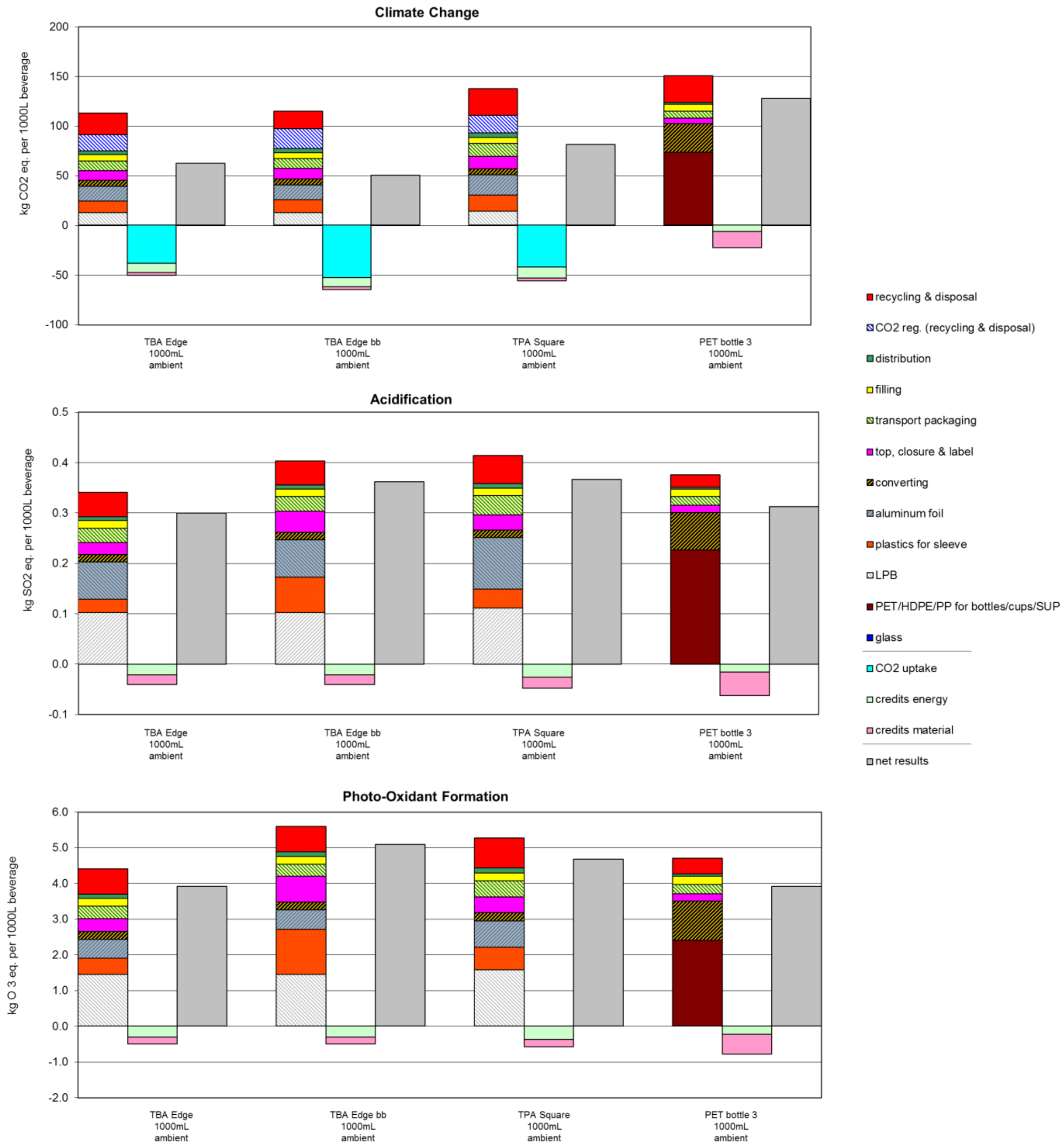



**Figure 148:** Indicator results for base scenarios of segment JNSD 1000mL, UNITED KINGDOM, allocation factor 50% (Part 1)

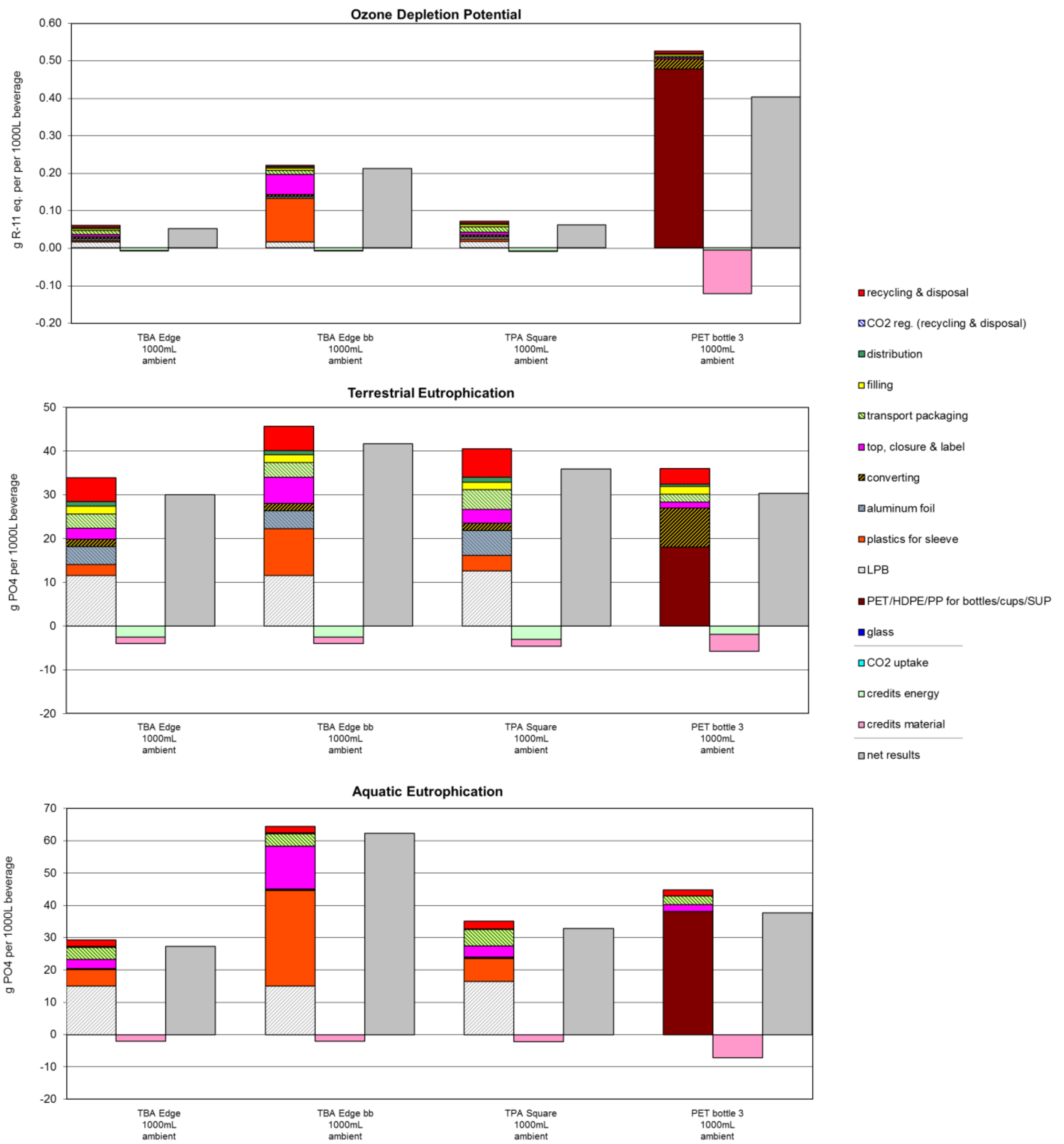



**Figure 149:** Indicator results for base scenarios of **segment JNSD 1000mL, UNITED KINGDOM**, allocation factor 50% (Part 2)

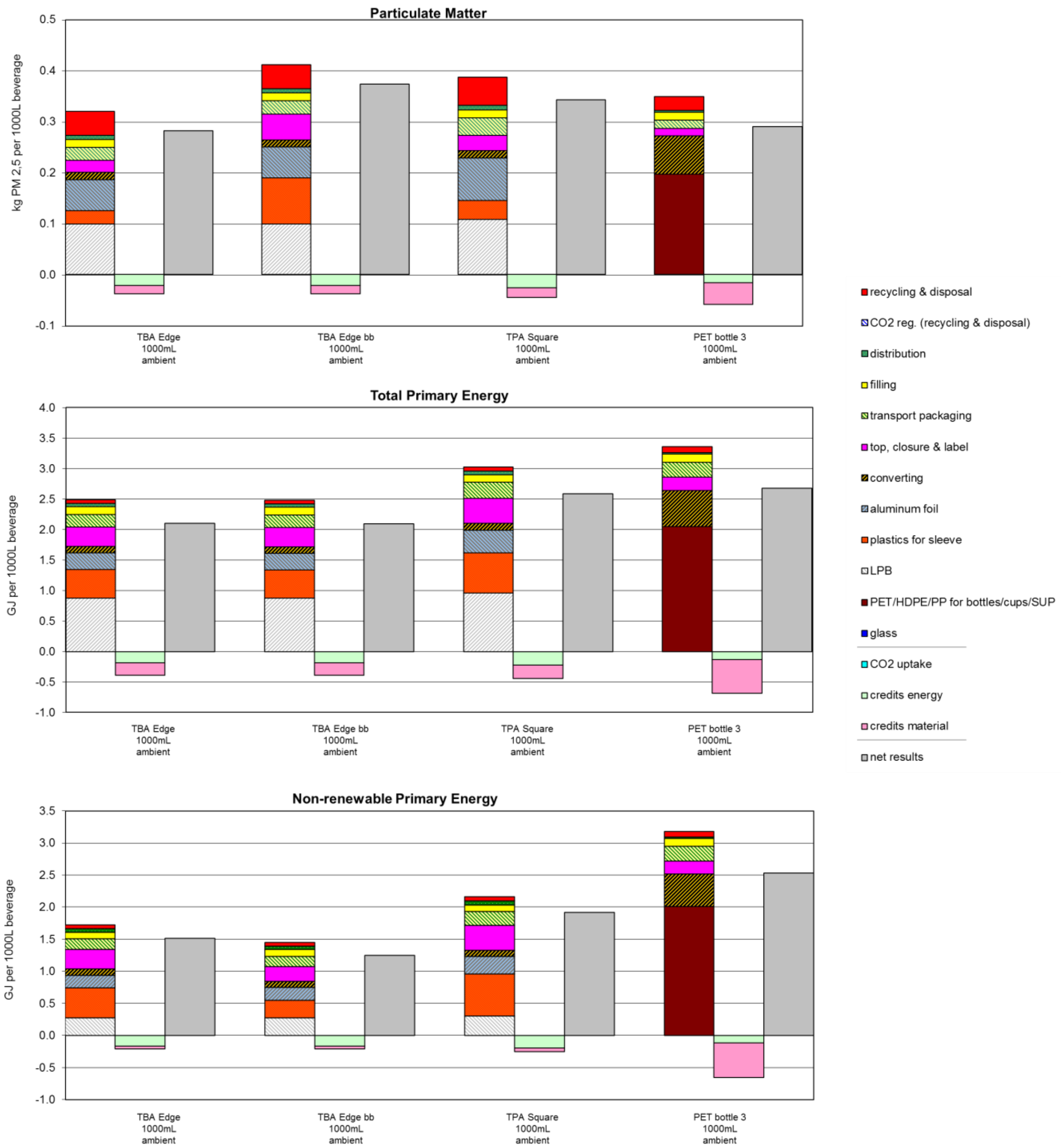



**Figure 150:** Indicator results for base scenarios of **segment JNSD 1000mL, UNITED KINGDOM**, allocation factor 50% (Part 3)

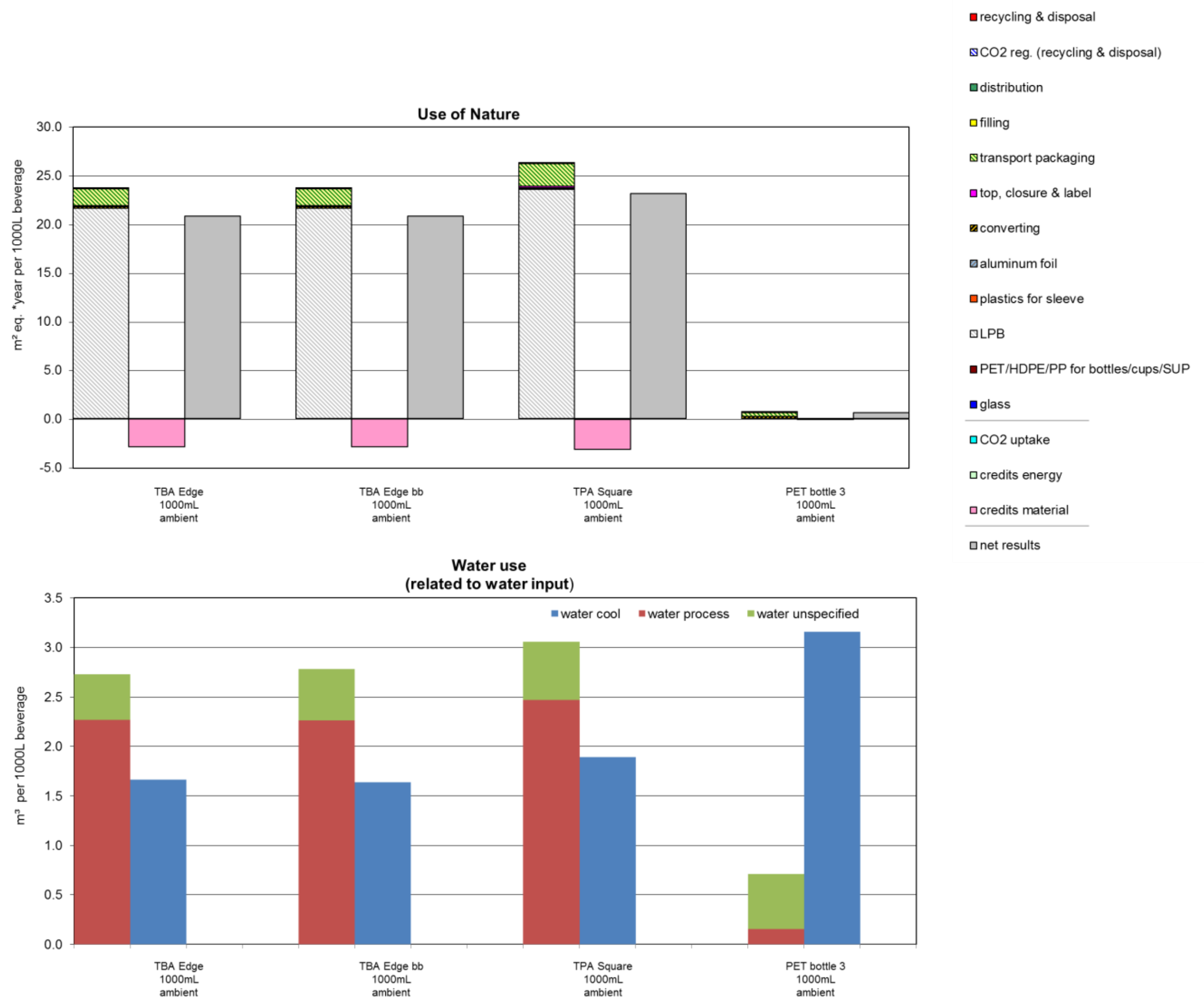



**Figure 151:** Indicator results for base scenarios of segment JNSD 1000mL, UNITED KINGDOM, allocation factor 50% (Part 4)

**Table 174:** Category indicator results per impact category for base scenarios of segment **segment JNSD 1000mL, UNITED KINGDOM** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TBA Edge 1000mL ambient | TBA Edge bb 1000mL ambient | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient |
|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 96.60 | 94.87 | 119.67 | 150.25 |
| | CO2 (reg) | 15.98 | 19.94 | 17.56 | 0.00 |
| | Credits* | -11.88 | -11.92 | -14.20 | -22.67 |
| | $CO_2$ uptake | -38.53 | -52.85 | -41.98 | 0.00 |
| | Net results (∑) | 62.17 | 50.03 | 81.04 | 127.59 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.34 | 0.40 | 0.41 | 0.38 |
| | Credits* | -0.04 | -0.04 | -0.05 | -0.06 |
| | Net results (∑) | 0.30 | 0.36 | 0.37 | 0.31 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 4.40 | 5.58 | 5.26 | 4.70 |
| | Credits* | -0.50 | -0.50 | -0.58 | -0.79 |
| | Net results (∑) | 3.90 | 5.09 | 4.68 | 3.91 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.06 | 0.22 | 0.07 | 0.53 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.12 |
| | Net results (∑) | 0.05 | 0.21 | 0.06 | 0.40 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 33.94 | 45.67 | 40.57 | 36.06 |
| | Credits* | -3.92 | -3.93 | -4.60 | -5.73 |
| | Net results (∑) | 30.03 | 41.74 | 35.97 | 30.33 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 29.25 | 64.30 | 34.98 | 44.71 |
| | Credits* | -2.05 | -2.05 | -2.23 | -7.18 |
| | Net results (∑) | 27.20 | 62.25 | 32.75 | 37.53 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.32 | 0.41 | 0.39 | 0.35 |
| | Credits* | -0.04 | -0.04 | -0.04 | -0.06 |
| | Net results (∑) | 0.28 | 0.37 | 0.34 | 0.29 |
| Total Primary Energy [GJ] | Burdens | 2.49 | 2.48 | 3.03 | 3.36 |
| | Credits* | -0.39 | -0.39 | -0.44 | -0.68 |
| | Net results (∑) | 2.11 | 2.10 | 2.59 | 2.68 |
| Non-renewable primary energy [GJ] | Burdens | 1.72 | 1.45 | 2.16 | 3.18 |
| | Credits* | -0.21 | -0.21 | -0.25 | -0.65 |
| | Net results (∑) | 1.52 | 1.25 | 1.92 | 2.53 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 23.68 | 23.67 | 26.25 | 0.69 |
| | Credits* | -2.88 | -2.88 | -3.13 | -0.05 |
| | Net results (∑) | 20.80 | 20.79 | 23.12 | 0.64 |
| Water use [$m^3$] | Water cool | 1.66 | 1.64 | 1.89 | 3.16 |
| | Water process | 2.27 | 2.26 | 2.47 | 0.15 |
| | Water unspec | 0.46 | 0.52 | 0.58 | 0.56 |

*material and energy credits

### 13.2.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 1000mL 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' (23%-51%) and 'Use of Nature' (90%-91%). It is also relevant regarding 'Photo-Oxidant Formation' (26%-33%), 'Acidification' (25%-30%), 'Terrestrial Eutrophication' (25%-31%), 'Particulate Matter' (24%-31%) and also the consumption of 'Total Primary Energy' (32%-35%).

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 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 shows burdens in most impact categories. Considerable burdens can be seen for the categories 'Acidification' (18%-25%) and 'Particulate Matter' (25%-22%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (7%-53%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are 'Climate Change', where the fossil plastics (10%-12%) and LPB (10%-11%) contribute about the same and the inventory category 'Non-renewable Primary Energy', where the plastics make up about 20% - 30% of the total burdens. If 'plastics for sleeve' contains bio-based plastics (i.e. for TBA Edge bio-based 1000mL ambient), this life cycle step plays a major role for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step 'top, closure & label' contributes to a considerable amount (7%-25%) in almost all impact categories. In case the plastics used for 'top, closure & label' are bio-based (i.e. TBA Edge bio-based 1000mL ambient), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a minor role (max 9%). It generates emissions, which contribute to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems show considerable shares of impacts (5%-21%) in all categories.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 9%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (33%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration and landfilling of packaging materials.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the UK these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extend from landfills. Material credits from material recycling are lower than energy credits in all impact categories except 'Aquatic Eutrophication' and 'Use of Nature' as in the UK the majority of beverage cartons is not recycled.. Material credits for 'Climate Change' are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the JNSD 1000mL segment, the biggest part of the environmental burdens (49%-91%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production, nevertheless a considerable share of burdens derives from the production of the PA additive. The high results of ‘Ozone Depletion Potential’ are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The ‘converting’ process of all regarded bottles shows considerable shares of impact (5%-30%) in all categories apart from ‘Aquatic Eutrophication’ with a share of impact less than 1%. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows minor shares of impacts (max 7%) in most categories mainly attributed to the plastics used for the closure.

The production and provision of ‘transport packaging’ for the bottle system shows small shares of impacts (1%-7%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 58% of the burdens. For most categories the relevant emissions derive from shrink foil production. The exception is ‘Aquatic Eutrophication’, where the emissions result from the production of paper for slipsheets.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 5%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (18%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. With a recycling rate of 57% for the clear plastic bottle, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

### 13.2.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 175:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, UNITED KINGDOM**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 62.17 | -51% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -87% |
| Acidification [kg $SO_2$ eq.] | 0.30 | -4% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 30.03 | -1% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 27.20 | -28% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.90 | 0% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.28 | -3% |

**Table 176:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, UNITED KINGDOM**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 50.03 | -61% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -47% |
| Acidification [kg $SO_2$ eq.] | 0.36 | 16% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 41.74 | 38% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 62.25 | 66% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 3.07 | 0% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.37 | 29% |

**Table 177:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, UNITED KINGDOM**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 81.04 | -36% |
| Ozone depletion potential [g R-11 eq.] | 0.06 | -85% |
| Acidification [kg $SO_2$ eq.] | 0.37 | 17% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.97 | 19% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 32.75 | -13% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.68 | 20% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.34 | 18% |

## 13.3 Results base scenarios DAIRY *189mL-500mL UNITED KINGDOM*

### 13.3.1 Presentation of results

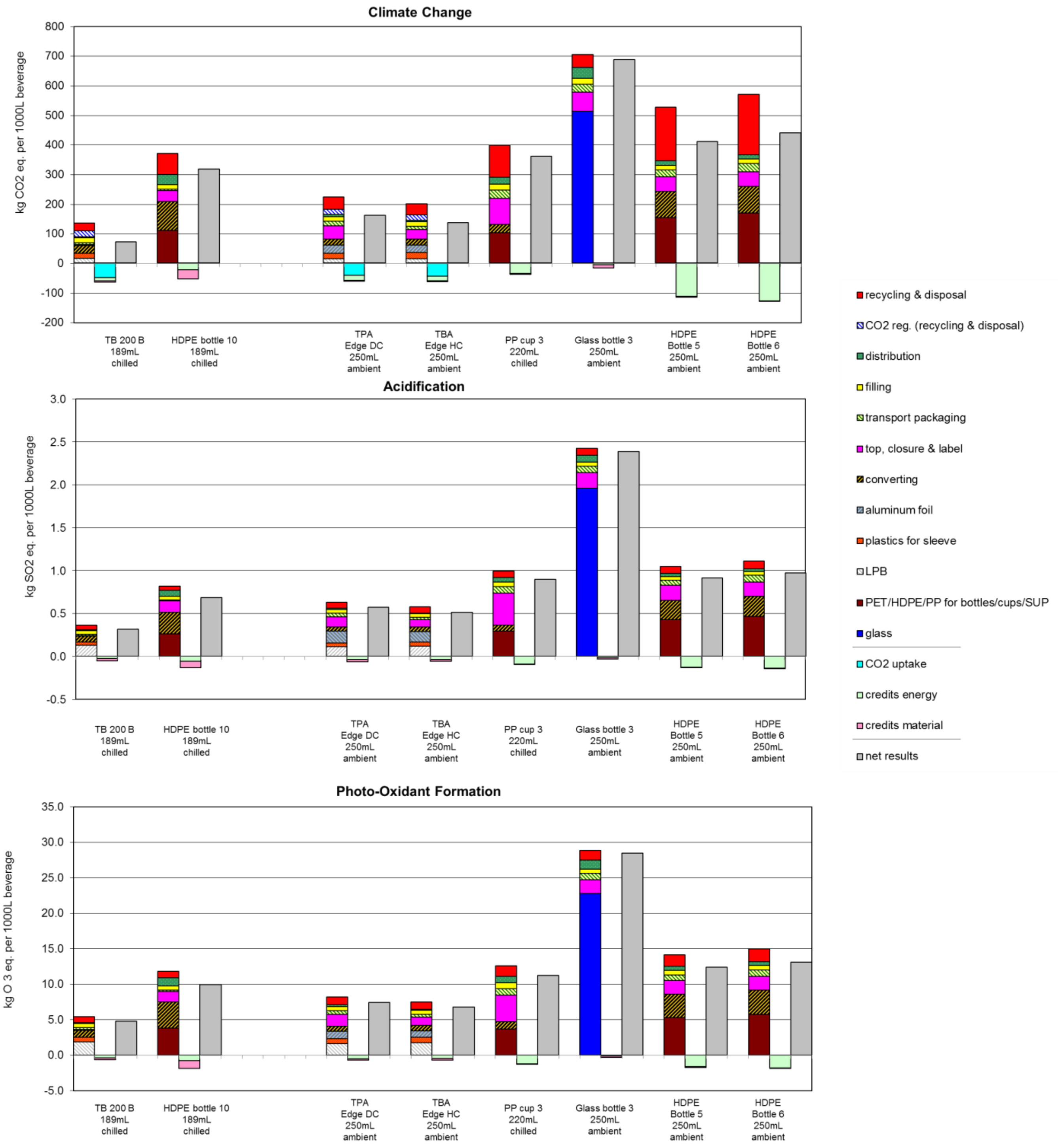



**Figure 152:** Indicator results for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (189mL-250mL)**, allocation factor 50% (Part 1)

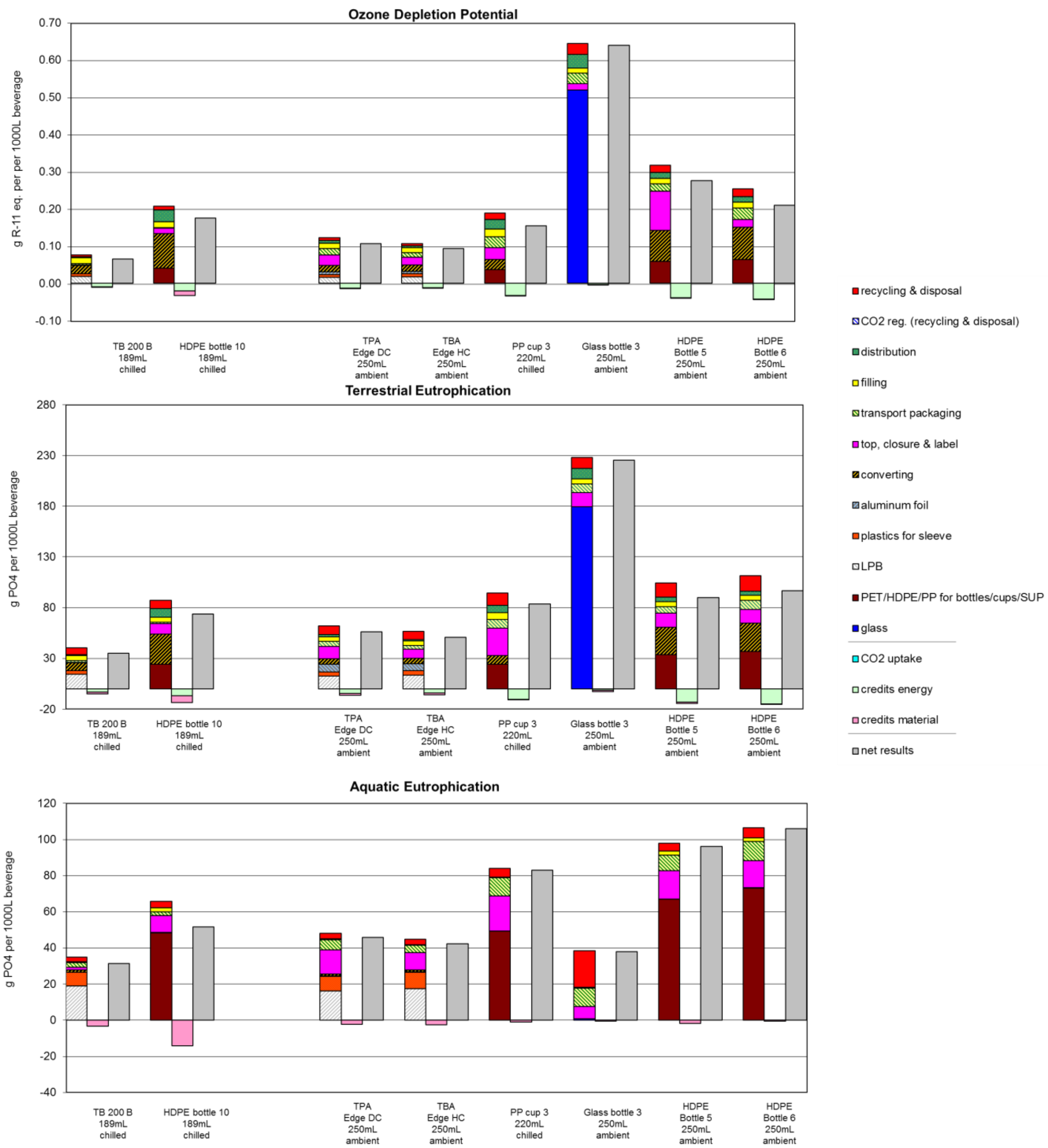



**Figure 153:** Indicator results for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (189mL -250mL)**, allocation factor 50% (Part 2)

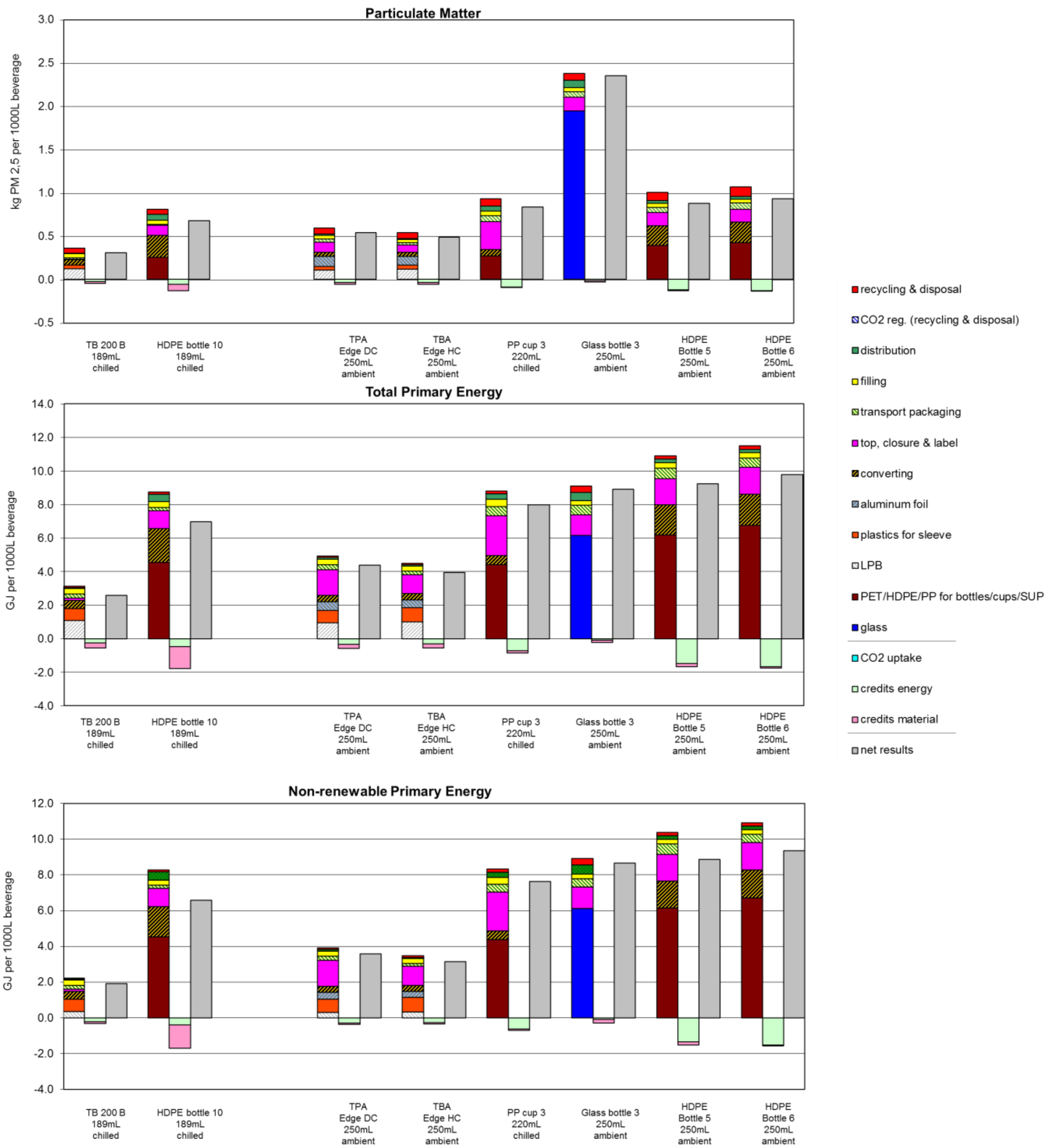



**Figure 154:** Indicator results for base scenarios of DAIRY 189mL-500mL UNITED KINGDOM (189mL -250mL), allocation factor 50% (Part 3)

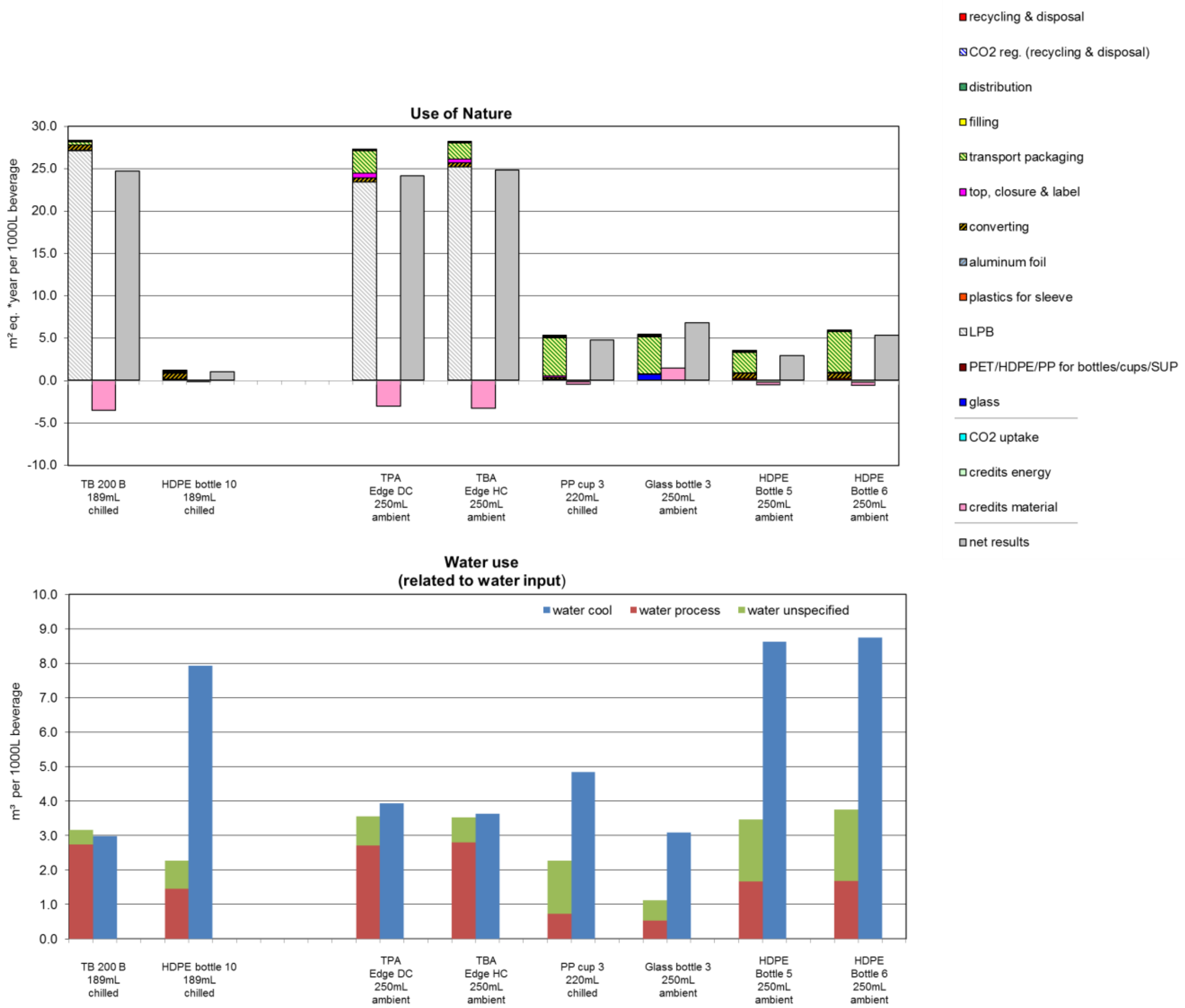



**Figure 155:** Indicator results for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (189mL -250mL)**, allocation factor 50% (Part 4)

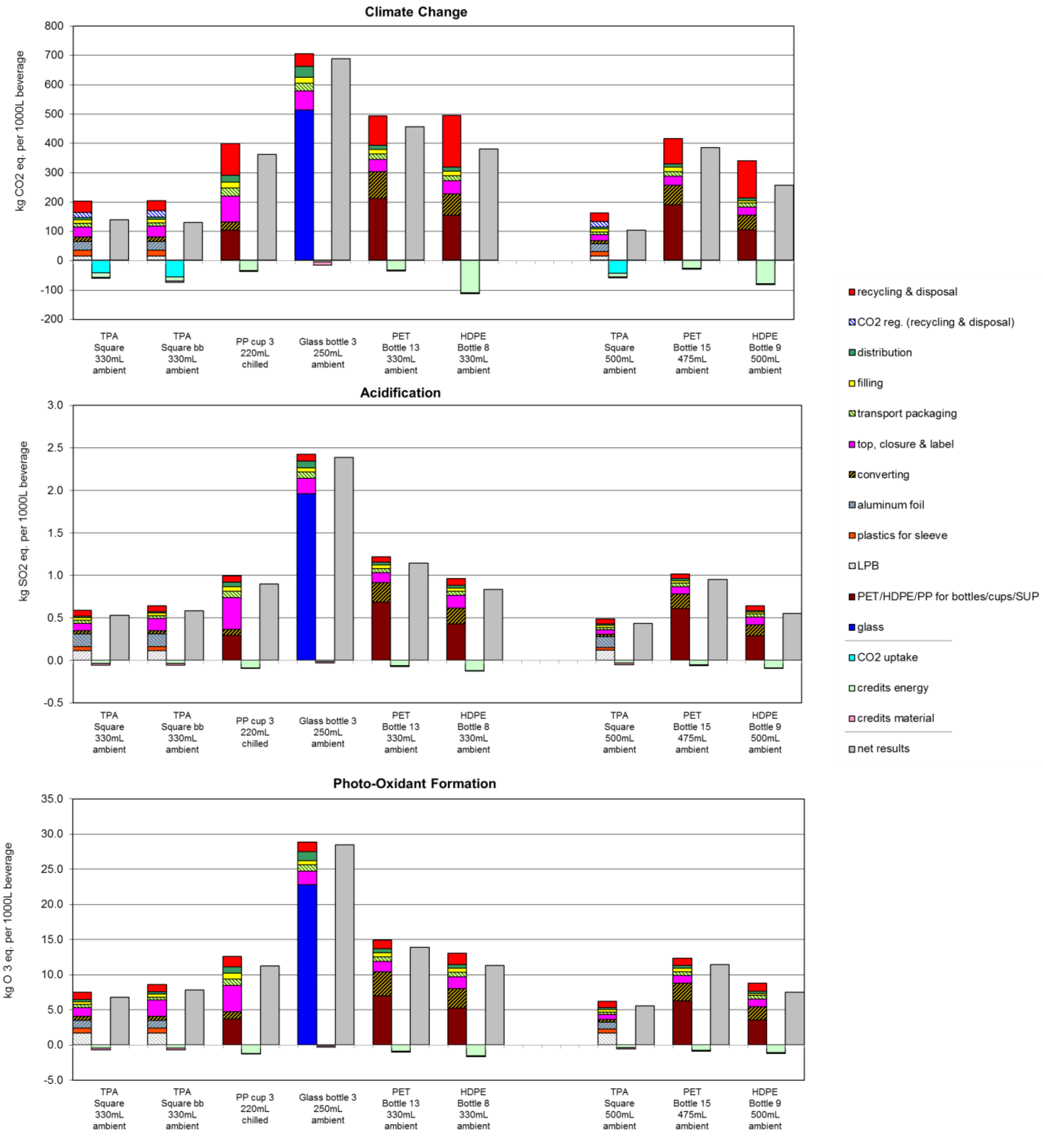



**Figure 156:** Indicator results for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL)**, allocation factor 50% (Part 1)

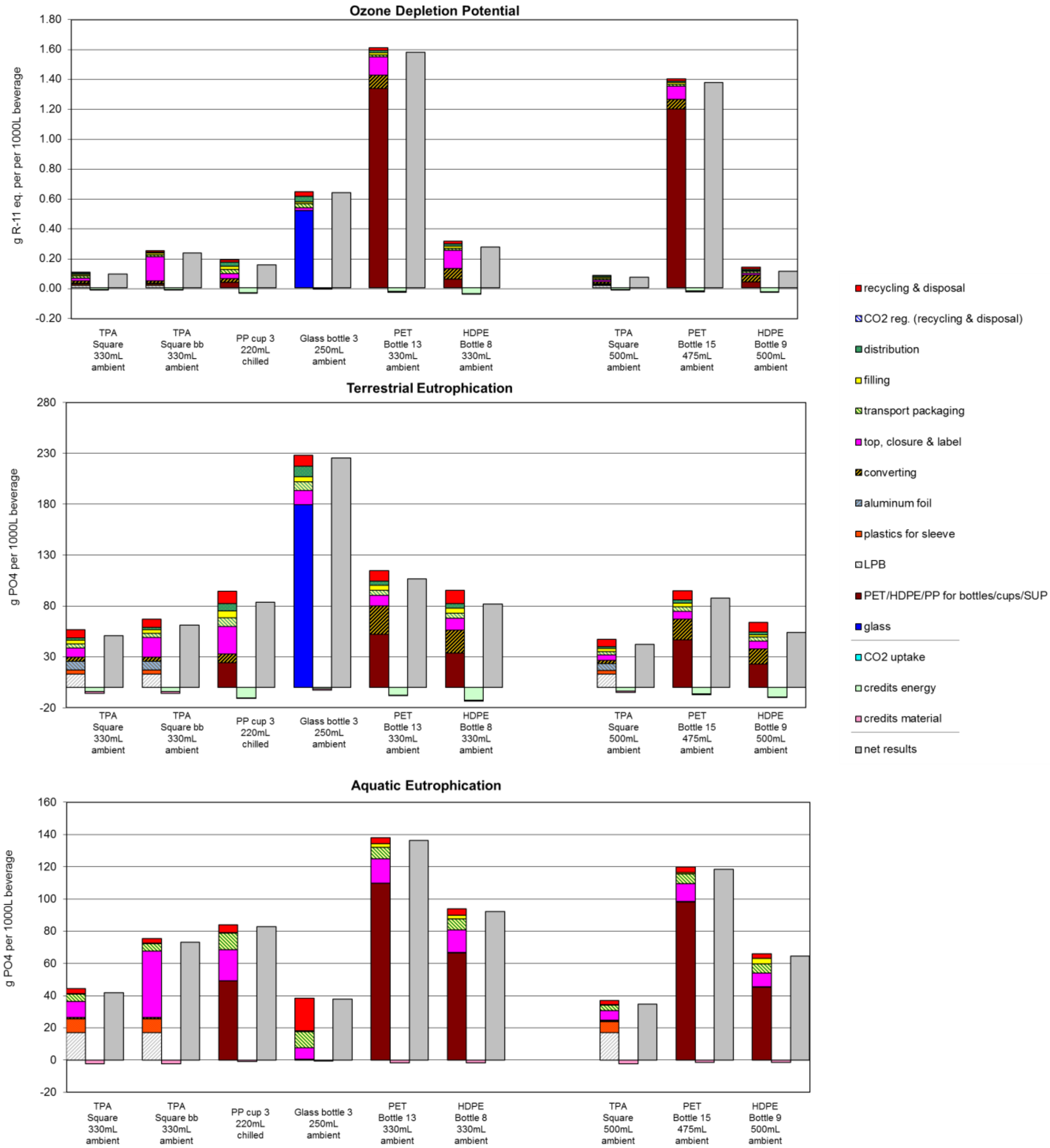



**Figure 157:** Indicator results for base scenarios of DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL), allocation factor 50% (Part 2)

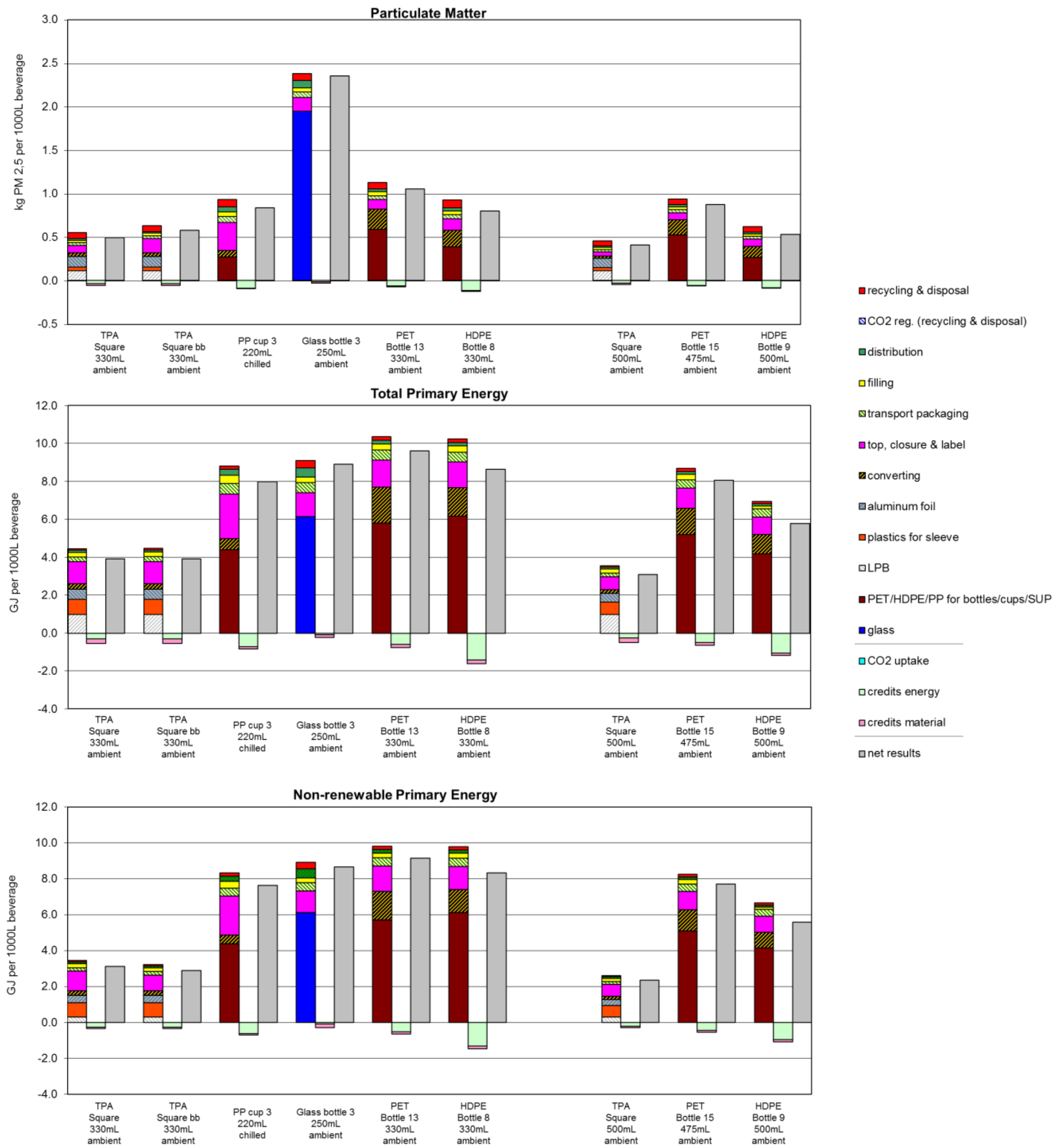



**Figure 158:** Indicator results for base scenarios of DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL), allocation factor 50% (Part 3)

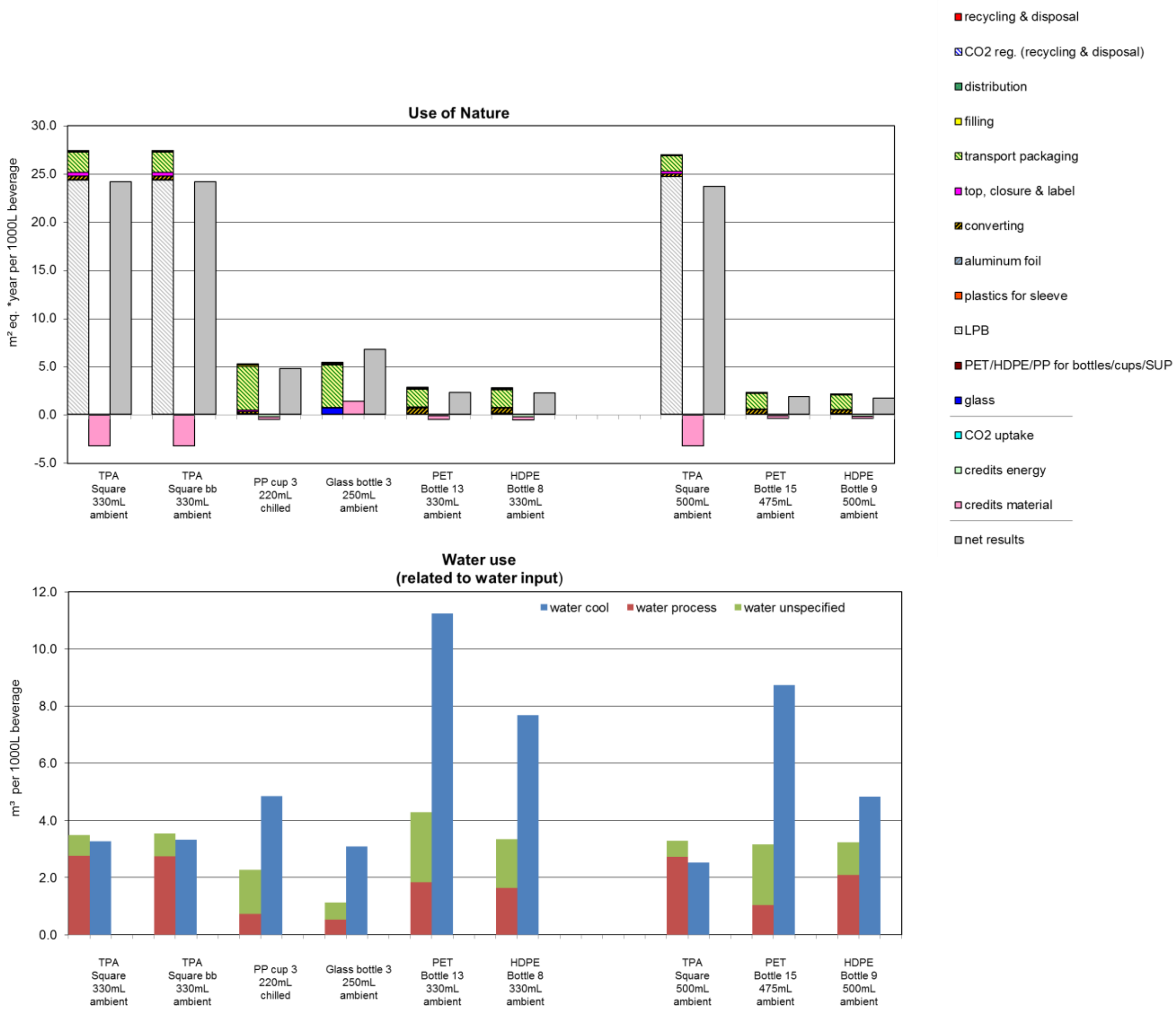



**Figure 159:** Indicator results for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL)**, allocation factor 50% (Part 4)

