INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

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

Final report

commissioned by Tetra Pak International SA

Heidelberg, April 2017

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Executive summary

Background, goal and scope

The "Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packagings for liquid food on the Nordic market" was commissioned by Tetra Pak® International SA and conducted by the Institut für Energie- und Umweltforschung (Institute for Energy and Environmental Research, ifeu) Heidelberg.

The study aims to provide an up-to date knowledge regarding the environmental strengths and weaknesses of Tetra Pak's key carton packages (partly with biobased material) as well as key competing packages in the beverage segments dairy, juice, nectar & still drinks (JNSD) and grab & go on the four Nordic markets.

The study covers the market situation of the Swedish, Norwegian, Finish and Danish market as observed in 2016. The choice of beverage cartons and of competing systems with different volumes for the packaging of dairy and JNSD was made by Tetra Pak. based on market relevance in the four analysed countries. The chosen competing bottles have a high relevance in the countries investigated and in some cases are pan-Nordic products. Due to the absence of bottles used for milk in Norway, the Swedish bottles are included for benchmarking purposes.

The study is performed in accordance with the relevant ISO standards (ISO 14040 and ISO 14044) and accompanied by a critical review process. The results of this study will be used by Tetra Pak. They shall further serve for information purposes of Tetra Pak's customers. The study is intended to be disclosed to the public.

The selection of the applied impact categories is based on the current practice in LCA and on the applicability of as less as uncertain characterisation models also with regard to the completeness and availability of the inventory data. The impact categories are 'Climate Change', 'Photo-oxidant Formation', 'Acidification', 'Stratospheric Ozone Depletion', 'Particulate Matter', 'Use of Nature' and 'Terrestrial Eutrophication' as well as 'Aquatic Eutrophication. Primary energy consumption – both total and non-renewable - is included as inventory categories.

For each packaging system in each of the beverage segment in the four countries analysed, a base scenario is defined and calculated. In these base scenarios a 50% allocation approach is used for open-loop-recycling.

The influence of the 50% allocation factor on the final results is demonstrated by calculating each scenario with a 100% allocation factor. In order to provide information on the influence of different data sets for the production of bio-based polyethylene, an additional sensitivity analysis is performed.

Furthermore, a sensitivity analysis is included to provide knowledge regarding the environmental performance of carton packaging systems compared to optimized weights of PET bottles.

Results and conclusions

Segment Dairy

In general the examined beverage carton systems analysed for the markets in Sweden, Finland, Denmark and Norway show lower burdens in all of the impact categories than their competing systems. An exception to this occurs in some categories if the carton contains a high share of bio-based polyethylene.

A considerable role for these generally low environmental impacts of beverage cartons plays the renewability of their paperboard components and a high use of renewable energies. Apart from the 'Tetra Top' the carton systems also benefit from the use of multi-use roll containers instead of one-way transport packaging. Lowest results are shown by those beverage carton systems without a separate closure system.

In the environmental impact category 'Climate Change' the cartons furthermore benefit from the use of bioplastics for sleeve and/or closure. However, a higher share of Bio-PE leads to higher environmental impacts in all other impact categories examined. In case of the substitution of fossil based polyethylene by bio-based polyethylene in the sleeve and closure the respective beverage cartons may lose their environmental advantage against the competing bottles in some impact categories.

The comparison of the 1000mL beverage cartons with a Tetra Rex with a filling volume of 1500 mL within the geographic scope of Sweden shows that the overall environmental impacts benefit from a larger volume size.

The sensitivity analysis on plastic bottle weights shows, that reducing the weight of plastic bottles will lead to lower environmental impacts in all four Nordic markets. When compared to the unaltered beverage cartons the results of the potential fossil-based lightweight bottles calculated may lead to a change in the overall ranking in some cases, especially in regard to the fully bio-based cartons. In the category 'Climate Change' however none of the potential lightweight bottles achieve lower results than any of the beverage cartons in Sweden, Finland, Denmark and Norway.

Segment Juice, Nectar & Still Drinks (JNSD)

In the segment *JNSD chilled* in Sweden the examined 'Tetra Rex OSO 34 1000 mL' shows the lowest results in most of the environmental categories. That makes it the most favourable choice for the packaging of chilled JNSD on the Swedish market when compared to the competing packaging systems examined in this study. A considerable role for these low environmental impacts plays the renewability of the paperboard components and a high use of renewable energies.

In the segment *JNSD ambient* the use of aluminium foil for ambient packaging increases the overall burdens of the beverage cartons in all four Nordic countries analysed.

However the cartons without bio-based polyethylene still show lower or similar results than the bottles examined in most of the impact categories in Sweden, Finland and Denmark

With an increased share of bio-based polyethylene 'Climate Change' results of beverage cartons improve. Results in all other impact categories however increase to an extent that compared to the PET bottle the carton loses its overall environmental advantage.

In this segment in Norway beverage cartons are only compared to the glass bottle. Compared to this packaging system the beverage cartons perform very favourably in all categories apart from 'Aquatic Eutrophication'.

The results of the applied sensitivity analysis for each geographic scope do not deliver any other insights than those of the segment dairy.

<u>Segment Grab & Go</u>

In the geographic scope of Sweden, Finland, Denmark and Norway the examined beverage carton systems without bio-based polyethylene for *Grab and Go* in the sub-segment <u>*Dairy chilled*</u> show lower burdens in all of the impact categories than their competing systems.

As the share of plastics in a small volume Tetra Top packaging is higher than other beverage cartons of bigger volumes, the choice of plastic material type, e.g. fossil or bio-based, plays a decisive role for the environmental performance.

In case of the 'Tetra Top Mini bio-based 330 mL' for Sweden, Finland and Denmark the impact results are only significantly lower in the impact category 'Climate Change' than those of the 'HDPE bottle 4'. For the Norwegian market no comparison with a plastic bottle within the subsegment Dairy chilled is made.

Again the volume size of the examined packaging systems has an influence on their results: The higher the volume the lower are the impacts according to the functional unit of 1000 L beverage.

In the sub-segment <u>*JNSD ambient*</u> of all four Nordic markets the beverage carton can be considered the packaging of choice when compared to the glass bottle from an environmental viewpoint.

For Sweden, Finland and Denmark no unambiguous conclusion can be drawn when compared to the APET bottle; at least not for the biobased cartons. From the environmental viewpoint generally the 'TBA edge HeliCap 250 mL' seems to be the best choice for Sweden, Finland, Denmark and Norway when compared to its carton based competitors

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

Overall conclusions and recommendations

Beverage cartons show relatively low life cycle assessment results in most examined environmental impact categories compared to their competing packaging systems in all segments and countries regarded in this study. They benefit from the use of renewable materials and energies in the production processes. Especially the use of paperboard as the main component leads to low impacts in many categories compared to the use of plastics or glass for bottles. Regarding climate change mitigation, the uptake of CO_2 leads to lower results in the respective impact category 'Climate Change', at least if half of the emissions originating from the incineration of used beverage cartons are allocated to the following system e.g. the Municipal Solid Waste Incinerators.

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 regarded.

From an overall environmental viewpoint, the use of bio-based plastics can therefore not be endorsed unreservedly. If there is a strong focus on climate change mitigation in Tetra Pak's environmental policy, though, the utilisation of bio-based polyethylene can be an applicable path to follow. In any case the consequences for the environmental performance in other impact categories should never be disregarded completely.

If the utilisation of bio-based polyethylene in beverage cartons remains part of Tetra Pak's environmental policy it is recommended to review the availability of other sources for bio-polymers, for example in regard to source material, to examine if lower environmental impacts can be achieved in other categories than climate change as well.

Abbreviations

ACE	Alliance for Beverage Cartons and the Environment
BC	Beverage carton
CED	Cumulative energy demand
CML	Centrum voor Milieukunde (Center of Environmental Science), Leiden University, Netherlands
COD	Chemical oxygen demand
CRD	Cumulative raw material demand
DC	DreamCap
DK	Denmark
EAA	European Aluminium Association
EEA	European Environment Agency
EU27+2	European Union & Switzerland and Norway
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (Brussels)
FI	Finland
GWP	Global Warming Potential
HBEFA	Handbuch für Emissionsfaktoren (Handbook for Emission Factors)
HC	HeliCap
ifeu	Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
JNSD	Juice, Nectars, Still Drinks
LCA	Life cycle assessment
LC	LightCap
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

NO	Norway
NO_X	Nitrogen oxides
ODP	Ozone Depletion Potential
pc	packs
PM2.5	Particulate matter with an aerodynamic diameter of 2.5 µm or smaller
PP	Polypropylene
SBM	Stretch blow moulding
SE	Sweden
TB	Tetra Brik
TBA	Tetra Brik Aseptic
TC	TwistCap
TPA	Tetra Prisma Aseptic
UBA	Umweltbundesamt (German Federal Environment Agency)
UHT	Ultra-heat treatment
VOC	Volatile organic compounds
WMO	World Meteorological Organization

1 Goal and scope

1.1 Background and objectives

As one of the world's leading suppliers, Tetra Pak® provides complete processing and carton packaging systems and machines for beverages, dairy products and food. Currently, the range of packaging systems comprises eleven alternatives, e.g. Tetra Brik®, Tetra Rex®, Tetra Top® [Tetra Pak 2013a]. 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.

On behalf of Tetra Pak, the Institut für Energie- und Umweltforschung (Institute for Energy and Environmental Research, ifeu) was commissioned to conduct a comparative LCA study on key carton packages as well as key competing packages in different beverage segments on the four Nordic markets Sweden, Finland, Norway and Denmark.

Tetra Pak conducted a similar LCA study in 2009 focusing on the Global Warming Potential (CO_2). However, since 2009 the packaging portfolio has been updated and improved, conditions have also changed regarding new packaging formats, use of bioplastics in closures and laminates and increased recycling levels. Moreover, the portfolio of competing packages especially PET and HDPE bottles in the milk and juice segments, has increased, bio-based and recycled content has been introduced and have increased during the last years. In order to be able to provide an up-to date knowledge regarding the environmental performance of Tetra Pak's carton packages in Sweden, Norway, Denmark and Finland an updated LCA is required.

The goal of the study is to conduct an LCA analysing the environmental performance of beverage carton systems in the segments dairy, juice and grab&go (chilled and ambient) compared to competing alternative packages (i.e. PET, HDPE and Glass packages) in four Nordic markets: Denmark, Finland, Norway and Sweden. The analysed packages of the segment grab & go contain either milk or juice.

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

(1) to provide an updated knowledge of the environmental strengths and weaknesses of carton packaging systems (partly with bio-based material) in the segments dairy (fresh milk & UHT), juice and grab & go (chilled and ambient) under the conditions of Denmark, Finland, Norway and Sweden.

(2) to compare the environmental performance of these cartons with those of its competing packaging systems (i.e. PET, HDPE, Glass packages) with high market relevance on the related markets.

(3) to provide a conversion factor from fossil plastics to bioplastics to be able to provide customers with robust information regarding future packaging alternatives, e.g. a CO_2 reduction per gram of raw material or relevant environmental information.

(4) to provide knowledge regarding the environmental performance of aseptic carton packages, if the aluminium barrier is replaced with a PE barrier.

(5) to provide knowledge regarding the environmental performance of carton packaging systems compared to optimized weights of PET bottles

As the **results of this study for the scopes (1), (2), (3) and (5) shall be used for internal and external communication**, the study will be critically reviewed according to ISO 14040/14044. **The results of (4) will be presented in annexes of the report** and shall provide additional insights to be used by Tetra Pak internally.

1.2 Organisation of the study

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

The members of the project panel are:

- **Tetra Pak:** Erik Lindroth, Erika Kloow, Martin Karlsson Thodenius
- **ifeu:** Stefanie Markwardt, Frank Wellenreuther, Jonas Harth, Andrea Drescher

1.3 Use of the study and target audience

The 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 to the public.
According to the ISO standards on LCA [ISO 14040 and 14044 (2006)], this requires a critical review process done 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:

- Håkan Stripple (chairman), IVL Swedish Environmental Research Institute, Sweden
- Ph.D. Alessandra Zamagni, Ecoinnovazione, Italy
- Prof. Dr. Birgit Grahl, INTEGRAHL, Germany

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 for the required shelf life of the product. 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. This means, that the products would be used up, before the lowest shelf life of any packaging is reached.

The primary packages examined are assumed to be technically equivalent regarding the mechanical protection of the packaged beverage during transport, the storage at the point-of-sale and the use phase.

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, in other words it includes the extraction and production of raw materials, converting processes, all transports and the final disposal or recycling of the packaging system.

In general, the study covers the following steps:

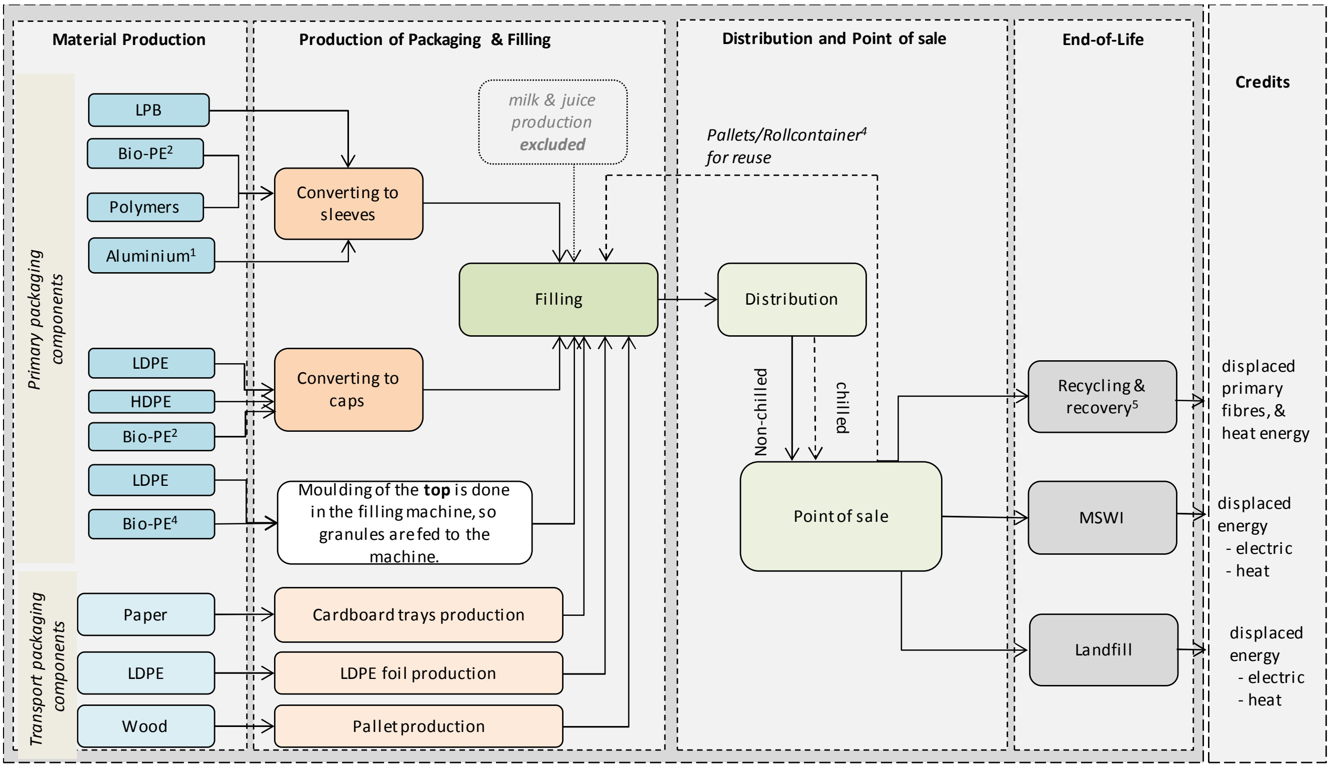
- production, converting, recycling and final disposal of the primary base materials used in the primary packaging elements from the studied systems (incl. closures)
- production, converting, recycling and final disposal of primary packaging elements and related transports
- production, recycling and 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 beverage cartons, roll container are used during the transport from fillers to the point of sale (see section 3). Rollcontainer have a weight of 38kg, mainly consist of steel and are reused between 200 to 500 times (IVL 2009; ERM 2010). In this study rollcontainer 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 rollcontainer itself will be 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
- losses of beverage at different points in the supply and consumption chain which might occur for instance in the filling process, during handling and storage, etc. as they are considered to be roughly the same for all examined packaging systems. Significant differences in the amount of lost beverage between the regarded packaging systems might be conceivable only if non-intended uses or product treatments are considered as for example in regard to different breakability of packages or potentially different amount of residues left in an emptied package due to the design of the package/closure.
  Further possible losses are directly related to the handling of the consumer in the use phase, which is not part of this study as handling behaviours are very different and difficult to assess. Therefore these possible beverage loss differences are not quantifiable as almost no data is available regarding these issues. In consequence a sensitivity analysis regarding beverage losses would be highly speculative and is not part of this study. This is indeed not only true for the availability of reliable data, but also uncertainties in inventory modelling methodology of regular and accidental processes and the allocation of potential beverage waste treatment aspects.
- transport of filled packages from the point of sale to the consumer as no relevant differences between the systems under examination are to be expected and the implementation would be highly speculative as no reliable data is available.
- use phase of packages at the consumers as no relevant differences between the systems under examination are to be expected (for example in regard to cleaning

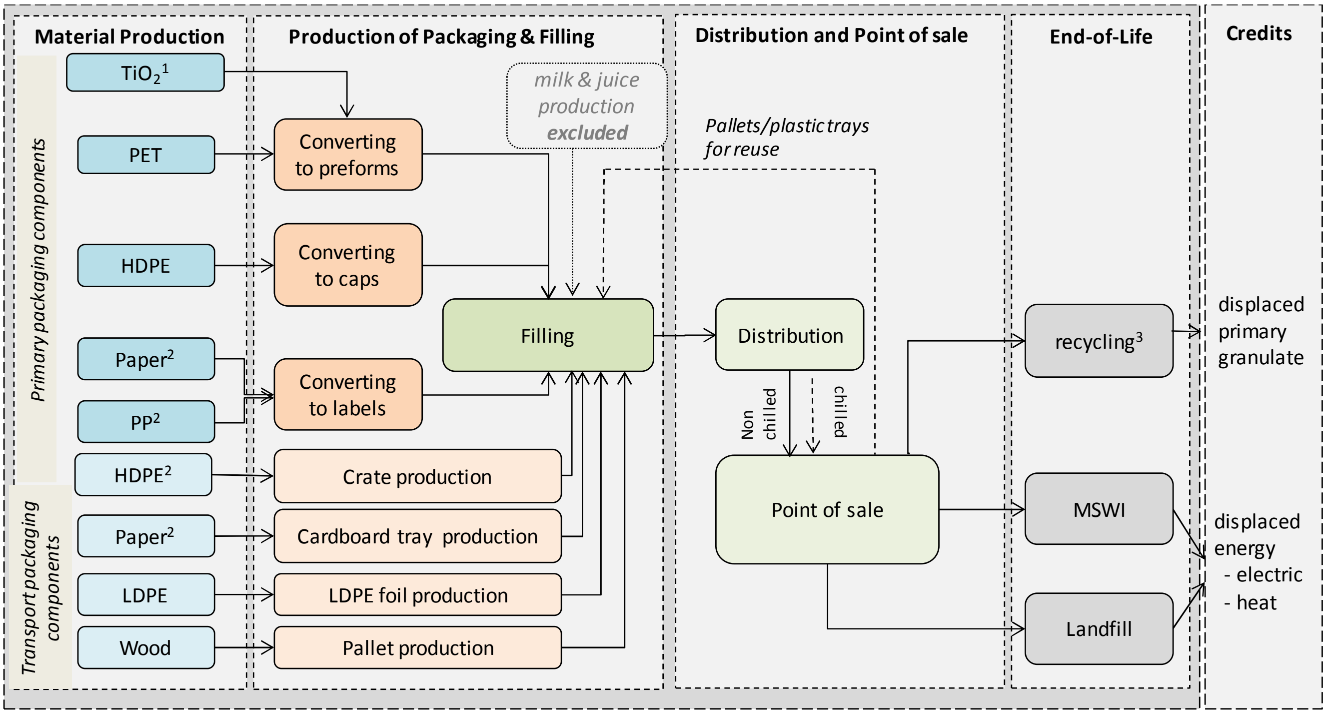
before disposal) and the implementation would be highly speculative as no reliable data is available.

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) and glass bottle (Figure 4).



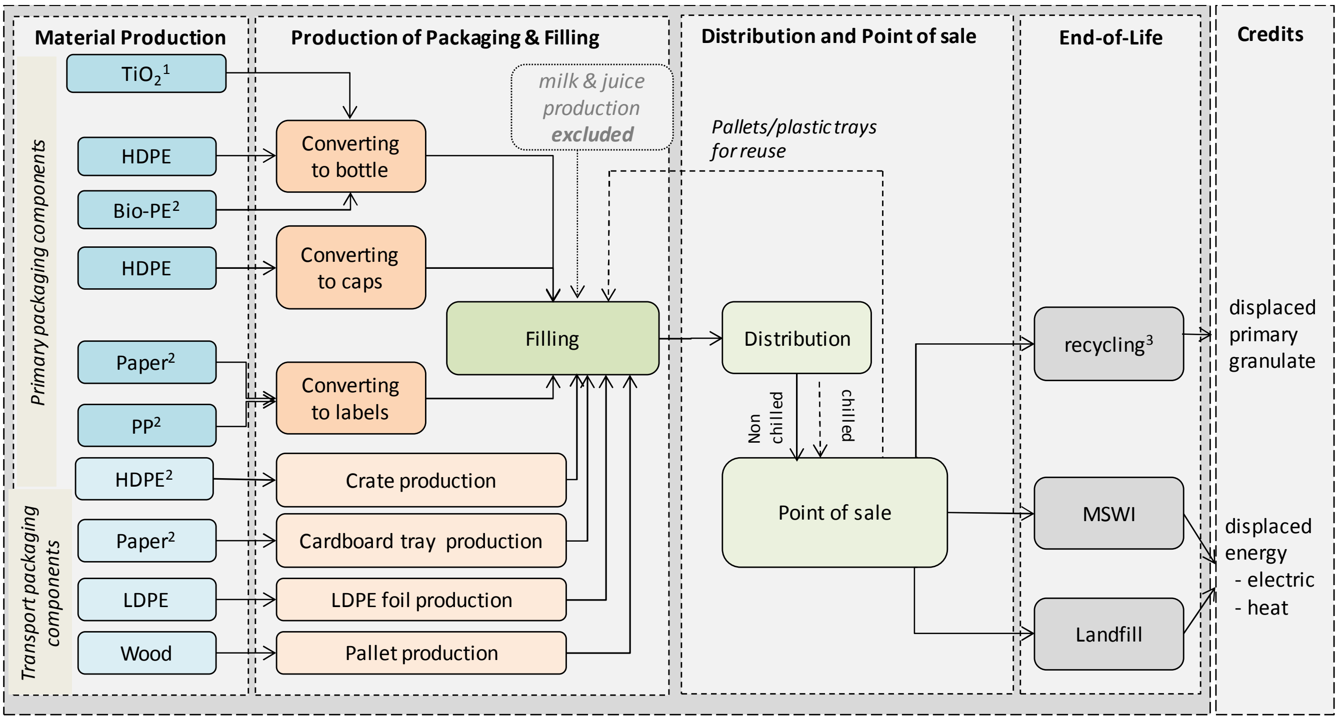
1 Aluminium does not apply for beverage cartons filled with chilled milk
2 for selected beverage cartons
3 for selected Tetra Top beverage cartons
4 weight of rollcontainer is considered for retail, production of rollcontainer is excluded
5 no material recycling of beverage cartons in Denmark

Figure 1: System boundaries of beverage cartons



[1] applies only for PET bottles for the packaging of milk
[2] applies for selected PET bottles
[3] applies only for PET bottles for the packaging of JNSD

Figure 2: System boundaries of PET bottles



[1] applies only for HDPE bottles for the packaging of milk
[2] applies for selected HDPE bottles
[3] applies only for HDPE bottles for the packaging of JNSD

Figure 3: System boundaries of HDPE bottles

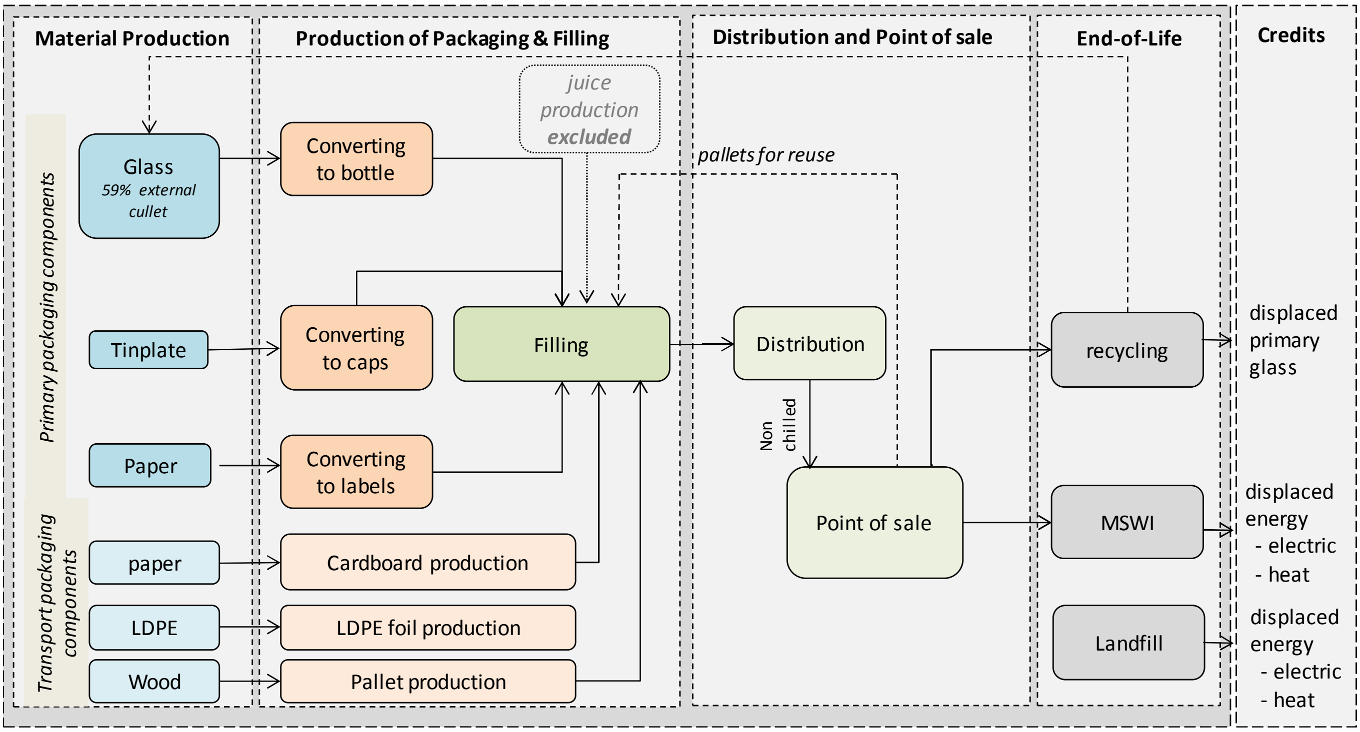


Figure 4: System boundaries of glass bottles

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. All energy inputs are considered, except the energy related to the material inputs from prechains which are cut off according to the mass related rule. Prechains with low input material shares, which would be excluded by the mass criterion, are nevertheless included if they are of environmental relevance, e.g. flows that include known toxic substances. 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. Furthermore glue and starch used in the corrugated cardboard production are cut off. 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 Sweden, Finland, Norway and Denmark. A certain share of the raw material production for packaging systems takes place in specific European countries. For these, country-specific data is used as well as European averages depending on the availability of datasets. Examples are the liquid packaging board 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 2016, as the packaging specifications listed in section 2 refer to 2016 as well as the market situation. Thus, the reference time period for the comparison is 2016. Where no figures are available for these years, the used data shall be as up-to-date as possible. Particularly with regard to data on end-of-life processes of the examined packages, the most current information available is used to correctly represent the recent changes in this area.

Most of the applied data refer to the period between 2002 and 2016. The process-specific data, such as filling data refer to 2016. 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 2011.

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

Technical reference

The process technology underlying the datasets used in the study reflects process configurations as well as technical and environmental levels which are typical for process operations in the reference period.

Completeness

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

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

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

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. 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. 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.

System-related allocation

The approach chosen for system-related allocation is illustrated in Figure 5and 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 1-2 (upper graph) in both, system A and system B, a virgin material (e.g. polymer) is produced, converted into a product which is used and finally disposed 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 1-2. 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 Figues 5 to Figure 7

The following graphs (figures 1-2 to 1-5) 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, the actual recycling efficiency as well as the actual substituted material including different substitution factors.

The allocation of final waste treatment is consistent with UBA LCA methodology [UBA 2000] 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 5 illustrates the general allocation approach used for uncoupled and coupled systems. The allocation methods used in this study are shown in Figure 16 and Figure 17. 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'), 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 6)

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].

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

Allocation with the 100% method (Figure 7)

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. The substitution factor of recycled fibres from beverage cartons has been set to 1. Further explanations on this issue can be found in section 3.13

- Paper fibres
  - from LPB (carton-based primary packaging): 1
  - in cardboard trays (secondary packaging): 0.9
- LDPE from foils: 0.94
- PET in bottles (bottle-to-bottle recycling): 1.0
- HDPE from closures (bottle-to-bottle recycling): 0.9
- Glass from bottles: 1

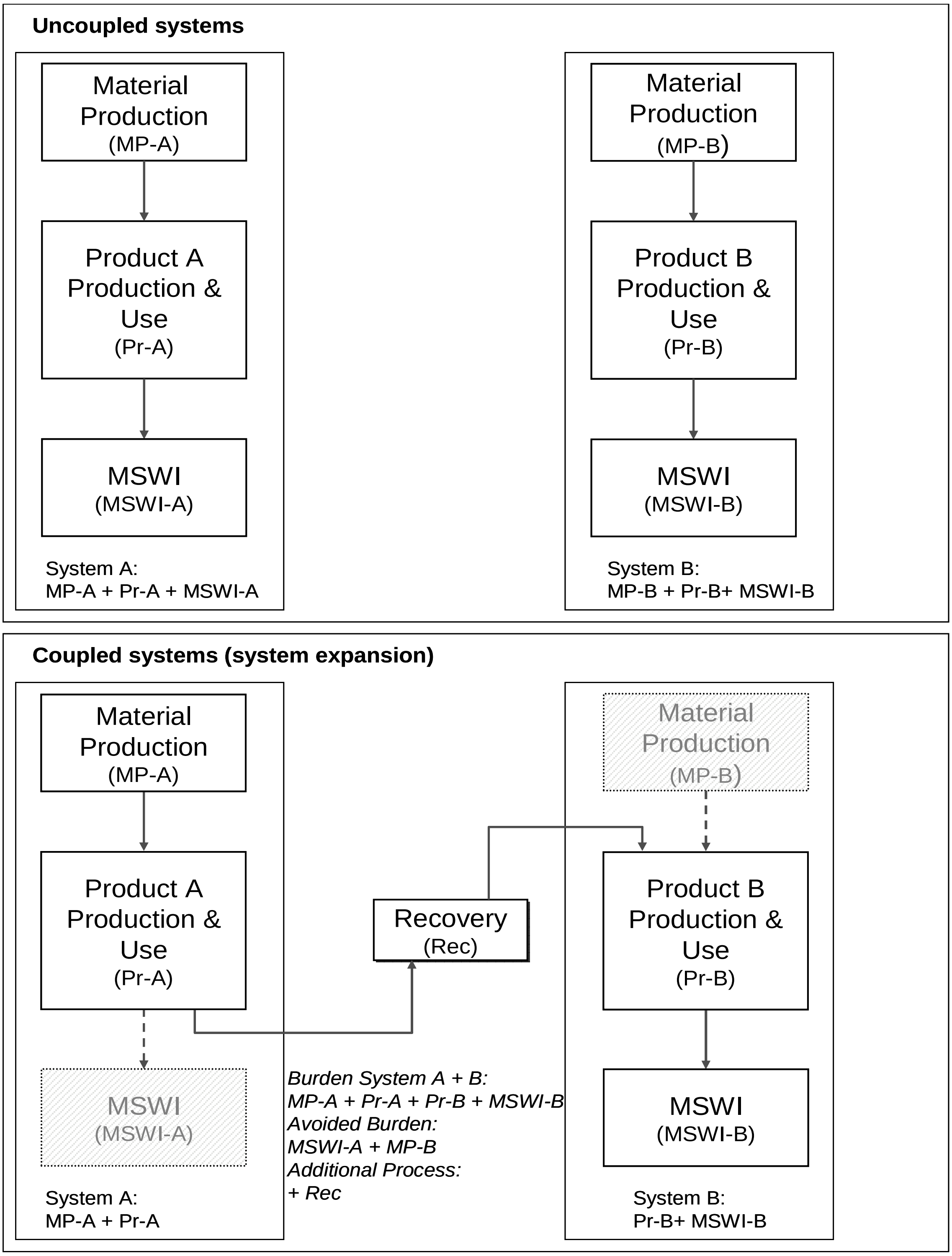


Figure 5: Additional system benefit/burden through recycling (schematic flow chart)

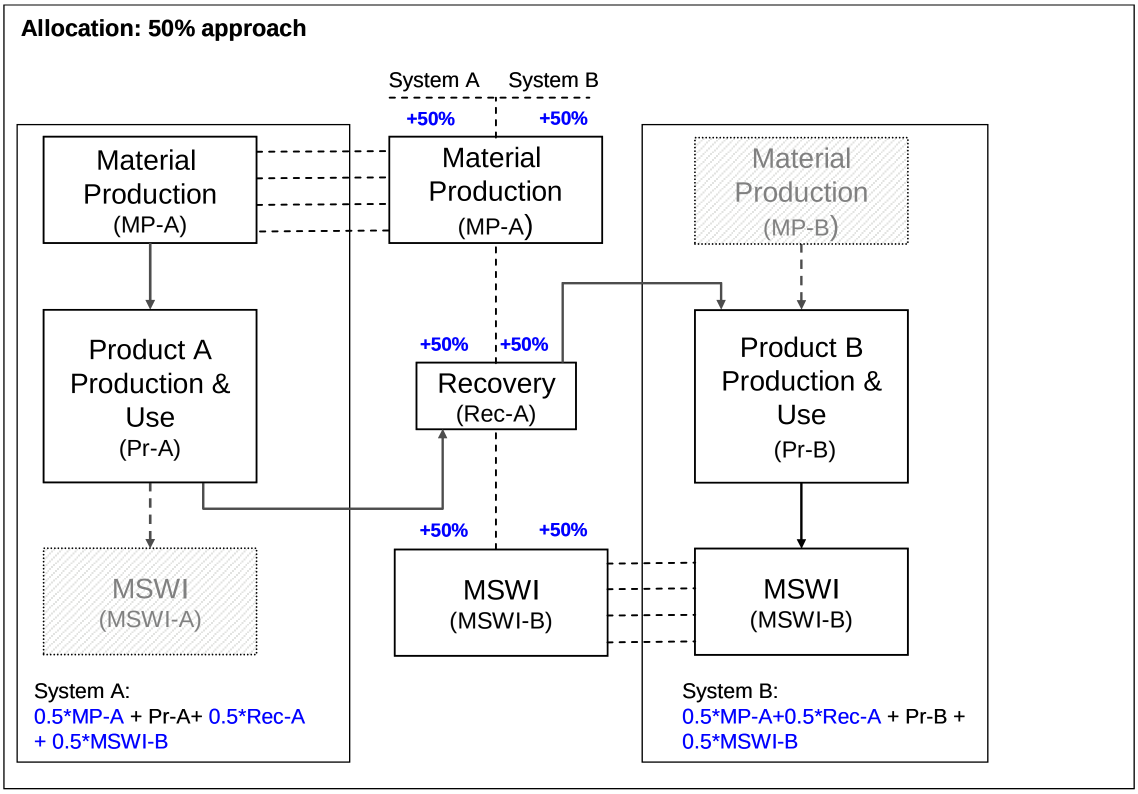


Figure 6: Principles of 50% allocation (schematic flow chart)

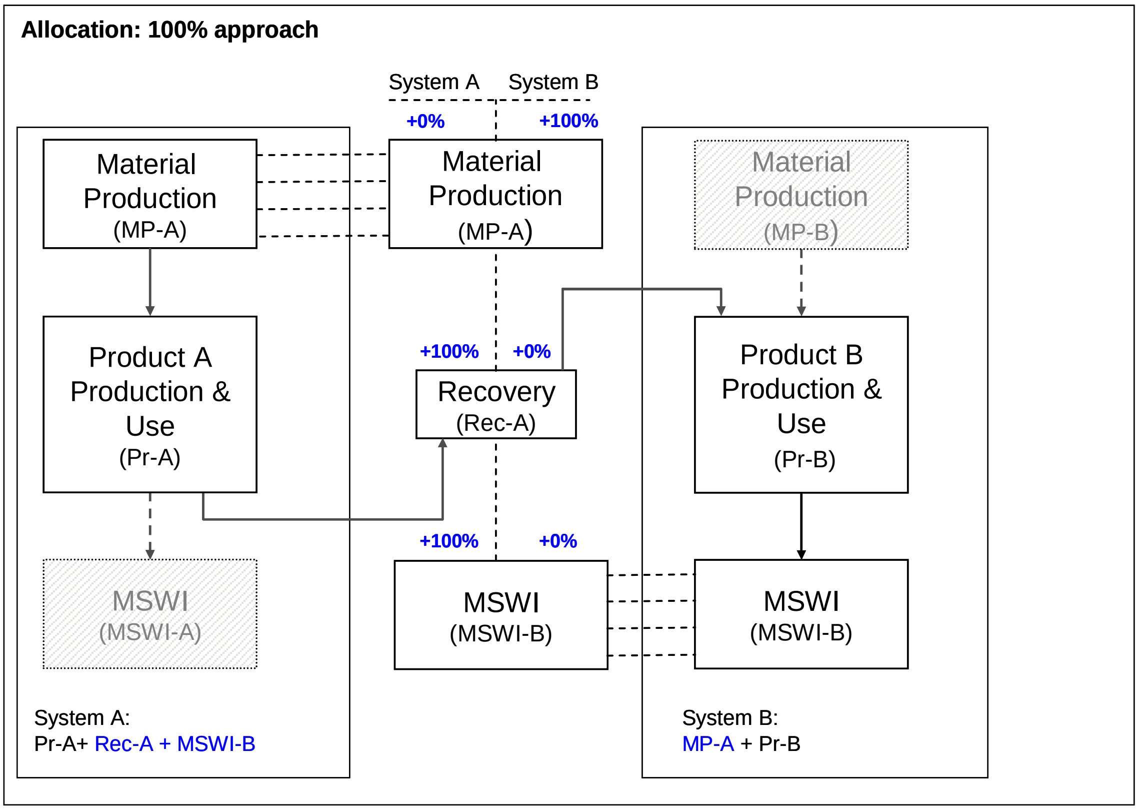


Figure 7: Principles of 100% allocation (schematic flow chart)

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. 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.

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.

Note on dLUC: Changes of the carbon balance in context of direct land use change (dLUC) can have an impact on the GWP as well. Within this study, the BRASKEM bio-PE dataset accounts a negative CO_2 value for dLUC and is reported separately. The related result show changes in soil organic carbon and above and below ground carbon stocks from conversion of land to sugarcane cultivation. The Bio-PE dataset compiled by ifeu does not account a negative CO_2 value for dLUC.

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 or Los Angeles 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-e / emission $_i$] 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/fu.

Eutrophication and oxygen-depletion

Eutrophication means the excessive supply of nutrients (inorganic phosphorus (P) and nitrogen (N) compounds - hereinafter referred to as P and N) to surface waters and soils. Increased levels of nutrients stimulate primary the growth of biomass, which may in case of excess production disrupt the future functioning of the food web and lead to consequences for plant and animal species and the functioning of these ecosystems. Both, aquatic and terrestrial ecosystems are affected by the supply of nutrients, but in different ways. An increased biomass production in terrestrial ecosystems could have a lasting effect on the sufficient availability of water and other nutrients than nitrogen and could result in potential displacement of species that are adapted to nutrient-poor conditions. Most aquatic ecosystems are primary affected by excessive production of primary biomass (algae growth), which could lead to secondary effects like oxygen depletion.

This could be reflected by different safeguard subjects. The safeguard subject for freshwater aquatic ecosystems is usually 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.

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.

Substances that may cause the impact are nitrogen, phosphorous and organic materials emitted to both air and water. Assuming that terrestrial systems are impacted through atmospheric depositions and usually limited by nitrogen, nitrogen emissions to air can be assigned to the impact category terrestrial eutrophication.

The situation for aquatic systems is more complex. They could be limited either by nitrogen, phosphorus or both, which may change over seasons. Effects of aquatic eutrophication are often related only to water emissions. This simplification is based on the assumption that atmospheric nutrient deposition is negligible compared to effluent releases [UBA 1999]. Effects “by atmospheric N deposition have hardly been incorporated in the setting of empirical critical loads for water” [Bobbink & Hettelingh 2011] and therefore, also in LCA. However, 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. The sensitivity of oligotrophic lakes to atmospheric nitrogen deposition has been investigated for example by [Bergström et al. 2006; 2008] for oligotrophic boreal lakes in Sweden exposed to different amounts of atmospheric N, by [Bergström & Jannson 2006] for 4000 oligotrophic lakes in Europe and North America and by [Elser et al. 2009] for oligotrophic lakes in Norway, Sweden and the United States. The surveys showed that an increased atmospheric nitrogen deposition leads to eutrophication with higher phytoplankton biomass. Furthermore, a shift from nitrogen limitation under low N deposition to phosphor limitation under high N deposition has been observed. [Elser et al. 2009] concluded that "increases in global atmospheric N transport during the coming decades are likely to substantially influence the ecology of lake food webs, even in lakes far from direct human disturbance." Therefore, the effect of aquatic eutrophication should also be related to air emissions. The spatial independence of generic LCI data makes it impossible to distinguish between air emissions deposited on land or water. The assignment of all nitrogen emissions from LCI to the impact category aquatic eutrophication would lead to double counting of the nitrogen emissions (if they are also assigned to terrestrial eutrophication). Furthermore, nitrogen emissions to air would dominate the results of aquatic eutrophication, which does not reflect the overall situation of aquatic eutrophication. For simplification purposes, the potential impacts of atmospheric nitrogen deposition on oligotrophic waters are assigned to the impact category terrestrial eutrophication. This solution is moreover supported by the potential impacts on oligotrophic lakes ("change in species composition of macrophyte communities, increased algal productivity and a shift in nutrient limitation of phytoplankton" [Bobbink & Hettelingh 2011]), which are in line with the safeguard subject of terrestrial eutrophication. Therefore, all nitrogen, phosphorous and organic material emissions to water are assigned to the impact category aquatic eutrophication.

As the LCA framework addresses potential environmental impacts calculated based on generic spatial independent global inventory data and the concept of "limiting nutrients" as proposed by [ReCiPe 2008] can be misleading, the characterisation factors by [Heijungs et al. 1992] were chosen for both eutrophication categories. With this characterisation factors, the magnitude of undesired supply of nutrients and oxygen depletion substances could be quantified without 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 eutrophication of surface waters also causes oxygen-depletion as a potential secondary impact. As measure of the possible perturbation of the oxygen levels in surface waters the Chemical Oxygen Demand (COD) is used.

In summary, the environmental impacts regarding eutrophication and oxygen depletion are addressed by 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 8: 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.

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**									

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. 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 is ready for application to almost any form of land use in central and northern Europe and has been also applied for individual agricultural productions in North- and South America (Kauertz et al. (2011), [Fehrenbach et al. 2016]). However solutions for all other regions and land use types around the globe need to be advanced. Due to these gaps in data availability the results of this category in this study cannot be used without hesitation. Results for the base scenarios will be included in this report for transparency, but they will not be 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 [Fehrenbach et. 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.

The idea central to the hemeroby concept follows the logic that intact ecosystems are not prone to higher levels of disturbance and negative impacts.

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.

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.
Most of the inventories applied in this study do not include the water released from the technosphere. Therefore, the 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 will be included in the inventory categories. A differentiation between process water, cooling water and water, unspecified is made. However, it includes neither any reference to the origin of this water, nor to its quality at the time of output/release. The respective results in this category are therefore of mere indicative nature and are not suited for conclusive quantitative statements related to either of the analysed packaging systems. The unit is m^3.

Primary Energy (Cumulative Energy Demand)

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

Total Primary Energy (Cumulative Energy Demand, total)

The Total Cumulative Energy Demand is a parameter to quantify the primary energy consumption of a system. It is calculated by adding the energy content of all used fossil fuels, nuclear and renewable energy (including biomass). This category is described in [VDI 1997] and has not been changed considerably since then. It is a measure for the overall energy efficiency of a system, regardless the type of energy resource which is used. The calculation of the energy content of biomass, e.g. wood, is based on the lower heating value of the dry mass. The unit for Total Primary Energy is MJ.

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

The category non-renewable primary energy (CED non-renewable) considers the primary energy consumption based on non-renewable, i.e. fossil and nuclear energy sources. The unit for Non-renewable Primary Energy is MJ.

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

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

1.8.2 Optional elements

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

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

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

2 Packaging systems and scenarios

In general terms, packaging systems can be defined based on the primary, secondary and tertiary packaging elements they are made up of. The composition of each of these individual packaging elements and their components' masses depend strongly on the function they are designed to fulfil, i.e. on requirements of the filler and retailer as well as the distribution of the packaged product to the point-of-sale. Main function of the examined primary packaging is the packaging and protection of beverages including milk. 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 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 milk and beverage categories, competing packaging systems have been selected. This selection was also chosen by Tetra Pak. The selection of these competing packaging systems was based on market relevance in the four analysed countries.

The chosen competing bottles have a high relevance in the countries investigated and in some cases are pan-Nordic products. In some cases, e.g. for milk in Norway there are no bottles used for milk. The Swedish bottles have here been included for benchmarking purposes.

2.2 Packaging specifications

Specifications of beverage carton packaging systems are provided by Tetra Pak. In Tetra Pak's internal database actual specifications of all primary packages sold are registered. Specification data for the secondary packaging were provided by Tetra Pak as well. Most of them were gathered for the related previous LCA [IVL 2009] and confirmed to be valid for the time scope 2016 as well.

The specifications of the competing packaging systems were determined by Tetra Pak in 2016 as well and are based on existing products. They were determined by weighing three individual sample bottles per bottle system bought at the point of sale. Specifications on primary and secondary packaging were determined by weighing each of the packaging systems several times. Specification data for the secondary and tertiary packaging were collected at points of sale.

The analysed PET bottle 2 900 mL and PET bottle 3 330 mL claim a recycled content on the label. According to the website of the filler, a recycled content of 50% rPET is published for the small smoothie and juice bottles. Store checks in Sweden done by Tetra Pak and ifeu (July 2016) showed a share of 25% rPET content claimed on the 900 mL bottles. These shares will be applied for the Nordic market within this study. The rPET content of these bottles in other countries of the Nordic region than Sweden might be lower. Applying a higher share should serve as a conservative approach (compared to the beverage carton) and additionally may provide insights on potential future developments on the Nordic market.

Data on tertiary packaging were taken from previous studies conducted for Tetra Pak (i.e. weight of pallet and shrink foil).In order to estimate the pallet configuration, i.e. the layers per pallet and bottles per pallet, a EUR-pallet was used. A maximum height was determined to 1.10 meters. Each packaging material, on tray, was then calculated and simulated in order to achieve the maximum number of trays on the pallet considering the maximum payload of a lorry. In order to acquire the number of primary packing on each tray the packaging pattern was attained at site. These simulations were conducted by Tetra Pak. A documentation of this procedure as well as of the determination of the packaging specifications of the competing packaging systems were sent to the review panel.

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

- Only **packaging systems in the same segment are compared to each other** (dairy versus dairy; juice versus juice).The differentiation between dairy and juice is also done in the segment grab & go.
- **Chilled and ambient beverage packaging systems are not compared to each other**

Table 6: List of beverage containers in segment **DAIRY**

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Brik (TB) 1000 ml	C	SE	HDPE bottle 1 900 ml	C	SE, DK, FI, NO
Tetra Brik Edge (TB Edge) Twist Cap 1000 ml	C	SE	HDPE bottle 2 900 ml	C	SE, DK, FI, NO
Tetra Brik Edge (TB edge) biobased Twist Cap 1000 ml	C	SE	PET bottle 1 1000 ml	C	SE, DK, FI, NO
Tetra Rex 1500 ml	C	SE			
Tetra Rex fully biobased 1500 ml	C	SE			
Tetra Rex 1000 ml	C	SE, DK, FI, NO			
Tetra Rex OSO 34 1000 ml	C	SE, DK, FI, NO			
Tetra Rex biobased OSO 34 1000 ml	C	SE, DK, FI, NO			
Tetra Rex fully biobased OSO 34 1000 ml	C	SE, DK, FI, NO			
Tetra Top 1000 ml	C	SE, DK, FI, NO			

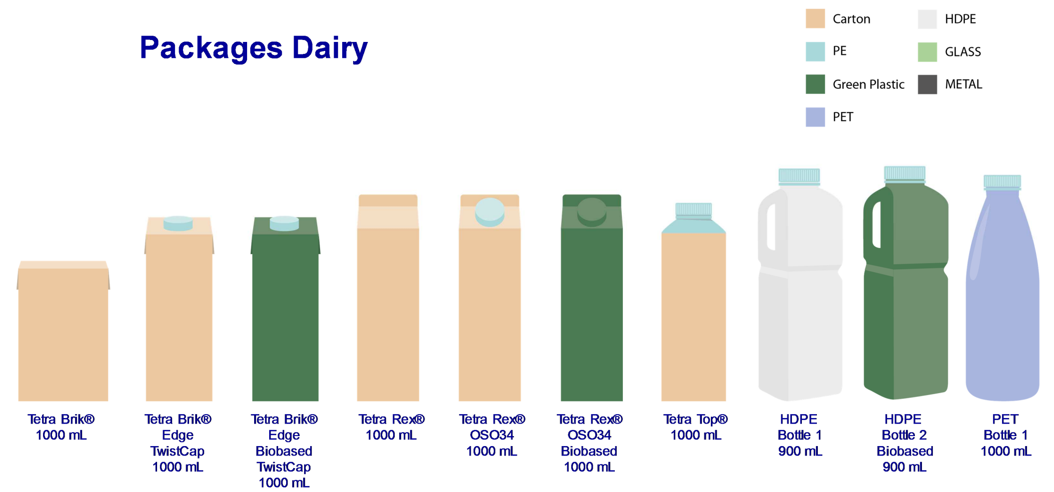


Figure 9: Pictures of analysed packaging systems in the segment dairy (Source: Tetra Pak©)

Table 7: List of beverage containers in segment **JNSD**

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Rex TwistCap (TC) 1000 ml	C	SE	HDPE bottle 3 1000 ml	C	SE
			PET bottle 2 900 ml	C	SE, DK, FI
			PET bottle 3 1000 ml	C	SE, DK, FI
			PET bottle 7 1000 ml	C	NO
			PET bottle 8 1000 ml	C	NO
Tetra Brik Aseptic Edge (TBA) LightCap (LC) 1000 ml	A	SE, DK, FI, NO	PET bottle 4 1000 ml	A	SE, DK, F
Tetra Brik Aseptic Edge (TBA) biobased LightCap (LC) 1000 ml	A	SE, DK, FI, NO	Glass bottle 1 900 ml	A	SE, DK, FI, NO
Tetra Prisma Aseptic Square (TPA Square) HeliCap (HC) 1000 ml	A	SE, DK, FI, NO			
Tetra Prisma Aseptic Square (TPA square) HeliCap (HC) biobased 1000 ml	A	SE, DK, FI, NO			

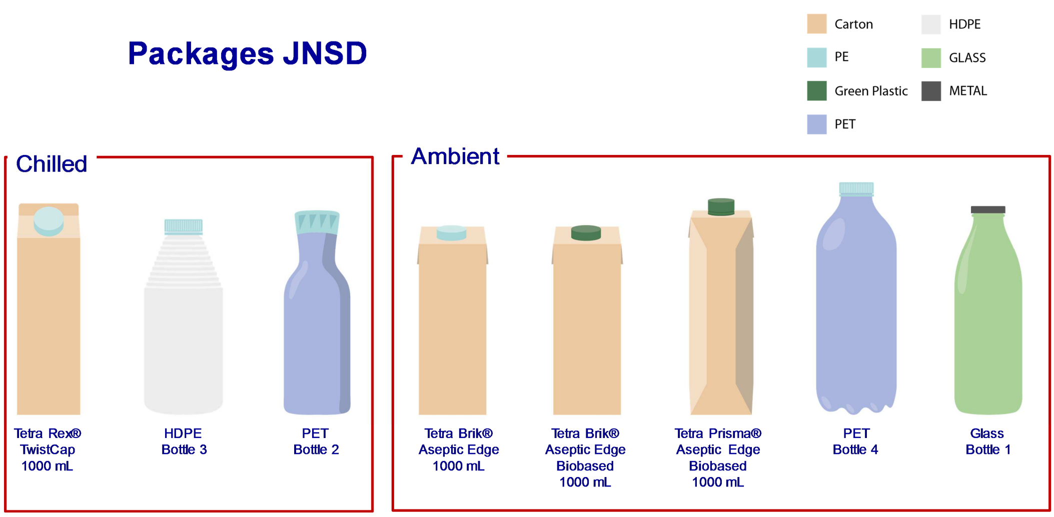


Figure 10: Pictures of analysed packaging systems in the segment JNSD (Source: Tetra Pak©)

Table 8: List of beverage containers in segment **Grab & Go**

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Top Midi 250 ml (Dairy)	C	SE	HDPE bottle 4 350 ml (Dairy)	C	SE, DK, FI
Tetra Top Midi 330 ml (Dairy)	C	SE	HDPE bottle 5 350 ml (Dairy)	C	SE, DK, FI
Tetra Top Mini 330 ml (Dairy)	C	SE, DK, FI, NO			
Tetra Top Mini biobased 330 ml (Dairy)	**C**	SE, DK, FI, NO			
			PET bottle 5 330 ml (Juice)	C	SE, DK, FI
			HDPE bottle 6 380 ml (Juice)	C	SE, DK, FI
			PET bottle 9 400 ml (Juice)	C	NO
Tetra Brik Aseptic Edge (TBA) HeliCap (HC) biobased 250 ml (Juice)	A	SE, DK, FI, NO	APET bottle 330 ml (Juice)	A	SE, DK, FI
Tetra Brik Aseptic Edge (TBA) HeliCap (HC) 250 ml (Juice)	A	SE, DK, FI, NO	Glass bottle 2 350 ml (Juice)	A	SE, DK, FI, NO
Tetra Prisma Aseptic square DreamCap (DC) biobased 330 ml (Juice)	A	SE, DK, FI, NO			
Tetra Prisma Aseptic square (TPA) HeliCap (HC) biobased 330 ml (Juice)	A	SE, DK, FI, NO			

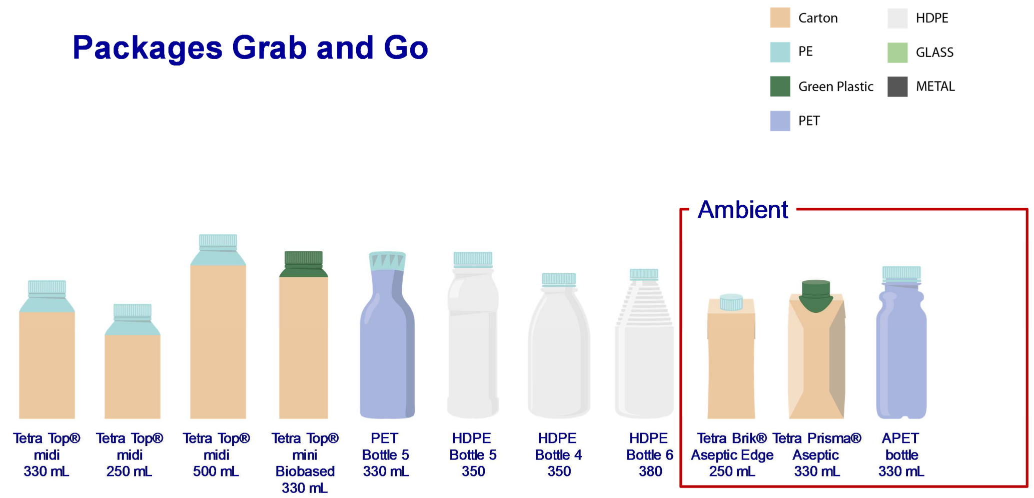


Figure 11: Pictures of analysed packaging systems in the segment Grab & Go (Source: Tetra Pak©)

Table 9: Packaging specifications for regarded carton systems for the *packaging of dairy in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI)*: components and masses [g/piece] - as applied in the model

		DAIRY									
Packaging components	**Unit**	**TB**	**TB Edge TC**	**TB Edge Biobased TC**	**Tetra Rex**	**Tetra Rex fully biobased**	**Tetra Rex**	**Tetra Rex OSO 34**	**Tetra Rex Biobased OSO 34**	**Tetra Rex fully biobased OSO 34**	**Tetra Top**
Volume [ml]		1000	1000	1000	1500	1500	1000	1000	1000	1000	1000
Geographic Scope		SE					SE, FI, DK, NO				
Chilled / ambient		chilled									
primary packaging (sum)	g	26.95	30.85	30.85	39.40	39.40	26.65	29.25	29.25	29.25	32.95
composite material (sleeve)	g	26.95	28.15	28.15	36.79	36.79	26.65	26.65	26.65	26.65	25.20
- liquid packaging board	g	22.7	23.1	23.1	32.41	32.41	23.1	23.1	23.1	23.1	21.2
- Polymers	g	4.23	5.05	2.45	4.38		3.57	3.57	3.57		3.97
- Bio polymers	g			2.60		4.38				3.57	
Top											4.45
Polymers											4.45
Closure	g	0.00	2.70	2.70	2.60	2.60	0.00	2.60	2.60	2.60	3.30
- Polymers	g		2.70		2.60			2.60			3.30
- Bio polymers	g			2.70		2.60			2.60	2.60	
secondary packaging (sum)	g										**135**
tray (corr.cardboard)	g										135
tertiary packaging (sum)	g										**25170**
Rollcontainer	g	38000	38000	38000			38000	38000	38000	38000	
pallet	g										25000
type of pallet	-										EURO
number of use cycles	-	200	200	200			200	200	200	200	25
stretch foil (per pallet) (LDPE)	g										170
pallet configuration											
cartons per tray /rollcontainer	pc	180	180	180	90	90	180	180	180	180	10
trays / shrink packs per layer	pc										5
layers per pallet/rollcontainer per lorry	pc	180	180	180	180	180	180	180	180	180	4
cartons per pallet	pc	32400	32400	32400	16200	16200	32400	32400	32400	32400	600

Table 10: Packaging specifications for regarded carton systems for the *packaging of JNSD in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI)*: components and masses [g/piece] - as applied in the model

JNSD						
Packaging components	**Unit**	**Tetra Rex TC**	**TBA Edge LC**	**TBA Edge biobased LC**	**TPA square HC**	**TPA square HC biobased**
Volume [ml]		1000	1000	1000	1000	1000
Geographic scope		SE	SE, FI, DK, NO			
Chilled/ ambient		chilled	ambient			
primary packaging (sum)	g	32.10	31.00	31.00	39.43	39.43
composite material (sleeve)	g	29.53	28.00	28.00	35.63	35.63
- liquid packaging board	g	24.2	21.6	21.6	25.7	25.7
- Polymers	g	5.31	5.00	2.3	8.01	8.01
- Bio-Polymers	g			2.70		
-Aluminium	g		1.40	1.40	1.93	1.93
closure	g	2.60	3.00	3.00	3.80	3.80
- Polymers	g	2.60	3.00		3.80	2.0
-Bio polymers	g			3.00		1.80
secondary packaging (sum)	g	94.50	249.75	249.75	297.00	297.00
tray (corr. cardboard)	g	94.50	249.75	249.75	297.00	297.00
tertiary packaging (sum)	g	**25170**	**25170**	**25170**	**25170**	**25170**
pallet	g	25000	25000	25000	25000	25000
type of pallet	-	EURO	EURO	EURO	EURO	EURO
number of use cycles	-	25	25	25	25	25
stretch foil (per pallet) (LDPE)	g	170	170	170	170	170
pallet configuration						
cartons per tray	pc	10	10	10	10	10
trays / shrink packs per layer	pc	15	16	16	14	14
layers per pallet	pc	4	5	5	5	5
cartons per pallet	pc	600	800	800	700	700

Table 11: Packaging specifications for regarded carton systems in the segment *Grab & Go in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI)*: components and masses [g/piece] - as applied in the model

		Grab & Go						
Packaging components	**Unit**	**Tetra Top Mini**	**Tetra Top Midi**	**Tetra Top Midi**	**Tetra Top Mini biobased**	**TBA Edge HC biobased**	**TBA Edge HC**	**TPA Square DC biobased**
Volume [ml]		330	250	330	330	250	250	330
Geographic Scope		SE, FI, DK, NO	SE	SE	SE, FI, DK, NO			
Dairy/JNSD		Dairy				JNSD		
Chilled / ambient		chilled				ambient		
primary packaging (sum)	g	16.70	16.42	17.88	16.70	12.75	12.75	16.68
composite material (sleeve)	g	10.50	9.44	10.90	10.50	10.05	10.05	12.92
- liquid packaging board	g	8.70	7.51	8.67	8.70	6.89	6.89	6.79
- Polymers	g	1.80	1.93	2.23	1.80	2.57	2.57	3.2
- Aluminium	g					0.59	0.59	0.93
Top		2.90	3.71	3.68	2.90			
Polymers		2.90	3.71	3.68				
Bio polymers					2.90			
closure	g	3.30	3.30	3.30	3.30	2.70	2.70	3.76
- Polymers	g	3.30	3.30	3.30		1.39	2.70	2.18
- Bio polymers	g				3.30	1.31		1.58
secondary packaging (sum)	g	74.25	67.50	74.25	74.25	121.50	121.50	182.50
tray (corr. cardboard)	g	74.25	67.50	74.25	74.25	121.50	121.50	182.50
tertiary packaging (sum)	g	**25170**	**25170**	**25170**	**25170**	**25170**	**25170**	**25170**
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
stretch foil (per pallet) (LDPE)	g	170	170	170	170	170	170	170
pallet configuration								
cartons per tray	pc	10	12	12	10	24	24	12
trays / shrink packs per layer	pc	22	19	19	22	15	15	19
layers per pallet	pc	7	8	7	7	7	7	8
cartons per pallet	pc	1540	1824	1596	1540	2160	2160	1824

Table 12: Packaging specifications for regarded alternative systems in the segment *Dairy in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI)*: components and masses [g/piece] - as applied in the model

		DAIRY		
Packing components	**Unit**	**HDPE bottle 1**	**HDPE bottle 2 (biobased)**	**PET bottle 1**
Volume [ml]		900	900	1000
Geographic scope		SE, FI, DK, NO	SE, FI, DK, NO	SE, FI, DK, NO
Chilled / ambient		chilled		
primary packaging (sum)	g	45.96	45.96	28.48
bottle	g	39.86	39.86	24.03
- PET	g			22.83
- HDPE	g	37.87		
- Bio-polymers			37.87	
-TiO2	g	1.99	1.99	1.20
Trip rate of bottle		1	1	1
Label				
paper				1.67
PP		2.19	2.19	
closure	g			
- HDPE	g	3.91	3.91	2,99
secondary packaging (sum)	g	253.50	253.50	852.00
crate (made of HDPE)		253.50	253.50	852.00
Trip rate of crate		100	100	100
tertiary packaging (sum)	g	**25480**	**25480**	**25480**
pallet	g	25000	25000	25000
type of pallet	-	EURO	EURO	EURO
number of use cycles	-	25	25	25
stretch foil (per pallet) (LDPE)	g	480	480	480
pallet configuration				
Bottles per crate	pc	10	10	8
crates per layer	pc	15	15	8
layers per pallet	pc	3	3	5
bottles per pallet	pc	450	450	320

Table 13: Packaging specifications for regarded alternative systems in the segment *JNSD in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI)*: components and masses [g/piece] – as applied in the model

		JNSD						
Packing components	**Unit**	**PET bottle 2**	**PET bottle 3**	**HDPE bottle 3**	**PET bottle 4**	**PET bottle 7**	**PET bottle 8**	**Glass bottle 1**
Volume [ml]		900	1000	1000	1000	1000	1000	750
Geographic scope		SE, FI, DK	SE, FI, DK	SE	SE, FI, DK	NO	NO	SE, FI, DK, NO
Chilled/ambient		chilled			ambient	chilled		ambient
primary packaging (sum)	g	51.14	40.09	51.14	37.95	50.95	35.12	369.90
bottle	g	38.96	35.22	44.73	29.40	45.12	31.03	361.70
- PET	g	38.96	35.22		29.40	45.12	31.03	
- HDPE	g			44.73				
- Glass								361.70
Recycled content[1]	%	25%						
trip rate of bottle		1	1	1	1	1	1	1
Label								
paper		2.13	1.99	2.68				2.54
PP					4.67	2.12	1.37	
closure	g							
- HDPE	g	9.80	2.68	3.73	3.68	3.71	2.72	
- tinplate	g							5.66
secondary packaging (sum)	g	43.50	140.45	16.50	11.97	140.45	140.45	58.35
tray (corr. cardboard)	g	31.50	140.45			140.45	140.45	42.13
shrink foil per tray (LDPE)	g	12.00		16.50	11.97			16.22
tertiary packaging (sum)	g	**25480**	**25480**	**25480**	**25480**	**25480**	**25480**	**25480**
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
stretch foil (per pallet) (LDPE)	g	480	480	480	480	480	480	480
pallet configuration								
bottles per tray	pc	6	6	6	6	6	6	6
trays / shrink packs per layer	pc	21	18	18	25	18	18	18
layers per pallet	pc	3	3	4	3	3	3	4
bottles per pallet	pc	378	324	432	450	324	324	432

[1] Assumption based on declaration on the product – see description regarding the determination of packaging specifications

Table 14: Packaging specifications for regarded alternative systems in the segment *Grab & Go in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI)*: components and masses [g/piece] – as applied in the model

Grab & Go								
Packing components	Unit	HDPE bottle 4	HDPE bottle 5	PET bottle 5	HDPE bottle 6	APET bottle	PET bottle 9	Glass bottle 2
Volume [ml]		350	350	330	380	330	400	250
Geographic scope		SE, FI, DK	SE, FI, DK	SE, FI, DK	SE, FI, DK	SE, FI, DK	NO	SE, FI, DK, NO
Dairy / Juice		Dairy		Juice				
Chilled/ambient		chilled				ambient	chilled	ambient
primary packaging (sum)	g	28.82	30.03	31.70	26.89	24.40	38.08	166.38
bottle	g	23.60	23.78	22.40	22.07	20.19	31.95	160.51
- PET	g			22.40		20.19	31.95	
- HDPE	g	22.42	22.59		22.07			
TiO2		1.18	1.19					
- Glass								160.51
Recycled content	%			25				
Trip rate of bottle		1	1	1	1	1	1	1
Label								
paper					1.34			1.43
PP		1.83	2.33	0.87		0.33	2.38	
closure	g							
- HDPE	g	3.39	3.92	8.18	3.48	3.88	3.75	
- tinplate	g							4.44
secondary packaging (sum)	g	6.23	80.59	25.61	7.79	7.50	45.95	55.02
tray (corr. cardboard)	g		80.59	18.20			35.81	40.26
shrink foil per tray (LDPE)	g	6.23		7.41	7.79	7.50	10.14	14.76
tertiary packaging (sum)	g	**25480**	**25480**	**25480**	**25480**	**25480**	**25480**	**25480**
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
stretch foil (per pallet) (LDPE)	g	480	480	480	480	480	480	480
pallet configuration								
bottles per tray	pc	6	8	8	4	8	12	12
trays / shrink packs per layer	pc	36	30	30	60	35	20	18
layers per pallet	pc	6	15	5	5	5	4	6
bottles per pallet	pc	1296	1200	1200	1200	1400	960	1296

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 Sweden, Denmark, Finland and Norway. The applied collection and recovery quotas are either based on published quotas or on quotas provided by Tetra Pak. If the collection rate is provided sorting residues of 10% for beverage cartons and plastic bottles and 2.5% for glass bottles are assumed. Thus, the recovery 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 15.

Table 15: Applied recovery quotas for beverage cartons, plastic and glass bottles in Sweden, Finland, Norway and Denmark: R – recovery quota; C – collection quota

Country	Packaging system	Recovery quota /collection quota	Reference year	Source
Sweden	Beverage carton	36.10%^{R}	2015	Tetra Pak
	Plastic bottles	38.40%^{R}	2014	[FTI 2015]
	Glass bottles	97.00%^{C}	2013	[FEVE 2015] (Svensk Glasåtervinning AB – 2013)
Finland	Beverage carton	38.00%^{R}	2014	[ACE 2016]
	Plastic bottles	0.00%[1]	2014	[TemaNord 2014]
	Glass bottles	77.00%^{C}	2013	[FEVE 2015]
Norway	Beverage carton	61.00%^{R}	2014	[ACE 2016]
	Plastic bottles	22.30%^{R}	2015[2]	(https://www.grontpunkt.no/gjenvinning/forbruker/plastemballasje; accessed July 2016)
	Glass bottles	90.00%^{C}	2013	[FEVE 2015]/[Miljødirektoratet 2015]
Denmark	Beverage carton	0.00%	2014	[ACE 2016]
	PET bottles HDPE bottles	0.00% 15.00%^{R}	2014	Plastics Europe/Eurostat/[TemaNord 2014]
	Glass bottles	98.00%^{C}	2012	[FEVE 2015] (Eurostat)

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 16.

[1] The plastic waste is not subject to recycling in Finland. It is collected within the energy waste fraction (see section 3.13)
[2] No specific year is given on the website. Authors assume that value of 22.30% refer to the year 2015

Table 16: Applied average rates for landfilling and incineration in in Sweden, Finland, Norway and Denmark

Country	MSWI/Landfill	Quota	Reference year	Source
Sweden	MSWI	98.70%	2014	calculated based on [Eurostat 2016]
	Landfill	1.30%		
Finland	MSWI	74.20%		
	Landfill	25.80%		
Norway	MSWI	95.00%		
	Landfill	5.00%		
Denmark	MSWI	97.60%		
	Landfill	2.40%		

The following simplified flow charts illustrate the applied end-of-life model of beverage carton, PET and HDPE bottles as well as the glass bottles separated by country and beverage (i.e. dairy of JNSD).

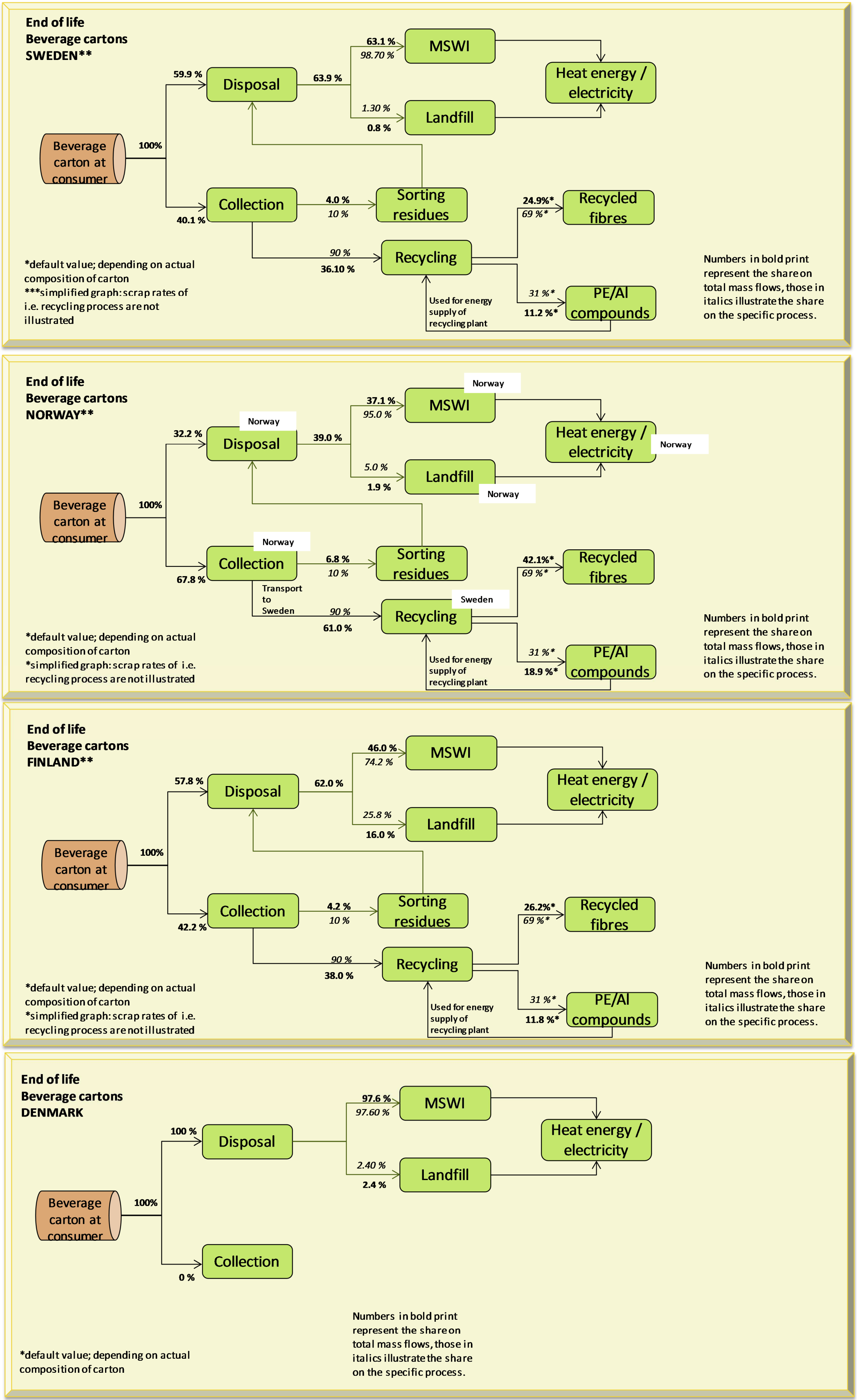


Figure 12: Applied average end-of-life quotas for the beverage cartons in Sweden, Denmark, Finland and Norway. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

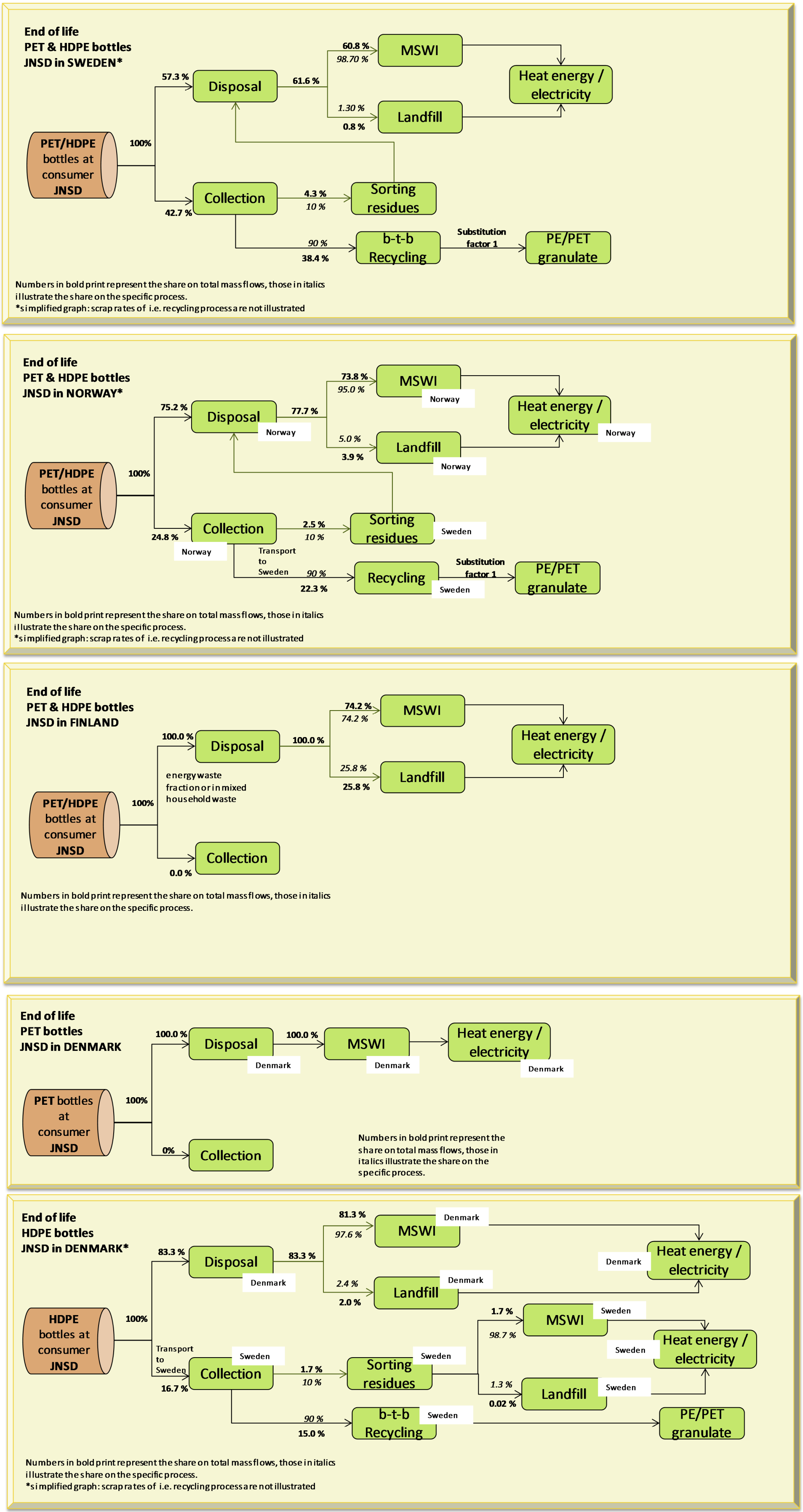


Figure 13: Applied average end-of-life quotas for the PET and HDPE bottles for **JNSD** in Sweden, Denmark, Finland and Norway. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

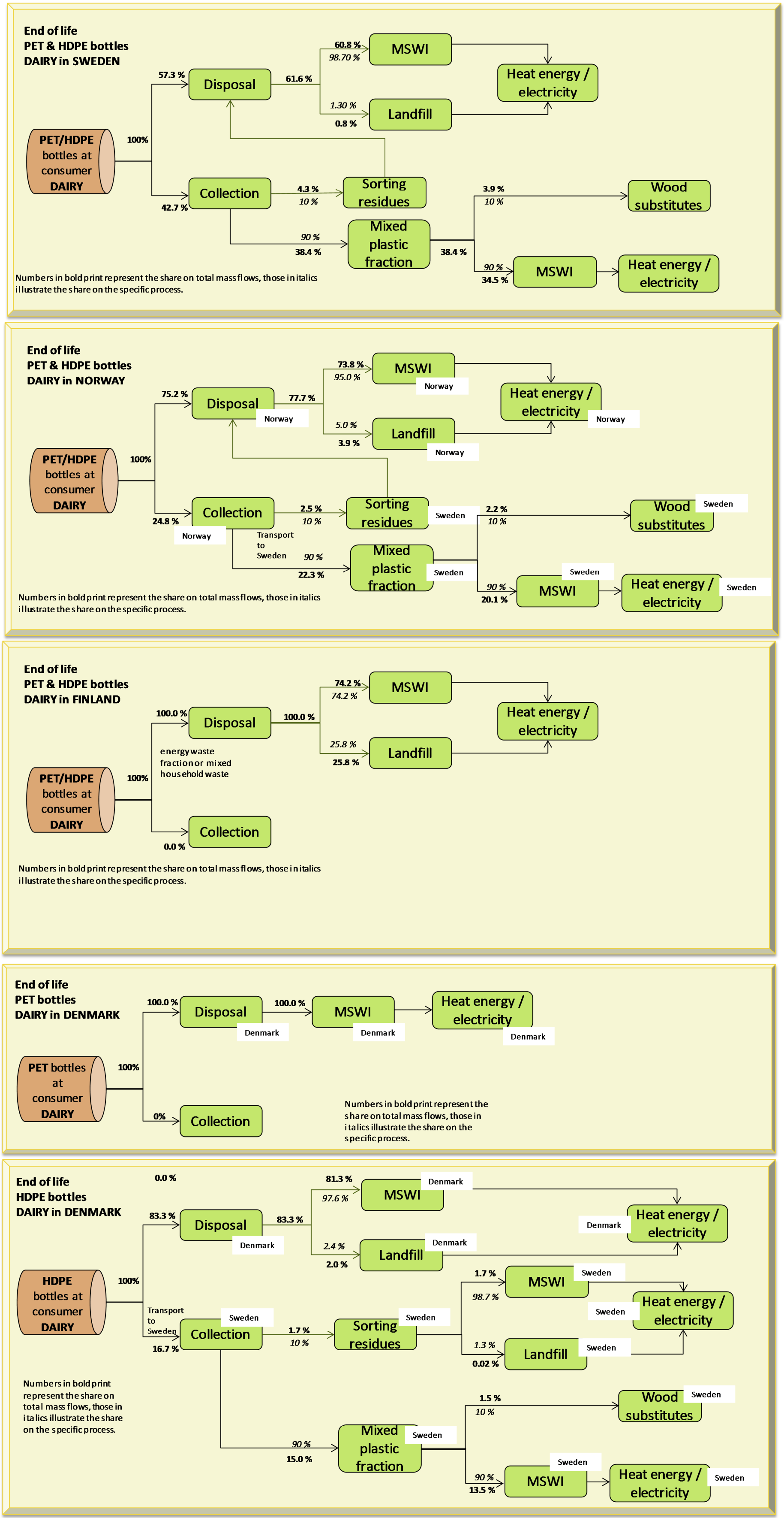


Figure 14: Applied average end-of-life quotas for the PET and HDPE bottles for **DAIRY** in Sweden, Denmark, Finland and Norway. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

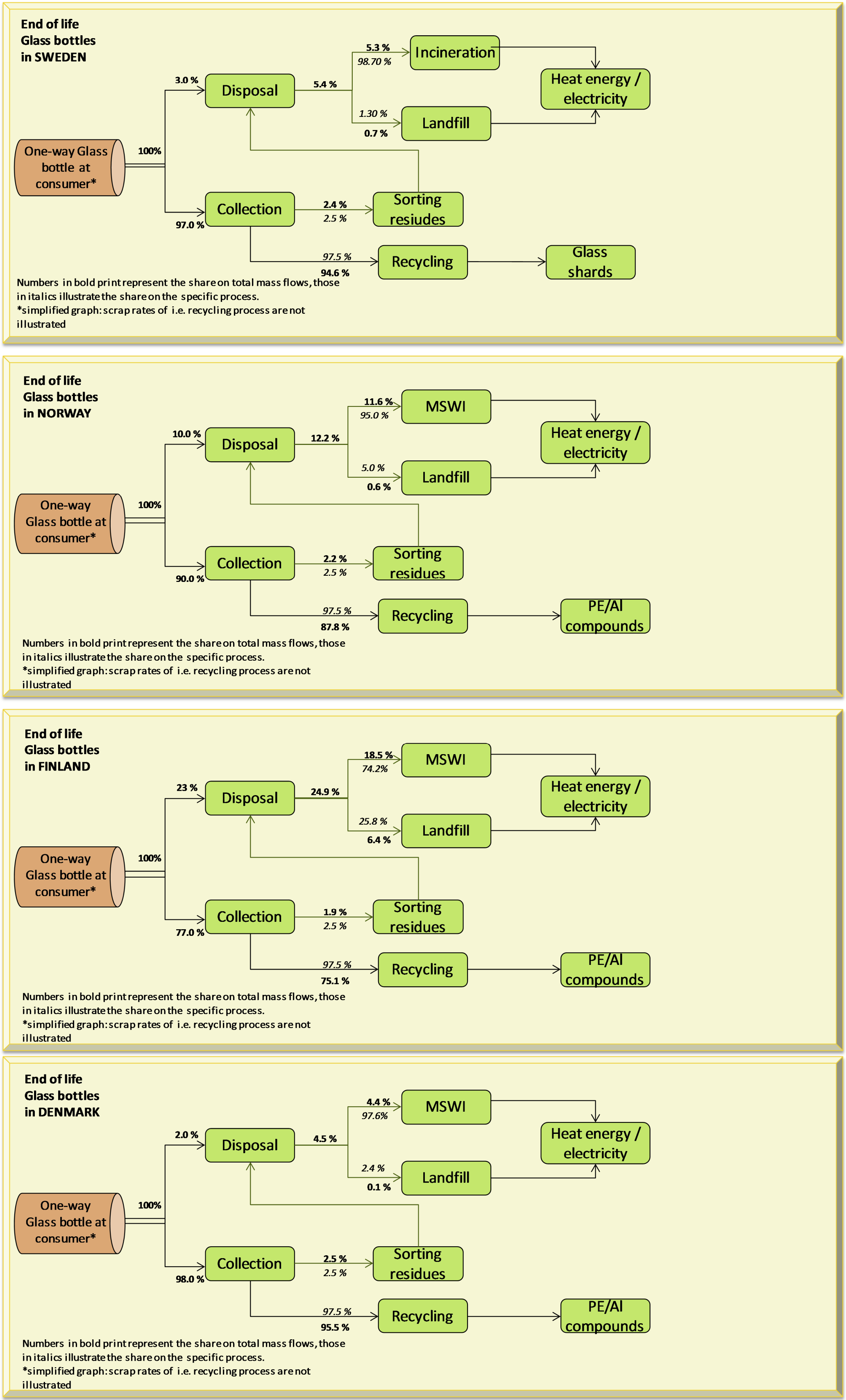


Figure 15: Applied average end-of-life quotas for Glass bottles in Sweden, Denmark, Finland and Norway. Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

2.4 Scenarios

2.4.1 Base scenarios

For each of the studied packaging systems a base scenario for the Swedish, Norwegian, Finnish and Danish 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 subjective 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% will be applied in a ‘sensitivity analysis 100’.

2.4.3 Sensitivity analysis regarding inventory dataset for bio-based PE

In the base scenarios of the study, bio-PE for the modelling of bio-based plastics will be modelled using ifeu’s own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem, the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, a sensitivity analysis applying the data of Braskem will be performed.

2.4.4 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles will be analysed and illustrated in break-even graphs.

Each of the plastic bottles will be additionally calculated with 10% and 30% less PET or HDPE. The values were derived as follows:

1) For each segment the bottle with the lowest weight was selected:
    - Dairy: PET bottle 1 – 22.83 g PET
    - JNSD: PET bottle 4 – 29.40 g PET
    - Grab & Go: APET bottle – 20.19 g PET
2) For each segment the lowest known weight of a plastic bottle was determined. This was done by consulting our in-house expert on plastic bottles, by considering information from projects conducted at ifeu as well as by literature research and publications.
   It became clear, that no more than a reduced weight of 30% is technologically feasible on the European market.

3) A weight reduction to the break-even point between bottles and beverage cartons seems not to be feasible. Considering the results in the base scenarios, the weight of most of the bottles analysed would need to be reduced to a weight which is not technically feasible.

In these analyses, the allocation factor applied for open-loop-recycling is 50%.

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

Table 17: 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
LLDPE	Plastics Europe, published April 2014	2011
BioPE	ifeu database based on different sources e.g. [MACEDO 2008] and [Chalmers 2009] – applied in base scenarios	2005-2011
BioPE	[Braskem 2013] – applied in sensitivity analysis	2012
PET	Plastics Europe, published online April 2011	2008
Titanium dioxide	Ecoinvent V.2.2	1997-2000
Tinplate	Worldsteel	2005/2006
Aluminium	EAA Environmental Profile report 2013 [EAA 2013]	2010
Corrugated cardboard	[FEFCO 2012]	2012
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	2016

Material / Process step	Source	Reference period
Filling plastic bottles	Data provided by Tetra Pak, gathered in 2009, updated in 2016 SBM is included in data for PET bottles	2016
Filling glass bottles	ifeu data obtained from various fillers	2012
Recovery		
Beverage carton recycling	Data from Fiskeby recycling plant (Sweden)	2016
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, Finland & Sweden, Norway, Denmark, Europe	ifeu database, based on statistics and power plant models	2012
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 3.1 [INFRAS 2010].	2009
rail transport	[EcoTransIT 2011]	2011
sea ship transport	[EcoTransIT 2011]	2011

3.1 Plastics

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

- Polypropylene (PP)
- High density polyethylene (HDPE)
- Low density polyethylene (LDPE)
- Linear Low density polyethylene (LLDPE)
- BioPE
- Polyethylentherephthalat (PET)

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 Linear Low Density Polyethylene (LLDPE)

Linear low density polyethylene (LLDPE) is either produced in the gas phase process in a fluidised bed reactor or in the solution process. Depending on the kind of co-monomer chosen, the kind of used technology has to be adapted. The present LCA study uses the ecoprofile published on the website of Plastics Europe [Plastics Europe 2014b].
The data set covers the production of LLDPE 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 9 participating polymerisation units. The data set represent 86% of LDPE production in Europe (EU27+2).

3.1.5 Bio-based Polyethylene (Bio-PE)

As outlined in section 2.4.3, two data sources for the production of bio-based Polyethylene (Bio-PE) are applied within this study:

- Bio-PE dataset compiled by ifeu based on [Macedo 2008] and [Chalmers 2009]
- [Braskem 2013]

The bio-based Polyethylene (PE) used by Tetra Pak is supplied by Braskem in Brazil. The PE is produced from ethanol based on sugar cane. For the inventory dataset for Bio-PE published by Braskem, the substitution approach was chosen, which is considered to be not suitable for the use in this LCA. Therefore the dataset compiled by ifeu based on [Macedo 2008] and [Chalmers 2009] is applied for the base scenarios. However, a sensitivity analysis applying the data of Braskem is performed.

- Bio-PE dataset compiled by ifeu based on [Macedo 2008] and [Chalmers 2009]

The ifeu dataset considers and combines cultivation data from Brazil [Macedo 2008], process data from the internal ifeu database for thick juice, fermentation and polymerization as well as LCA data on Bio-Ethylene based on Chalmers (2009). Allocation between the products of fermentation and molasses is based on the related heating value. The on-site incineration of Bagasse is considered and is based on data from the US Environmental Protection Agency [EPA 1996]. Bagasse serves as by-product of the production of thick juice. The data refer to the time period between 2005 and 2011. The dataset is used for the modelling of Bio-HDPE and Bio-LDPE in this study.

- Bio-PE dataset by Braskem [Braskem 2013]

Braskem finalised an LCA study in 2013 providing data for HDPE made from sugarcane [Braskem 2013]. Although the data are for HDPE, they are also used for LPDE in this study. The LCA report on BioPE from Braskem is confidential. Therefore the detailed documentation of the data is not available, however a public summary report [Braskem 2013, Summary] is available. The LCA study was conducted in accordance with ISO 14040/44 and accompanied by a critical review process. Data for Braskem's manufacturing of bio-based PE refers to the 2012 production year. Since the bio-based ethylene plant start-up commenced in 2011, 2012 production still included periods of improvement and process refinement. As mentioned above, the inventory dataset for Bio-PE published by Braskem applies a substitution approach. No allocation between Bio-PE and co-products take place. Instead an inventory of the production of natural gas is credited for the produced excess electricity, although natural gas is used for only 4.6 % of the production of Brazilian electricity. The subjective choice of the credited dataset may have a bigger influence on the overall inventory results than the process data of the actual PE production. With such an approach, the inventory result is more dependent on subjective choices like this than on actual production data. Due to the fact that data are provided in an aggregated manner an adaption of the inventory data is not possible. This aggregation leads to several other intransparencies of the dataset. For example, it is not possible to fully comprehend how a negative impact on climate change from land use change occurs without access to the underlying assumptions and models. The substitution approach in general and the at least questionable choice of credited inventory data specifically as well as the mentioned intransparencies make this dataset not suitable for the use in this LCA without the additional application of a sensitivty analysis.

3.1.6 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 ecoprofile published on the website of Plastics Europe with a reference year of 2008 [Plastics Europe 2011], that represents the production in European PET plants. Primary data from foreground processes of PTA and PET producers were collected in 2009 for the year 2008. Five PTA plants in Belgium, Italy, the Netherlands, Spain and the United Kingdom supplied data with an overall PTA volume of 2.1 million tonnes – this represents 77% of the European production volume (2.7 million tonnes). For PET production data from 14 production lines at 12 sites in Germany, Greece, Italy, Lithuania, the Netherlands, Spain and the United Kingdom could be obtained. With 1.7 million tonnes they cover 72% of the European bottle grade PET production.

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). 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 for the closures of glass bottles were collected from European steel producers published by the World Steel association (2011). The reference time of the inventory data is 2005/2006 and includes all relevant prechains.

3.4 Glass and glass bottles

The data used for the manufacture of hollow glass were the same as the data acquired and documented for [UBA 2000]. The data set prepared by the glass industry for use in the UBA study gave a representative cross-section of the technologies and energy resources that are used. 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 electricity prechains were updated to represent the situation in 2012. More recent data from BVGlas is available. However, ifeu could not obtain permission to use it for this study. From the author’s perspective it is acceptable to apply older data gathered for [UBA 2000] as technologies in glass production processes didn’t improve during the last years.

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. The dataset is the most recent available.

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 3.1), including a forestry model to calculate inventories for this sub-system. Energy required is supplied by electricity as well as by on-site energy production by incineration of wood and bark. The specific energy sources were taken into account.

3.6 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2012 [FEFCO 2012] 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 2012.

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated cardboard trays. According to [FEFCO 2012] this fraction on average is 15% in Europe. Due to a lack of more specific information this split was also used for the present study.