**Table 178:** Category indicator results per impact category for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (189mL-200mL)**-burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TB 200 B 189mL chilled | HDPE Bottle 10 189mL chilled |
|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 115.76 | 370.86 |
| | CO2 (reg) | 19.38 | 0.00 |
| | Credits* | -15.69 | -53.94 |
| | $CO_2$ uptake | -48.28 | 0.00 |
| | Net results (∑) | 71.16 | 316.92 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.36 | 0.82 |
| | Credits* | -0.05 | -0.13 |
| | Net results (∑) | 0.31 | 0.69 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 5.39 | 11.81 |
| | Credits* | -0.66 | -1.90 |
| | Net results (∑) | 4.73 | 9.90 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.08 | 0.21 |
| | Credits* | -0.01 | -0.03 |
| | Net results (∑) | 0.07 | 0.18 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 40.45 | 87.29 |
| | Credits* | -5.05 | -13.51 |
| | Net results (∑) | 35.40 | 73.79 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 34.75 | 65.69 |
| | Credits* | -3.30 | -14.14 |
| | Net results (∑) | 31.45 | 51.55 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.36 | 0.81 |
| | Credits* | -0.05 | -0.13 |
| | Net results (∑) | 0.31 | 0.68 |
| Total Primary Energy [GJ] | Burdens | 3.14 | 8.77 |
| | Credits* | -0.53 | -1.78 |
| | Net results (∑) | 2.60 | 6.99 |
| Non-renewable primary energy [GJ] | Burdens | 2.23 | 8.27 |
| | Credits* | -0.31 | -1.70 |
| | Net results (∑) | 1.92 | 6.58 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 28.25 | 1.14 |
| | Credits* | -3.58 | -0.18 |
| | Net results (∑) | 24.67 | 0.97 |
| Water use [$m^3$] | Water cool | 2.99 | 7.93 |
| | Water process | 2.75 | 1.45 |
| | Water unspec | 0.42 | 0.82 |

*material and energy credits

**Table 179:** Category indicator results per impact category for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (250mL)**-burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | TBA Edge HC 250mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
|---|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 205.17 | 182.00 | 398.41 | 703.64 | 526.42 | 568.88 |
| | CO2 (reg) | 17.73 | 18.63 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Credits* | -19.78 | -18.62 | -37.88 | -16.82 | -116.22 | -129.03 |
| | $CO_2$ uptake | -41.61 | -44.82 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Net results (∑) | 161.52 | 137.19 | 360.53 | 686.82 | 410.20 | 439.86 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.63 | 0.57 | 0.99 | 2.42 | 1.05 | 1.11 |
| | Credits* | -0.06 | -0.06 | -0.09 | -0.03 | -0.13 | -0.14 |
| | Net results (∑) | 0.57 | 0.52 | 0.90 | 2.39 | 0.91 | 0.97 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 8.14 | 7.47 | 12.55 | 28.80 | 14.13 | 14.96 |
| | Credits* | -0.77 | -0.74 | -1.34 | -0.36 | -1.80 | -1.87 |
| | Net results (∑) | 7.37 | 6.73 | 11.20 | 28.44 | 12.33 | 13.09 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.12 | 0.11 | 0.19 | 0.64 | 0.32 | 0.25 |
| | Credits* | -0.01 | -0.01 | -0.03 | 0.00 | -0.04 | -0.04 |
| | Net results (∑) | 0.11 | 0.09 | 0.15 | 0.64 | 0.28 | 0.21 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 62.30 | 56.79 | 94.55 | 228.11 | 104.37 | 111.76 |
| | Credits* | -6.06 | -5.81 | -10.74 | -2.68 | -14.08 | -14.92 |
| | Net results (∑) | 56.24 | 50.97 | 83.81 | 225.43 | 90.29 | 96.84 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 47.96 | 44.72 | 83.82 | 38.43 | 97.77 | 106.40 |
| | Credits* | -2.32 | -2.43 | -0.99 | -0.61 | -1.86 | -0.54 |
| | Net results (∑) | 45.64 | 42.29 | 82.83 | 37.82 | 95.90 | 105.86 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.59 | 0.54 | 0.93 | 2.38 | 1.00 | 1.07 |
| | Credits* | -0.06 | -0.06 | -0.09 | -0.03 | -0.13 | -0.14 |
| | Net results (∑) | 0.54 | 0.49 | 0.84 | 2.35 | 0.88 | 0.93 |
| Total Primary Energy [GJ] | Burdens | 4.95 | 4.50 | 8.82 | 9.12 | 10.92 | 11.52 |
| | Credits* | -0.56 | -0.54 | -0.83 | -0.21 | -1.66 | -1.73 |
| | Net results (∑) | 4.39 | 3.96 | 7.99 | 8.91 | 9.27 | 9.80 |
| Non-renewable primary energy [GJ] | Burdens | 3.92 | 3.47 | 8.31 | 8.92 | 10.37 | 10.91 |
| | Credits* | -0.35 | -0.32 | -0.70 | -0.28 | -1.50 | -1.56 |
| | Net results (∑) | 3.57 | 3.15 | 7.61 | 8.64 | 8.86 | 9.35 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.21 | 28.08 | 5.25 | 5.38 | 3.49 | 5.90 |
| | Credits* | -3.11 | -3.33 | -0.51 | 1.37 | -0.59 | -0.66 |
| | Net results (∑) | 24.09 | 24.75 | 4.74 | 6.76 | 2.90 | 5.25 |
| Water use [$m^3$] | Water cool | 3.94 | 3.63 | 4.85 | 3.09 | 8.62 | 8.74 |
| | Water process | 2.71 | 2.80 | 0.73 | 0.53 | 1.67 | 1.68 |
| | Water unspec | 0.84 | 0.73 | 1.54 | 0.60 | 1.80 | 2.07 |

*material and energy credits

**Table 180:** Category indicator results per impact category for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (250mL-330mL)** -burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
|---|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 182.62 | 181.59 | 398.41 | 703.64 | 492.81 | 493.61 |
| | CO2 (reg) | 18.17 | 21.76 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Credits* | -18.68 | -18.75 | -37.88 | -16.82 | -37.32 | -113.78 |
| | $CO_2$ uptake | -43.35 | -55.98 | 0.00 | 0.00 | 0.00 | 0.00 |
| | Net results (∑) | 138.76 | 128.63 | 360.53 | 686.82 | 455.49 | 379.83 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.59 | 0.64 | 0.99 | 2.42 | 1.22 | 0.96 |
| | Credits* | -0.06 | -0.06 | -0.09 | -0.03 | -0.07 | -0.13 |
| | Net results (∑) | 0.53 | 0.58 | 0.90 | 2.39 | 1.14 | 0.83 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.45 | 8.54 | 12.55 | 28.80 | 14.87 | 12.99 |
| | Credits* | -0.74 | -0.74 | -1.34 | -0.36 | -1.05 | -1.72 |
| | Net results (∑) | 6.72 | 7.80 | 11.20 | 28.44 | 13.81 | 11.28 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.25 | 0.19 | 0.64 | 1.61 | 0.31 |
| | Credits* | -0.01 | -0.01 | -0.03 | 0.00 | -0.03 | -0.04 |
| | Net results (∑) | 0.09 | 0.23 | 0.15 | 0.64 | 1.58 | 0.28 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 56.86 | 67.34 | 94.55 | 228.11 | 114.82 | 95.43 |
| | Credits* | -5.80 | -5.82 | -10.74 | -2.68 | -8.19 | -13.47 |
| | Net results (∑) | 51.06 | 61.52 | 83.81 | 225.43 | 106.63 | 81.96 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 44.23 | 75.32 | 83.82 | 38.43 | 137.85 | 93.70 |
| | Credits* | -2.37 | -2.37 | -0.99 | -0.61 | -1.64 | -1.62 |
| | Net results (∑) | 41.86 | 72.95 | 82.83 | 37.82 | 136.21 | 92.07 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.55 | 0.63 | 0.93 | 2.38 | 1.12 | 0.92 |
| | Credits* | -0.06 | -0.06 | -0.09 | -0.03 | -0.07 | -0.12 |
| | Net results (∑) | 0.49 | 0.57 | 0.84 | 2.35 | 1.05 | 0.80 |
| Total Primary Energy [GJ] | Burdens | 4.47 | 4.48 | 8.82 | 9.12 | 10.37 | 10.26 |
| | Credits* | -0.54 | -0.54 | -0.83 | -0.21 | -0.75 | -1.60 |
| | Net results (∑) | 3.93 | 3.94 | 7.99 | 8.91 | 9.62 | 8.66 |
| Non-renewable primary energy [GJ] | Burdens | 3.45 | 3.23 | 8.31 | 8.92 | 9.79 | 9.77 |
| | Credits* | -0.33 | -0.33 | -0.70 | -0.28 | -0.65 | -1.45 |
| | Net results (∑) | 3.13 | 2.90 | 7.61 | 8.64 | 9.14 | 8.32 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.35 | 27.35 | 5.25 | 5.38 | 2.80 | 2.78 |
| | Credits* | -3.23 | -3.23 | -0.51 | 1.37 | -0.49 | -0.57 |
| | Net results (∑) | 24.12 | 24.11 | 4.74 | 6.76 | 2.31 | 2.21 |
| Water use [$m^3$] | Water cool | 3.28 | 3.33 | 4.85 | 3.09 | 11.24 | 7.69 |
| | Water process | 2.75 | 2.75 | 0.73 | 0.53 | 1.84 | 1.63 |
| | Water unspec | 0.73 | 0.78 | 1.54 | 0.60 | 2.45 | 1.71 |

*material and energy credits

**Table 181:** Category indicator results per impact category for base scenarios of **DAIRY 189mL-500mL UNITED KINGDOM (500mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 500mL ambient | PET Bottle 15 500mL ambient | HDPE Bottle 9 500mL ambient |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 143.35 | 414.31 | 339.55 |
| | CO2 (reg) | 18.19 | 0.00 | 0.00 |
| | Credits* | -15.71 | -30.72 | -83.57 |
| | $CO_2$ uptake | -43.99 | 0.00 | 0.00 |
| | Net results (∑) | 101.83 | 383.58 | 255.98 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.49 | 1.02 | 0.64 |
| | Credits* | -0.05 | -0.06 | -0.09 |
| | Net results (∑) | 0.44 | 0.95 | 0.55 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.17 | 12.32 | 8.74 |
| | Credits* | -0.64 | -0.90 | -1.26 |
| | Net results (∑) | 5.53 | 11.41 | 7.48 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.08 | 1.40 | 0.14 |
| | Credits* | -0.01 | -0.03 | -0.03 |
| | Net results (∑) | 0.07 | 1.38 | 0.11 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 47.29 | 94.99 | 63.99 |
| | Credits* | -5.03 | -7.03 | -9.84 |
| | Net results (∑) | 42.26 | 87.96 | 54.15 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 36.93 | 119.51 | 65.90 |
| | Credits* | -2.37 | -1.42 | -1.29 |
| | Net results (∑) | 34.55 | 118.09 | 64.61 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.46 | 0.93 | 0.62 |
| | Credits* | -0.05 | -0.06 | -0.09 |
| | Net results (∑) | 0.41 | 0.87 | 0.53 |
| Total Primary Energy [GJ] | Burdens | 3.57 | 8.70 | 6.97 |
| | Credits* | -0.48 | -0.64 | -1.18 |
| | Net results (∑) | 3.09 | 8.06 | 5.79 |
| Non-renewable primary energy [GJ] | Burdens | 2.62 | 8.25 | 6.65 |
| | Credits* | -0.27 | -0.55 | -1.07 |
| | Net results (∑) | 2.35 | 7.70 | 5.58 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.91 | 2.30 | 2.12 |
| | Credits* | -3.28 | -0.43 | -0.42 |
| | Net results (∑) | 23.63 | 1.87 | 1.71 |
| Water use [$m^3$] | Water cool | 2.52 | 8.74 | 4.83 |
| | Water process | 2.72 | 1.04 | 2.09 |
| | Water unspec | 0.56 | 2.12 | 1.14 |

*material and energy credits

### 13.3.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the DAIRY 189mL-500mL 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' (22%-54%) and 'Use of Nature' (86%-96%). It is also relevant regarding 'Photo-Oxidant Formation' (19%-34%), 'Acidification' (17%-35%), 'Terrestrial Eutrophication' (20%-36%), 'Particulate Matter' (18%-35%) and also the consumption of 'Total Primary Energy' (19%-35%).

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 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 ambient beverage cartons systems shows burdens in most impact categories. High burdens can be seen for the categories 'Acidification' (22%-26%) and 'Particulate Matter' (19%-23%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production. In case of chilled beverage cartons no aluminium layer is needed, and therefore no burdens are shown.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (3%-31%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are 'Climate Change', where the fossil plastics (8%-13%) and LPB (6%-12%) contribute about the same and the inventory category 'Non-renewable Primary

Energy’, where the plastics make up about 20% - 30% of the total burdens. If ‘plastics for sleeve’ contains bio-based plastics (i.e. for TPA Square bio-based 330mL ambient), this life cycle step plays a major role for the overall burdens in all categories apart from ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The life cycle step ‘top, closure & label’ contributes for the 250mL-500mL beverage cartons considerably (15%-37%) to almost all impact categories due to the heavy closures in comparison to the weight of the sleeve materials. In case of the TB 200 B this step has low shares of burdens (max 6%) as this carton has no top or closure but only a straw. In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TPA Square bio-based 330mL ambient), the results are higher than for the cartons wit fossil based plastics in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (2%-16%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process. The exception is the TB 200 B which shows a considerable share of impacts (2%-29%) in most categories.

The production and provision of ‘transport packaging’ for the beverage carton systems show minor shares of impacts (1-14%) in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 12%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.  The exception is the TB 200 B which shows a considerable share of impacts (2%-21%) in the life cycle step ‘filling’ in most categories.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (26%-34%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration and landfilling of packaging materials.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the UK these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extend from landfills. Material credits from material recycling are lower than energy credits in all impact categories except 'Aquatic Eutrophication' and 'Use of Nature' as in the UK the majority of beverage cartons is not recycled.. Material credits for 'Climate Change' are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for 'Aquatic Eutrophication' and 'Use of Nature' result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles**

In the regarded plastic bottle systems in the DAIRY 189mL-500mL segment, the biggest part of the environmental burdens (19%-86%) is also caused by the production of the base materials of the bottles in most impact and inventory categories.

Even though this is true for all bottles, differences can be observed depending on the kind of plastic used. In general, for most impact categories the burdens from plastic production (life cycle step 'PET/HDPE/PP for bottles/cups/SUP' in the graphs) are higher for the HDPE bottle than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows a comparatively low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide. Nevertheless the PET Bottle 15 in this segment is around 30% heavier than the comparable HDPE Bottle 9. Combined with a slightly lower volume this leads to higher burdens of the PET Bottle 15 Bottle in all categories.

The 'converting' process of all regarded bottles shows considerable shares of impacts (5%-61%) in all categories apart from 'Aquatic Eutrophication' with shares of impacts less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable shares of impacts (2%-39%) in all categories mainly attributed to the different plastics used for the closures. Shares of this step are decreasing with the growing volume of cartons due to the heavier closures in comparison to the weight of the sleeves. Higher shares of burdens especially in the categories 'Acidification' and Particulate Matter' can be seen the HDPE bottles of this segment due to the additional aluminium pull tab.

The production and provision of 'transport packaging' for the bottle systems show minor shares of impacts (1%-12%) in all categories except of 'Use of Nature' in which the paper production contributes to (65%-80%) of the burdens. In case of HDPE Bottle 10 for most categories the relevant emissions derive from shrink foil production. In case of all other bottles in this segment all relevant emissions derive from production of paper for trays and slipsheets as well from the production of stretch foil.

For HDPE Bottle 10 because of the heavy weight of the roll containers and their smaller capacity the life cycle step 'distribution' shows minor shares of impacts (max 15%) which are slightly higher compared to the cartons transported on pallets. For all other bottles in this segment the 'distribution' step shows only small shares of burdens (max. 6%) in most impact categories and therefore doesn't play an important role for the overall results in any category.

The life cycle step 'filling' shows only small shares of burdens (max. 10%) in most impact categories. Therefore this step doesn't play an important role for the overall results in any category.

The impact of the fossil-based plastic bottles' 'recycling & disposal' life cycle step is highest regarding 'Climate Change' (20%-38%). The majority of the burdens derive from MSWI where the incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. In case of HDPE Bottle 10 57% of the clear plastic bottle are recycled. In this case greenhouse gases are generated also by the energy production required in the respective recycling processes and respectively less by incineration in MSWI.

The influence of credits on the net result is considerable in most categories. With a recycling rate of 57% for the clear plastic bottles HDPE Bottle 10, the received material credits are higher than the credits for energy. For all other white opaque bottles no primary granulate is credited as they are incinerated in MSWIs. The received material credits for these bottles are inconsiderable compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

**PP cups** (specifications see section 2.2.2)

In the regarded PP Cup 3 system in the DAIRY 189mL-500mL segment, the biggest part of the environmental burdens (26%-59%) are caused by the production of the base materials of the cups in most impact and inventory categories (next to 'top, closure & label' and 'recycling & disposal').

The 'converting' process of the regarded PP Cup 3 shows minor shares of impacts (6%-14%) in all categories apart from 'Aquatic Eutrophication' with shares of impacts less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable shares of impacts (17%-37%) in most categories attributed to the different plastics and especially aluminium used for the closures.

The production and provision of ‘transport packaging’ for the PP Cup 3 show minor shares of impacts (5%-16%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 86% of the burdens.

The life cycle step ‘filling’ shows only small shares of burdens (max 11%) for the PP cup 3 in most impact categories. Therefore this step plays not an important role for the overall results in any category.

The life cycle step ‘distribution’ shows minor shares of burdens (max. 14%) in most impact categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The impact of the PP Cup’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (27%). The majority of the burdens derive from MSWI. The incineration of cups in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. For the white opaque PP Cup 3 no primary granulate is credited as they are incinerated in MSWIs, the received material credits for this bottle are inconsiderable compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

**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 (69%-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’ (26%) and ‘Use of Nature’ (81%) transport packaging also plays a visible role.

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.

Despite of the recycling rate of 67% material credits are very low as 64% of the recycled glass is used for the production of glass bottles in a closed loop approach. Material credits are only given for recycled material that substitutes primary material in open loop models (i.e. 3%).

### 13.3.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as ‘Use of Nature’, due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than

10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 182:** Comparison of net results: **TB 200 B 189mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TB 200 B 189mL chilled …** | ...are lower (green) / higher (orange) than those of | |
|---|---|---|
| **50% allocation** | TB 200 B 189mL chilled | HDPE Bottle 10 189mL chilled |
| Climate Change [kg $CO_2$eq] | 71.16 | -78% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -63% |
| Acidification [kg $SO_2$ eq.] | 0.31 | -54% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 35.40 | -52% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 31.45 | -39% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.73 | -52% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | -54% |

**Table 183:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Edge DC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | | | | |
|---|---|---|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 161.53 | -55% | -76% | -61% | -63% |
| Ozone depletion potential [g R-11 eq.] | 0.11 | -31% | -83% | -61% | -49% |
| Acidification [kg $SO_2$ eq.] | 0.57 | -37% | -76% | -38% | -41% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 56.24 | -33% | -75% | -38% | -42% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 45.64 | -45% | 21% | -52% | -57% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.37 | -34% | -74% | -40% | -44% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.54 | -36% | -77% | -39% | -42% |

**Table 184:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TBA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | | | |
|---|---|---|---|---|---|
| **50% allocation** | TBA Edge HC 250mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 137.19 | -62% | -80% | -67% | -69% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -40% | -85% | -66% | -56% |
| Acidification [kg $SO_2$ eq.] | 0.52 | -43% | -78% | -44% | -47% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 50.97 | -39% | -77% | -44% | -47% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.29 | -49% | 12% | -56% | -60% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.73 | -40% | -76% | -45% | -49% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -42% | -79% | -44% | -48% |

**Table 185:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Square DC 330mL ambient** | | ...are lower (green) / higher (orange) than those of | | | |
|---|---|---|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 138.76 | -62% | -80% | -70% | -63% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -40% | -86% | -94% | -66% |
| Acidification [kg $SO_2$ eq.] | 0.53 | -41% | -78% | -54% | -37% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.06 | -39% | -77% | -52% | -38% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 41.86 | -49% | 11% | -69% | -55% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.72 | -40% | -76% | -51% | -40% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -41% | -79% | -53% | -38% |

**Table 186:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of | | | |
|---|---|---|---|---|---|
| **50% allocation** | TPA Square DC bb 330mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 128.63 | -64% | -81% | -72% | -66% |
| Ozone depletion potential [g R-11 eq.] | 0.23 | 51% | -63% | -85% | -15% |
| Acidification [kg $SO_2$ eq.] | 0.58 | -35% | -76% | -49% | -30% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 61.52 | -27% | -73% | -42% | -25% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 72.95 | -12% | 93% | -46% | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.80 | -30% | -73% | -44% | -31% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.57 | -31% | -76% | -45% | -28% |

**Table 187:** Comparison of net results: **TPA Square 500mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Square 500mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square 500mL ambient | PET Bottle 15 500mL ambient | HDPE Bottle 9 5000mL ambient |
| Climate Change [kg $CO_2$eq] | 101.83 | -73% | -60% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -95% | -34% |
| Acidification [kg $SO_2$ eq.] | 0.44 | -54% | -21% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 42.26 | -52% | -22% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 34.55 | -71% | -47% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.53 | -52% | -26% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | -53% | -23% |

# *13.4* Results base scenarios DAIRY (CREAM) *300mL-330mL UNITED KINGDOM*

## 13.4.1 Presentation of results

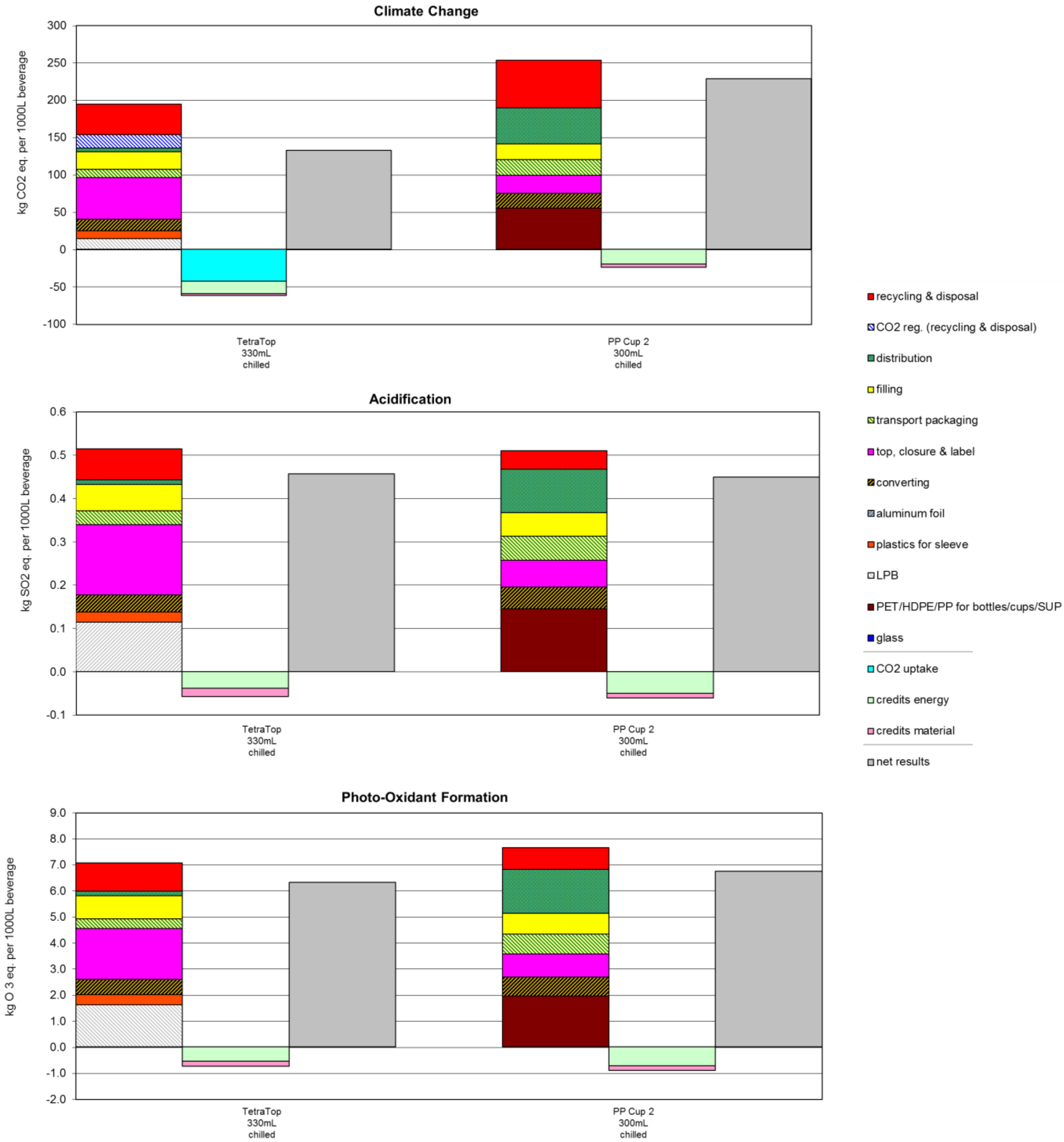



**Figure 160:** Indicator results for base scenarios of segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM, allocation factor 50% (Part 1)

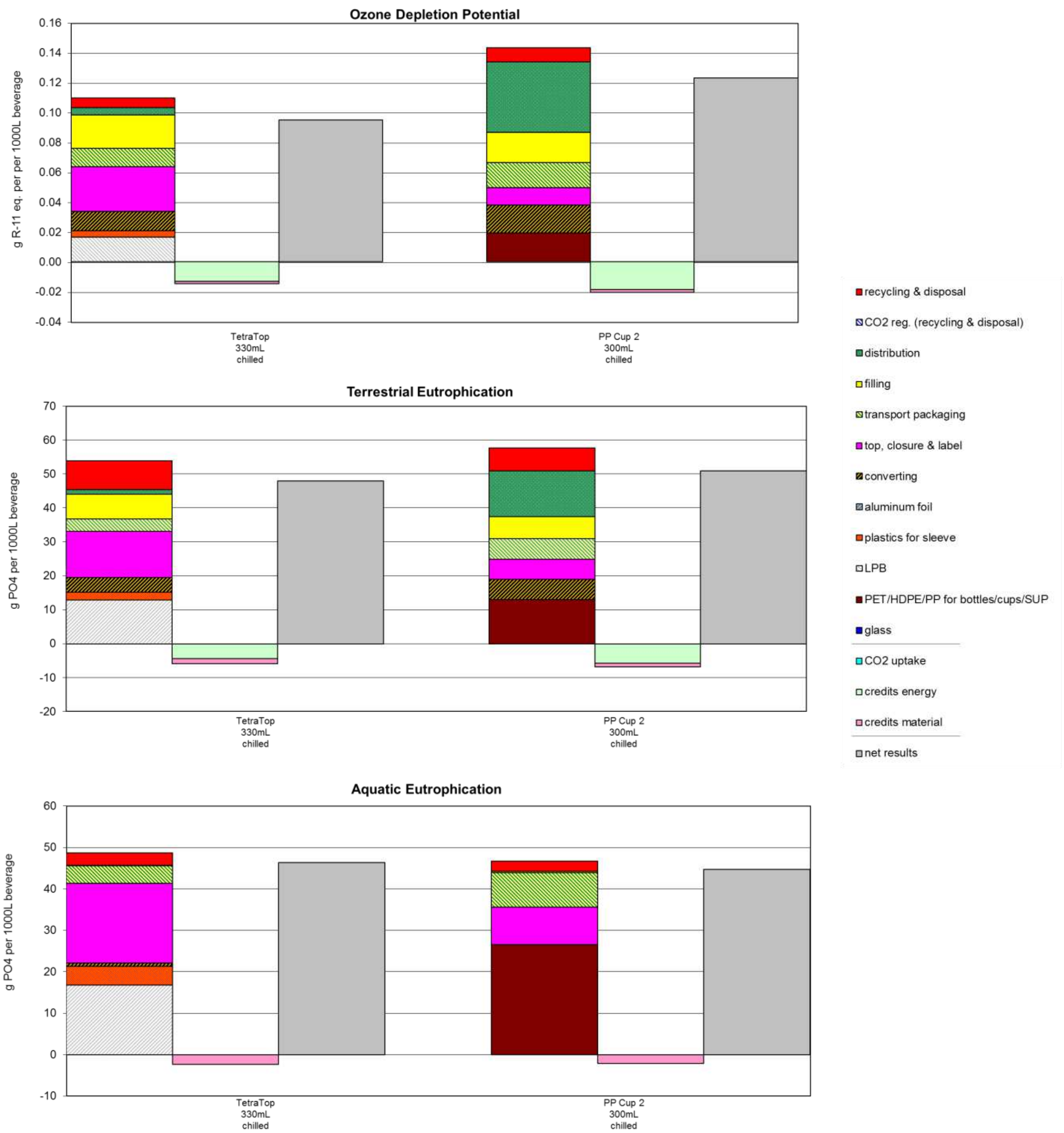



**Figure 161:** Indicator results for base scenarios of **segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**, allocation factor 50% (Part 2)

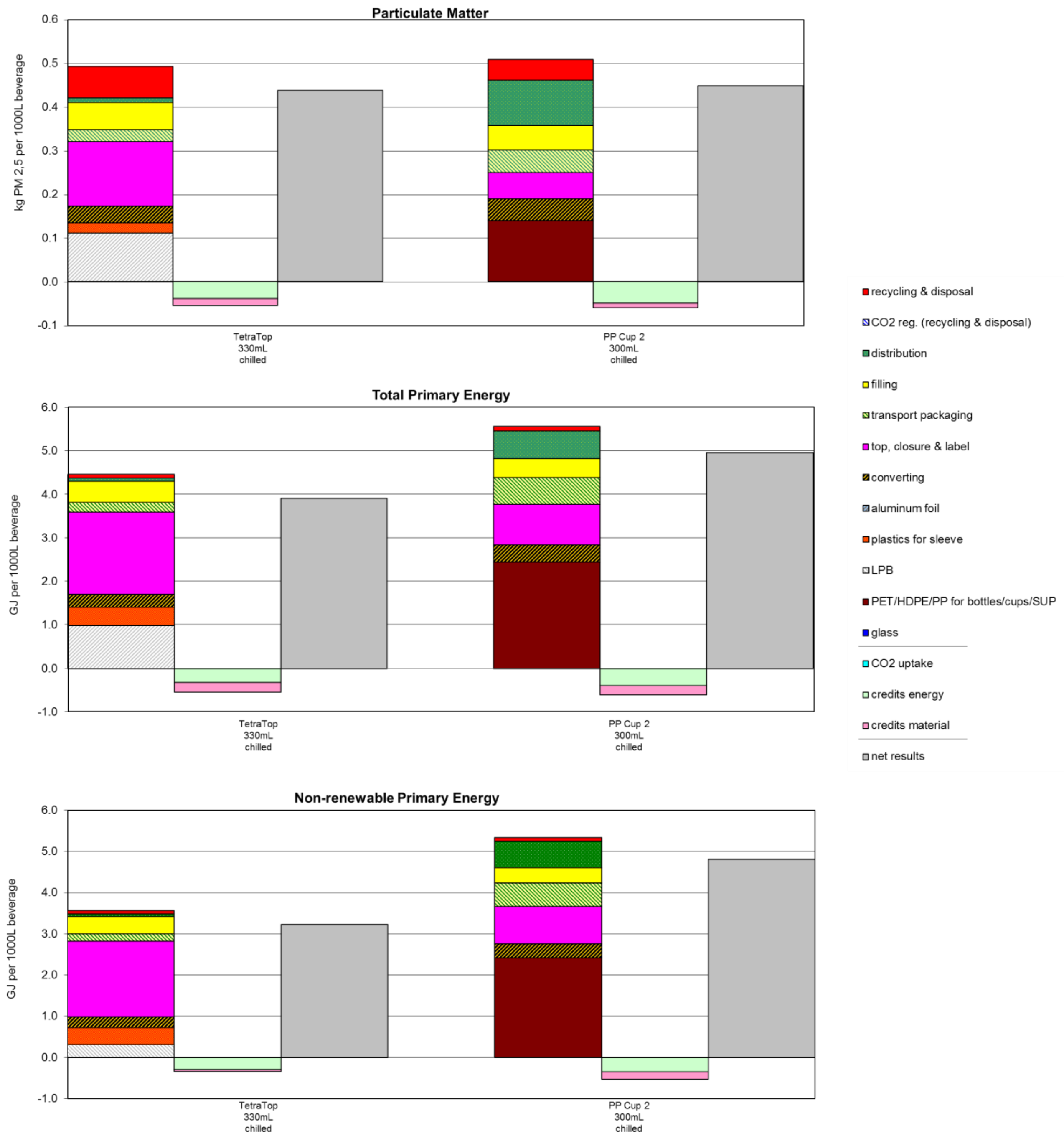



**Figure 162:** Indicator results for base scenarios of segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM, allocation factor 50% (Part 3)

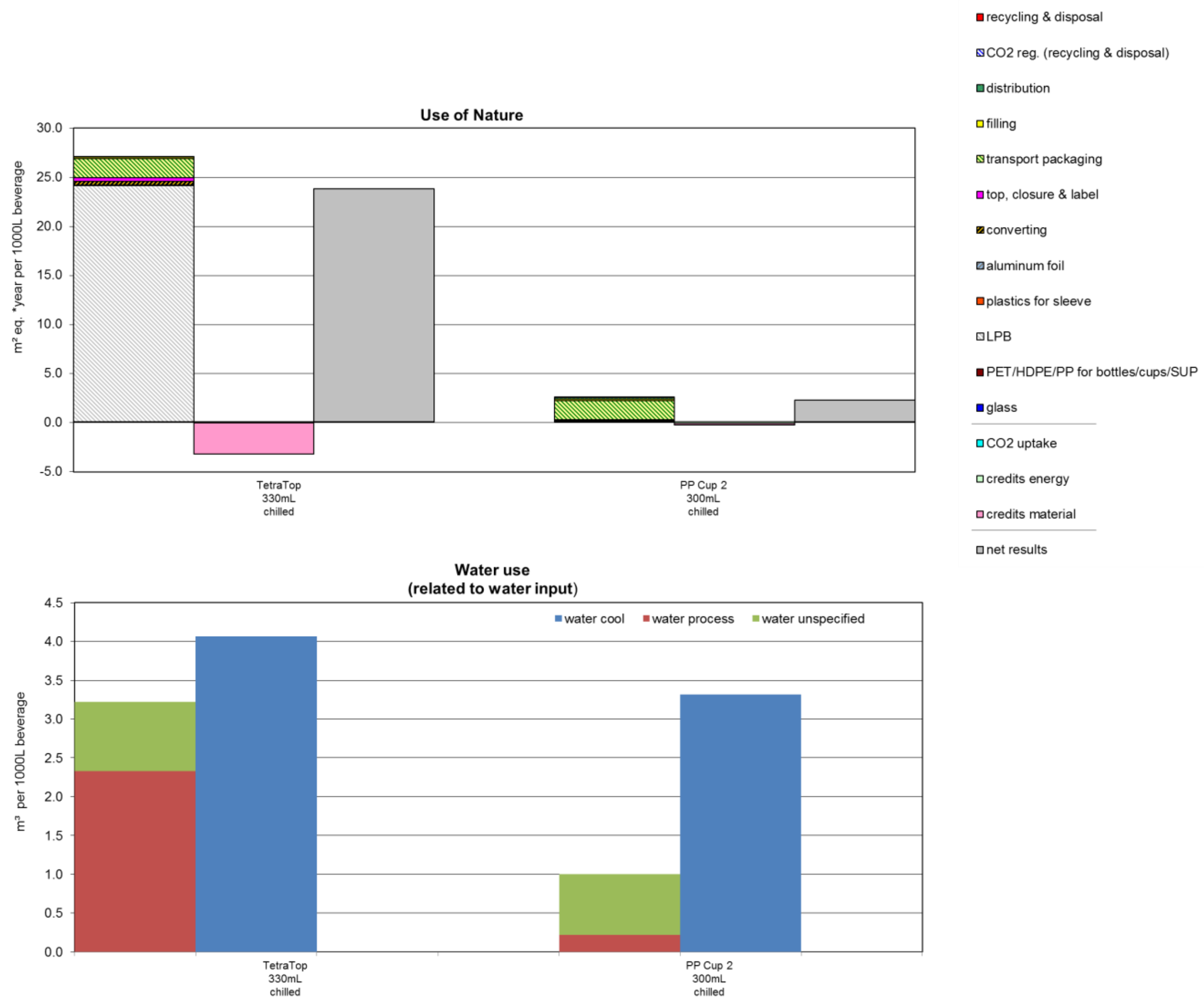



**Figure 163:** Indicator results for base scenarios of **segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**, allocation factor 50% (Part 4)

**Table 188:** Category indicator results per impact category for base scenarios of **segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TetraTop 330mL chilled | PP Cup 2 300mL chilled |
|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 176.30 | 252.78 |
| | CO2 (reg) | 17.90 | 0.00 |
| | Credits* | -19.07 | -24.37 |
| | $CO_2$ uptake | -42.96 | 0.00 |
| | Net results (∑) | 132.16 | 228.42 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.51 | 0.51 |
| | Credits* | -0.06 | -0.06 |
| | Net results (∑) | 0.46 | 0.45 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.06 | 7.65 |
| | Credits* | -0.74 | -0.89 |
| | Net results (∑) | 6.32 | 6.76 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.14 |
| | Credits* | -0.01 | -0.02 |
| | Net results (∑) | 0.10 | 0.12 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 53.90 | 57.75 |
| | Credits* | -5.88 | -6.83 |
| | Net results (∑) | 48.02 | 50.92 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 48.64 | 46.68 |
| | Credits* | -2.35 | -2.08 |
| | Net results (∑) | 46.30 | 44.60 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.49 | 0.51 |
| | Credits* | -0.05 | -0.06 |
| | Net results (∑) | 0.44 | 0.45 |
| Total Primary Energy [GJ] | Burdens | 4.46 | 5.57 |
| | Credits* | -0.55 | -0.60 |
| | Net results (∑) | 3.91 | 4.96 |
| Non-renewable primary energy [GJ] | Burdens | 3.56 | 5.33 |
| | Credits* | -0.34 | -0.53 |
| | Net results (∑) | 3.23 | 4.80 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.00 | 2.51 |
| | Credits* | -3.24 | -0.28 |
| | Net results (∑) | 23.76 | 2.23 |
| Water use [$m^3$] | Water cool | 4.07 | 3.32 |
| | Water process | 2.33 | 0.22 |
| | Water unspec | 0.89 | 0.78 |

*material and energy credits

### 13.4.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton system regarded in the DAIRY (CREAM) 300mL-330mL 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’ (34%) and ‘Use of Nature’ (89%). It is also relevant regarding ‘Photo-Oxidant Formation’ (23%), ‘Acidification’, (22%) ‘Terrestrial Eutrophication’ (24%), ‘Particulate Matter’ (23%) and also the consumption of ‘Total Primary Energy’ (22%).

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 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’.

As the beverage carton in this segment is chilled, no aluminium layer is needed, and therefore no results are shown for this step.

The production of ‘plastics for sleeve’ of the beverage cartons shows minor shares of burdens (max 12%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change (plastics 5%, LPB 7%) and the inventory category ‘Non-renewable Primary Energy’ (plastics 12%, LPB 9%) where the plastics and LPB contribute about the same.

The life cycle step ‘top, closure & label’ contributes for the 300mL-330mL beverage cartons considerably (28%-51%) to all impact categories except ‘Use of Nature’ due to the heavy closure and top in comparison to the weight of the sleeve materials.

The converting process generally plays a minor role (max. 11%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems show minor shares of impacts (max. 12%) in all categories. The highest shares of burdens are seen in the categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. This is due the use of cardboard trays and slipsheets for the secondary and tertiary packaging of all examined beverage cartons.

The life cycle steps ‘filling’ and ‘distribution’ show only minor shares of burdens (max 21%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (30%). Greenhouse gases are generated by the energy production required in the respective recycling and disposal processes as well as by incineration and landfilling of packaging materials.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the UK these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extend from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the UK the majority of beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**PP cups** (specifications see section 2.2.2)

In the regarded PP Cup 2 system in the DAIRY (CREAM) 300mL-330mL segment, the biggest part of the environmental burdens are caused by the production of the base materials of the cups (up to 33%) in most impact and inventory categories next to the step distribution with shares of impact up to 57%.

The 'converting' process of the regarded PP Cup 2 shows minor shares of impacts (5%-13%) in all categories apart from 'Aquatic Eutrophication' with shares of impacts less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable shares of impacts (3%-19%) in most categories attributed to the different plastics used for the closures.

The production and provision of 'transport packaging' for the PP Cup 2 show minor shares of impacts (8%-18%) in all categories except of 'Use of Nature' in which the paper production contributes to (77%) of the burdens. The relevant emissions derive from shrink foil production and from the production of paper for trays.

The life cycle step 'filling' shows only minor shares of burdens (max 14%) for the PP cup 2 in most impact categories.

The life cycle step 'distribution' shows high shares of burdens (2%-57%) in most impact categories due to the heavy weight of the roll containers and their smaller capacity as well as the large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The impact of the PP Cup's 'recycling & disposal' life cycle step is highest regarding 'Climate Change' (25%). The incineration of cups in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. For the white opaque PP Cup 2 no primary granulate is credited as they are incinerated in MSWIs, the received material credits for this bottle are inconsiderable compared to the credits for energy. The energy credits of all bottles mainly originate from the incineration plants.

### 13.4.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than

10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 189:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**

| The net results of **TT 330mL chilled …** | ...are lower (green) / higher (orange) than those of | |
|---|---|---|
| **50% allocation** | TT 330mL chilled | PP Cup 2 300mL chilled |
| Climate Change [kg $CO_2$eq] | 132.16 | -42% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -23% |
| Acidification [kg $SO_2$ eq.] | 0.46 | 2% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 48.02 | -6% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 46.30 | 4% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.32 | -6% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.44 | -2% |

# 13.5 Results base scenarios JNSD 200mL-330mL UNITED KINGDOM

## 13.5.1 Presentation of results

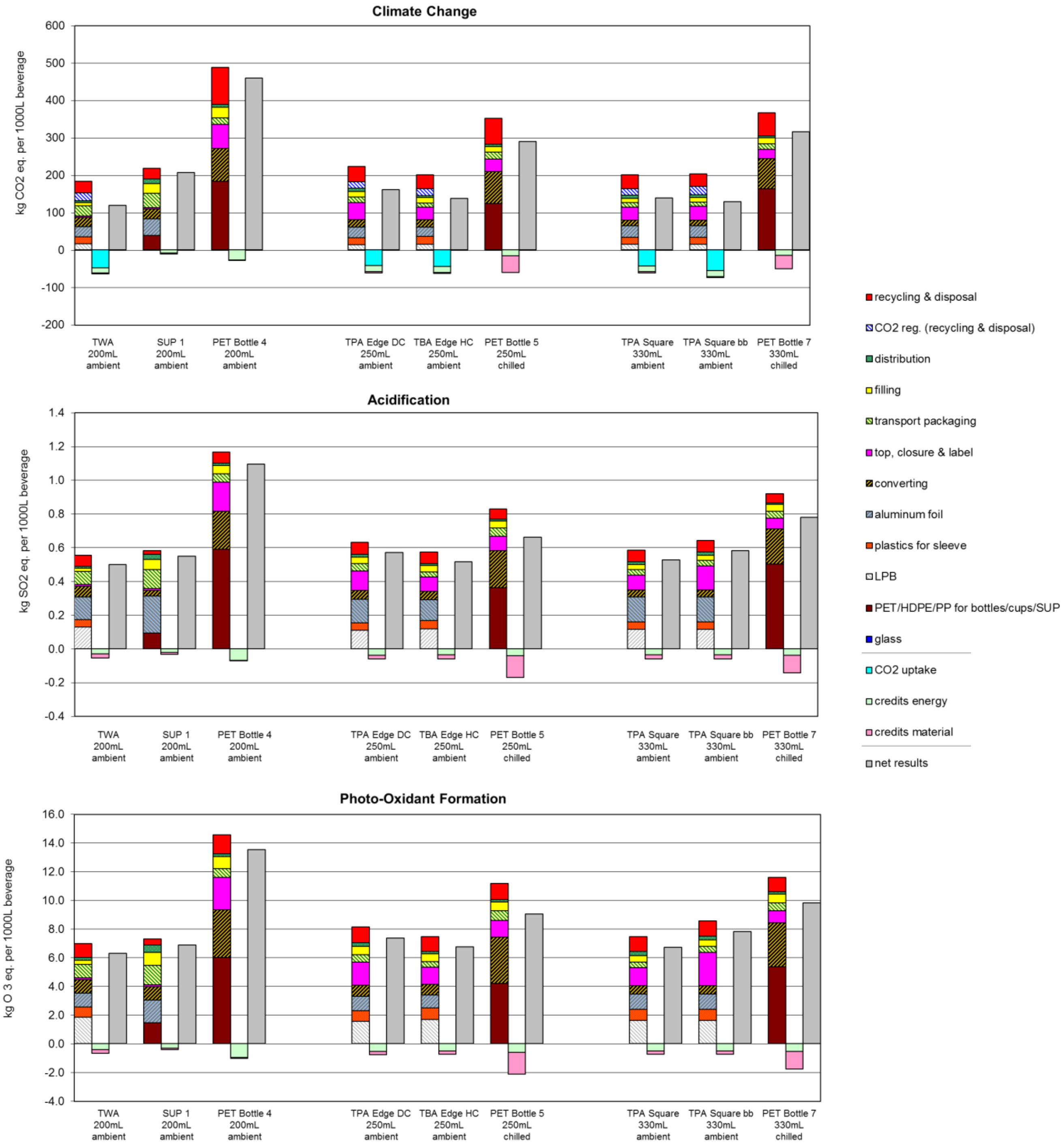



**Figure 164:** Indicator results for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM**, allocation factor 50% (Part 1)

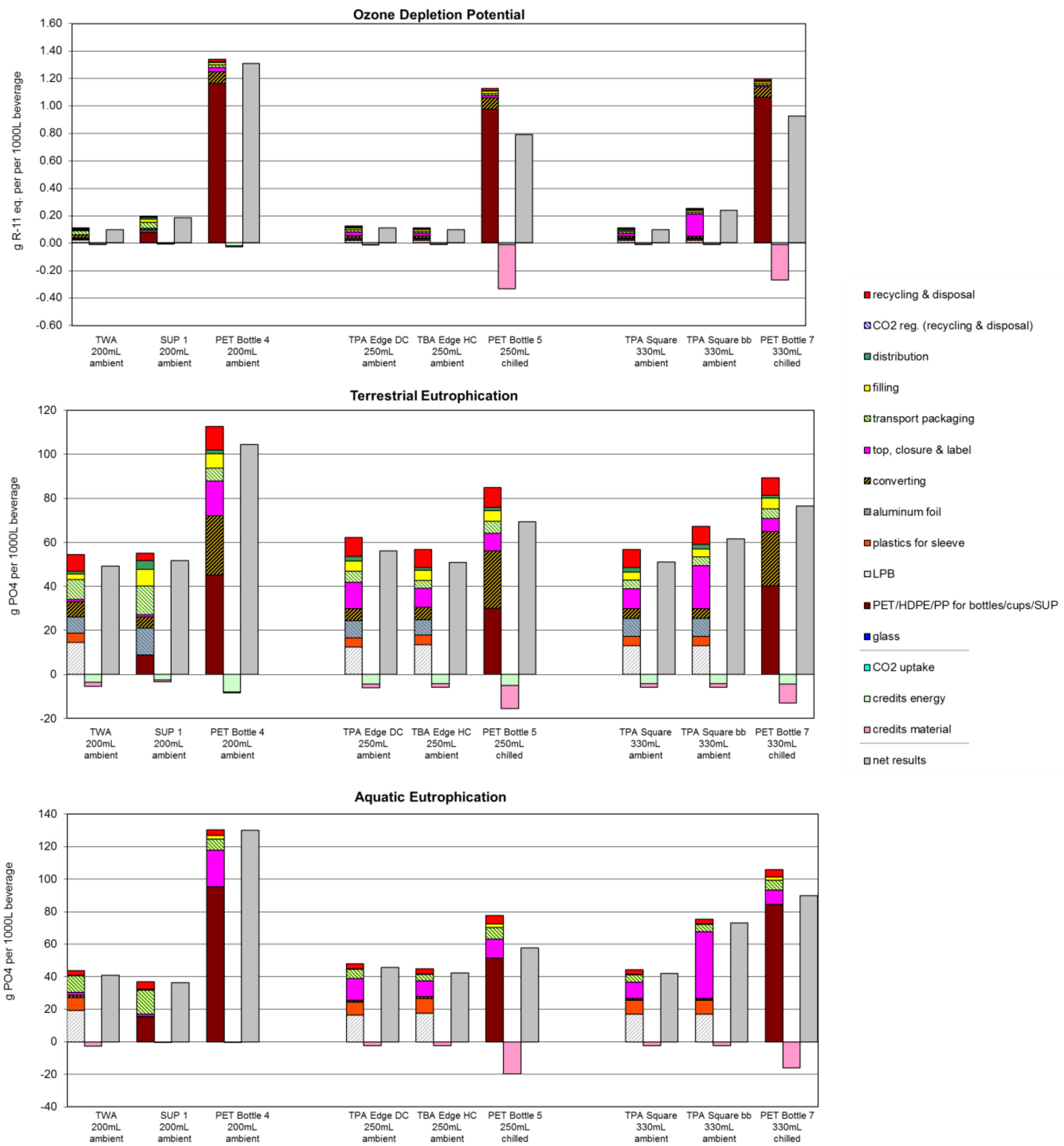



**Figure 165:** Indicator results for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM**, allocation factor 50% (Part 2)