3.7 Titanium dioxide

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

The data used in this study is taken from ecoinvent database 2.2 [ECOINVENT 2.2] and represents a 50% - 50% mix of those two production processes. The data refers to the years 1997 – 2000 and is representative for Europe.

3.8 Converting

3.8.1 Converting of beverage cartons

The manufacture of composite board was modelled using European average converting data from Tetra Pak that refer to the year 2009. 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.

3.8.2 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 were gathered in 2009 and updated in 2016.

3.8.3 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 2016] and crosschecked with the internal ifeu database.

3.9 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.

3.10 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 2016, 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. For the filling of plastic bottles, data were collected by Tetra Pak in 2009 and updated in 2016. 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 are still evaluated to be valid for 2016, as filling machines and technologies have not changed since then.

3.11 Transport settings

Table 18 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 supplier.

Table 18: 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* 500 / road*	
Aluminium	250 / road*	
Paper board for composite board	200 / road*** 1300 / sea*** 400 / rail***	
Cardboard for trays	primary fibres: 500 / sea, 400 / rail, 250 / road*** secondary fibres: 300/road***	
Wood for pallets	100 / road*	
LDPE stretch foil	500/road (material production site = converter)*	
Trays		500 / road*
Pallets		100 / road*
Converted carton rolls		SE:2200 / road** FI: 2650 / road** NO: 2140 / road** DK: 1550 / road**

*Assumption/Calculation; **provided by Tetra Pak; ***taken from published LCI reports

3.12 Distribution of filled packs from filler to point of sale

Distribution distances have been taken from the previous LCA conducted for the Nordic market in 2009 [IVL 2009].

Table 19 shows the applied distribution distances. Warehouse is the place where the products are temporary stored and then distributed to the different point of slaes (i.e. supermarkets). No distances for return trips are given in [IVL 2009]. 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. For this reason 33% 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 the full return trip to the warehouse is attributed as an empty return trip to the examined system.

Table 19: Distribution distances in km for the examined packaging systems in Sweden, Finland, Norway and Denmark based on [IVL 2009] and adapted by ifeu

		Distribution distance [km] as applied in this study			
		Distribution Step 1		Distribution step 2	
country	**Total transport distance as applied in [IVL 2009]**	**filler > warehouse** (delivery)	**warehouse > filler** (return trip)	**warehouse > POS** (delivery)	**POS > warehouse** (return trip)
Sweden	200	134	60	66	66
Finland	200	134	60	66	66
Norway	200	134	60	66	66
Denmark	100	67	60	33	33

3.13 Recovery and recycling

Beverage cartons

In Finland, Norway and Sweden beverage cartons are typically sorted into a beverage carton fraction, which subsequently is sent to a paper recycling facility for fibre recovery. The secondary fibre material is used e.g. as a raw material for cardboard. The PE-Al compounds resulting from the recycling process are not recycled but incinerated for energy generation at the recycling plant. Credits are given for the secondary fibres and the surplus of energy.

This recycling process is modelled based on process data gathered by IVL for the “Material recycling versus energy recovery of used beverage cartons” study [IVL 2013]. The study provides the efficiency and the energy and water consumption of the recycling process as well as an approach to calculate the PE-Al composition. The data also consider the quality of the secondary fibres (fibres are usually shorter). Therefore a substitution factor of 1 is applied. The data represents the recycling process in the Swedish Fiskeby plant, which is also representative for the recycling of the beverage cartons sold in Norway, since they are recycled in Sweden. The same data is also applied for the Finnish scenarios but in combination with a Finnish electricity prechain as no other country-specific recycling datasets are publicly available.

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.

Used juice and dairy bottles are not collected via a deposit system in Sweden, Finland, Denmark and Norway:

Sorted plastic packaging waste in Sweden is transported to one of four contracted sorting facilities [TemaNord 2014] and recycled Sweden.

According to new agreements from 2014 the plastic packaging waste from Gront Punkt Norge and FTI in Norway are sorted in Sweden and partly in Germany [TemaNord 2014]. Within this study the recycling of packaging waste will be modelled to take place in Sweden. Due to a more favourable electricity grid mix this approach is evaluated as conservative approach (compared to the beverage carton).

The majority of plastic waste from households in Finland is collected within the energy waste fraction or in mixed household waste. The plastic waste is not subject to recycling [TemaNord 2014].

In Denmark also PET bottles without deposits are being collected and transferred to incineration. Collected plastic waste apart from PET bottles is mainly exported to Sweden, Germany or the Netherlands. Within this study a conservative approach from the view of beverage carton is applied: Due to a more favourable electricity grid mix in Sweden compared to Germany and Netherlands the recycling of packaging waste will be modelled to take place in Sweden.

The recycling of non-refundable juice bottles is based on the 'quasi-closed-loop-model'. It is presumed that all recycled packagings made of PET/HDPE feed a material pool serving as source for recycled material. Material which is not used is credited. This approach is applied to avoid allocation according to ISO 14040 ff. Due to the fact that the plastic industries do not provide quality-differentiated PET/HDPE datasets a bottle-to-bottle recycling has to be assumed independent whether the food or non-food segment is examined. Thus a mix of both can be represented in the material pool.

The white opaque plastic bottles used for the packaging of milk are not sorted into the specific recycling fractions. Instead they end up in a mixed plastic fraction and undergo thermal treatment instead of regranulation.

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 59%. 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.

3.14 Background data

3.14.1 Transport processes

Lorry transport

The dataset used is based on standard emission data that were collated, validated, extrapolated and evaluated for the German, Austrian and Swiss Environment Agencies (UBA Berlin, UBA Vienna and BUWAL Bern) in the 'Handbook of emission factors' [INFRAS 2010]. The 'Handbook' is a database application referring to the year 2009 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 2008.

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 55%. Energy use is based on an average fleet composition of this ship category with data taken from [EcoTransIT World 2011]. 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 2011]. 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 2011]. Emission factors and fuel consumption have been applied for direct emissions based on [EcoTransIT World 2011].

[1] Twenty-foot Equivalent Unit

3.14.2 Electricity generation

Modelling of electricity generation is particularly relevant for the production of base materials as well as for converting, filling processes and recycling processes. Electric power supply is modelled using country specific grid electricity mixes, since the environmental burdens of power production varies strongly depending on the electricity generation technology. The country-specific electricity mixes are obtained from a master network for grid power modelling maintained and annually updated at ifeu as described in [ifeu 2013]. It is based on national electricity mix data by the International Energy Agency (IEA)[1]. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2012 for the production of paperboard and the market related mix of energy suppliers in the year 2012 for all other processes depending on their location (e.g. energy for filling process: either Sweden, Finland, Norway, Denmark; energy for corrugated cardboard production: European). The applied shares of energy sources to the related market are given in Table 20.

Table 20: Share of energy source to specific energy mix, reference year 2012.

country / Energy source	EU 28	Sweden	Finland	Denmark	Norway
Hard coal	16.09%	0.28%	9.89%	32.61%	0.02%
Brown coal	10.52%	0.23%	5.12%	0.00%	0.00%
Fuel oil	2.16%	0.37%	0.43%	0.85%	0.03%
Natural gas	18.52%	0.71%	10.06%	13.34%	1.75%
Nuclear energy	26.61%	37.10%	32.37%	0.00%	0.00%
Hydropower/Wind/Solar	*20.45%*	*52.66%*	*25.75%*	*34.47%*	*97.83%*
Hydropower	*56.96%*	*91.59%*	*97.10%*	*0.16%*	*98.91%*
Windpower	*32.27%*	*8.38%*	*2.87%*	*98.90%*	*1.09%*
Solar energy	*9.91%*	*0.02%*	*0.03%*	*0.94%*	*0.00%*
Geothermal energy	0.85%	0.00%	0.00%	0.00%	0.00%
Biomass energy	3.89%	6.04%	15.11%	10.97%	0.17%
Waste	1.75%	2.63%	1.26%	7.76%	0.20%

3.14.3 Municipal waste incineration

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

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

Table 21: Electrical and thermal efficiencies of the incineration plants in the four studied markets.

Country	Electrical efficiency	Thermal efficiency	Reference period	Source
Denmark	14%	54%	2008	[CEWEP 2010][1]
Finland	7%	48%	2012	[CEWEP 2015]
Norway	7%	48%	2012	[CEWEP 2015]
Sweden	7%	80%	2013	[CEWEP 2016]

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.

3.14.4 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 1996], 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.

[1] The CEWEP reports are published annually, but for Denmark, only older versions are available

4 Results Sweden

In this section, the results of the examined packaging systems for Sweden 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 including additives, e.g. carbon black (**'PET/HDPE'**)
- 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')**
- sorting, recycling and disposal processes **('recycling & disposal')**
- CO_2 emissions from incineration of biobased and renewable materials **('CO2 reg. (EOL)'**; in the following also the term regenerative CO2 emissions is used

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**')

For the sensitivity analysis including the BRASKEM bio-PE dataset the sector '**CO2 – direct landuse change**' (dLUC) is introduced. This sector shows changes in soil organic carbon and above and below ground carbon stocks from conversion of land to sugarcane cultivation. The BRASKEM dataset accounts a negative CO2 value for dLUC.

The material and energy credits are summed up into one category ('**credits energy/material**').

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 can be considered a common practice for LCA studies comparing different product systems. This means differences ≤ 10% are considered as insignificant.

4.1 Results base scenarios DAIRY SWEDEN

4.1.1 Presentation of results DAIRY Sweden

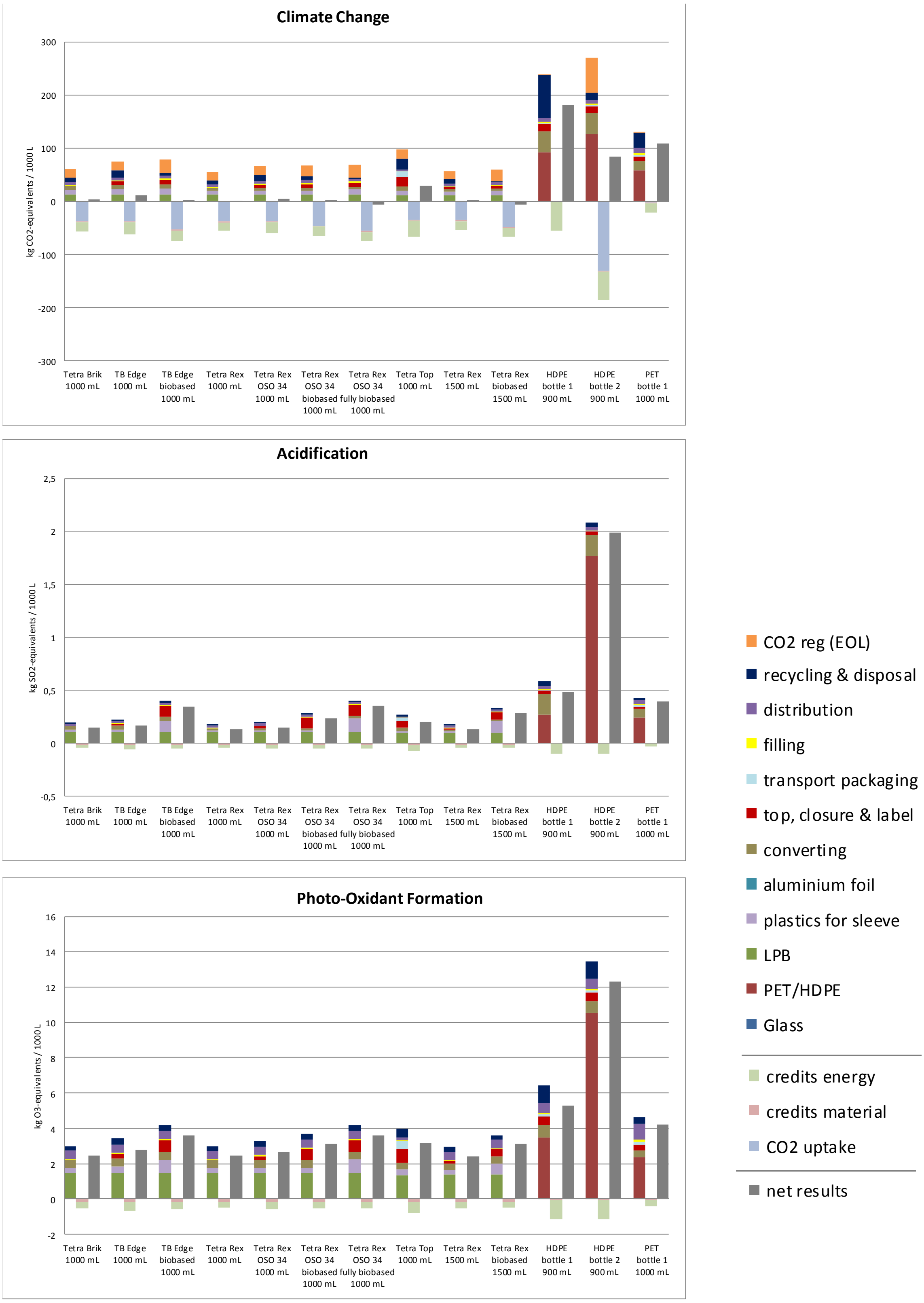


Figure 16: Indicator results for base scenarios of **segment Dairy, Sweden**, allocation factor 50% (Part 1)

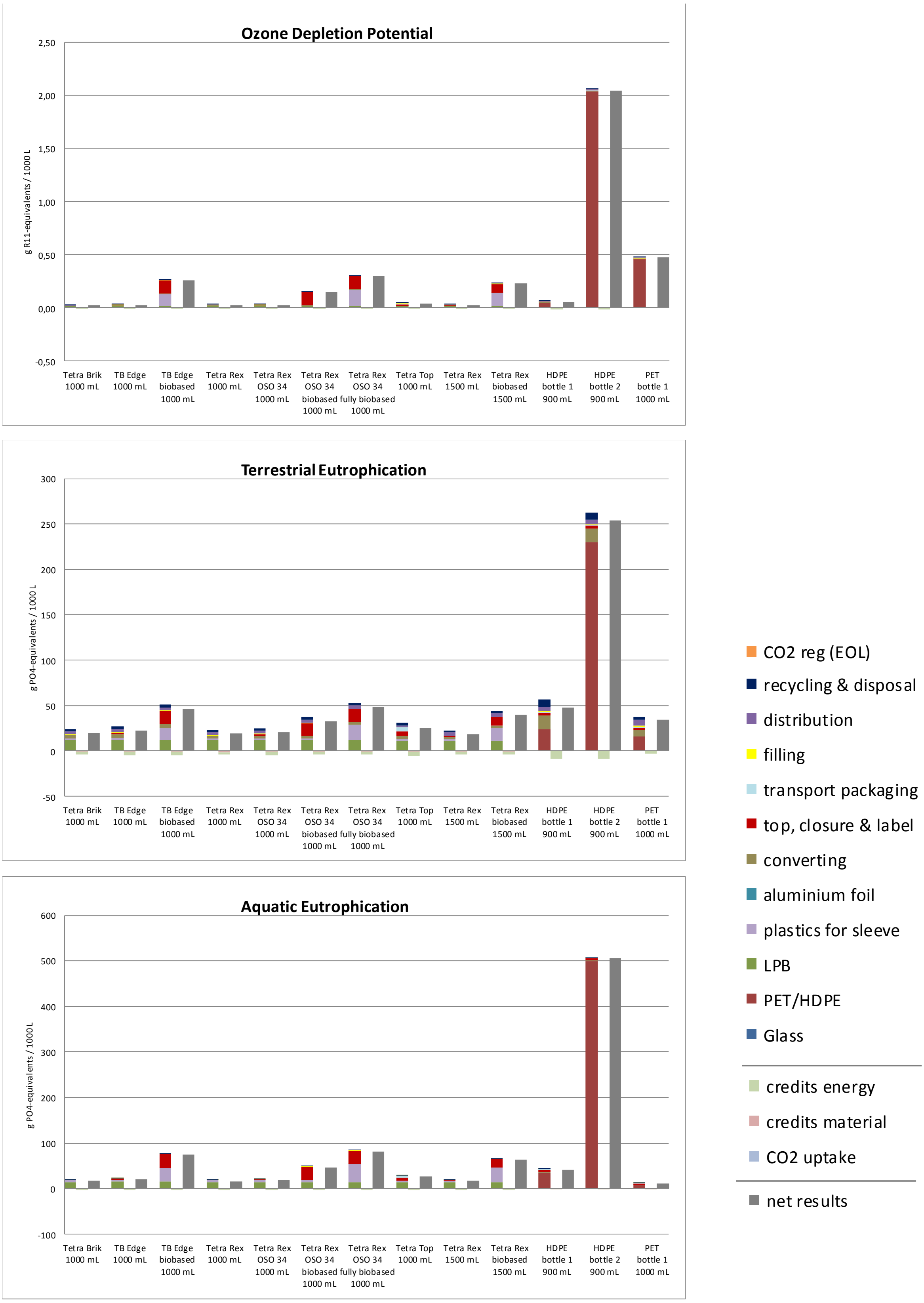


Figure 17 Indicator results for base scenarios of **segment Dairy, Sweden**, allocation factor 50% (Part 2)

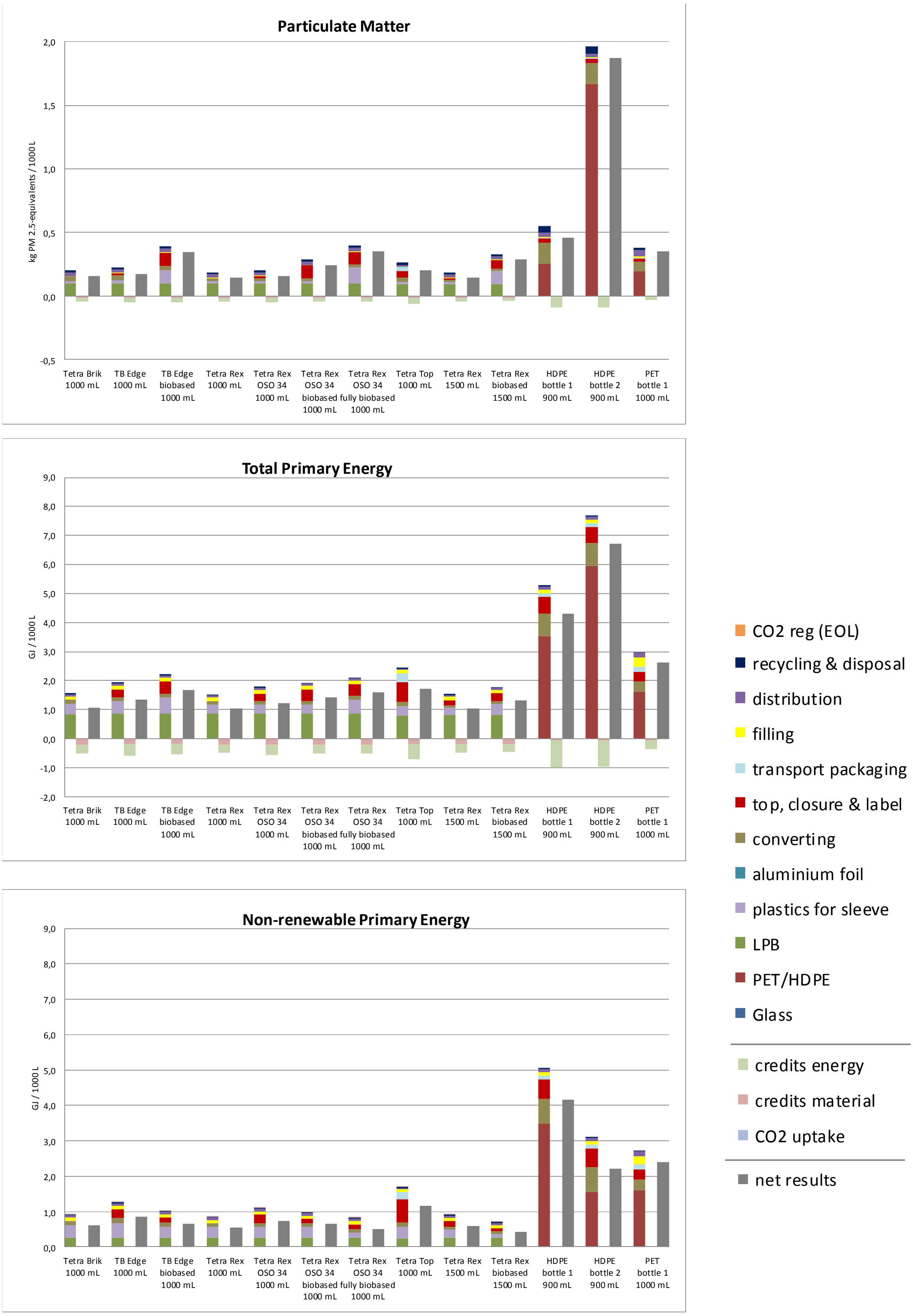


Figure 18: Indicator results for base scenarios of segment Dairy, Sweden, allocation factor 50% (Part 3)

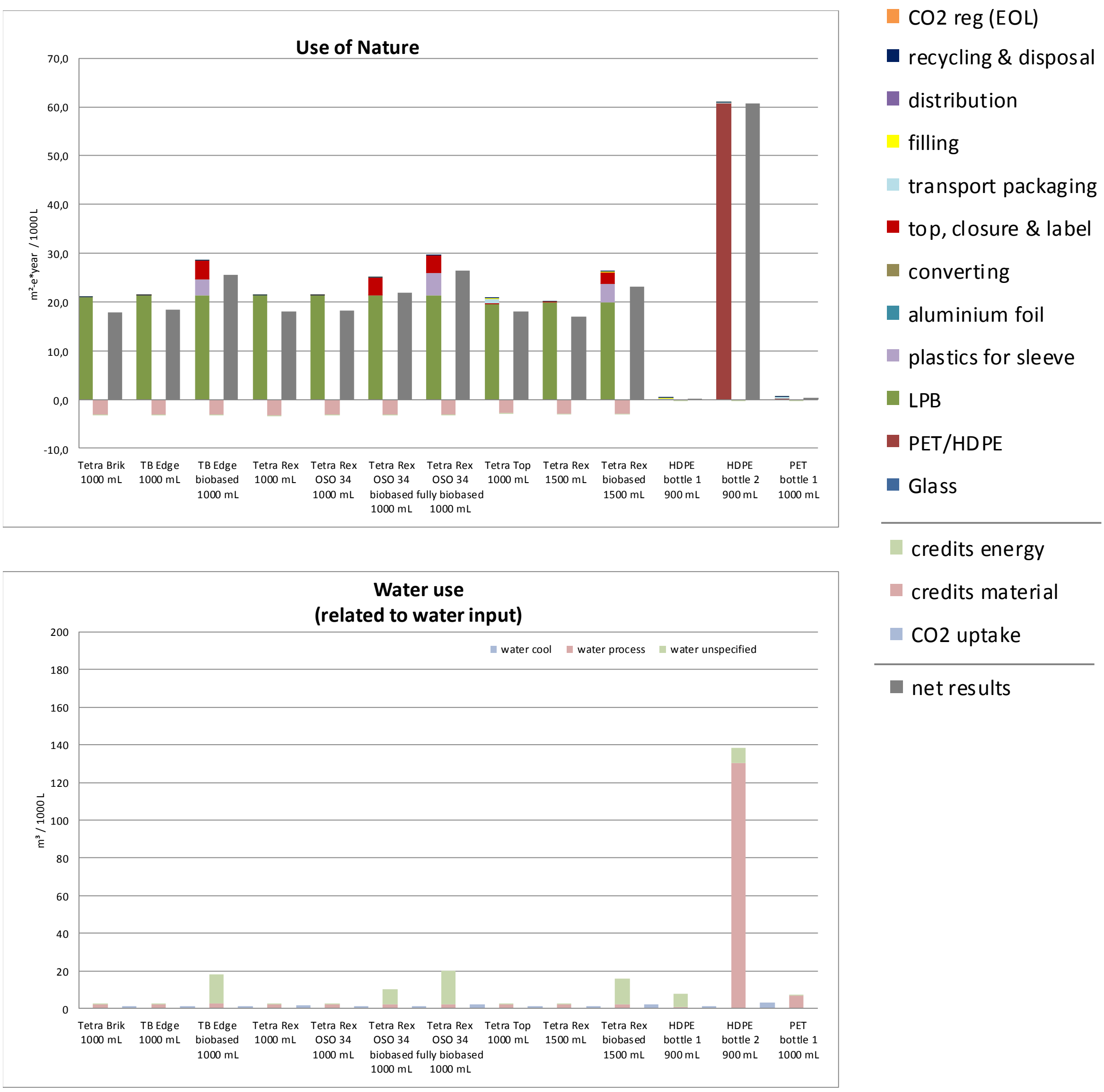


Figure 19: Indicator results for base scenarios of **segment Dairy, Sweden**, allocation factor 50% (Part 4)

Table 22: Category indicator results per impact category for base scenarios of segment DAIRY, Sweden- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Sweden, allocation factor 50 %		Tetra Brik 1000 mL	Tetra Brik Edge 1000 mL	Tetra Brik Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	44.37	58.24	53.28	39.24	49.29
	CO2 (reg)	15.84	16.28	24.61	16.06	16.18
	Credits	-19.28	-25.01	-22.15	-18.41	-22.45
	CO_2 uptake	-37.39	-38.02	-53.46	-37.99	-37.99
	Net results (∑)	3.54	11.50	2.29	-1.10	5.04
Acidification [kg SO_2-equivalents]	Burdens	0.20	0.22	0.40	0.18	0.20
	Credits	-0.05	-0.06	-0.05	-0.05	-0.05
	Net results (∑)	0.15	0.17	0.34	0.13	0.14
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	3.00	3.43	4.19	2.98	3.27
	Credits	-0.54	-0.66	-0.60	-0.53	-0.61
	Net results (∑)	2.46	2.77	3.60	2.46	2.67
Ozone Depletion [g R-11-equivalents]	Burdens	0.02	0.03	0.27	0.03	0.03
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01
	Net results (∑)	0.02	0.02	0.26	0.02	0.03
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	23.89	26.94	50.96	22.86	24.92
	Credits	-4.15	-5.04	-4.58	-4.04	-4.66
	Net results (∑)	19.75	21.90	46.38	18.82	20.26
Aquatic eutrophication [g PO_4-equivalents]	Burdens	18.84	22.54	77.04	18.55	20.87
	Credits	-2.14	-2.09	-2.09	-2.21	-2.15
	Net results (∑)	16.70	20.45	74.95	16.35	18.72
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.20	0.23	0.39	0.19	0.21
	Credits	-0.04	-0.05	-0.05	-0.04	-0.05
	Net results (∑)	0.16	0.18	0.34	0.14	0.16
Total Primary Energy [GJ]	Burdens	1.56	1.94	2.21	1.52	1.79
	Credits	-0.50	-0.60	-0.55	-0.49	-0.56
	Net results (∑)	1.06	1.34	1.67	1.03	1.23
Non-renewable primary energy [GJ]	Burdens	0.93	1.27	1.03	0.86	1.11
	Credits	-0.32	-0.41	-0.37	-0.31	-0.37
	Net results (∑)	0.61	0.85	0.66	0.56	0.73
Use of Nature [m^2-equivalents*year]	Burdens	21.01	21.41	28.54	21.35	21.40
	Credits	-3.11	-3.01	-3.01	-3.20	-3.10
	Net results (∑)	17.90	18.41	25.53	18.15	18.30
Water use [m^3]	Water cool	0.96	1.26	1.05	1.17	1.40
	Water process	2.06	2.31	2.43	2.07	2.09
	Water unspec	0.26	0.30	15.52	0.27	0.30

Table 23: Category indicator results per impact category for base scenarios of segment DAIRY, Sweden- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Sweden, allocation factor 50 %		Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex Biobased 1500 mL
Climate change [kg CO_2-equivalents]	Burdens	46.96	43.47	80.17	41.69	37.29
	CO2 (reg)	20.17	25.92	16.77	15.09	22.46
	Credits	-19.69	-19.69	-32.28	-19.23	-17.39
	CO_2 uptake	-45.86	-55.84	-34.94	-35.56	-48.97
	Net results (∑)	1.57	-6.13	29.73	1.99	-6.61
Acidification [kg SO_2-equivalents]	Burdens	0.29	0.40	0.27	0.18	0.33
	Credits	-0.05	-0.05	-0.07	-0.05	-0.04
	Net results (∑)	0.24	0.35	0.20	0.13	0.29
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	3.67	4.16	3.95	2.95	3.61
	Credits	-0.55	-0.55	-0.80	-0.53	-0.49
	Net results (∑)	3.12	3.61	3.15	2.42	3.12
Ozone Depletion [g R-11-equivalents]	Burdens	0.15	0.30	0.05	0.03	0.23
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01
	Net results (∑)	0.14	0.30	0.04	0.02	0.23
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	37.13	52.70	31.32	22.55	43.42
	Credits	-4.21	-4.21	-6.12	-4.09	-3.79
	Net results (∑)	32.92	48.49	25.20	18.46	39.63
Aquatic eutrophication [g PO_4-equivalents]	Burdens	48.72	83.84	28.50	18.63	65.92
	Credits	-2.15	-2.15	-1.97	-2.04	-2.04
	Net results (∑)	46.57	81.69	26.53	16.58	63.87
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.29	0.39	0.26	0.18	0.33
	Credits	-0.04	-0.04	-0.06	-0.04	-0.04
	Net results (∑)	0.24	0.35	0.20	0.14	0.29
Total Primary Energy [GJ]	Burdens	1.93	2.10	2.44	1.54	1.78
	Credits	-0.51	-0.51	-0.71	-0.49	-0.46
	Net results (∑)	1.42	1.59	1.73	1.05	1.32
Non-renewable primary energy [GJ]	Burdens	0.99	0.83	1.70	0.92	0.71
	Credits	-0.33	-0.33	-0.54	-0.32	-0.29
	Net results (∑)	0.66	0.51	1.17	0.60	0.42
Use of Nature [m^2-equivalents*year]	Burdens	25.04	29.64	20.75	20.02	26.21
	Credits	-3.10	-3.10	-2.71	-2.96	-2.96
	Net results (∑)	21.94	26.54	18.04	17.06	23.25
Water use [m^3]	Water cool	1.32	1.14	1.93	1.17	0.97
	Water process	2.15	2.23	1.98	2.01	2.11
	Water unspec	8.07	17.89	0.34	0.27	13.48

Table 24: Category indicator results per impact category for base scenarios of segment DAIRY, Sweden - burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Sweden, allocation factor 50 %		HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	236.56	204.72	128.84
	CO2 (reg)	0.24	64.95	1.58
	Credits	-55.39	-54.66	-18.84
	CO_2 uptake	0.00	-131.36	-2.66
	Net results (∑)	181.41	83.65	108.92
Acidification [kg SO_2-equivalents]	Burdens	0.58	2.08	0.43
	Credits	-0.10	-0.10	-0.03
	Net results (∑)	0.48	1.98	0.39
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	6.45	13.47	4.64
	Credits	-1.18	-1.17	-0.42
	Net results (∑)	5.27	12.30	4.22
Ozone Depletion [g R-11-equivalents]	Burdens	0.07	2.06	0.48
	Credits	-0.02	-0.02	-0.01
	Net results (∑)	0.05	2.04	0.47
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	56.43	262.34	37.59
	Credits	-8.97	-8.85	-3.11
	Net results (∑)	47.46	253.48	34.48
Aquatic eutrophication [g PO_4-equivalents]	Burdens	42.26	506.84	11.80
	Credits	-0.43	-0.43	-0.53
	Net results (∑)	41.84	506.42	11.28
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.55	1.96	0.38
	Credits	-0.09	-0.09	-0.03
	Net results (∑)	0.46	1.87	0.35
Total Primary Energy [GJ]	Burdens	5.29	7.70	2.98
	Credits	-0.98	-0.97	-0.36
	Net results (∑)	4.31	6.73	2.62
Non-renewable primary energy [GJ]	Burdens	5.07	3.12	2.73
	Credits	-0.92	-0.91	-0.33
	Net results (∑)	4.15	2.22	2.40
Use of Nature [m^2-equivalents*year]	Burdens	0.32	61.01	0.56
	Credits	-0.25	-0.25	-0.15
	Net results (∑)	0.06	60.75	0.41
Water use [m^3]	Water cool	1.96	0.99	3.22
	Water process	0.71	130.19	6.81
	Water unspec	7.20	8.28	0.06

4.1.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the dairy 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 significant share of the burdens of the impact categories 'Aquatic Eutrophication' and 'Use of Nature'. It is also relevant regarding 'Photo-Oxidant Formation' 'Acidification', 'Terrestrial Eutrophication', 'Particulate Matter' and the consumption of 'Total Primary Energy' and 'Non-renewable Primary Energy'.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category 'Non-renewable Primary Energy', where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the 'TB Edge bio-based', the 'Tetra Rex fully bio-based' and the 'Tetra Rex bio-based' due to the production of bio-based PE and relatively lower for 'Tetra Top' where the plastics of top and closure show the highest burdens.

The sector top, closure & label plays a role in almost all impact categories. The one exception obviously being the 'Tetra Brik' and 'Tetra Rex 1000 mL' without a separate closure. The impacts of the production of plastics for the closures is higher for 'TB Edge bio-based', 'Tetra Rex OSO 34 bio-based', 'Tetra Rex fully bio-based' and 'Tetra Rex bio-based' than for the 'TB Edge', 'Tetra Rex OSO 34' and Tetra Rex 1500 mL with a fossil-based closure in all categories apart from 'Non-renewable Primary Energy'. The sector is especially important for 'Tetra Top' as its combined Top and Cap uses about three times more plastic than the other closure systems of the other beverage cartons.

Especially if bio-based plastics are used for sleeve and/or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role for the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

CO_2 emissions from incineration of biobased and renewable materials (CO2 reg (EOL)) play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. For the different Tetra Edge and Tetra Rex packaging systems the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal. It's the other way around for the 'Tetra Top' as the higher share of fossil-based plastics in that packaging system leads to more non-regenerative CO_2 emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Sweden 36.1% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category Use of Nature. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 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. Exceptions are the 'Ozone Depletion Potential' of the 'HDPE bottle 1' and the 'Aquatic Eutrophication' of 'PET bottle 1' as well as 'Use of Nature' of both these fossil-based plastic bottles.

For the three regarded bottles three different plastics are used: Fossil-based HDPE for the 'HDPE bottle 1'm bio-based PE for the 'HDPE bottle 2' and fossil-based PET for the 'PET bottle 1'. The closures of all three of them are made from HDPE. Therefore the impacts of plastics production on different categories vary accordingly. For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for both HDPE bottles than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide. The even higher burdens of bio-based PE of the 'HDPE bottle 2' originate from field emissions of N_2O from the use of nitrogen fertilisers on sugarcane fields. The agricultural background of the 'HDPE bottle 2' also means that for 'Use of Nature' the production of Bio-PE is the main contributor to this category.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the fossil-based plastic bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the white opaque plastic bottles do not undergo a material recycling, the amount of bottle waste incinerated is relatively high. The regenerative CO_2 emissions from the bio-based 'HDPE bottle 2' are of course similarly high, but they are attributed to the sector CO_2 reg (EOL).

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. 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 insignificant compared to the credits for energy.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

4.1.3 Comparison between packaging systems

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

Table 25: Comparison of net results: **Tetra Brik 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Brik 1000 mL** are lower (green)/ higher (orange) than those of											
	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-69%	55%	422%	-30%	125%	158%	-88%	78%	154%	-98%	-96%	-97%
Acidification	-11%	-57%	12%	2%	-38%	-58%	-26%	12%	-48%	-69%	-93%	-62%
Photo-Oxidant Formation	-11%	-32%	0%	-8%	-21%	-32%	-22%	2%	-21%	-53%	-80%	-42%
Ozone Depletion Potential	-16%	-92%	-7%	-17%	-86%	-93%	-43%	-6%	-91%	-61%	-99%	-96%
Terrestrial Eutrophication	-10%	-57%	5%	-3%	-40%	-59%	-22%	7%	-50%	-58%	-92%	-43%
Aquatic Eutrophication	-18%	-78%	2%	-11%	-64%	-80%	-37%	1%	-74%	-60%	-97%	48%
Particulate Matter	-11%	-55%	9%	0%	-36%	-55%	-23%	10%	-46%	-66%	-92%	-55%
Total Primary Energy	-21%	-36%	3%	-14%	-25%	-33%	-39%	1%	-19%	-75%	-84%	-60%
Non-renewable Primary Energy	-29%	-8%	9%	-17%	-8%	20%	-48%	1%	43%	-85%	-73%	-75%

Table 26: Comparison of net results: **Tetra Brik Edge 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **TB Edge1000 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	225%	402%	1144%	128%	631%	288%	-61%	477%	274%	-94%	-86%	-89%
Acidification	12%	-52%	26%	15%	-30%	-53%	-17%	27%	-42%	-66%	-92%	-58%
Photo-Oxidant Formation	13%	-23%	13%	4%	-11%	-23%	-12%	15%	-11%	-47%	-77%	-34%
Ozone Depletion Potential	19%	-90%	11%	-2%	-83%	-92%	-32%	11%	-89%	-54%	-99%	-95%
Terrestrial Eutrophication	11%	-53%	16%	8%	-33%	-55%	-13%	19%	-45%	-54%	-91%	-36%
Aquatic Eutrophication	22%	-73%	25%	9%	-56%	-75%	-23%	23%	-68%	-51%	-96%	81%
Particulate Matter	12%	-49%	22%	12%	-28%	-50%	-13%	23%	-39%	-62%	-91%	-50%
Total Primary Energy	27%	-19%	30%	9%	-5%	-16%	-22%	28%	2%	-69%	-80%	-49%
Non-renewable Primary Energy	40%	29%	52%	16%	29%	68%	-27%	42%	100%	-80%	-62%	-65%

Table 27: Comparison of net results: **Tetra Brik Edge biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **TB Edge biobased 1000 mL** are lower (green)/ higher (orange) than those of										
	Tetra Brik 1000 mL	TB Edge 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-35%	-80%	308%	-55%	46%	-92%	15%	135%	-99%	-97%	-98%
Acidification	133%	108%	161%	138%	45%	72%	163%	21%	-28%	-83%	-12%
Photo-Oxidant Formation	46%	30%	46%	35%	15%	14%	49%	15%	-32%	-71%	-15%
Ozone Depletion Potential	1149%	951%	1064%	933%	79%	611%	1071%	15%	385%	-87%	-45%
Terrestrial Eutrophication	135%	112%	146%	129%	41%	84%	151%	17%	-2%	-82%	35%
Aquatic Eutrophication	349%	266%	359%	300%	61%	183%	352%	17%	79%	-85%	565%
Particulate Matter	120%	95%	139%	119%	41%	70%	141%	20%	-25%	-82%	-2%
Total Primary Energy	57%	24%	62%	36%	17%	-4%	59%	27%	-61%	-75%	-36%
Non-renewable Primary Energy	9%	-22%	18%	-10%	0%	-43%	10%	56%	-84%	-70%	-72%

Table 28: Comparison of net results: **Tetra Rex 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Rex1000 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-131%	-110%	-148%	-122%	-170%	82%	-104%	-155%	83%	-101%	-101%	-101%
Acidification	-11%	-20%	-62%	-9%	-44%	-62%	-34%	1%	-54%	-73%	-93%	-66%
Photo-Oxidant Formation	0%	-11%	-32%	-8%	-21%	-32%	-22%	2%	-21%	-53%	-80%	-42%
Ozone Depletion Potential	7%	-10%	-91%	-11%	-85%	-92%	-39%	1%	-90%	-58%	-99%	-95%
Terrestrial Eutrophication	-5%	-14%	-59%	-7%	-43%	-61%	-25%	2%	-53%	-60%	-93%	-45%
Aquatic Eutrophication	-2%	-20%	-78%	-13%	-65%	-80%	-38%	-1%	-74%	-61%	-97%	45%
Particulate Matter	-8%	-18%	-58%	-8%	-41%	-59%	-29%	1%	-50%	-69%	-92%	-59%
Total Primary Energy	-3%	-23%	-38%	-16%	-27%	-35%	-41%	-2%	-22%	-76%	-85%	-61%
Non-renewable Primary Energy	-8%	-34%	-16%	-24%	-16%	10%	-52%	-7%	32%	-87%	-75%	-77%

Table 29: Comparison of net results: **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Rex OSO 34 1000 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	42%	-56%	120%	558%	220%	182%	-83%	153%	176%	-97%	-94%	-95%
Acidification	-2%	-13%	-58%	10%	-39%	-59%	-28%	10%	-49%	-70%	-93%	-63%
Photo-Oxidant Formation	9%	-4%	-26%	8%	-15%	-26%	-15%	10%	-15%	-49%	-78%	-37%
Ozone Depletion Potential	21%	2%	-90%	13%	-83%	-92%	-31%	13%	-89%	-53%	-99%	-95%
Terrestrial Eutrophication	3%	-7%	-56%	8%	-38%	-58%	-20%	10%	-49%	-57%	-92%	-41%
Aquatic Eutrophication	12%	-8%	-75%	15%	-60%	-77%	-29%	13%	-71%	-55%	-96%	66%
Particulate Matter	0%	-11%	-54%	9%	-36%	-55%	-22%	10%	-45%	-66%	-92%	-55%
Total Primary Energy	16%	-8%	-26%	19%	-13%	-23%	-29%	17%	-7%	-71%	-82%	-53%
Non-renewable Primary Energy	21%	-14%	11%	32%	11%	45%	-37%	22%	73%	-82%	-67%	-69%

Table 30: Comparison of net results: **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Rex OSO 34 biobased 1000 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 fully biobased	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-56%	-86%	-31%	243%	-69%	126%	-95%	-21%	124%	-99%	-98%	-99%
Acidification	61%	43%	-31%	79%	64%	-32%	18%	81%	-17%	-51%	-88%	-39%
Photo-Oxidant Formation	27%	13%	-13%	27%	17%	-14%	-1%	29%	0%	-41%	-75%	-26%
Ozone Depletion Potential	599%	488%	-44%	551%	478%	-51%	298%	555%	-36%	171%	-93%	-69%
Terrestrial Eutrophication	67%	50%	-29%	75%	62%	-32%	31%	78%	-17%	-31%	-87%	-5%
Aquatic Eutrophication	179%	128%	-38%	185%	149%	-43%	76%	181%	-27%	11%	-91%	313%
Particulate Matter	56%	39%	-29%	69%	55%	-30%	21%	71%	-15%	-47%	-87%	-30%
Total Primary Energy	34%	6%	-15%	38%	15%	-11%	-18%	35%	8%	-67%	-79%	-46%
Non-renewable Primary Energy	9%	-22%	0%	19%	-10%	31%	-43%	10%	56%	-84%	-70%	-72%

Table 31: Comparison of net results: **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Rex OSO 34 fully biobased 1000 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Top 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-273%	-153%	-367%	-457%	-222%	-490%	-121%	-407%	7%	-103%	-107%	-106%
Acidification	138%	111%	2%	166%	142%	48%	75%	167%	23%	-27%	-82%	-10%
Photo-Oxidant Formation	47%	30%	0%	47%	35%	16%	15%	49%	16%	-31%	-71%	-14%
Ozone Depletion Potential	1326%	1101%	14%	1229%	1079%	104%	712%	1238%	31%	454%	-86%	-38%
Terrestrial Eutrophication	146%	121%	5%	158%	139%	47%	92%	163%	22%	2%	-81%	41%
Aquatic Eutrophication	389%	299%	9%	400%	336%	75%	208%	393%	28%	95%	-84%	624%
Particulate Matter	124%	99%	2%	143%	123%	44%	73%	146%	22%	-24%	-81%	0%
Total Primary Energy	50%	19%	-4%	55%	30%	12%	-8%	52%	21%	-63%	-76%	-39%
Non-renewable Primary Energy	-17%	-40%	-23%	-9%	-31%	-23%	-57%	-16%	19%	-88%	-77%	-79%

Table 32: Comparison of net results: **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Top1000 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Rex 1500 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	739%	159%	1198%	2800%	490%	1790%	585%	1391%	549%	-84%	-64%	-73%
Acidification	36%	21%	-42%	52%	38%	-15%	-43%	53%	-30%	-58%	-90%	-49%
Photo-Oxidant Formation	28%	14%	-12%	28%	18%	1%	-13%	30%	1%	-40%	-74%	-25%
Ozone Depletion Potential	76%	48%	-86%	64%	45%	-75%	-88%	65%	-84%	-32%	-98%	-92%
Terrestrial Eutrophication	28%	15%	-46%	34%	24%	-23%	-48%	36%	-36%	-47%	-90%	-27%
Aquatic Eutrophication	59%	30%	-65%	62%	42%	-43%	-68%	60%	-58%	-37%	-95%	135%
Particulate Matter	29%	15%	-41%	40%	29%	-17%	-42%	42%	-30%	-56%	-89%	-42%
Total Primary Energy	63%	29%	4%	68%	41%	22%	9%	65%	31%	-60%	-74%	-34%
Non-renewable Primary Energy	92%	37%	76%	109%	59%	76%	130%	94%	174%	-72%	-47%	-51%

Table 33: Comparison of net results: **Tetra Rex 1500 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Rex1500 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	Tetra Rex biobased 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-44%	-83%	-13%	281%	-60%	27%	133%	-93%	130%	-99%	-98%	-98%
Acidification	-11%	-21%	-62%	-1%	-9%	-45%	-63%	-35%	-54%	-73%	-93%	-66%
Photo-Oxidant Formation	-2%	-13%	-33%	-2%	-9%	-23%	-33%	-23%	-23%	-54%	-80%	-43%
Ozone Depletion Potential	7%	-10%	-91%	-1%	-12%	-85%	-93%	-39%	-90%	-59%	-99%	-95%
Terrestrial Eutrophication	-7%	-16%	-60%	-2%	-9%	-44%	-62%	-27%	-53%	-61%	-93%	-46%
Aquatic Eutrophication	-1%	-19%	-78%	1%	-11%	-64%	-80%	-37%	-74%	-60%	-97%	47%
Particulate Matter	-9%	-19%	-59%	-1%	-9%	-42%	-59%	-30%	-50%	-69%	-92%	-59%
Total Primary Energy	-1%	-22%	-37%	2%	-15%	-26%	-34%	-39%	-20%	-76%	-84%	-60%
Non-renewable Primary Energy	-1%	-29%	-9%	7%	-18%	-9%	19%	-48%	41%	-86%	-73%	-75%

Table 34: Comparison of net results: **Tetra Rex biobased 1500 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

segment DAIRY (chilled), Sweden	The net results of **Tetra Rex biobased 1500 mL** are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000 mL	TB Edge 1000 mL	TB Edge biobased 1000 mL	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	Tetra Rex 1500 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-287%	-158%	-389%	-501%	-231%	-521%	-8%	-122%	-432%	-104%	-108%	-106%
Acidification	94%	72%	-17%	116%	97%	21%	-19%	43%	118%	-41%	-86%	-27%
Photo-Oxidant Formation	27%	13%	-13%	27%	17%	0%	-14%	-1%	29%	-41%	-75%	-26%
Ozone Depletion Potential	987%	815%	-13%	913%	799%	56%	-24%	519%	919%	322%	-89%	-52%
Terrestrial Eutrophication	101%	81%	-15%	111%	96%	20%	-18%	57%	115%	-16%	-84%	15%
Aquatic Eutrophication	283%	212%	-15%	291%	241%	37%	-22%	141%	285%	53%	-87%	466%
Particulate Matter	84%	63%	-16%	100%	83%	18%	-18%	42%	102%	-37%	-85%	-18%
Total Primary Energy	24%	-2%	-21%	28%	7%	-7%	-17%	-24%	26%	-69%	-80%	-50%
Non-renewable Primary Energy	-30%	-50%	-36%	-24%	-42%	-36%	-16%	-64%	-29%	-90%	-81%	-82%