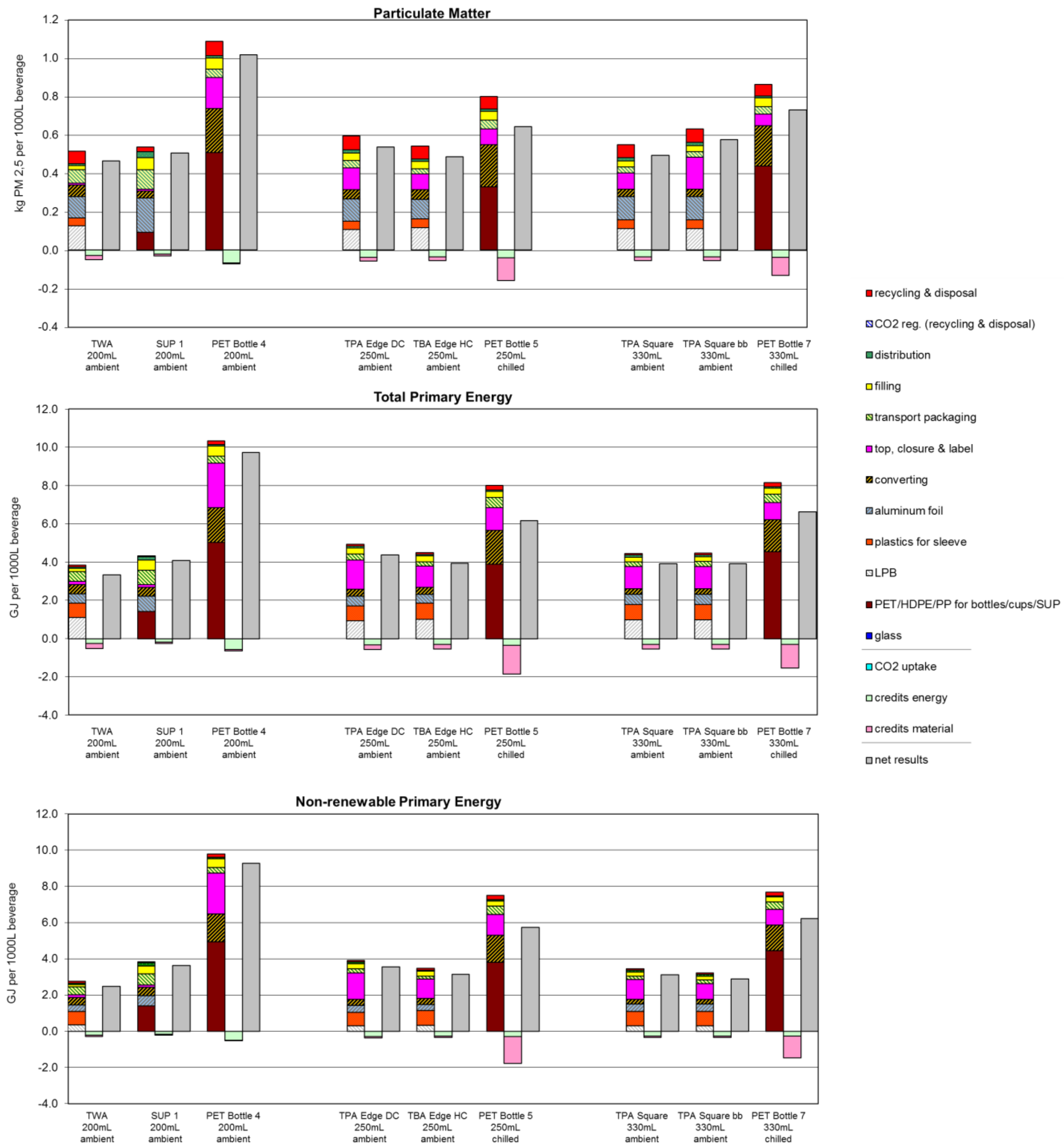



**Figure 166:** Indicator results for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM**, allocation factor 50% (Part 3)

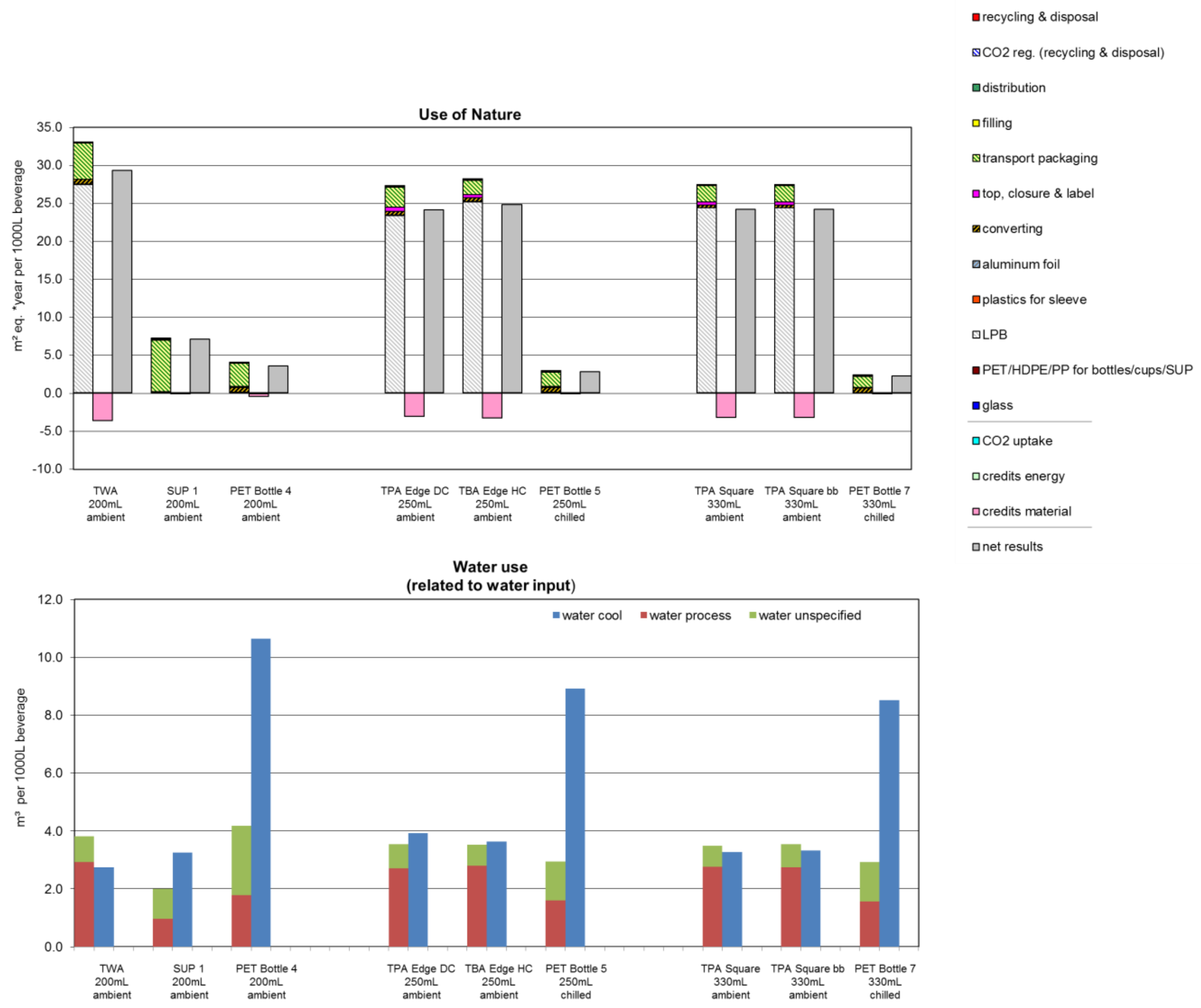



**Figure 167:** Indicator results for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM**, allocation factor 50% (Part 4)

**Table 190:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM (200mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TWA 200mL ambient | SUP 1 200mL ambient | PET Bottle 4 200mL ambient |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 162.29 | 217.86 | 487.58 |
| | CO2 (reg) | 21.19 | 0.00 | 0.00 |
| | Credits* | -16.04 | -11.31 | -28.82 |
| | $CO_2$ uptake | -48.86 | 0.00 | 0.00 |
| | Net results (∑) | 118.57 | 206.55 | 458.76 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.55 | 0.58 | 1.17 |
| | Credits* | -0.05 | -0.03 | -0.07 |
| | Net results (∑) | 0.50 | 0.55 | 1.10 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.95 | 7.29 | 14.54 |
| | Credits* | -0.67 | -0.41 | -1.02 |
| | Net results (∑) | 6.29 | 6.88 | 13.52 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.19 | 1.34 |
| | Credits* | -0.01 | -0.01 | -0.03 |
| | Net results (∑) | 0.09 | 0.18 | 1.31 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 54.52 | 55.06 | 112.65 |
| | Credits* | -5.26 | -3.21 | -8.21 |
| | Net results (∑) | 49.26 | 51.85 | 104.43 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 43.54 | 36.69 | 130.13 |
| | Credits* | -2.62 | -0.33 | -0.45 |
| | Net results (∑) | 40.92 | 36.36 | 129.68 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.51 | 0.54 | 1.09 |
| | Credits* | -0.05 | -0.03 | -0.07 |
| | Net results (∑) | 0.46 | 0.51 | 1.02 |
| Total Primary Energy [GJ] | Burdens | 3.85 | 4.33 | 10.36 |
| | Credits* | -0.51 | -0.24 | -0.62 |
| | Net results (∑) | 3.35 | 4.10 | 9.74 |
| Non-renewable primary energy [GJ] | Burdens | 2.76 | 3.84 | 9.77 |
| | Credits* | -0.28 | -0.20 | -0.51 |
| | Net results (∑) | 2.48 | 3.64 | 9.27 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 32.94 | 7.10 | 4.00 |
| | Credits* | -3.65 | -0.07 | -0.52 |
| | Net results (∑) | 29.29 | 7.04 | 3.48 |
| Water use [$m^3$] | Water cool | 2.75 | 3.26 | 10.64 |
| | Water process | 2.93 | 0.96 | 1.79 |
| | Water unspec | 0.89 | 1.03 | 2.39 |

*material and energy credits

**Table 191:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM (250mL)** burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Edge DC 250mL ambient | TBA Edge HC 250mL ambient | PET Bottle 5 250mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 204.95 | 182.00 | 350.81 |
| | CO2 (reg) | 17.73 | 18.63 | 0.00 |
| | Credits* | -19.78 | -18.62 | -61.15 |
| | $CO_2$ uptake | -41.60 | -44.82 | 0.00 |
| | Net results (∑) | 161.31 | 137.19 | 289.66 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.63 | 0.57 | 0.83 |
| | Credits* | -0.06 | -0.06 | -0.17 |
| | Net results (∑) | 0.57 | 0.52 | 0.66 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 8.13 | 7.47 | 11.17 |
| | Credits* | -0.77 | -0.74 | -2.13 |
| | Net results (∑) | 7.36 | 6.73 | 9.04 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.12 | 0.11 | 1.12 |
| | Credits* | -0.01 | -0.01 | -0.34 |
| | Net results (∑) | 0.11 | 0.09 | 0.79 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 62.24 | 56.79 | 84.85 |
| | Credits* | -6.06 | -5.81 | -15.40 |
| | Net results (∑) | 56.18 | 50.97 | 69.44 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 47.95 | 44.72 | 77.39 |
| | Credits* | -2.32 | -2.43 | -19.78 |
| | Net results (∑) | 45.63 | 42.29 | 57.62 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.59 | 0.54 | 0.80 |
| | Credits* | -0.06 | -0.06 | -0.16 |
| | Net results (∑) | 0.54 | 0.49 | 0.64 |
| Total Primary Energy [GJ] | Burdens | 4.95 | 4.50 | 8.03 |
| | Credits* | -0.56 | -0.54 | -1.85 |
| | Net results (∑) | 4.39 | 3.96 | 6.19 |
| Non-renewable primary energy [GJ] | Burdens | 3.92 | 3.47 | 7.49 |
| | Credits* | -0.35 | -0.32 | -1.77 |
| | Net results (∑) | 3.57 | 3.15 | 5.73 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.20 | 28.08 | 2.89 |
| | Credits* | -3.11 | -3.33 | -0.13 |
| | Net results (∑) | 24.09 | 24.75 | 2.76 |
| Water use [$m^3$] | Water cool | 3.93 | 3.63 | 8.92 |
| | Water process | 2.70 | 2.80 | 1.59 |
| | Water unspec | 0.84 | 0.73 | 1.35 |

*material and energy credits

**Table 192:** Category indicator results per impact category for base scenarios of **segment JNSD 200mL-330mL UNITED KINGDOM (330mL)** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 330mL ambient | TPA Square bb 330mL ambient | PET Bottle 7 330mL chilled |
|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 182.62 | 181.59 | 366.20 |
| | CO2 (reg) | 18.17 | 21.76 | 0.00 |
| | Credits* | -18.68 | -18.75 | -51.02 |
| | $CO_2$ uptake | -43.35 | -55.98 | 0.00 |
| | Net results (∑) | 138.76 | 128.63 | 315.17 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.59 | 0.64 | 0.92 |
| | Credits* | -0.06 | -0.06 | -0.14 |
| | Net results (∑) | 0.53 | 0.58 | 0.78 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 7.45 | 8.54 | 11.58 |
| | Credits* | -0.74 | -0.74 | -1.78 |
| | Net results (∑) | 6.72 | 7.80 | 9.80 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.11 | 0.25 | 1.19 |
| | Credits* | -0.01 | -0.01 | -0.27 |
| | Net results (∑) | 0.09 | 0.23 | 0.92 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 56.86 | 67.34 | 89.41 |
| | Credits* | -5.80 | -5.82 | -12.92 |
| | Net results (∑) | 51.06 | 61.52 | 76.49 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 44.23 | 75.32 | 105.72 |
| | Credits* | -2.37 | -2.37 | -15.98 |
| | Net results (∑) | 41.86 | 72.95 | 89.74 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.55 | 0.63 | 0.86 |
| | Credits* | -0.06 | -0.06 | -0.13 |
| | Net results (∑) | 0.49 | 0.57 | 0.73 |
| Total Primary Energy [GJ] | Burdens | 4.47 | 4.48 | 8.17 |
| | Credits* | -0.54 | -0.54 | -1.53 |
| | Net results (∑) | 3.93 | 3.94 | 6.65 |
| Non-renewable primary energy [GJ] | Burdens | 3.45 | 3.23 | 7.68 |
| | Credits* | -0.33 | -0.33 | -1.46 |
| | Net results (∑) | 3.13 | 2.90 | 6.22 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 27.35 | 27.35 | 2.29 |
| | Credits* | -3.23 | -3.23 | -0.12 |
| | Net results (∑) | 24.12 | 24.11 | 2.18 |
| Water use [$m^3$] | Water cool | 3.28 | 3.33 | 8.51 |
| | Water process | 2.75 | 2.75 | 1.56 |
| | Water unspec | 0.73 | 0.78 | 1.37 |

*material and energy credits

### 13.5.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD 200mL-330mL 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’ (34%-44%) and ‘Use of Nature’ (83%-90%). It is also relevant regarding ‘Photo-Oxidant Formation’ (19%-26%), ‘Acidification’ (18%-23%), ‘Terrestrial Eutrophication’ (20%-27%), ‘Particulate Matter’ (18%-25%) and also the consumption of ‘Total Primary Energy’ (20%-29%).

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 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 shows burdens in most impact categories. High burdens can be seen for the categories ‘Acidification’ (22%-25%) and ‘Particulate Matter’ (19%-22%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of ‘plastics for sleeve’ of the beverage cartons shows considerable shares of burdens (7%-27%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The two exceptions are climate change, where the plastics (8%-10%) and LPB (6%-9%) contribute about the same and the inventory category ‘Non-renewable Primary Energy’, where the plastics make up about 20% until 30% of the total burdens. If ‘plastics for sleeve' contains bio-based plastics (i.e. for TPA Square 330mL bio-based ambient), this life cycle step plays a major role for the overall burdens in all categories apart from 'Climate Change' and 'Non-renewable Primary Energy'.

The life cycle step 'top, closure & label' contributes to a considerable amount (15%-66%) in almost all impact categories with the exception of the TWA with only minor burdens (max. 6%) in this step as this carton has no closure and only a straw~~.~~ In case the plastics used for 'top, closure & label' are bio-based (i.e. TPA Square bio-based 330mL), the results are considerably higher than for cartons with fossil based cartons in all categories except 'Climate Change' and 'Non-renewable Primary Energy'.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories 'Particulate Matter', 'Terrestrial Eutrophication', 'Acidification' and 'Total Primary Energy'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

The converting process generally plays a considerable role (max 20%). It generates emissions, which contribute to the impact categories 'Climate Change', 'Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the beverage carton systems shows considerable shares (5%-14%) of impacts in all categories. One exception is the TWA 200 with higher shares of burdens (14%-29%) from transport packaging in all categories due to its large amount of secondary packaging per functional unit of packaging for 1000L of beverage.

The life cycle steps 'filling' and 'distribution' show only small shares of burdens (max. 13%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step 'recycling & disposal' of the regarded beverage cartons is most relevant in the impact categories 'Climate Change' (26%-28%). Greenhouse gases are also generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI.

'CO2 reg. (recycling & disposal)' describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the UK these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extend from landfills. Material credits from material recycling are lower than energy credits in all impact categories except 'Aquatic Eutrophication' and 'Use of Nature' as in the UK the majority of beverage cartons is not recycled. Material credits for 'Climate Change' are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for 'Aquatic Eutrophication' and 'Use of Nature' result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of 'Ozone Depletion Potential'

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle systems in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens (35%-89%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production, nevertheless in the case of ambient PET bottles a considerable share of burdens derives from the production of the PA additive. The high results of 'Ozone Depletion Potential' are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET as well as due to high emissions of nitrous oxide from the PA production.

The 'converting' process of all regarded bottles shows considerable shares of impacts (6%-31%) in all categories apart from 'Aquatic Eutrophication' with shares of impact less than 1%. Emissions from 'converting' process almost exclusively derive from electricity production.

The life cycle step 'top, closure & label' shows considerable (1%-23%) impacts in most categories mainly attributed to the plastics used for the closure. Especially PET Bottle 4 shows higher shares of impacts in this step because if it's heavy closure.

The production and provision of 'transport packaging' for the bottle system show minor shares of impacts (1%-9%) in all categories except of 'Use of Nature' in which the paper production contributes to 63%-75% of the burdens. All relevant emissions derive from production of paper for trays and slipsheets as well as from shrink foil production. The exception is 'Aquatic Eutrophication', where the emissions result from the production of paper for slipsheets and trays.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 6%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (17%-20%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. With a recycling rate of 57% for the clear plastic bottle, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

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

In the regarded SUP in the JNSD 200mL-330mL segment, the biggest part of the environmental burdens is caused by the production of the base materials of the pouch in most impact and inventory categories. The burdens mainly derive from aluminium (up to 37%) and plastics (up to 42%) production with a higher share of burdens from aluminium in the impact categories ‘Acidification’ and ‘Particulate Matter’ due to $SO_2$ and $NO_x$ emissions from the aluminium production

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

The production and provision of ‘transport packaging’ for the SUP show considerable shares of impacts (16%-41%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 95% of the burdens. All relevant emissions derive from production of paper for trays and slipsheets as well as from the production of stretch foil.

The life cycle steps ‘filling’ and ‘distribution’ show only small shares of burdens (max. 14%) for the SUP in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the SUP’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (13%). The incineration of cups 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 almost all SUPs are incinerated. The energy credits mainly originate from the incineration plants.

### 13.5.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment.

Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 193:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TWA 200mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TWA 200mL ambient | SUP 1 200mL ambient | PET Bottle 4 200mL ambient |
| Climate Change [kg $CO_2$eq] | 118.57 | -43% | -74% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -47% | -93% |
| Acidification [kg $SO_2$ eq.] | 0.50 | -9% | -54% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 49.26 | -5% | -53% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.92 | 13% | -68% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.29 | -9% | -53% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.46 | -8% | -54% |

**Table 194:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 161.31 | -44% |
| Ozone depletion potential [g R-11 eq.] | 0.11 | -86% |
| Acidification [kg $SO_2$ eq.] | 0.57 | -14% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 56.18 | -19% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 45.63 | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.36 | -19% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.54 | -17% |

**Table 195:** Comparison of net results: **TPA Edge HC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Edge HC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 137.19 | -53% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -88% |
| Acidification [kg $SO_2$ eq.] | 0.52 | -22% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 50.97 | -27% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 42.29 | -27% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.73 | -26% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -24% |

**Table 196:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square DC 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 138.76 | -56% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -90% |
| Acidification [kg $SO_2$ eq.] | 0.53 | -32% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 51.06 | -33% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 41.86 | -53% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.72 | -31% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -32% |

**Table 197:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **50% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 128.63 | -59% |
| Ozone depletion potential [g R-11 eq.] | 0.23 | -75% |
| Acidification [kg $SO_2$ eq.] | 0.58 | -25% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 61.52 | -20% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 72.95 | -19% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.80 | -20% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.57 | -21% |

## *13.6* Results base scenarios JNSD WATER *330mL-500mL UNITED KINGDOM*

### 13.6.1 Presentation of results

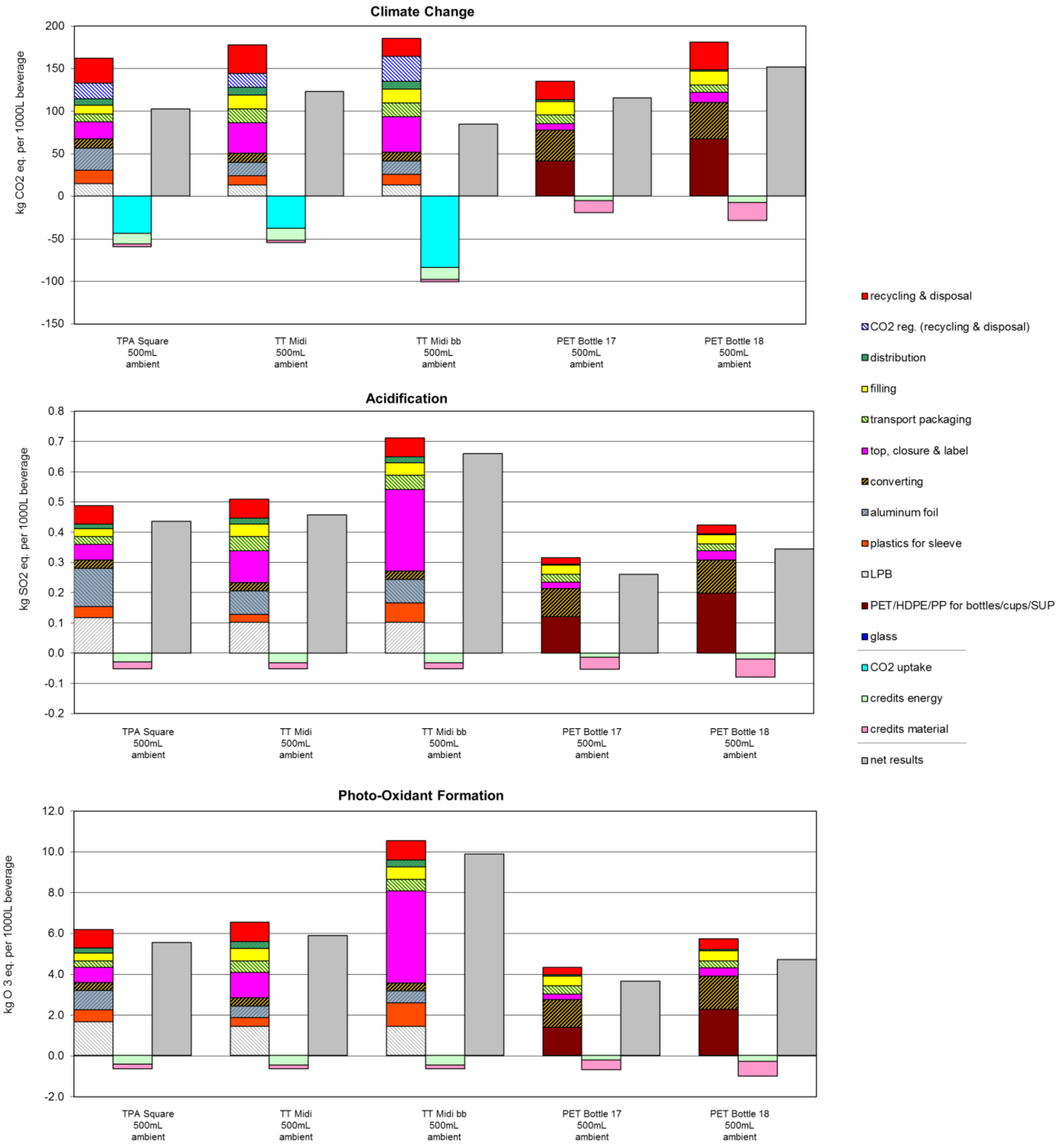



**Figure 168:** Indicator results for base scenarios of **segment JNSD WATER 330mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 1)

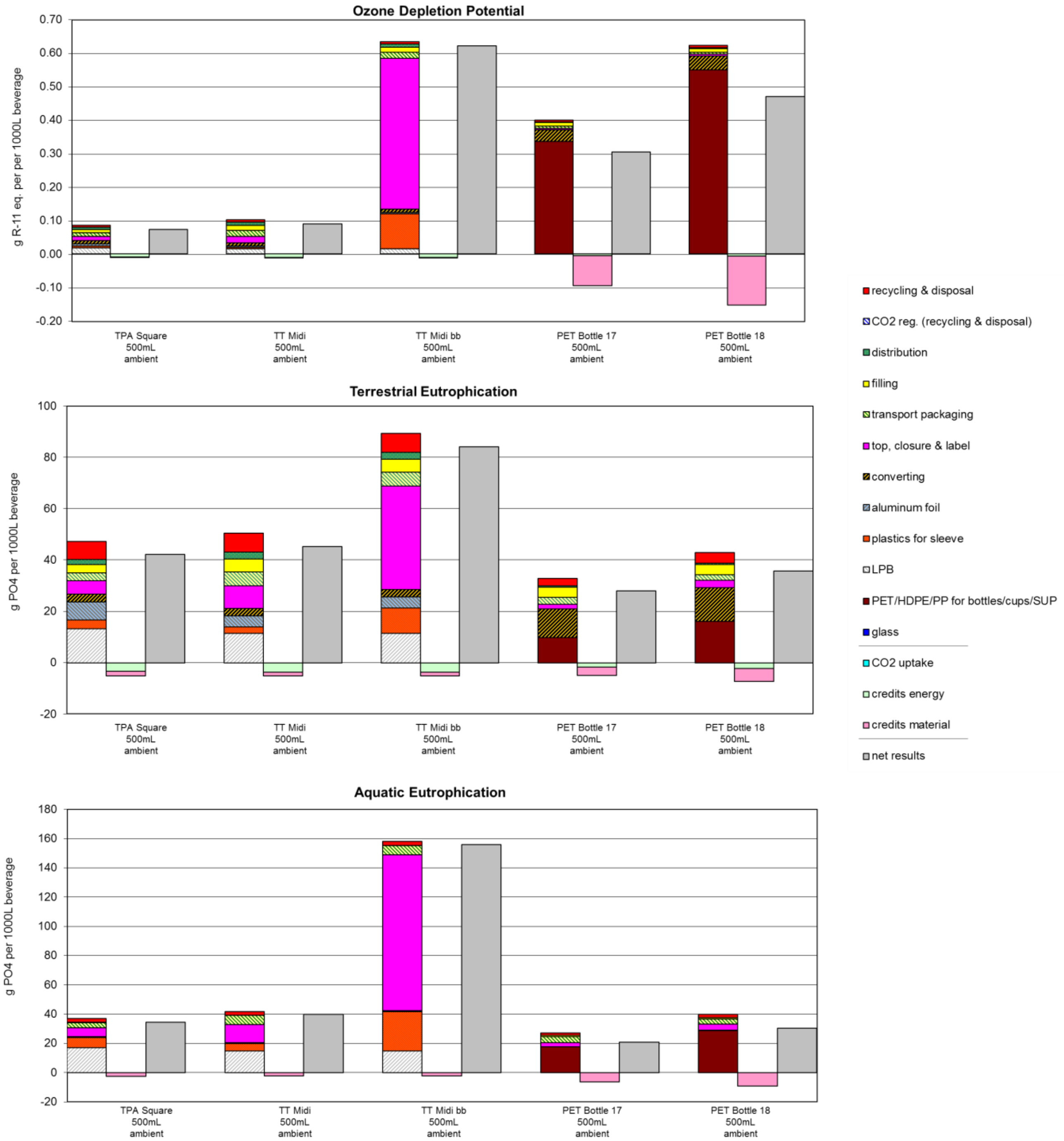



**Figure 169:** Indicator results for base scenarios of **segment JNSD WATER 330mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 2)

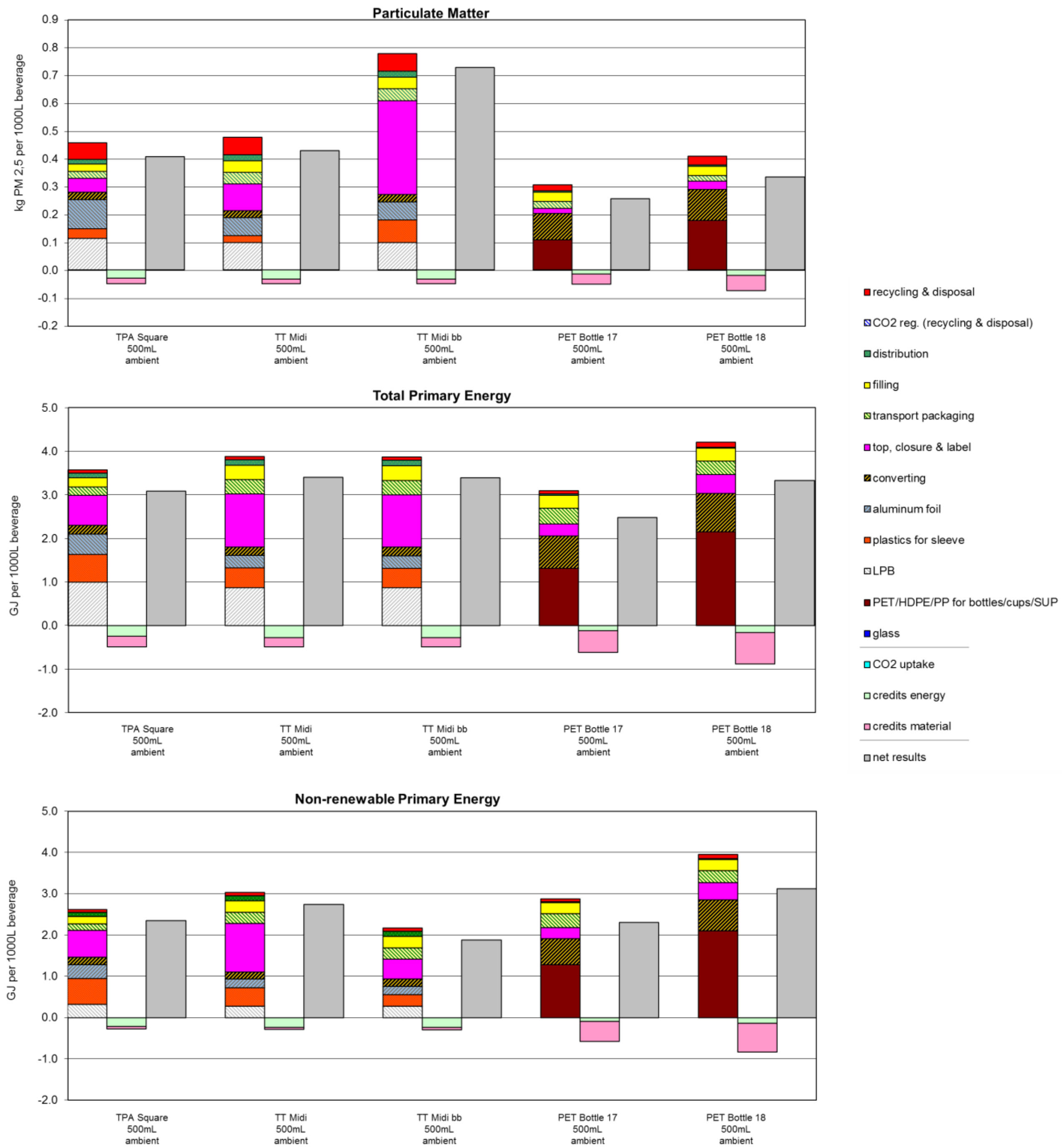



**Figure 170:** Indicator results for base scenarios of segment JNSD WATER 330mL-500mL UNITED KINGDOM, allocation factor 50% (Part 3)

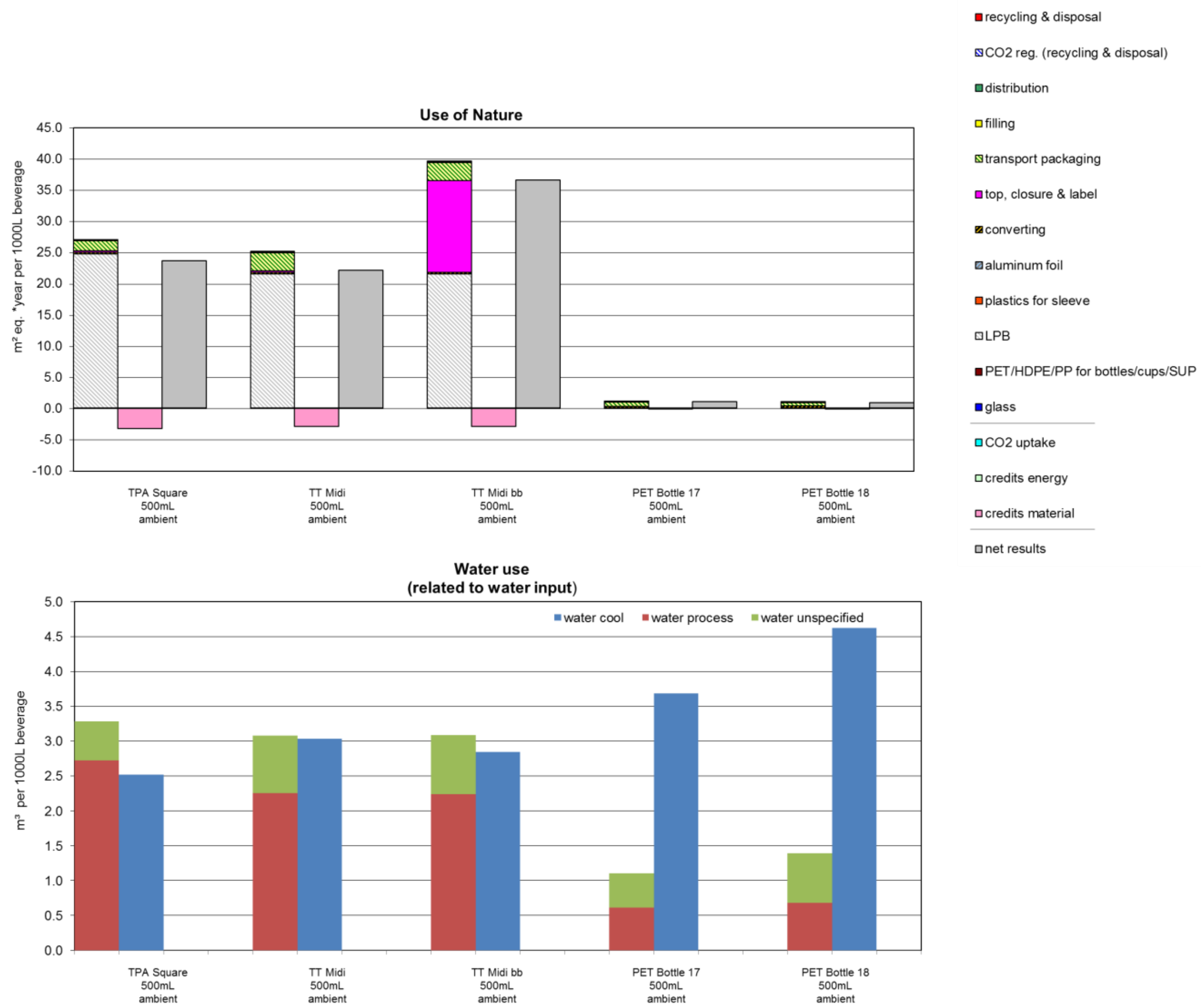



**Figure 171:** Indicator results for base scenarios of **segment JNSD WATER 330mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 4)

**Table 198:** Category indicator results per impact category for base scenarios of **segment JNSD WATER 330mL-500mL UNITED KINGDOM** - burdens, Credits* and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

| allocation factor 50 % | | TPA Square 500mL ambient | TT 500mL ambient | TT bb 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
|---|---|---|---|---|---|---|
| Climate change [kg $CO_2$-equivalents] | Burdens | 143.35 | 161.12 | 155.76 | 134.69 | 180.29 |
| | CO2 (reg) | 18.19 | 16.40 | 29.17 | 0.00 | 0.00 |
| | Credits* | -15.71 | -16.45 | -16.60 | -19.74 | -28.81 |
| | $CO_2$ uptake | -43.99 | -38.28 | -84.30 | 0.00 | 0.00 |
| | Net results (∑) | 101.83 | 122.79 | 84.03 | 114.95 | 151.47 |
| Acidification [kg $SO_2$-equivalents] | Burdens | 0.49 | 0.51 | 0.71 | 0.31 | 0.42 |
| | Credits* | -0.05 | -0.05 | -0.05 | -0.05 | -0.08 |
| | Net results (∑) | 0.44 | 0.46 | 0.66 | 0.26 | 0.34 |
| Photo-Oxidant Formation [kg $O_3$-equivalents] | Burdens | 6.17 | 6.53 | 10.53 | 4.33 | 5.72 |
| | Credits* | -0.64 | -0.65 | -0.65 | -0.70 | -1.01 |
| | Net results (∑) | 5.53 | 5.88 | 9.88 | 3.64 | 4.71 |
| Ozone Depletion [g R-11-equivalents] | Burdens | 0.08 | 0.10 | 0.63 | 0.40 | 0.62 |
| | Credits* | -0.01 | -0.01 | -0.01 | -0.10 | -0.15 |
| | Net results (∑) | 0.07 | 0.09 | 0.62 | 0.30 | 0.47 |
| Terrestrial eutrophication [g $PO_4$-equivalents] | Burdens | 47.29 | 50.48 | 89.40 | 32.89 | 43.02 |
| | Credits* | -5.03 | -5.12 | -5.16 | -4.96 | -7.25 |
| | Net results (∑) | 42.26 | 45.36 | 84.24 | 27.93 | 35.77 |
| Aquatic eutrophication [g $PO_4$-equivalents] | Burdens | 36.93 | 41.84 | 157.78 | 27.02 | 39.67 |
| | Credits* | -2.37 | -2.13 | -2.13 | -6.26 | -9.28 |
| | Net results (∑) | 34.55 | 39.71 | 155.65 | 20.76 | 30.39 |
| Particulate matter [kg PM 2,5-equivalents] | Burdens | 0.46 | 0.48 | 0.78 | 0.31 | 0.41 |
| | Credits* | -0.05 | -0.05 | -0.05 | -0.05 | -0.07 |
| | Net results (∑) | 0.41 | 0.43 | 0.73 | 0.26 | 0.33 |
| Total Primary Energy [GJ] | Burdens | 3.57 | 3.89 | 3.88 | 3.10 | 4.21 |
| | Credits* | -0.48 | -0.48 | -0.48 | -0.61 | -0.88 |
| | Net results (∑) | 3.09 | 3.41 | 3.40 | 2.49 | 3.34 |
| Non-renewable primary energy [GJ] | Burdens | 2.62 | 3.03 | 2.17 | 2.88 | 3.95 |
| | Credits* | -0.27 | -0.29 | -0.29 | -0.58 | -0.84 |
| | Net results (∑) | 2.35 | 2.74 | 1.88 | 2.30 | 3.12 |
| Use of Nature [$m^2$-equivalents*year] | Burdens | 26.91 | 25.01 | 39.50 | 1.05 | 0.93 |
| | Credits* | -3.28 | -2.93 | -2.94 | -0.05 | -0.06 |
| | Net results (∑) | 23.63 | 22.08 | 36.56 | 1.00 | 0.87 |
| Water use [$m^3$] | Water cool | 2.52 | 3.03 | 2.85 | 3.69 | 4.63 |
| | Water process | 2.72 | 2.26 | 2.24 | 0.62 | 0.68 |
| | Water unspec | 0.56 | 0.82 | 0.85 | 0.49 | 0.72 |

*material and energy credits

### 13.6.2 Description and interpretation

**Beverage carton systems** (specifications see section 2.2.1)

For the beverage carton systems regarded in the JNSD (WATER) 330mL-500mL 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' (9%-47%) and 'Use of Nature' (53%-92%). It is also relevant regarding 'Photo-Oxidant Formation' (13%-25%), 'Acidification' (14%-24%), 'Terrestrial Eutrophication' (13%-28%), 'Particulate Matter' (13%-25%) and also the consumption of 'Total Primary Energy' (22%-28%).

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 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 ambient beverage cartons systems shows burdens in most impact categories. High burdens can be seen for the categories 'Acidification' (11%-26%) and 'Particulate Matter' (8%-23%). These result from $SO_2$ and $NO_x$ emissions from the aluminium production.

The production of 'plastics for sleeve' of the beverage cartons shows considerable shares of burdens (4%-24%) in most impact categories. These are considerably lower than those of the LPB production, which is easily explained by its lower material share than that of LPB. The exception is the inventory category 'Non-renewable Primary Energy', where the plastics and LPB contribute about 10% - 30% of the total burdens. If 'plastics for sleeve' contains bio-based plastics (i.e. for TT Midi bio-based 500mL ambient), this life cycle step plays a major role for the overall burdens in all categories apart from ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The life cycle step ‘top, closure & label’ contributes considerably (11%-71%) to almost all impact categories due to the heavy closures in comparison to the weight of the sleeve materials, especially for the Tetra Top beverage carton systems with their heavy tops. In case the plastics used for ‘top, closure & label’ are bio-based (i.e. TT Midi bio-based 500mL ambient), the results are even higher in all categories except ‘Climate Change’ and ‘Non-renewable Primary Energy’.

The reason for the big influence of bio-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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the categories ‘Particulate Matter’, ‘Terrestrial Eutrophication’, ‘Acidification’ and ‘Total Primary Energy’. The burning of bagasse on the field leads to a considerable contribution to ‘Particulate Matter’.

The converting process generally plays a minor role (max 11%). It generates emissions, which contribute to the impact categories 'Climate Change', ‘Acidification', 'Terrestrial Eutrophication' and 'Photo-Oxidant Formation'. Main source of the emissions relevant for these categories is the electricity demand of the converting process.

The production and provision of ‘transport packaging’ for the beverage carton systems shows considerable shares (3%-18%) of impacts in all categories.

The life cycle steps ‘filling’ and ‘distribution’ show only minor shares of burdens (max. 15%) for all beverage carton systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The life cycle step ‘recycling & disposal’ of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’ (27%-29%). Greenhouse gases are also generated by the energy production required in the respective recycling and disposal processes as well as by incineration of packaging materials in MSWI.

‘CO2 reg. (recycling & disposal)’ describes separately all regenerative $CO_2$ emissions from recycling and disposal processes. In case of beverage cartons in the UK these derive mainly from the incineration of bio-based plastics and paper and degraded paperboard on landfills. They play an important role 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.

Energy credits result from the recovery of energy in mainly incineration plants and to a minor extend from landfills. Material credits from material recycling are lower than energy credits in all impact categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ as in the UK the majority of beverage cartons is not recycled. Material credits for ‘Climate Change’ are especially low because the production of substituted primary paper fibres has low greenhouse gas emissions. Higher material credits for ‘Aquatic Eutrophication’ and ‘Use of Nature’ result from substituted primary paper fibres. Together, energy and material credits play an important role on the net results in all categories apart of ‘Ozone Depletion Potential’

The uptake of $CO_2$ by trees harvested for the production of paperboard and by sugarcane for bio-based plastics play 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. It should be noted that to the energy recovery at incineration plants the allocation factor 50 % is applied. This explains the difference between the uptake and the impact from emissions of regenerative $CO_2$.

**Plastic bottles** (specifications see section 2.2.2)

In the regarded PET plastic bottle system in the WATER 500mL segment, the biggest part of the environmental burdens (30%-88%) is also caused by the production of the base materials of the bottles in most impact and inventory categories. The burdens mainly derive from PET production and converting. The high results of ‘Ozone Depletion Potential’ are due to the high emissions of methyl bromide in the production of terephtalic acid (PTA) for PET.

The ‘converting’ process of all regarded bottles shows considerable shares of impacts (7%-34%) in all categories apart from ‘Aquatic Eutrophication’ with shares of impacts less than 1%.. Emissions from ‘converting’ process almost exclusively derive from electricity production.

The life cycle step ‘top, closure & label’ shows minor (1%-11%) impacts in most categories mainly attributed to the plastics used for the closure.

The production and provision of ‘transport packaging’ for the bottle system show minor shares of impacts (1%-15%) in all categories except of ‘Use of Nature’ in which the paper production contributes to 52%-64% of the burdens. All relevant emissions derive from production of paper for slipsheets as well as from shrink foil production. The exception is ‘Aquatic Eutrophication’, where the emissions result from the production of paper for slipsheets.

The life cycle steps ‘filling’ and ‘distribution’ show only minor shares of burdens (max. 12%) for all bottle systems in most impact categories. Therefore none of these steps play an important role for the overall results in any category.

The impact of the plastic bottle’s ‘recycling & disposal’ life cycle step is highest regarding ‘Climate Change’ (16%-18%). The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions.

The influence of credits on the net result is considerable in most categories. With a recycling rate of 57% for the clear plastic bottle, the received material credits are higher than the credits for energy. The energy credits mainly originate from the incineration plants.