4.2 Results base scenarios JNSD SWEDEN

4.2.1 Presentation of results JNSD Sweden

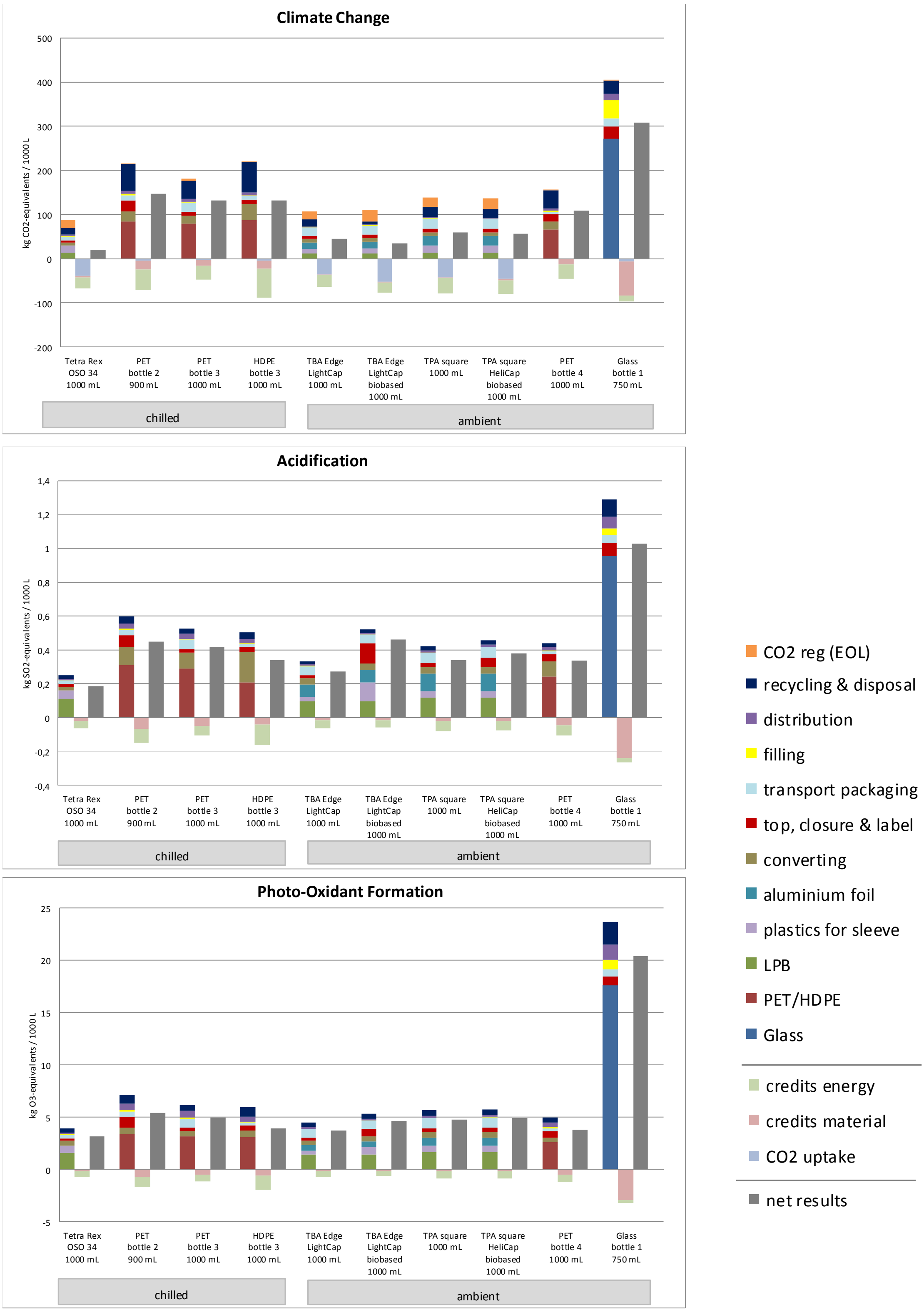


Figure 20: Indicator results for base scenarios of **segment JNSD, Sweden**, allocation factor 50% (Part 1)

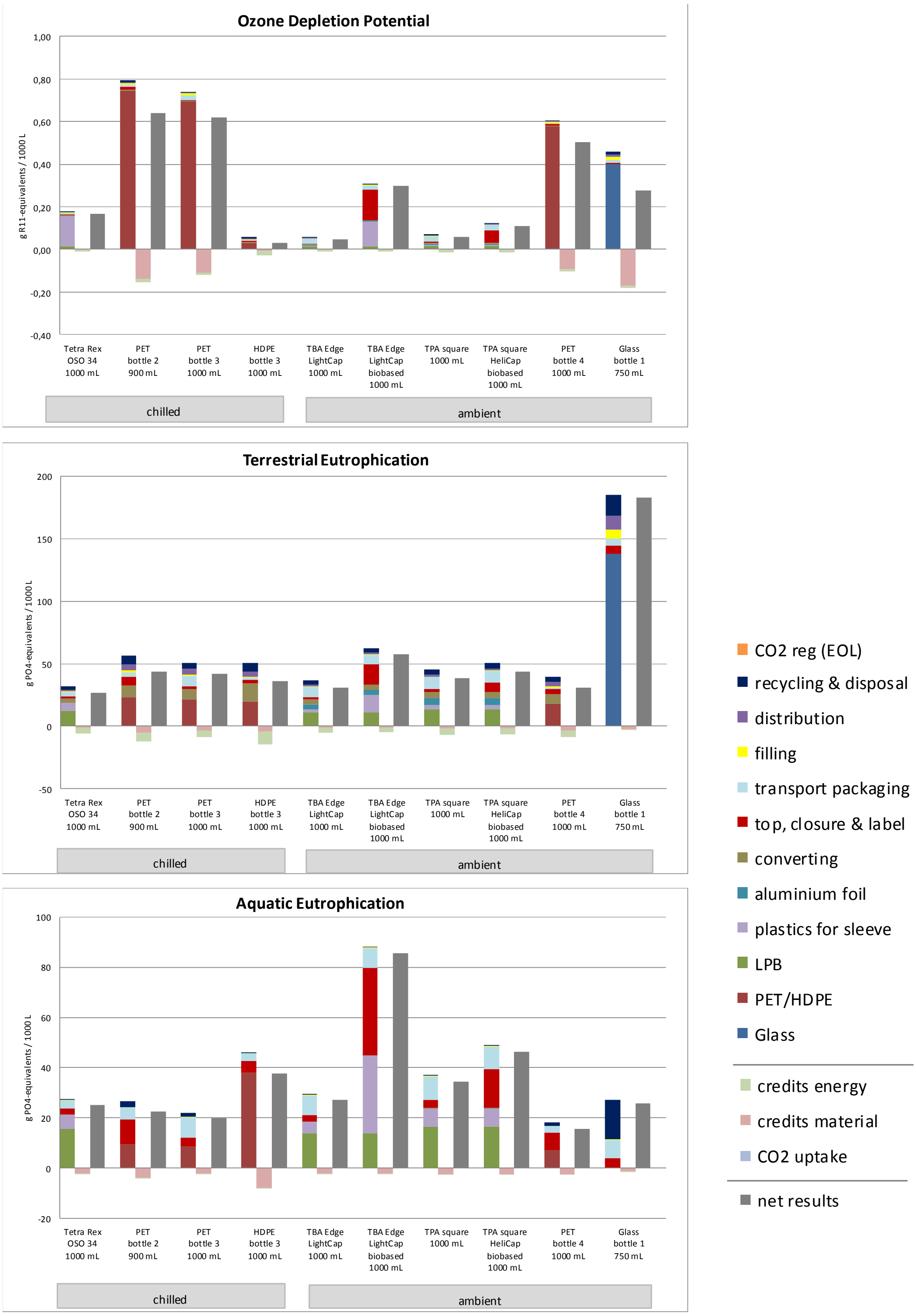


Figure 21: Indicator results for base scenarios of segment JNSD, Sweden, allocation factor 50% (Part 2)

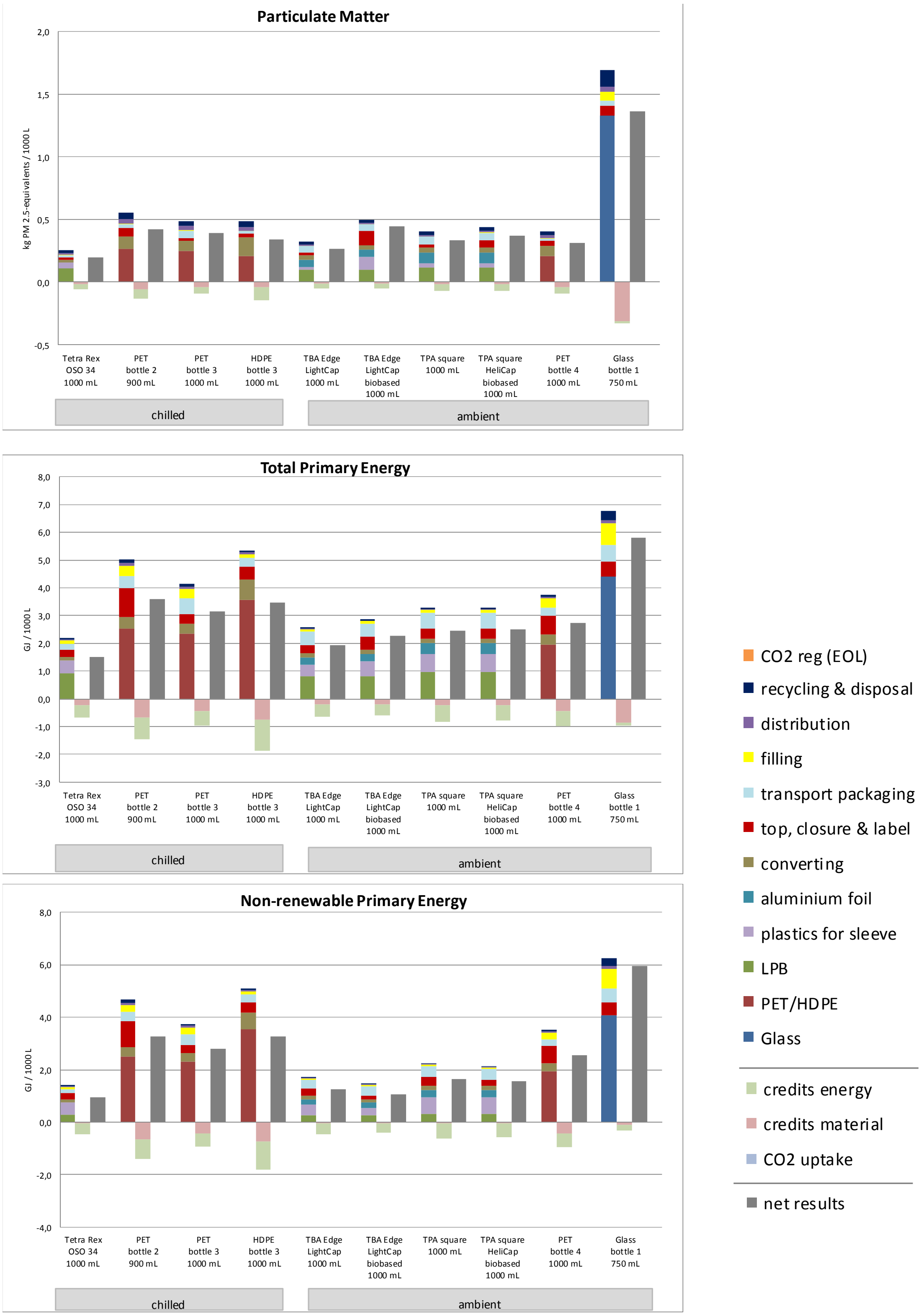


Figure 22: Indicator results for base scenarios of segment JNSD, Sweden, allocation factor 50% (Part 3)

Figure 23: Indicator results for base scenarios of **segment JNSD, Sweden**, allocation factor 50% (Part 4)

Table 35: Category indicator results per impact category for base scenarios of segment JNSD chilled, Sweden- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD chilled Sweden, allocation factor 50 %		Tetra Rex OSO 34 1000 mL	PET bottle 2 900 mL	PET bottle 3 1000 mL	HDPE bottle 3 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	69.58	213.44	175.63	218.82
	CO2 (reg)	18.26	3.08	4.81	2.58
	Credits	-27.73	-66.23	-45.00	-84.05
	CO_2 uptake	-39.86	-4.21	-2.85	-4.94
	Net results (∑)	20.25	146.08	132.58	132.40
Acidification [kg SO_2-equivalents]	Burdens	0.25	0.60	0.52	0.50
	Credits	-0.06	-0.15	-0.11	-0.16
	Net results (∑)	0.18	0.45	0.42	0.34
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	3.88	7.11	6.16	5.93
	Credits	-0.73	-1.74	-1.19	-2.02
	Net results (∑)	3.16	5.37	4.97	3.91
Ozone Depletion [g R-11-equivalents]	Burdens	0.18	0.79	0.74	0.06
	Credits	-0.01	-0.15	-0.12	-0.03
	Net results (∑)	0.17	0.64	0.62	0.03
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	32.24	56.22	50.71	50.72
	Credits	-5.58	-12.51	-8.61	-14.58
	Net results (∑)	26.66	43.71	42.10	36.14
Aquatic eutrophication [g PO_4-equivalents]	Burdens	27.34	26.42	22.00	45.83
	Credits	-2.37	-4.02	-2.19	-8.08
	Net results (∑)	24.97	22.40	19.81	37.75
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.25	0.55	0.48	0.48
	Credits	-0.06	-0.13	-0.09	-0.15
	Net results (∑)	0.19	0.42	0.39	0.34
Total Primary Energy [GJ]	Burdens	2.18	5.04	4.13	5.35
	Credits	-0.67	-1.45	-0.97	-1.88
	Net results (∑)	1.52	3.59	3.16	3.46
Non-renewable primary energy [GJ]	Burdens	1.41	4.68	3.75	5.09
	Credits	-0.46	-1.41	-0.94	-1.82
	Net results (∑)	0.94	3.27	2.81	3.27
Use of Nature [m^2-equivalents*year]	Burdens	23.19	0.95	1.97	0.51
	Credits	-3.29	-0.06	-0.04	-0.07
	Net results (∑)	19.90	0.89	1.93	0.44
Water use [m^3]	Water cool	1.52	3.29	2.77	1.69
	Water process	2.29	7.06	6.54	0.62
	Water unspec	0.33	0.16	0.05	6.16

Table 36: Category indicator results per impact category for base scenarios of segment JNSD ambient, Sweden- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD ambient Sweden, allocation factor 50 %		TBA edge LightCap 1000 mL	TBA edge LightCap biobased 1000 mL	TPA square HeliCap 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate change [kg CO_2-equivalents]	Burdens	89.33	84.00	116.81	112.90	155.44	402.67
	CO2 (reg)	17.98	26.93	21.52	23.30	0.22	1.31
	Credits	-27.76	-24.58	-36.64	-34.44	-46.26	-90.17
	CO_2 uptake	-35.55	-52.18	-42.28	-45.86	0.00	-6.22
	Net results (∑)	44.00	34.18	59.41	55.91	109.40	307.59
Acidification [kg SO_2-equivalents]	Burdens	0.33	0.52	0.42	0.45	0.44	1.29
	Credits	-0.06	-0.06	-0.08	-0.08	-0.10	-0.26
	Net results (∑)	0.27	0.46	0.34	0.38	0.34	1.03
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	4.45	5.28	5.64	5.74	4.97	23.65
	Credits	-0.72	-0.65	-0.92	-0.88	-1.21	-3.24
	Net results (∑)	3.73	4.63	4.72	4.86	3.77	20.41
Ozone Depletion [g R-11-equivalents]	Burdens	0.06	0.31	0.07	0.12	0.61	0.46
	Credits	-0.01	-0.01	-0.01	-0.01	-0.10	-0.18
	Net results (∑)	0.05	0.30	0.06	0.11	0.50	0.28
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	36.56	62.42	45.68	50.64	39.64	185.20
	Credits	-5.49	-4.97	-7.06	-6.71	-8.67	-2.09
	Net results (∑)	31.07	57.45	38.62	43.93	30.98	183.12
Aquatic eutrophication [g PO_4-equivalents]	Burdens	29.20	87.89	36.74	48.81	18.05	27.00
	Credits	-2.15	-2.15	-2.45	-2.46	-2.60	-1.38
	Net results (∑)	27.05	85.74	34.29	46.35	15.45	25.62
Particulate matter [kg PM 2,5-equivalents]	Burdens	0.32	0.50	0.40	0.44	0.40	1.69
	Credits	-0.06	-0.05	-0.07	-0.07	-0.09	-0.33
	Net results (∑)	0.26	0.45	0.33	0.37	0.31	1.36
Total Primary Energy [GJ]	Burdens	2.58	2.87	3.28	3.28	3.74	6.78
	Credits	-0.65	-0.59	-0.83	-0.79	-0.99	-0.97
	Net results (∑)	1.93	2.28	2.46	2.49	2.75	5.81
Non-renewable primary energy [GJ]	Burdens	1.73	1.47	2.26	2.15	3.51	6.26
	Credits	-0.46	-0.41	-0.61	-0.58	-0.96	-0.31
	Net results (∑)	1.26	1.06	1.65	1.57	2.55	5.95
Use of Nature [m^2-equivalents*year]	Burdens	21.73	29.41	25.85	27.48	0.31	1.75
	Credits	-3.00	-3.00	-3.41	-3.44	-0.04	-0.06
	Net results (∑)	18.73	26.41	22.44	24.05	0.27	1.69
Water use [m^3]	Water cool	1.43	1.20	1.77	1.65	2.58	0.00
	Water process	2.41	2.54	2.90	2.92	6.23	0.00
	Water unspec	0.31	16.69	0.40	3.91	0.13	0.00

4.2.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the JNSD segment, in most impact categories one of the biggest parts 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 considerable share of the burdens of the impact categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. It is also significantly relevant regarding ‘Photo-Oxidant Formation’ ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’ and the consumption of ‘Total Primary Energy’ and to a lower extent ‘Non-renewable Primary Energy’.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category ‘Non-renewable Primary Energy’, where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories ‘Climate Change’, ‘Acidification’ and ‘Particulate Matter’ as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the closures are higher for 'TBA edge LightCap bio-based' and 'TPA square HeliCap bio-based' than for the beverage cartons with a fossil-based closure in all categories apart from 'Non-renewable Primary Energy'.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sector transport packaging plays a more important role for almost all categories than for the beverage cartons used for the packaging of dairy. This is because the JNSD cartons use one-way secondary packaging (cardboard trays) instead of roll containers.

The sectors filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role for the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

CO_2 emissions from incineration of biobased and renewable materials (CO2 reg (EOL)) play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Sweden 36.1% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category Use of Nature. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

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

For the four regarded plastic bottles two different plastics are used: Fossil-based HDPE for the 'HDPE bottle 3' and fossil-based PET for the 'PET bottle 2', 'PET bottle 3' and 'PET bottle 4'. The closures of all four of them are made from HDPE. For the impact categories 'Climate Change', 'Acidification', 'Photo-Oxidant Formation', 'Ozone Depletion Potential', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Particulate Matter' the burdens from PET production (sector PET/HDPE in the graphs) are the highest single contributor to the overall burdens.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from fossil-based HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the PET bottles' recycling & disposal sector is most significant regarding 'Climate Change'. More than half of the used plastic bottles in Sweden are incinerated in MSWIs. This causes high greenhouse gas emissions.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the plastic bottle waste is incinerated in MSWIs, the received material credits are insignificant compared to the credits for energy.

Glass bottle

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

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact categories 'Climate Change', 'Aquatic Eutrophication' and 'Use of Nature' 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'.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

4.2.3 Comparison between packaging systems

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

Table 37: Comparison of net results: **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD chilled, Sweden**

segment JNSD (chilled), Sweden	The net results of **Tetra Rex OSO 34 1000mL** are lower (green)/ higher (orange) than those of		
	PET bottle 2 900 mL	PET bottle 3 1000 mL	HDPE bottle 3 1000 mL
Climate Change	-86%	-85%	-85%
Acidification	-59%	-56%	-46%
Summer Smog	-41%	-36%	-19%
Ozone Depletion Potential	-74%	-73%	482%
Terrestrial Eutrophication	-39%	-37%	-26%
Aquatic Eutrophication	11%	26%	-34%
Human Toxicity: PM 2.5	-54%	-51%	-43%
Total Primary Energy	-58%	-52%	-56%
Non-renewable Primary Energy	-71%	-66%	-71%

Table 38: Comparison of net results: **Tetra Brik Aseptic Edge Light Cap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

segment JNSD (ambient), Sweden	The net results of **TBA EdgeLightCap1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap biobased 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	29%	-26%	-21%	-60%	-86%
Acidification	-42%	-21%	-28%	-20%	-74%
Photo-Oxidant Formation	-19%	-21%	-23%	-1%	-82%
Ozone Depletion Potential	-84%	-18%	-58%	-91%	-83%
Terrestrial Eutrophication	-46%	-20%	-29%	0%	-83%
Aquatic Eutrophication	-68%	-21%	-42%	75%	6%
Particulate Matter	-41%	-21%	-28%	-15%	-81%
Total Primary Energy	-15%	-22%	-23%	-30%	-67%
Non-renewable Primary Energy	19%	-23%	-20%	-50%	-79%

Table 39: Comparison of net results: **Tetra Brik Edge LightCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

segment JNSD (ambient), Sweden	The net results of **TBA Edge LightCap biobased 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	-22%	-42%	-39%	-69%	-89%
Acidification	71%	36%	23%	37%	-55%
Photo-Oxidant Formation	24%	-2%	-5%	23%	-77%
Ozone Depletion Potential	539%	424%	171%	-41%	8%
Terrestrial Eutrophication	85%	49%	31%	85%	-69%
Aquatic Eutrophication	217%	150%	85%	455%	235%
Particulate Matter	69%	34%	21%	44%	-67%
Total Primary Energy	18%	-7%	-9%	-17%	-61%
Non-renewable Primary Energy	-16%	-36%	-32%	-58%	-82%

Table 40: Comparison of net results: **TPA square 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

segment JNSD (ambient), Sweden	The net results of **TPA square1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000 mL	TBA Edge LightCap biobased 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	35%	74%	6%	-46%	-81%
Acidification	26%	-26%	-10%	1%	-67%
Photo-Oxidant Formation	27%	2%	-3%	25%	-77%
Ozone Depletion Potential	22%	-81%	-48%	-89%	-79%
Terrestrial Eutrophication	24%	-33%	-12%	25%	-79%
Aquatic Eutrophication	27%	-60%	-26%	122%	34%
Particulate Matter	26%	-25%	-10%	7%	-76%
Total Primary Energy	27%	8%	-1%	-11%	-58%
Non-renewable Primary Energy	31%	56%	5%	-35%	-72%

Table 41: Comparison of net results: **TPA square HeliCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

segment JNSD (ambient), Sweden	The net results of **TPA square HeliCap biobased 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000 mL	TBA Edge LightCap biobased 1000 mL	TPA square 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	27%	64%	-6%	-49%	-82%
Acidification	40%	-18%	11%	12%	-63%
Photo-Oxidant Formation	30%	5%	3%	29%	-76%
Ozone Depletion Potential	136%	-63%	93%	-78%	-60%
Terrestrial Eutrophication	41%	-24%	14%	42%	-76%
Aquatic Eutrophication	71%	-46%	35%	200%	81%
Particulate Matter	39%	-17%	11%	18%	-73%
Total Primary Energy	29%	9%	1%	-9%	-57%
Non-renewable Primary Energy	24%	48%	-5%	-38%	-74%

4.3 Results base scenarios *Grab & Go SWEDEN*

4.3.1 Presentation of results Grab & Go Sweden

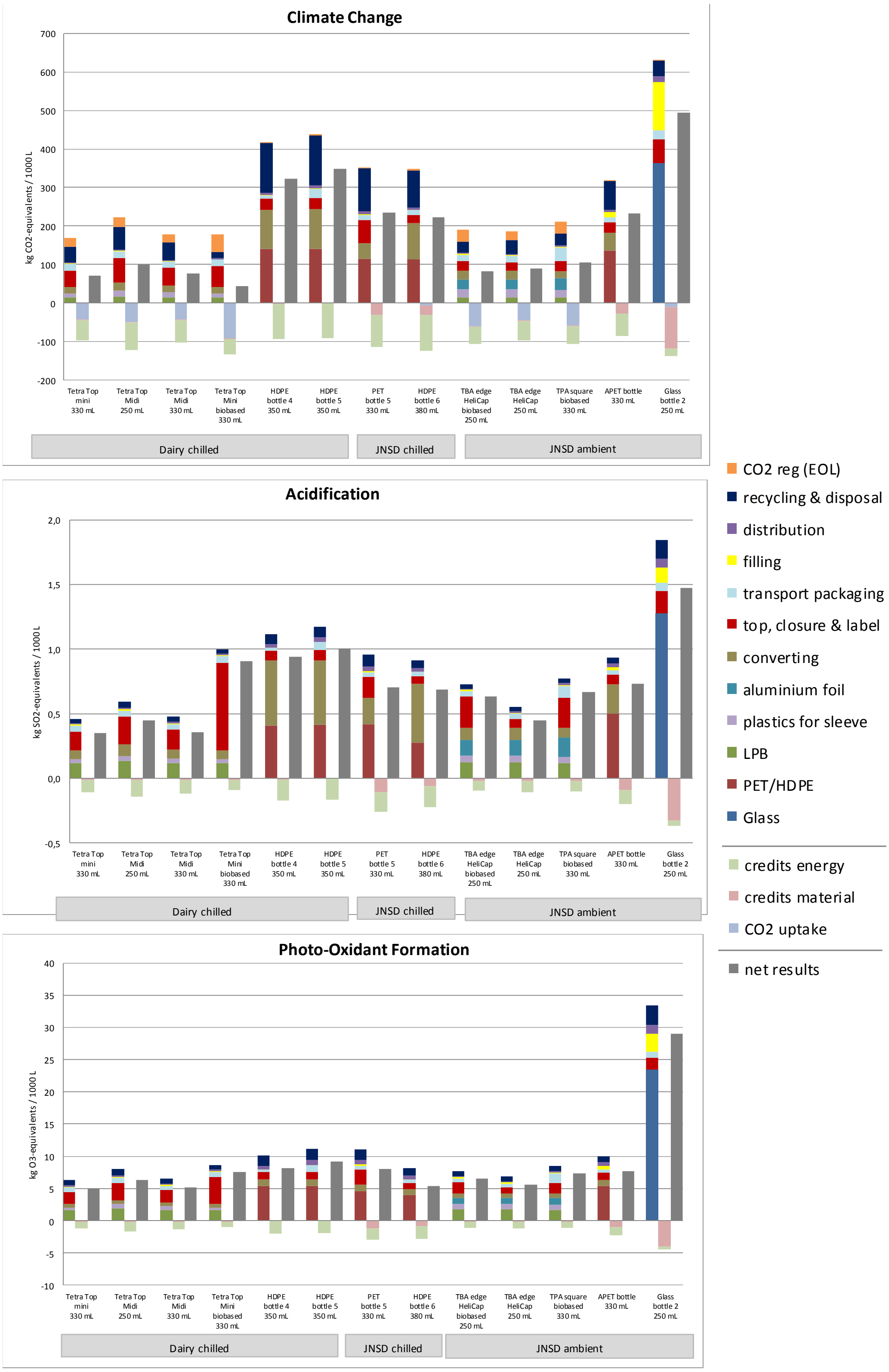


Figure 24: Indicator results for base scenarios of **segment Grab & Go, Sweden**, allocation factor 50% (Part 1)

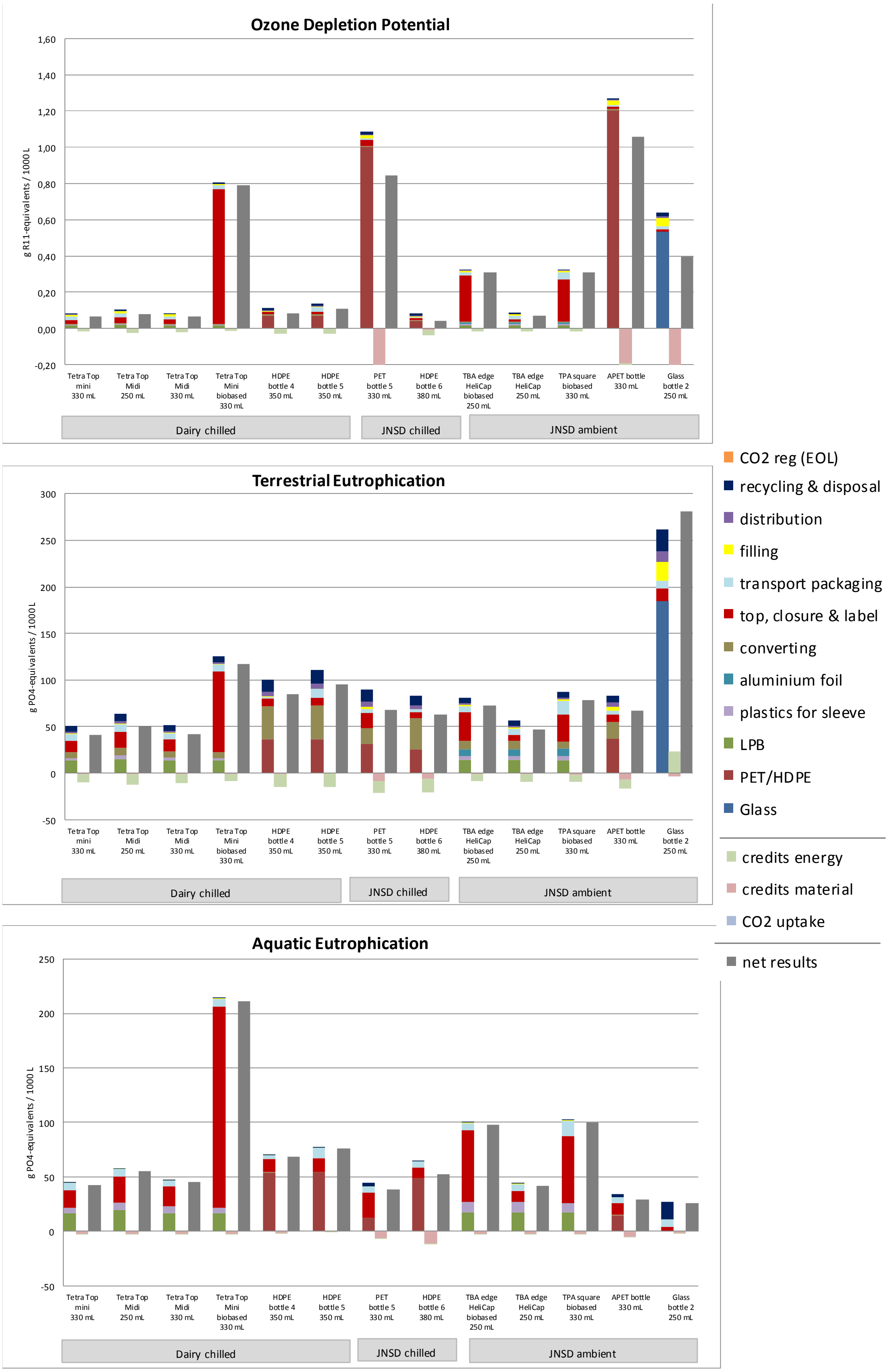


Figure 25: Indicator results for base scenarios of **segment Grab & Go, Sweden**, allocation factor 50% (Part 2)

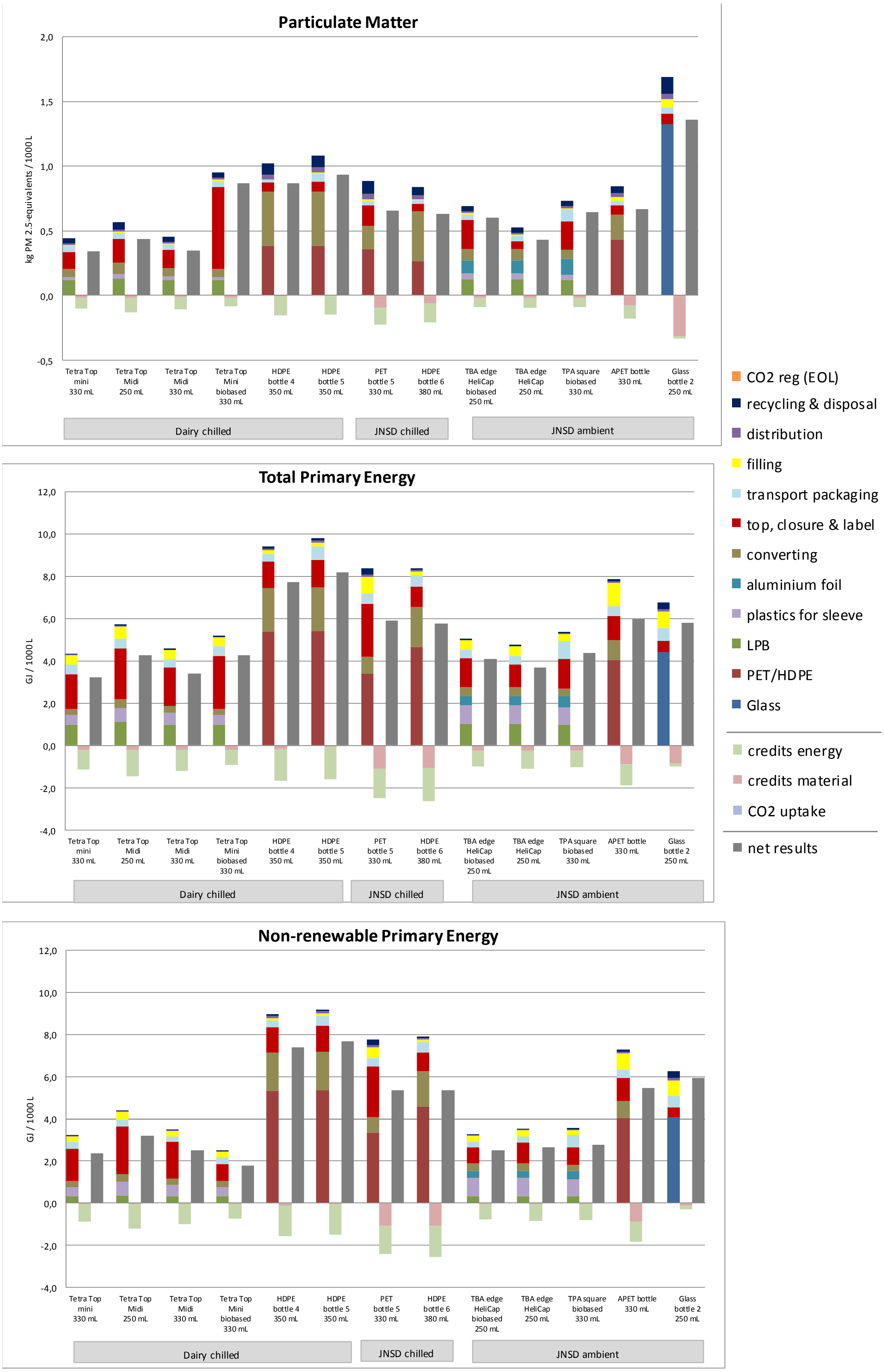


Figure 26: Indicator results for base scenarios of **segment Grab & Go, Sweden**, allocation factor 50% (Part 3)

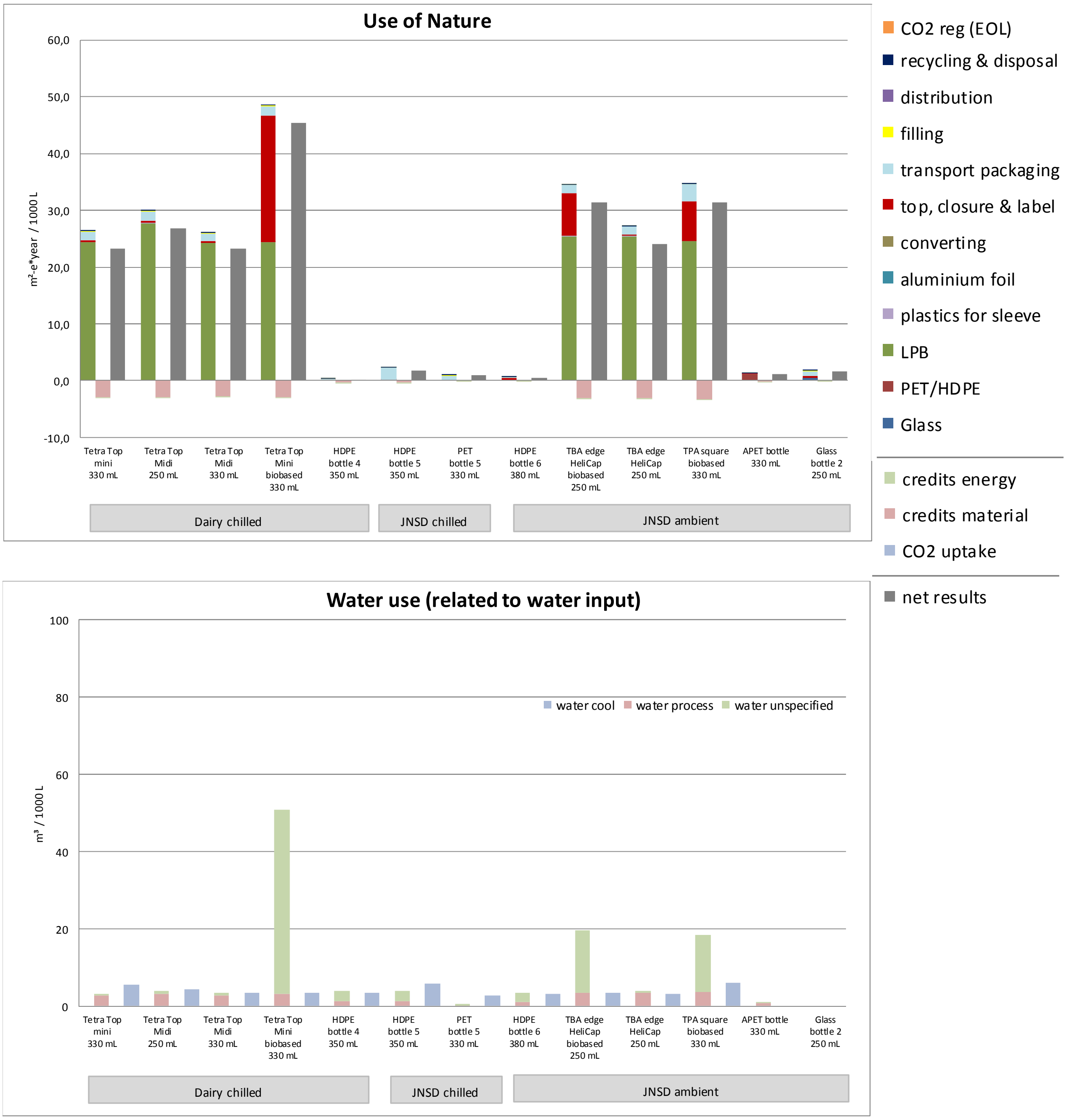


Figure 27: Indicator results for base scenarios of **segment Grab & Go, Sweden**, allocation factor 50% (Part 4)

Table 42: Category indicator results per impact category for base scenarios of segment Grab & Go, Sweden- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, Dairy chilled Sweden, allocation factor 50 %		Tetra Top Mini 330 mL	Tetra Top Midi 250 mL	Tetra Top Midi 330 mL	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate change [kg CO_2-equivalents]	Burdens	146.40	197.17	157.07	131.28	415.78	434.61
	CO2 (reg)	21.80	24.92	21.55	47.26	0.22	4.11
	Credits	-53.92	-73.33	-59.25	-43.30	-93.07	-91.34
	CO_2 uptake	-43.39	-49.44	-43.24	-91.25	0.00	0.00
	Net results (∑)	70.88	99.32	76.12	43.99	322.93	347.37
Acidification [kg SO_2-equivalents]	Burdens	0.46	0.59	0.48	1.00	1.11	1.17
	Credits	-0.11	-0.15	-0.12	-0.09	-0.17	-0.17
	Net results (∑)	0.35	0.45	0.36	0.91	0.94	1.01
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	6.25	8.03	6.57	8.65	10.12	11.12
	Credits	-1.27	-1.68	-1.37	-1.05	-2.01	-1.94
	Net results (∑)	4.98	6.35	5.20	7.60	8.11	9.18
Ozone Depletion [g R-11-equivalents]	Burdens	0.08	0.10	0.08	0.81	0.11	0.14
	Credits	-0.02	-0.03	-0.02	-0.02	-0.03	-0.03
	Net results (∑)	0.06	0.08	0.06	0.79	0.08	0.11
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	50.75	63.64	51.99	125.14	100.19	110.43
	Credits	-9.73	-12.86	-10.50	-8.02	-15.16	-14.76
	Net results (∑)	41.01	50.78	41.49	117.12	85.03	95.67
Aquatic eutrophication [g PO_4-equivalents]	Burdens	44.87	57.53	47.19	213.82	70.05	76.84
	Credits	-2.29	-2.31	-2.10	-2.28	-1.42	-0.43
	Net results (∑)	42.59	55.22	45.10	211.54	68.63	76.41
Particulate matter [kg PM 2,5-equivalents]	Burdens	0.44	0.56	0.46	0.95	1.02	1.08
	Credits	-0.10	-0.13	-0.11	-0.08	-0.15	-0.15
	Net results (∑)	0.34	0.43	0.35	0.87	0.87	0.94
Total Primary Energy [GJ]	Burdens	4.35	5.72	4.59	5.20	9.42	9.81
	Credits	-1.11	-1.45	-1.19	-0.93	-1.68	-1.60
	Net results (∑)	3.24	4.27	3.41	4.28	7.74	8.21
Non-renewable primary energy [GJ]	Burdens	3.25	4.42	3.51	2.52	8.96	9.19
	Credits	-0.90	-1.22	-0.99	-0.73	-1.58	-1.50
	Net results (∑)	2.34	3.19	2.52	1.79	7.38	7.69
Use of Nature [m^2-equivalents*year]	Burdens	26.35	29.92	26.04	48.44	0.41	2.26
	Credits	-3.05	-3.02	-2.78	-3.04	-0.39	-0.40
	Net results (∑)	23.31	26.90	23.26	45.40	0.02	1.86
Water use [m^3]	Water cool	3.91	5.54	4.29	3.30	3.36	3.46
	Water process	2.66	3.10	2.65	3.02	1.17	1.16
	Water unspec	0.51	0.76	0.62	47.67	2.61	2.61

Table 43: Category indicator results per impact category for base scenarios of segment Grab & Go, Sweden burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, JNSD chilled Sweden, allocation factor 50 %		PET bottle 5 330 mL	HDPE bottle 6 380 mL
Climate change [kg CO_2-equivalents]	Burdens	349.52	344.40
	CO2 (reg)	1.18	3.30
	Credits	-115.48	-117.52
	CO_2 uptake	0.00	-6.48
	Net results (∑)	235.23	223.69
Acidification [kg SO_2-equivalents]	Burdens	0.96	0.91
	Credits	-0.26	-0.23
	Net results (∑)	0.70	0.68
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	11.07	8.19
	Credits	-2.98	-2.83
	Net results (∑)	8.09	5.36
Ozone Depletion [g R-11-equivalents]	Burdens	1.09	0.08
	Credits	-0.24	-0.04
	Net results (∑)	0.84	0.04
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	89.64	83.21
	Credits	-21.51	-20.41
	Net results (∑)	68.13	62.80
Aquatic eutrophication [g PO_4-equivalents]	Burdens	45.00	64.15
	Credits	-6.62	-11.43
	Net results (∑)	38.38	52.72
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.89	0.84
	Credits	-0.23	-0.21
	Net results (∑)	0.66	0.63
Total Primary Energy [GJ]	Burdens	8.38	8.40
	Credits	-2.49	-2.64
	Net results (∑)	5.90	5.76
Non-renewable primary energy [GJ]	Burdens	7.77	7.91
	Credits	-2.41	-2.55
	Net results (∑)	5.36	5.35
Use of Nature [m^2-equivalents*year]	Burdens	1.02	0.65
	Credits	-0.08	-0.09
	Net results (∑)	0.95	0.56
Water use [m^3]	Water cool	5.63	2.58
	Water process	921.74	0.87
	Water unspec	0.38	2.40

Table 44: Category indicator results per impact category for base scenarios of segment Grab & Go, Sweden- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, JNSD ambient Sweden, allocation factor 50 %		TBA edge HeliCap biobased 250 mL	TBA edge HeliCap 250 mL	TPA square DreamCap biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate change [kg CO_2-equivalents]	Burdens	159.13	163.84	179.78	318.19	630.74
	CO2 (reg)	30.43	22.40	31.66	1.15	1.94
	Credits	-46.20	-51.77	-48.15	-86.64	-127.92
	CO_2 uptake	-61.23	-45.36	-58.34	0.00	-10.51
	Net results (∑)	82.13	89.11	104.95	232.70	494.25
Acidification [kg SO_2-equivalents]	Burdens	0.73	0.55	0.77	0.93	1.84
	Credits	-0.10	-0.11	-0.10	-0.20	-0.37
	Net results (∑)	0.63	0.45	0.67	0.73	1.47
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.65	6.84	8.53	10.01	33.42
	Credits	-1.11	-1.23	-1.16	-2.29	-4.46
	Net results (∑)	6.53	5.61	7.37	7.72	28.95
Ozone Depletion [g R-11-equivalents]	Burdens	0.33	0.09	0.33	1.27	0.64
	Credits	-0.02	-0.02	-0.02	-0.21	-0.24
	Net results (∑)	0.31	0.07	0.31	1.06	0.39
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	81.02	56.40	87.42	83.42	261.46
	Credits	-8.52	-9.42	-8.89	-16.46	19.89
	Net results (∑)	72.50	46.98	78.53	66.95	281.35
Aquatic eutrophication [g PO_4-equivalents]	Burdens	100.12	44.00	102.25	34.25	27.00
	Credits	-2.34	-2.34	-2.44	-4.95	-1.38
	Net results (∑)	97.78	41.66	99.80	29.30	25.62
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.69	0.52	0.73	0.85	1.69
	Credits	-0.09	-0.10	-0.09	-0.18	-0.33
	Net results (∑)	0.60	0.43	0.64	0.67	1.36
Total Primary Energy [GJ]	Burdens	5.06	4.77	5.39	7.89	6.78
	Credits	-0.98	-1.08	-1.02	-1.89	-0.97
	Net results (∑)	4.08	3.69	4.37	6.00	5.81
Non-renewable primary energy [GJ]	Burdens	3.29	3.52	3.56	7.29	6.26
	Credits	-0.77	-0.87	-0.81	-1.84	-0.31
	Net results (∑)	2.51	2.66	2.75	5.45	5.95
Use of Nature [m^2-equivalents*year]	Burdens	34.52	27.20	34.69	1.27	1.75
	Credits	-3.13	-3.14	-3.29	-0.21	-0.06
	Net results (∑)	31.39	24.06	31.40	1.06	1.69
Water use [m^3]	Water cool	3.23	3.39	3.04	5.91	0.00
	Water process	3.39	3.27	3.57	0.75	0.00
	Water unspec	16.22	0.57	14.84	0.20	0.00

4.3.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the Grab & Go segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. It is also relevant regarding ‘Photo-Oxidant Formation’ ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’ and the consumption of ‘Total Primary Energy’ and ‘Non-renewable Primary Energy’.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category ‘Non-renewable Primary Energy’, where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories ‘Climate Change’, ‘Acidification’ and ‘Particulate Matter’ as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the top and closures is higher for the four Tetra Top packaging systems than for the TBA edge and TBA square cartons as more plastic is used for the top element of those packaging systems.

Especially if bio-based plastics are used for top and/or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category for most packaging systems.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

CO_2 emissions from incineration of biobased and renewable materials (CO2 reg (EOL)) play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. For the 'Tetra Top Mini bio-based' the CO2 reg (EOL) emissions are significantly higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Sweden 36.1% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category 'Use of Nature'. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 Grab & Go 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. Exceptions are the 'Ozone Depletion Potential' of the HDPE bottles as well as 'Use of Nature' of all regarded plastic bottles.

For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for the HDPE bottles than for the PET bottles with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category. An exception is the sector filling for the PET bottles, because the filling process includes the stretch blowing of the preforms to bottles as this takes place at the filling plant.

The impact of the plastic bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the overall Swedish recycling rate of plastic bottles is only 38.4% the amount of bottle waste incinerated is very high.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants.

Glass bottle

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

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact category 'Climate Change', the sector top, closure & label 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'.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

4.3.3 Comparison between packaging systems

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

Table 45: Comparison of net results: **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Sweden**

segment Grab & Go DAIRY chilled, Sweden	The net results of **Tetra Top Mini 330 mL** are lower (green)/ higher (orange) than those of				
	Tetra Top Midi 250 mL	Tetra Top Midi 330 mL	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	-29%	-7%	61%	-78%	-80%
Acidification	-21%	-1%	-61%	-63%	-65%
Summer Smog	-22%	-4%	-34%	-39%	-46%
Ozone Depletion Potential	-18%	2%	-92%	-22%	-40%
Terrestrial Eutrophication	-19%	-1%	-65%	-52%	-57%
Aquatic Eutrophication	-23%	-6%	-80%	-38%	-44%
Human Toxicity: PM 2.5	-21%	-2%	-60%	-60%	-63%
Total Primary Energy	-24%	-5%	-24%	-58%	-61%
Non-renewable Primary Energy	-27%	-7%	31%	-68%	-70%

Table 46: Comparison of net results: **Tetra Top Midi 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Sweden**

segment Grab & Go DAIRY chilled, Sweden	The net results of **Tetra TopMidi250 mL** are lower (green)/ higher (orange) than those of				
	Tetra Top Mini 330 mL	Tetra Top Midi 330 mL	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	40%	30%	126%	-69%	-71%
Acidification	27%	25%	-51%	-53%	-56%
Summer Smog	28%	22%	-16%	-22%	-31%
Ozone Depletion Potential	22%	24%	-90%	-5%	-27%
Terrestrial Eutrophication	24%	22%	-57%	-40%	-47%
Aquatic Eutrophication	30%	22%	-74%	-20%	-28%
Human Toxicity: PM 2.5	26%	24%	-50%	-50%	-53%
Total Primary Energy	32%	25%	0%	-45%	-48%
Non-renewable Primary Energy	36%	27%	78%	-57%	-58%

Table 47: Comparison of net results: **Tetra Top Midi 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Sweden**

segment Grab & Go DAIRY chilled, Sweden	The net results of **Tetra TopMidi330 mL** are lower (green)/ higher (orange) than those of				
	Tetra Top Mini 330 mL	Tetra Top Midi 250 mL	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	7%	-23%	73%	-76%	-78%
Acidification	1%	-20%	-61%	-62%	-65%
Summer Smog	4%	-18%	-32%	-36%	-43%
Ozone Depletion Potential	-2%	-19%	-92%	-23%	-41%
Terrestrial Eutrophication	1%	-18%	-65%	-51%	-57%
Aquatic Eutrophication	6%	-18%	-79%	-34%	-41%
Human Toxicity: PM 2.5	2%	-19%	-60%	-60%	-62%
Total Primary Energy	5%	-20%	-20%	-56%	-59%
Non-renewable Primary Energy	7%	-21%	41%	-66%	-67%

Table 48: Comparison of net results: **Tetra Top Mini biobased 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Sweden**

segment Grab & Go DAIRY chilled, Sweden	The net results of **Tetra Top Mini biobased 330 mL** are lower (green)/ higher (orange) than those of				
	Tetra Top Mini 330 mL	Tetra Top Midi 250 mL	Tetra Top Midi 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	-38%	-56%	-42%	-86%	-87%
Acidification	158%	103%	154%	-4%	-10%
Summer Smog	52%	20%	46%	-6%	-17%
Ozone Depletion Potential	1124%	906%	1146%	859%	633%
Terrestrial Eutrophication	186%	131%	182%	38%	22%
Aquatic Eutrophication	397%	283%	369%	208%	177%
Human Toxicity: PM 2.5	152%	99%	147%	0%	-7%
Total Primary Energy	32%	0%	26%	-45%	-48%
Non-renewable Primary Energy	-24%	-44%	-29%	-76%	-77%

Table 49: Comparison of net results: **Tetra Top Mini biobased 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Sweden**

segment Grab & Go JNSD ambient, Sweden	The net results of **TBA Edge HeliCap biobased 250 mL** are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap 250 mL	TPA square biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	-8%	-22%	-65%	-83%
Acidification	42%	-6%	-14%	-57%
Photo-Oxidant Formation	16%	-11%	-15%	-77%
Ozone Depletion Potential	356%	0%	-71%	-22%
Terrestrial Eutrophication	54%	-8%	8%	-74%
Aquatic Eutrophication	135%	-2%	234%	282%
Particulate Matter	41%	-6%	-10%	-56%
Total Primary Energy	10%	-7%	-32%	-30%
Non-renewable Primary Energy	-6%	-9%	-54%	-58%

Table 50: Comparison of net results: **Tetra Brik Aseptic Edge Mini 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Sweden**

segment Grab & Go JNSD ambient, Sweden	The net results of **TBA Edge HeliCap 250 mL** are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250 mL	TPA square biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	9%	-15%	-62%	-82%
Acidification	-29%	-34%	-39%	-70%
Photo-Oxidant Formation	-14%	-24%	-27%	-81%
Ozone Depletion Potential	-78%	-78%	-94%	-83%
Terrestrial Eutrophication	-35%	-40%	-30%	-83%
Aquatic Eutrophication	-57%	-58%	42%	63%
Particulate Matter	-29%	-33%	-36%	-68%
Total Primary Energy	-9%	-15%	-38%	-36%
Non-renewable Primary Energy	6%	-3%	-51%	-55%

Table 51: Comparison of net results: **Tetra Prisma Aseptic square Mini 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Sweden**

segment Grab & Go JNSD ambient, Sweden	The net results of **TPA square biobased 330 mL** are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250 mL	TBA Edge HeliCap 250 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	28%	18%	-55%	-79%
Acidification	6%	51%	-9%	-55%
Photo-Oxidant Formation	13%	31%	-5%	-75%
Ozone Depletion Potential	0%	356%	-71%	-22%
Terrestrial Eutrophication	8%	67%	17%	-72%
Aquatic Eutrophication	2%	140%	241%	290%
Particulate Matter	7%	50%	-4%	-53%
Total Primary Energy	7%	18%	-27%	-25%
Non-renewable Primary Energy	10%	4%	-50%	-54%

5 Sensitivity Analyses Sweden

5.1 Dairy Sweden

5.1.1 Sensitivity analysis on system allocation DAIRY Sweden

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 subjective 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%.

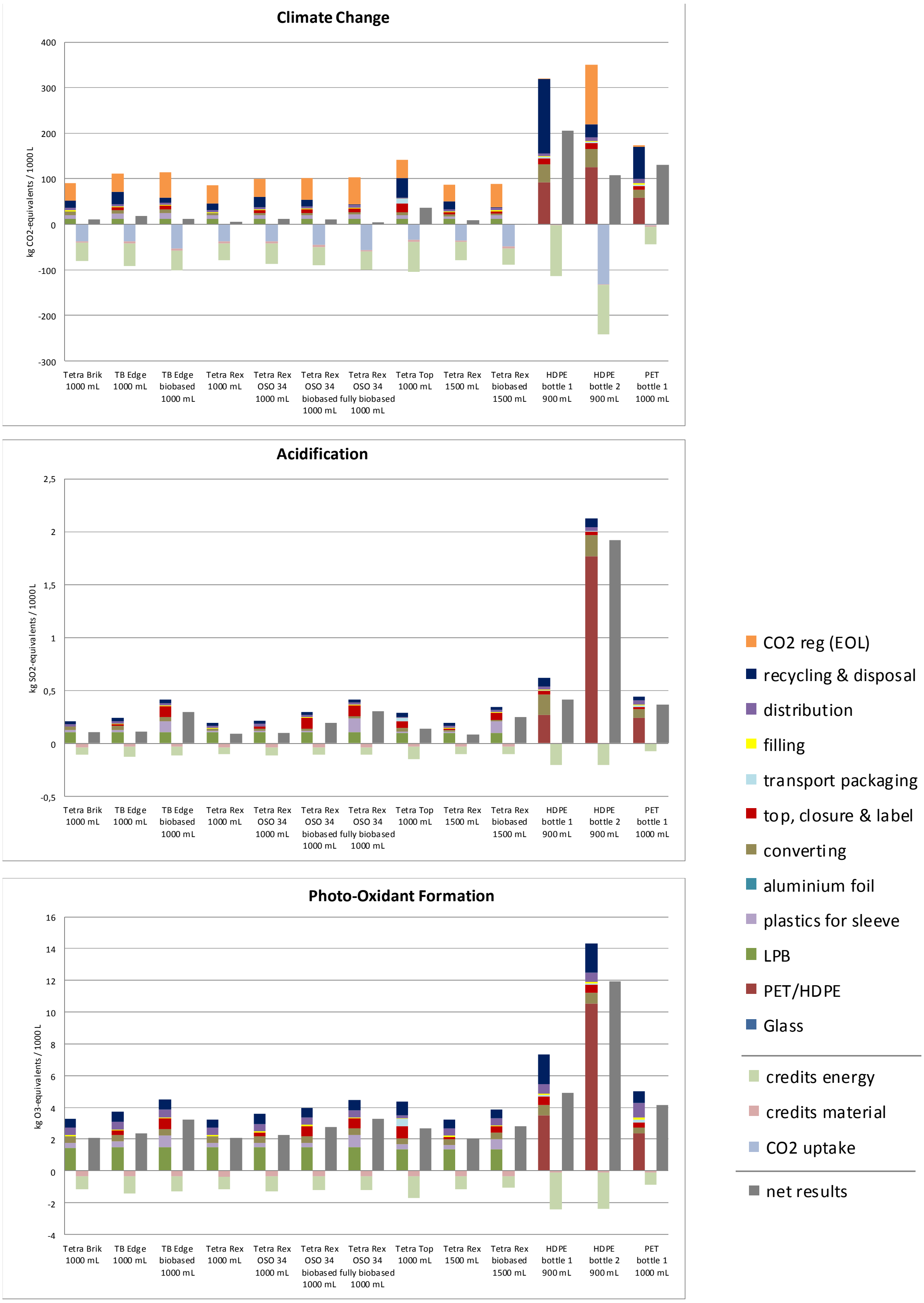


Figure 28: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Sweden**, allocation factor 100% (Part 1)

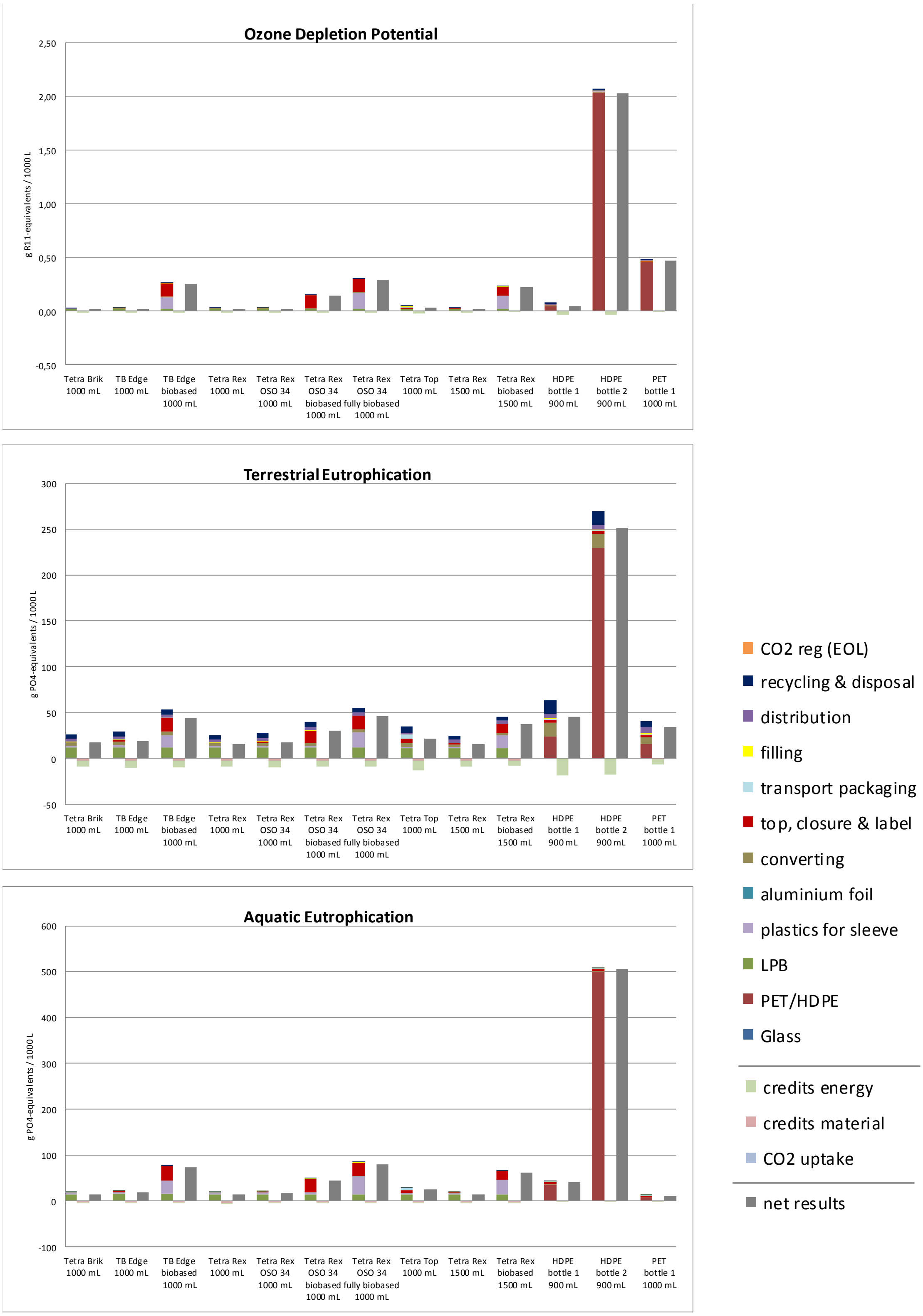


Figure 29: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Sweden** , allocation factor 100% (Part 2)

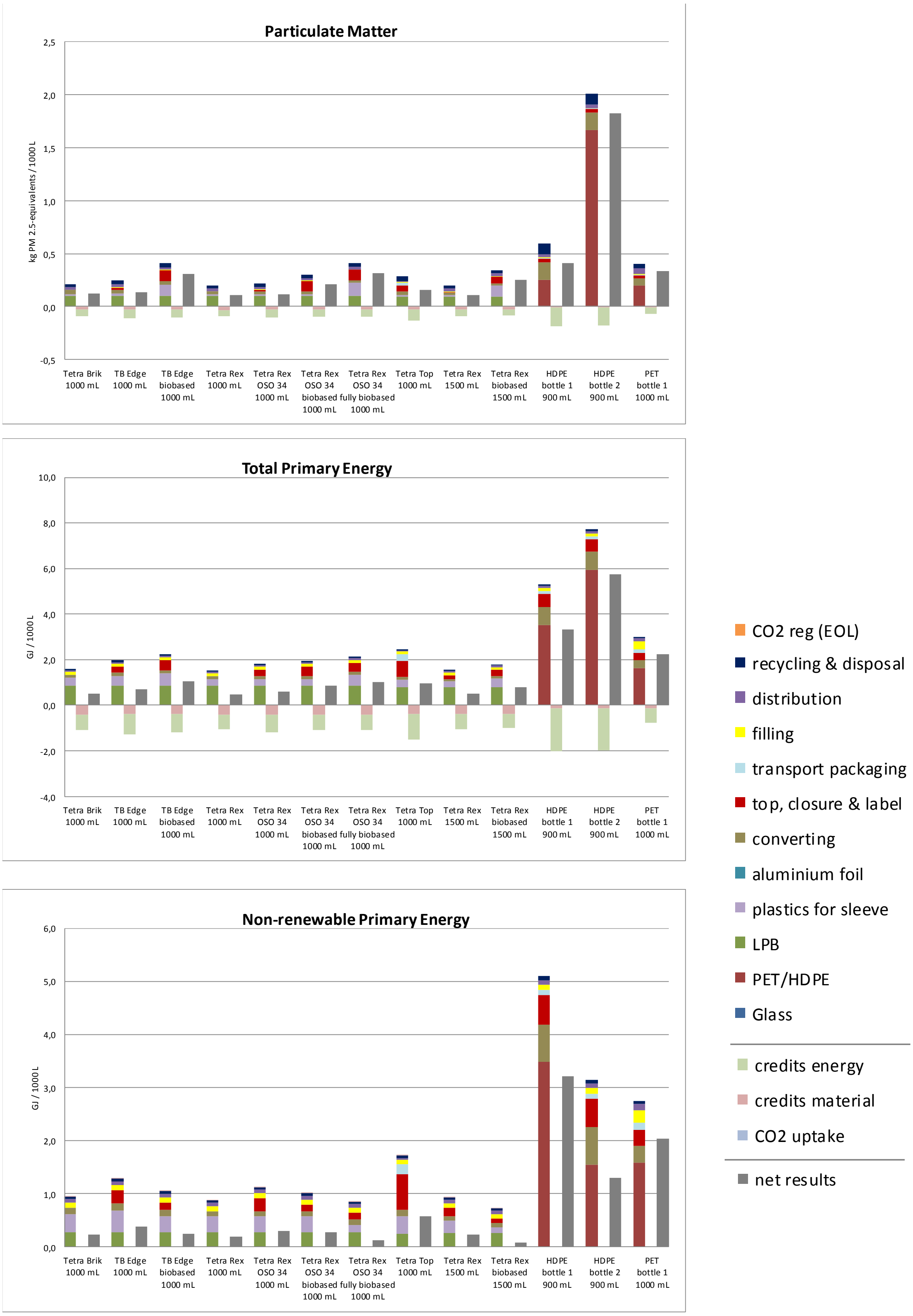


Figure 30: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Sweden**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all systems examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case the allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Swedish market the electricity credited is the Swedish grid mix with its relatively low share of fossil energy sources.

5.1.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

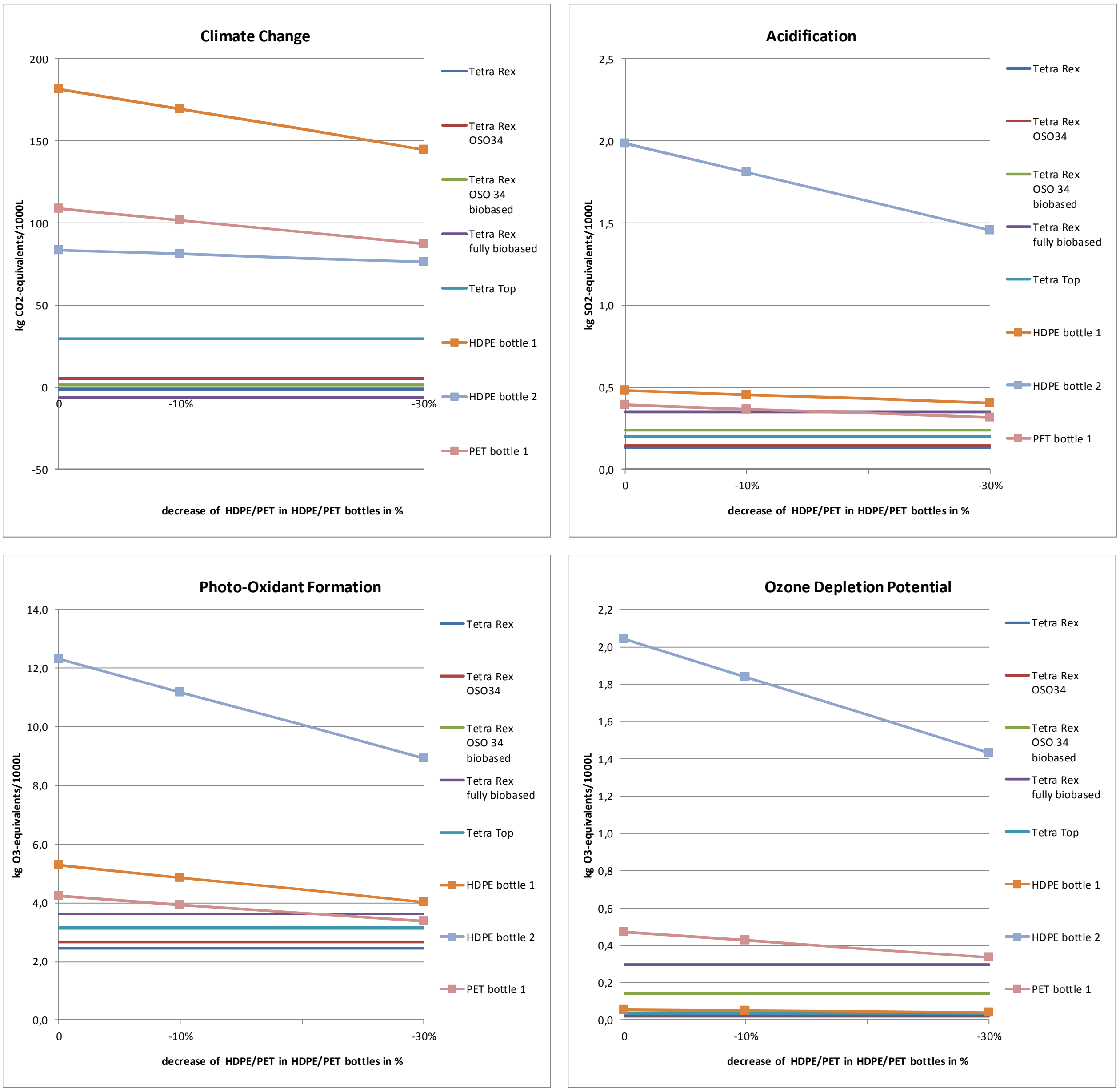


Figure 31: Indicator results for sensitivity analysis on plastic bottle weights of **segment DAIRY, Sweden**, allocation factor 50% (Part 1)

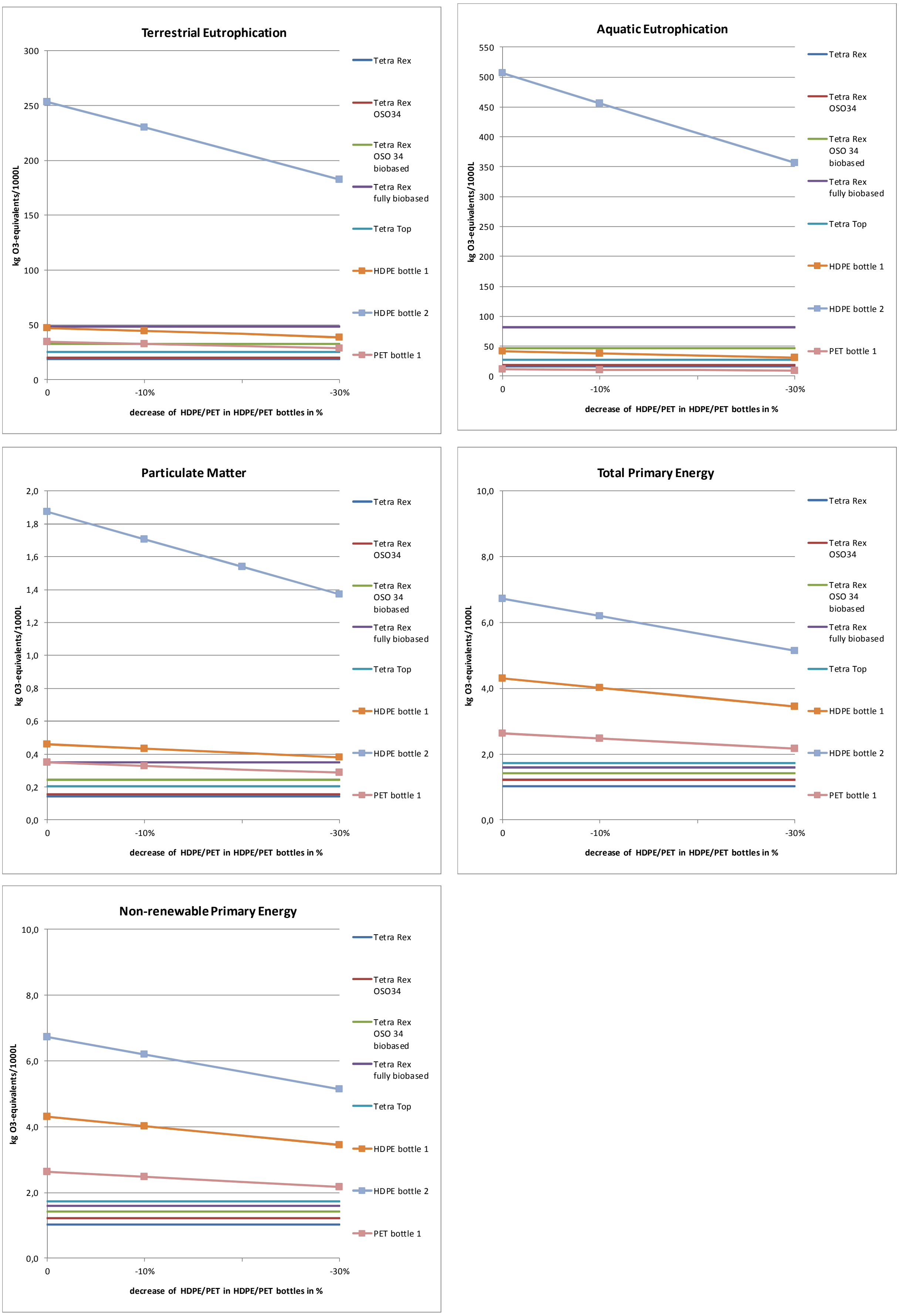


Figure 32: Indicator results for sensitivity analysis on plastic bottle weights of **segment DAIRY, Sweden**, allocation factor 50% (Part 2)

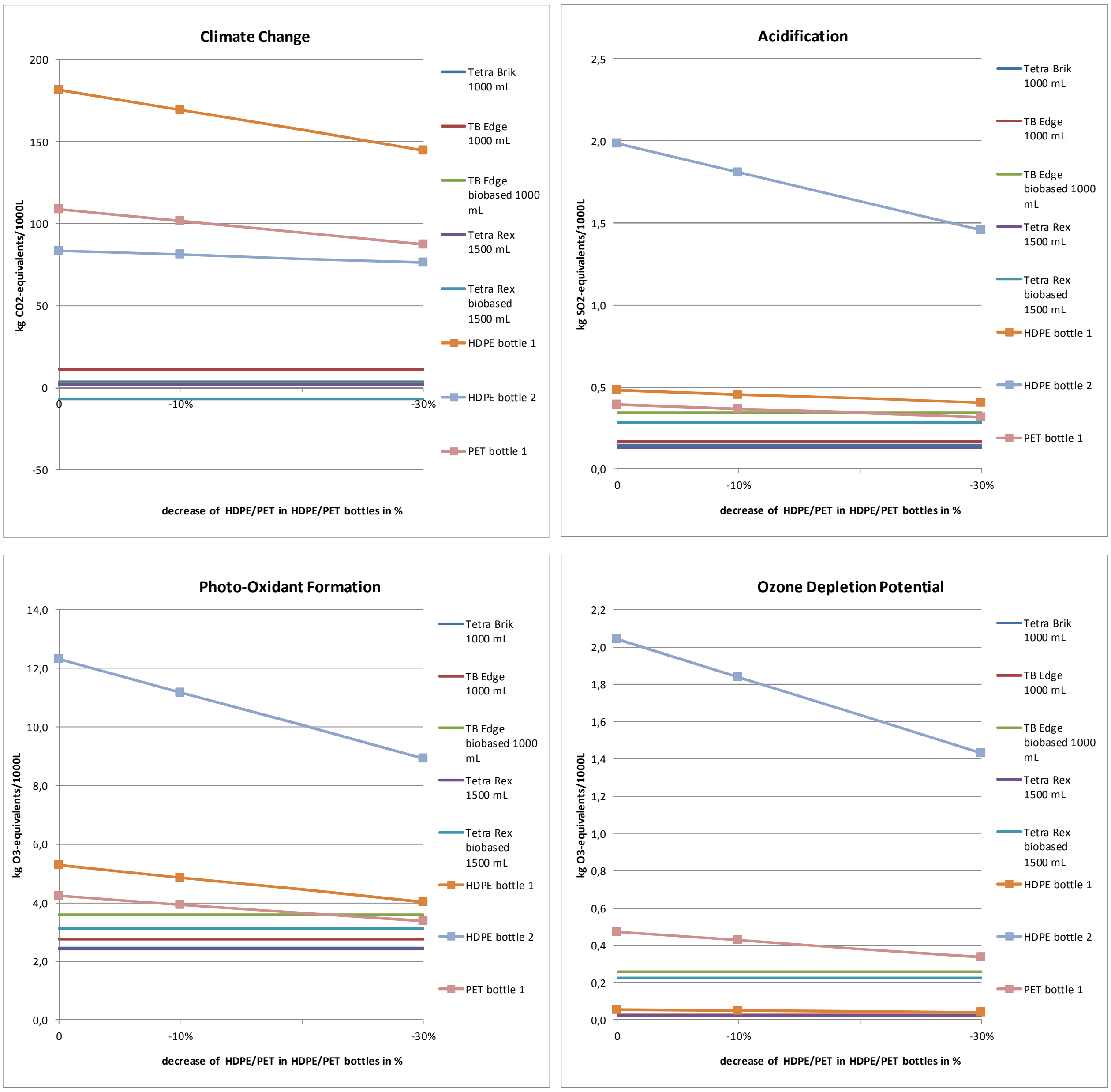


Figure 33: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Sweden, allocation factor 50% (Part 3)

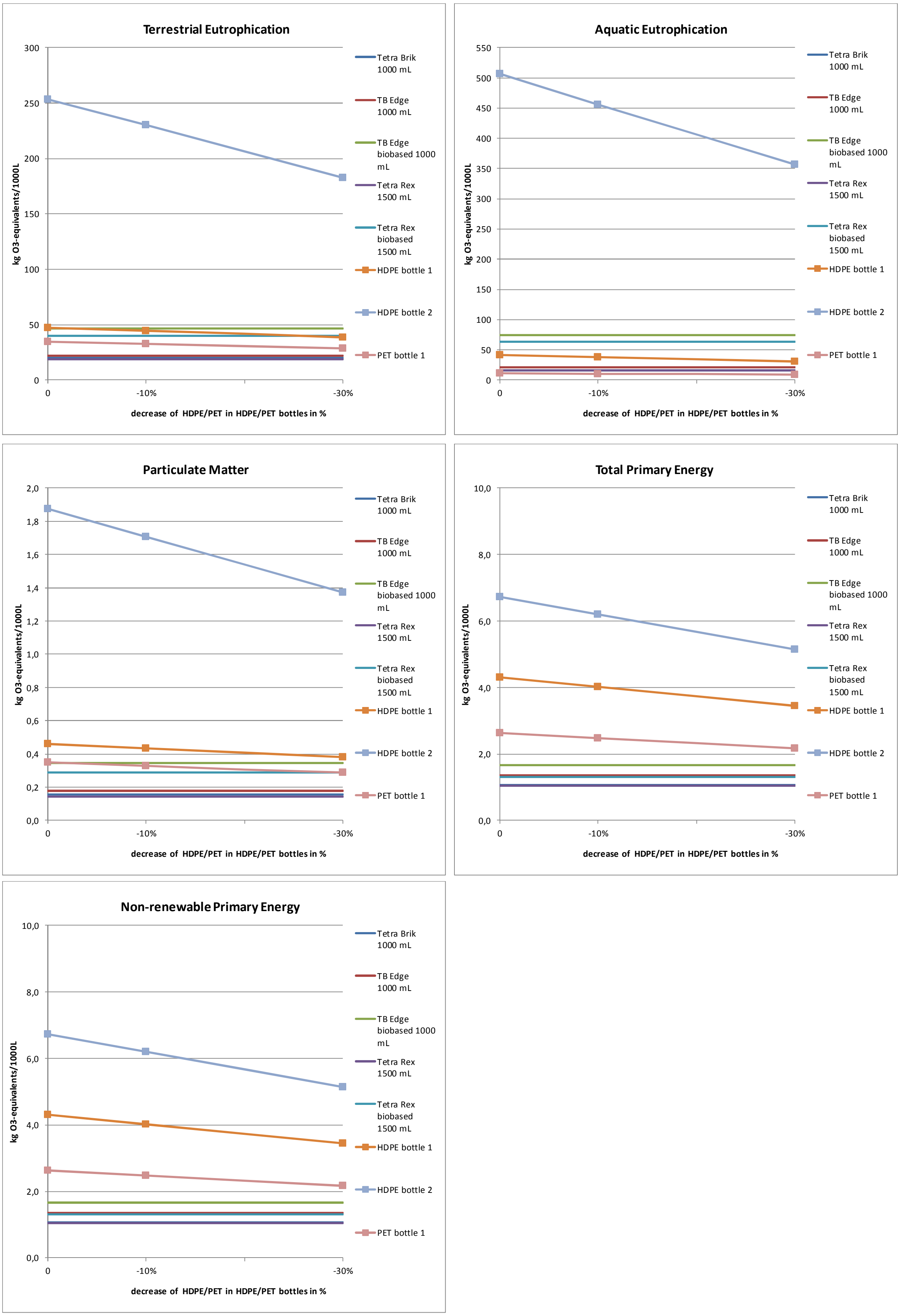


Figure 34: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Sweden, allocation factor 50% (Part 4)^

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In most cases, though, even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of beverage cartons is met.

The lightweight HDPE bottles 'HDPE bottle 1' and 'HDPE bottle 2' would never achieve lower results than any beverage carton that showed a lower results in the base scenarios. There is one exception though: the 'HDPE bottle 1' reaches break-even with The 1500 ml 'Tetra Rex bio-based' at about 27% weight reduction in the impact category 'Terrestrial Eutrophication'.

A lightweight version of the 'PET bottle 1' reaches break-even with 'Tetra Rex fully bio-based' and the 1500 ml 'Tetra Rex bio-based' in the categories 'Acidification' (at ca. 15% and ca. 20% respectively) and 'Photo-Oxidant Formation (at ca. 20% for both cartons). It also breaks even with 'Tetra Rex OSO 34 bio-based' at 'Terrestrial Eutrophication' at about 10% weight reduction.

For the impact category 'Climate Change' and in the inventory categories related to primary energy demand none of the lightweight bottles achieves lower results than any of the beverage cartons.

5.1.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

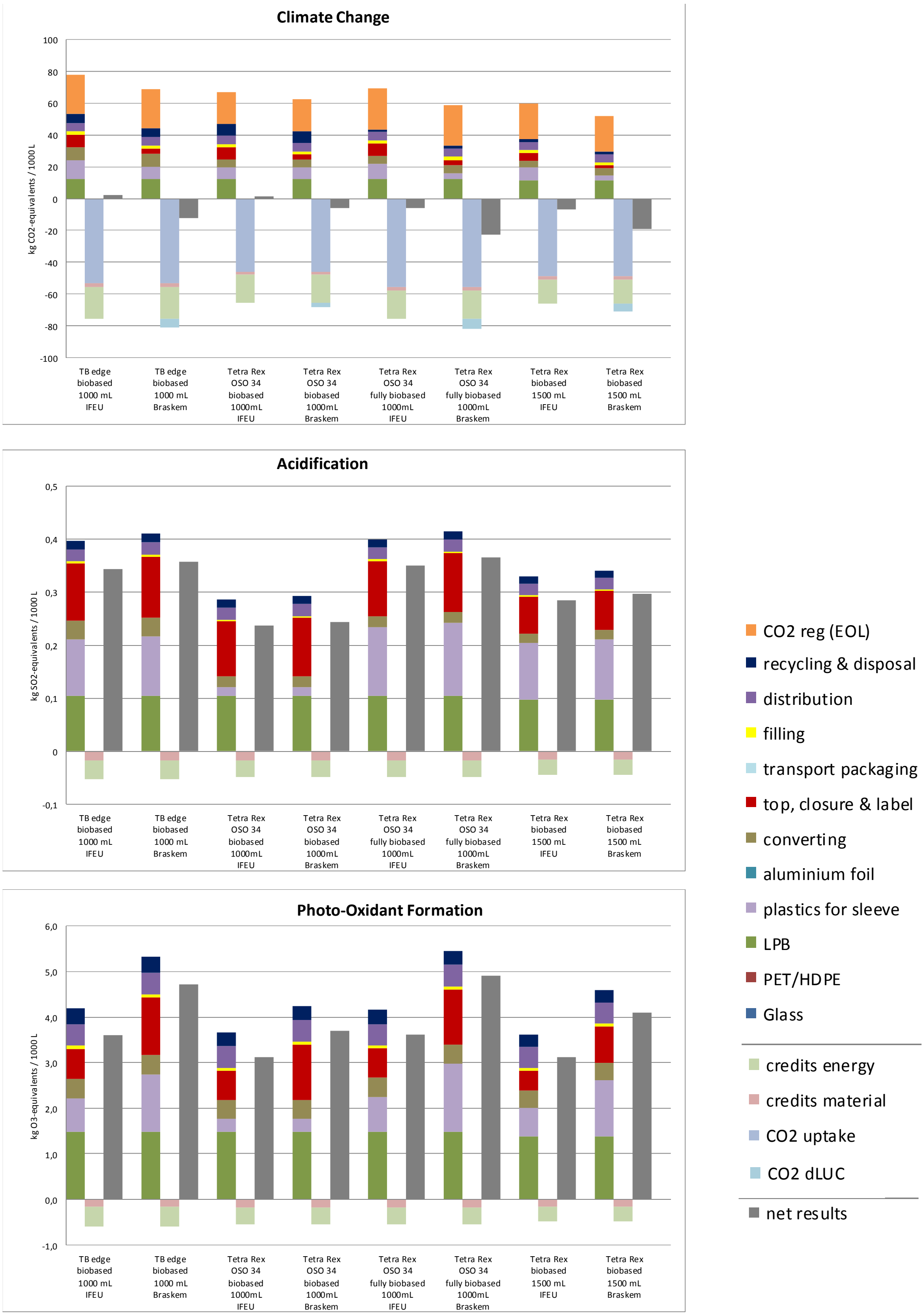


Figure 35: Indicator results for sensitivity analysis on Bio-PE of **segment DAIRY, Sweden**, allocation factor 50% (Part 1)

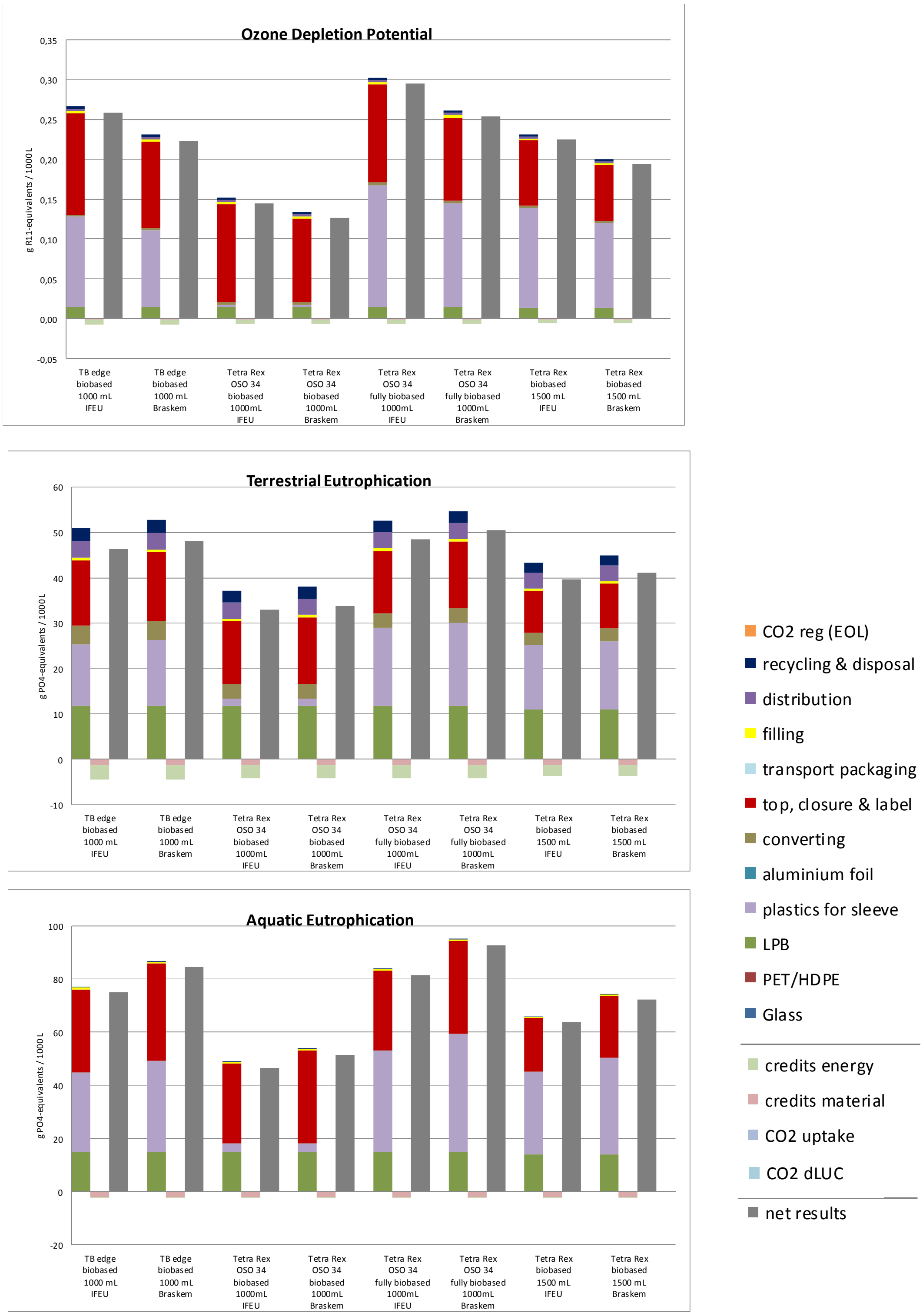


Figure 36: Indicator results for sensitivity analysis on Bio-PE of **segment DAIRY, Sweden**, allocation factor 50% (Part 2)

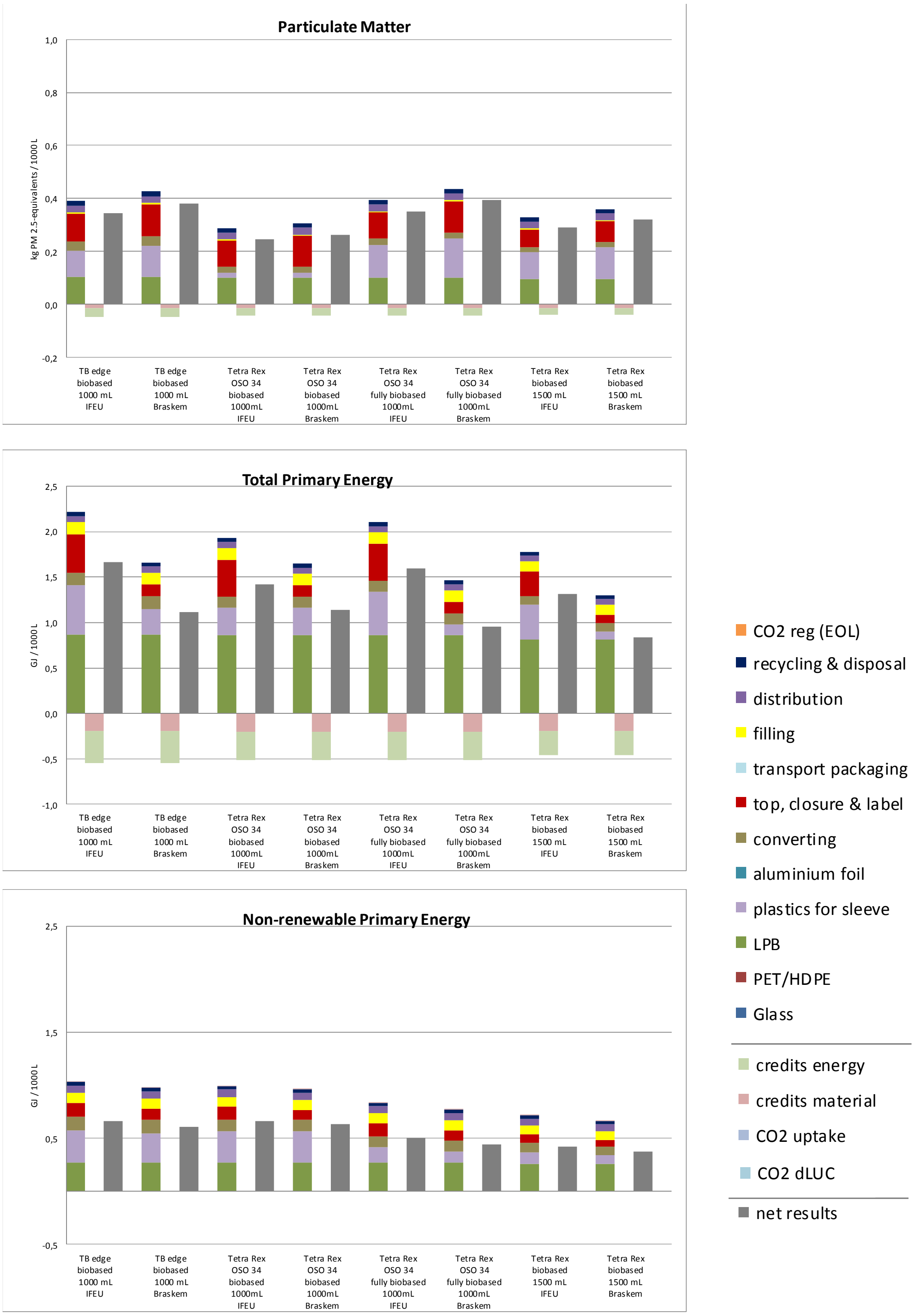


Figure 37: Indicator results for sensitivity analysis on Bio-PE of segment DAIRY, Sweden, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the TB edge and Tetra Rex cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower' Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of dairy packaging on the Swedish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

5.2 JNSD Sweden

5.2.1 Sensitivity analysis on system allocation JNSD Sweden

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 subjective 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%.