### 13.6.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 199:** Comparison of net results: **TPA Square 500mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL UNITED KINGDOM**

| The net results of **TPA Square 500mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **50% allocation** | TPA Square 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change [kg $CO_2$eq] | 101.83 | -11% | -33% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -76% | -84% |
| Acidification [kg $SO_2$ eq.] | 0.44 | 67% | 27% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 42.26 | 51% | 18% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 34.55 | 66% | 14% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.53 | 52% | 17% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | 60% | 22% |

**Table 200:** Comparison of net results **TT 500mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL UNITED KINGDOM**

| The net results of **TT 500mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TT 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change [kg $CO_2$eq] | 122.79 | 7% | -19% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -71% | -81% |
| Acidification [kg $SO_2$ eq.] | 0.46 | 75% | 33% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 45.36 | 62% | 27% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 39.71 | 91% | 31% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.88 | 62% | 25% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.43 | 67% | 28% |

**Table 201:** Comparison of net results: **TT bio-based 500mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL UNITED KINGDOM**

| The net results of **TT 500 biobased water, Gut…** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **50% allocation** | TT bb 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change [kg $CO_2$eq] | 84.03 | -27% | -45% |
| Ozone depletion potential [g R-11 eq.] | 0.62 | 104% | 32% |
| Acidification [kg $SO_2$ eq.] | 0.66 | 153% | 92% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 84.24 | 202% | 136% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 155.65 | 650% | 412% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 9.88 | 171% | 110% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.73 | 185% | 118% |

# 14 Sensitivity Analyses United Kingdom

## 14.1 Sensitivity Analyses DAIRY 1000mL-2000mL UNITED KINGDOM

### 14.1.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

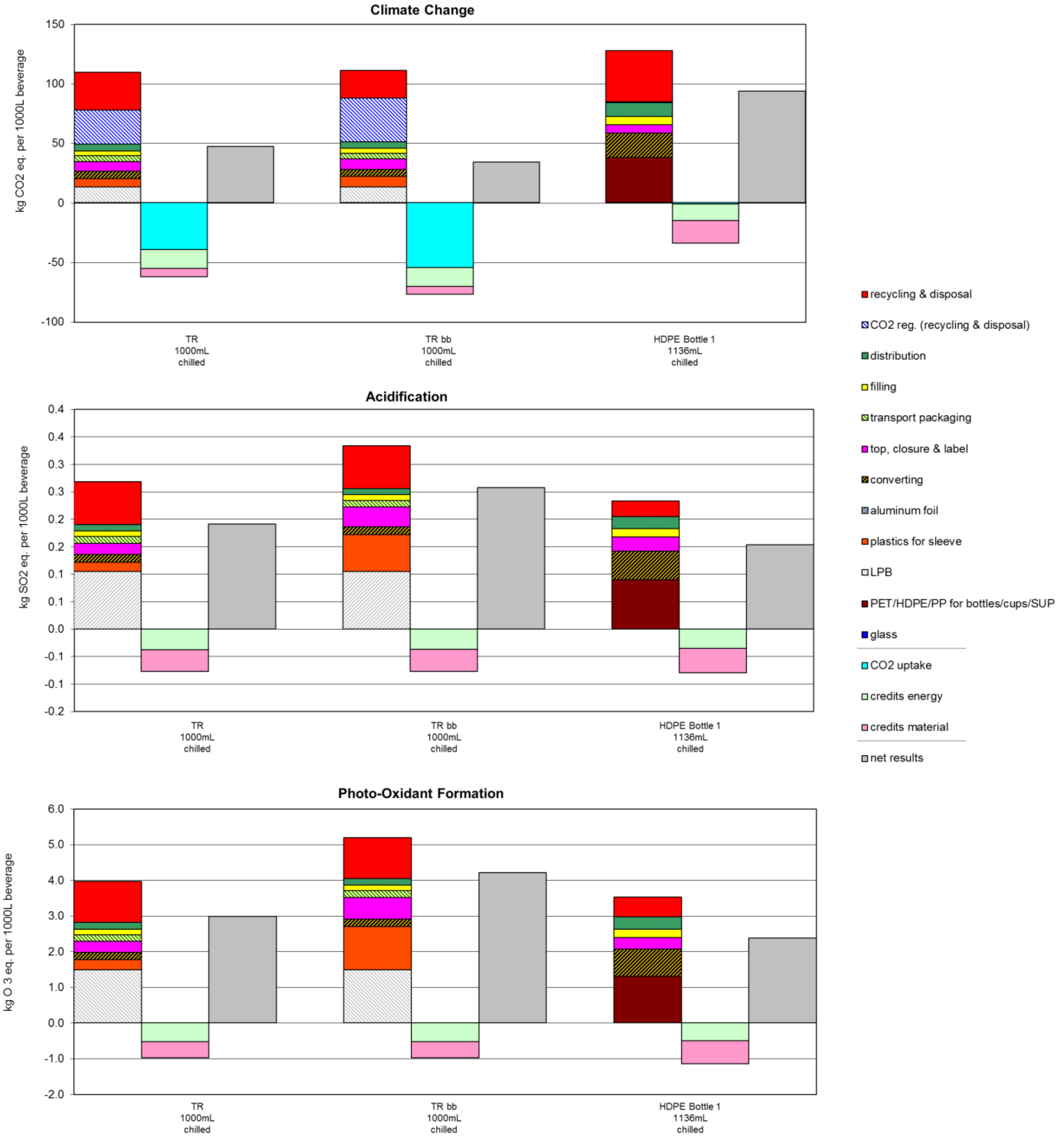



**Figure 172:** Indicator results for sensitivity analysis on system allocation of segment DAIRY 1000mL-2000mL UNITED KINGDOM, allocation factor 100% (Part 1)

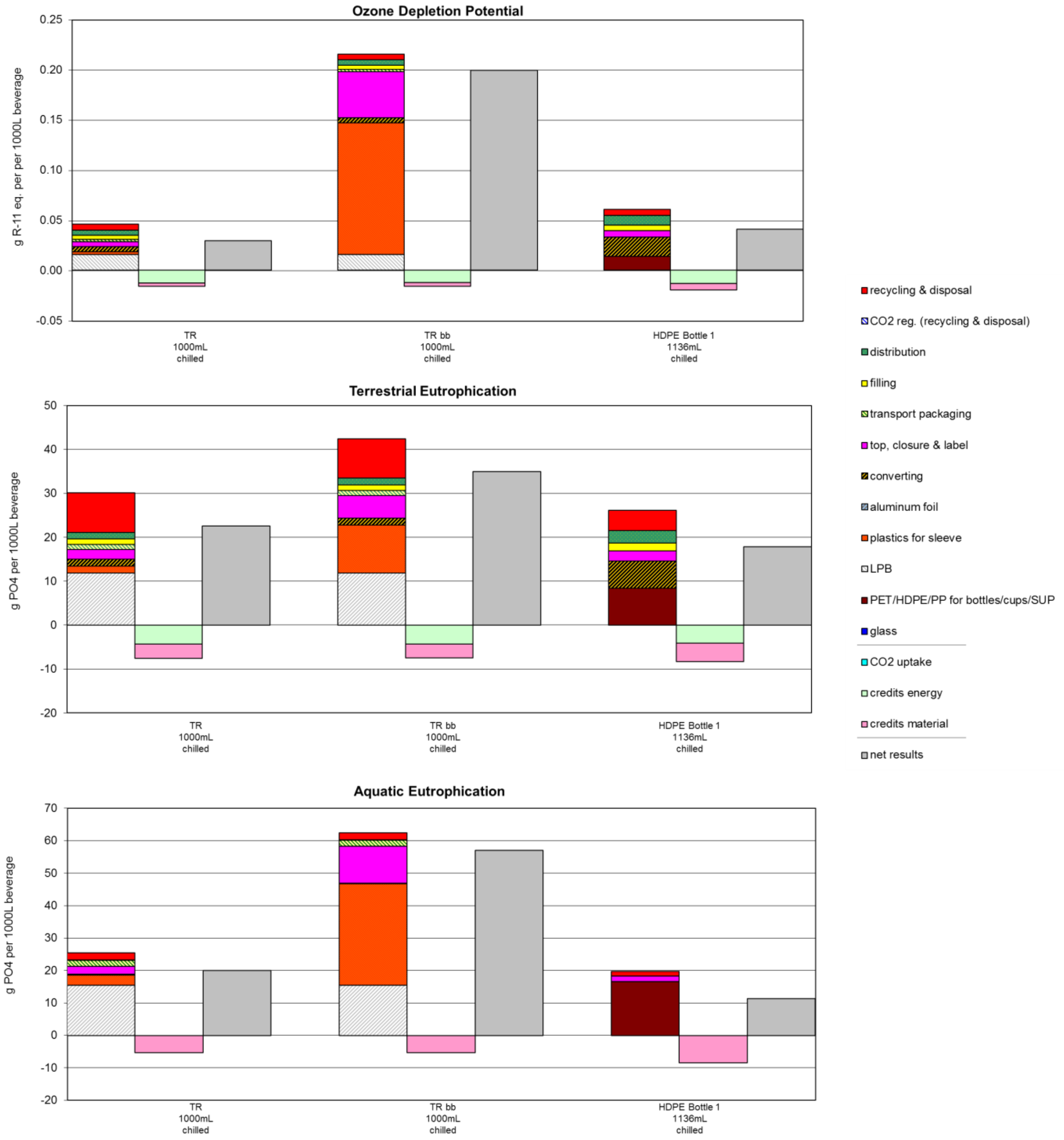



**Figure 173:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 100% (Part 2)

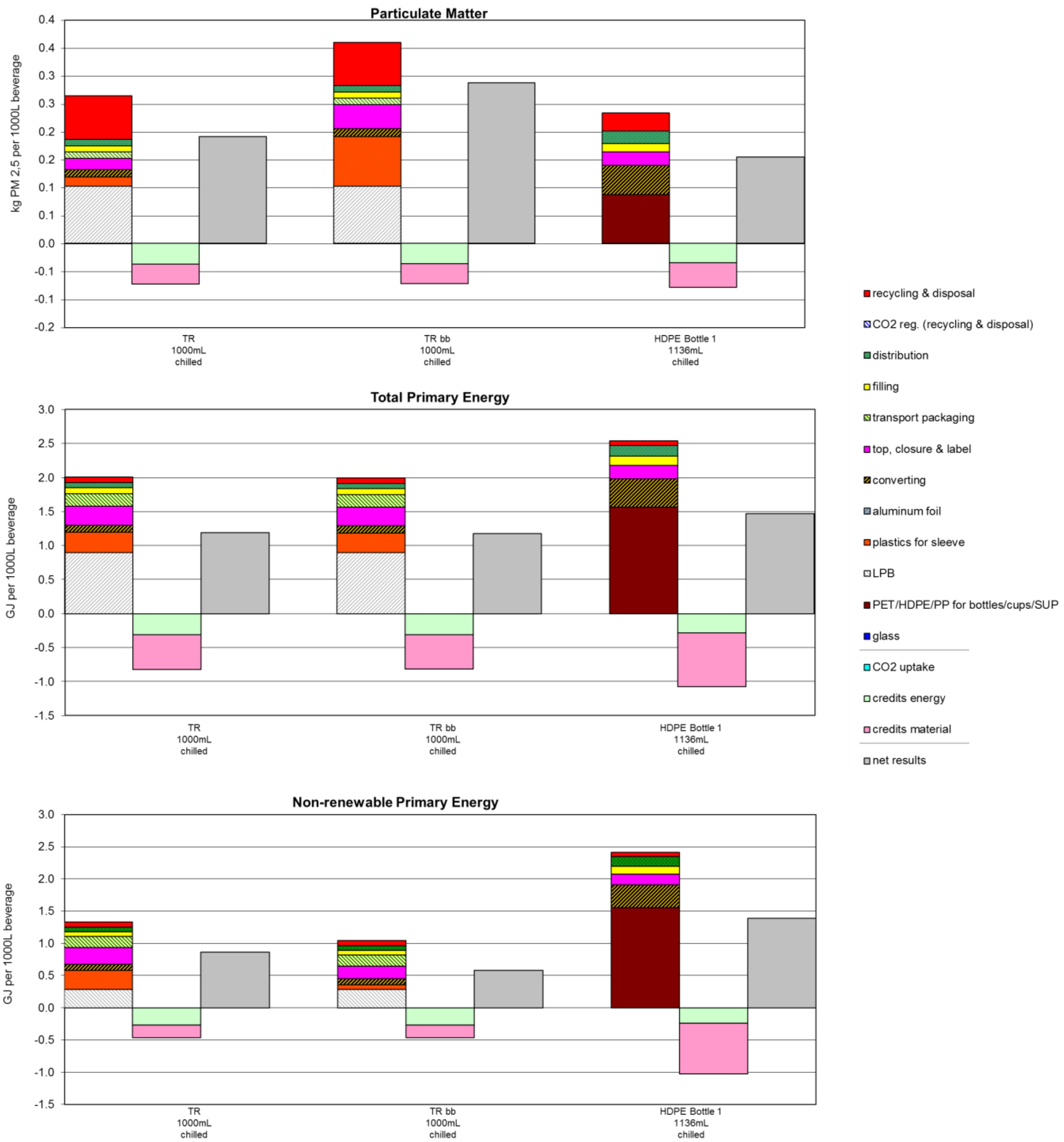



**Figure 174:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 100% (Part 3)

## 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 UK applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor. These are dominated by the credits received for recycled paper board.

In the case of plastic bottles the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 202:** Comparison of net results: **TR 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, UNITED KINGDOM**

| **TR 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TR 1000mL chilled | HDPE Bottle 1 1136mL chilled |
| Climate Change [kg $CO_2$eq] | 47.26 | -49% |
| Ozone depletion potential [g R-11 eq.] | 0.03 | -28% |
| Acidification [kg $SO_2$ eq.] | 0.19 | 25% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 22.63 | 26% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 20.01 | 77% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 2.98 | 26% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.19 | 23% |

**Table 203:** Comparison of net results: **TR bio-based 1000mL** versus its competing alternative packaging systems in **segment DAIRY 1000mL-2000mL, UNITED KINGDOM**

| The net results of **TR bb 1000mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TR bb 1000mL chilled | HDPE Bottle 1 1136mL chilled |
| Climate Change [kg $CO_2$eq] | 33.95 | -64% |
| Ozone depletion potential [g R-11 eq.] | 0.20 | 389% |
| Acidification [kg $SO_2$ eq.] | 0.26 | 68% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 34.99 | 95% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 56.96 | 405% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.21 | 78% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.29 | 86% |

### 14.1.2 Sensitivity analysis regarding recycled content in HDPE bottles

All HDPE bottles in the base scenarios are modelled with 100% primary HDPE. In case of the UK, in 2009 the Dairy Roadmap (formerly known as Milk Roadmap) was introduced [Dairy Roadmap 2015]. This roadmap set goals for raising the content of recycled HDPE in fresh milk bottles to 30% by 2015 and 50% by 2020. The 30% mark had been reached in 2014. Nevertheless the current recycled HDPE content is substantially lower due to capacity reduction for recycled HDPE in the UK [WRAP 2018]. As it is unclear if there is still a certain share of rHDPE contained in UK HDPE bottles the base scenarios are modelled without rHDPE. In order to take the formerly reached mark of 30% rHDPE and the still valid goal of 50% rHDPE in 2020 of the Dairy Roadmap into account, sensitivity analyses are conducted for the chilled dairy bottles containing fresh milk on the UK market as described in Table 30 In these analyses. The allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

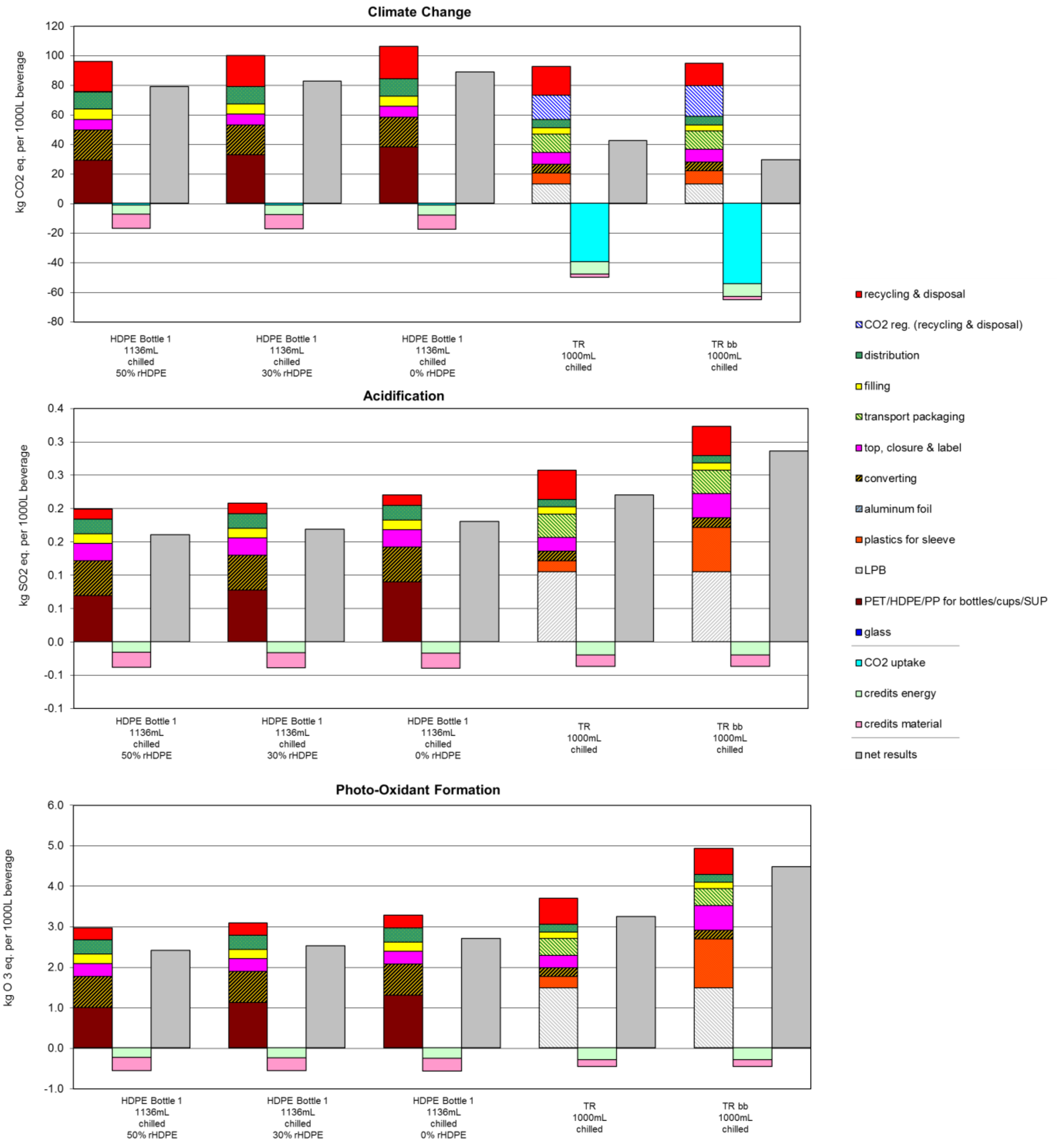



**Figure 175:** Indicator results for sensitivity analysis on recycled content in HDPE bottles of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 50% (Part 1)

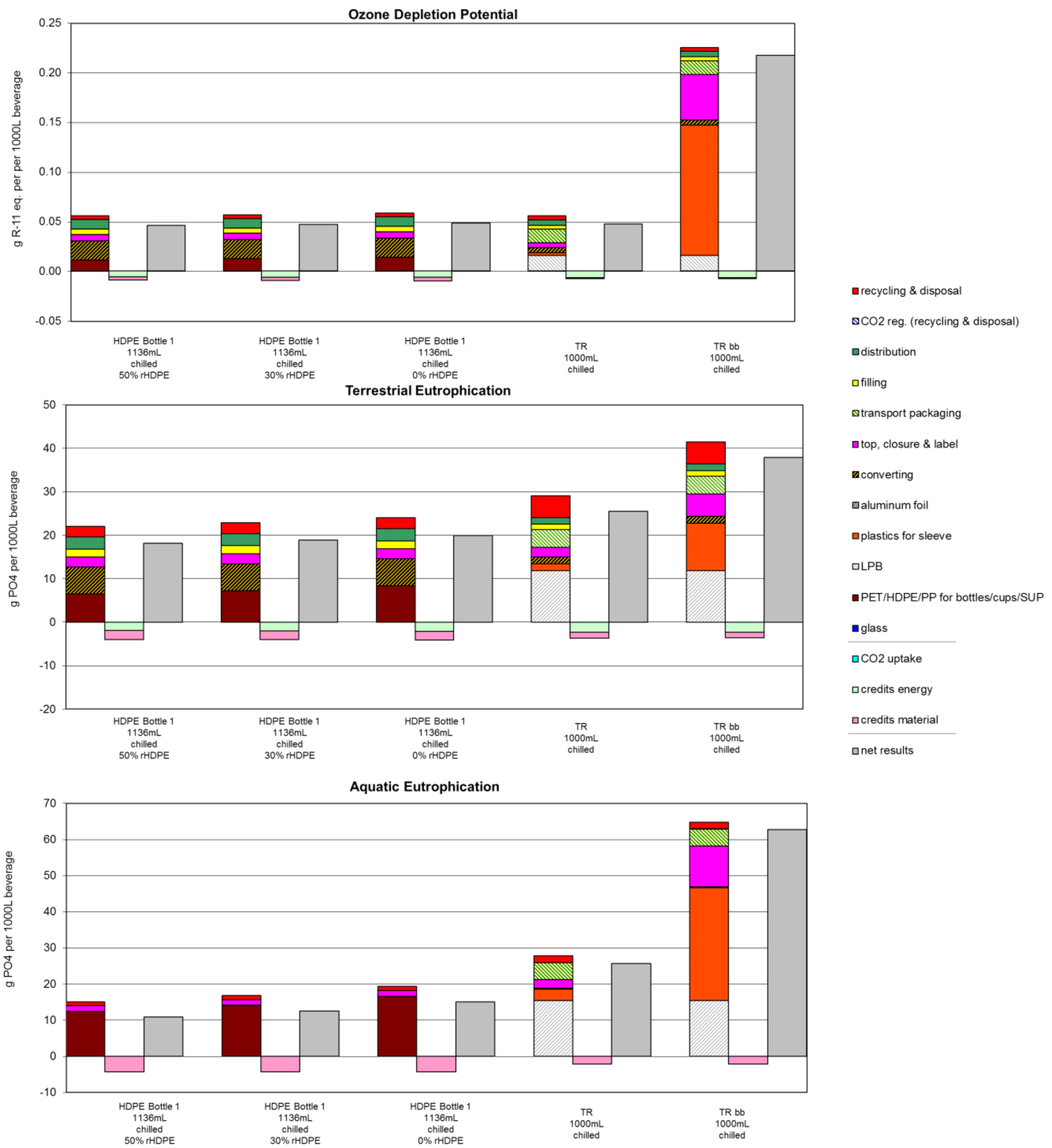



**Figure 176:** Indicator results for sensitivity analysis on recycled content in HDPE bottles of **segment DAIRY 1000mL-2000mL UNITED KINGDOM**, allocation factor 50% (Part 2)

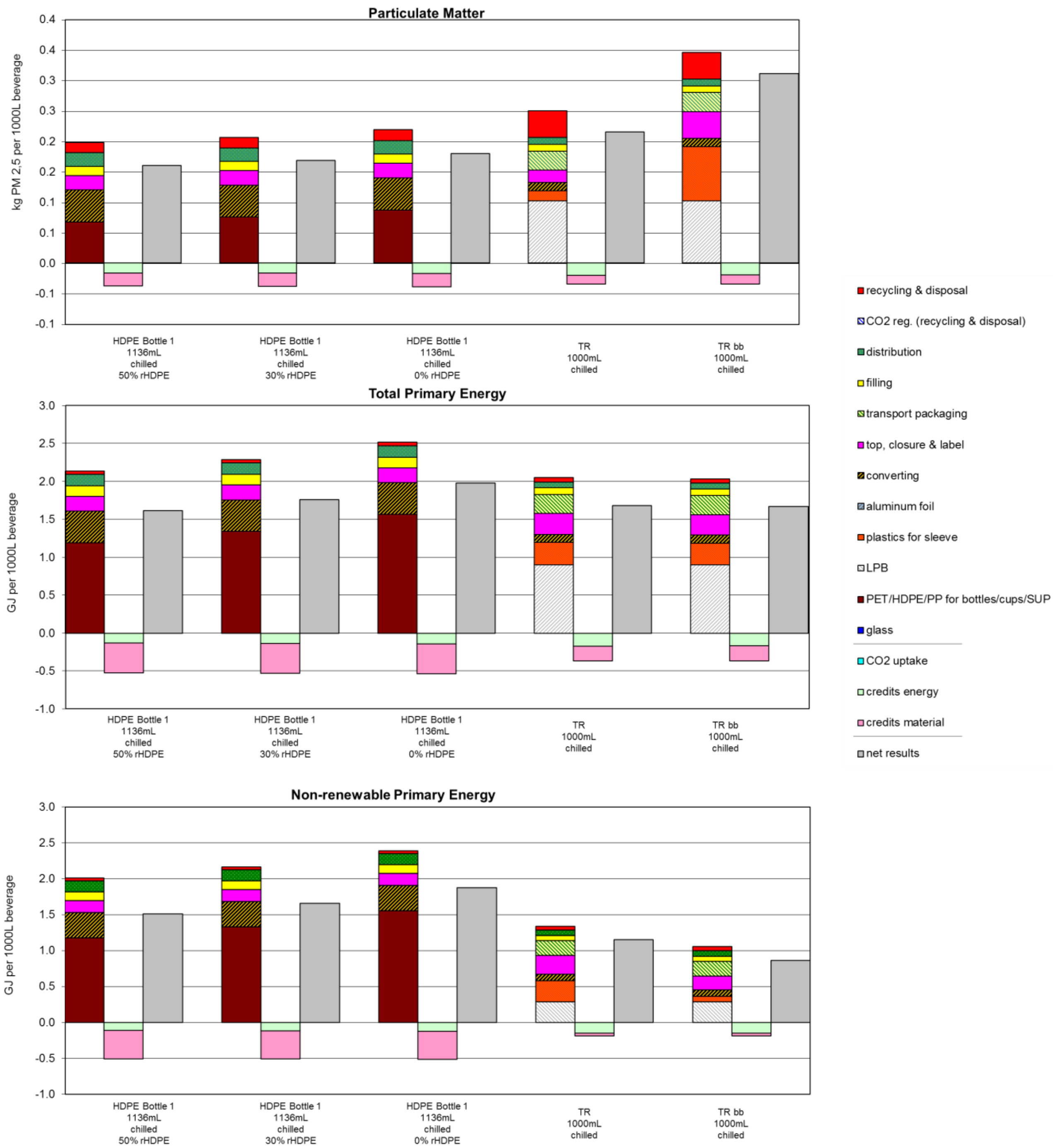



**Figure 177:** Indicator results for sensitivity analysis on recycled content in HDPE bottles of **segment DAIRY 1000mL-2000mL UNITED KINGDOM,** allocation factor 50% (Part 3)

**Description and interpretation**

Increasing the share of recycled HDPE to 30% reduces the impacts of the production of HDPE. This leads to 3% - 17% lower net results. With a share of 50% rHDPE net results reduce from 11% - 23%. The highest reductions can be seen in 'Aquatic Eutrophication' and the smallest reductions in 'Ozone deletion potential'.

For most of the impact categories and compared systems the ranking of net results stays the same when applying 30% and 50% rHDPE. One exception is 'Total Primary Energy" where the 50% rHDPE Bottle1 shows now higher net results than the TR 1000mL chilled.

## 14.2 Sensitivity Analyses JNSD 1000mL UNITED KINGDOM

### 14.2.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

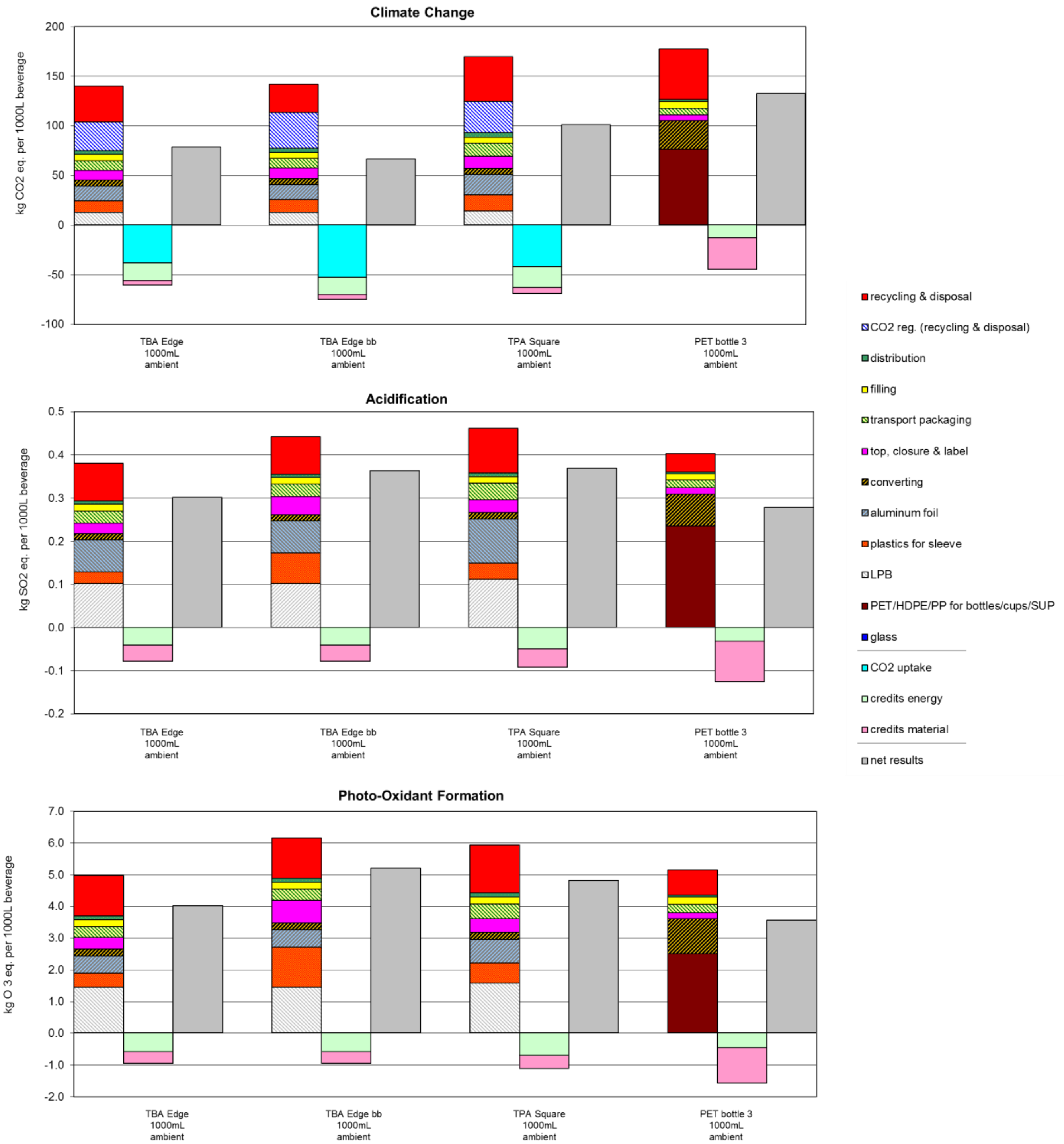



**Figure 178:** Indicator results for sensitivity analysis on system allocation of segment JNSD 1000mL UNITED KINGDOM, allocation factor 100% (Part 1)

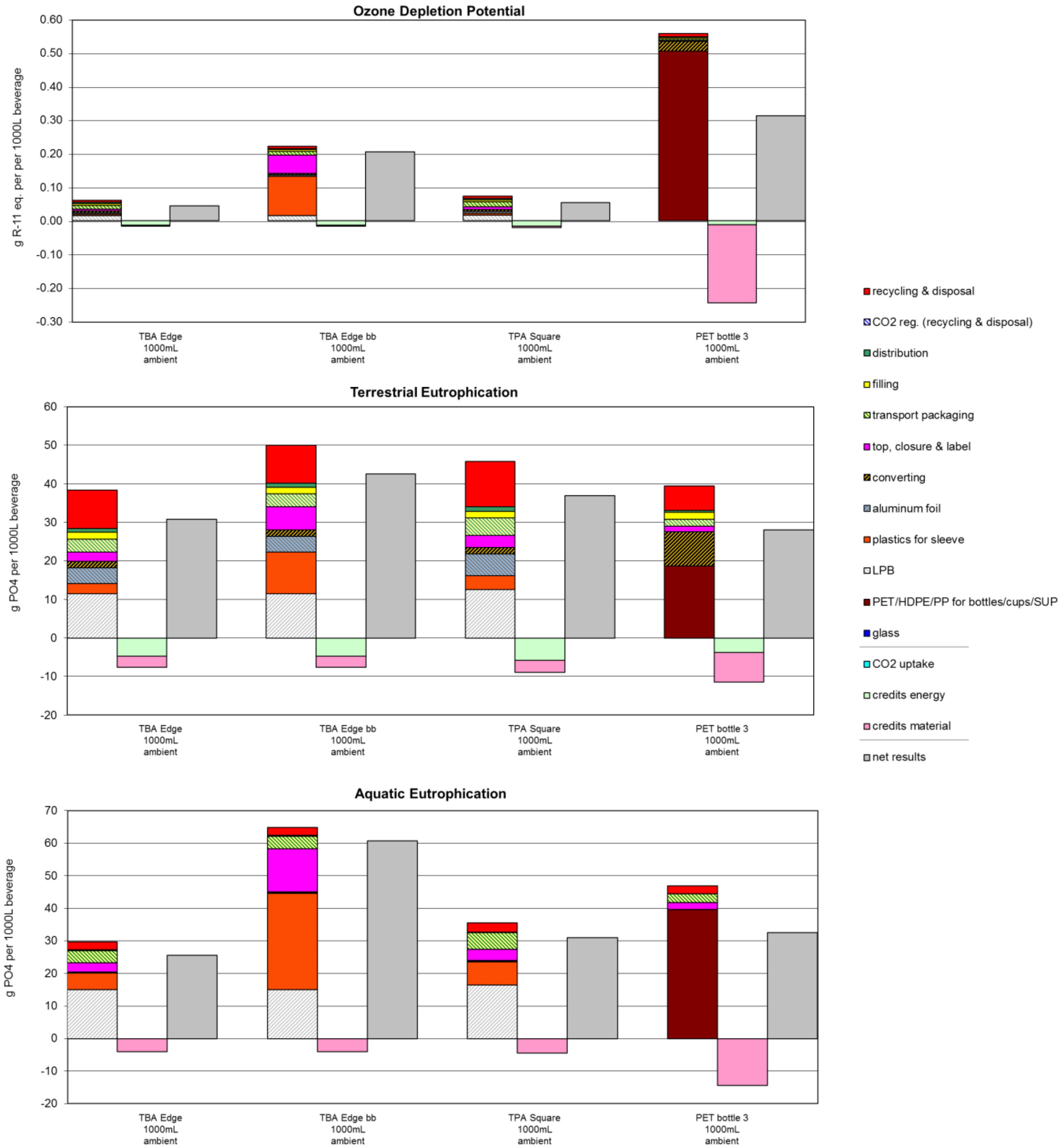



**Figure 179:** Indicator results for sensitivity analysis on system allocation of segment JNSD 1000mL UNITED KINGDOM, allocation factor 100% (Part 2)

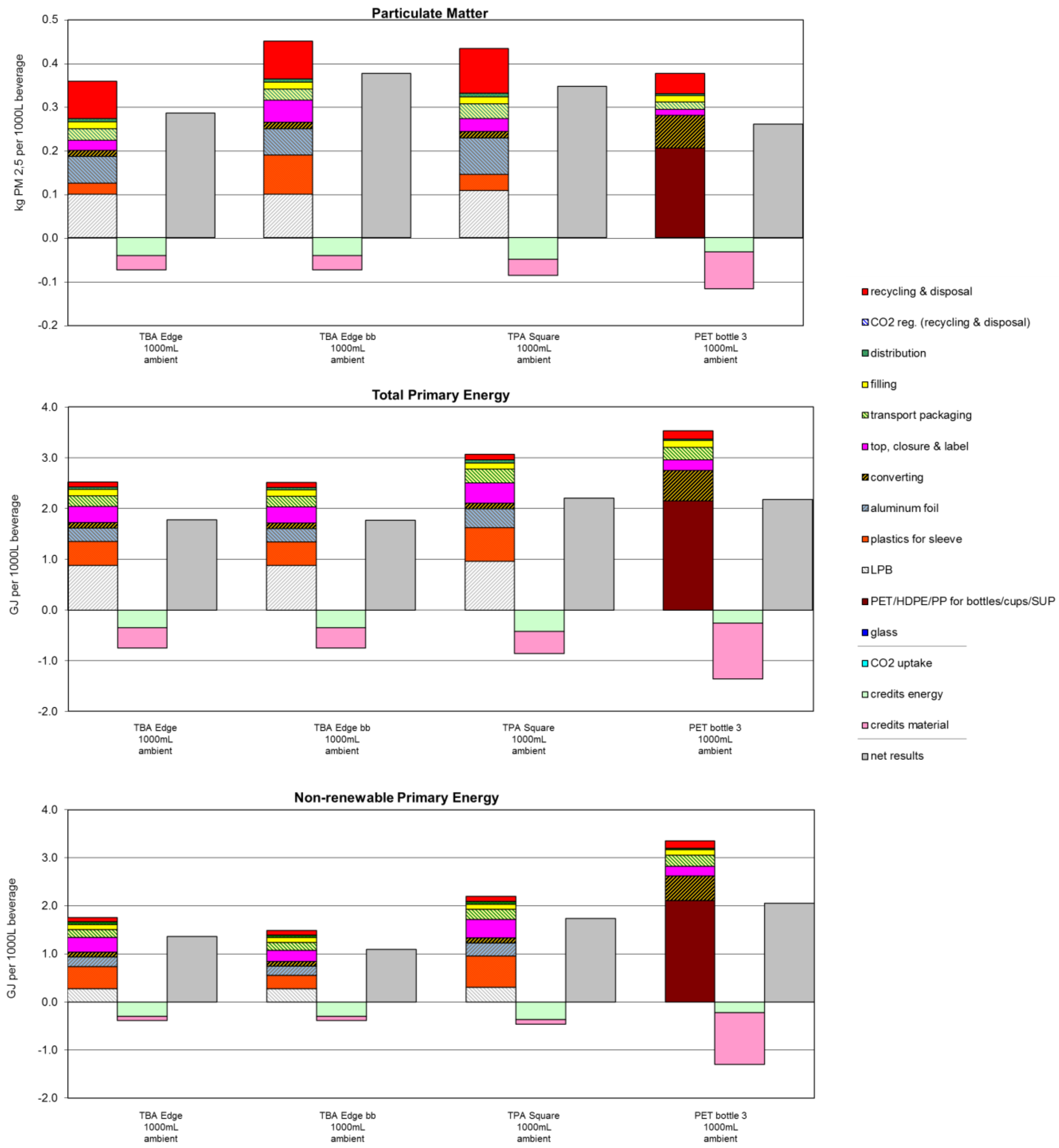



**Figure 180:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 1000mL UNITED KINGDOM**, allocation factor 100% (Part 3)

### 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 UK applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor. These are dominated by the credits received for recycled paper board.

In the case of plastic bottles the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 204:** Comparison of net results: **TBA Edge 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, UNITED KINGDOM**

| The net results of **TBA Edge 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TBA Edge 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 78.62 | -40% |
| Ozone depletion potential [g R-11 eq.] | 0.04 | -86% |
| Acidification [kg $SO_2$ eq.] | 0.30 | 8% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 30.87 | 10% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 25.53 | -22% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.01 | 13% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.29 | 10% |

**Table 205:** Comparison of net results: **TBA Edge bio-based 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, UNITED KINGDOM**

| The net results of **TBA Edge bb 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TBA Edge bb 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 66.41 | -50% |
| Ozone depletion potential [g R-11 eq.] | 0.21 | -34% |
| Acidification [kg $SO_2$ eq.] | 0.36 | 31% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 42.59 | 52% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 60.57 | 86% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.19 | 46% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.38 | 45% |

**Table 206:** Comparison of net results: **TBA Square 1000 mL** versus its competing alternative packaging systems in **segment JNSD 1000m, UNITED KINGDOM**

| The net results of **TPA Square 1000mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square 1000mL ambient | PET Bottle 3 1000mL ambient |
| Climate Change [kg $CO_2$eq] | 100.50 | -24% |
| Ozone depletion potential [g R-11 eq.] | 0.05 | -83% |
| Acidification [kg $SO_2$ eq.] | 0.37 | 33% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.98 | 32% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 30.96 | -5% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.81 | 35% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.35 | 33% |

## 14.3 Sensitivity Analyses DAIRY 189mL-500mL UNITED KINGDOM

### 14.3.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

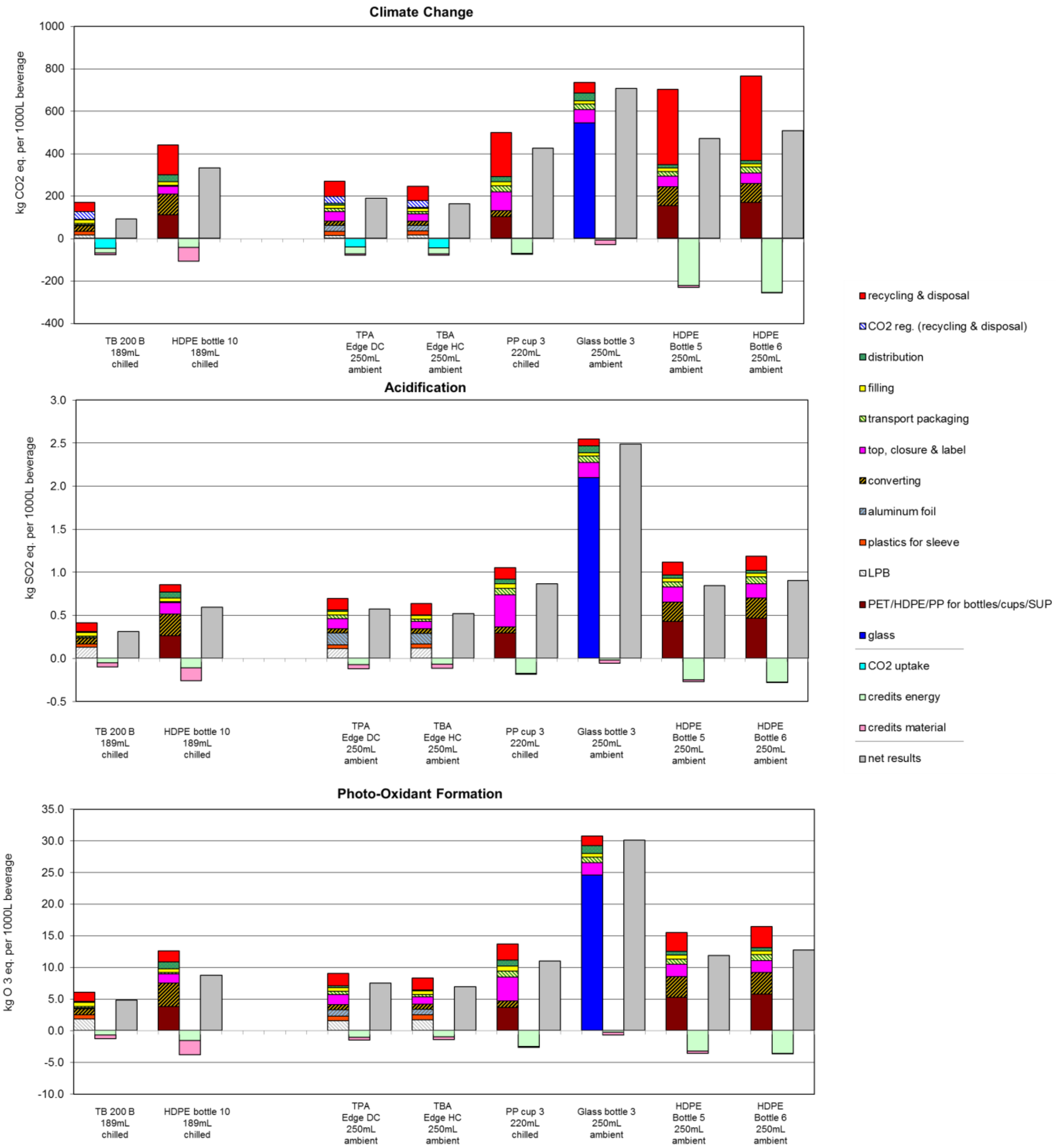



**Figure 181:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL UNITED KINGDOM (189mL-250mL)**, allocation factor 100% (Part 1)

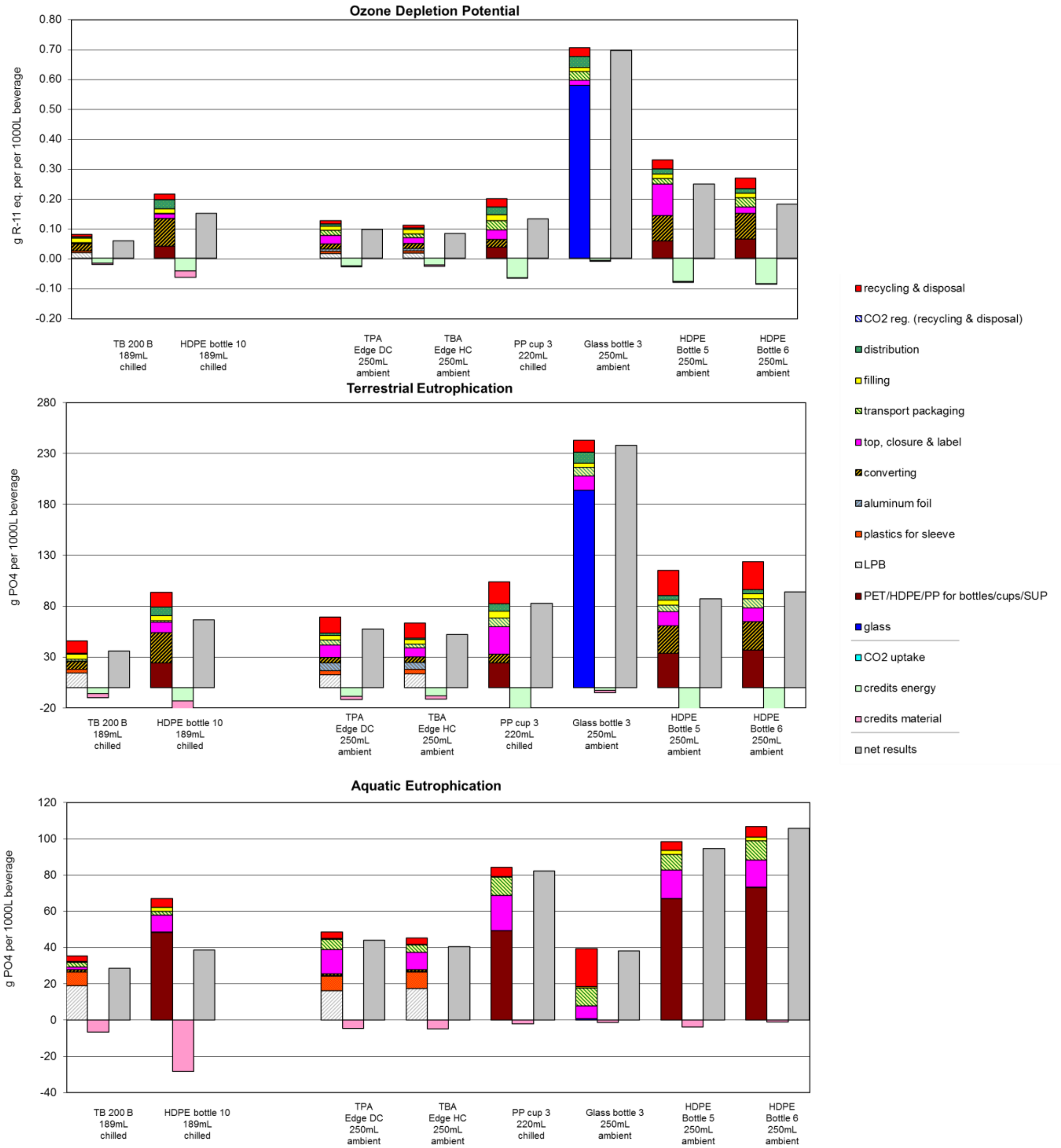



**Figure 182:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL UNITED KINGDOM (189mL-250mL)**, allocation factor 100% (Part 2)

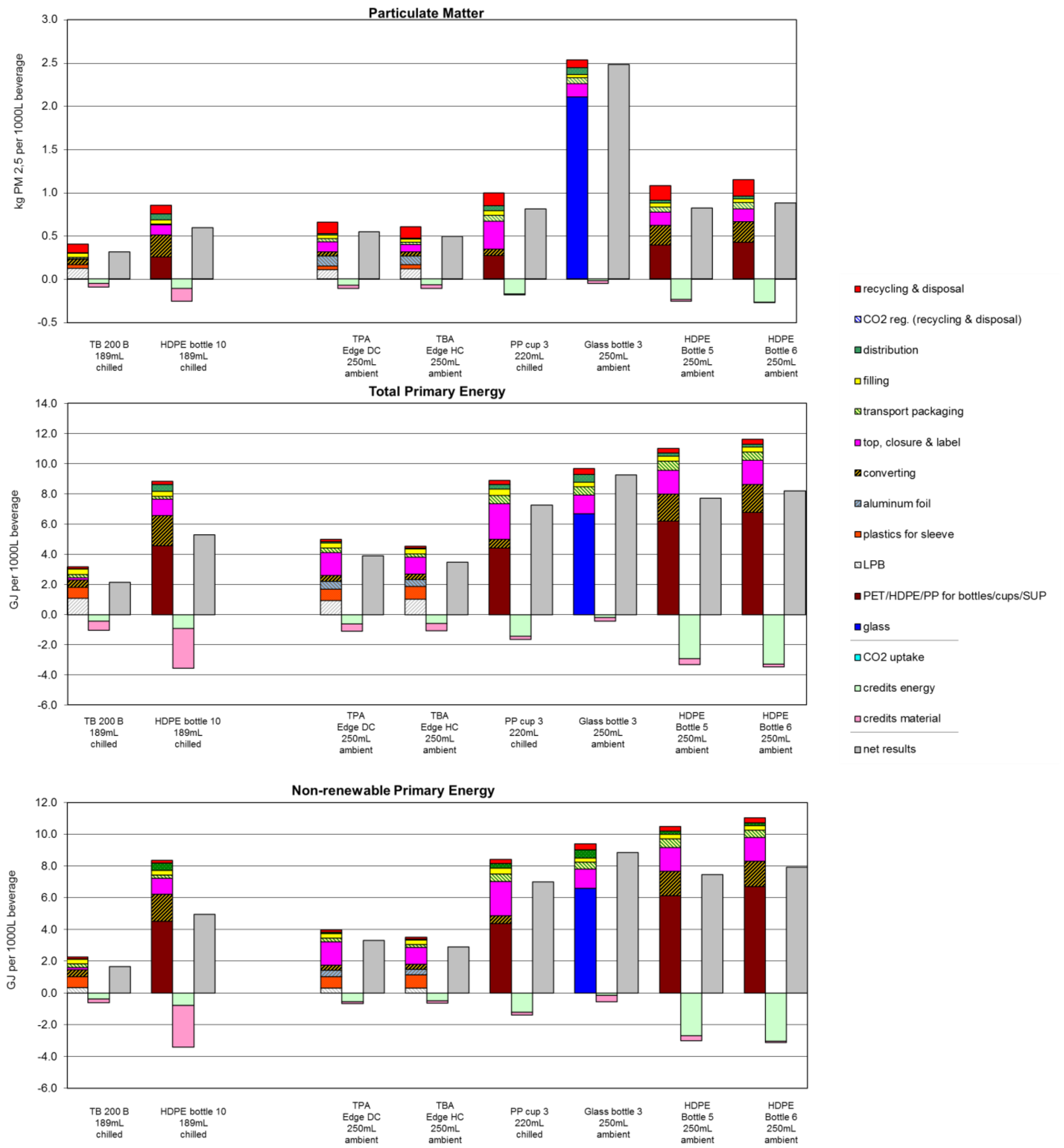



**Figure 183:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL UNITED KINGDOM (189mL-250mL),** allocation factor 100% (Part 3)

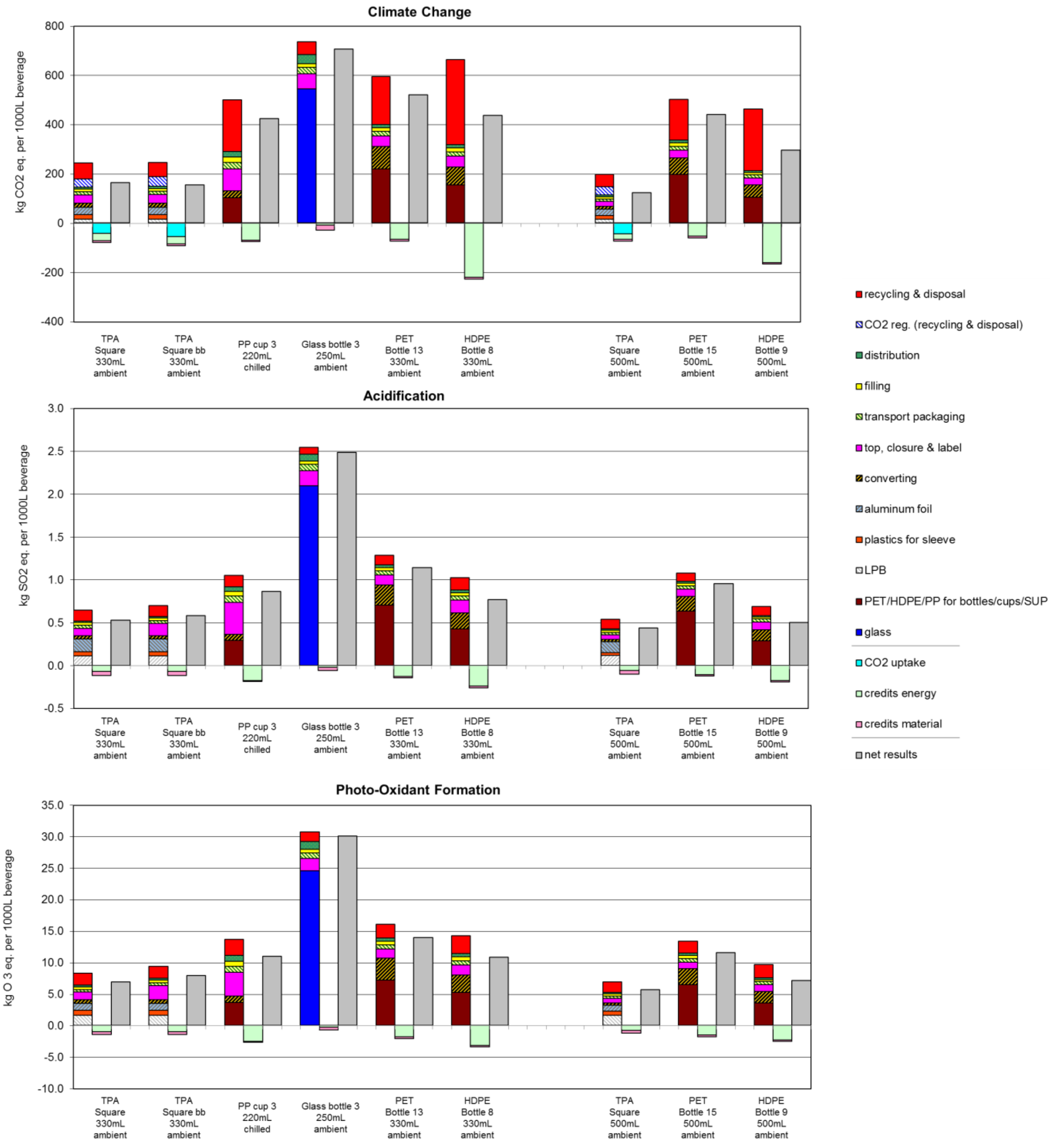



**Figure 184:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL)**, allocation factor 100% (Part 1)

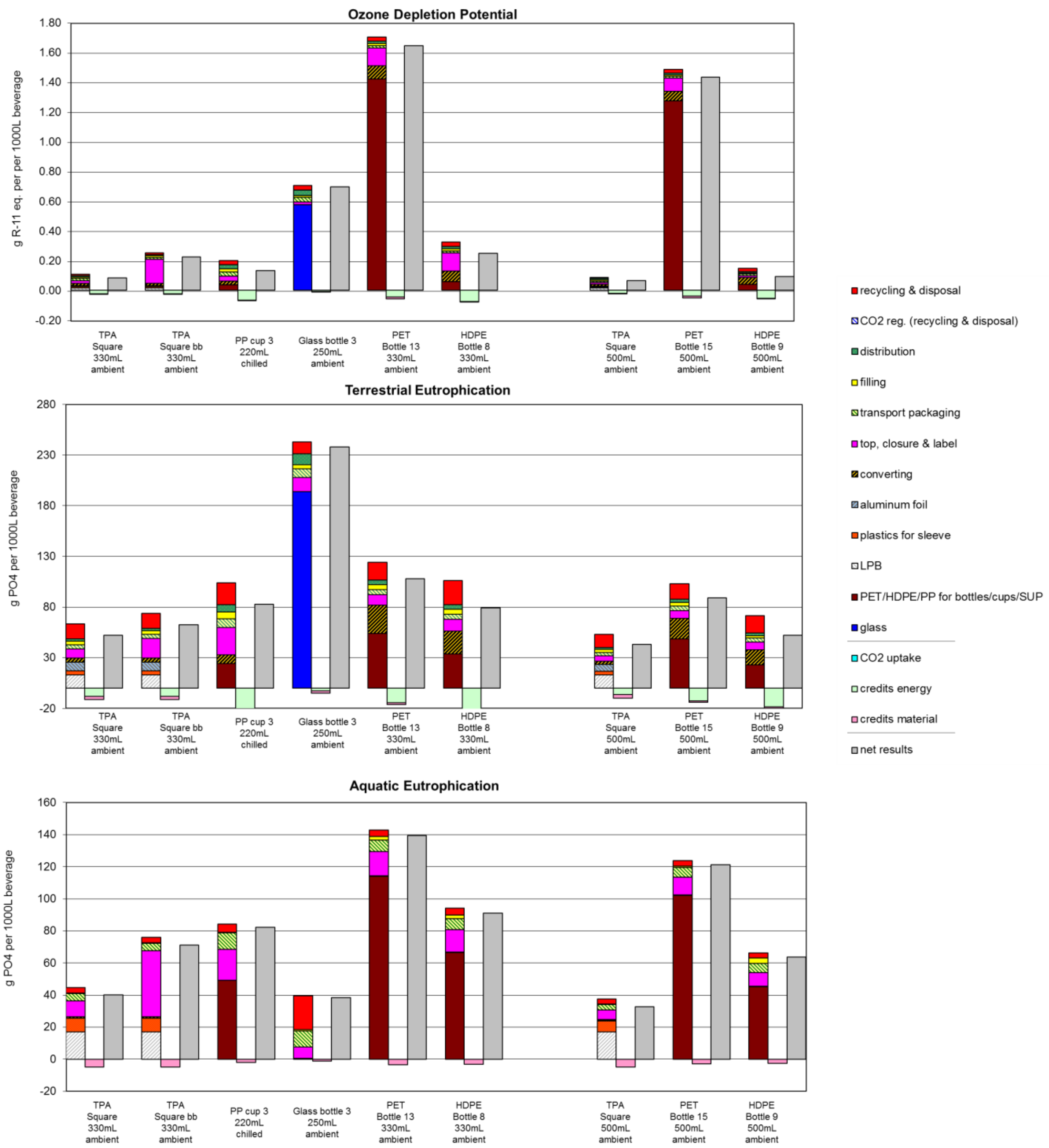



**Figure 185:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL)**, allocation factor 100% (Part 2)

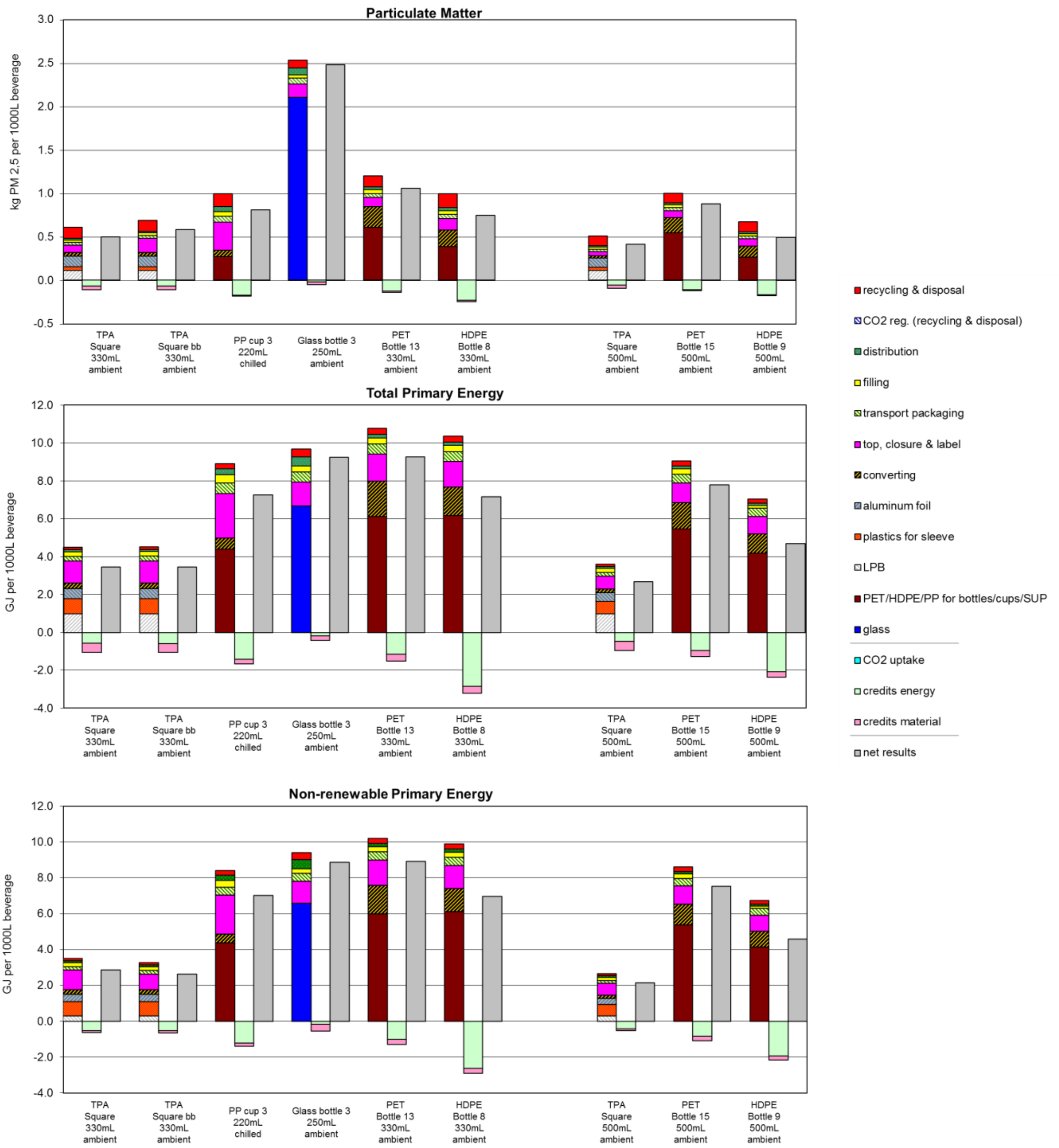



**Figure 186:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY 189mL-500mL UNITED KINGDOM (330mL-500mL)**, allocation factor 100% (Part 3)

## 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 UK applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor.  These are dominated by the credits received for recycled paper board.

In the cases of HDPE plastic bottles and PP cups the net result decrease in most impact categories with the exception of 'Climate Change'. For 'Climate Change' net results increase when applying the 100% allocation factor as burdens from recycling and disposal are higher than energy and material credits. In contrast, for PET bottles all impact categories increase due to the lower caloric value of PET than HDPE leading to lower energy credits.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for beverage carton systems, plastic bottles and PP cups due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

In the case of the glass bottle net result increase in all impact and inventory categories due to low credits. Despite of the recycling rate of 67% material credits are very low as 64% of the recycled glass is used for the production of glass bottles in a closed loop approach. Material credits are only given for recycled material that substitutes primary material in open loop models (i.e. 3%).

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 207:** Comparison of net results: **TB 200 B 189mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TB 200 B 189mL chilled …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TB 200 B 189mL chilled | HDPE Bottle 10 189mL chilled |
| Climate Change [kg $CO_2$eq] | 91.41 | -72% |
| Ozone depletion potential [g R-11 eq.] | 0.06 | -62% |
| Acidification [kg $SO_2$ eq.] | 0.31 | -47% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 36.10 | -46% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 28.65 | -26% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 4.80 | -45% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.31 | -48% |

**Table 208:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Edge DC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of | | | |
|---|---|---|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 188.36 | -56% | -73% | -60% | -63% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -27% | -86% | -61% | -46% |
| Acidification [kg $SO_2$ eq.] | 0.57 | -34% | -77% | -32% | -36% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 57.53 | -30% | -76% | -34% | -39% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 43.85 | -47% | 15% | -54% | -58% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.53 | -32% | -75% | -37% | -41% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.54 | -33% | -78% | -34% | -38% |

**Table 209:** Comparison of net results: **TBA Edge HC 250mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TBA Edge HC 250mL ambient** | ...are lower (green) / higher (orange) than those of | | | | |
|---|---|---|---|---|---|
| **100% allocation** | TBA Edge HC 250mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | HDPE Bottle 5 250mL ambient | HDPE Bottle 6 250mL ambient |
| Climate Change [kg $CO_2$eq] | 163.06 | -61% | -77% | -65% | -68% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -37% | -88% | -66% | -54% |
| Acidification [kg $SO_2$ eq.] | 0.52 | -40% | -79% | -39% | -42% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.29 | -37% | -78% | -40% | -45% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.37 | -51% | 6% | -57% | -62% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.90 | -37% | -77% | -42% | -46% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -39% | -80% | -40% | -44% |

**Table 210:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Square DC 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | | | |
|---|---|---|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 164.04 | -61% | -77% | -68% | -62% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -38% | -88% | -95% | -67% |
| Acidification [kg $SO_2$ eq.] | 0.53 | -39% | -79% | -54% | -31% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.33 | -37% | -78% | -52% | -34% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.00 | -51% | 5% | -71% | -56% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.88 | -38% | -77% | -51% | -37% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.50 | -38% | -80% | -53% | -33% |

**Table 211:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Square DC bb 330mL ambient …** | ...are lower (green) / higher (orange) than those of | | | | |
|---|---|---|---|---|---|
| **100% allocation** | TPA Square DC bb 330mL ambient | PP Cup 3 250mL chilled | Glass Bottle 3 250mL ambient | PET Bottle 13 330mL ambient | HDPE Bottle 8 330mL ambient |
| Climate Change [kg $CO_2$eq] | 153.90 | -64% | -78% | -70% | -65% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | 69% | -68% | -86% | -10% |
| Acidification [kg $SO_2$ eq.] | 0.59 | -32% | -76% | -49% | -24% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 62.80 | -24% | -74% | -42% | -21% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 71.09 | -13% | 86% | -49% | -22% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.97 | -28% | -73% | -43% | -27% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.58 | -28% | -77% | -45% | -22% |

**Table 212:** Comparison of net results: **TPA Square 500mL** versus its competing alternative packaging systems **segment DAIRY 189mL-500mL UNITED KINGDOM**

| The net results of **TPA Square 500mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TPA Square 500mL ambient | PET Bottle 15 500mL ambient | HDPE Bottle 9 5000mL ambient |
| Climate Change [kg $CO_2$eq] | 123.11 | -72% | -58% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -95% | -29% |
| Acidification [kg $SO_2$ eq.] | 0.44 | -54% | -13% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.35 | -51% | -17% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 32.65 | -73% | -49% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.67 | -51% | -21% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | -53% | -16% |

### 14.3.2 Sensitivity analysis regarding bio-based plastics in HDPE bottles

To consider potential future developments in terms of bio-based material in plastic bottles a sensitivity analysis is performed for the packaging systems listed in Table 28. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

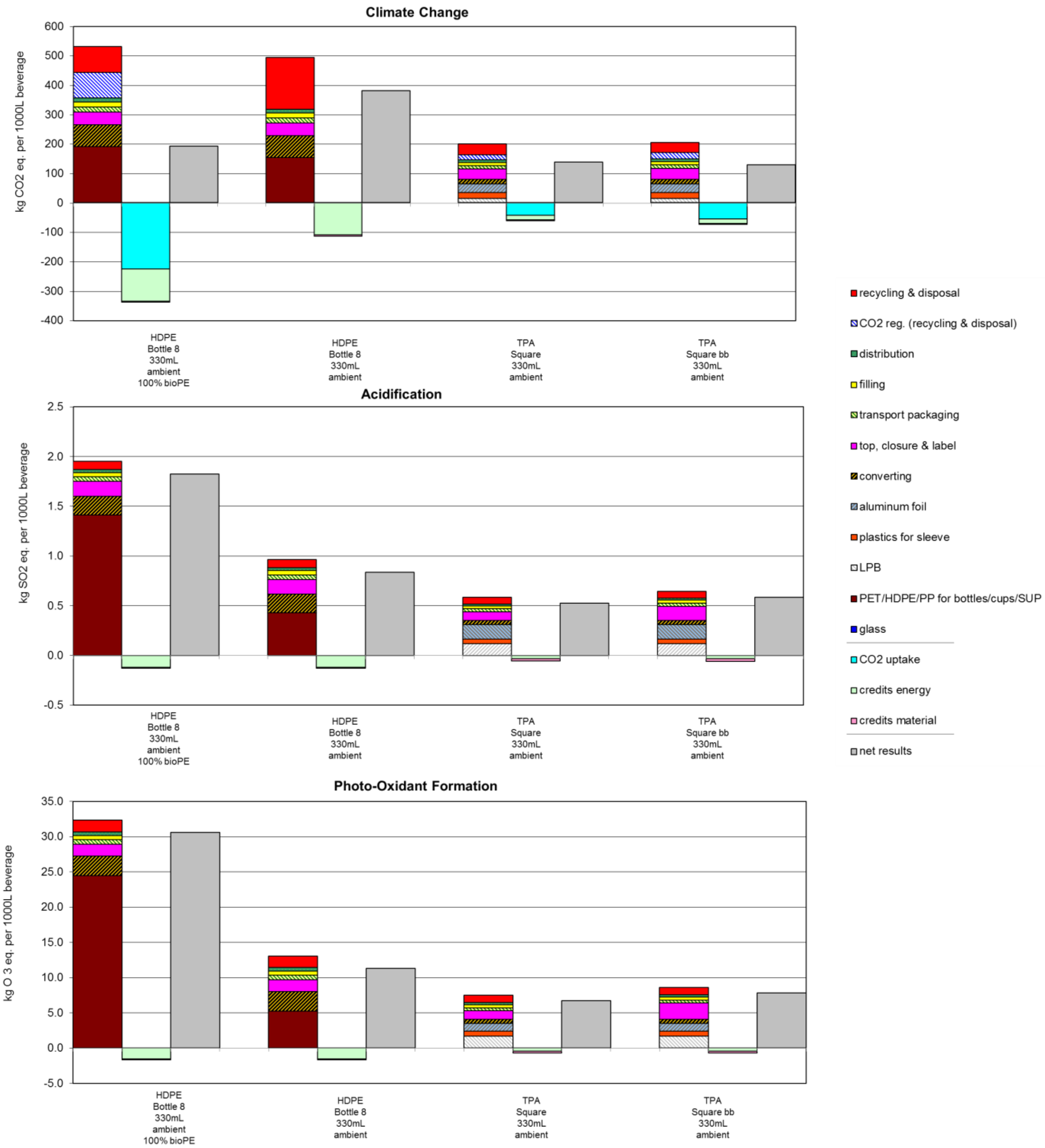



**Figure 187:** Indicator results for sensitivity analysis on bio-based plastics in HDPE bottles of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 1)

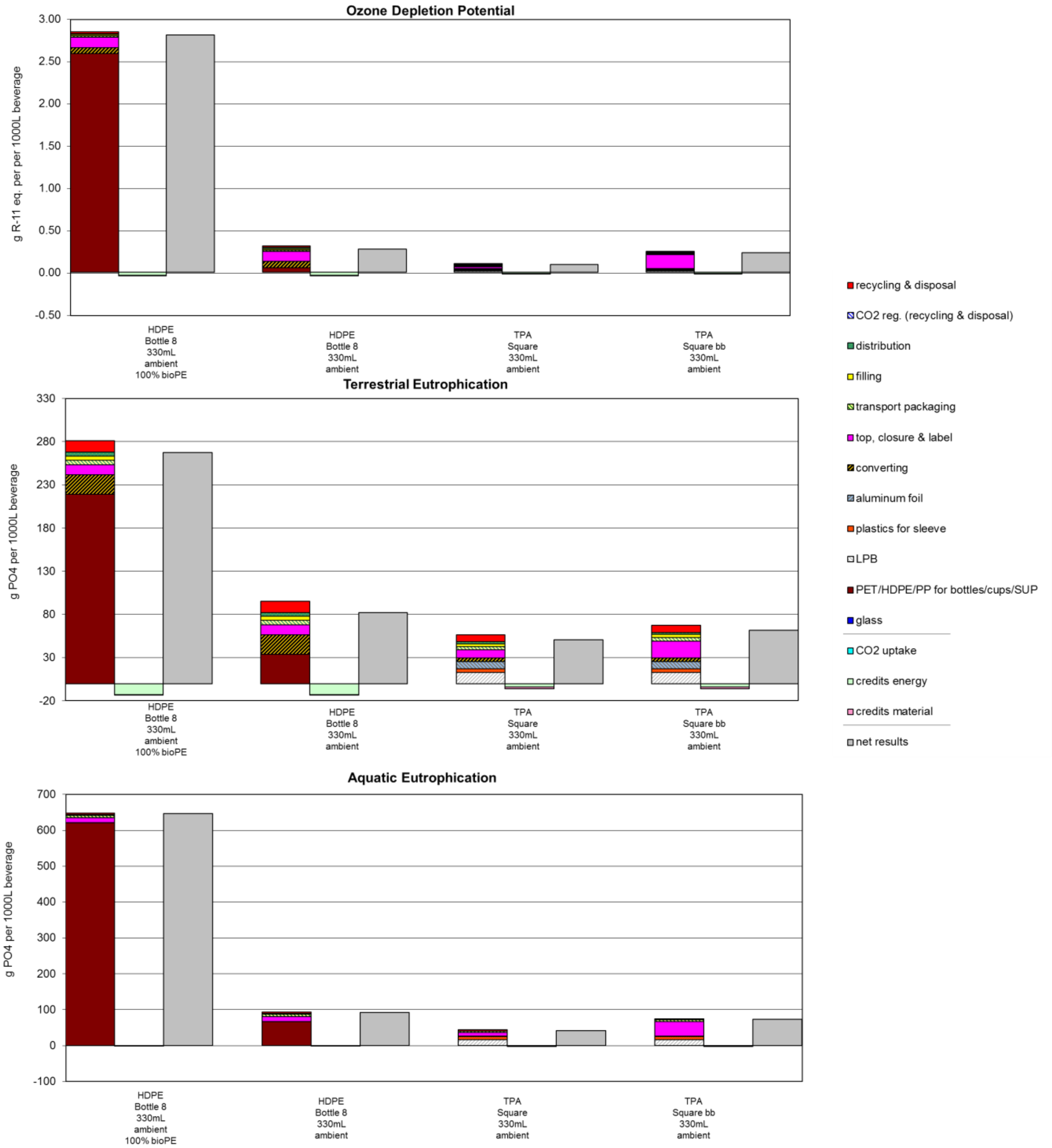



**Figure 188:** Indicator results for sensitivity analysis on bio-based plastics in HDPE bottles of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 2)

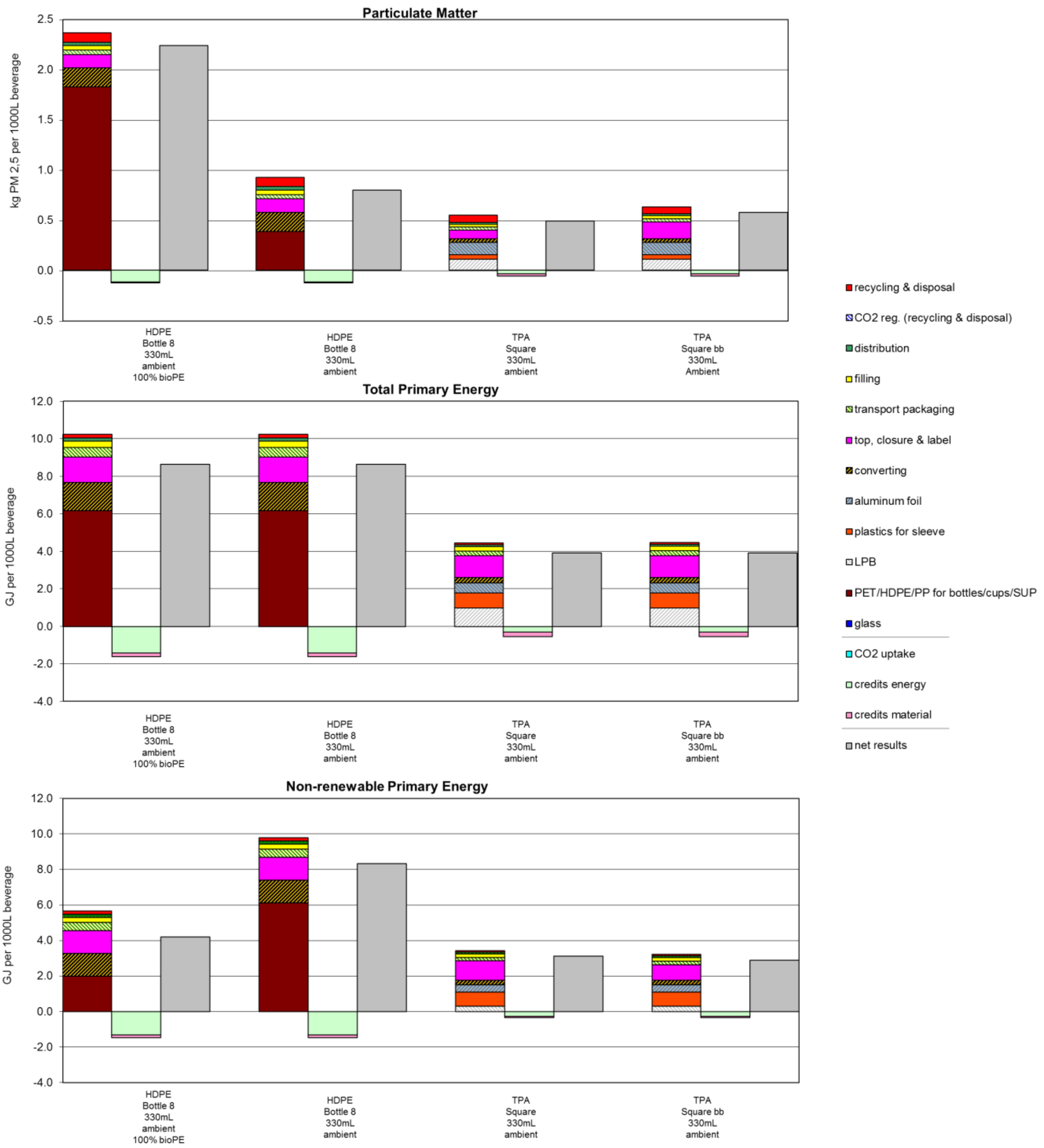



**Figure 189:** Indicator results for sensitivity analysis on bio-based plastics in HDPE bottles of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 3)

## Description and Interpretation

Replacing fossil HDPE with bio-based HDPE reduces the impacts of the step plastic production in the impact category 'Climate Change' The reason for the impact reduction for 'Climate Change' is the high CO2 uptake of the bio-based HDPE.

In all other impact categories the use of bio-based HDPE leads to much higher impacts. The reasons are 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 $N_2O$ from the use of nitrogen fertilisers on sugarcane fields. The high energy demand of the production of thick juice for Bio PE is reflected in the impact categories 'Particulate Matter', 'Terrestrial Eutrophication' and 'Acidification'. The burning of bagasse on the field leads to a considerable contribution to 'Particulate Matter'.

Regarding the primary energy inventory categories, net results are higher for 'Total Primary Energy' and lower for 'Non-renewable Primary Energy' compared with the HDPE Bottle 8 of the base scenario.

This is due to the higher energy demand of the production of thick juice for Bio PE. The energy used for this process is mainly renewable, though.

The described changes in net results do not change the net results' ranking of the compared packaging systems.

### 14.3.3 Sensitivity analysis regarding plastic bottle weight

To consider potential future developments in terms of weight of the plastic bottles, a sensitivity analysis with reduced bottle weight is 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 graphs.

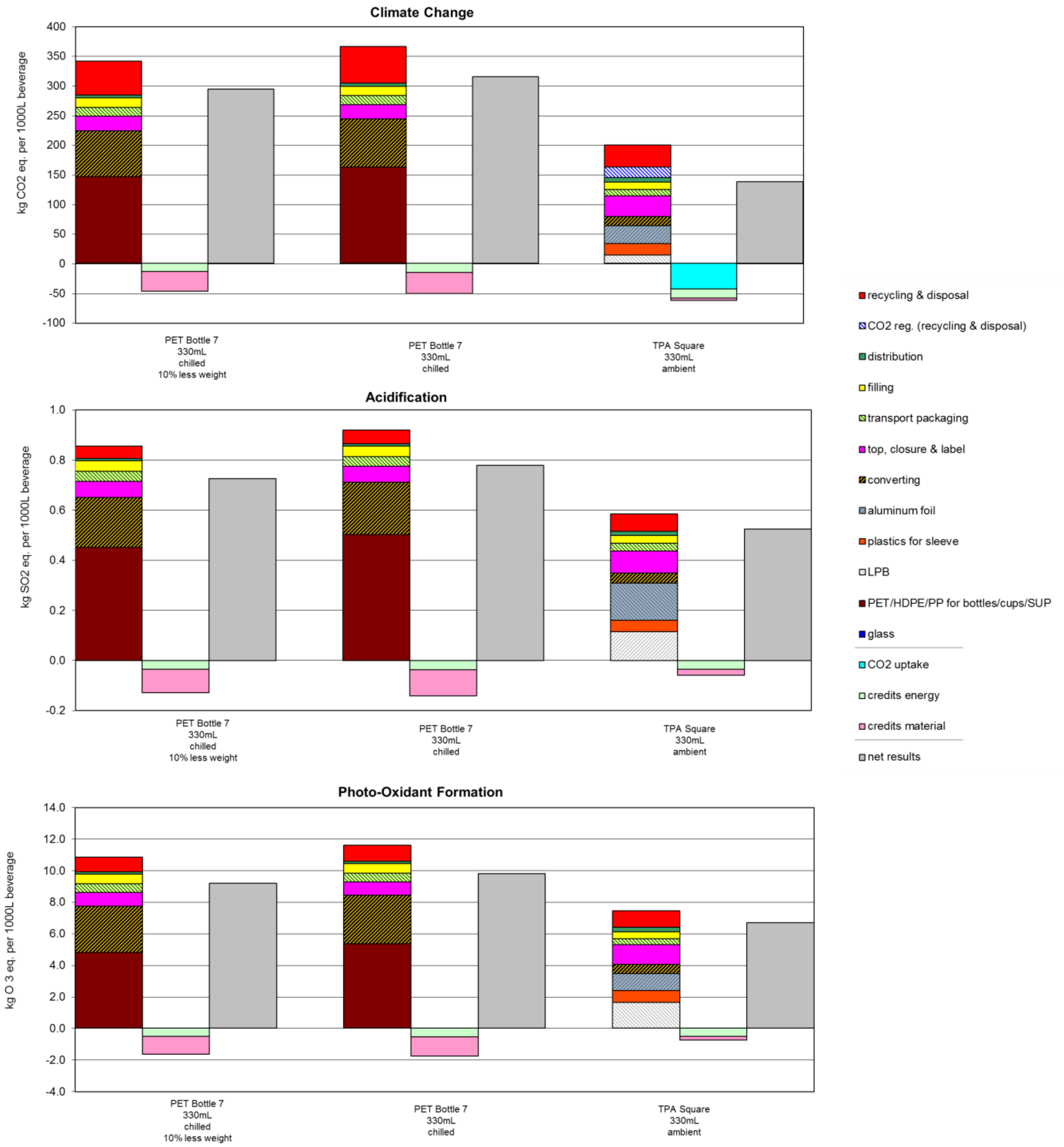



**Figure 190:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 1)

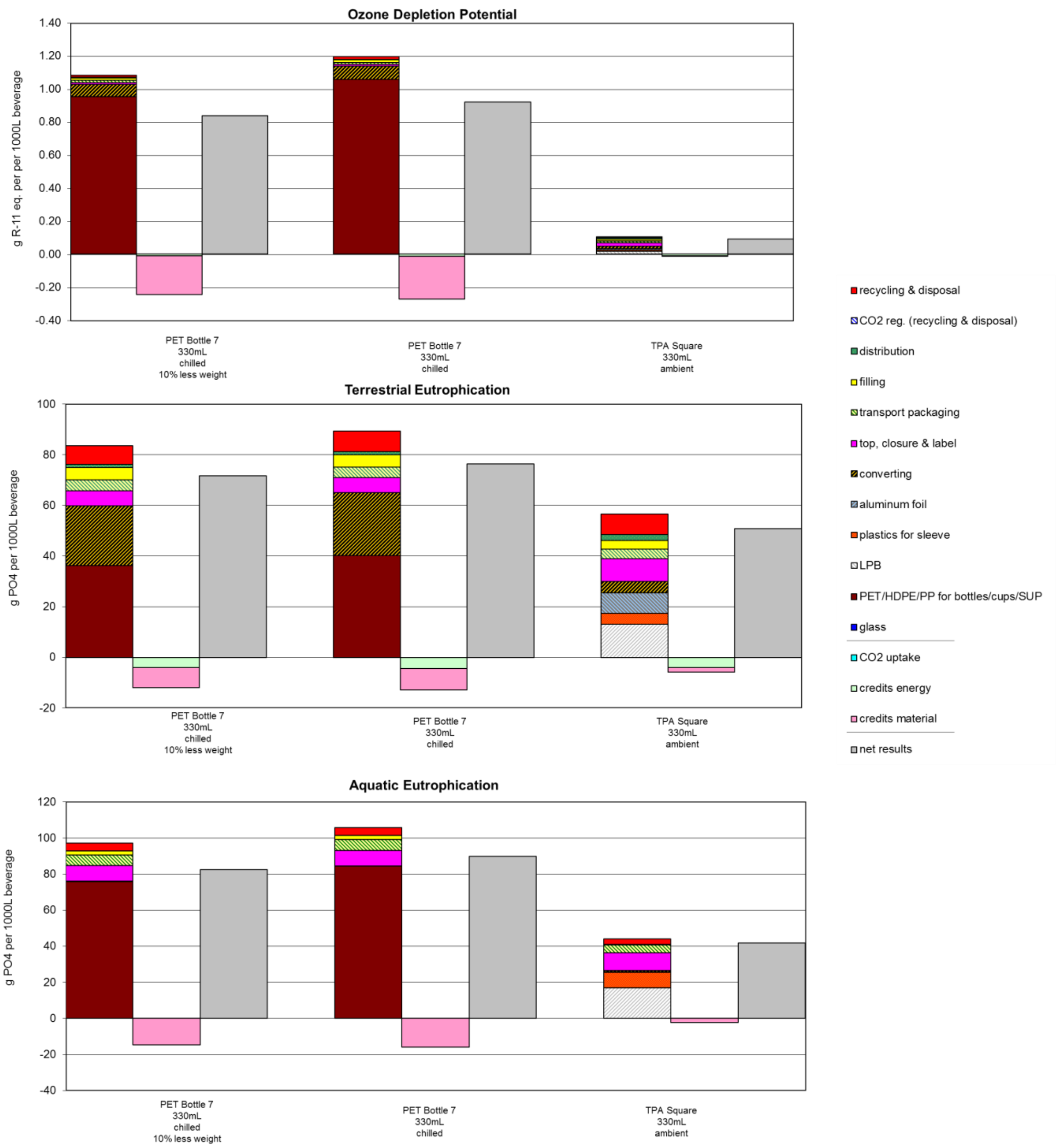



**Figure 191:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 2)

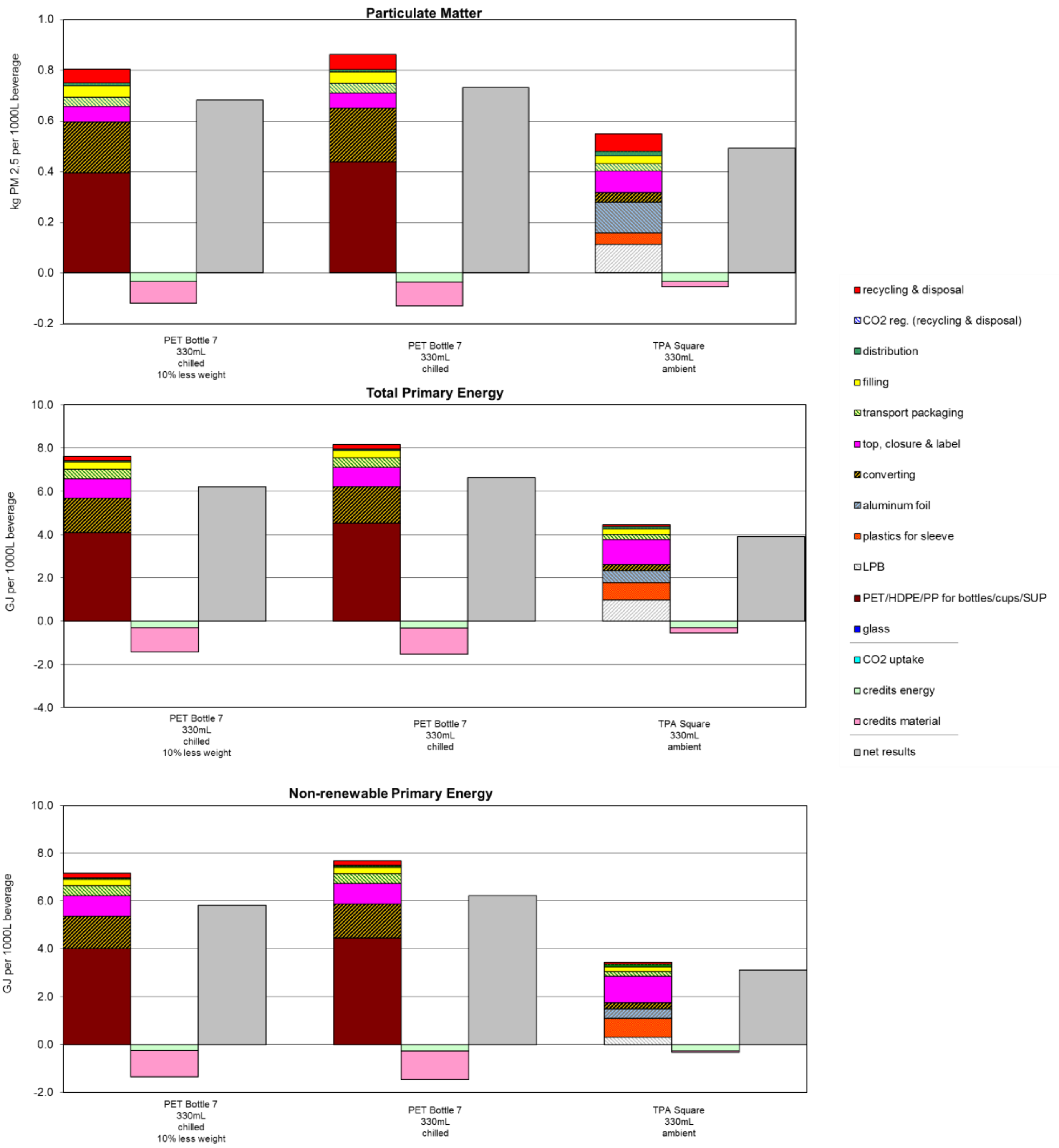



**Figure 192:** Indicator results for sensitivity analysis on plastic bottle weight of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 3)

## Description and Interpretation

The reduction of PET bottle weight by 10% reduces the impacts in most lifecycle steps and also the credits. The reduction of net results ranges only from 6% - 9%.

The described changes in net results do not change the net results' ranking of the compared packaging systems.

### 14.3.4 Sensitivity analysis regarding alternative barrier material in beverage cartons

To consider alternative barrier materials instead of aluminium in beverage cartons, a sensitivity analysis with fossil PE instead of aluminium is performed for the packaging systems listed in Table 32. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

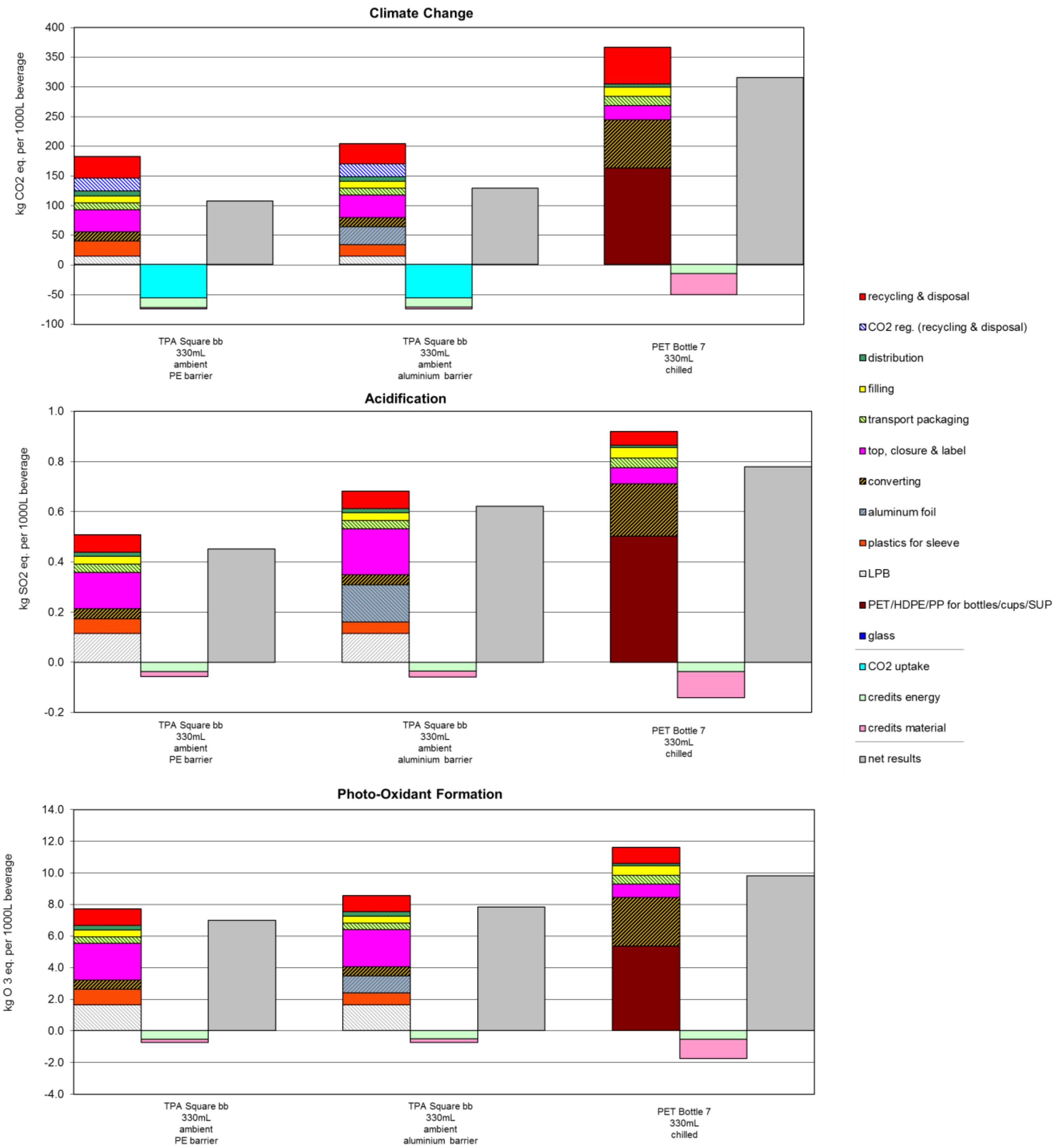



**Figure 193:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 1)

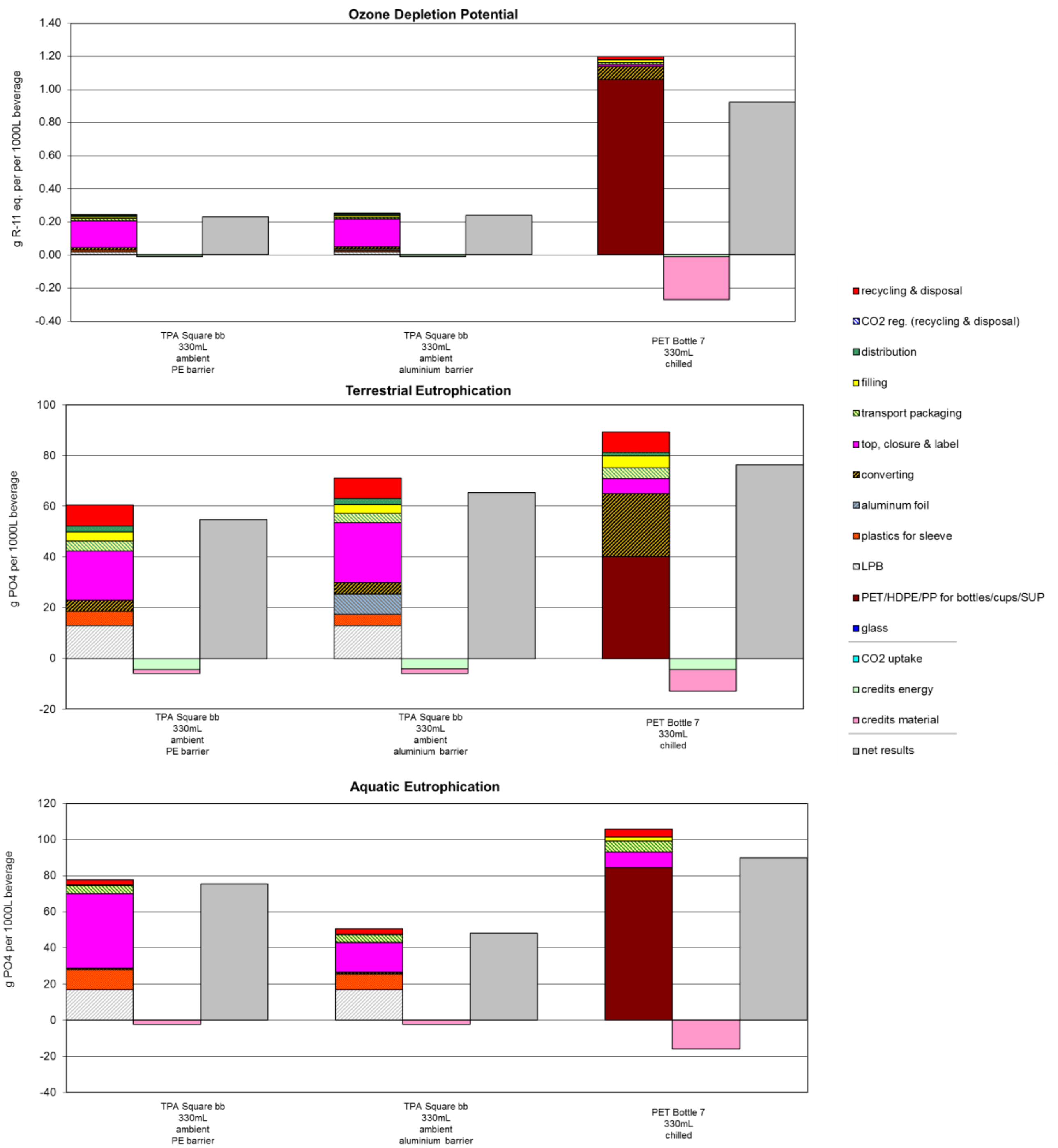



**Figure 194:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 2)

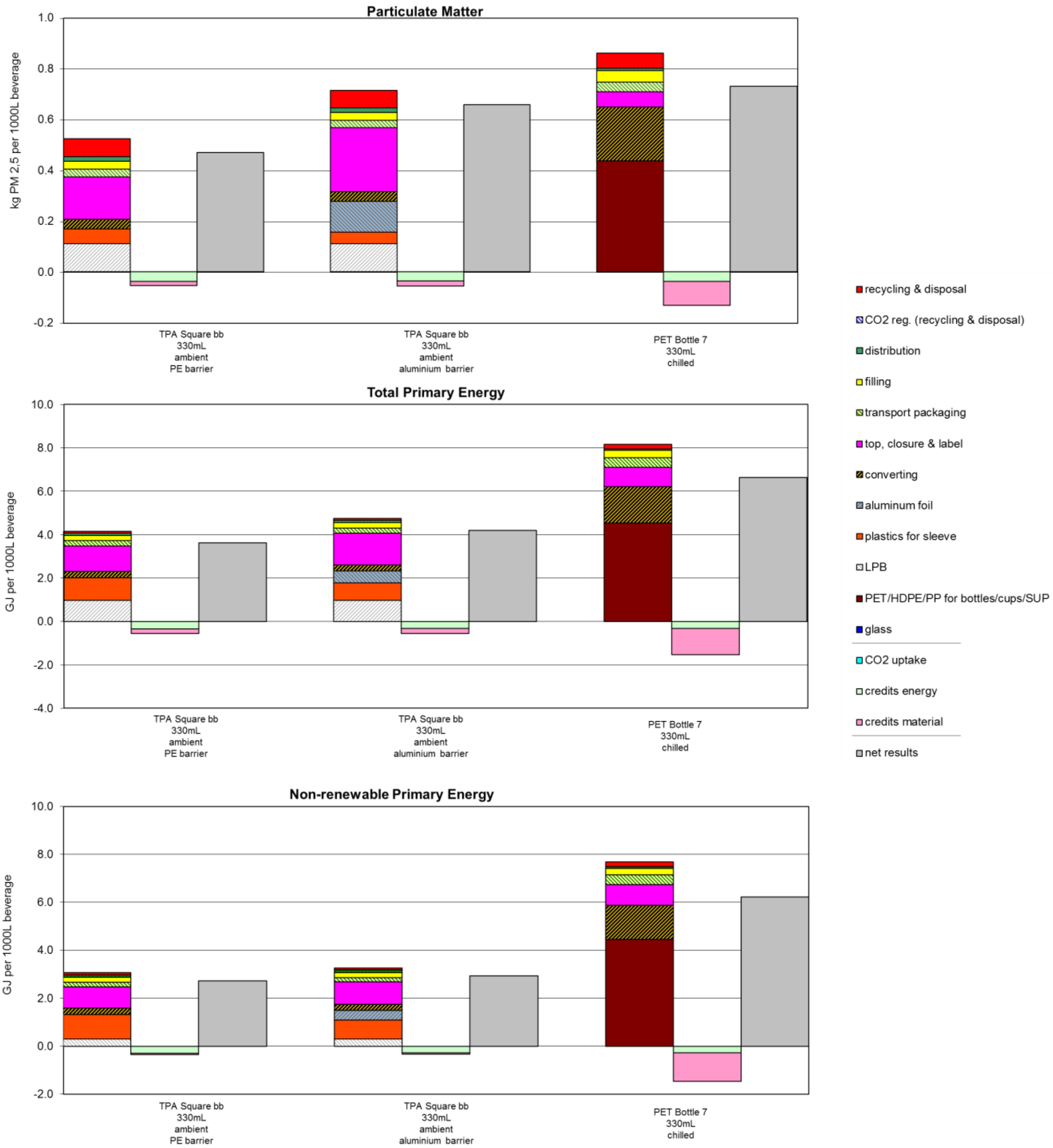



**Figure 195:** Indicator results for sensitivity analysis on alternative barrier material in beverage cartons of **segment DAIRY 189mL-500mL UNITED KINGDOM**, allocation factor 50% (Part 3)

## Description and Interpretation

Replacing the aluminium layer in the sleeves by a PE layer leads to reductions of net results of 16% - 21% in the impact categories ‘Particulate Matter’, ‘Climate Change’ and ‘Acidification’. Lower reductions of 6% - 10% can be seen in the categories ‘Total Primary Energy’, ‘Non-renewable Primary Energy’, ‘Terrestrial Eutrophication’ and ‘Photo-Oxidant Formation’. On the other hand 5% higher net results can be seen for ‘Aquatic Eutrophication’. Almost no changes of net results can be seen for ‘Ozone Depletion’.

The described changes in net results do not change the net results' ranking of the compared packaging systems.