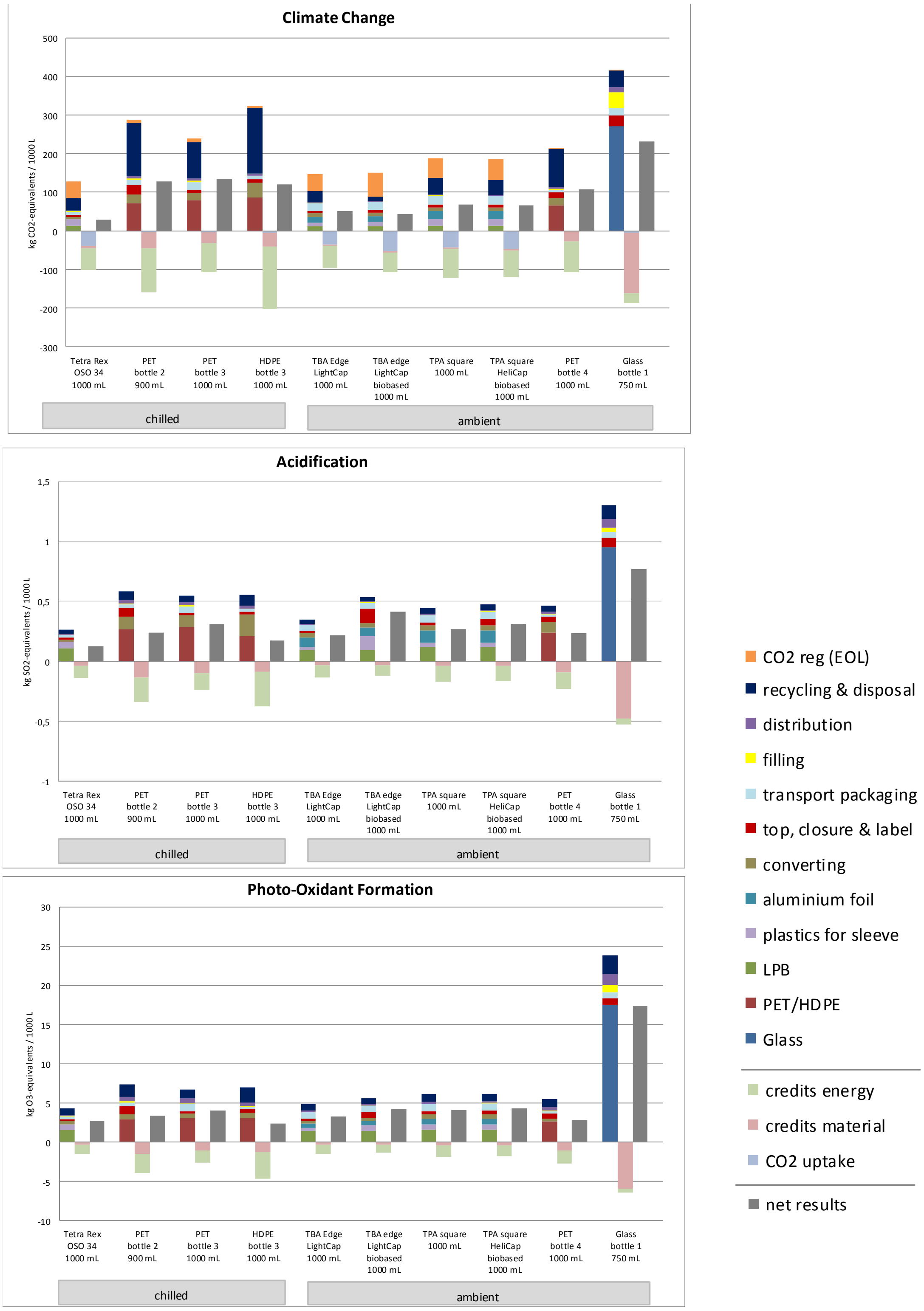


Figure 38: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Sweden**, allocation factor 100% (Part 1)

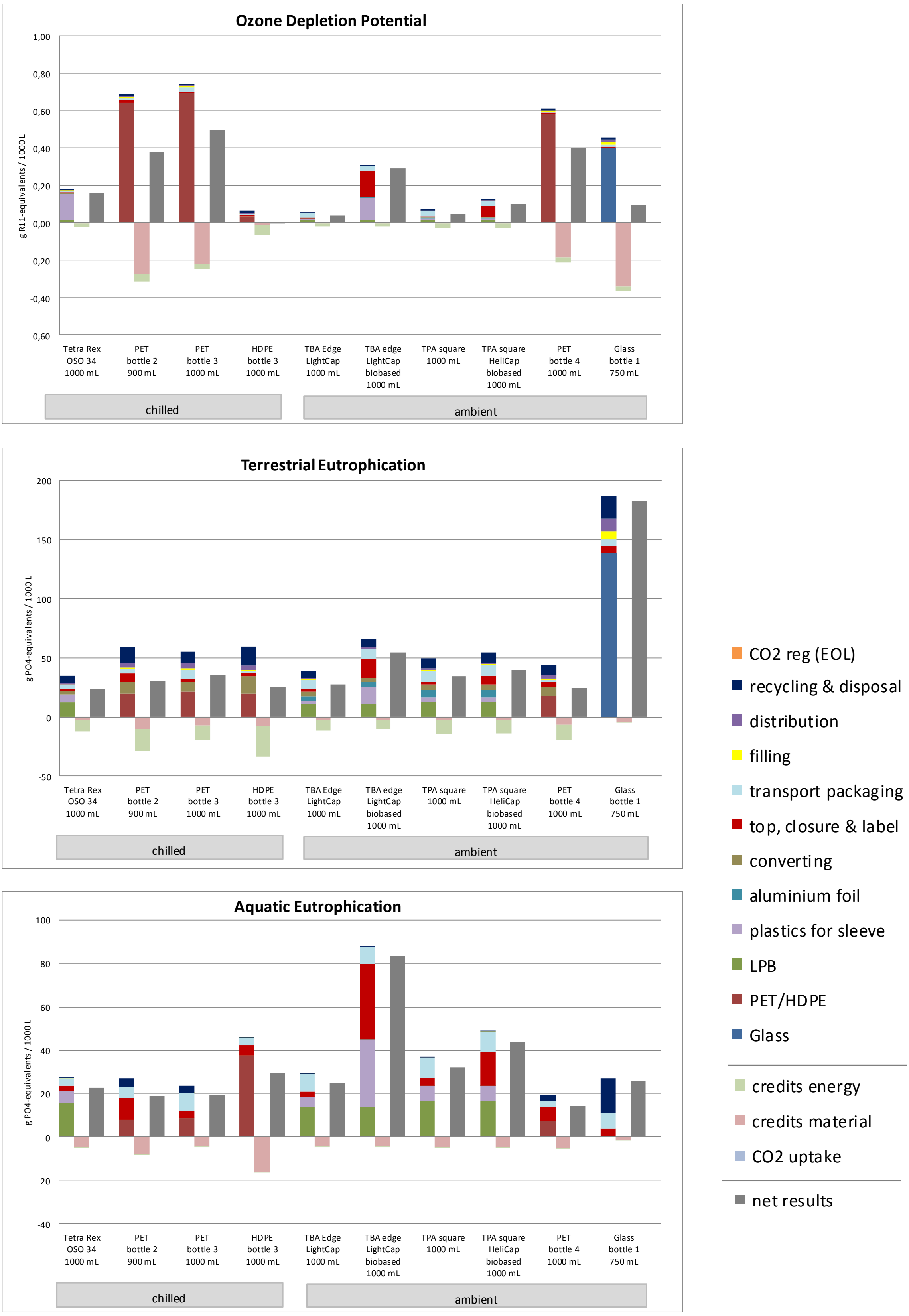


Figure 39: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Sweden** , allocation factor 100% (Part 2)

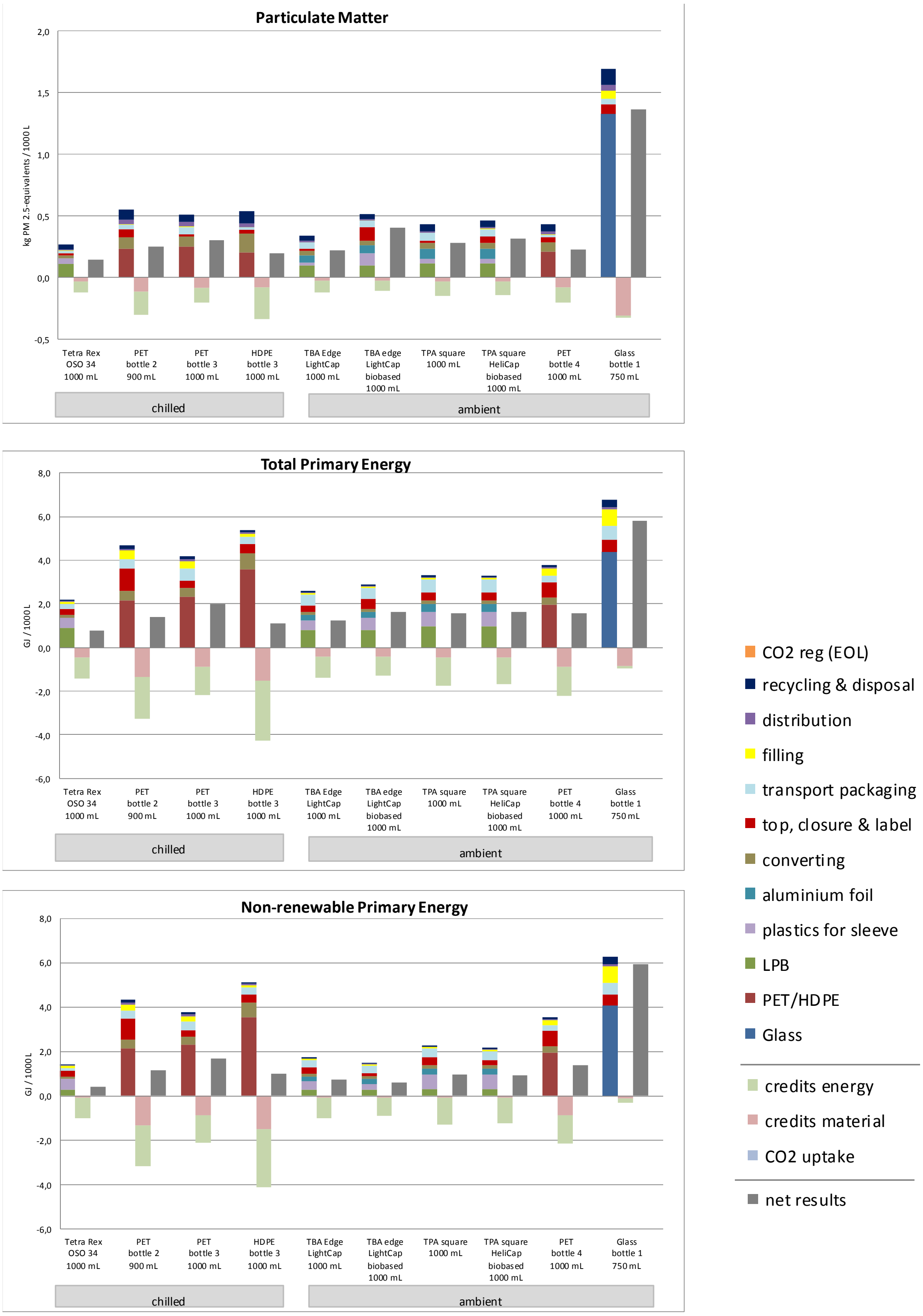


Figure 40: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Sweden**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means, that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Swedish market the electricity credited is the Swedish grid mix with its relatively low share of fossil energy sources.

5.2.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are analysed and illustrated in this sensitivity analysis for details please see section 2.4.4). Results are shown in the following break even graphs.

5.2.3 Sensitivity analysis regarding plastic bottle weights JNSD Sweden

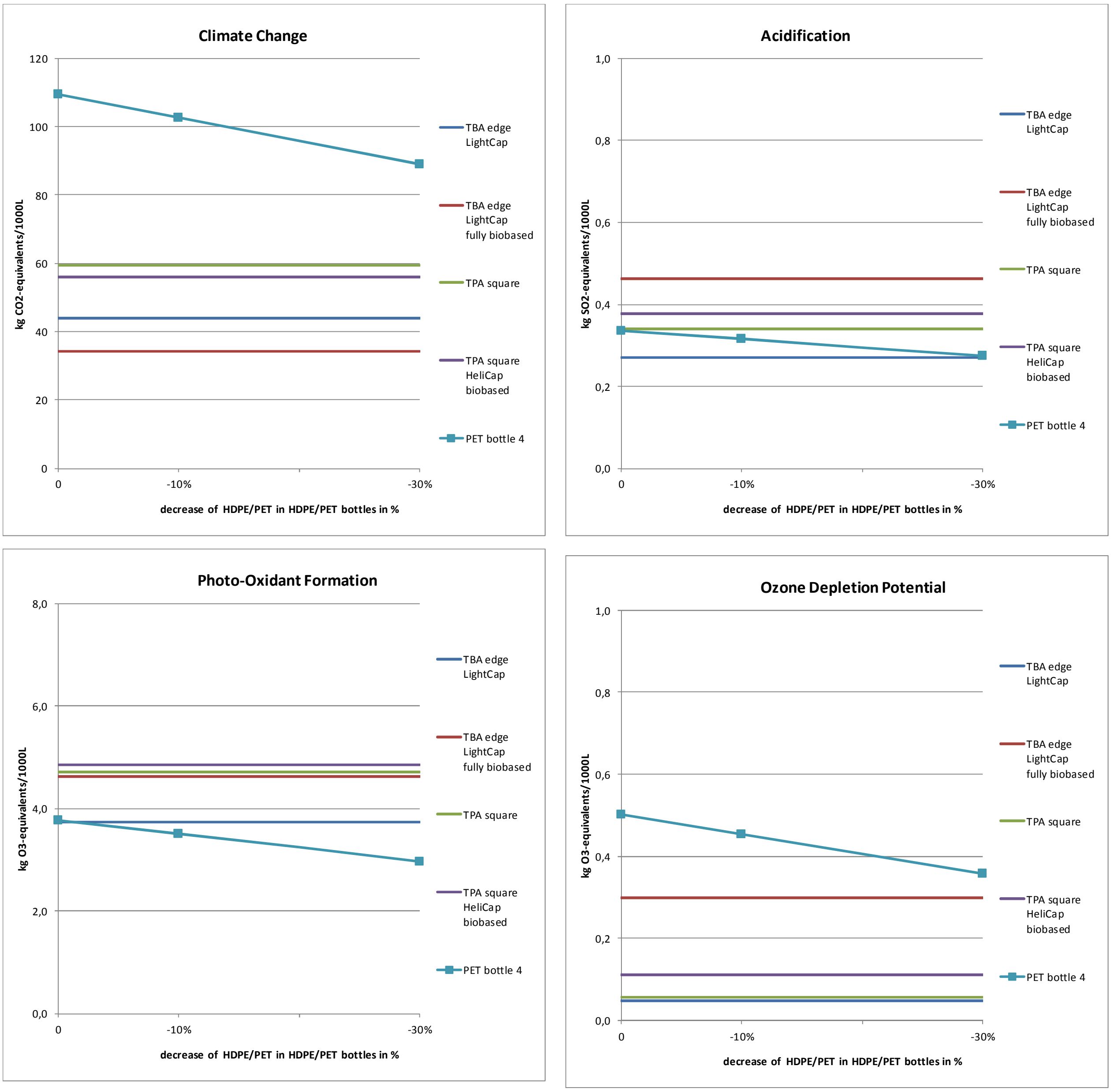


Figure 41: Indicator results for sensitivity analysis on plastic bottle weights of **segment JNSD ambient, Sweden**, allocation factor 50% (Part 1)

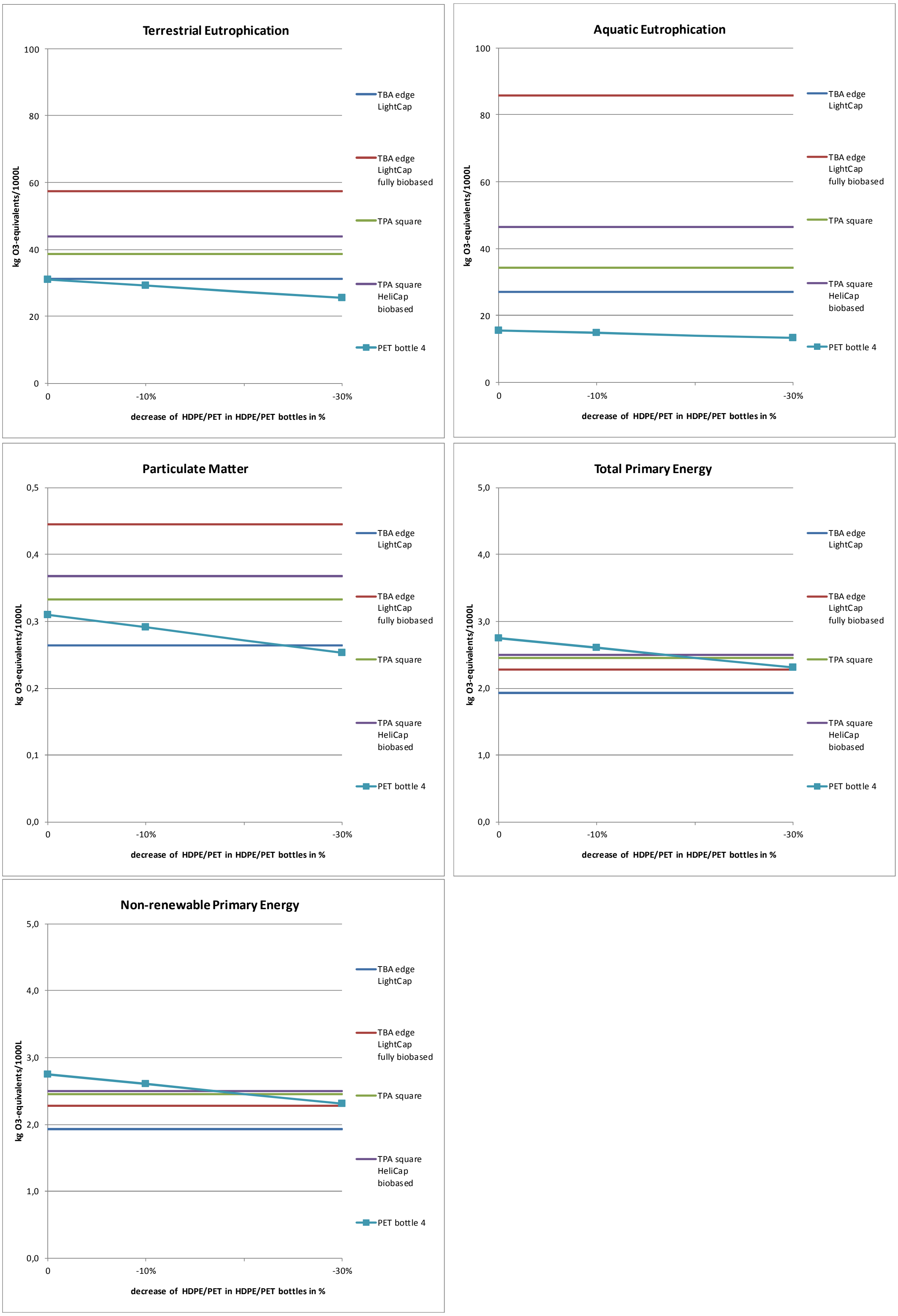


Figure 42: Indicator results for sensitivity analysis on plastic bottle weights of **segment JNSD ambient, Sweden**, allocation factor 50% (Part 2)

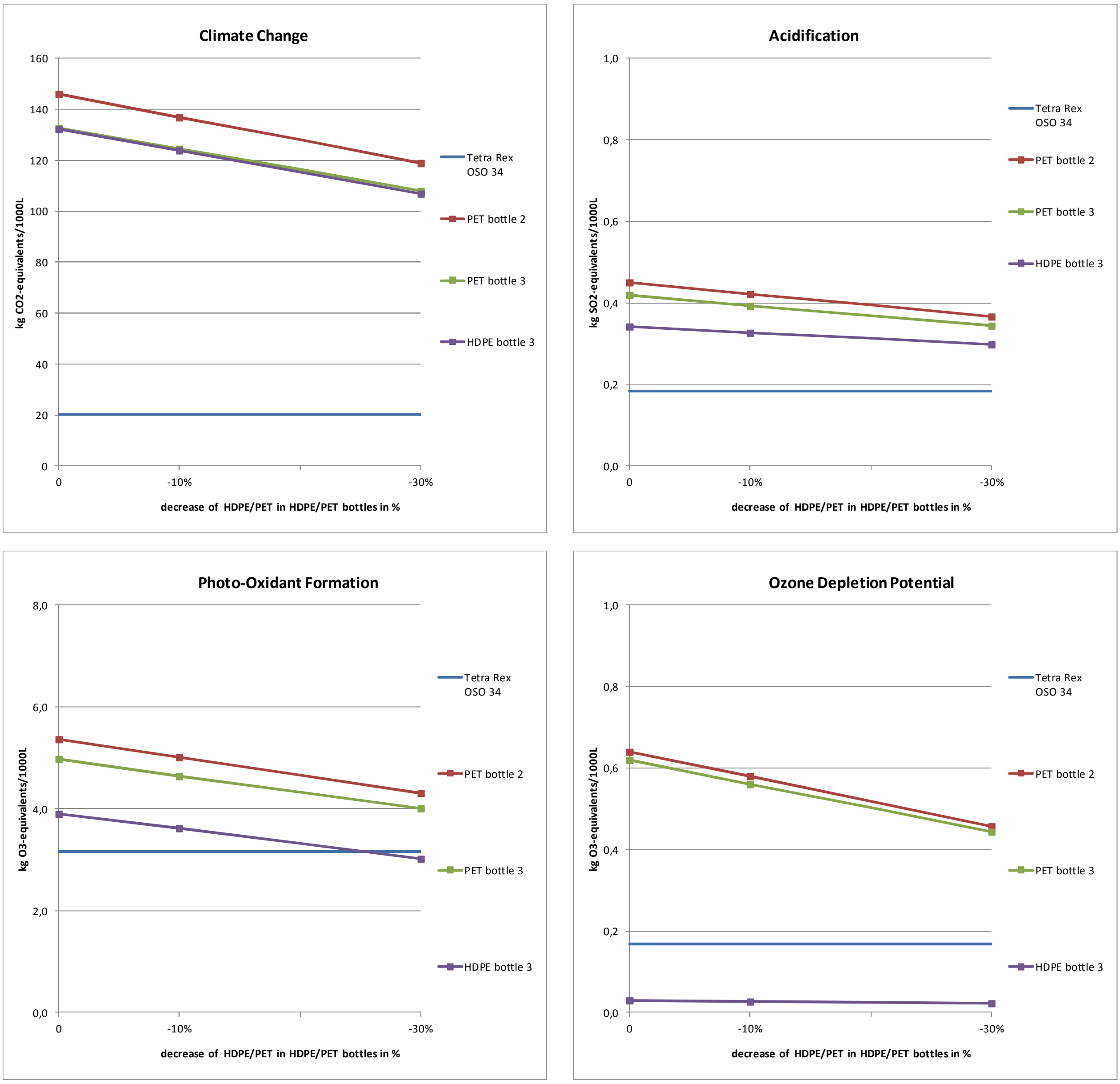


Figure 43: Indicator results for sensitivity analysis on plastic bottle weights of **segment JNSD chilled, Sweden**, allocation factor 50% (Part 1)

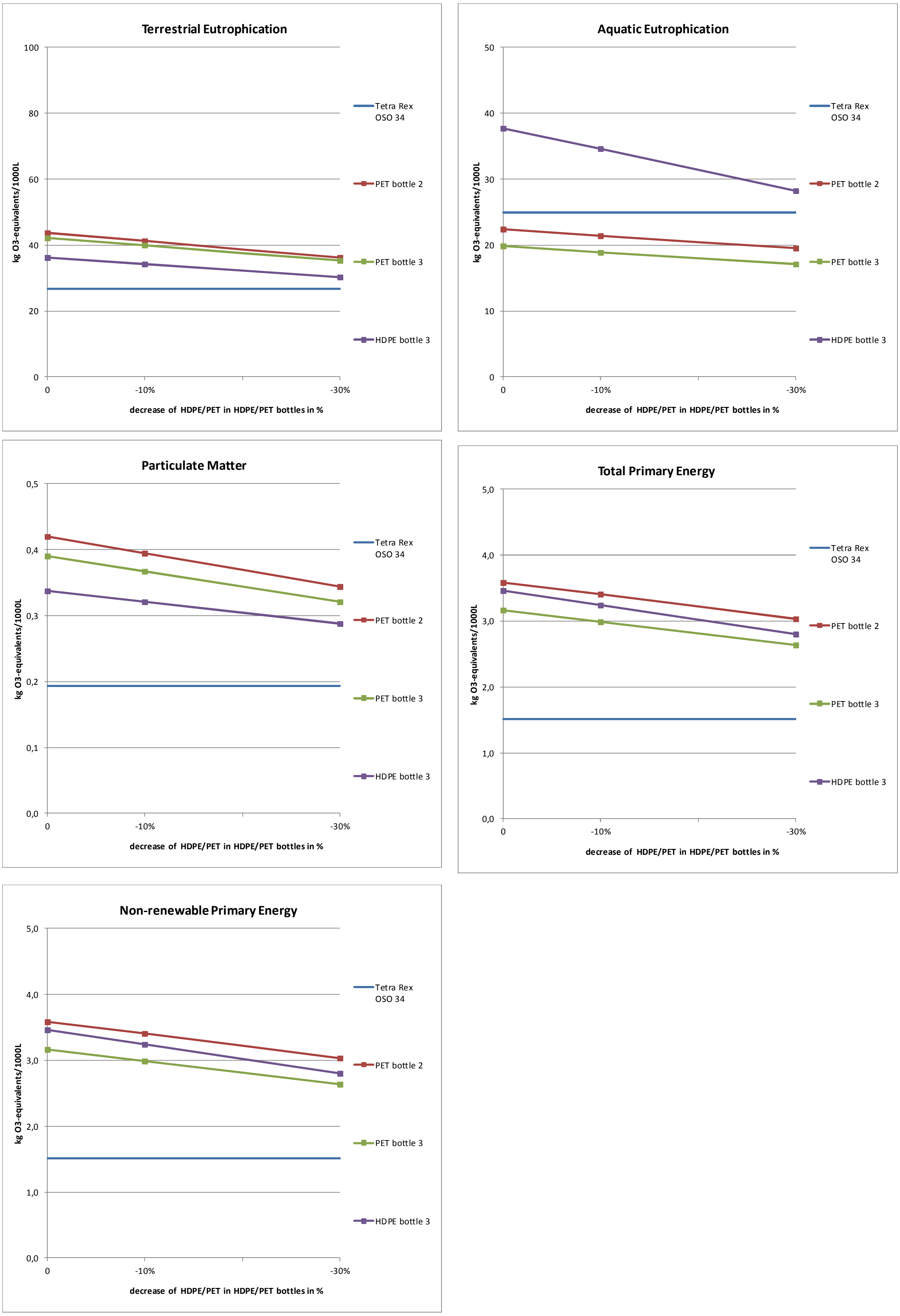


Figure 44: Indicator results for sensitivity analysis on plastic bottle weights of **segment JNSD chilled, Sweden**, allocation factor 50% (Part 2)

Description and Interpretation

For the JNSD ambient segment the ‘PET bottle 4’ is recalculated with reduced weight.

A lightweight version of the ‘PET bottle 4’ does not achieve lower results than any of the regarded beverage cartons in the impact categories ‘Climate Change’ and ‘Ozone Depletion Potential’, even if its weight is reduced by 30%.

It reaches break-even though with ‘TBA edge LightCap’ in ‘Photo-Oxidant Formation’ at about 2% weight reduction and with the same carton in ‘Particulate Matter’ at about 24% weight reduction.

In the JNSD chilled segment only the ‘HDPE bottle 3’ achieves a break-even with the only beverage carton in this segment, the ‘Tetra Rex OSO 34’. The break-even occurs in the impact category ‘Photo-Oxidant Formation’ at about 25% weight reduction.

5.2.4 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu’s own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

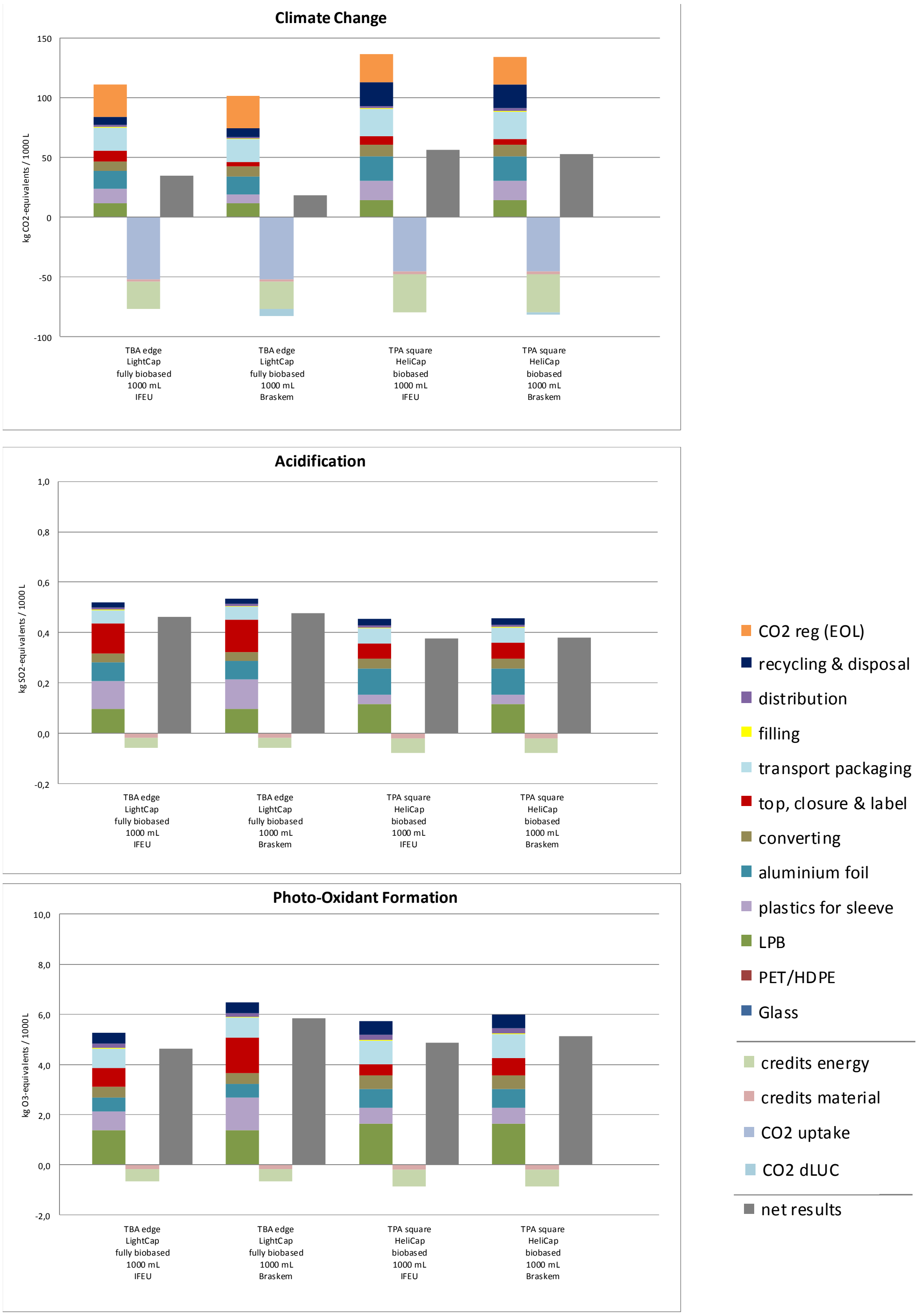


Figure 45: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Sweden**, allocation factor 50% (Part 1)

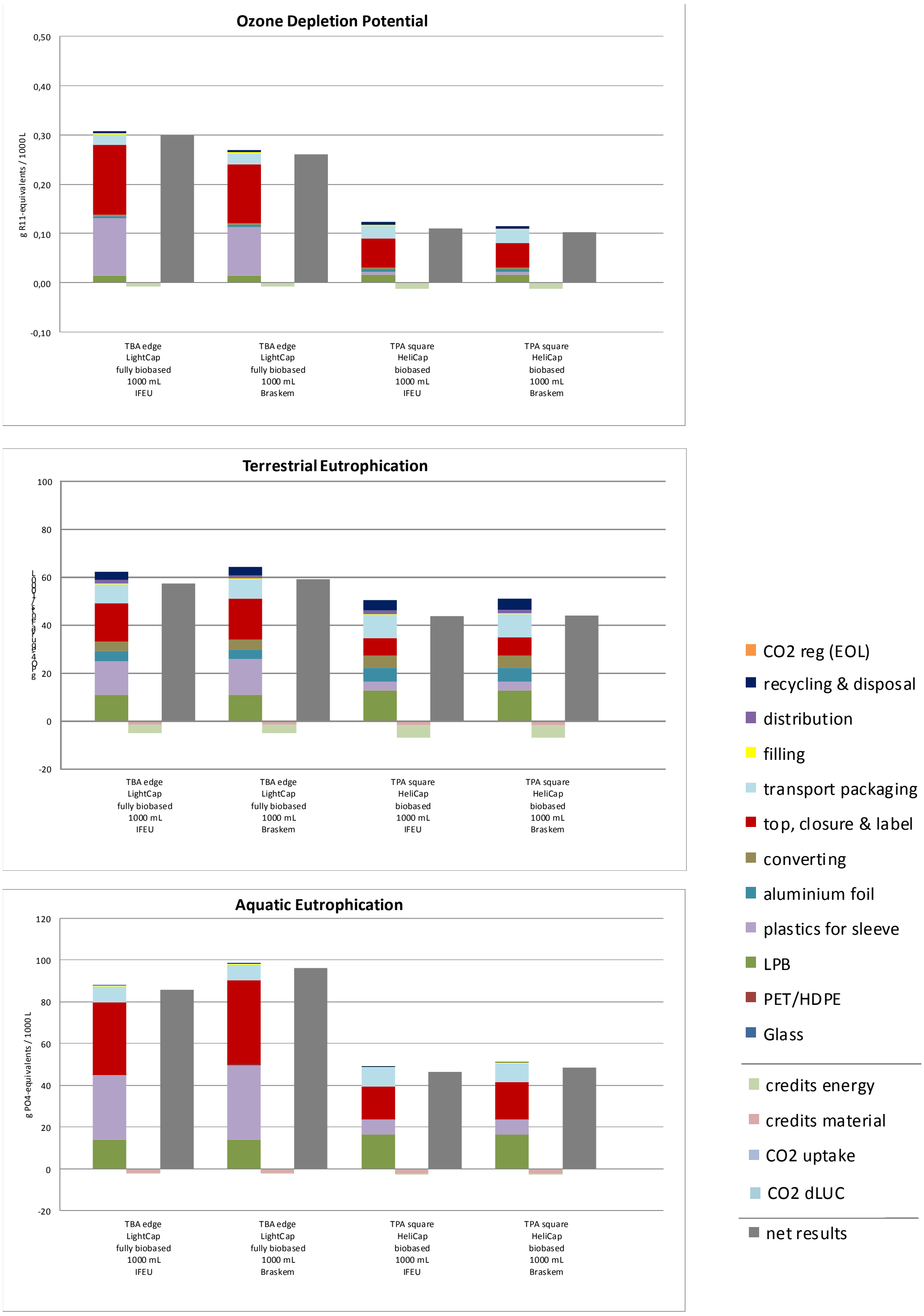


Figure 46: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Sweden**, allocation factor 50% (Part 2)

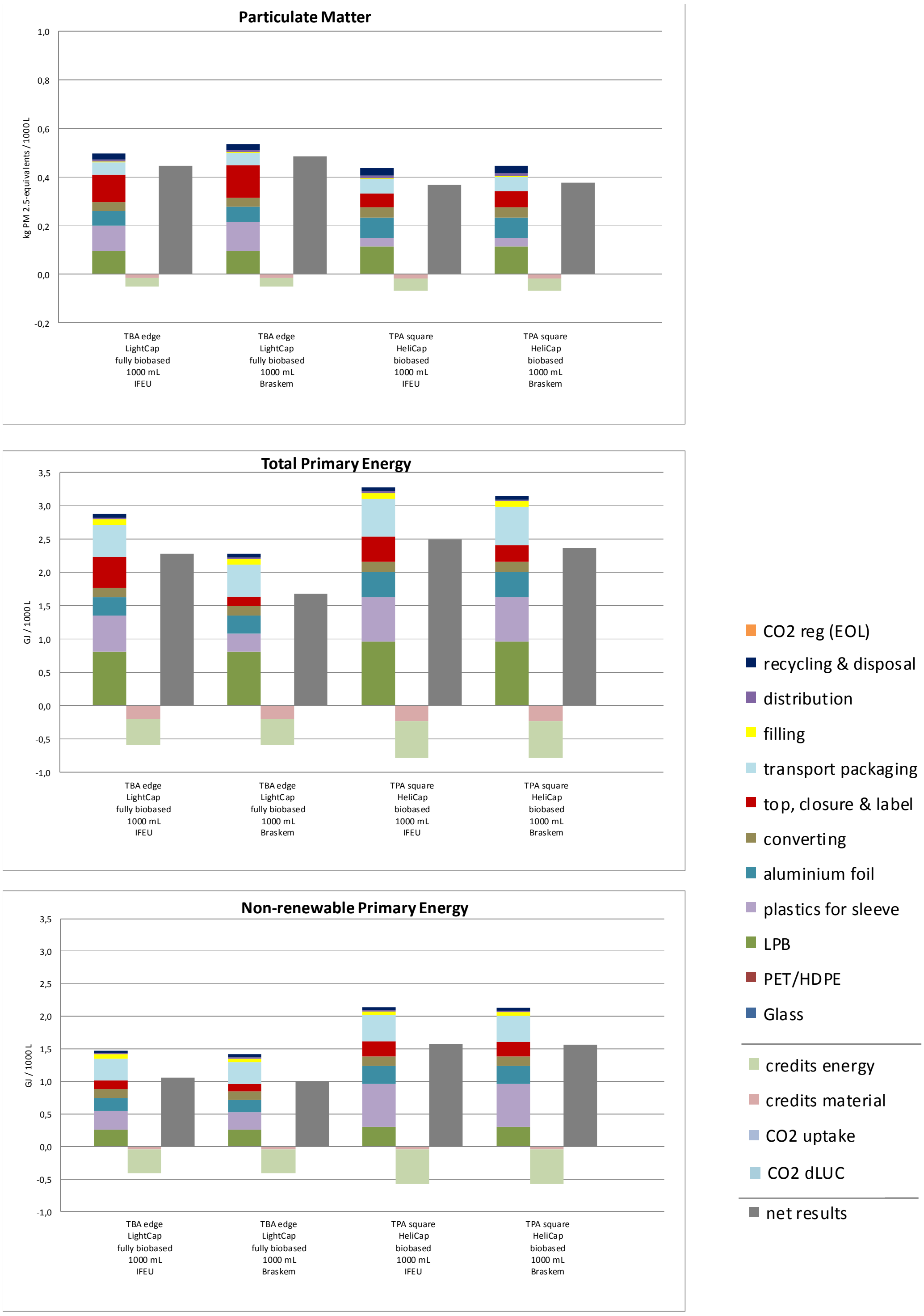


Figure 47: Indicator results for sensitivity analysis on Bio-PE of segment JNSD, Sweden, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the TBA edge and TPA square cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower 'Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of JNSD packaging on the Swedish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

5.3 Grab & Go Sweden

5.3.1 Sensitivity analysis on system allocation Grab & Go Sweden

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 subjective 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%.

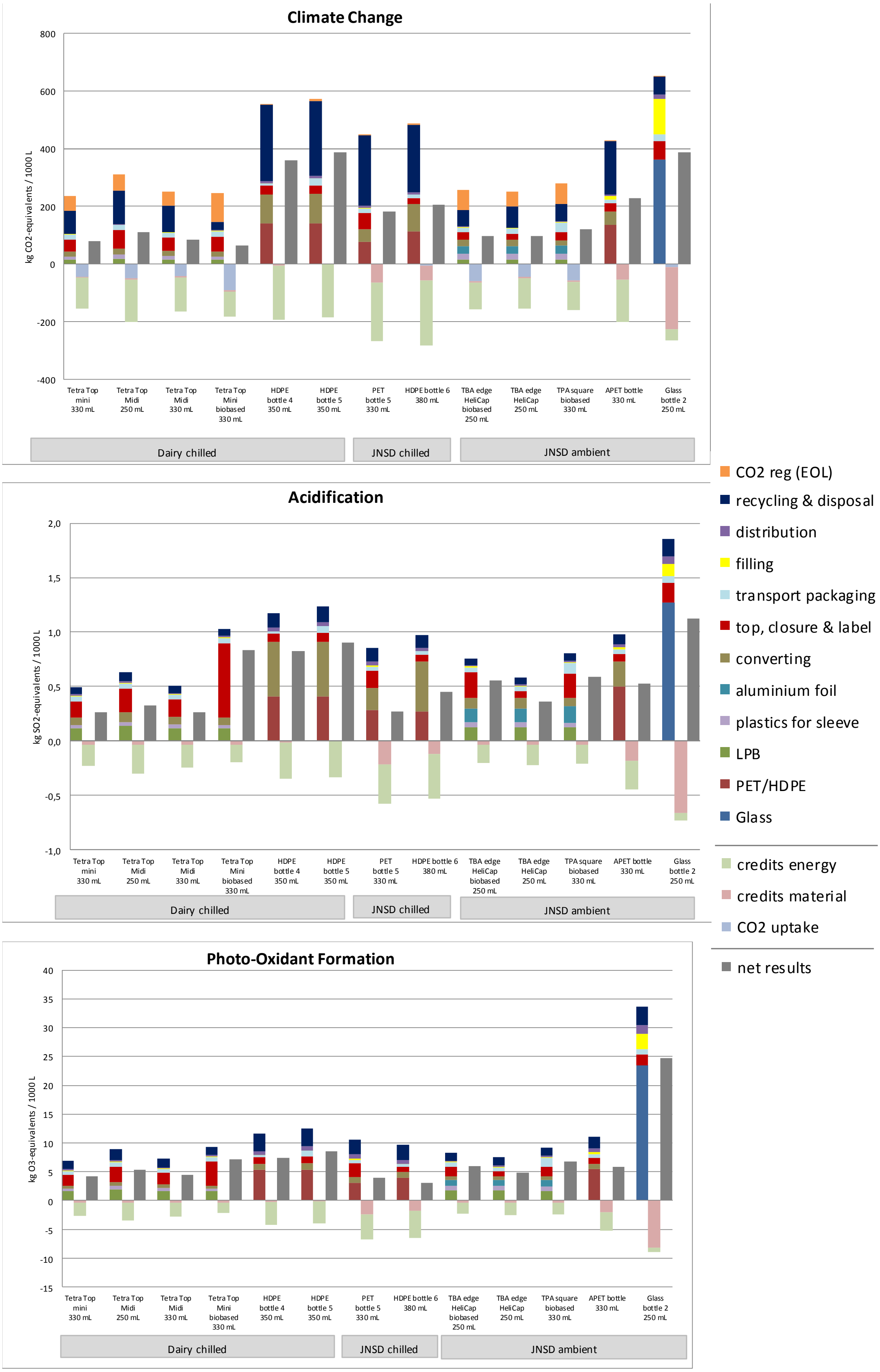


Figure 48: Indicator results for sensitivity analysis on system allocation of segment Grab & Go, Sweden, allocation factor 100% (Part 1)

Figure 49: Indicator results for sensitivity analysis on system allocation of **segment Grab & Go, Sweden** , allocation factor 100% (Part 2)

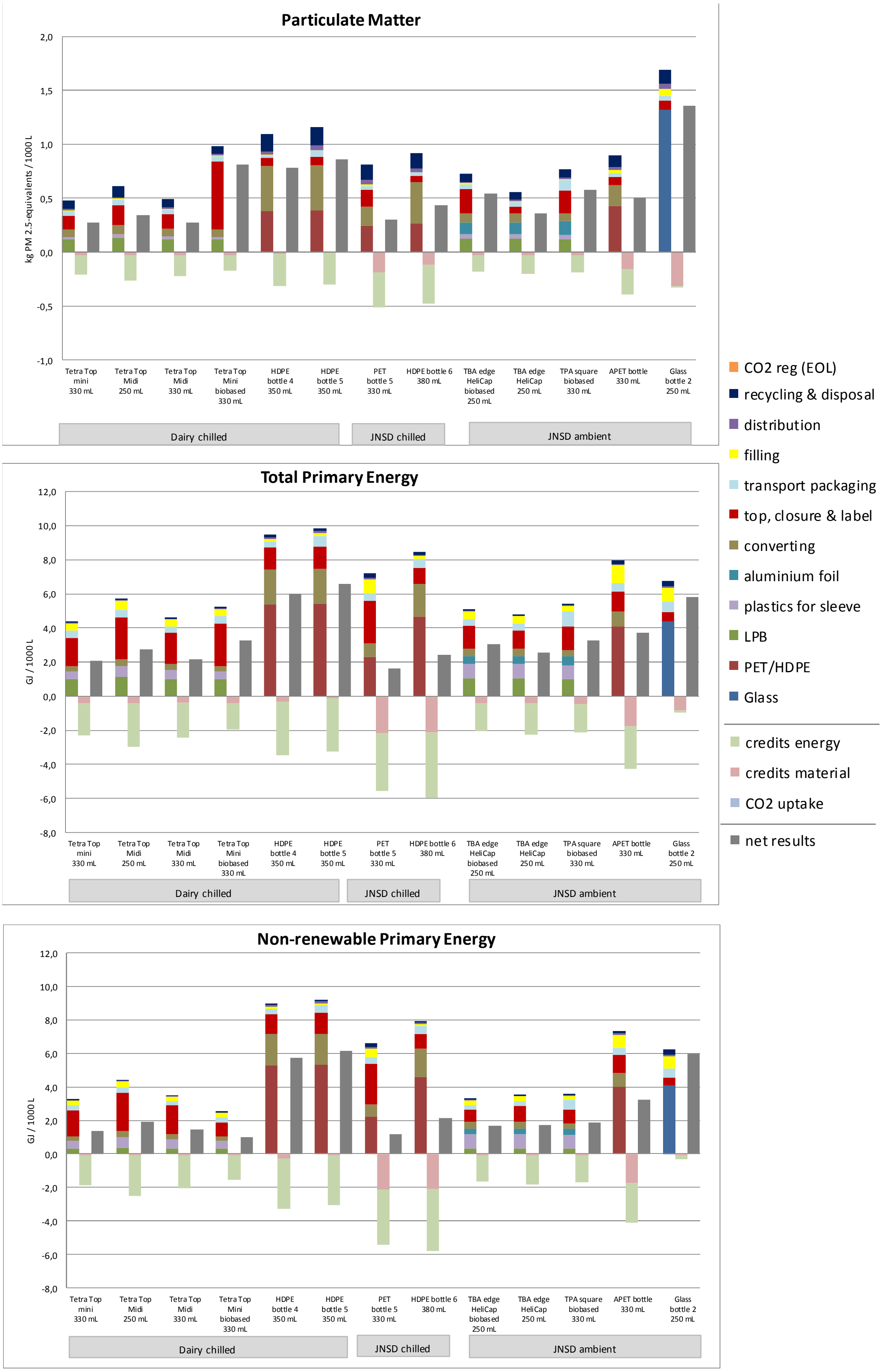


Figure 50: Indicator results for sensitivity analysis on system allocation of **segment Grab & Go, Sweden**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means, that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Swedish market the electricity credited is the Swedish grid mix with its relatively low share of fossil energy sources.