## 14.4 Sensitivity Analyses DAIRY (CREAM) *300mL-330mL* UNITED KINGDOM

### 14.4.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

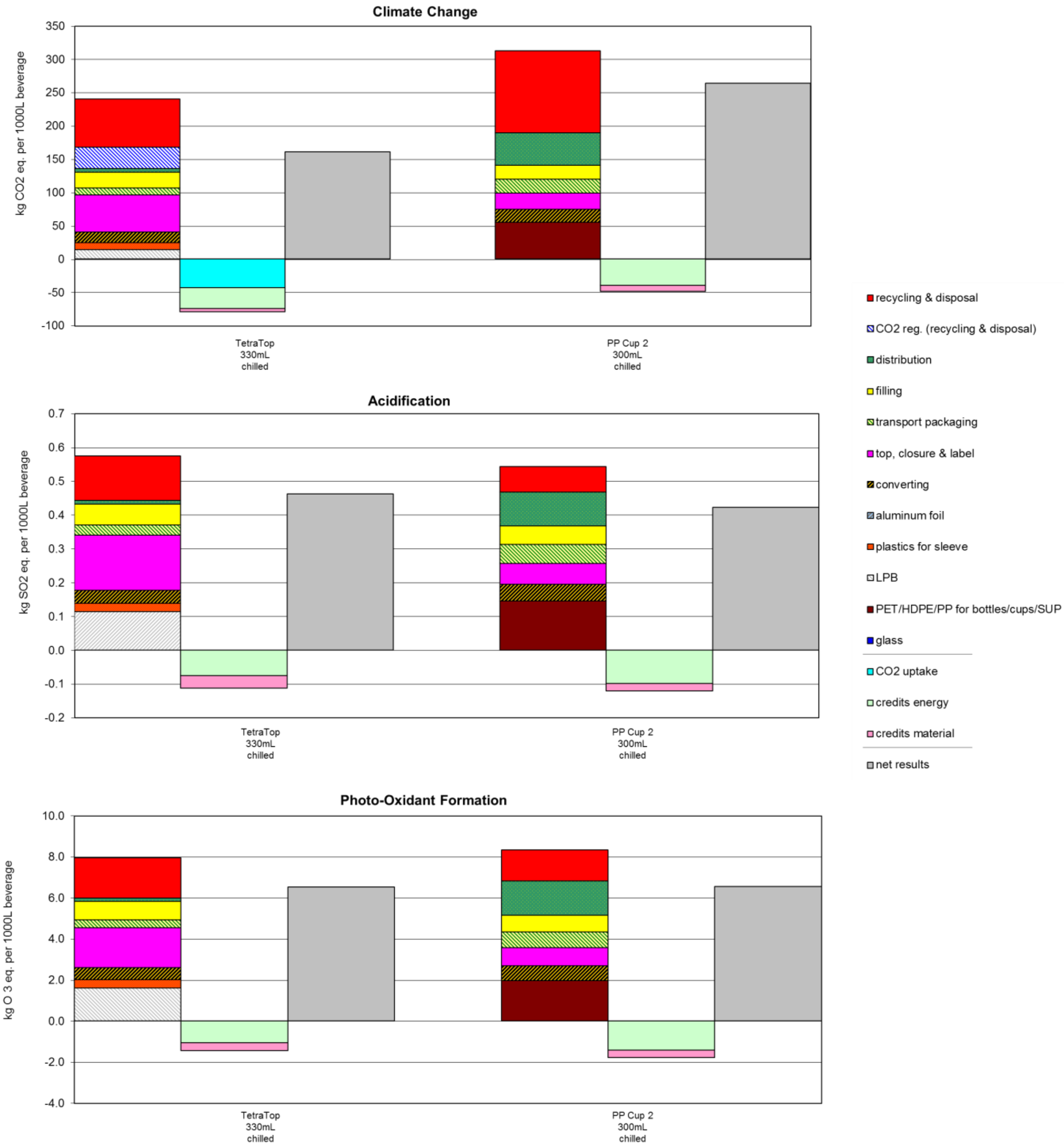



**Figure 196:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**, allocation factor 100% (Part 1)

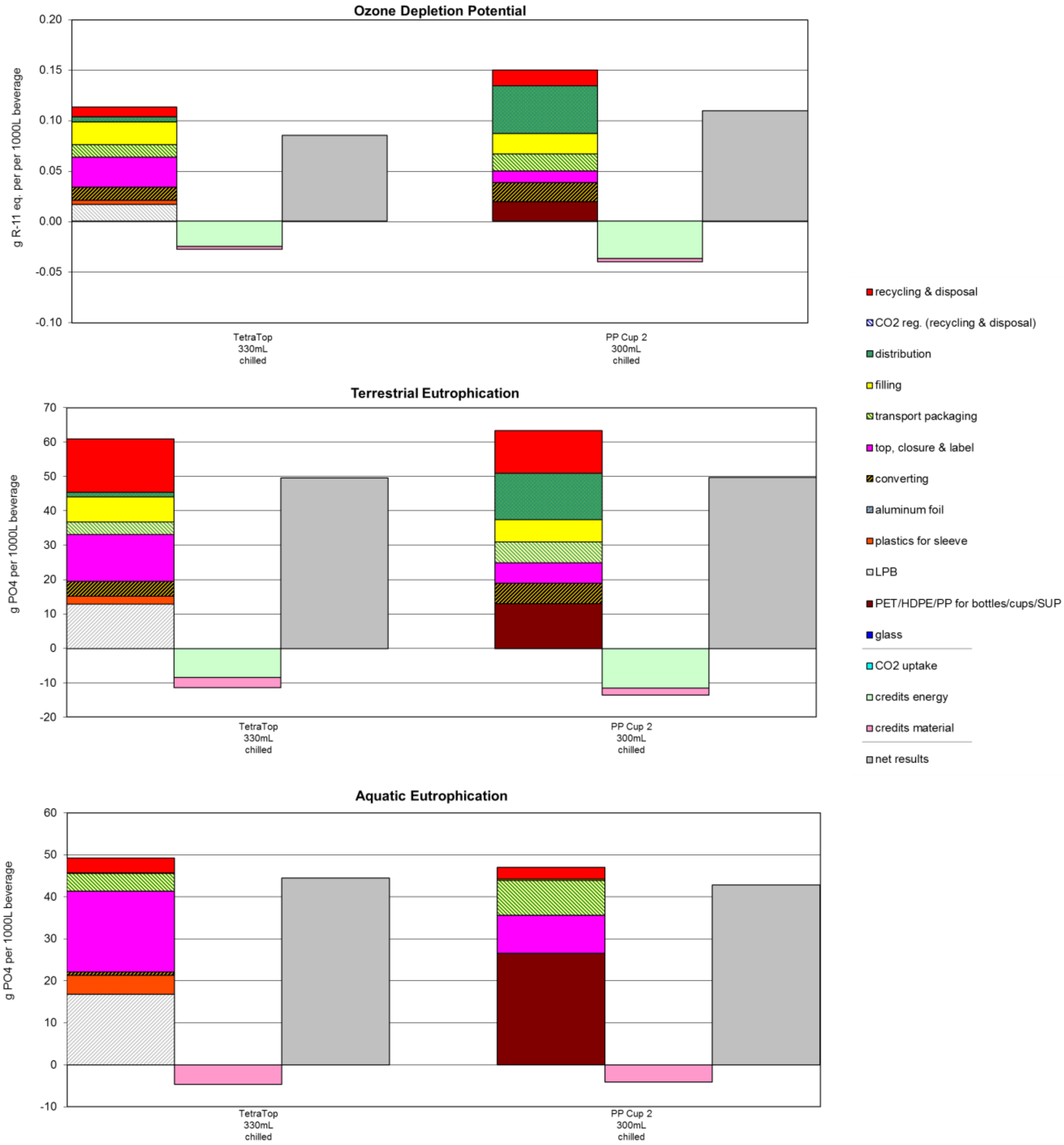



**Figure 197:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**, allocation factor 100% (Part 2)

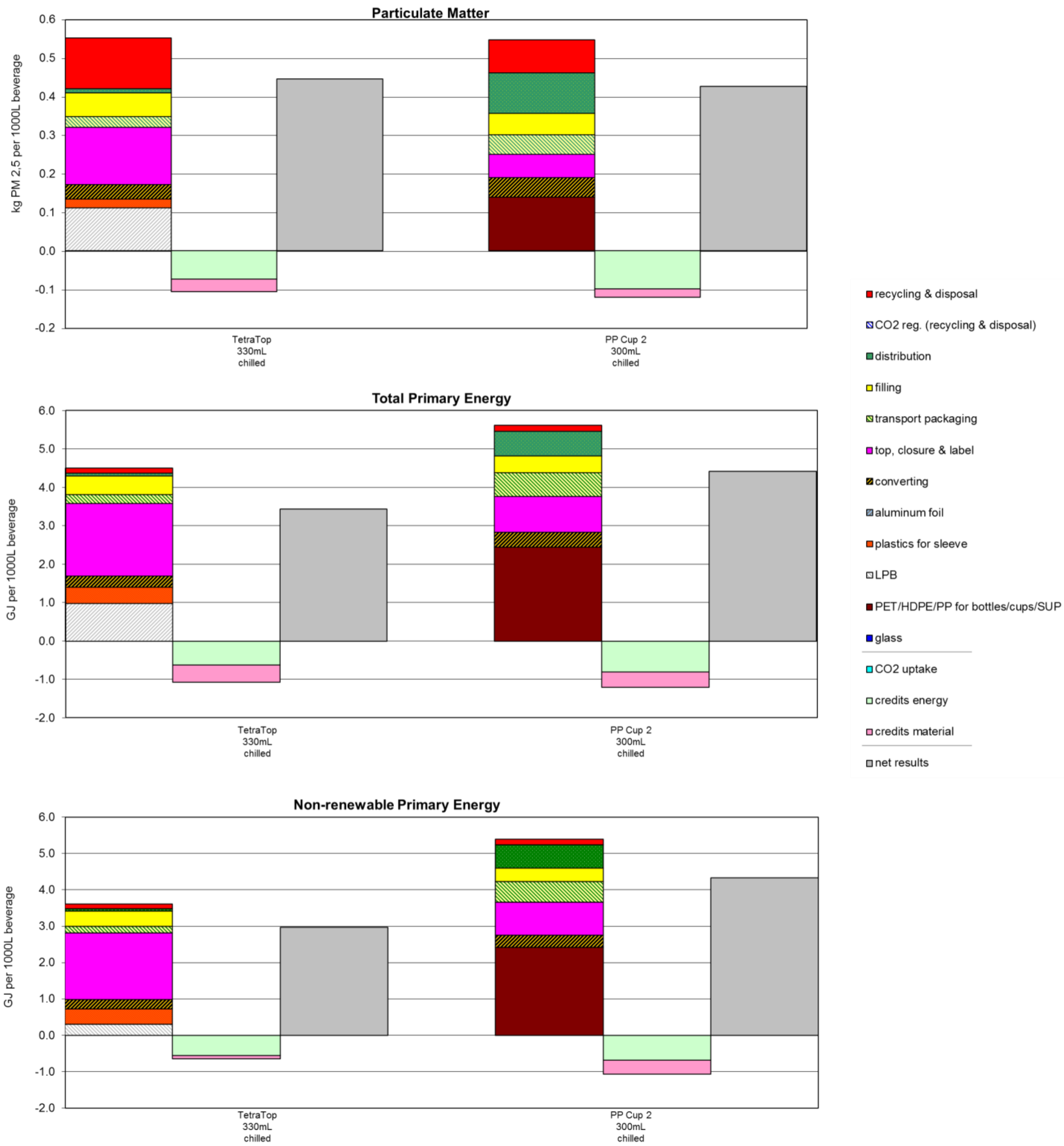



**Figure 198:** Indicator results for sensitivity analysis on system allocation of **segment DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**, allocation factor 100% (Part 3)

## 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 UK applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor. These are dominated by the credits received for recycled paper board.

In the case of the PP Cup 2 the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for beverage carton systems, plastic bottles and PP cups due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following table shows the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 213:** Comparison of net results: **TT 330mL** versus its competing alternative packaging systems **DAIRY (CREAM) 300mL-330mL UNITED KINGDOM**

| The net results of **TT 330mL chilled …** | ...are lower (green) / higher (orange) than those of | |
|---|---|---|
| **100% allocation** | TT 330mL chilled | PP Cup 2 300mL chilled |
| Climate Change [kg $CO_2$eq] | 160.63 | -39% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -22% |
| Acidification [kg $SO_2$ eq.] | 0.46 | 10% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 49.55 | 0% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 44.47 | 4% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.51 | 0% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.45 | 5% |

## 14.5 Sensitivity Analyses JNSD 200ml-330ml UNITED KINGDOM

### 14.5.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard’s recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

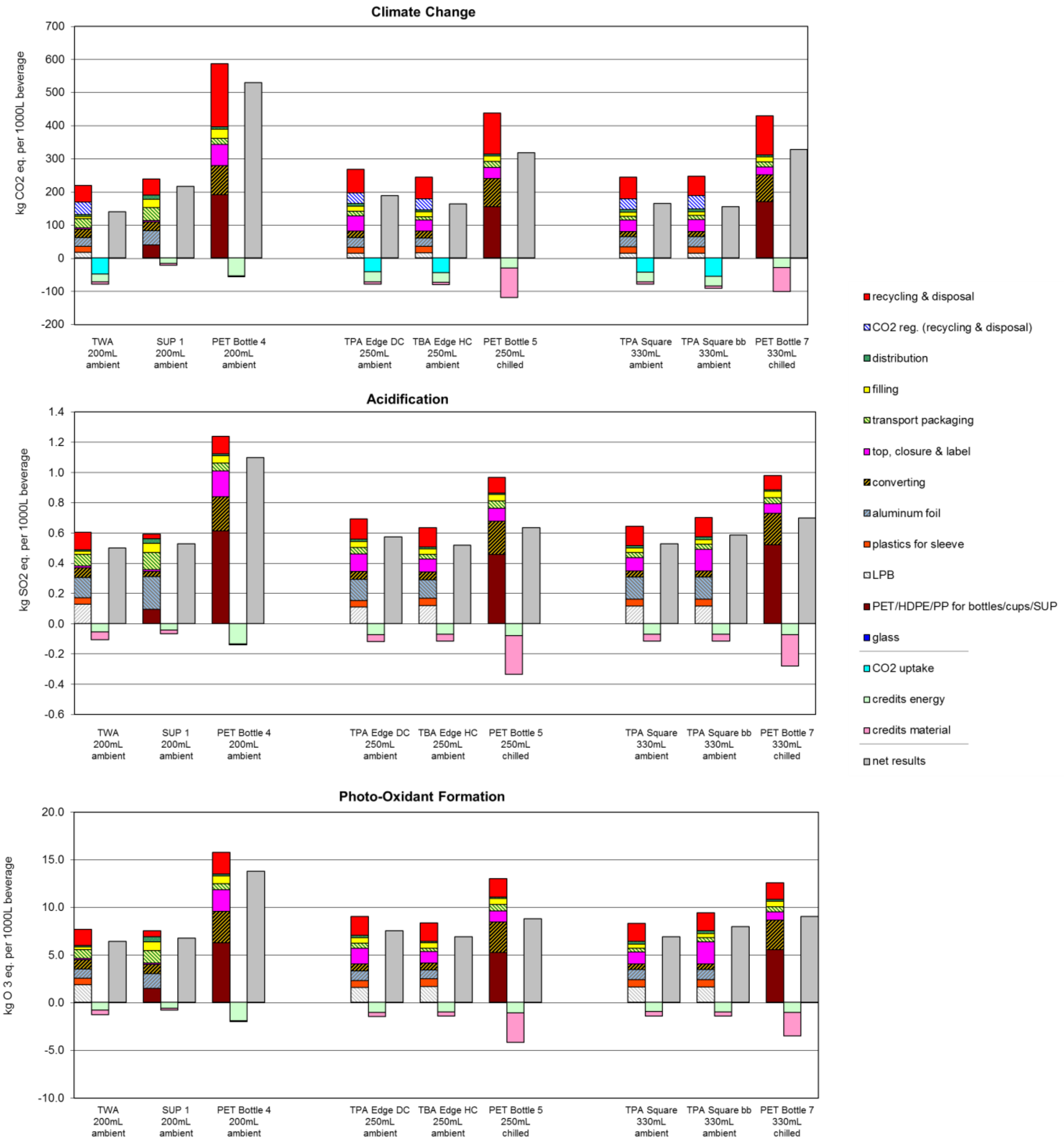



**Figure 199:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml UNITED KINGDOM**, allocation factor 100% (Part 1)

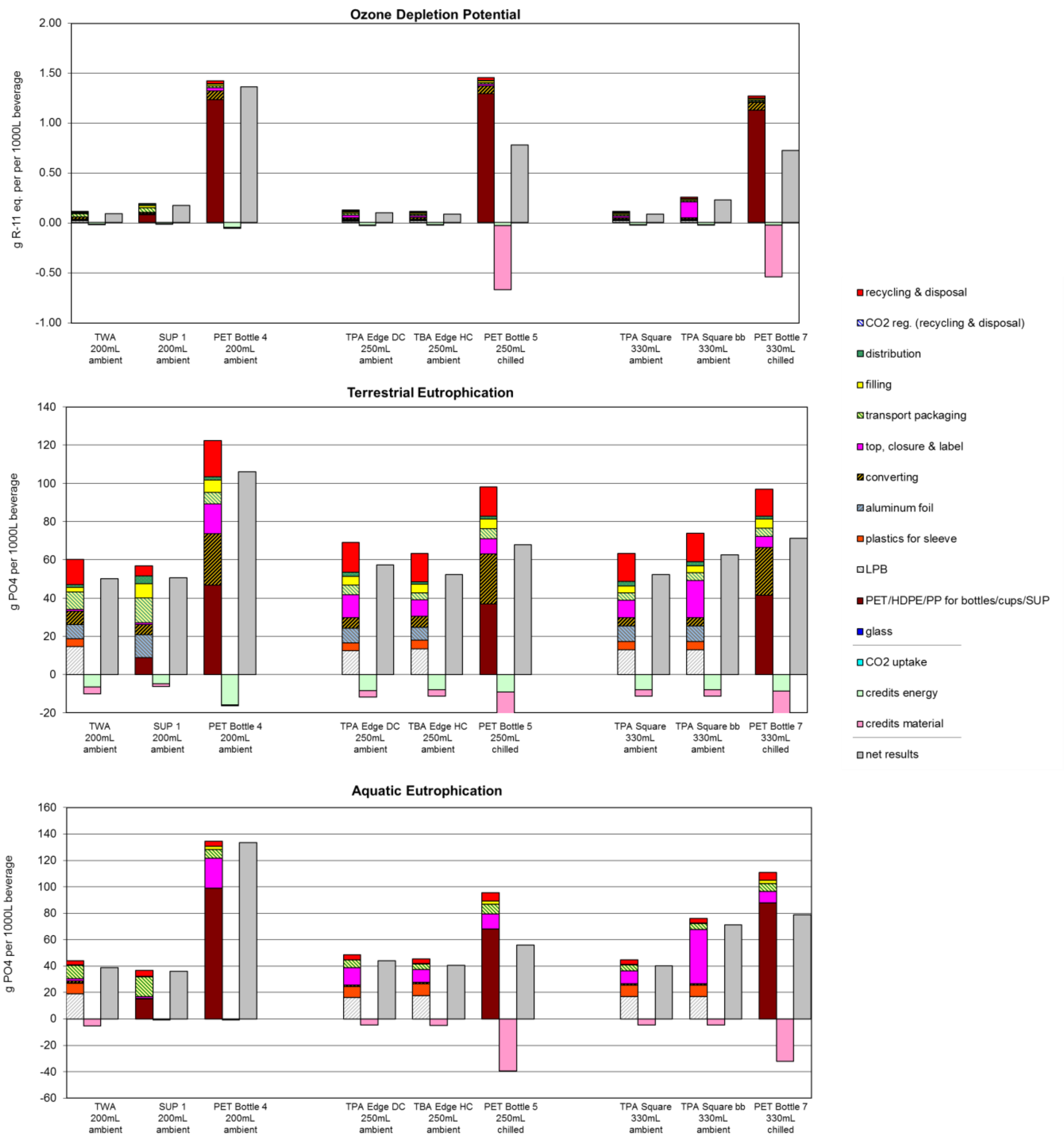



**Figure 200:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml UNITED KINGDOM**, allocation factor 100% (Part 2)

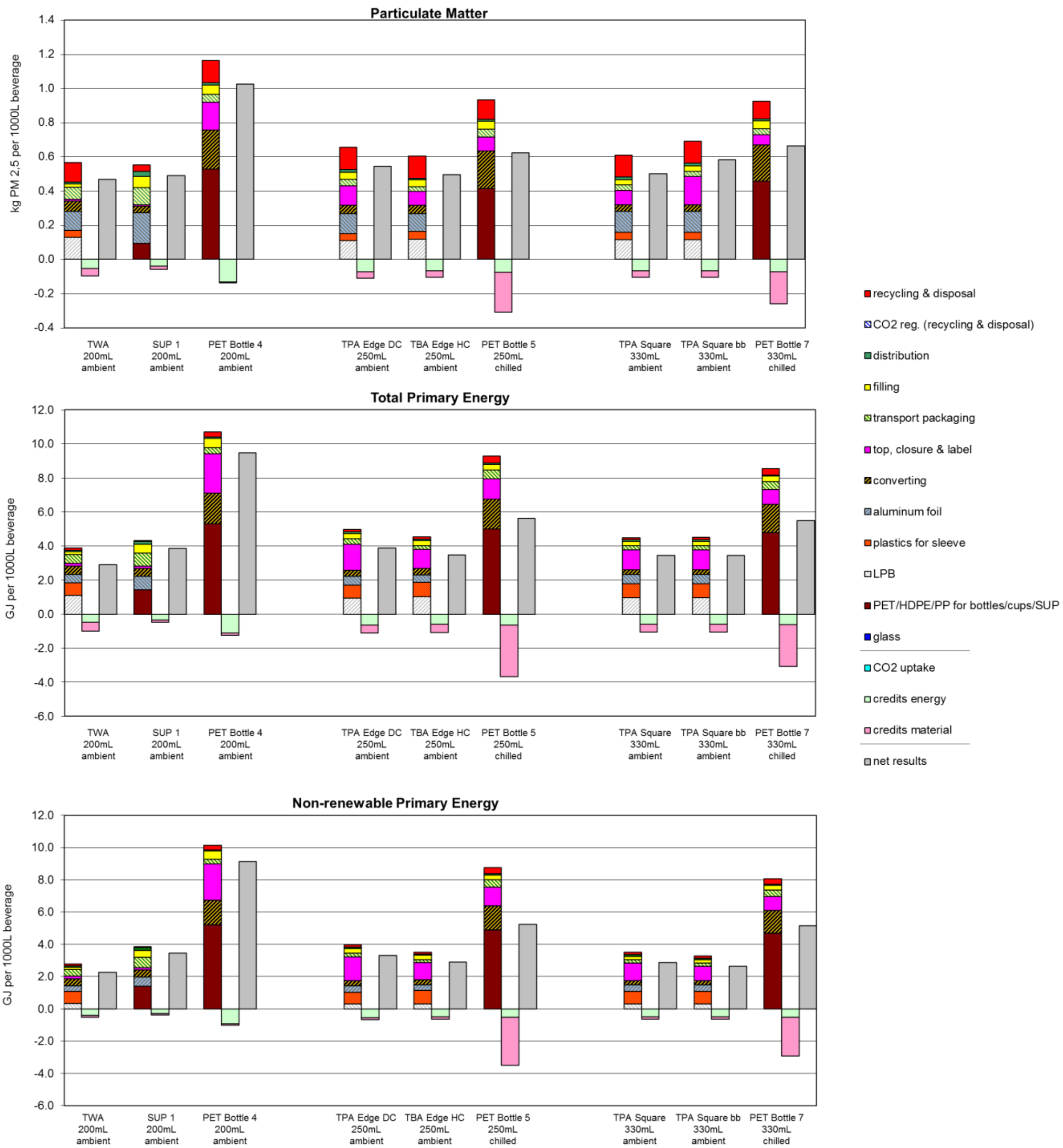



**Figure 201:** Indicator results for sensitivity analysis on system allocation of **segment JNSD 200ml-330ml UNITED KINGDOM**, allocation factor 100% (Part 3)

## 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 UK applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor.  These are dominated by the credits received for recycled paper board.

In the cases of most plastic bottles and SUP the net result decrease in most impact categories with the exception of 'Climate Change'. For 'Climate Change' net results increase when applying the 100% allocation factor as burdens from recycling and disposal are higher than energy and material credits. The exception is PET Bottle 4 for which all impact categories increase. Because being an opaque bottle, the PET Bottle 4 is not materially recycled.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for all packaging systems due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 214:** Comparison of net results: **TWA 200mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TWA 200mL ambient …** | ...are lower (green) / higher (orange) than those of | | |
|---|---|---|---|
| **100% allocation** | TWA 200mL ambient | SUP 1 200mL ambient | PET Bottle 4 200mL ambient |
| Climate Change [kg $CO_2$eq] | 139.73 | -35% | -74% |
| Ozone depletion potential [g R-11 eq.] | 0.09 | -50% | -94% |
| Acidification [kg $SO_2$ eq.] | 0.50 | -5% | -55% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 50.19 | -1% | -53% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 38.78 | 8% | -71% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.41 | -5% | -53% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.47 | -4% | -54% |

**Table 215:** Comparison of net results: **TPA Edge DC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Edge DC 250mL ambient …** | ...are lower (green) / higher (orange) than those of | |
|---|---|---|
| **100% allocation** | TPA Edge DC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 188.14 | -41% |
| Ozone depletion potential [g R-11 eq.] | 0.10 | -88% |
| Acidification [kg $SO_2$ eq.] | 0.57 | -10% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 57.47 | -16% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 43.84 | -21% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.52 | -14% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.54 | -13% |

**Table 216:** Comparison of net results: **TPA Edge HC 250mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TBA Edge HC 250mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TBA Edge HC 250mL ambient | PET Bottle 5 250ml chilled |
| Climate Change [kg $CO_2$eq] | 163.06 | -49% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -89% |
| Acidification [kg $SO_2$ eq.] | 0.52 | -18% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.29 | -23% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.37 | -28% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.90 | -22% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.49 | -21% |

**Table 217:** Comparison of net results: **TPA Square DC 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Square DC 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square DC 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 164.04 | -50% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -89% |
| Acidification [kg $SO_2$ eq.] | 0.53 | -24% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 52.33 | -27% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 40.00 | -49% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.88 | -24% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.50 | -25% |

**Table 218:** Comparison of net results: **TPA Square DC bio-based 330mL** versus its competing alternative packaging **segment JNSD 200ml-330ml UNITED KINGDOM**

| The net results of **TPA Square DC bb 330mL ambient** are lower (green) / higher (orange) than those of | |
|---|---|
| **100% allocation** | PET Bottle 7 330mL chilled |
| Climate Change | -53% |
| Ozone depletion potential | -68% |
| Acidification | -10% |
| Terrestrial Euthrophication | -6% |
| Aquatic Eutrophication | -41% |
| Photo-Oxidant Formation | -1% |
| Particulate matter PM2.5 | 1% |

| The net results of<br>**TPA Square DC bb 330mL ambient …** | | ...are lower (green) / higher (orange) than those of |
|---|---|---|
| **100% allocation** | TPA Square DC bb 330mL ambient | PET Bottle 7 330mL chilled |
| Climate Change [kg $CO_2$eq] | 153.90 | -53% |
| Ozone depletion potential [g R-11 eq.] | 0.22 | -69% |
| Acidification [kg $SO_2$ eq.] | 0.59 | -16% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 62.80 | -12% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 71.09 | -10% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 7.97 | -12% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.58 | -12% |

### 14.5.2 Sensitivity analysis regarding recycled content in PET bottles

All PET bottles in the base scenarios are assumed to contain the European average of 11.7% recycled PET. As PET bottles could be produced with 100% recycled content a sensitivity analysis is performed 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.

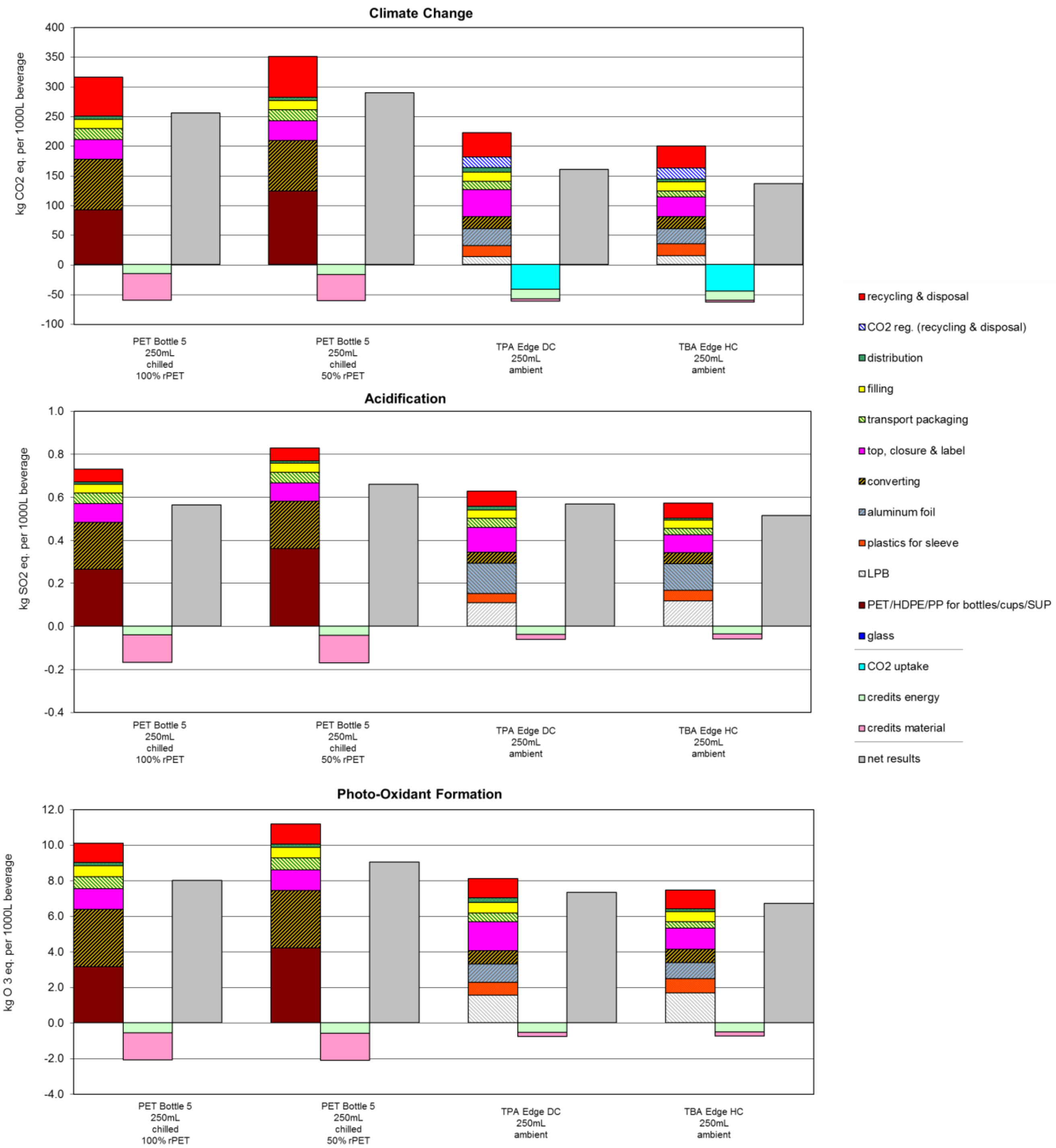



**Figure 202:** Indicator results for sensitivity analysis on recycled content in PET bottles of **segment JNSD 200ml-330ml UNITED KINGDOM**, allocation factor 50% (Part 1)

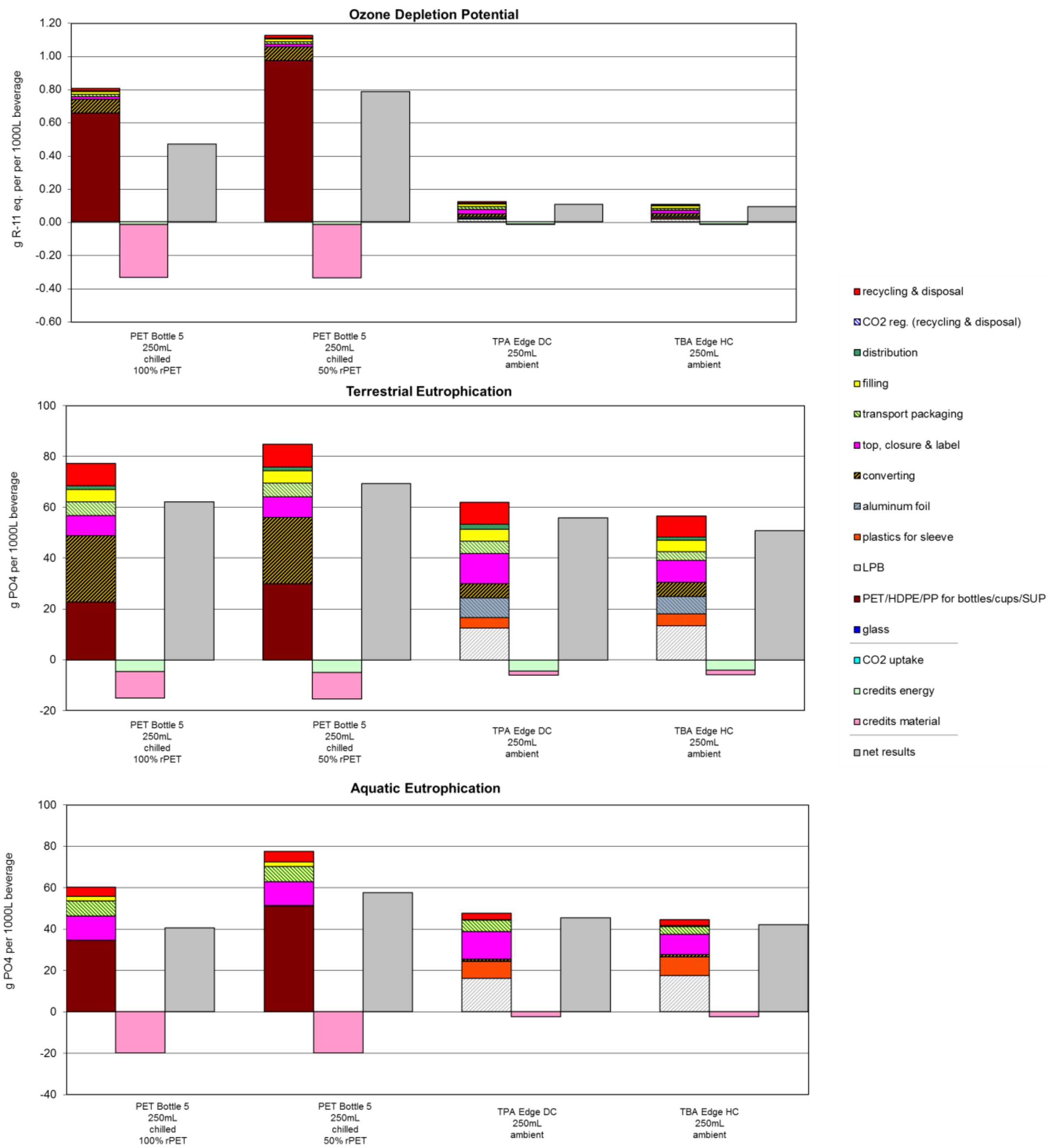



**Figure 203:** Indicator results for sensitivity analysis on recycled content in PET bottles of **segment JNSD 200ml-330ml UNITED KINGDOM**, allocation factor 50% (Part 2)

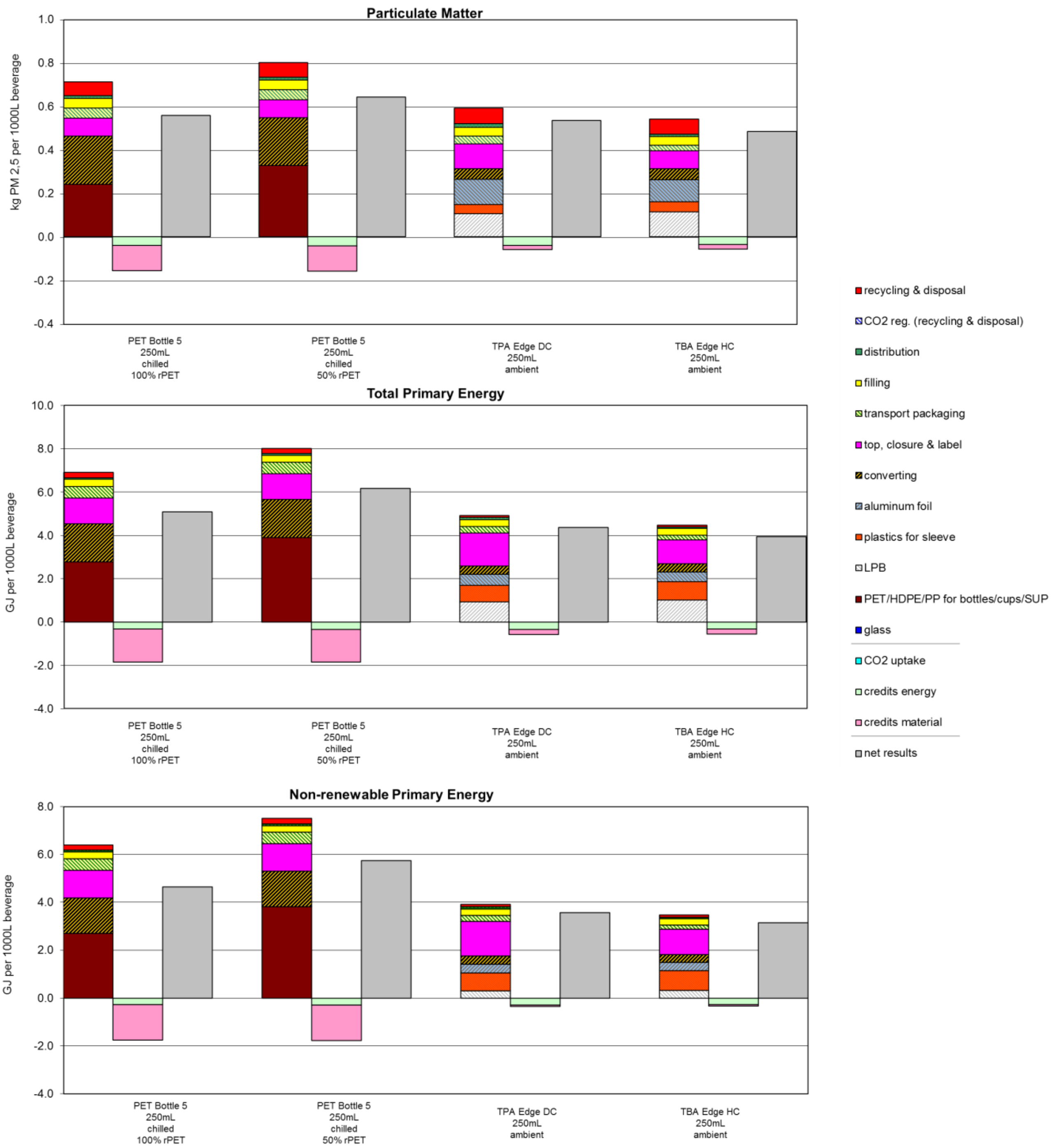



**Figure 204:** Indicator results for sensitivity analysis on recycled content in PET bottles of **segment JNSD 200ml-330ml UNITED KINGDOM**, allocation factor 50% (Part 3)

## Description and Interpretation

Increasing the share of recycled PET from the European average of 11.7% to 100% reduced the impact of the production of PET. This leads to lower net results, with the highest reduction (40%) in 'Ozone Depletion Potential' and smallest reduction (10%) in 'Terrestrial Eutrophication'.

The described changes in net results do not change the net results' ranking of most compared packaging systems in most impact categories. Exceptions are 'Acidification' where the 100% rPET Bottle 5 has now slightly lower results than the TPA Edge DC 250mL ambient and 'Aquatic Eutrophication' where the 100% rPET Bottle 5 has now slightly lower results than both compared beverage carton systems.

## 14.6 Sensitivity Analyses JNSD WATER 330mL-500mL UNITED KINGDOM

### 14.6.1 Sensitivity analysis on system allocation

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standard's recommendation on value choices, this sensitivity analysis is conducted to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied. The following graphs show the results of the sensitivity analysis on system allocation with an allocation factor of 100%.

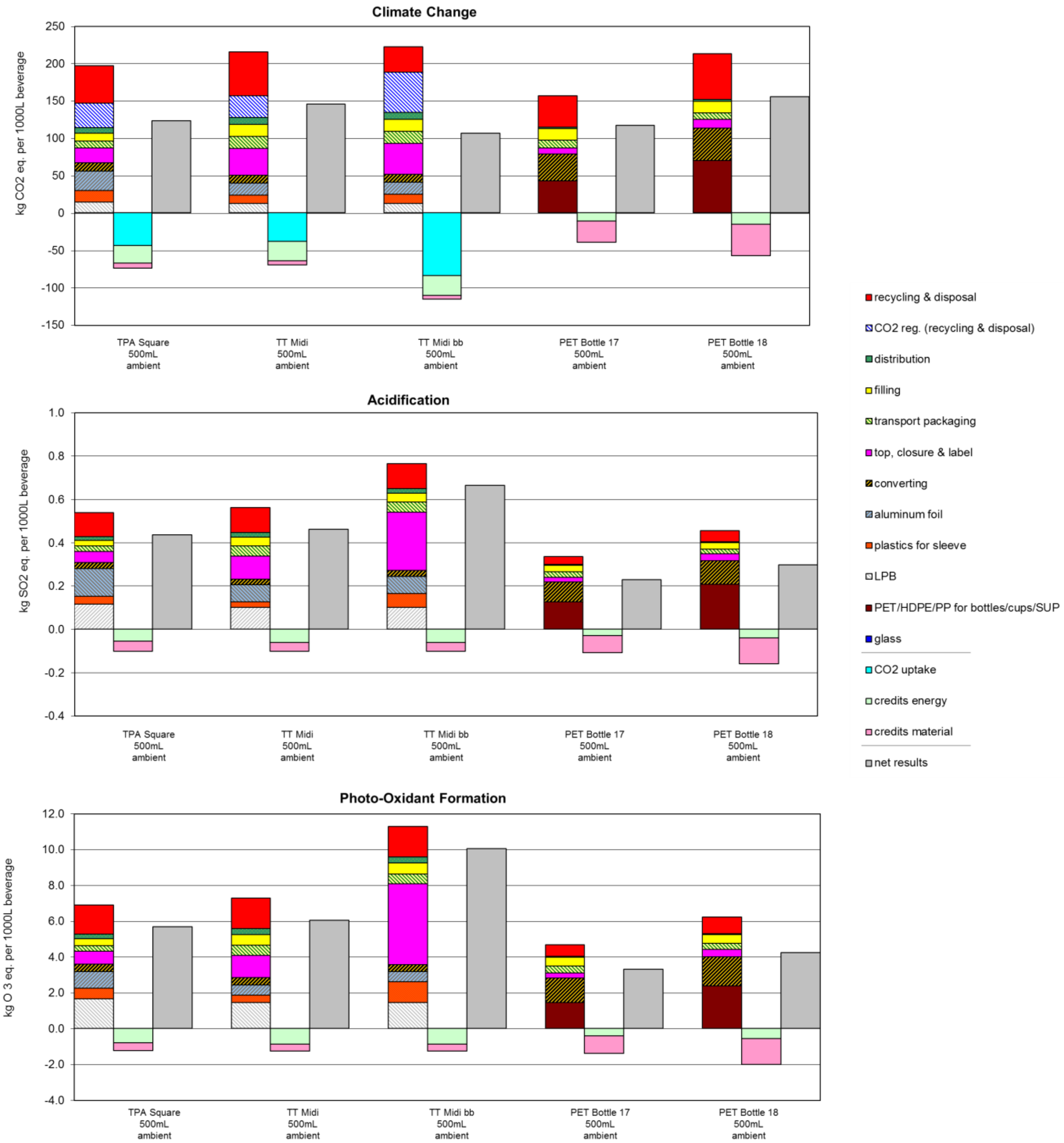



**Figure 205:** Indicator results for sensitivity analysis on system allocation of segment JNSD WATER 330mL-500mL UNITED KINGDOM, allocation factor 100% (Part 1)

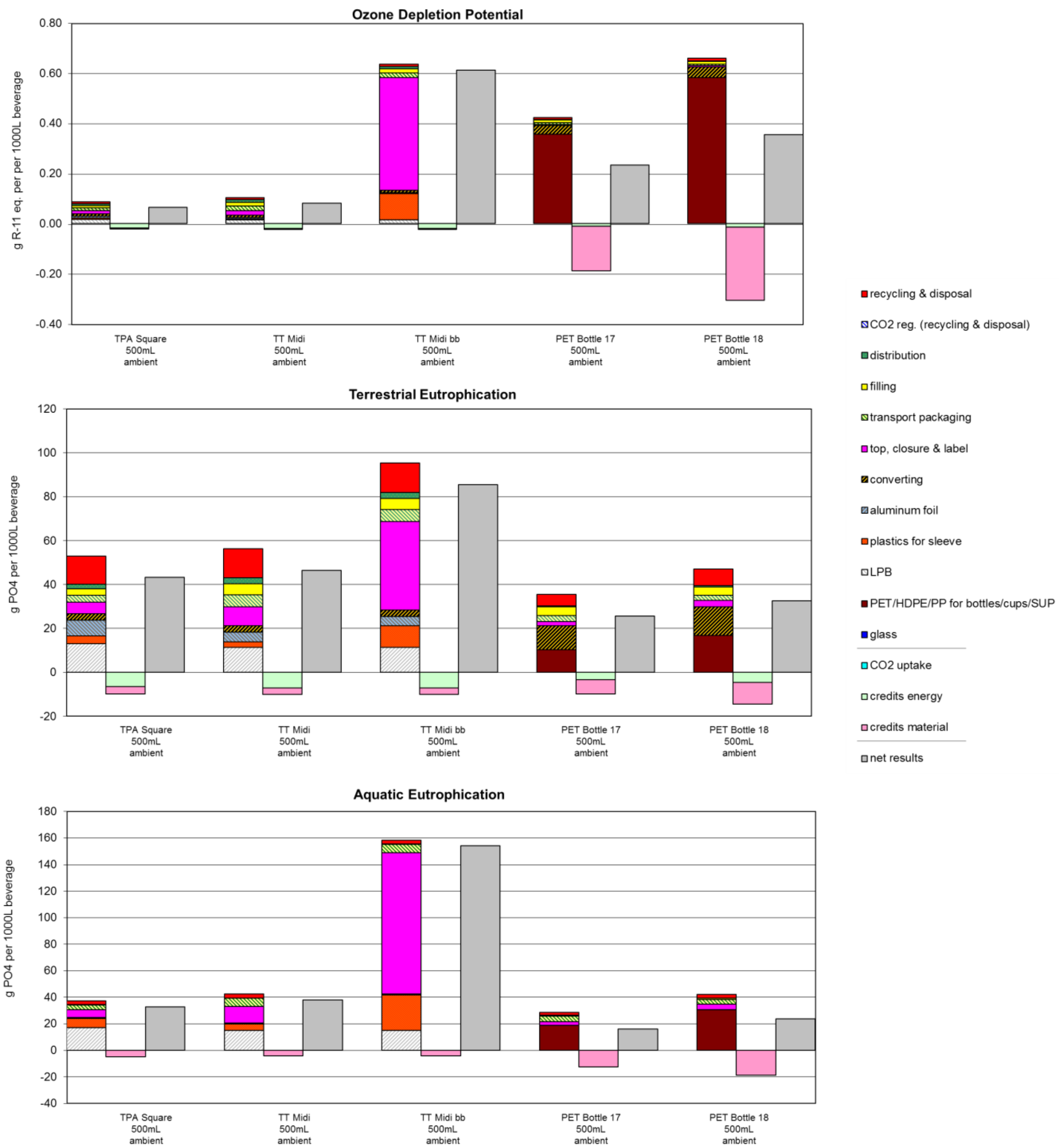



**Figure 206:** Indicator results for sensitivity analysis on system allocation of **segment JNSD WATER 330mL-500mL UNITED KINGDOM**, allocation factor 100% (Part 2)

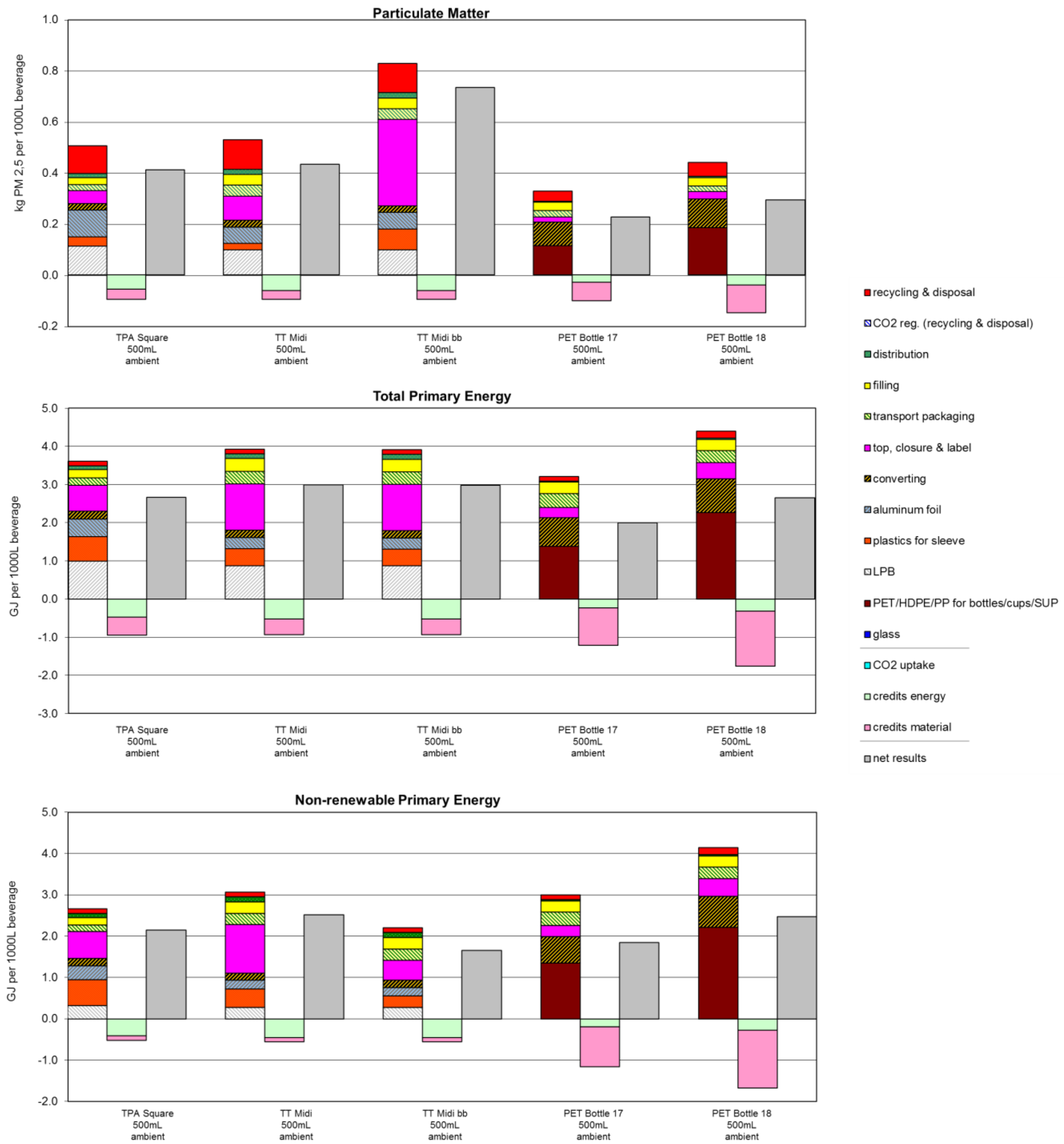



**Figure 207:** Indicator results for sensitivity analysis on system allocation of **segment JNSD WATER 330mL-500mL UNITED KINGDOM**, allocation factor 100% (Part 3)

## 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 UK applying the allocation factor 100% instead of 50% leads to higher net results in almost all impact categories. This is because the absolute value of the credits is lower than that of the burdens from recycling and disposal when applying the 50% allocation factor. This is because there are only low energy credits due to the low share of incinerated beverage cartons. In the case of 'Climate Change' also the allocation factor is not applied for the CO2 uptake, therefore the credits for the CO2 uptake don't increase when applying the 100% allocation factor. Exceptions are the impact categories 'Ozone Depletion Potential' and 'Aquatic Eutrophication' for which net results decrease when applying the 100% allocation factor. These are dominated by the credits received for recycled paper board.

In the case of plastic bottles the net result decrease in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens due to the low share of incinerated bottles.

For the inventory categories 'Total Primary Energy' and 'Non-renewable Energy' net results decrease when rising the allocation factor to 100% for both, beverage carton systems and plastic bottles due to the lower energy demand in the recycling and disposal processes compared to the processes of avoided energy and material production.

**Comparison between packaging systems**

The following tables show the net results of the regarded beverage cartons systems for all impact categories compared to their competitive packaging systems in the same segment. Inventory categories as well as 'Use of Nature', due to its data uncertainties (see 1.8.1), will not be considered further on for comparisons and conclusions. Differences lower than 10% are considered to be insignificant and are indicated by hatched colors (please see section 1.6 on precision and uncertainty).