5.3.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are be analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

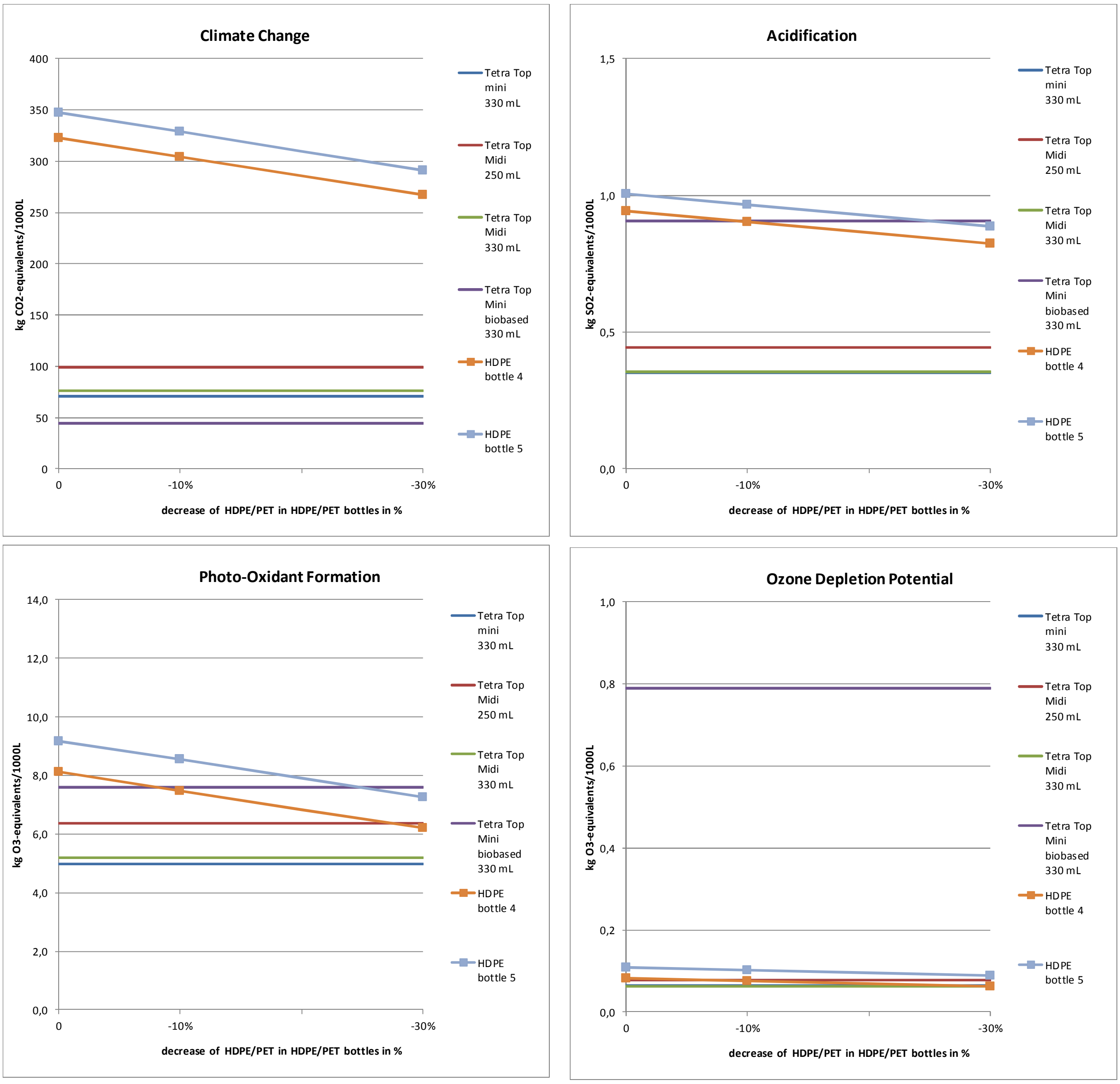
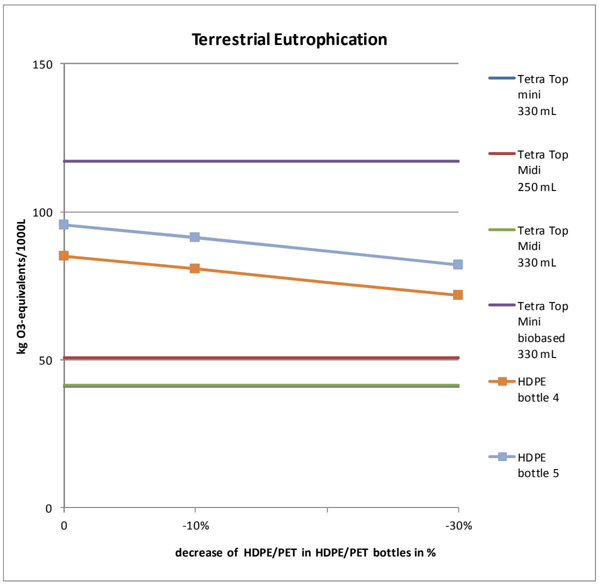
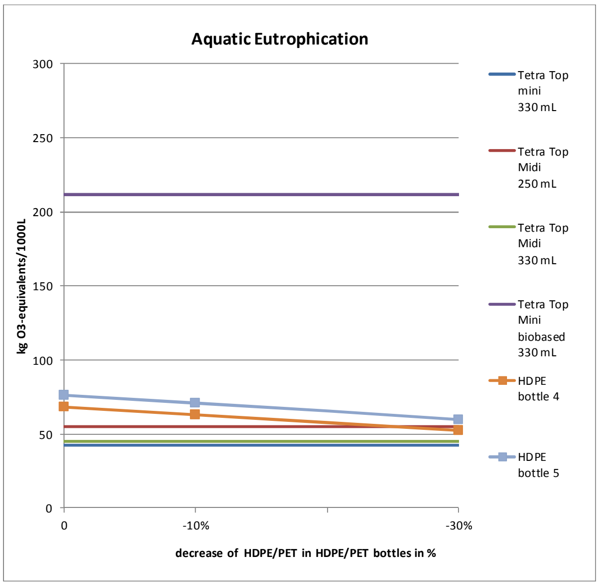
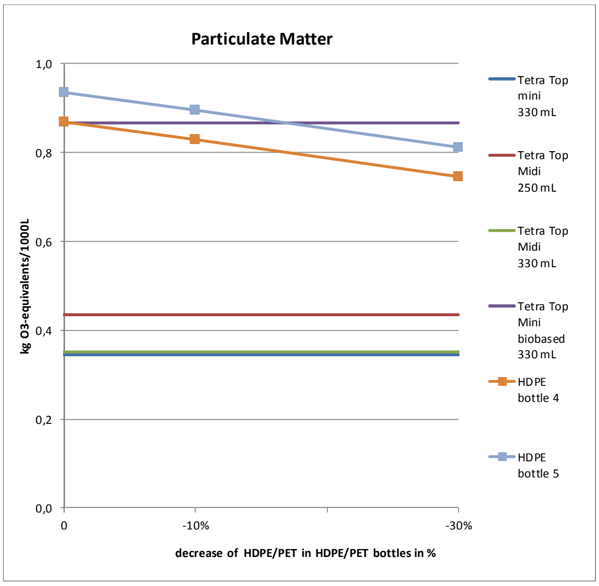
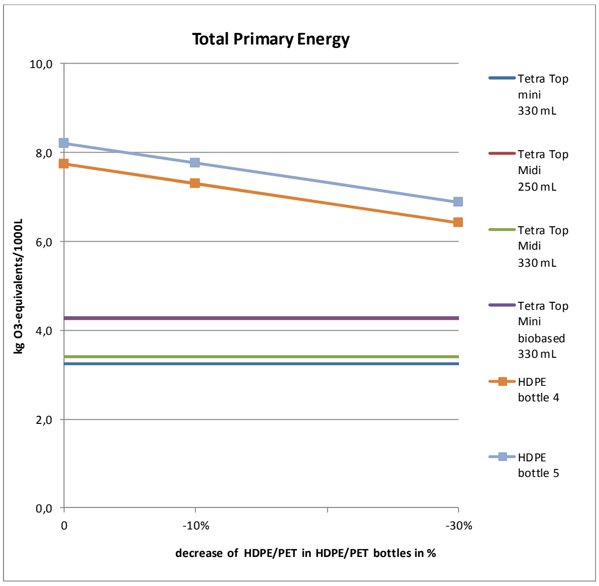


Figure 51: Indicator results for sensitivity analysis on plastic bottle weights of **segment Grab & Go DAIRY chilled, Sweden**, allocation factor 50% (Part 1)









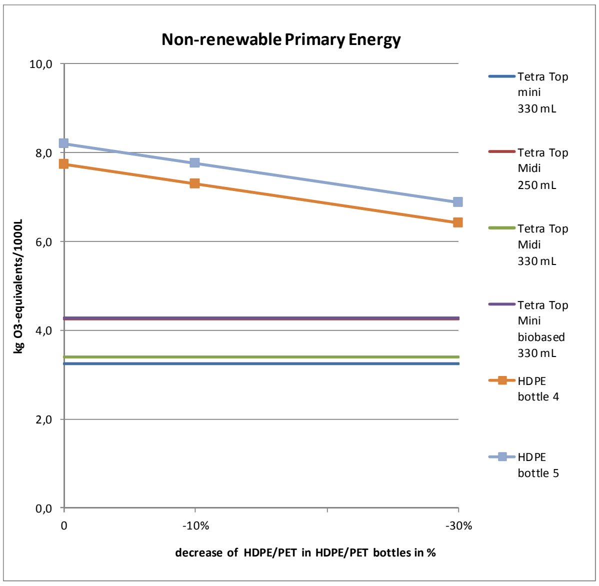


Figure 52: Indicator results for sensitivity analysis on plastic bottle weights of **segment Grab & Go DAIRY chilled, Sweden**, allocation factor 50% (Part 2)

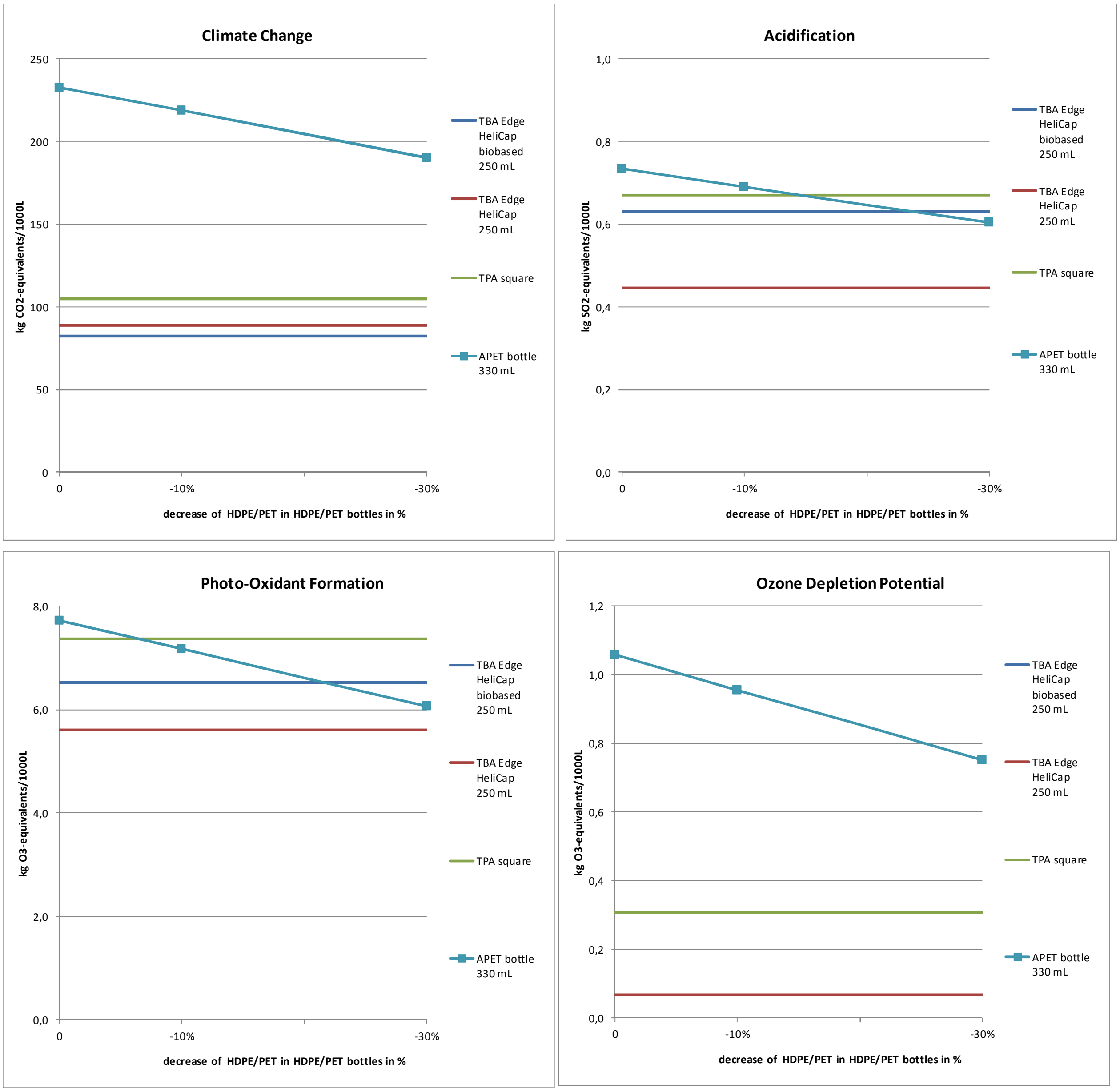


Figure 53: Indicator results for sensitivity analysis on plastic bottle weights of **segment Grab & Go JNSD ambient, Sweden**, allocation factor 50% (Part 1)

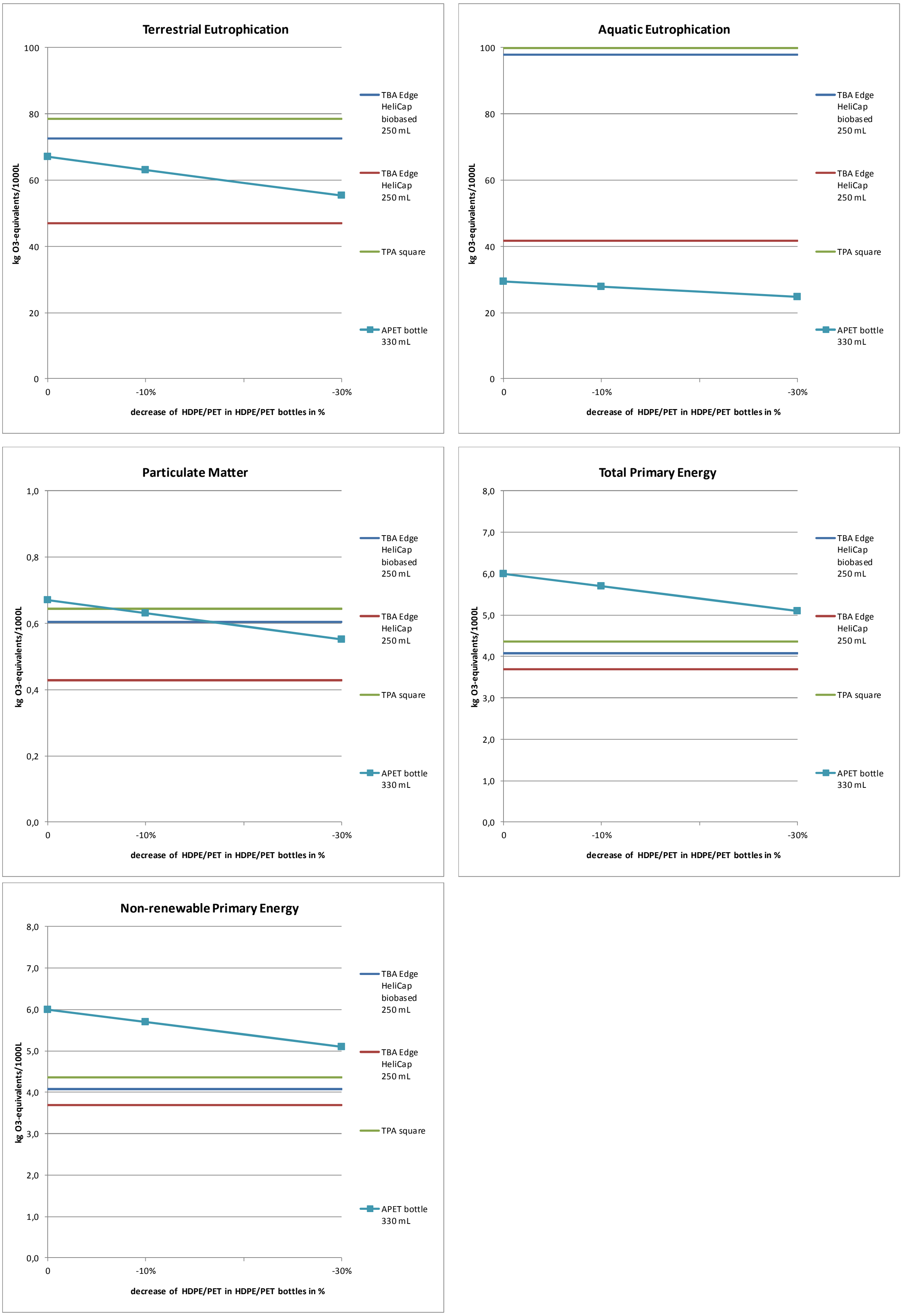


Figure 54: Indicator results for sensitivity analysis on plastic bottle weights of **segment Grab & Go JNSD ambient, Sweden**, allocation factor 50% (Part 2)

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In many cases, though even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of a beverage carton is met.

No lightweight bottle achieves a new 'rank' when compared to beverage cartons in the categories 'Climate Change' in both, the chilled and ambient segment.

In the Grab & Go chilled segment both recalculated bottles, the 'HDPE bottle 4' and 'HDPE bottle 5' break even with 'Tetra Top Mini biobased' in the categories 'Acidification' and 'Photo-Oxidant Formation' at weight reduction between 7% and 25%.

The 'HDPE bottle 4' also breaks even with the 250 mL 'Tetra Top Midi' in 'Photo-Oxidant Formation' at about 27% weight and in 'Ozone Depletion Potential' at ca. 5% weight reduction, as well as in 'Aquatic Eutrophication' at about 25% weight reduction.

In the Grab & Go ambient segment the 'APET bottle' breaks even with 'TPA square' and 'TBA Edge HeliCap bio-based' in 'Acidification' at about 15% and ca. 23% weight reduction, in 'Photo-Oxidant Formation' at ca. 7% and 20% weight reduction and in the impact category 'Particulate Matter' at about 6% and 15% weight reduction.

5.3.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

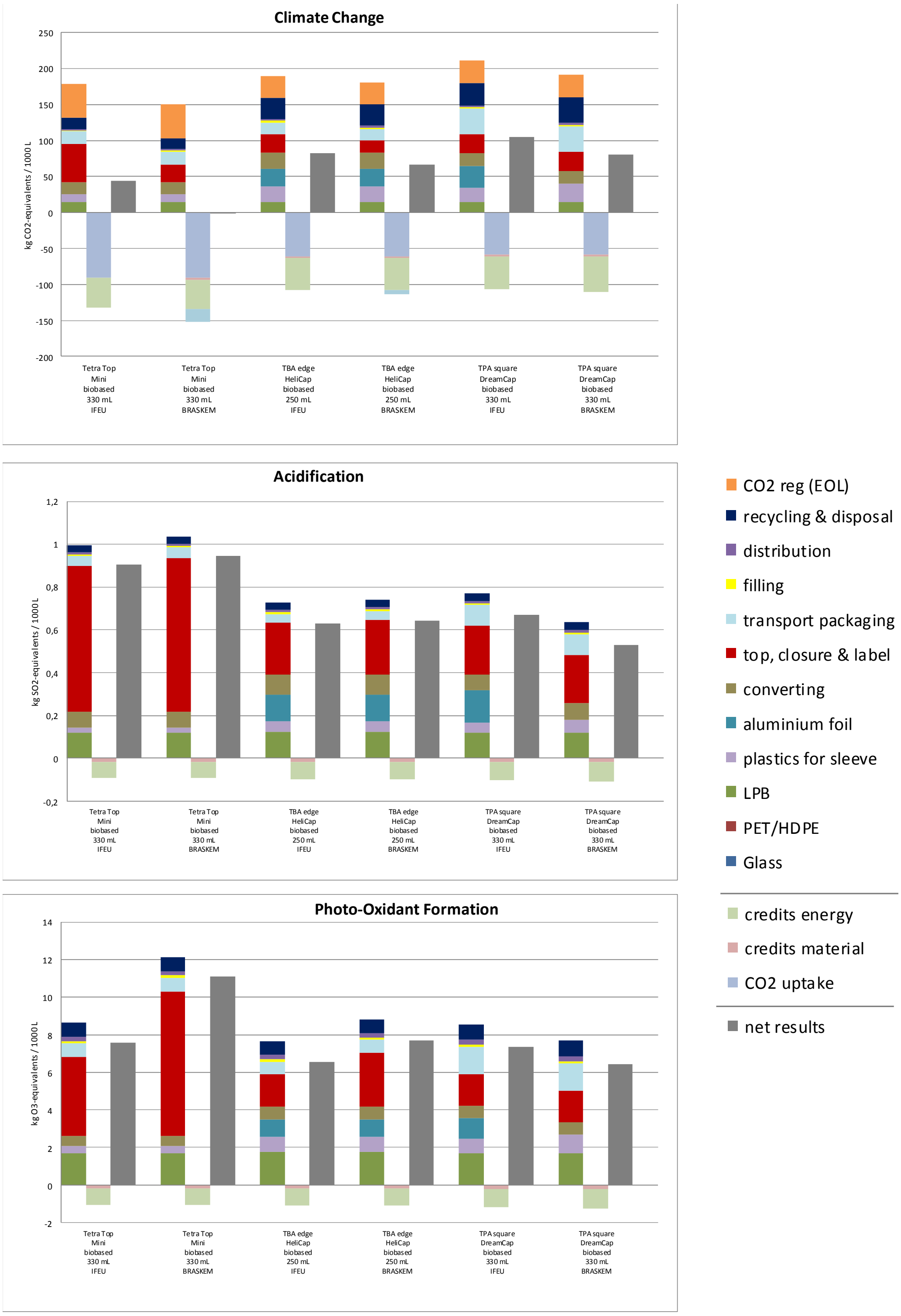


Figure 55: Indicator results for sensitivity analysis on Bio-PE of **segment** Grab & Go, **Sweden**, allocation factor 50% (Part 1)

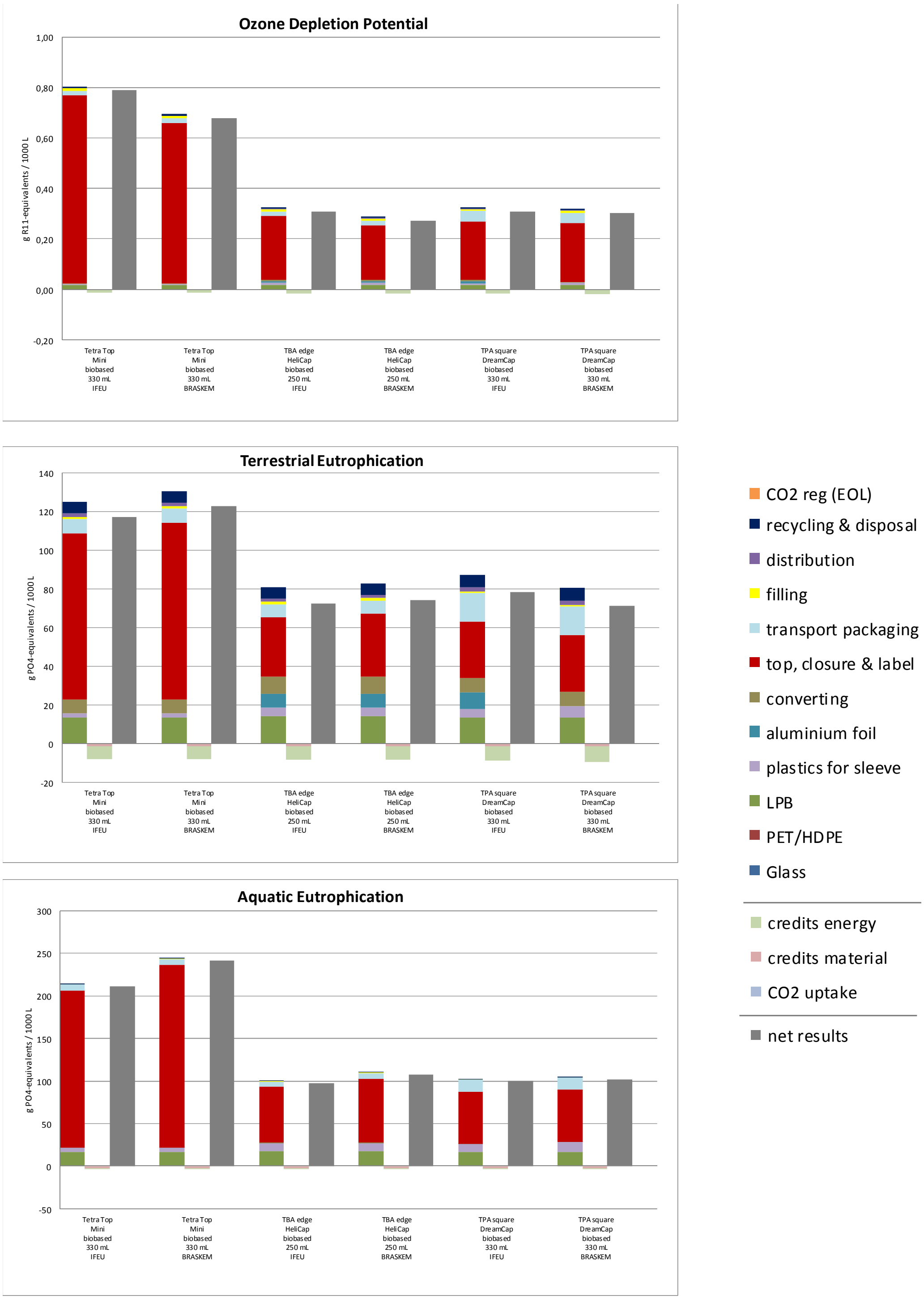


Figure 56: Indicator results for sensitivity analysis on Bio-PE of **segment Grab & Go, Sweden**, allocation factor 50% (Part 2)

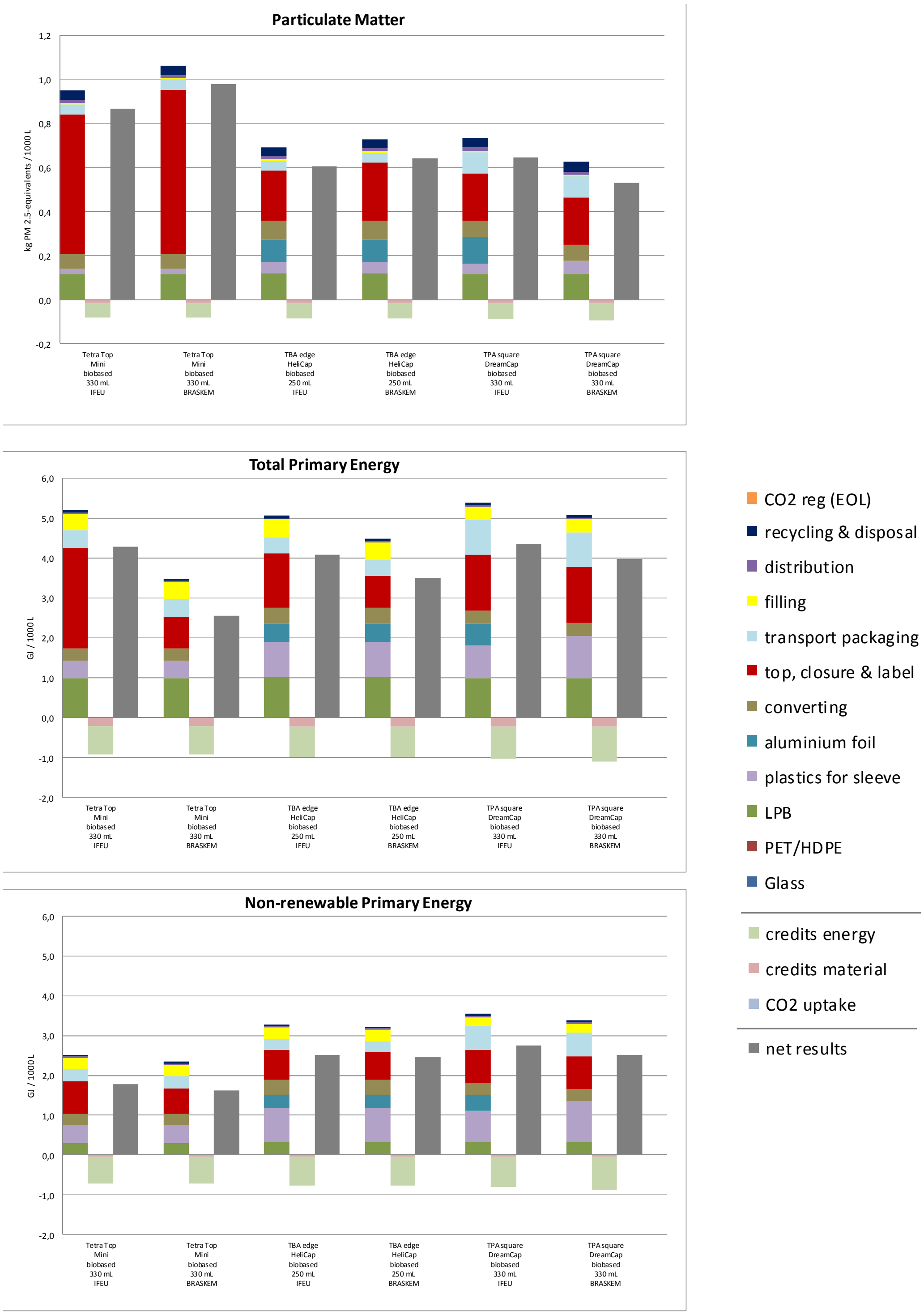


Figure 57: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Sweden**, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the beverage cartons with bio-based plastics of the Grab & go segment modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower' Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of grab & go packaging on the Swedish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

6 Conclusions Sweden

6.1 Dairy Sweden

In general the examined beverage carton systems show lower burdens in all of the impact categories than their competing systems. An exception to this occurs in some categories if the carton contains a high share of biobased polyethylene.

This is especially true in the base scenarios where an allocation factor of 50% is applied. For example the 'Tetra Rex OSO 34 fully biobased 1000 mL' and 'Tetra Rex biobased 1500 mL' even show negative net results in this case. This is due to the fact that only half of the regenerative CO_2-emissions of end-of-life are accounted to the beverage carton. This is however not the case if an allocation factor of 100% is applied: the results are positive but still very low.

A considerable role for these generally low environmental impacts of beverage cartons plays the renewability of their paperboard components and a high use of renewable energies.

Apart from the 'Tetra Top' the carton systems also benefit from the use of multi-use roll containers instead of one-way transport packaging.

Lowest results are shown by those beverage carton systems without a separate closure system.

In the environmental impact category 'Climate Change' the cartons furthermore benefit from the use of bioplastics for sleeve and/or closure. However, a higher share of Bio-PE leads to higher environmental impacts in all other impact categories examined. In case of the substitution of fossil based polyethylene by biobased polyethylene in the sleeve and closure the respective beverage cartons may lose their environmental advantage against the competing bottles in some impact categories.

The comparison of the 1000mL beverage cartons with a Tetra Rex with a filling volume of 1500 mL shows that the overall environmental impacts benefit from a larger volume size.

The sensitivity analysis on plastic bottle weights shows, that reducing the weight of plastic bottles will lead to lower environmental impacts. When compared to the unaltered beverage cartons the results of the potential fossil-based lightweight bottles calculated may lead to a change in the overall ranking in some cases, especially in regard to the fully bio-based cartons. In the category 'Climate Change' however none of the potential lightweight bottles achieve lower results than any of the beverage cartons.

6.2 JNSD Sweden

In the segment JNSD chilled the examined ‘Tetra Rex OSO 34 1000 mL’ shows the lowest results in most of the environmental categories. That makes it the most favourable choice for the packaging of chilled JNSD on the Swedish market when compared to the competing packaging systems examined in this study.

A considerable role for these low environmental impacts plays the renewability of the paperboard components and a high use of renewable energies.

In the segment JNSD ambient the use of aluminium foil for ambient packaging increases the overall burdens of the beverage cartons. However the cartons without biobased polyethylene still show lower or similar results than the bottles examined in most of the impact categories.

With an increased share of biobased polyethylene ‘Climate Change’ results of beverage cartons improve. Results in all other impact categories however increase to an extent that compared to the PET bottle the carton loses its overall environmental advantage.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

6.3 Grab & Go Sweden

The examined beverage carton systems without biobased polyethylene for Grab and Go in the subsegment Dairy chilled show lower burdens in all of the impact categories than their competing systems.

As the share of plastics in a small volume Tetra Top packaging is higher than other beverage cartons of bigger volumes, the choice of plastic material type, e.g. fossil or biobased, plays a decisive role for the environmental performance. In case of the ‘Tetra Top Mini biobased 330 mL’ the impact results are only significantly lower in the impact category ‘Climate Change’ than those of the ‘HDPE bottle 4’.

Again volume size of the examined packaging systems has an influence on their results: The higher the volume the lower are the impacts according to the functional unit of 1000 L beverage.

In the subsegment JNSD ambient the beverage carton can be considered the packaging of choice when compared to the glass bottle from an environmental viewpoint. Compared to the APET bottle, though, no unambiguous conclusion can be drawn; at least not for the biobased cartons. From the environmental viewpoint generally the ‘TBA edge HeliCap 250 mL’ seems to be the best choice.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

7 Results Finland

In this section, the results of the examined packaging systems for Finland are presented separately for the different segments. The following individual life cycle elements are illustrated in sectoral (stacked) bar charts:

- Production and transport of glass including converting to bottle (**'glass'**)
- production and transport of HDPE/PET for bottles including additives, e.g. TiO_2 ('**HDPE/PET for bottle**')
- production and transport of liquid packaging board ('**liquid packaging board**')
- production and transport of plastics and additives for beverage carton ('**plastics for sleeve**')
- production and transport of aluminium & converting to foil ('**aluminium foil for sleeve**')
- production and transport of base materials for closure, top and label and related converting for cartons and plastic bottles ('**top closure&label**')
- converting processes of cartons and plastic bottles and transport to filler ('**converting**')
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays ('**transport packaging**')
- filling process including packaging handling ('**filling**')
- retail of the packages from filler to the point-of-sale ('**distribution**')
- sorting, recycling and disposal processes – all emissions except regenerative CO_2 ('**recycling/disposal**')
- CO_2 emissions from incineration of biobased and renewable materials **('CO2 reg. (EOL)'**; in the following also the term regenerative CO2 emissions is used

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 section 1.8) 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 energy recovery (replacing e.g. grid electricity) (‘**credits energy**’)
- credits for material recycling (‘**credits material**’)
- 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. Therefore, the category indicator results represent potential environmental impacts per functional unit.

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

- sectoral results of the packaging system itself (stacked bar ‘environmental burdens’)
- credits given for secondary products leaving the system (negative stacked bar ‘credits’)
- 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 (i.e. milk, JNSD) to the point of sale including the end-of-life of the packaging materials.

For the sensitivity analysis including the BRASKEM bio-PE dataset the sector ‘**CO_2 – direct land use change**’ (dLUC) is introduced. This sector shows changes in soil organic carbon and above and below ground carbon stocks from conversion of land to sugarcane cultivation. The BRASKEM dataset accounts a negative CO2 value for dLUC.

7.1 Results Dairy Finland

7.1.1 Presentation of results DAIRY Finland

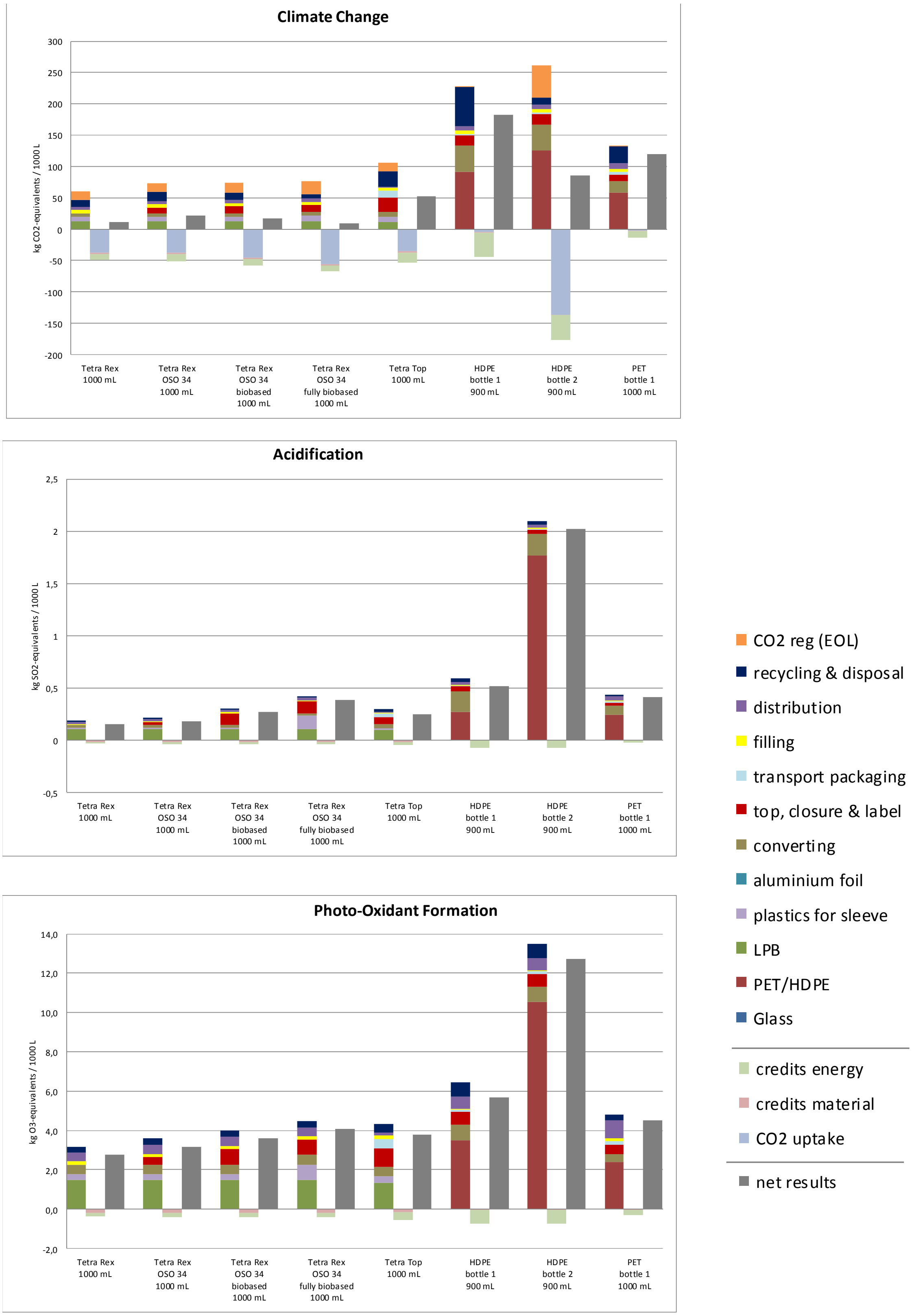


Figure 58: Indicator results for base scenarios of **segment Dairy, Finland**, allocation factor 50% (Part 1)

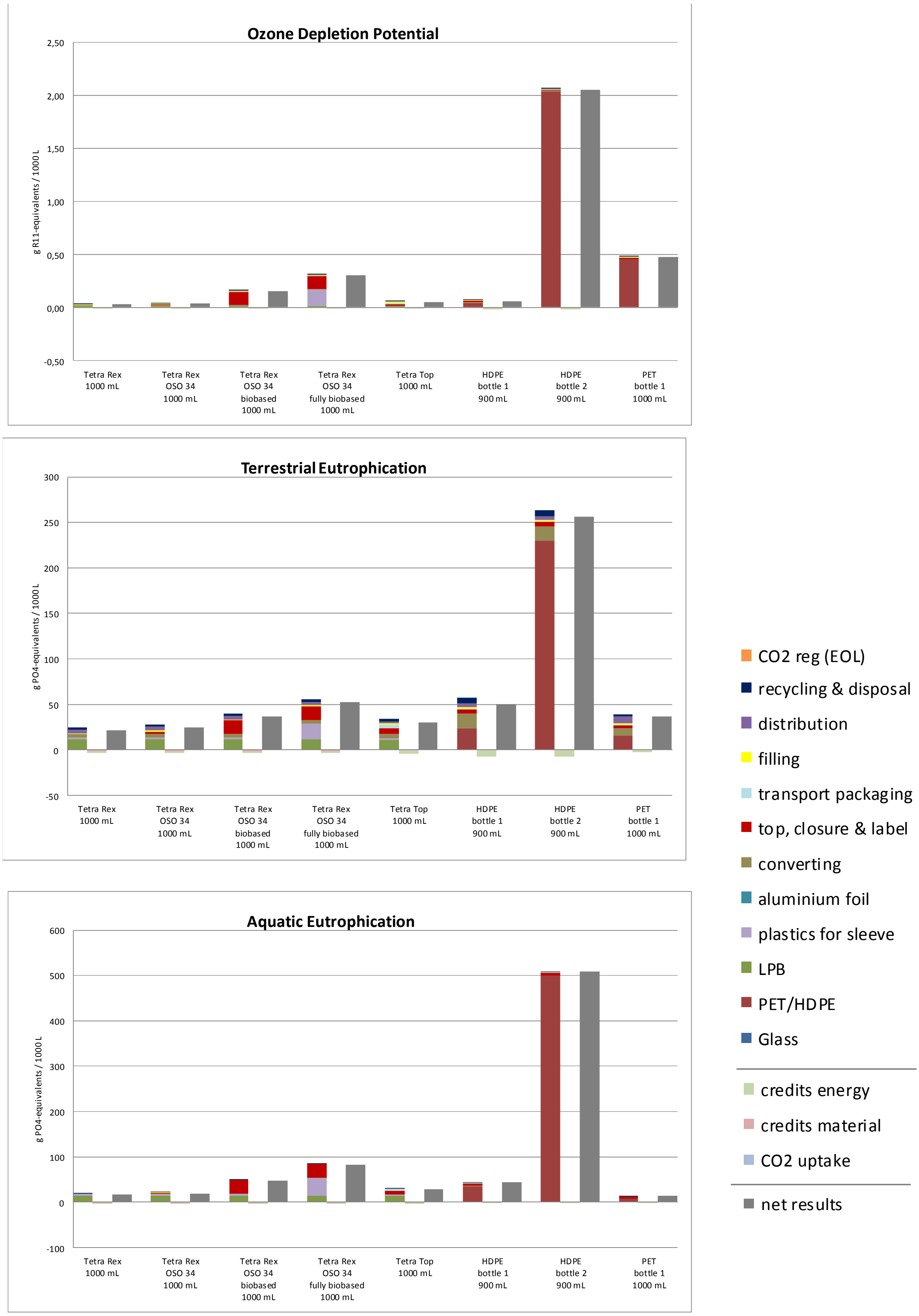


Figure 59 Indicator results for base scenarios of **segment Dairy, Finland**, allocation factor 50% (Part 2)