**Table 219:** Comparison of net results: **TPA Square 500mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL UNITED KINGDOM**

| The net results of **TPA Square 500mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TPA Square 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change [kg $CO_2$eq] | 123.11 | 5% | -21% |
| Ozone depletion potential [g R-11 eq.] | 0.07 | -72% | -82% |
| Acidification [kg $SO_2$ eq.] | 0.44 | 91% | 47% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 43.35 | 68% | 33% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 32.65 | 103% | 38% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 5.67 | 72% | 34% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.41 | 81% | 41% |

**Table 220:** Comparison of net results **TT 500mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL UNITED KINGDOM**

| The net results of **TT 500mL ambient** are lower (green) / higher (orange) than those of | | |
|---|---|---|
| **100% allocation** | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change | 12% | -16% |
| Ozone depletion potential | -72% | -82% |
| Acidification | 87% | 44% |
| Terrestrial Euthrophication | 64% | 30% |
| Aquatic Eutrophication | 118% | 48% |
| Photo-Oxidant Formation | 78% | 37% |
| Particulate matter PM2.5 | 76% | 37% |

| The net results of **TT 500mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TT 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change [kg $CO_2$eq] | 145.42 | 24% | -6% |
| Ozone depletion potential [g R-11 eq.] | 0.08 | -66% | -77% |
| Acidification [kg $SO_2$ eq.] | 0.46 | 102% | 55% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 46.58 | 81% | 43% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 38.04 | 137% | 61% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 6.04 | 83% | 43% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.43 | 91% | 48% |

**Table 221:** Comparison of net results: **TT bio-based 500mL** versus its competing alternative packaging **segment JNSD WATER 330mL-500mL UNITED KINGDOM**

| The net results of **TT bb 500mL ambient …** | | ...are lower (green) / higher (orange) than those of | |
|---|---|---|---|
| **100% allocation** | TT bb 500mL ambient | PET Bottle 17 500mL ambient | PET Bottle 18 500mL ambient |
| Climate Change [kg $CO_2$eq] | 106.40 | -9% | -31% |
| Ozone depletion potential [g R-11 eq.] | 0.61 | 162% | 73% |
| Acidification [kg $SO_2$ eq.] | 0.66 | 190% | 124% |
| Terrestrial Euthrophication [g $PO_4$ eq.] | 85.47 | 232% | 162% |
| Aquatic Eutrophication [g $PO_4$ eq.] | 153.99 | 857% | 552% |
| Photo-Oxidant Formation [kg $O_3$ eq.] | 10.03 | 205% | 138% |
| Particulate matter PM2.5 [kg PM 2.5 eq] | 0.73 | 222% | 150% |

# 15 Conclusions United Kingdom

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 UK 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.

## 15.1 DAIRY 1000mL-2000mL UNITED KINGDOM

In the comparison of the examined beverage carton systems with fossil based plastics to all bottles in this segment, no unambiguous result can be observed. In this segment, the examined beverage carton system with fossil based plastics shows lower environmental impacts in ‘Climate Change’ and ‘Ozone Depletion Potential’ but higher or similar impacts in all other categories than the compared HDPE bottle.

In case of the beverage carton containing bio-based plastics, environmental impacts in the category ‘Climate Change’ are lower than those of the carton with fossil based plastics. However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. This leads to the beverage carton showing lower impacts in ‘Climate Change’ only and higher impacts in all other categories compared to the HDPE bottle.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a very limited influence on the assessment of the environmental impacts in this segment.

The sensitivity analysis regarding recycled content in the HDPE bottle shows, that a higher share of rHDPE leads to generally favourable results for the bottle. Even with the applied shares of 30% and 50% rHDPE, the HDPE bottle in this segment does not show lower environmental impacts than the compared beverage carton systems.

## 15.2 JNSD 1000mL UNITED KINGDOM

In the comparison of the examined beverage carton systems with fossil based plastics to all bottles in this segment, no unambiguous result can be observed. In this segment the examined beverage carton systems with fossil based plastics, show lower environmental impacts in ‘Climate Change’ and ‘Ozone depletion potential’ and lower or similar in

'Aquatic Eutrophication' than the PET bottle. In the other categories these beverage cartons perform similar or worse than the PET bottle.

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

The sensitivity analysis on system allocation shows that while the choice of allocation factor has certain influence on the assessment of the environmental impacts but only for the comparison of the beverage cartons with fossil based plastics it leads to changes in ranking in one category each.

## 15.3 DAIRY *189mL-500mL UNITED KINGDOM*

In this segment, all examined beverage carton systems with fossil based plastics show lower environmental impacts in all of the impact categories than the plastic bottles and the PP cup with which they are compared. Compared to the glass bottle the cartons show lower impacts in all categories apart from 'Aquatic Eutrophication'.

A similar picture can be observed for the comparison of the beverage carton with a small amount of bio-based plastics (e.g. TPA Square DC bb 330mL ambient). The only difference is that this beverage carton shows higher or similar impacts in 'Ozone depletion potential' than the PP cup and the HDPE Bottle 8, respectively.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a limited influence on the assessment of the environmental impacts in this segment.

The sensitivity analysis regarding bio-based plastics in HDPE bottles shows, similar as for the beverage cartons with bio-based plastics, higher impacts in all categories except 'Climate Change'. Regarding this category, considerable lower impacts can be observed but these still remain higher than those of the compared beverage cartons.

The sensitivity analysis regarding plastic bottle weight shows that a reduction of bottle weight leads to lower environmental impacts of the bottles. A weight reduction of 10% as applied in this sensitivity analysis shows no influence for the comparison with the regarded beverage carton.

The sensitivity analysis regarding alternative barrier material in beverage cartons shows that a substitution of aluminium foil by PE leads to lower environmental impacts in almost all categories. This has no influence for the comparison with the regarded beverage carton.

## 15.4 DAIRY (CREAM) *300mL-330mL UNITED KINGDOM*

In this segment the examined beverage carton system with fossil based plastics, show lower environmental impacts in 'Climate Change' and 'Ozone depletion potential' than the PP cup. In the other categories this beverage carton performs similar than the PET bottle depending on the applied allocation factor.

## 15.5 JNSD 200ml-330ml UNITED KINGDOM

In this segment examined beverage carton systems with fossil based plastics show lower environmental impacts than the compared PET bottles in all of the examined impact categories except for 'Acidification' where the results are similar when the allocation factor 100% is applied. Compared to the SUP the beverage carton system shows no clear favourability except for 'Climate Change' and 'Ozone depletion potential'.

In case of the beverage carton containing bio-based plastics (i.e TPA Square DC bb 330mL ambient), environmental impacts in the category 'Climate Change' are lower than those of the respective carton with fossil based plastics (i.e TPA Square DC 330mL ambient). However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. The influence of bio-based plastics is limited, though, as only a small share of plastics is bio-based. That means that also the TPA Square DC bb 330mL ambient shows lower or similar impacts in all categories.

The sensitivity analysis on system allocation shows, that the choice of allocation factor has only a limited influence on the assessment of the environmental impacts in this segment.

The sensitivity analysis regarding recycled content in PET bottles shows, that a higher share of rPET leads to generally favourable results for the bottle. A theoretical share of 100% rPET applied, does not lead to a better environmental performance than the regarded beverage carton in all environmental impact categories.

## 15.6 JNSD (WATER) 330ml-500ml UNITED KINGDOM

In this segment the examined beverage carton system TPA Square 500mL ambient shows higher impacts than the compared PET bottles in all examined categories except for 'Climate Change' and 'Ozone depletion potential'. In these two categories it shows lower impacts or in case of the comparison with the light PET Bottle 17 only similar ones. Almost the same is valid for of the TT 500mL ambient with its relatively high share of plastic. When compared with the PET Bottle 17 the TT 500mL ambient shows similar or even higher impacts in the category 'Climate Change' respective of the choice of allocation factor.

In case of the TT bb 500mL ambient containing bio-based plastics, environmental impacts in the category 'Climate Change' are lower or similar than those of cartons with fossil based plastics and also those of the bottles respective of the choice of allocation factor.

However, the use of bio-based plastics also leads to higher environmental impacts in all other impact categories examined. This leads to the beverage carton showing much higher impacts in several categories than the compared bottles.

The sensitivity analysis on system allocation shows that the choice of allocation factor has a small influence on the assessment of the environmental impacts.

# 16 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, including cream and yoghurt and JNSD including still water. Even though carton packaging systems, plastic bottles and glass bottles, cups and SUP 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, that have been chosen by Tetra Pak. Even though this selection is based on market data it does not represent the whole markets of Belgium, the Netherlands, Ireland and the United Kingdom.

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 method**:
The selection of the environmental categories applied in this study covers impact categories and assessment methods considered by the authors to be the most appropriate to assess the potential environmental impact. It should be noted that the use of different impact assessment methods could lead to other results concerning the environmental

ranking of packaging systems. The results are valid only for the specific characterisation model used for the step from inventory data to impact assessment.

Limitations concerning the analysed **categories**:
The results are valid only for the environmental impact categories, which were examined. They are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

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 Belgium, the Netherlands, Ireland or the United Kingdom, 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 **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.

# 17 Overall conclusion and recommendations

The following overall conclusions summarise the findings of the analyzed packaging comparisons in the four regarded markets. These overall conclusions should not be used for statements of specific packaging systems in specific markets. Regarding conclusions of specific packaging systems in a specific market, the detailed conclusion section of each market should be consulted.

The beverage carton systems analysed in this study show different environmental performances depending on different segments and markets 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 or aluminium. Beverage cartons on the other hand benefit from their high share of LPB. The production of LPB utilises mainly renewable energy leading to lower environmental impacts. The additional advantage of beverage cartons regarding ‘Climate Change’ in particular lies in the uptake of CO2 during the growth of trees, whose wood is the main material of LPB.

Compared to the regarded glass bottles beverage cartons show lower impacts in all categories apart from ‘Aquatic Eutrophication’ resulting from paper production and apart from ‘Ozone Depletion Potential’ in case of some beverage cartons with bio-based plastics.

Beverage cartons with fossil based plastics show lower environmental impacts than their compared alternative packaging systems in almost all segments within the four studied markets in most impact categories, especially regarding ‘Climate Change’. No general environmental advantage of beverage cartons compared to plastic bottles or cups in impact categories apart from advantages in ‘Climate Change’ can be observed in the segments JNSD 1000mL (BE, NEL, IRL, UK), DAIRY 1000mL-2000mL (NEL, IRL, UK), DAIRY (CREAM) 300mL-330mL (IRL). No general advantage of beverage cartons including ‘Climate Change’ can be seen in the segment WATER (NEL, UK).

In the segment of still WATER, environmental performances of beverage cartons and PET bottles show no general advantages for either packaging systems. In most analysed impact categories the difference of the compared packaging systems is lower than 10% and thereore insignificant (see section 1.6). In case of the Dutch market an environmental advantage of beverage cartons can be seen only for the impact category ‘Climate Change’. In case of the examined packaging systems on the UK market, a general recommendation of beverage cartons can not be based on environmental criteria anymore. A reason for these results is that the analyzed water PET bottles are lightweighted and contain no barrier materials. Whereas the beverage cartons contain mostly an aluminium barrier layer)

The use of bio-based polyethylene, though does not deliver such an unambiguous benefit. While the utilisation of bio-based polyethylene instead of fossil-based material leads to lower results in 'Climate Change' the emissions from the production of this bio-polyethylene, including its agricultural background system, increase the environmental impacts in all the other impact categories considered.

From the findings of this study the authors develop the following recommendations:

- From an environmental viewpoint beverage cartons with fossil based plastics can be recommended as the packaging of choice for most segments within the four studied markets (see exceptions describes in this section above).
- Because of the additional impacts in all categories except 'Climate Change' resulting from the production of bio-based plastics, the use of bio-based plastics can not be endorsed unreservedly. If there is a strong focus on climate change mitigation in Tetra Pak's environmental policy, though, the utilization of bio-based polyethylene can be an applicable path to follow as the 'Climate Change' impacts of bio-based plastics are lower than those of fossil based plastics. 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 play a crucial role in the life cycle of the 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.
- The sensitivity analysis regarding an alternative barrier material for beverage cartons shows that the substitution of aluminium leads to environmental improvements for the respective cartons. It is therefore recommended to utilise a material substituting aluminium with the same barrier capacities as aluminium. The actual environmental impacts of such a material should be assessed additionally.
- 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.

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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. Inventory categories (for example water use) used in this study are not further explained in this appendix. (see section 1.8).

## 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. 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.

[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.

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]**<br>**[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 Enviroment 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 operationalised 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 |
|---|---|---|
| 1 | • Natural | undisturbed ecosystem, pristine forest |
| 2 | • close-to-nature | close-to-nature forest management |
| 3 | • partially close to nature | intermedium forest management, Highly diversified structured agroforestry systems |
| 4 | • semi-natural | half-natural forest management, Extensive grassland, mixed orchards |
| 5 | • partially distant to nature | mono-cultural forest, Intensified grassland (pastures); Agriculture with medium large cuts |
| 6 | • distant-to-nature | Highly intensified agricultural land, large areas cleared landscape |
| 7 | • 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 characterised by factor 1. Each class ascending towards naturalness is characterised 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 ($DNP_i$) |
|---|---|
| 1 | 0 |
| 2 | 0.0313 |
| 3 | 0.0625 |
| 4 | 0.125 |
| 5 | 0.25 |
| 6 | 0.5 |
| 7 | 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])

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# Appendix B: Critical Review Report

*Critical Review Report*
*on the LCA report*
*"Comparative Life Cycle Assessment of Tetra Pak® carton packages and alternative packaging systems for beverages and liquid food on the North West Europe market"*
*dated October 2018*

*ISO 14 040 & ISO 14 044*
*ISO/TS 14071*

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SOL 17-030.2

8th of October 2018

for

**Tetra Pak**

# 1 Introduction

The Institute for Energy and Environmental Research Heidelberg GmbH (ifeu) has prepared a LCA report "Comparative Life Cycle Assessment of Tetra Pak® carton packages and alternative packaging systems for beverages and liquid food on the North West Europe market" dated October 2018 for Tetra Pak.

The goal of this LCA study was to "***conduct an LCA analysing the environmental performance of beverage carton systems compared to competing alternative beverage packaging systems on four individual markets***.

*Competing packaging systems include:*

- *PET bottles*
- *HDPE bottles*
- *Single use glass bottles*
- *PP cups Stand up pouches."*

As stated latter on in the report "*The main objectives of the study are:*

*(1) to provide knowledge of the environmental strengths and weaknesses of carton packaging systems (partly with bio-based material) on four individual markets in the described segments and markets.*

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

*Further objectives are addressed through sensitivity analyses*:"

This study seeks to follows the requirements of ISO 14040/14044 standards. "*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. The study and/or its results are therefore intended to be disclosed."* Therefore, Tetra Pak has requested a Critical review (CR) panel to make a CR of the LCA report of the comparative LCA (elaborated to be transmitted to third-parties).

The present CR report is the "Final CR report", including the detailed tables prepared by the CR panel under the direction of Philippe Osset (Solinnen). This CR report is dedicated to being integrated, as a whole, within the final LCA report of Tetra Pak

# 2 Composition of the panel

The CR panel consisted of the following members, independent from the overall study content, and external to Tetra Pak, and the related business interests:

- Dipl. Eng. Philippe Osset, Solinnen, LCA expert. Philippe has acted as the chair of the CR panel,
- BEng. Ph.D. Leigh Holloway, Eco3 Design Ltd,
- MSc. CEnv. Will Schreiber, 3Keel LLP

The intention of the panel set up was to make available competencies which cover the studied topic.

The reviewers were independent from the study, in line with the requirements stated in ISO/TS 14071.

# 3 Nature of the CR work, CR process and limitations

The CR panel has worked according to the requirements of ISO 14040:2006 and 14044:2006 concerning CR. They have also taken into account ISO/TS 14071 requirements.

According to ISO 14044, the CR process has worked in order to check if:

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

The first task of the CR was *to provide Tetra Pak* and ifeu with detailed comments in order to allow Tetra Pak to improve its work. These comments have covered methodology choice, results and reporting. The panel has checked the *plausibility* of the data used. Additionally, the present final CR report *provides the future reader* of the LCA report and user of the LCI with information that will help understanding the LCA report and the LCI data they use.

The CR was performed during the on-going of the study. The analysis and the verification of individual datasets are outside the scope of the review. The exhaustive verification of the LCI and LCIA results are outside the scope of the critical review: sample tests have been made throughout the report concerning the plausibility of the LCI and LCIA results. From these tests, the comments have been generated in order to be as generic as possible, requesting changes which apply everywhere in the report – which sound necessary due to the wide scope of the work.

The CR work has started in December 2017 and was completed in October 2018. During this period, different oral and written exchanges have been held between the CR panel, ifeu, and Tetra Pak, including clarification exchanges regarding the CR comments, and the production of two sets of detailed comments by the CR panel, and four new versions of the LCA report by Tetra Pak. New LCI calculations have been done after the first detailed comments of the panel.

The CR set of 188 comments covered the following points:

- Methodology ISO (9 key comments),
- Methodology Science (30 key comments),
- Data and Calculations (55 key comments),
- Analysis and interpretation (12 key comments)
- Report writing (82 comments)

Various language and style issues remain in the final LCA report that could result in the misinterpretation of results.

Significant efforts have been made by the authors to alleviate the main concerns arisen in the previous versions of the LCA report: consistent use of the functional unit throughout the document; justification of allocations; choice of impact assessment methods; database updates; and inclusion of foreground inventory data for inputs and outputs. As a whole, the final result has improved as compared to the first version, towards the requirement of the reference standards.

This final CR report is the synthesis of the final comments by the reviewers about the LCA report from Tetra Pak. The remaining detailed comments are provided within this final CR report, together with the full detailed exchanges as appendices.

The present CR report is delivered to Tetra Pak. The CR panel cannot be held responsible for the use of its work by any third party, including Tetra Pak, as concerns related to the final presentation and discussion of results have been presented to the authors and Tetra Pak. The conclusions of the CR panel cover the full LCA report from Tetra Pak and no other report, extract or publication which may eventually be done are covered by our review. The CR panel conclusions have been set given the current state of the report and the information which has been received. These CR panel conclusions could have been different in a different context.

# 4 Conclusions of the review – Critical Review Statement

**As a whole, <u>the panel considers that the requirements of the reference standards have been applied when dealing with the goal as stated in chapter one of the present CR report</u>.**

The panel notes that the study doesn't cover the scope of refillable/reusable packaging, since these systems have not been selected to be included in the scope of the study. Care should be taken on claims regarding material comparisons for some of the studied formats will have significantly different impacts if refillable/reusable systems are present.

The LCA report presented, for each four geographical markets, the results, and the sensitivity analysis that could be extracted are presented, but no analysis of the differences between markets are given. To have all these studies in one LCA report but not show all the differences, or even comment on them, between market places is a loss of value added and could lead to misstatements made by non-technical interpreters of the results.

The final LCA report answers the goals which are mentioned in the introduction of the present CR report, with the exception of the comparison across markets, within the scope of the limitations that are mentioned in the LCA report and the detailed panel comments which are provided in the next chapter.

# 5 Detailed comments

The following lines bring some highlights that a reader of the final LCA report may use to assist his reading and understanding of the LCA report. It includes also some critical comments which were not addressed, or which were addressed in a way which is different from what the CR panel expected. The comments which have been fully addressed no longer appear here. The reading of the detailed comments and answers (see the table in appendices) is recommended.

## *5.1 Consistency of methods used with ISO 14044 requirements*

The final structure of the LCA report reflects the ISO standard requirements. The methods that have been selected for reference calculations are clearly presented, including the choices for end of life modeling ("UBA LCA methodology") and impact assessment methods. These choices are consistent with ISO 14044 requirements.

Different choices for end of life modeling (such as the CFF – Circular Footprint Formula – of the PEF – Product Environmental Footprint of the DG ENV) could have led to different conclusions. Further LCA studies will probably have to take into account this formula if it spreads (including through regulation set up) within Europe.

The use of former impact assessment methods is explained by the wish to have consistent LCIA calculations over Tetra Pak studies, but no assessment of the evolution of results with previous studies is done. Further LCA studies by Tetra Pak would benefit to use state of the art methods to enable meta-analyses of current LCA studies in this sector. For sure, the availability of LCI which are updated/developed to be used with the new methods will help.

As an example, as far as water use is concerned, further studies will benefit from using the AWARE methodology, which might have a potential effect on the results of the comparisons.

As far as GWP, the calculations being done in relation to biogenic carbon accounting, the last requirements of ISO 14067 have not been applied due to the lack of time to recalculate all results after the publication of ISO 14067:2018 (in August 2018), and no assessment of the potential effect on the comparisons of the application of ISO 14067:2018 requirements is done. Further LCA studies will have to take these ISO 14067:2018 requirements into account as reference in the calculations.

Sensitivity analyses and allocations are appropriate for the different markets being studied and are based on relevant data from those markets.

## *5.2 Scientific and technical validity*

The efforts made by the authors to solve previous issues on the use of outdated methods and databases have enhanced the scientific and technical validity of the study. A stronger conclusion about the validity of the study would require a thorough verification of inventories and models, which is out of the scope of this CR report. The assumptions used by the practitioners are relevant and appropriate for the products being assessed and are made clear in the report.

## *5.3 Appropriateness of data used in relation to the goal of the study*

Gathered data are mainly appropriate when dealing with the goal of the study as mentioned in the present CR report.

The recycling quotas in Belgium have been noted to be very high as compared to other countries in Europe.

The use of disaggregated ifeu data for glass production instead of the recent aggregated FEVE data is presented due to the need of disaggregated data for the analysis and interpretation. The study would have benefited of the use of disaggregated FEVE data, since it might have had an influence on the results of the comparison.

Whilst not all data is as current as it should be in this type of study, the practitioners have updated data where possible to bring the data timelines in line with the wider scope of the analysis. Comparative product profiles have been compiled fairly and reflect the current market landscape and technologies for the selected average products.

### 5.4 Validity of interpretations in the scope of the limitations of the study

The interpretations presented in the LCA report are supported by figures that are based on the environmental characterization results. These interpretations are found to be in accordance with the goal and scope of the study, although they are not always provided in an easy to understand narrative or format, in particular in the discussion of the overall conclusions and recommendations.

Each country has been assessed individually and exclude a consolidated interpretation across markets. This consolidated interpretation could have brought value to the overall understanding of the study.

The limitation chapters of the LCA report (chapter 16) present the main limitations of the LCA report. Beyond the scope of this CR process, potential limitations in terms of inventory data (quality and quantity) or environmental impacts chosen could affect the validity of the interpretations reported.

Some of the language in the report is more broad reaching than the results suggest, in particular around the broad conclusions stated around environmentally preferable formats. These should be read in the context of the specific market analyses otherwise they could be misinterpreted.

### 5.5 Transparency and consistency

ifeu has provided to the panel all the information that the panel requested. The final LCA report presents in a transparent manner all the choices that have been made during the study.

The study has been drafted in a manner that makes it difficult for non-technical experts to understand or appropriately interpret the results. These matters have been raised by the review panel and some areas have been improved, but gaps still remain. The volume of material included in the study further impairs the accessibility of the results. Of particular concern is the use of broad conclusions being drawn in the conclusion and market chapters that, whilst presenting caveats, should not be written using generous language that is not wholly applicable in an unqualified manner.

## 6 Appendices

The detailed CR tables exchanged during the work are the appendices of the present CR report. They recap the detailed exchanges between the CR panel and Tetra Pak.

| Initials | Index | Version of the report | First Line number in the report | Other line numbers in the report | Detail | Nature of the comment | Level of importance of the comment | Reviewer Comments and Questions (detailed) | Reviewer Recommendation | Nature of the answer from the practitioner | Line in the new report where the modification is done | Answer from the practitioner (according to each draft) | Check by the review | Ref to new Index when needed | Further answer from the practitioner | Line in the new report where the modification is done |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOL | 1 | November 2017 | 0 | 0 | packaging systems for liquid food | R. Report writing | 3. Editorial | Why use "liquid food" here and "beverage" in all the report ? | Use beverage | Taken into account | title | in title we used liquid food and beverages | ok | | | |
| LH | 2 | November 2017 | 0 | Title | …packaging systems for liquid food….' | R. Report writing | 3. Editorial | Title refers to liquid food but report refers to beverages | Change title to 'beverages' | Taken into account | title | in title we used liquid food and beverages | ok | | | |
| LH | 3 | November 2017 | 79 | 79 | Beverage | R. Report writing | 3. Editorial | Should the report refer to 'liquid food' as per title or 'beverages' - see above comment on the title | See above comment | Taken into account | title | in title we used liquid food and beverages | ok | | | |
| WS | 1 | November 2017 | 80 | 80-82 | The goal of the study is to conduct an LCA analysing the environmental performance of beverage carton systems in both, chilled and ambient segments dairy and Juice, Nectars & Still Drinks (JNSD) compared to competing alternative packages (i.e. PET, HDPE, Stand up pouch and Glass packages) in the four Northwest European markets: United Kingdom, Ireland, Belgium and Netherlands. | R. Report writing | 3. Editorial | Long and confusing sentence. | Suggest using either a table or bullets to convey coverage. At the minimum, the sentence should be broken up between the beverage formats and the markets. This same issue is repeated in lines 87-92. | Taken into account | 182 | changed to bullet points | ok | | | |
| LH | 4 | November 2017 | 84 | 84 | Approxamitily | R. Report writing | 3. Editorial | Spelling mistake. | Change to 'Approximately' | Taken into account | 169 | corrected | ok | | | |
| LH | 5 | November 2017 | 91 | 91 | Grap & go' | R. Report writing | 3. Editorial | Spelling mistake | Change to 'Grab & Go' | Taken into account | 170 | corrected | ok | | | |
| LH | 6 | November 2017 | 91 | 91 | pack sizes | R. Report writing | 3. Editorial | Mention of grab and go and ambient / chilled packs. But no mention of sizes. | Add a reference / comment on size (ml) | Taken into account | 212 | now referred to the bullet points above | ok | | | |
| LH | 7 | November 2017 | 93 | 93 | cartons with those of its' | R. Report writing | 3. Editorial | The word 'its' is not needed | Delete word 'its' | Taken into account | 190 | corrected | ok | | | |
| LH | 8 | November 2017 | 96 | 96 | 'aseptic' | R. Report writing | 3. Editorial | This is the first time this is used. | Perhaps add a sentence of explanation as to what this means | Taken into account | 196 | changed to ambient | ok | | | |
| LH | 9 | November 2017 | 98 | 98/99 | Size of carton not referred to | R. Report writing | 3. Editorial | Mention of analysis of cartons but size is not clear | Add size into text (ml) | Taken into account | 212 | description of systems deleted and reference to tables 24-27 added | ok | | | |
| LH | 10 | November 2017 | 101 | 101 | optimized weights | R. Report writing | 3. Editorial | Not clear what the term 'optimized' means | Clarify | Taken into account | 201 | clarified | ok | | | |
| LH | 11 | November 2017 | 105 | 105/106 | Comparing to cartons on Belgian and UK market | A. Analysis and interpretation | 2. Comment | Belgian and UK markets included in comparison but not UK or Ireland. | Explain / clarify why this is the case | Taken into account | 212 | clarified in general for all sensitivities | ok | | | |
| LH | 12 | November 2017 | 109 | 109/110 | Belgian and UK markets | A. Analysis and interpretation | 2. Comment | As above comment | As above | Taken into account | 212 | clarified in general for all sensitivities | ok | | | |
| LH | 13 | November 2017 | 114 | 114 | -3 | R. Report writing | 3. Editorial | The results of (3)….' What does (3) refer to - the previous list? | Clarify in text | Taken into account | 217 | reference to (3) moved directly after the references of the oter scopes | ok | | | |
| SOL | 2 | November 2017 | 126 | 126 | According to the ISO standards on LCA [ISO 14040 and 14044 (2006)], this requires a critical review process done by a critical review panel | I. Methodology (ISO) | 1. Discrepancy | A the statement as to whether the study intends to support comparative assertions intended to be disclosed to the public is required | Add "comparative" in L123, or any other element from 1.1 | Taken into account | 230 | corrected | ok | | | |
| LH | 14 | November 2017 | 127 | 127 | ..critical review process done by….' | R. Report writing | 3. Editorial | Word 'done' should be changed | Change to 'undertaken' or 'performed' | Taken into account | 234 | corrected | ok | | | |
| SOL | 3 | November 2017 | 137 | 137 | The function examined in this LCA study is the packaging of beverages for retail. | I. Methodology (ISO) | 2. Comment | Need precision on the performance characteristics (e.g. opacity level) and if there are any omission of additional functions in comparisons | Specify some key performance characteristics and omitted functions if any | Taken into account | 251 | Shelf times and time in stores added for beverages. | ok | | | |
| LH | 15 | November 2017 | 140 | 140-143 | Comment on shelf-life | D. Data and calculations | 2. Comment | The long shelf life is mentioned but not quantified. | Quantify or give and example to help clarify | Taken into account | 251 | Shelf times and time in stores added for beverages. | ok | | | |
| WS | 2 | November 2017 | 140 | 140-143 | The maximum shelf life of all regarded packaging systems is long enough that no beverage losses are to be expected because of discarded filled packages | S. Methodology (science) | 1. Discrepancy | Chilled packages will have a shorter life than ambient. How is home waste considered? This is separate from shelf life in retail. | | Taken into account | 251 | Shelf times and time in stores added for beverages. | | | | |
| SOL | 4 | November 2017 | 142 | 142 | This means, that the products would be used up, before the lowest shelf life of any packaging is reached | I. Methodology (ISO) | 2. Comment | What is the product life span… one day, one month, one year, ten years? In relation of what is the average duration in the shelf (refill)?<br>If the product life span is one year, and the average duration in shelf two days, then the demonstration is done… | Add quantitative information (order of magnitude) regarding the different affirmations. | Taken into account | 251 | Shelf times and time in stores added for beverages. | ok | | | |
| SOL | 5 | November 2017 | 144 | 144 | The primary packages examined are assumed to be technically equivalent | I. Methodology (ISO) | 2. Comment | "Assumed" is strange. The technical equivalency needs to be supported by something else than an "assumption". Any test? | Elaborate (negligible, gap informations …) | Taken into account | 255 | term "assumed" changed to "are". Reason are explained later in detail | ok | | | |
| LH | 16 | November 2017 | 144 | 144-146 | Comments on assumption of technical equivalency | D. Data and calculations | 2. Comment | Technical equivalency of packs is 'assumed' | Can this be clarified or some explanation / data shown to back up this 'assumption'. Appears to be explained in section 1.5 but some reference could be made here. | Taken into account | 255 | term "assumed" changed to "are". Reason are explained later in detail | ok | | | |

| Initials | Index | Version of the report | First Line number in the report | Other line numbers in the report | Detail | Nature of the comment | Level of importance of the comment | Reviewer Comments and Questions (detailed) | Reviewer Recommendation | Nature of the answer from the practitioner | Line in the new report where the modification is done | Answer from the practitioner (according to each draft) | Check by the review | Ref to new Index when needed | Further answer from the practitioner | Line in the new report where the modification is done |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WS | 3 | November 2017 | 153 | 153 | and production of raw materials, converting processes, all transports and the final disposal | R. Report writing | 3. Editorial | | | Not taken into account | | comments were missing | | | | |
| WS | 4 | November 2017 | 164 | 164 | transports of packaging material from producers to fillers | r. Report writing | 3. Editorial | | | Not taken into account | | comments were missing | | | | |
| WS | 5 | November 2017 | 165 | 165 | filling processes, which are fully assigned to the packaging system. | r. Report writing | 3. Editorial | | | Not taken into account | | comments were missing | | | | |
| LH | 17 | November 2017 | 194 | 194 | Effects from accidents | R. Report writing | 2. Comment | Unclear as to what this means - what are 'accidents' does this include breakages? | Please clarify in text with brief explanation | Taken into account | 305 | corrected | ok | | | |
| WS | 6 | November 2017 | 203 | 203-205 | 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. | I. Methodology (ISO) | 1. Discrepancy | If the use phase is excluded, a full cradle to grave assessment is not taking place. Cradle to gate + end of life is. This is an inconsistency given the consideration of energy used in chilled transport of packages. | | Taken into account | 263 | study design as "cradle to grave without use phase" mentioned in the beginning | | | | |
| WS | 7 | November 2017 | 206 | 206-208 | In consequence a sensitivity analysis regarding beverage losses would be highly speculative and is not part of this study. | S. Methodology (science) | 1. Discrepancy | This is what a sensitivity analysis would show with some clear assumptions. Disagree that it should be excluded because of a lack of reliable data. WRAP (UK) have done considerable assessment on food and beverage waste in the home. | | Taken into account | 318 | more clarification added | | | | |
| LH | 18 | November 2017 | 211 | 211-213 | transport of filled packages | D. Data and calculations | 2. Comment | Transport efficiencies of pouches could be considerably different than bottles and cartons due to their shape | Consider validity of assumption made in report | Not taken into account | | discussed and ignored in 1st review call | ok | | | |
| SOL | 6 | November 2017 | 221 | 221 | Figure 1: System boundaries of beverage cartons | R. Report writing | 2. Comment | What is the meaning of the word "displaced" in the figure ? Is it equivalent to "avoided" | Clarify the word, and any difference with avoided | Taken into account | 336 ff / 434 | as remembered from the call:<br>accepted as it is, displaced means avoided as in substituted | ok, a kind of consequential approach. Some text in the report to state what is behind would be useful (it is not in ISO) | | regarding the application of credit, a referance to the allocation chapter added | 439 |
| WS | 8 | November 2017 | 221 | 221 | System boundaries for beverage carton | S. Methodology (science) | 1. Discrepancy | Flow chart indicates that landfill is resulting in displaced energy and heat; this is incorrect as landfill displaces nothing - it emits. | | Taken into account | 336 ff | average landfills recover landfill gas for energy recovery | | | | |
| WS | 9 | November 2017 | 224 | 224 | System boundaries for PET bottles | S. Methodology (science) | 1. Discrepancy | ibid | | Taken into account | 336 ff | average landfills recover landfill gas for energy recovery | | | | |
| WS | 10 | November 2017 | 226 | 226 | System boundaries for HDPE bottles | S. Methodology (science) | 1. Discrepancy | ibid | | Taken into account | 336 ff | average landfills recover landfill gas for energy recovery | | | | |
| WS | 11 | November 2017 | 229 | 229 | System boundaries for PP cups | S. Methodology (science) | 1. Discrepancy | ibid | | Taken into account | 336 ff | average landfills recover landfill gas for energy recovery | | | | |
| WS | 12 | November 2017 | 232 | 232 | System boundaries of glass bottles | S. Methodology (science) | 1. Discrepancy | ibid | | Taken into account | 336 ff | average landfills recover landfill gas for energy recovery | | | | |
| WS | 13 | November 2017 | 235 | 235 | System boundaries for stand up pouch | S. Methodology (science) | 1. Discrepancy | ibid - sensitivity analysis should also include potential recycling | | Not taken into account | | discussed and ignored in 1st review call | | | | |
| LH | 19 | November 2017 | 246 | 246 | ..which are cut off according to the mass related rule | D. Data and calculations | 2. Comment | Text seems a little confusing. Says less than 5% is not included but then goes on to say prechains with low mass are included (even though they would be excluded due to mass cut off rule) | Make sure text is clear. Might need a small alteration? | Taken into account | 363 | reworded for clarification | ok | | | |
| WS | 14 | November 2017 | 249 | 249-252 | Based on the mass-related cut-off the amount of printing ink used for the surface of beverage 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 carton examined in this study. | S. Methodology (science) | 1. Discrepancy | Ink carries a very high environmental impact and typically covers a greater surface area on a carton than the other formats (i.e. used in greater quantities). It should be included. | | Taken into account | 371 | Reference regarding low impact of ink added | | | | |
| LH | 20 | November 2017 | 263 | 263 | Paragraph on Geographical scope | D. Data and calculations | 2. Comment | Most figures seem to be for European countries. This means that Tetra Pak source the materials only form Europe? | Clarify. If it is indeed the case make a statement in the paragraph which shows this - it helps to strengthen the decision to use European data. | Taken into account | 286 | reworded for clarification | ok | | | |
| WS | 15 | November 2017 | 273 | 273 | packaging specifications listed in section 2 refer to 2017 as well as the market situation | R. Report writing | 3. Editorial | Incomplete sentence | | Taken into account | 392 | corrected | | | | |
| WS | 16 | November 2017 | 278 | 278 | Most of the applied data refer to the period between 2002 and 2017. | I. Methodology (ISO) | 1. Discrepancy | Impact profiles and industry have changed considerably over this fifteen year timespan. Data should be within the last five years, no more than ten. | | Taken into account | 397, 402 | reference to data table and chapter 3 added | | | | |

| Initials | Index | Version of the report | First Line number in the report | Other line numbers in the report | Detail | Nature of the comment | Level of importance of the comment | Reviewer Comments and Questions (detailed) | Reviewer Recommendation | Nature of the answer from the practitioner | Line in the new report where the modification is done | Answer from the practitioner (according to each draft) | Check by the review | Ref to new Index when needed | Further answer from the practitioner | Line in the new report where the modification is done |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WS | 17 | November 2017 | 305 | 305-307 | The database is continuously updated. Background processes such as energy generation, transportation, MSWI and landfill were taken from the most recent version of it. | R. Report writing | 2. Comment | Further details regarding updates and suitability to be added. Currently requires reader to trust database is using appropriate, and current, data. | | Taken into account | 397, 402 | reference to data table and chapter 3 added | | | | |
| SOL | 7 | November 2017 | 315 | 315 | To define the significance of differences of results, an estimated significance threshold of 10 % is chosen as pragmatic approach. | R. Report writing | 3. Editorial | 10% is small as such… but the way the conclusions will be written might be ok. To be checked when reading the next version of the report | Nothing to be done at that stage. | Not taken into account | | discussed and ignored in 1st review call | ok | | | |
| LH | 21 | November 2017 | 315 | 315 | Threshold of 10% | D. Data and calculations | 2. Comment | Where does this 10% come from - is there anything to back this up? Data, publications, standard practice in most LCAs? | Back up the 10% statement if possible. | Taken into account | 435 | added reference [Kupfer et al 2017] | ok | | | |
| SOL | 8 | November 2017 | 331 | 331, 380 to 805, 1585 | General methodology | S. Methodology (science) | 2. Comment | The goal of the critical review is not to assess the conformance of the report with PEF. Nevertheless, when key issues are left opened in ISO (i.e. the practitioner has to make a choice) and are detailed within PEF with choices and recommendations, it would be interesting to evaluate if the report is in line with PEF choices, or justify why alternative choices have been done, or do one or two sensitivity analyses The report will be communicated in Europe, and this question might raise. | Action might be all along the report, dealing with allocations, end of life calculations (CFF vs. UBA 2016), biogenic carbon, IA methods (PEF vs. UBA 2016), electricity consumption model… The European countries where the report will be used (not Germany) might question the choice "UBA" instead of PEF | Taken into account | 552 | not a PEF study, but relation to PEF briefly mentioned in allocation section | ok, the choice of UBA approach is transparent | | | |
| LH | 22 | November 2017 | 342 | 342 | ….coupled processes is generally carried out via the mass.' | D. Data and calculations | 2. Comment | This might need explaining. Why is it carried out by mass? Usual practice? | Clarify or put very brief explanation in text as to why this approach is acceptable. | Taken into account | 461 | "as this is usual practice " added | ok | | | |
| LH | 23 | November 2017 | 350 | 350 | Exclusion of beverage transport impacts | D. Data and calculations | 2. Comment | Further explain why it is excluded. | Simple statement to the effect that as all packaging contains beverages and the functional unit used in the study is related to the beverage the transport impacts will be the same across all options and alternatives so does not need to be included in a comparative study such as this. | Taken into account | 474 | Statement added | ok | | | |
| LH | 24 | November 2017 | 353 | 353 | System Related Allocation | R. Report writing | 3. Editorial | Explanation of A and B and how they apply to this report is a little confusing. | Clarify if possible | Taken into account | 479 | "'System A' shall represent systems under study in this LCA" stated in section "system related allocation" | ok | | | |
| SOL | 9 | November 2017 | 354 | 354 | in Figure 5and 6. | R. Report writing | 3. Editorial | "in Figure 5 and 6." | "in Figure 5 and 6." | Taken into account | 477 | added space | ok | | | |
| LH | 25 | November 2017 | 355 | 355 | product system A and B | R. Report writing | 3. Editorial | Product system A (and B) would be better placed in the text with inverted commas. E.g. 'Product system A' | Add in inverted commas | Taken into account | 478 ff | inverted commas added | ok | | | |
| SOL | 10 | November 2017 | 356 | 356 | In figure 1-2 | R. Report writing | 3. Editorial | Refer to the figure 7 ? | | Taken into account | 479 | reference changed to figure 7 | ok | | | |
| SOL | 11 | November 2017 | 368 | 368 | General notes regarding Figure 7 to Figure 9 | R. Report writing | 3. Editorial | Refer to the figure 8 to 9 ? | | Taken into account | 492 | paragraph refers to all figures 7-9 | ok | | | |
| LH | 26 | November 2017 | 377 | 377-379 | Reference to data discussed | R. Report writing | 3. Editorial | To allow understanding include ref here to relevant diagrams / pages later in report | Add a refence in at this point once the later sections including this info are added in. | Taken into account | 504 | references added | ok | | | |
| LH | 27 | November 2017 | 404 | 404 | Coupled and uncoupled | R. Report writing | 3. Editorial | Not fully clear what coupled and un-coupled mean in this context | Add a very brief comment / explanation here to help reader understand. | Taken into account | 530 | explanation added | ok | | | |
| WS | 18 | November 2017 | 501 | 501 | It has to be noted; that the impact categories, represent the | R. Report writing | 3. Editorial | Remove semi colon | | Taken into account | 629 | corrected | | | | |
| WS | 20 | November 2017 | 525 | 525 | dLUC | S. Methodology (science) | 2. Comment | iLUC also needs to be considered | | Not taken into account | 654 | no robust methodology or data available for iLUC | | | | |
| SOL | 12 | November 2017 | 528 | 528 | The related result show changes in soil organic carbon and above and below ground carbon stocks from conversion | R. Report writing | 3. Editorial | Replace by "…soil organic carbon above and below …" | | Taken into account | 658 | sentence order changed (part of removed dLUC section) | ok | | | |
| WS | 19 | November 2017 | 528 | 528 | changes in soil organic carbon and above and below ground carbon stocks from conversion | R. Report writing | 3. Editorial | Duplicate and | | Taken into account | 658 | sentence order changed (part of removed dLUC section) | | | | |
| LH | 28 | November 2017 | 529 | 529-530 | Accounting for negative CO2 | D. Data and calculations | 2. Comment | Bio-PE dataset does not account a negative CO2 value | Add brief explanation of why and how the affects the calcs / results compared to datasets that do. | Taken into account | 659 | section removed as not relevant for this study (e.g. no use of braskem dataset) | ok | | | |
| LH | 29 | November 2017 | 543 | 543 | Los Angeles smog | R. Report writing | 3. Editorial | Los Angeles smog is not a commonly used term | Remove from text? | Taken into account | 672 | removed | ok | | | |
| LH | 30 | November 2017 | 549 | 549 (and subsequent lines) | [kg O3-e / emission i] | R. Report writing | 3. Editorial | [kg O3-e / emission i] - what does the 'i' mean here? | Explain the notation of the unit? | Taken into account | 680 | simplified wording | ok | | | |
| LH | 31 | November 2017 | 573 | 573 (and subsequent lines) | Kg O3-e / fu | R. Report writing | 3. Editorial | Kg O3-e / fu - what does the 'fu' mean here? | Explain the notation of the unit? | Taken into account | 720 | fu=functional unit | ok | | | |
| WS | 21 | November 2017 | 653 | 653 | Examples of elementary flows | R. Report writing | 2. Comment | | Move before description of impact categories and add sources | Taken into account | 641 | tabled moved | | | | |
| LH | 32 | November 2017 | 685 | Para starting 685 | overall paragraph | R. Report writing | 3. Editorial | Seems to contradict itself. Says concept can be applied to central and northern Europe but then says cannot be used without hesitation | Perhaps clarify why it isn't being used or try and word paragraph differently to get rid of the apparent contradiction. | Taken into account | 817 | section reworded | ok | | | |
| LH | 33 | November 2017 | 698 | 698-699 | Text | R. Report writing | 3. Editorial | This text would be better placed on page 26 closer to the beginning of the explanation of the hemeroby concept. | Move text | Taken into account | 798 | text moved | ok | | | |
| LH | 34 | November 2017 | 769 | 769 | ….LCA during the last three…. | R. Report writing | 3. Editorial | Wording would be better as …..LCA over the last three years…. | Change text | Taken into account | 896 | changed to over | ok | | | |

| Initials | Index | Version of the report | First Line number in the report | Other line numbers in the report | Detail | Nature of the comment | Level of importance of the comment | Reviewer Comments and Questions (detailed) | Reviewer Recommendation | Nature of the answer from the practitioner | Line in the new report where the modification is done | Answer from the practitioner (according to each draft) | Check by the review | Ref to new Index when needed | Further answer from the practitioner | Line in the new report where the modification is done |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LH | 35 | November 2017 | 837 | 837-838 | Market relevance | R. Report writing | 3. Editorial | Clarify that the market relevance (and therefore completing packages) are different in each 3 regions. I.e. they are specific. Change to 'relevance in each of the | Change text | Taken into account | 965 | corrected | ok | | | |
| LH | 37 | November 2017 | 839 | Para Packaging Specification | Use of 'averages' | D. Data and calculations | 2. Comment | Average data for competitors compared to specific data for Tetra Pak. Could this affect the results and be 'beneficial' to the Tetra Pak packaging? | Justify the use of average data with respect to this? | Taken into account | 981 | more clarification added | ok | | | |
| LH | 36 | November 2017 | 846 | 846 | Weighing examples | D. Data and calculations | 2. Comment | How many examples were weighed. Were there enough for the samples to be representative? | Clarify | Taken into account | 981 | more clarification added | ok | | | |
| WS | 22 | November 2017 | 846 | 846 | Competitor weight samples | R. Report writing | 2. Comment | No description of how competitor products were determined, and therefore if they are representative of average bottles in each market | | Taken into account | 965, 981 | more clarification added | | | | |
| LH | 38 | November 2017 | 863 | 863 | Use of 'SUP' | R. Report writing | 3. Editorial | First use of 'SUP'? Explain what this means | Add to text | Taken into account | 996 | corrected | ok | | | |
| LH | 39 | November 2017 | 865 | Para starting line 865 | Data on secondary packaging | D. Data and calculations | 2. Comment | Would seem that the data used here could be a little 'weak' | Could it be strengthened in some way. Lots of assumptions used. | Not taken into account | 999 | no better data available, considered sufficient as main (i.r. to impact relevance) characterisations are the choice of material. These are known. | ok | | | |
| LH | 40 | November 2017 | 892 | Table after line 892 | Text | R. Report writing | 3. Editorial | Would be useful to see country listed next to each packaging option. Also no table number? | Add in column for country origin / use. Labe table with table number | Taken into account | 1027 | This table will be deleted in the report. It's only for information for the review panel and TP, so the samples can be allocated to the Bottle Ids | ok | | | |
| SOL | 13 | November 2017 | 907 | 907 | Closure | D. Data and calculations | 3. Editorial | | Closure data could be in bold (harmonization) | Taken into account | 1042 ff | corrected | ok | | | |
| SOL | 14 | November 2017 | 907 | 907 | TBA Slim HeliCap 23 | D. Data and calculations | 2. Comment | Tertiary packaging total is 27551. Are there really 5 cardboard layers? (just one for the square HeliCap in 910) | | Not taken into account | 1042 | Data from TP like this. Makes sense because of the shape of the packs. Stacking 1000ml TBA Slim packs would be unstable without slip-sheets as the cap is only on one side of the long surface of the top | ok | | | |
| LH | 41 | November 2017 | 912 | Table 14, 15 | cartons per pallet figures | D. Data and calculations | 2. Comment | Some large differences in units per pallet for different alternatives - even those of comparative size | Check this? Add some explanation in text as to why this is? | Taken into account | 1045 / 1106 | checked and explained | Where is the explanation? | | explanation in line 1143 | 1143 |
| LH | 42 | November 2017 | 918 | Table 16 | number of use cycles tertiary packaging | D. Data and calculations | 2. Comment | Large differences across alternatives e.g.. 200 v 25. | Check this? Add some explanation in text as to why this is? | Taken into account | 1050 / 1145 | as remembered from the call:<br>accepted as it is, 200 are roll containers, 25 are pallets | Is it worth adding a footnote on this? | | in table it should be clear if it is a rollconatiner or pallet | 1173 |
| WS | 23 | November 2017 | 918 | 918 | Table 16, 17, 18, 19, 20, 21 | R. Report writing | 2. Comment | Add rPET as a separate line to show assumed content | | Taken into account | 1051 ff | rPET content added.<br>We also changed the unit of the additives from % to grams | | | | |
| LH | 43 | November 2017 | 929 | Table 18 | Bottles per pallet figures | D. Data and calculations | 2. Comment | Some large differences in units per pallet for different alternatives - even those of comparative size | Check this? Add some explanation in text as to why this is? | Taken into account | 1054 | checked and explained | As LH 42 | | explanation in line 1143 | 1143 |
| SOL | 15 | November 2017 | 946 | 1253 | Recovery quota | D. Data and calculations | 2. Comment | In the scope of PEF, R1 (integration of recycled content) and R2 (recovery rates) have been provided at European level by the industry. | Can you position the values which are taken in relation with these R1 and R2? And justify your choices when they are different (same as SOL 8) | Not taken into account | 1070 | PEF R2 numbers not available for all examined countries. Even if they are, R2 can not be 100% compared to recycling rates as used in this study | ok, see also SOL 24 | | | |
| LH | 44 | November 2017 | 954 | Table 23 | Figures | D. Data and calculations | 2. Comment | Figures for Ireland are old compared to others | Check if still relevant and representative | Taken into account | 1078 | 2012 is still the most up to date data for Ireland on Eurostat | ok | | | |
| WS | 24 | November 2017 | 956 | 956 | Figure 11 | S. Methodology (science) | 3. Editorial | Landfill does not have significant energy recovery and other emissions should be shown | | Not taken into account | 1083 ff | simplified graphs do not show emissions at all, though small, landfill credits are existent and cannot be omitted in graph | | | | |
| LH | 45 | November 2017 | 958 | Figures 11 and onwards | MSWI / Landfill Energy / heat | D. Data and calculations | 2. Comment | How was the split of these figures calculated. Where is the data from? | Discuss data source | Taken into account | 1082 | connection between flowcharts and data table explained in text | ok | | | |
| LH | 46 | November 2017 | 974 | 974 | allocation factor for recycling | D. Data and calculations | 2. Comment | 50% figure is the same across all countries in the study? Is this correct? | Clarify / justify | Not taken into account | | discussed and ignored in 1st review call | ok | | | |
| SOL | 16 | November 2017 | 1015 | 1015 | Table 28 - ecoinvent 2.2 | D. Data and calculations | 1. Discrepancy | The use of Ecoinvent 2.2 looks obsolete for most practitioners in Europe (including in the scope of PEF). Looking at 274&275, the as up-to-date as possible data are Ecoinvent 3.4.<br>In 1151 some arguments are given… with regards to Ecoinvent 3.1… | Change to Ecoinvent v3.3 or v3.4. or justify why Ecoinvent 2.2 would be better / acceptable for the specific data sets which are covered. | Taken into account | 1141 | Ecoinvent 3.4 dataset used | ok, huge work | | | |
| SOL | 17 | November 2017 | 1015 | 1107 | Table 28 - PA6 | D. Data and calculations | 2. Comment | Process data are dated 2012, 7 sites | Please be consistent for Plastics Europe (other data have been accessed in April 2014) | Taken into account | 1141, 1249 | more clarification added in PA6 Paragraph | ok | | | |
| SOL | 18 | November 2017 | 1015 | 1099 | Table 28 - PET | D. Data and calculations | 2. Comment | PET bottle grade is dated 2016 with 12 sites from 2015… which is better then 2011 and ref year 2008 | Having an overview of Plastics Europe recent eco-profile data might be very relevant, based on the fact that these data are key for comparisons | Taken into account | 1141, 1239 | New PET Dataset used | ok | | | |
| SOL | 19 | November 2017 | 1015 | 1138, 1286 | Table 28 - Glass | D. Data and calculations | 2. Comment | FEVE has released new glass for bottle production data in 2017<br>http://feve.org/new-life-cycle-assessment-proves-industry-success-reducing-environmental-footprint/ | Consider using FEVE data, which might be very relevant, based on the fact that these data are key for comparisons | Taken into account | 1285 | Reasoning added in chapter 3.4. | Comment | See SOL 27 | See SOL 27 | See SOL 27 |
| LH | 47 | November 2017 | 1015 | Table 28 | Data | D. Data and calculations | 2. Comment | Some data sources quite old. | No newer sources? | Taken into account | 1141 | TiO2, PET, Carbon black updated, explanation for "old" PA6 given in text | ok | | | |
| WS | 25 | November 2017 | 1015 | 1015 | Table 28 | I. Methodology (ISO) | 1. Discrepancy | BioPE using an old data set and not necessarily reflective of sugarcane sourcing undertaken by supplier; TiO2 using a very old factor - v3.4 currently out in ecoinvent; Tetra Pak data for converting from 2009 - too old for a study dependent on primary data. Preform and HDPE bottle production should use PlasticsEurope data; all end of life recovery data is out of date | | Taken into account | 1141 | Bio PE: only newer data available is by Braskem, not used and explained in section 3.1.4.TiO2 data updated. Converting is latest data available. Collection of newer data out of scope of this study. Plastic production data from PlasticsEurope is used. Converting data not available from PlasticsEurope | | | | |
| LH | 48 | November 2017 | 1017 | Section 3.1 | Figures on 'representative production' figures | D. Data and calculations | 2. Comment | Figures for polymers are 'representative of market %'. Do we need the same figures for the Tetra Pak cartons? What % of market? | Discuss if this is needed | Not taken into account | | discussed and ignored in 1st review call | ok | | | |
| LH | 49 | November 2017 | 1063 | Para starting 1063 | Bio-PE | D. Data and calculations | 2. Comment | Any estimate of % of BIO-PE market? We have this for other polymers in the report. | Discuss if this is needed | Not taken into account | Para staring 1180 | no robust data available | ok | | | |
| LH | 50 | November 2017 | 1078 | 1078 | Braskem's manufacturing | R. Report writing | 3. Editorial | Include location of Braskem's manufacturing here. | Add into text | Not taken into account | 1198 | dataset not used in study | ok | | | |
| LH | 51 | November 2017 | 1112 | 1112 - 1113 | Ammonium sulphate | D. Data and calculations | 2. Comment | Why was this approach not consistent? Can it be explained a little more? | Add simple comment / explanation to text | Taken into account | 1249 | further explanation added | ok | | | |
| LH | 52 | November 2017 | 1116 | Para 3.2 (line 1116) | European production | D. Data and calculations | 2. Comment | Confirm that Tetra Pak only purchases materials from European sources?<br>Comment applies to other section of report too such as 3.6 | Add to text | Taken into account | 1265 | added clarifications to respective sections | ok | | | |
| LH | 53 | November 2017 | 1136 | 1136 | 95% of annual production | D. Data and calculations | 2. Comment | 95% of annual production of Europe or global? | Clarify | Taken into account | 1274 | European | ok | | | |
| LH | 54 | November 2017 | 1143 | 1143 | Glass production | D. Data and calculations | 2. Comment | No mention of geography or 5 of market | Add in information | Taken into account | 1277 | German production | ok | | | |

| Initials | Index | Version of the report | First Line number in the report | Other line numbers in the report | Detail | Nature of the comment | Level of importance of the comment | Reviewer Comments and Questions (detailed) | Reviewer Recommendation | Nature of the answer from the practitioner | Line in the new report where the modification is done | Answer from the practitioner (according to each draft) | Check by the review | Ref to new Index when needed | Further answer from the practitioner | Line in the new report where the modification is done |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| WS | 26 | November 2017 | 1148 | 1148, 1184 | The dataset is the most recent available. | I. Methodology (ISO) | 1. Discrepancy | 2009 for an internal business metric is too old and not temporally relevant to the study. | | Not taken into account | 1287, 1333 | no newer LPB data is officially available, ifeu has access to confidential 2011/2012 data, that shows that no significant change to 2009 has occurred. Converting date update out of the scope of this study, as effort is surprisingly high. As converting of BCs does not show very high impact on overall results, old dataset is considered sufficient. | | | tetra pak is buying from nordic mills, no newer data from them | 1301 |
| LH | 55 | November 2017 | 1174 | 1174/5 | Sulphate | D. Data and calculations | 2. Comment | Is the sulphate process likely to be different (in terms of environmental impacts) than the chloride process? | Discuss - alter and add to text if necessary | Taken into account | 1319 | Ecoinvent 3.4 dataset used for sulphate and chloride process | ok | | | |
| LH | 56 | November 2017 | 1182 | 1182 | Carbon Black data | D. Data and calculations | 2. Comment | There is carbon black data in Ecoinvent 3.4 - could be newer and more relevant | Check Eco invent data | Taken into account | 1324 | Ecoinvent 3.4 dataset used | ok | | | |
| LH | 57 | November 2017 | 1186 | 1186 | Board data | D. Data and calculations | 2. Comment | Data for beverage cartons in EcoInvent 3.4 - timescale listed as 2009-2017 could be more relevant | Check Eco invent data | Not taken into account | 1287 | no EU average LPB data in ecoinvent, global dataset in ecoinvent is based on same data as the used dataset, but with added inappropriate global prechains | ok | | | |
| LH | 58 | November 2017 | 1197 | 1197 | preform production | R. Report writing | 3. Editorial | include reference to process used in preform manufacture - injection moulding. | Include in test | Not taken into account | 1349 | It is referred to Tetra Pak Data | ok | | | |
| LH | 59 | November 2017 | 1206 | 1206 | HDPE conversion data | D. Data and calculations | 2. Comment | Is there a more independent source of data rather than Tetra Pak? | Use non-Tetra Pak data if available and relevant | Taken into account | 1350, 1357 | further explanation added | ok | | | |
| LH | 60 | November 2017 | 1214 | 1214 | Electricity | D. Data and calculations | 2. Comment | Clarify that grid electricity figure were used for each relevant country / region of manufacture. | Clarify text | Taken into account | 1365 | further explanation added | ok | | | |
| LH | 61 | November 2017 | 1224 | 1224 | electricity use for filling | D. Data and calculations | 2. Comment | Is this data linked to grid electricity? | Confirm | Taken into account | 1378 | confirmed and further explanation added | ok | | | |
| LH | 62 | November 2017 | 1232 | 1232 | logistic sector | D. Data and calculations | 2. Comment | How many were consulted? Was the sample big enough to give 'representative' data? | Confirm number of consultations and add into text. | Not taken into account | 1383 | no specific survey for this study, information collected from logistics and suppliers in other, similar, confidential studies | ok | | | |
| LH | 63 | November 2017 | 1233 | Table 29 | Distances | D. Data and calculations | 2. Comment | Distances for converter carton rolls are high - where are these made - Scandinavia? Might help to include a location for each of the elements in this table if possible | Discuss and add into table if possible. | Taken into account | 1384 | carton rolls produced at Tetra Pak converting plants in Germany, Hungary and Spain. Average distances per examined market calculated. Info added to table 29 | ok | | | |
| WS | 27 | November 2017 | 1236 | 1236 | products are temporary stored | R. Report writing | 3. Editorial | typo | | Taken into account | 1387 | corrected | | | | |
| LH | 64 | November 2017 | 1245 | 1245 | 33% empty return trip | D. Data and calculations | 2. Comment | Can this figure be justified? Reference? | Add in reference if possible. | Taken into account | 1397 / 1504 | based on expert judgment (Benedikt Kauertz from ifeu) | ok - but would be better if the figure could be justified in some way. | | | |
| LH | 65 | November 2017 | 1258 | 1258 | assumption | D. Data and calculations | 2. Comment | ...aluminium compounds are assumed' to undergo.....' Can this assumption be justified? | Add in reference or justification. | Taken into account | 1410 / 1518 | as remembered from the call:<br>accepted as it is, Best knowledge of Tetra Pak | ok - but would be better if the figure could be justified in some way. | | | |
| LH | 66 | November 2017 | 1270 | 1270 | Recycling of bottles | D. Data and calculations | 2. Comment | Is the view of bottle recycling available form another source than Tetra Pak - this adds to the independence of the study | Looks for other source of information about this recycling and use it in report if possible in place of Tetra Pak reference. | Taken into account | 1425 | no other sources found | ok | | | |
| WS | 28 | November 2017 | 1278 | 1278 | To the author's knowledge, the white opaque plastic bottles used | I. Methodology (ISO) | 2. Comment | Evidence should be used for the assumption that white plastic is wholly not recycled. | | Taken into account | 1436 | more clarification and reference added | | | | |
| LH | 67 | November 2017 | 1299 | 1299 - 1302 | Additional fuel consumption for cooled transport | D. Data and calculations | 2. Comment | Is this data not include din the INFRAS dataset? | Discuss | Not taken into account | 1459 | Cooling will be added in 2018 to the ecotranist tool. Not yet available | ok | | | |
| SOL | 20 | November 2017 | 1316 | 1330 | Electricity Generation | D. Data and calculations | 2. Comment | What about electricity consumption on the market, taking into account import/export. E.g. The mix for consumption has been provided in the scope of PEF for each European country | The electricity consumed should be considered as input (not produced). | Not taken into account | 1474 | the national electricity production mixes are used as also the national emission reporting is on a territorial base. Also Import/export shares are changing fast and often. | ok, this is a technical argument which is acceptable | | | |
| LH | 68 | November 2017 | 1330 | Table 31 | Age of data | D. Data and calculations | 2. Comment | Energy mixes could have changed since 2012 and in some cases will have affected the overall impacts quite considerably. | Check data and see if an updated version can be used. | Taken into account | 1487 | updated to 2015 Data | ok | | | |
| LH | 69 | November 2017 | 1363 | 1363 | Age of data | D. Data and calculations | 2. Comment | Reference data is over 20 years old. More up to date reference of data is needed. | Source newer data / reference for use in report. | Taken into account | 1520 | degradation rate in landfills recently examined in yet unpublished work for ACE resulting in unchanged degradation rate. Basically Micales & Skog still relevant. | ok | | | |
| SOL | 21 | March 2018 | 1596 | | Bio-based plastic | D. Data and calculations | 2. Comment | The use of Bio-based plastics looks like being a carbon sink (TBA Edge bb 1000 mL when compared with TBA Edge 1000 mL - CO2 uptakes looks like being higher that CO2 reg. + recycling & disposal) | A general elaboration on that point would be welcomed, including proofs - does that mean that the Bio-based plastic shall not degrade in landfill? Forever? Which proof? ISO 14067 (current work version) considers that all emissions occurring at the end of life (whatever be the time horizon) should be accounted for in the calculation | Not taken into account | - | Where in ISO 14067 is a reference to bio-based material? Do you understand that this way, that final emissions of all materials, including fossil ones, should be accounted for? Is there a similar reference in 14040/44? | Comment | See SOL28 | See SOL28 | See SOL28 |
| SOL | 22 | March 2018 | 2836 | | Use of Nature | S. Methodology (science) | 2. Comment | How have you accessed to the level (2 to 7) of nature used for the LCI you have used | Please add after 2847 how information have been set for existing LCI "where this information was not available". Which assumptions? | Taken into account | 903 | relevant line mentioned in call | ok | | | |
| SOL | 23 | March 2018 | 874 | | Water Used | S. Methodology (science) | 2. Comment | Water use is interesting as such (see ISO 14046), and the chapter starting L874 is clear about what is not possible to get. Nevertheless, having an information on what is "consumed" (the net between input and output) is a start towards "water footprint" which is most often possible (not requesting to make the difference) and an improvement | Provide the information about water release to rivers (with or without details) | Not taken into account | | water outputs often not included in datasets | | See SOL38 | See SOL38 | See SOL38 |
| LH | 70 | March 2018 | All figures | | Water Use | A. Analysis and interpretation | 2. Comment | Cooling water - shown as 'water use'. Does this take into account that it is recycled round the system? It the 'use' actually at this level of is the figures shown how much cooling water is needed - but not necessarily 'used'? | Clarify | Taken into account | 1005 | we will clarify the meaning of "used", not consumption. But keep term used as in ISO it is clarified, corrected | ok | | | |
| LH | 71 | March 2018 | Appendix A - Impact Categories | | Impacts categories are listed and explained | A. Analysis and interpretation | 1. Discrepancy | All impacts shown in graphs are explained except water use. | Include explanation of water use in the Appendix. | Taken into account | 7985 | we should refer to section 1.8, corrected | Can't see anything at line 7958. Mention of water scarcity in section 1.8 | | water use is included in "inventory category" water use is now mentioned as an example | 8081 |
| LH | 72 | March 2018 | Results on Waster Use | All sections | Water use figures shown in graphs | D. Data and calculations | 2. Comment | Cooling water requirement for larger capacity packs is much higher than smaller ones per 1000L. Also cooling water used for similar packs in different markets appears to differ. | Can this be checked? | Taken into account | All result graphs | BE, NL, IE, UK cooling water of small packages is always higher than of large packages | ok | | | |

| Initials | Index | Version of the report | First Line number in the report | Other line numbers in the report | Detail | Nature of the comment | Level of importance of the comment | Reviewer Comments and Questions (detailed) | Reviewer Recommendation | Nature of the answer from the practitioner | Line in the new report where the modification is done | Answer from the practitioner (according to each draft) | Check by the review | Ref to new Index when needed | Further answer from the practitioner | Line in the new report where the modification is done |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOL | 24 | March 2018 | 1072 | Table 22 | Recycling rates in Belgium | D. Data and calculations | 2. Comment | The "recycling quota" for Belgium for beverage carton looks very high: is it a technical recycling rate ? or an "agreement" recycling rate ? The technical one is adapted for LCA. | Please add the formula for the calculation of the percentage from the source, indicating what is as numerator and what is as denominator. In fact this is a general comment that can be dealt in a general manner (with a check in each source maybe). | Taken into account | 1172 | we can add remark to separate collection in text, corrected | ok | 100% for glass packaging, what a discipline! It is hardly plausible. A close look at FOST 2017 would be needed (our of the scope of the current CR). Due to the goal of the project, let's state that this is a conservative choice. | | |
| SOL | 25 | March 2018 | 1596 | all other GhG graphics | Climate Chance | R. Report writing | 3. Editorial | A chance for climate? Maybe... | Modify the title of the graphics (Climate Change) | Taken into account | all Climate Change graphs | corrected | ok | | | |
| LH | 73 | March 2018 | All figures on Climate Change | | Title - spelling mistake | R. Report writing | 3. Editorial | Title says 'Climate Chance' | Change to 'Climate Change' | Taken into account | all Climate Change graphs | corrected | ok | | | |
| LH | 74 | March 2018 | 1546 | All subsequent sections | CO2 or CO2e? | A. Analysis and interpretation | 3. Editorial | Is this just CO2 or should it be CO2e? | Check and change if necessary | Taken into account | | it is CO2 | ok | | | |
| LH | 75 | March 2018 | 1561 | All subsequent sections | CO2 or CO2e? | A. Analysis and interpretation | 3. Editorial | Is this just CO2 or should it be CO2e? | Check and change if necessary | Taken into account | | it is CO2 | ok | | | |
| LH | 76 | March 2018 | 1580 | All subsequent sections | This can be considered....' | S. Methodology (science) | 3. Editorial | If it IS common practice then say 'This is common practice' - adds more weight to the approach. | Check and change if necessary | Taken into account | 1686 and similar | corrected | ok | | | |
| LH | 77 | March 2018 | All figures | | Legend text | A. Analysis and interpretation | 3. Editorial | CO2 Reg (recycling & disposal) - is it CO2 or CO2e? | Check and change if necessary | Taken into account | | it is CO2 | ok | | | |
| LH | 78 | March 2018 | All tables | | Credits' | R. Report writing | 3. Editorial | Credits is for materials and energy? | Perhaps change the title of the rows to 'Credits (materials & energy)' so it is clear? | Taken into account | all result tables | footnote added to each table | ok | | | |
| LH | 79 | March 2018 | 1552 | All subsequent sections | It is assumed that those secondary materials are used by a subsequent system' | S. Methodology (science) | 2. Comment | Is this a valid assumption - can it be backed up with evidence or reference. Perhaps chance wording to use a different word to 'assumption'. | Consider wording or add reference / justification | Taken into account | 1658 | corrected, we drop assumption | ok | | | |
| WS | 8 | March 2018 | 169 | | Inconsistent product type label | R. Report writing | 2. Comment | Grab & Go named with approximate content volume whereas the other is just 1,000ml. 'grab & go' is a meaningless name. | Either brand both types of product groups, or neither. | Taken into account | 280 | segments are named by volume ranges | ok | | | |
| WS | 10 | March 2018 | 223 | Throughout | "It is being conducted..." | R. Report writing | 3. Editorial | Tense is inconsistent; all should be past tense rather than future | | Taken into account | 322 and other future tenses | future tense removed | ok | | | |
| WS | 10 | March 2018 | 242 | | 3keel | R. Report writing | 3. Editorial | Change to "3Keel" | | Taken into account | 342 | corrected | ok | | | |
| WS | 12 | March 2018 | 318 | | "aviable for losses at the point of sail" | R. Report writing | 3. Editorial | Typos | | Taken into account | 417 | corrected | ok | | | |
| WS | 13 | March 2018 | 337 | All subsequent sections | PET does not show recycled content % | R. Report writing | 3. Editorial | Glass charts below show recycled content proportion; PET is using recycled content as noted elsewhere in the report, but it is not shown here. | | Taken into account | 437, 439 | recycled content added to PET and HDPE chart | ok | | | |
| WS | 13 | March 2018 | 337 | All subsequent sections | | R. Report writing | 3. Editorial | Plastic flow chart does not show stretch blow moulding phase | Either adjust 'converting to preforms' to include moulding, or add additional step | Taken into account | 437 | additional step added | ok | | | |
| WS | 15 | March 2018 | 345 | | Flow line missing to landfill | R. Report writing | 3. Editorial | add line | | Taken into account | 445 | corrected | ok | | | |
| WS | 27 | March 2018 | 640 | | Reference not found | R. Report writing | 3. Editorial | | | Taken into account | 738 | corrected | ok | | | |
| WS | 37 | March 2018 | 969 | | Table 15: They are provided by... | R. Report writing | 3. Editorial | Confusing sentence. | Table description should not use this language. | Taken into account | 1060 | corrected | ok | | | |
| WS | 37 | March 2018 | 976 | | Are the bottles market specific? Or generic assumption? | S. Methodology (science) | 3. Editorial | Not clear if the two sample product are for each market, or if they are being assumed to be the same in other markets if a similar product is present. | | Taken into account | 1067 | one or two for each country | ok | | | |
| WS | 49 | March 2018 | 1052 | | HDPE recycled content | S. Methodology (science) | 3. Editorial | Is recycled content assumed for HDPE? | If so, please make explicit. If not, please explain why. | Taken into account | 1226 | sensitivity analysis for UK fresh milk bottle with 30% and 50% rHDPE added | ok | | | |
| WS | 76 | March 2018 | 1489 | | Table 31 | R. Report writing | 3. Editorial | | Add source to reference year | Taken into account | 1594 | corrected | ok | | | |
| LH | 85 | June 2018 | Gen | | SA | A. Analysis and interpretation | 2. Comment | Sensitivity analysis seems to be appropriate with no obvious errors or issues | No reco. | | | - | ok | | | |
| SOL | 44 | June 2018 | Gen | | Countries | D. Data and calculations | 2. Comment | No differences in order of magnitude were detected in the comparison of the impact of several products. This shows a kind of robustness of the model. | No reco. | | | - | ok | | | |
| LH | 83 | June 2018 | Gen | | Countries | A. Analysis and interpretation | 2. Comment | It is difficult to compare overall result across different countries due to the specific comparison in each country being different. I.e. different sizes and weights of Tetra Pak packages used in each country and also the differences in the alternatives being used for comparison. However I could not find any obvious discrepancies in how the comparisons were done across different countries. | No reco. | Goal has been precised | | - | ok | | | |
| LH | 86 | June 2018 | Gen | | Countries | A. Analysis and interpretation | 2. Comment | Detailed interpretations, country by country appear to be consistent in approach | No reco. | | | - | ok | | | |
| SOL | 41 | June 2018 | 274 | | Reusable packaging | D. Data and calculations | 2. Comment | This comment follows SOL33.<br>Reusable packaging have not been studied. Having reusable packaging is sometimes seen as one of the key action in the scope of the circular economy policies at European and national level (some countries plan to ban one-way plastic products).<br><br>The study could have shown the positioning and provided some interesting remarks on why recycling is better than reuse in some cases...<br><br>Whatsoever, L301 states that the goal is "to compare the environmental performance of these cartons with those of competing packaging systems with high market relevance on the related markets".<br>Since reusable packaging are not studied, it means that they are not of "high market relevance on the related markets". | Having somewhere one paragraph / figure with the demonstration (or at least arguments) which support the fact that reusable packaging are not of "high market relevance" or less relevant that the studied packaging would bring a plus to the study. e.g. market shares ?<br><br>Mention in the list of packaging "one-way" when significant reusable packaging exist - of course only when (if!) this kind of packaging are relevant for the markets and the studied products..<br><br>In the limitations, mentions that re-usable packaging exist and have not been included in the scope of the study - of course only when the relevance of this kind of packaging is not negligible for the markets and the studied products. | limitation of refillabe packs added | 1070 | | ok | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SOL | 29 | June 2018 | 415 | | Missing table | R. Report writing | 2. Comment | Missing table is mentioned (this is the final draft) | Table to be added (we'll see if there are comments on it) | in final draft line 511, missing table was mentioned in first result report line 415 | 520 | | ok | | | |
| SOL | 38 | June 2018 | 874 | 993 & 994 | Water use | S. Methodology (science) | 2. Comment | Water output from technosphere is available in Ecoinvent 3.4 data sheets. Water output from technosphere has been implemented in most recent databases… in line with the work mentionned in the report in lines 989, in order to apply AWARE.<br><br>It is then stated in L993&994 "However, most of the inventories applied in this study still do not include the water released from the technosphere". This is a source of regret for the interpretation of the study, since cardboard is always attacked for its need of water at the production stage. The current study will not enable to provide quantitative information to answer this attack. | According to the remark, the interpretation regarding "water use" should be done with care since, **if all the water used is released in the same place after use**, water use is indeed first a technical issue (will there be enough flow of water to let my process function?) and not an environmental issue. | discussed and accepted in call | 1005 | | Noted | | | |
| SOL | 40 | June 2018 | 1019 | | Lower heating value | D. Data and calculations | 2. Comment | The choice of LHV (not Higher Heating Value HHV) as measurement method for Primary Energy is appropriate and has to be done consistently for all energy fuels. | Adding the fact that the LHV is used for all fuels to calculate all primary energy indicators would add some value to the paragraph (it is not just an example for wood – the only fuel for which an extrapolation has to be done is nuclear) | information added | 1028 | | ok | | | |
| WS | 83 | June 2018 | 1171 | | UK and IE recycling statistics confidential | S. Methodology (science) | 2. Comment | These statistics are confidential to Tetra Pak, however ACE data is used for other markets. Why wouldn't ACE data be used for these two markets as well? | | IRL and NL: applied recycling rates correspond to ACE reference year 2016 rates<br><br>UK: applied recycling rate is lower than the ACE reference year 2016 rate. Tetra Pak/ACE UK has adjusted the rate downwards after submitting to ACE Europe due to a change in calculation method (Lower recycling rate = conservative approach in the view of beverage cartons)<br><br>BEL: applied recycling rate is lower than the ACE reference year 2016 rate. After discussion with TP the high ACE 2016 rate of 97.5% seems very high (due to the inclusion of pilot procets for seperate collection of beverage cartons[Fost 2017]. That's why a lower more conservative rate of 90% is applied which takes the lower recycling rates of 2014 and 2015 into account. The applied rate of 90% fits also to new 2017 data published by the Belgian recycling firm FOST. | 1203/1212 | | | | | |
| WS | 84 | June 2018 | 1171 | | WRAP | S. Methodology (science) | 2. Comment | Use of WRAP (2011) data on stand up pouch recycling statistics | Please describe why this is still believed to be representative and current? | adde: The most up-to-date data at the time of modelling and calculation is used. | 1199 | | | | | |
| LH | 89 | June 2018 | 1247 | | Barrier | D. Data and calculations | 2. Comment | Alternative barrier materials – the sensitivity analysis on all countries looks at the effects of changing from Aluminium to PE for barrier materials. First mentioned in line 1247, then section 5.1.5 and subsequent sections for each country. Is the functional performance of PE as good as Aluminium? Is it a fair comparison? | Elaborate somewhere in the report? | proxy because of confidentially<br>added in report that the funcionalty is not the same, just a proxy | 1288 | | | | | |
| WS | 85 | June 2018 | 1317 | | Braskem data not being used | 5. Methodology (science) | 2. Comment | What efforts were made to get updated data from Braskem? The exclusion of their own study is well justified, but that study is old and they have a current supply arrangement. | | new bio PE Braskem data is used | 1340 | | | | | |
| LH | 88 | June 2018 | Gen | | Datasets | D. Data and calculations | 2. Comment | Still some concerns over the age of some of the datasets and their relevance to materials and markets today. | Update? | we use latest available, accepted in call | | | | | | |
| SOL | 27 | June 2018 | 1398 | | Co-products | S. Methodology (science) | 2. Comment | A question might occur regarding the choices which have been done for the selected glass production data sheets.<br><br>Chapter 1.7. regarding multi-output processes states that "If different [than mass] 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".<br><br>According to the answer regarding FEVE data, these BVGlass data are of special importance (allocation has not been done by mass). | Can you please provide a reference to the lines where the explanations regarding the way the surplus energy production of glass production (i.e. co-product) has been dealt by the glass production data source BVGlass (I have not found it in the report) or just add close to line 1398 an explanation?<br><br>Additionally, it is mentioned L 1605 to 1608 that MSWI produce electricity and heat (in addition to their main function which is to treat waste). '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".<br><br>On the other hand, you state, as answer for not taking FEVE data, "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. This **substitution** follows a consequential LCA approach, whereas this LCA is conducted as an attributional LCA.".<br><br>Can you provide an explanation of why what is done for MSWI energy production cannot be done for FEVE glass manufacturers energy production? Similarly, "credits energy" appear in the report in the introduction page of each interpretation chapter for a given market… | surpluse heat is aggregated in the dataset. Can not be shown seperatly in our credits or cannot been taken out<br><br>lower cullet rate because it is container glass for everthy , bfglass only for food | 1408 | | ok for adding the explanation on line 1408. L1556 would have benefited from a clarification of the fact that you use IFEU data and not FEVE data | | | |
| WS | 86 | June 2018 | 1407 | | Datasets | 5. Methodology (science) | 2. Comment | ifeu database reference checked against ecoinvent 3.1 | Validate whether any LPB process steps/impacts have been updated in ecoinvent 3.4. | it is the same as in 3.4, changed to 3.4 in the report | 1418 | | | | | |
| WS | 87 | June 2018 | 1441 | 1442 | PET and preform data update took place, why not for converting? | 5. Methodology (science) | 2. Comment | If ifeu did an assessment on some new datapoints provided for one old study, why not do the same for converting? It feels fairly inexcusable that primary data for the commissioning company is 9 years out of date. | | not as old as mentioned, data is 2013, text not updated --> changed to 2013 in report<br><br>no newer excisting data collection high effort for TP, only done for a full ACE update | 1452 | | | | | |

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| WS | 88 | June 2018 | 1580 | | Treatment of renewable energy market instruments not discussed | 5. Methodology (science) | 2. Comment | | Provide clarity on whether any company purchases or use of renewables outside of IEA statistical data is used. I don't think it has, but clarification is needed. | Clarification added : All processes using external electricity use of the IEA country specific mix.<br><br>Renewable energy is used on site (see section 3.5 Production of LPB) | 1593 | | | | | |
| SOL | 28 | June 2018 | 1702 | 7729 to 7731 8037 | Uptake of CO2 and bio-based products (incl. Cardboard and bio-based PE) | 5. Methodology (science) | 2. Comment | The choice mentioned in L 8037 is appropriate.<br>ISO/NP FDIS 14067 mentions (the vote on it has been positive with this content)<br><br>- in 6.4.8 "All GHG emissions and removals shall be calculated as if released or removed at the beginning of the assessment period without taking into account an effect of delayed GHG emissions and removals"<br>- and in 6.4.9.3 "When biogenic carbon is stored in a product for a specified time, this carbon shall be treated in accordance with the provisions in 6.4.8".<br><br>Then, it might be a surprise (and at least something to explain somewhere around L8037) when the net balance of GHG along a studied LC is negative (as mentioned in L1809 and L1810 – it is due to the so-called "50% allocation", but it is not clear, according to figure 8 L703 that this 50% allocation is an issue regarding carbon uptake - since 50% allocation seems having no side effect on mass balances).<br><br>As a note :<br>- As stated in ISO 14067 "This [ISO 14067] document is an aspect-specific environmental management standard and is the generic standard for the quantification of the carbon footprint of products".<br>- As stated in ISO/IEC Directive Part 1 from 2018, "ISO technical committee, subcommittee, project committee or International Workshop developing sector-, aspect- or element-specific environmental management standards shall […] not interpret, change, or subtract from the requirements of the generic ISO 14000 series environmental management systems, environmental auditing, environmental labelling, life-cycle assessment and greenhouse gas management standards.".<br>- Since ISO 14044 states nothing specific (and then nothing contradictory) regarding these issues, then this chapter of ISO 14067 applies in LCA regarding calculation of Carbon footprint. Remark: the fact that footprints are calculated according to ISO 14044 requirements is mentioned in Amendment A1 to ISO 14044. | So far, it would be good that the current report position itself as compared to the choice of the approved new ISO 14067.<br><br>In addition, it would be good to remind to which product is allocated the GHG which do not appear in studied the LC (i.e. the other 50%)?<br><br>Making a sensitivity analysis taking into account the future ISO 14067 requirements in order to see if the results of the comparisons change would be highly welcomed. | We agree that a comparison with ISO 14067 and a respective sensitivity analysis would be interesting, but seems not absolutely necessary. Especially with the regard of limited time and money budget of this study. | | | Noted | | | |
| SOL | 39 | June 2018 | 1718 | and following... | Qualitative assertions | R. Report writing | 1. Discrepancy | "significant" (i.e. more than the uncertainty range, see also PO 32) is one of the very important information that we need, as clearly stated in L1850 to 1852. This "significant" terminology is used in phrases and tables, which is good.<br><br>It can either be used for an absolute value, or for a difference.<br><br>On the other hand, a range of synonyms are used in both contexts: "to a lesser extent" (is it -2% -10% -30%?) "to a small amount" "small burden" "The production of 'plastics for sleeve' of the beverage cartons shows considerable burdens in most impact categories. These are considerably lower than those of LPB production"… The first "considerable" is absolute… does it means a kind of normalisation? The second one is "relative"? What is the range? -100% -300%. "big influence" "minor role" "important role"…<br><br>"shows high impacts in most categories" (more than 10%, 20%, 50 % ?)<br>"show impacts in all categories" (different from zero? between 5% and 15% ? sometimes high, sometimes small ?)<br>"shows only small burdens in most impact categories" (under 0,01%, 2%, 10% ?)<br><br>Qualitative assertions may be understood in very different manners by experts readers. e.g. I have already reviewed a report where the writer said that, when writing "huge difference", he had in mind more than 5%!<br><br>An issue : qualitative wordings cannot be challenged during critical review... in a way that we are not going to discuss if 15% is a "minor", "small" or a "medium" burden... or 20% is a "considerable" value or not.<br><br>For example, when a difference for a given impact is so-called "small", does it always mean "non significant" or that the compared products are "equivalent"? What about "very small" as compared to small? | When a qualitative wording is used, wherever in the report, it should indicate approx. the same quantitative range. And a "correspondence table" or "redacted text" should be added somewhere to qualify.<br><br>If the correspondences are variable from one packaging to another one, or from one indicator to another one, then all qualitative assertions should be accompanied by the percentage they qualify to let readers understand.<br><br>In fact, as much as possible provide a percentage (even rounded) in the text instead of a qualitative assertion, and provide an information regarding the fact that the difference is significant or not.<br><br>Note: the supply of the tables with most percentages is a good help to partly understand the text. | percentages added | 1738 and following | | ok | | | |
| LH | 87 | June 2018 | 2270 | 2271 | | R. Report writing | 3. Editorial | Some strange comments in the interpretation such as section 4.4.2 line no 2270-71. This says that aluminium foil has no Impact because aluminium foil isn't used. Seems to be a redundant statement. | Change redaction | changed "no burdens" to "no results" | 2298 | | | | | |
| WS | 91 | June 2018 | 3032 | | Conclusions | R. Report writing | 1. Discrepancy | Paragraph correctly notes that PET bottle has better performance, however this is not discussed clearly in overall conclusions. Findings like this are being buried in the substantial report and may be overlooked by those that are skimming top level results. | | we start at the conclusions tat the overall conclusioans can not be used for specific products.<br>Refer to the market summaries.<br><br>Exceptions for general advantege of cartons are added | 7799, 7818 | | | | | |
| WS | 92 | June 2018 | 7718 | 7720 | Conclusions | R. Report writing | 2. Comment | Very broad claim that should be caveated | Add a comparitive graph or something to justify the caveats to this broad brush statement, or provide an explicit list of exceptions. | paragraph added at the begiining of the overall conclusion section, that for conclusions of specifc pakaging sytsems, the market specific conclusions shoudl be consulted | 7799 | | | | | |
| WS | 94 | June 2018 | 7728 | 7729 | | R. Report writing | 1. Discrepancy | LPB utilises mainly renewable energy. Renewable energy use and approaches are not discussed (see line WS 88) | | renewable energy for LPB production is on site; accepted in call | | | | | | |
| WS | 95 | June 2018 | 7742 | 7745 | Exception to broad claim in WS94 | R. Report writing | 2. Comment | See WS 93 and WS 94 | This should, at the minimum, be moved to be placed right below the overarching comments. | moved up | 7823 | | | | | |

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| SOL | 36 | June 2018 | 7981 | | Uncertainties | S. Methodology (science) | 2. Comment | No uncertainty range is provided in the description of the IA methods | As mentioned in SOL 32, some phrases including an estimate of the uncertainty of each IA method would be welcomed (and taken into account in the redaction of the | discussed and accepted in call | | | ok | | | |
| SOL | 37 | June 2018 | 8079 | | Sources of CF | S. Methodology (science) | 2. Comment | The DG JRC ILCD handbook "Recommendation for LCIA in the European context does not list the Eutrophication method you have used. Additionally, the last PEF recommendations are also different. | Can you position the Eutrophication method that you source (Heijungs et al 1992) as compared to the methods which are listed in the DG JRC ILCD handbook "Recommendation for LCIA in the European context"? and/or justify why you have not taken into account one of the recommended (and available) method and CF. This comment may also apply to the other IA methods. | We added to reasoning of choice of methods in chapter 1.8.1: "Further, the choice of characterisation methods follows earlier studies for Tetra Pak in order to keep a consistency and allow comparisons" | 730 | | Reason is clear and acceptable. Nevertheless, some practicies improve, and at a given point, when an impact assessment method has been improved, it is good to change for the current state of the art - if a comparison is expected with former studies, then recalculation of former LCIA applying new method is a valid approach (used in financial accountancy). Additionaly, no assessment of differences with previous studies results is done | | | |
| WS | 93 | June 2018 | Gen | | Structure of report | R. Report writing | 1. Discrepancy | No format specific conclusions across markets | As a cross-product and market study there should be clear consolidated results | Comaprisons between the marktes are not the goal of the study, study is indeed four studies in one pack,<br><br>clarification added | 271 | | noted. Goal has not been modified | | | |
| SOL | 42 | June 2018 | Gen | | Structure of report | R. Report writing | 2. Comment | Interpretations are "similar" in many chapters. | In order to improve the reader's understanding of the report, it would be wise to highlight the differences in the analysis / interpretations between the products, even if you keep all that is common in each chapter. | it is on purpose, so each market can be looked at seperatly<br>Also it is easier find differences, when the chapters are built up similarily; discussed and accepted in call | | | ok | | | |
| SOL | 43 | June 2018 | Gen | | Structure of report | R. Report writing | 2. Comment | The analyses (of contribution) and interpretation (comparative, to answer to the goal) are gathered in a single chapter, and even sometimes presented within the same paragraph, with the same wording. | It would be more relevant to separate the contribution analysis and the comparison in different chapters. | comparisons are seperatly (as tables); discussed and accepted in call | | | ok | | | |
| LH | 84 | June 2018 | Gen | | Structure of report | R. Report writing | 2. Comment | All the packaging specifications are listed in section 2.2, early on in the report. When reading the results sections there is no detail that refers back to this. | It would help to just have a reference back to this section so readers know where to go remind themselves of what the packaging is and helps to contextualise the results. | we added references in the sub headings of each "Description and interpretation" section to the specification section. Specification section subdivided into "beverage cartons systems" and "alternative packaging systems" | 1733 and foloowing headings | | | | | |
| LH | 80 | June 2018 | Gen | | Grab & Go | S. Methodology (science) | 2. Comment | What is the rationale for removing the Grab & Go categories and also adding size ranges across the different beverage categories | ? | was the request of the review panel | | | ok | | | |
| LH | 82 | June 2018 | Gen | | Terminology | A. Analysis and interpretation | 2. Comment | Discussion and Interpretation sections for each of the beverage categories in each of the countries appear to give a good account of what is included and the possible reasons for the differences in impacts. Some good discussion included. However mny of the terms used are open to interpretation and would mean different things to different readers. | It would improve the overall value of these sections if there was some sort of quantification used to help describe the differences. | percanteges added | 1738 and following | | ok | | | |
| WS | 89 | June 2018 | Results | | All sections fairly difficult to understand | R. Report writing | 1. Discrepancy | It is very difficult to compare data and results in the way this section has been written, particularly when aligning with conclusions and recommendations. This way is basically treating the study as multiple LCAs that all are just packaged in a single file, rather than one LCA assessment with multiple boundaries. Fairly simple things like which market has a better profile for the same product are almost impossible to infer from this without doing a supplementary analysis. This also holds true for understanding the impacts of the sensitivity analysis across the board in each market. | | more clarified in the goal of the study chapter | 271 | | | | | |
| WS | 90 | June 2018 | Results | | Net results table colour coding is confusing and the layout is poor | R. Report writing | 1. Discrepancy | The percentages on their own make this a difficult table for non-technical specialists to understand and could lead to incorrect claims. | Include all comparative raw data in these tables without colour coding, then have colour coding for percent change. | absolut values for base packaging system added to tables | 1872 and following tables | | | | | |
| LH | 81 | June 2018 | Gen | | Conclusions | A. Analysis and interpretation | 2. Comment | Overall final conclusions and recommendations look to be a fair discussion of the findings. | However due to the overall size and detail of the calculations and interpretation undertaken perhaps a little more detail and discussion in the conclusions would have been appropriate. For many reader this will be the most important section as it is unlikely they will read through the whole report | Overall conclusions expanded a little. For further detailed concluions reference to conclusions chapters of each market | 7799 | | | | | |
| WS | 77 | June 2018 | 348 | 351 | | R. Report writing | 3. Editorial | | Sentences should be clear that these comments relate to Ambient only. A separate paragraph would also help with | paragraph added | 357 | | | | | |
| WS | 78 | June 2018 | 365 | | Typo | R. Report writing | 3. editorial | "all transports" | | corrected | 371 | | ok | | | |
| WS | 79 | June 2018 | 417 | | Typo | R. Report writing | 3. editorial | "point of sail" | | corrected | 423 | | ok | | | |
| WS | 80 | June 2018 | 418 | | Typo | R. Report writing | 3. editorial | extra full stop | Remove | corrected | | | ok | | | |
| WS | 81 | June 2018 | 486 | 492 | | R. Report writing | 3. Editorial | Indication is that most data here is for 2017 from Tetra Pak, when it is only the specifications and supply chains | Explicit reference to low quality of Tetra Pak factory data should be present | clarification added | 498 | | | | | |
| WS | 82 | June 2018 | 1069 | | Typo | R. Report writing | 3. Editorial | Extra full stop | Remove | corrected | | | ok | | | |
| SOL | 26 | June 2018 | 1208 | | Wording | R. Report writing | 3. Editorial | "Subjective choices" is an appropriate term, but "according to the ISO Standards" , "value choices" is the correct terminology. The word "subjective" is not used in ISO 14044. | Modify the wording (of course, an explanation can be provided regarding the terms "value choices"). To be done throughout the report (or explain as introduction that you use an alternate wording as compared to ISO). | changed to value choices throughout the report | 1247 | | ok | | | |
| SOL | 33 | June 2018 | 7734 | | Regarded | R. Report writing | 3. Editorial | Some journalists will extract the following phrase "**From an environmental viewpoint beverage cartons with fossil based plastics can be recommended as the packaging of choice for most segments on all markets regarded**".<br>As stated in the limitations chapters, just the studied formats and markets can be the basis for conclusions… which is the idea of the phrase, but I feel that the wording can lead to misinterpretation: "most segments" is only valid for the studied segments. "all markets regarded" is a strange wording(?). | "From an environmental viewpoint, beverage cartons with fossil based plastics can be recommended as the packaging of choice for most of the studied segments within the 4 studied markets" | corrected as proposed | 7814 | | ok | | | |
| SOL | 34 | June 2018 | 7743 | | | R. Report writing | 3. Editorial | "Very close" | Referring here (as done in the body of the report) to the 10% difference (or more, see SOL 32 in the ISO sheet) to reach a significant difference might be welcomed | wording changed | 7824 | | ok,<br>typo remain: "systmens" | | | |

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| SOL | 35 | June 2018 | 7757 | 7758 | Higher | R. Report writing | 3. Editorial | "Higher", ok. But does it modify the results of the comparisons? | If yes, this additional information is important to mention here "incl. Reaching an inversion of the comparison results" or something like this... | removed, as it is only an indication and not calculated as a sensitivity | 7861 | | ok | | | |
| ifeu | | | | | changes in packaging specification | | | | | TR 1000 mL, TR bb 1000mL (UK, IRL):<br>secondary packaging is now LDPE shrink pack instead of cardboard<br><br>TB 200 B (UK):<br>secondary packaging is now LDPE shrink pack instead of cardboard<br>volume is 189mL instead of 200mL<br><br>TT 500 mL ambient WATER and TT bb 500 mL WATER (UK)<br>secondary packaging is now cardboard inseatd of LDPE shrink pack | | | noted | | | |
| ifeu | | | | | correction of comparison percentages in the impact category 'Photo-Oxidant Formation' | | | | | in the Final draft the comparison percentages in the impact category 'Photo-Oxidant Formation' were based on the wrong method.<br>This is now corrected. | | | noted | | | |

| Requirements | Initials | Index | Line number (if relevant) | Nature of the comment | Reviewer Comment (detailed) | Reviewer Recommendation | Detailed answer | Check by the reviewer |
|---|---|---|---|---|---|---|---|---|
| a) **General aspects** | | | | | | | | |
| 1) LCA commissioner, practitioner of LCA (internal or external) | | | | | OK | | | |
| 2) date of report | | | | | OK | | | |
| 3) statement that the study has been conducted according to the requirements of this [ISO 14044] International Standard | | | | | OK | | | |
| | | | | | | | | |
| b) **Goal of the study** | | | | | | | | |
| 1) reasons for carrying out the study | | | | | OK | | | |
| 2) its intended applications | | | | | OK | | | |
| 3) the target audiences | | | | | OK | | | |
| 4) statement as to whether the study intends to support comparative assertions intended to be disclosed to the public | | | | | OK (1.3 and 1.6) | | | |
| | | | | | | | | |
| c) **Scope of the study** | | | | | | | | |
| 1) function, including | | | | | | | | |
| i) statement of performance characteristics | LH | 1 | 351 | | Unclear (1.4) | | added: packaging as protection of… | ok |
| ii) any omission of additional functions in comparisons | SOL | 30 | | | NO, some elements appear in the limitation chapter 16 (L7657 – 7662). | In 1.4, add a phrase stating the missing functions (if any) + justification for not taking them into account, or the fact that no other function is fulfilled(?) by the studied packaging | discussed and accepted in call, listed in limitations | ok |
| 2) functional unit, including | | | | | | | | |
| i) consistency with goal and scope | | | | | OK | | | |
| ii) definition | | | | | OK | | | |
| iii) result of performance measurement | LH | 2 | | | Unclear | | inlc performnce measures are fullflied, ie because they can be tranported in a bulk… | ok |
| 3) system boundary, including | | | | | | | | |
| i) omissions of life cycle stages, processes or data needs | | | | | OK | | | |
| ii) quantification of energy and material inputs and outputs | | | | | OK | | | |
| iii) assumptions about electricity production | | | | | OK | modif | | ok |
| 4) cut-off criteria for initial inclusion of inputs and output, including | | | | | | | | |
| i) description of cut-off criteria and assumptions | | | | | OK | | | |
| ii) effect of selection on results | LH | 3 | 436 | | Unclear (1.5) | | consideration of the not used steps doesn't lead to packaging specific changes. Add a tatement at the end of exclusion, that they don't chnage the comparison between packagings | ok |
| iii) inclusion of mass, energy and environmental cut-off criteria | | | | | OK | | | |
| | | | | | | | | |
| d) **Life cycle inventory analysis and LCC analysis** | | | | | | | | |
| 1) data collection procedures | | | | | OK | | | |
| 2) qualitative and quantitative description of unit processes | | | | | OK | | | |
| 3) sources of published literature | | | | | OK | | | |
| 5) validation of data, including | | | | | | | | |
| i) data quality assessment | SOL | 29 | 520 | | Not OK | One table is missing, see SOL 29 | missing table is in line 520 | ok |
| ii) treatment of missing data | | | | | Partially ok | Water output not covered | | |
| 7) allocation principles and procedures, including | | | | | | | | |
| i) documentation and justification of allocation procedures | | | | | OK | | | |
| ii) uniform application of allocation procedures | | | | | OK | | | |
| 4) calculation procedures | | | | | OK | | | |
| 6) sensitivity analysis for refining the system boundary | | | | | OK | | | |
| | | | | | | | | |
| e) **Life cycle impact assessment**, where applicable | | | | | | | | |
| 1) the LCIA procedures, calculations and results of the study | | | | | OK | | | |
| 2) limitations of the LCIA results relative to the defined goal and scope of the LCA | | | | | OK (chapter 16 – L7683) | | | |
| 3) the relationship of LCIA results to the defined goal and scope | | | | | OK | | | |
| 4) the relationship of the LCIA results to the LCI results | | | | | OK | | | |
| 5) impact categories and category indicators considered, including a rationale for their selection and a reference to their source | | | | | OK | | | |
| 6) descriptions of or reference to all characterization models, characterization factors and methods used including all assumptions and limitations | | | | | OK | | | |

| Requirements | Initials | Index | Line number (if relevant) | Nature of the comment | Reviewer Comment (detailed) | Reviewer Recommendation | Detailed answer | Check by the reviewer |
|---|---|---|---|---|---|---|---|---|
| 7) descriptions of or reference to all value-choices used in relation to impact categories, characterization models, characterization factors, normalization, grouping, weighting and, elsewhere in the LCIA, a justification for their use and their influence | | | | | OK | | | |
| 8) a statement that the LCIA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks, and, when included as a part of the LCA, also | | | | | OK (incl. Chapter 16 – L7691) | | | |
| i) a description and justification of the definition and description of any new impact categories, category indicators or characterization models used for the LCIA | | | | | NR | | | |
| ii) a statement and justification of any grouping of the impact categories | | | | | NR | | | |
| iii) any further procedures that transform the indicator results and a justification of the selected references, weighting factors, etc. | | | | | NR | | | |
| iv) any analysis of the indicator results, for example sensitivity and uncertainty analysis or the use of environmental data, including any implication for the results | | | | | NR | | | |
| v) data and indicator results reached prior to any normalization, grouping or weighting shall be made available together with the normalized, grouped or weighted results | | | | | NR | | | |
| | | | | | | | | |
| f) **Life cycle interpretation** | | | | | | | | |
| 1) the results | | | | | OK | | | |
| 2) assumptions and limitations associated with the interpretation of results, both methodology and data related | | | | | OK | | | |
| 3) data quality assessment | | | | | OK | | | |
| 4) full transparency in terms of value-choices, rationales and expert judgments | | | | | OK | | | |
| | | | | | | | | |
| g) **Critical review details**, where applicable | | | | | | | | |
| 1) name and affiliation of reviewers | | | | | Will be | | | |
| 2) critical review report | | | | | Will be | | | |
| 3) responses to recommendations | | | | | Will be | | | |
| | | | | | | | | |
| **For LCA studies supporting comparative assertions intended to be disclosed to the public, the following issues shall also be addressed by the report** | | | | | | | | |
| a) analysis of material and energy flows to justify their inclusion or exclusion | | | | | OK | | | |
| b) assessment of the precision, completeness and representativeness of data used | SOL | 31 | 520 | | Precision and completeness ok, Table about representativeness is missing in 1.6 | Add a table | added to table 1 | ok |
| c) description of the equivalence of the systems being compared | | | | | OK, found in chapter 16 L7710-7711 | | | |
| d) description of the critical review process | | | | | Will be | | | |
| e) an evaluation of the completeness of the LCIA | | | | | Ok, found in chapter 16 | | | |
| f) a statement as to whether or not international acceptance exists for the selected category indicators and a justification for their use | LH | 4 | 808 | | Only some | | We added to reasoning of choice of methods in chapter 1.8.1: "Further, the choice of characterisation methods follows earlier studies for Tetra Pak in order to keep a consistency and allow comparisons" | ok |
| g) an explanation for the scientific and technical validity and environmental relevance of the category indicators used in the study | | | | | OK | | | |
| h) the results of the uncertainty and sensitivity analyses | SOL | 32 | | | What is in 1.6 and 4 etc. (10% overall uncertainty) seems optimistic for some IA (see DG JRC ILCD handbook "Recommendation for LCIA in the European context") | A differentiation could have been done between impacts during interpretation. | ok | |
| i) evaluation of the significance of the differences found | SOL | 32 | | | In section 17 - a little limited The note on significance can be seen as optimistic in the case of some results of some IA calculations (see comment on h). This is well mentioned in figure 10 (L 865) regarding tox. | A differentiation could have been done between impacts during interpretation. | ok | |