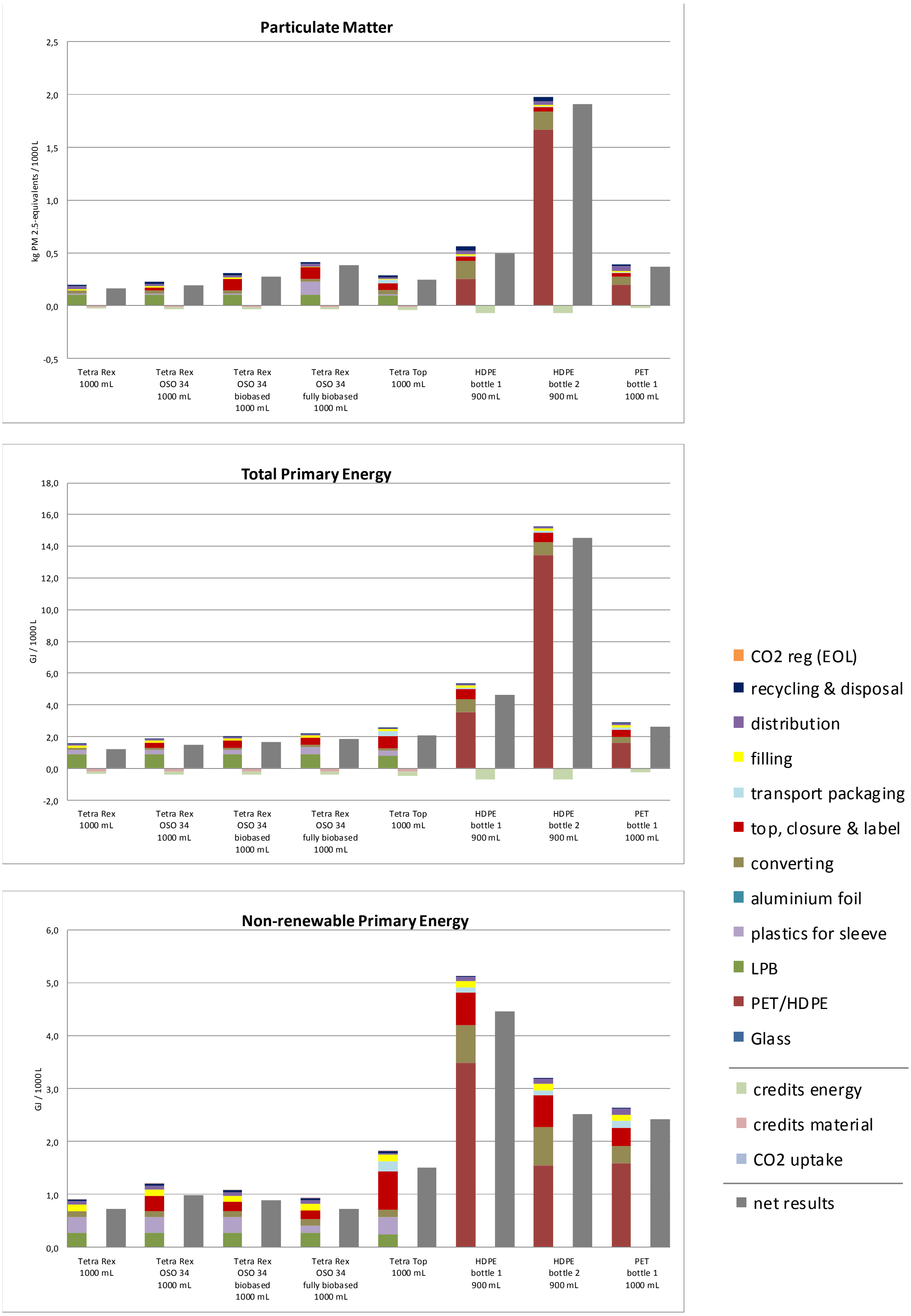


Figure 60: Indicator results for base scenarios of **segment Dairy, Finland**, allocation factor 50% (Part 3)

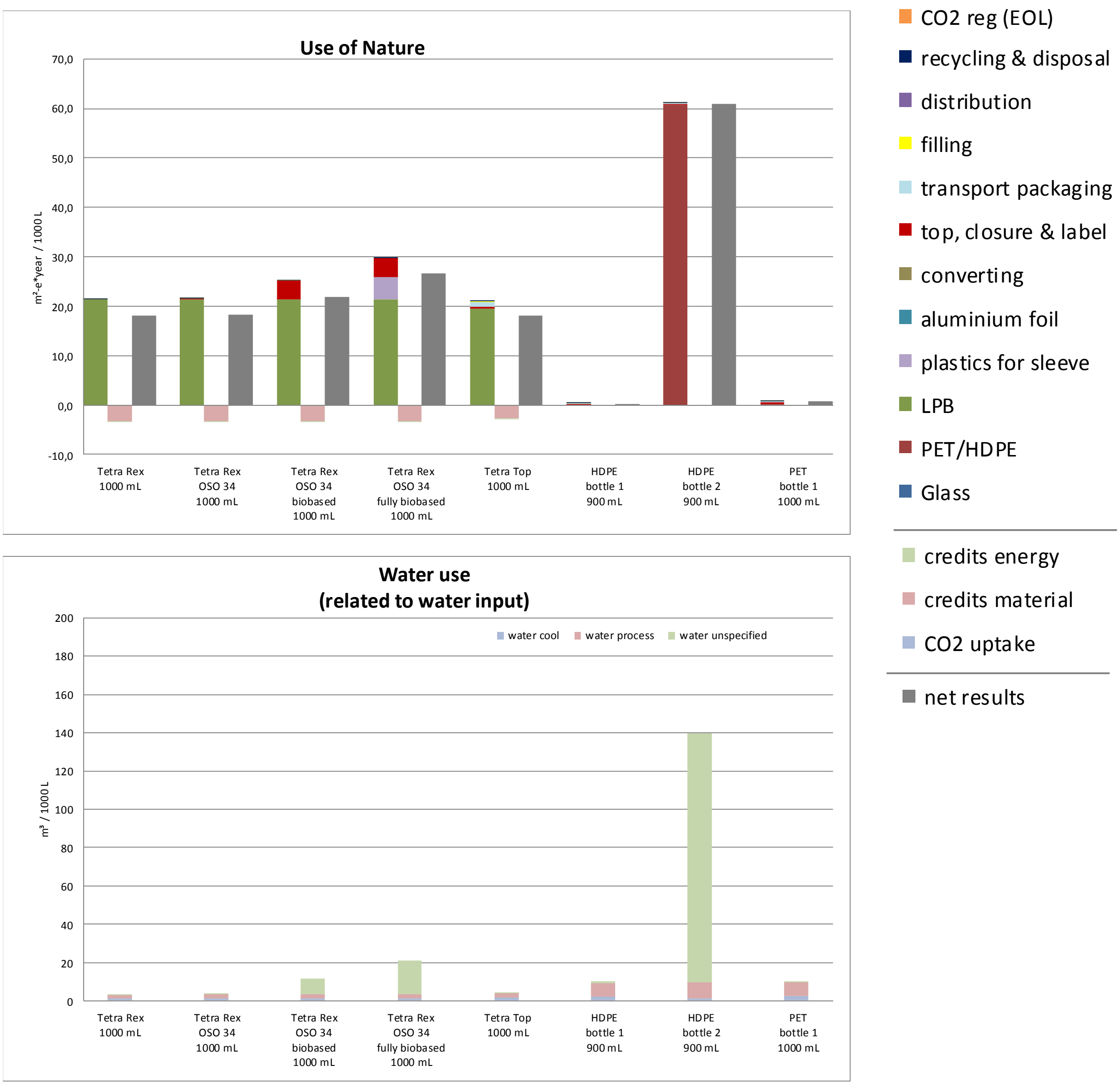


Figure 61: Indicator results for base scenarios of segment Dairy, Finland, allocation factor 50% (Part 4)

Table 52: Category indicator results per impact category for base scenarios of segment DAIRY, Finland- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Finland, allocation factor 50 %		Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	47.13	59.82	58.18	55.53	92.33
	CO2 (reg)	12.93	13.07	16.36	21.29	13.82
	Credits	-10.80	-13.06	-11.70	-11.70	-18.77
	CO_2 uptake	-37.99	-37.99	-45.86	-55.84	-34.94
	Net results (∑)	11.28	21.84	16.98	9.28	52.44
Acidification [kg SO_2-equivalents]	Burdens	0.19	0.22	0.31	0.42	0.29
	Credits	-0.03	-0.04	-0.04	-0.04	-0.05
	Net results (∑)	0.15	0.18	0.27	0.38	0.25
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	3.16	3.59	3.99	4.48	4.34
	Credits	-0.39	-0.43	-0.40	-0.40	-0.55
	Net results (∑)	2.77	3.16	3.59	4.08	3.79
Ozone Depletion [g R-11-equivalents]	Burdens	0.03	0.04	0.16	0.31	0.06
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01
	Net results (∑)	0.03	0.04	0.16	0.31	0.05
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	24.26	27.58	39.79	55.36	34.52
	Credits	-3.00	-3.37	-3.12	-3.12	-4.25
	Net results (∑)	21.27	24.22	36.67	52.24	30.28
Aquatic eutrophication [g PO_4-equivalents]	Burdens	18.79	21.85	49.70	84.81	29.83
	Credits	-2.30	-2.24	-2.24	-2.24	-2.04
	Net results (∑)	16.49	19.61	47.46	82.57	27.79
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.20	0.23	0.31	0.41	0.29
	Credits	-0.03	-0.03	-0.03	-0.03	-0.04
	Net results (∑)	0.17	0.19	0.28	0.38	0.25
Total Primary Energy [GJ]	Burdens	1.56	1.89	2.03	2.20	2.56
	Credits	-0.37	-0.41	-0.38	-0.38	-0.49
	Net results (∑)	1.19	1.48	1.65	1.82	2.08
Non-renewable primary energy [GJ]	Burdens	0.91	1.20	1.08	0.93	1.82
	Credits	-0.18	-0.22	-0.20	-0.20	-0.32
	Net results (∑)	0.73	0.98	0.89	0.73	1.50
Use of Nature [m^2-equivalents*year]	Burdens	21.40	21.58	25.22	29.82	20.98
	Credits	-3.35	-3.25	-3.25	-3.25	-2.83
	Net results (∑)	18.04	18.33	21.97	26.58	18.15
Water use [m^3]	Water cool	0.97	1.29	1.19	1.02	1.81
	Water process	2.07	2.11	2.17	2.24	2.00
	Water unspec	0.27	0.31	8.07	17.89	0.35

Table 53: Category indicator results per impact category for base scenarios of segment DAIRY, Finland - burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Finland, allocation factor 50 %		HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	227.51	209.48	132.25
	CO2 (reg)	0.02	52.01	1.77
	Credits	-39.87	-39.87	-11.28
	CO_2 uptake	-4.94	-136.29	-2.66
	Net results (∑)	182.72	85.33	120.07
Acidification [kg SO_2-equivalents]	Burdens	0.59	2.10	0.44
	Credits	-0.07	-0.07	-0.02
	Net results (∑)	0.52	2.02	0.41
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	6.45	13.48	4.80
	Credits	-0.75	-0.75	-0.29
	Net results (∑)	5.69	12.73	4.51
Ozone Depletion [g R-11-equivalents]	Burdens	0.08	2.07	0.48
	Credits	-0.02	-0.02	-0.01
	Net results (∑)	0.06	2.05	0.48
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	57.26	263.31	38.81
	Credits	-7.14	-7.14	-2.19
	Net results (∑)	50.11	256.17	36.62
Aquatic eutrophication [g PO_4-equivalents]	Burdens	44.26	508.93	14.42
	Credits	-0.43	-0.43	-0.53
	Net results (∑)	43.83	508.50	13.89
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.56	1.97	0.39
	Credits	-0.07	-0.07	-0.02
	Net results (∑)	0.49	1.91	0.37
Total Primary Energy [GJ]	Burdens	5.34	15.25	2.85
	Credits	-0.73	-0.73	-0.25
	Net results (∑)	4.61	14.52	2.61
Non-renewable primary energy [GJ]	Burdens	5.13	3.20	2.64
	Credits	-0.68	-0.68	-0.22
	Net results (∑)	4.45	2.52	2.42
Use of Nature [m^2-equivalents*year]	Burdens	0.38	61.06	0.79
	Credits	-0.10	-0.10	-0.06
	Net results (∑)	0.27	60.96	0.73
Water use [m^3]	Water cool	2.11	1.15	2.61
	Water process	7.19	8.28	6.87
	Water unspec	0.72	130.18	0.06

7.1.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the dairy segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. It is also relevant regarding ‘Photo-Oxidant Formation’ ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’ and the consumption of ‘Total Primary Energy’ and ‘Non-renewable Primary Energy’.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category ‘Non-renewable Primary Energy’, where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the ‘Tetra Rex fully bio-based’ due to the production of bio-based PE and relatively lower for ‘Tetra Top’ where the plastics of top and closure show the highest burdens.

The sector top, closure & label plays a role in almost all impact categories. The one exception obviously being the ‘Tetra Rex’ without a separate closure. The impacts of the production of plastics for the closures is higher for ‘Tetra Rex OSO 34 bio-based’ and ‘Tetra Rex fully bio-based’ than for the ‘Tetra Rex OSO 34’ with a fossil-based closure in all categories apart from ‘Non-renewable Primary Energy’. The sector is especially important for ‘Tetra Top’ as its combined Top and Cap uses about three times more plastic than the ‘OSO’ closure of the other beverage cartons.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from ‘Climate Change’ are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’, ‘Photo-Oxidant Formation’, ‘Terrestrial Eutrophication‘ and to a lower extent ‘Acidification’. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories ‘Acidification’, and ‘Terrestrial eutrophication’ are mainly caused by NO_2 emissions from incineration plants.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging’s end-of-life. For the different Tetra Rex packaging systems the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal. It’s the other way around for the ‘Tetra Top’ as the higher share of fossil-based plastics in that packaging system leads to more non-regenerative CO_2 emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Finland 38% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category ‘Use of Nature’. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category ‘Climate Change’. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 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. Exceptions are the ‘Ozone Depletion Potential’ of the ‘HDPE bottle 1’ and the ‘Aquatic Eutrophication’ of ‘PET bottle 1’ as well as ‘Use of Nature’ of both these fossil-based plastic bottles.

For the three regarded bottles three different plastics are used: Fossil-based HDPE for the ‘HDPE bottle 1’m bio-based PE for the ‘HDPE bottle 2’ and fossil-based PET for the ‘PET bottle 1’. The closures of all three of them are made from HDPE. Therefore the impacts of plastics production on different categories vary accordingly. For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for both HDPE bottles than for the PET bottle with the exception of ‘Ozone Depletion Potential’ where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide. The even higher burdens of bio-based PE of the ‘HDPE bottle 2’ originate from field emissions of N_2O from the use of nitrogen fertilisers on sugarcane fields. The agricultural background of the ‘HDPE bottle 2’ also means that for ‘Use of Nature’ the production of Bio-PE is the main contributor to this category.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from ‘Ozone Depletion Potential’, ‘Aquatic Eutrophication’ and ‘Use of Nature’.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the fossil-based plastic bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the white opaque plastic bottles do not undergo a material recycling, the amount of bottle waste incinerated is relatively high. The regenerative CO_2 emissions from the bio-based 'HDPE bottle 2' are of course similarly high, but they are attributed to the sector CO_2 reg (EOL).

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the white plastic bottle waste is incinerated in MSWIs, the received material credits are insignificant compared to the credits for energy.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

7.1.3 Comparison between packaging systems

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

Table 54: Comparison of net results: **Tetra Rex 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

segment DAIRY (chilled), Finland	The net results of **Tetra Rex1000 mL** are lower (green)/ higher (orange) than those of						
	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-48%	-34%	22%	-78%	-94%	-87%	-91%
Acidification	-14%	-42%	-60%	-37%	-70%	-92%	-63%
Photo-Oxidant Formation	-12%	-23%	-32%	-27%	-51%	-78%	-38%
Ozone Depletion Potential	-19%	-81%	-91%	-42%	-51%	-99%	-94%
Terrestrial Eutrophication	-12%	-42%	-59%	-30%	-58%	-92%	-42%
Aquatic Eutrophication	-16%	-65%	-80%	-41%	-62%	-97%	19%
Particulate Matter	-13%	-40%	-57%	-33%	-66%	-91%	-55%
Total Primary Energy	-20%	-28%	-35%	-43%	-74%	-92%	-54%
Non-renewable Primary Energy	-26%	-18%	-1%	-52%	-84%	-71%	-70%

Table 55: Comparison of net results: **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

segment DAIRY (chilled), Finland	The net results of **Tetra RexOSO 341000 mL** are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	94%	29%	135%	-58%	-88%	-74%	-82%
Acidification	16%	-33%	-53%	-27%	-65%	-91%	-57%
Photo-Oxidant Formation	14%	-12%	-22%	-17%	-44%	-75%	-30%
Ozone Depletion Potential	24%	-77%	-88%	-29%	-40%	-98%	-92%
Terrestrial Eutrophication	14%	-34%	-54%	-20%	-52%	-91%	-34%
Aquatic Eutrophication	19%	-59%	-76%	-29%	-55%	-96%	41%
Particulate Matter	15%	-31%	-50%	-23%	-61%	-90%	-49%
Total Primary Energy	24%	-10%	-19%	-29%	-68%	-90%	-43%
Non-renewable Primary Energy	35%	11%	34%	-35%	-78%	-61%	-59%

Table 56: Comparison of net results: **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

segment DAIRY (chilled), Finland	The net results of **Tetra Rex OSO 34 biobased 1000 mL** are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	51%	-22%	83%	-68%	-91%	-80%	-86%
Acidification	74%	50%	-30%	9%	-48%	-87%	-35%
Photo-Oxidant Formation	29%	14%	-12%	-5%	-37%	-72%	-20%
Ozone Depletion Potential	435%	333%	-49%	209%	161%	-92%	-67%
Terrestrial Eutrophication	72%	51%	-30%	21%	-27%	-86%	0%
Aquatic Eutrophication	188%	142%	-43%	71%	8%	-91%	242%
Particulate Matter	66%	44%	-28%	12%	-44%	-86%	-26%
Total Primary Energy	38%	11%	-10%	-21%	-64%	-89%	-37%
Non-renewable Primary Energy	22%	-10%	21%	-41%	-80%	-65%	-63%

Table 57: Comparison of net results: **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

segment DAIRY (chilled), Finland	The net results of **Tetra Rex OSO 34 fully biobased 1000 mL** are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-18%	-58%	-45%	-82%	-95%	-89%	-92%
Acidification	147%	113%	42%	55%	-26%	-81%	-8%
Photo-Oxidant Formation	47%	29%	14%	8%	-28%	-68%	-9%
Ozone Depletion Potential	955%	753%	97%	508%	414%	-85%	-36%
Terrestrial Eutrophication	146%	116%	42%	73%	4%	-80%	43%
Aquatic Eutrophication	401%	321%	74%	197%	88%	-84%	494%
Particulate Matter	130%	100%	39%	55%	-22%	-80%	3%
Total Primary Energy	53%	23%	11%	-12%	-61%	-87%	-30%
Non-renewable Primary Energy	1%	-26%	-18%	-51%	-84%	-71%	-70%

7.2 Results JNSD Finland

7.2.1 Presentation of results JNSD Finland

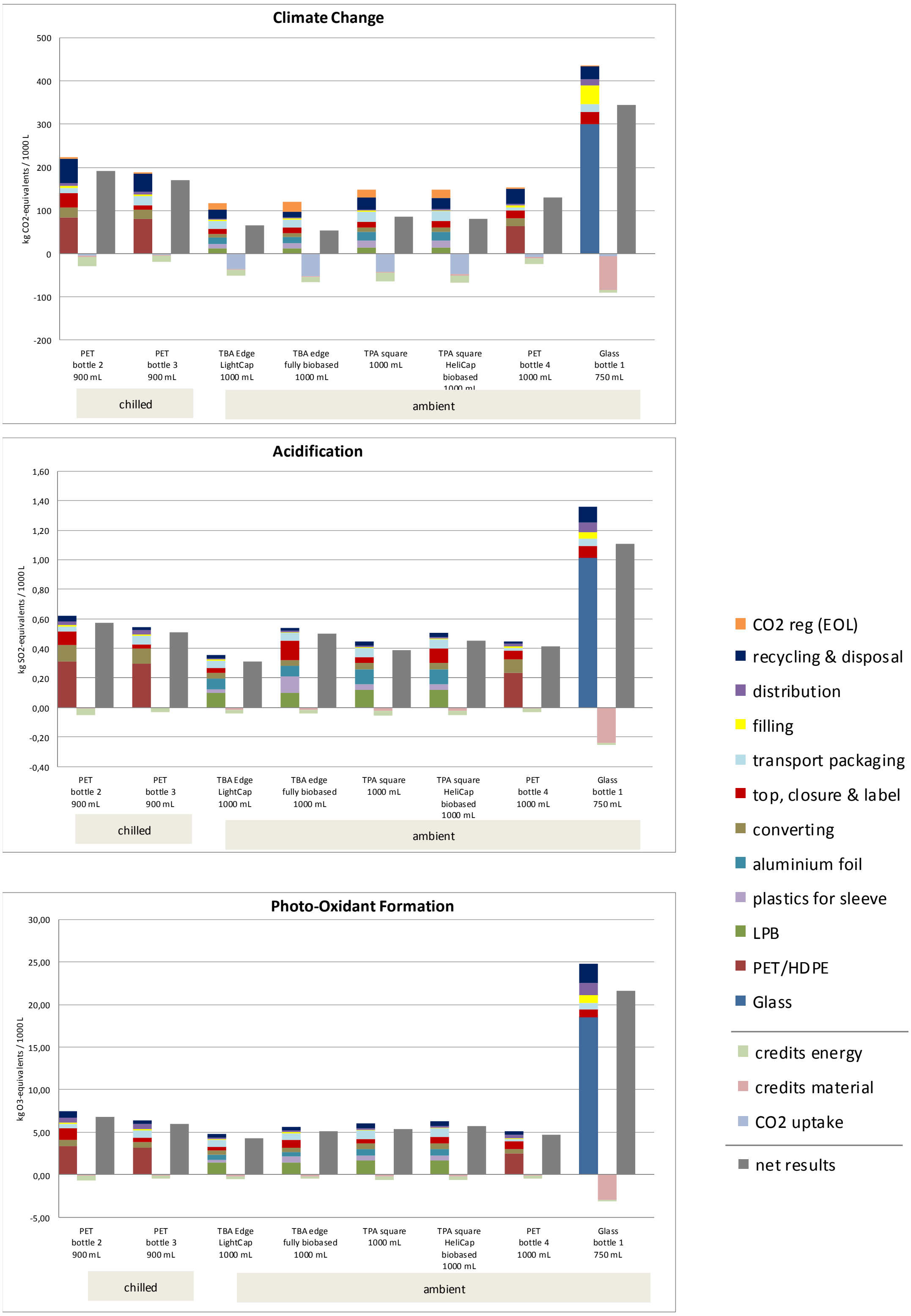


Figure 62: Indicator results for base scenarios of **segment JNSD, Finland**, allocation factor 50% (Part 1)

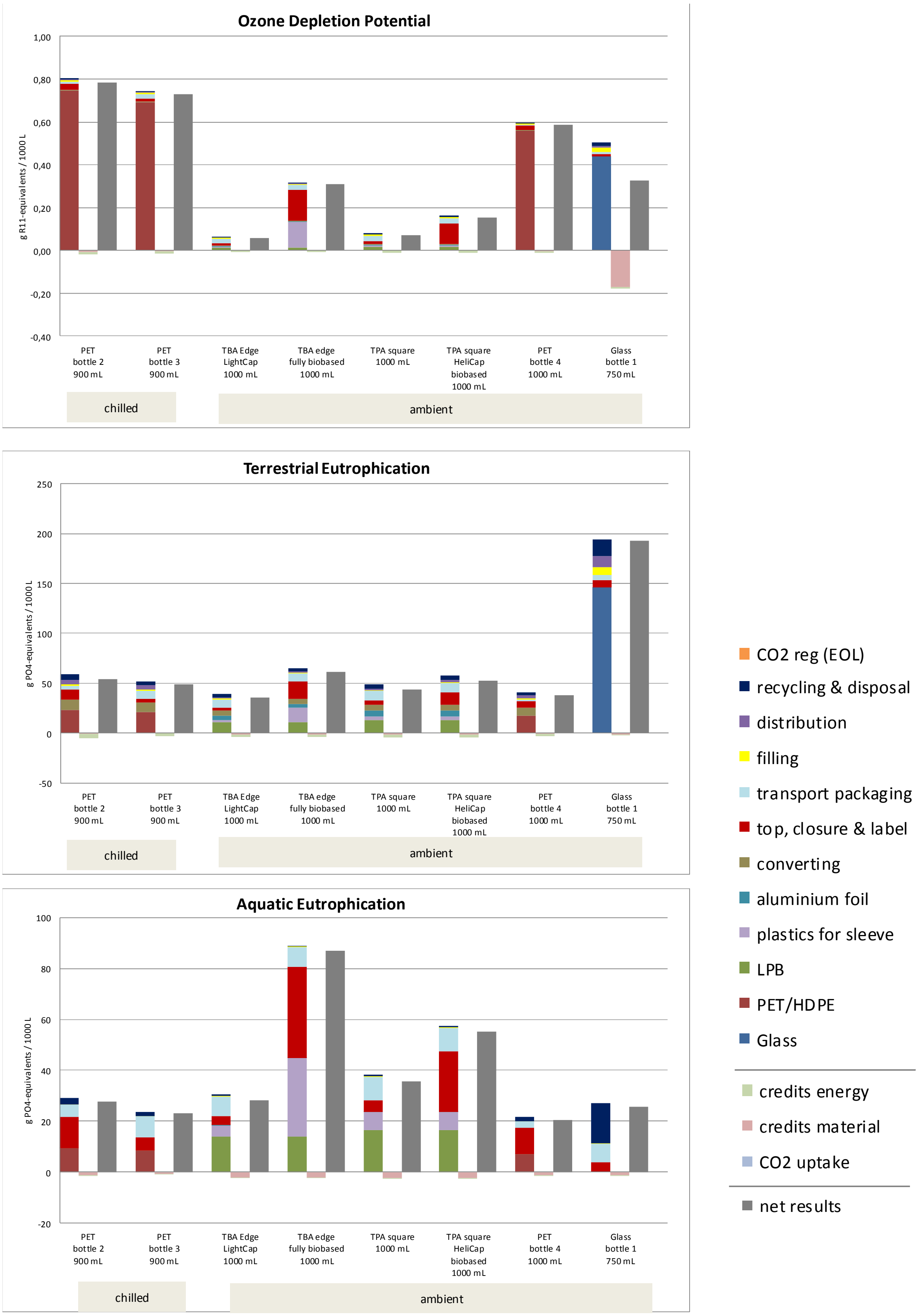


Figure 63: Indicator results for base scenarios of **segment JNSD, Finland**, allocation factor 50% (Part 2)

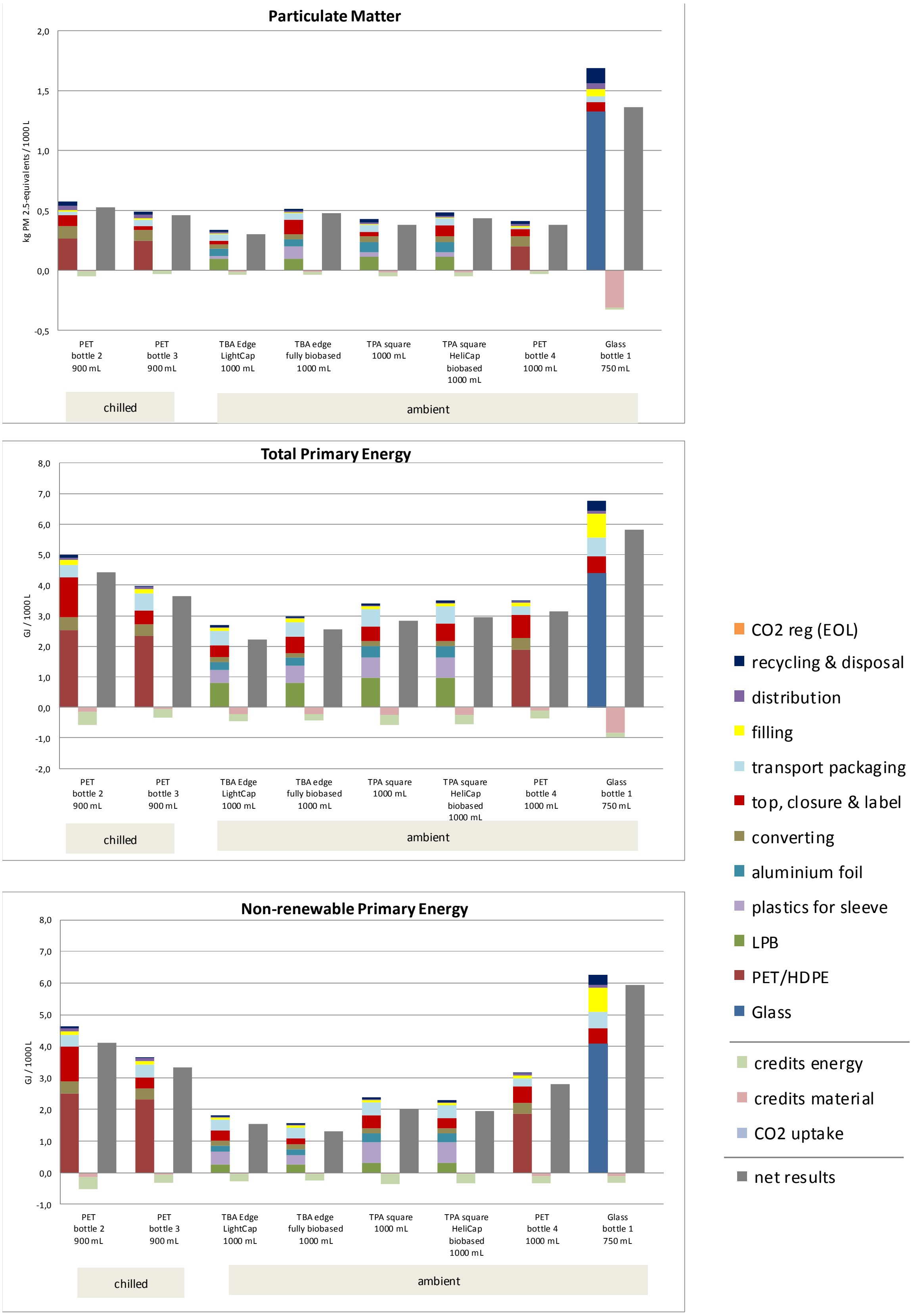


Figure 64: Indicator results for base scenarios of **segment JNSD, Finland**, allocation factor 50% (Part 3)

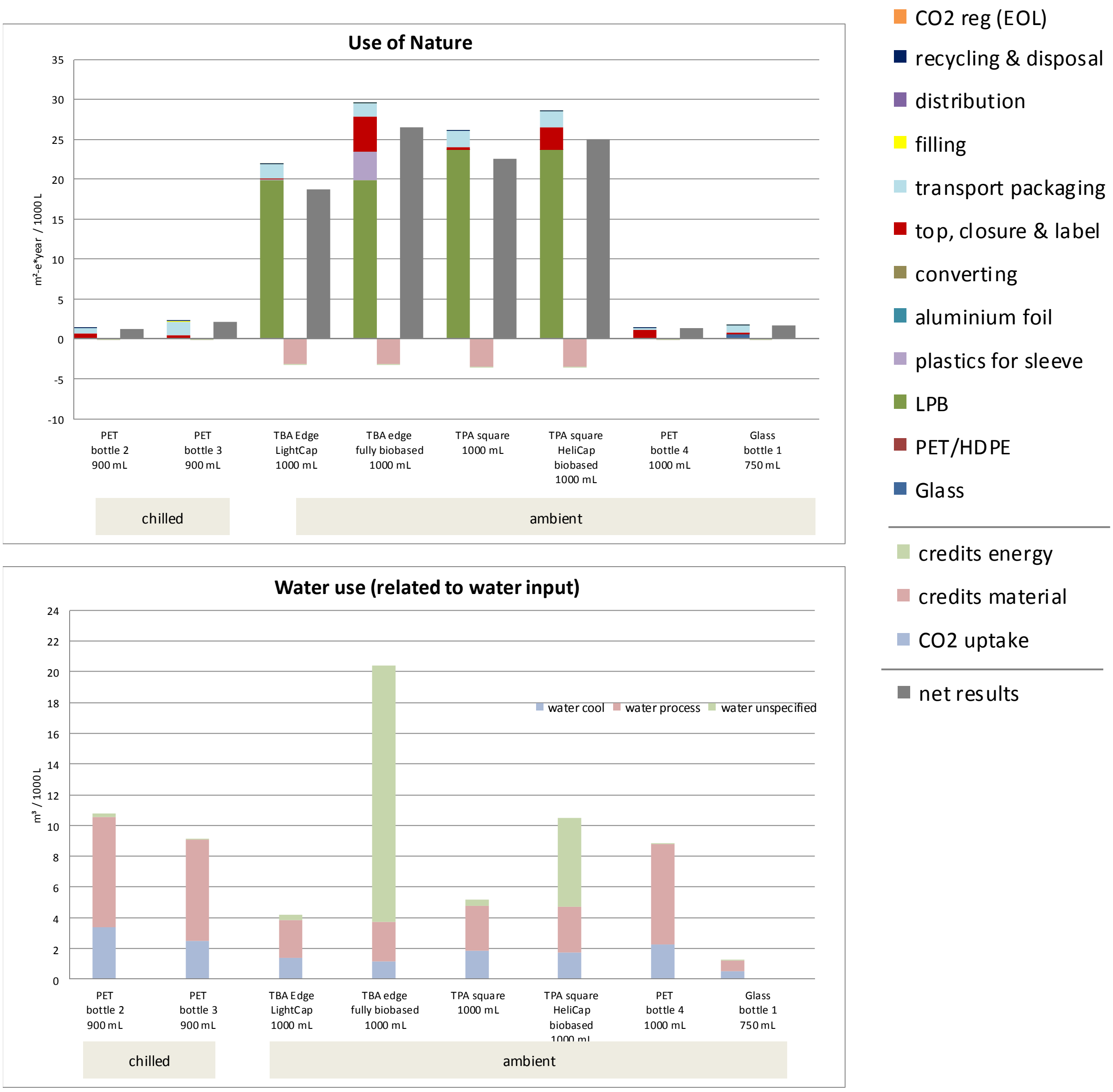


Figure 65: Indicator results for base scenarios of **segment JNSD, Finland**, allocation factor 50% (Part 4)

Table 58: Category indicator results per impact category for base scenarios of segment JNSD chilled, Finland- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD chilled Finland, allocation factor 50 %		PET bottle 2 900 mL	PET bottle 3 900 mL
Climate change [kg CO_2-equivalents]	Burdens	219.60	184.33
	CO2 (reg)	3.12	4.71
	Credits	-25.88	-16.34
	CO_2 uptake	-4.21	-2.85
	Net results (∑)	192.62	169.85
Acidification [kg SO_2-equivalents]	Burdens	0.62	0.54
	Credits	-0.05	-0.03
	Net results (∑)	0.57	0.51
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.44	6.41
	Credits	-0.67	-0.42
	Net results (∑)	6.77	5.99
Ozone Depletion [g R-11-equivalents]	Burdens	0.80	0.76
	Credits	-0.02	-0.01
	Net results (∑)	0.78	0.75
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	58.85	52.55
	Credits	-5.01	-3.20
	Net results (∑)	53.85	49.36
Aquatic eutrophication [g PO_4-equivalents]	Burdens	29.10	24.06
	Credits	-1.37	-0.59
	Net results (∑)	27.73	23.47
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.58	0.50
	Credits	-0.05	-0.03
	Net results (∑)	0.53	0.47
Total Primary Energy [GJ]	Burdens	4.97	4.06
	Credits	-0.56	-0.35
	Net results (∑)	4.40	3.71
Non-renewable primary energy [GJ]	Burdens	4.62	3.71
	Credits	-0.52	-0.32
	Net results (∑)	4.10	3.40
Use of Nature [m^2-equivalents*year]	Burdens	1.36	2.21
	Credits	-0.09	-0.07
	Net results (∑)	1.27	2.14
Water use [m^3]	Water cool	3.37	2.54
	Water process	7.20	6.64
	Water unspec	0.19	0.06

Table 59: Category indicator results per impact category for base scenarios of segment JNSD ambient, Finland- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD ambient Finland, allocation factor 50 %		TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square HeliCap 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate change [kg CO_2-equivalents]	Burdens	101.58	97.68	130.68	129.09	150.00	434.79
	CO2 (reg)	14.88	22.41	17.85	20.13	4.04	0.99
	Credits	-16.21	-14.63	-21.36	-20.41	-16.27	-85.11
	CO_2 uptake	-35.55	-52.18	-42.28	-47.73	-8.31	-6.22
	Net results (∑)	64.71	53.28	84.89	81.08	129.46	344.45
Acidification [kg SO_2-equivalents]	Burdens	0.35	0.54	0.44	0.50	0.45	1.36
	Credits	-0.04	-0.04	-0.06	-0.05	-0.03	-0.25
	Net results (∑)	0.31	0.50	0.39	0.45	0.41	1.11
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	4.77	5.60	6.03	6.29	5.08	24.77
	Credits	-0.50	-0.47	-0.64	-0.62	-0.43	-3.16
	Net results (∑)	4.27	5.13	5.39	5.67	4.65	21.61
Ozone Depletion [g R-11-equivalents]	Burdens	0.07	0.32	0.08	0.16	0.60	0.50
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01	-0.18
	Net results (∑)	0.06	0.31	0.07	0.15	0.59	0.33
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	39.26	65.12	48.90	57.26	40.97	194.51
	Credits	-3.89	-3.61	-4.94	-4.78	-3.18	-1.36
	Net results (∑)	35.36	61.51	43.96	52.48	37.79	193.15
Aquatic eutrophication [g PO_4-equivalents]	Burdens	30.42	89.11	38.30	57.56	21.60	27.00
	Credits	-2.23	-2.23	-2.53	-2.53	-1.12	-1.38
	Net results (∑)	28.19	86.89	35.77	55.03	20.48	25.62
Particulate matter [kg PM 2,5-equivalents]	Burdens	0.34	0.52	0.43	0.48	0.41	1.69
	Credits	-0.04	-0.04	-0.05	-0.05	-0.03	-0.33
	Net results (∑)	0.30	0.48	0.38	0.44	0.38	1.36
Total Primary Energy [GJ]	Burdens	2.68	2.98	3.41	3.50	3.50	6.78
	Credits	-0.46	-0.43	-0.57	-0.56	-0.37	-0.97
	Net results (∑)	2.22	2.55	2.84	2.95	3.13	5.81
Non-renewable primary energy [GJ]	Burdens	1.82	1.57	2.38	2.29	3.15	6.26
	Credits	-0.27	-0.25	-0.36	-0.34	-0.34	-0.31
	Net results (∑)	1.55	1.32	2.02	1.95	2.81	5.95
Use of Nature [m^2-equivalents*year]	Burdens	21.93	29.60	26.09	28.60	1.37	1.75
	Credits	-3.13	-3.13	-3.56	-3.56	-0.06	-0.06
	Net results (∑)	18.80	26.48	22.52	25.04	1.31	1.69
Water use [m^3]	Water cool	1.42	1.17	1.83	1.74	2.28	0.00
	Water process	2.43	2.56	2.92	2.96	6.50	0.00
	Water unspec	0.31	16.70	0.40	5.78	0.08	0.00

7.2.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the JNSD segment, in most impact categories one of the biggest parts 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 considerable share of the burdens of the impact categories 'Aquatic Eutrophication' and 'Use of Nature'. It is also significantly relevant regarding 'Photo-Oxidant Formation' 'Acidification', 'Terrestrial Eutrophication', 'Particulate Matter' and the consumption of 'Total Primary Energy' and to a lower extent 'Non-renewable Primary Energy'.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category 'Non-renewable Primary Energy', where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the 'TBA edge LightCap fully bio-based' due to the production of bio-based PE.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories 'Climate

Change', 'Acidification' and 'Particulate Matter' as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the closures are higher for 'TBA edge LightCap fully bio-based' and 'TPA square HeliCap bio-based' than for the beverage cartons with a fossil-based closure in all categories apart from 'Non-renewable Primary Energy'.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sector transport packaging plays a more important role for almost all categories than for the beverage cartons used for the packaging of dairy. This is because the JNSD cartons use one-way secondary packaging (cardboard trays) instead of roll containers.

The sectors filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. Especially for the 'TBA edge LightCap fully bio-based' the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Finland 38% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category 'Use of Nature'. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

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

All regarded plastic bottles for chilled and ambient JNSD segment alike are made from PET. The closures of all three of them are made from HDPE. For the impact categories 'Climate Change', 'Acidification', 'Photo-Oxidant Formation', 'Ozone Depletion Potential', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Particulate Matter' the burdens from PET production (sector PET/HDPE in the graphs) are the highest single contributor to the overall burdens.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from fossil-based HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the plastic bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the collection rate of plastic bottles in Finland is 0% the amount of bottle waste incinerated is relatively high.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the plastic bottle waste is incinerated in MSWIs, the received material credits are insignificant compared to the credits for energy.

Glass bottle

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

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact categories 'Climate Change', 'Aquatic Eutrophication' and 'Use of Nature' 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'.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

7.2.3 Comparison between packaging systems

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

JNSD ambient

Table 60: Comparison of net results: **Tetra Brik Aseptic Edge LightCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Finland**

segment JNSD (ambient), Finland	The net results of **TBA EdgeLightCap1000 mL** are lower (green)/ higher (orange) than those of				
	TBA edge fully biobased 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	21%	-24%	-20%	-50%	-81%
Acidification	-38%	-21%	-31%	-25%	-72%
Photo-Oxidant Formation	-17%	-21%	-25%	-8%	-80%
Ozone Depletion Potential	-81%	-18%	-62%	-90%	-82%
Terrestrial Eutrophication	-43%	-20%	-33%	-7%	-82%
Aquatic Eutrophication	-68%	-21%	-49%	38%	10%
Particulate Matter	-37%	-20%	-31%	-21%	-78%
Total Primary Energy	-13%	-22%	-25%	-29%	-62%
Non-renewable Primary Energy	17%	-23%	-20%	-45%	-74%

Table 61: Comparison of net results: **Tetra Brik Aseptic Edge fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Finland**

segment JNSD (ambient), Finland	The net results of **TBA edgefully biobased1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	-18%	-37%	-34%	-59%	-85%
Acidification	61%	28%	11%	21%	-55%
Photo-Oxidant Formation	20%	-5%	-9%	10%	-76%
Ozone Depletion Potential	436%	342%	103%	-47%	-5%
Terrestrial Eutrophication	74%	40%	17%	63%	-68%
Aquatic Eutrophication	208%	143%	58%	324%	239%
Particulate Matter	59%	27%	10%	27%	-65%
Total Primary Energy	15%	-10%	-14%	-19%	-56%
Non-renewable Primary Energy	-15%	-35%	-32%	-53%	-78%

Table 62: Comparison of net results **Tetra Prisma Aseptic square 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Finland**

segment JNSD (ambient), Finland	The net results of **TPA square 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000 mL	TBA edge fully biobased 1000 mL	TPA square HeliCap biobased 1000 mL	Glass bottle 1 750 mL	PET bottle 4 1000 mL
Climate Change	31%	59%	5%	-75%	-34%
Acidification	26%	-22%	-13%	-65%	-6%
Photo-Oxidant Formation	26%	5%	-5%	-75%	16%
Ozone Depletion Potential	21%	-77%	-54%	-79%	-88%
Terrestrial Eutrophication	24%	-29%	-16%	-77%	16%
Aquatic Eutrophication	27%	-59%	-35%	40%	75%
Particulate Matter	26%	-21%	-13%	-72%	0%
Total Primary Energy	28%	11%	-4%	-51%	-9%
Non-renewable Primary Energy	30%	53%	4%	-66%	-28%

Table 63: Comparison of net results **Tetra Prisma Aseptic square HeliCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Finland**

segment JNSD (ambient), Finland	The net results of **TPA square HeliCap biobased 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000 mL	TBA edge fully biobased 1000 mL	TPA square 1000 mL	Glass bottle 1 750 mL	PET bottle 4 1000 mL
Climate Change	25%	52%	-4%	-76%	-37%
Acidification	46%	-10%	16%	-59%	9%
Photo-Oxidant Formation	33%	10%	5%	-74%	22%
Ozone Depletion Potential	164%	-51%	118%	-53%	-74%
Terrestrial Eutrophication	48%	-15%	19%	-73%	39%
Aquatic Eutrophication	95%	-37%	54%	115%	169%
Particulate Matter	45%	-9%	15%	-68%	15%
Total Primary Energy	33%	16%	4%	-49%	-6%
Non-renewable Primary Energy	26%	47%	-4%	-67%	-31%

7.3 Results Grab & Go Finland

7.3.1 Presentation of results Grab & Go Finland

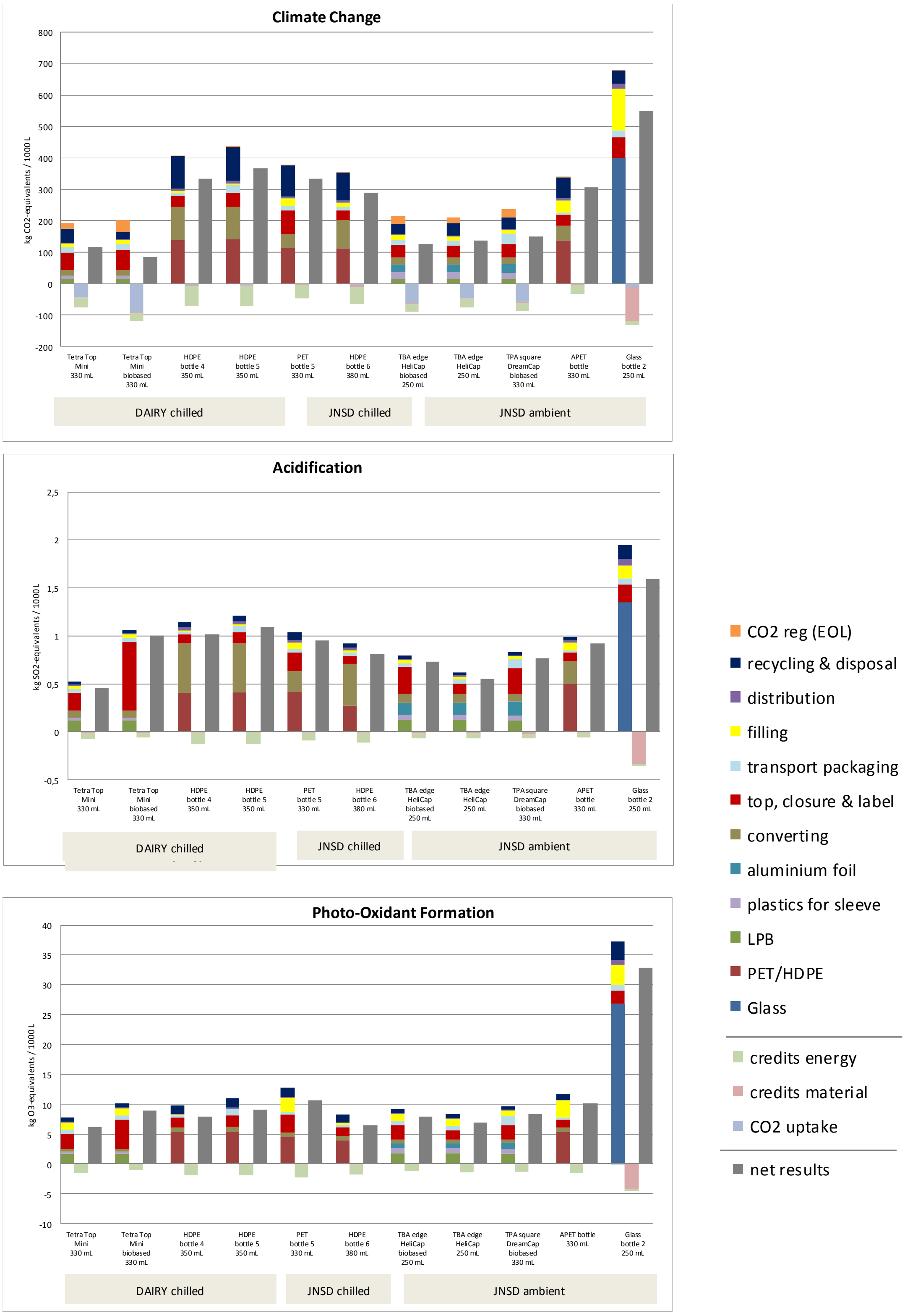


Figure 66: Indicator results for base scenarios of **segment Grab & Go, Finland**, allocation factor 50% (Part 1)

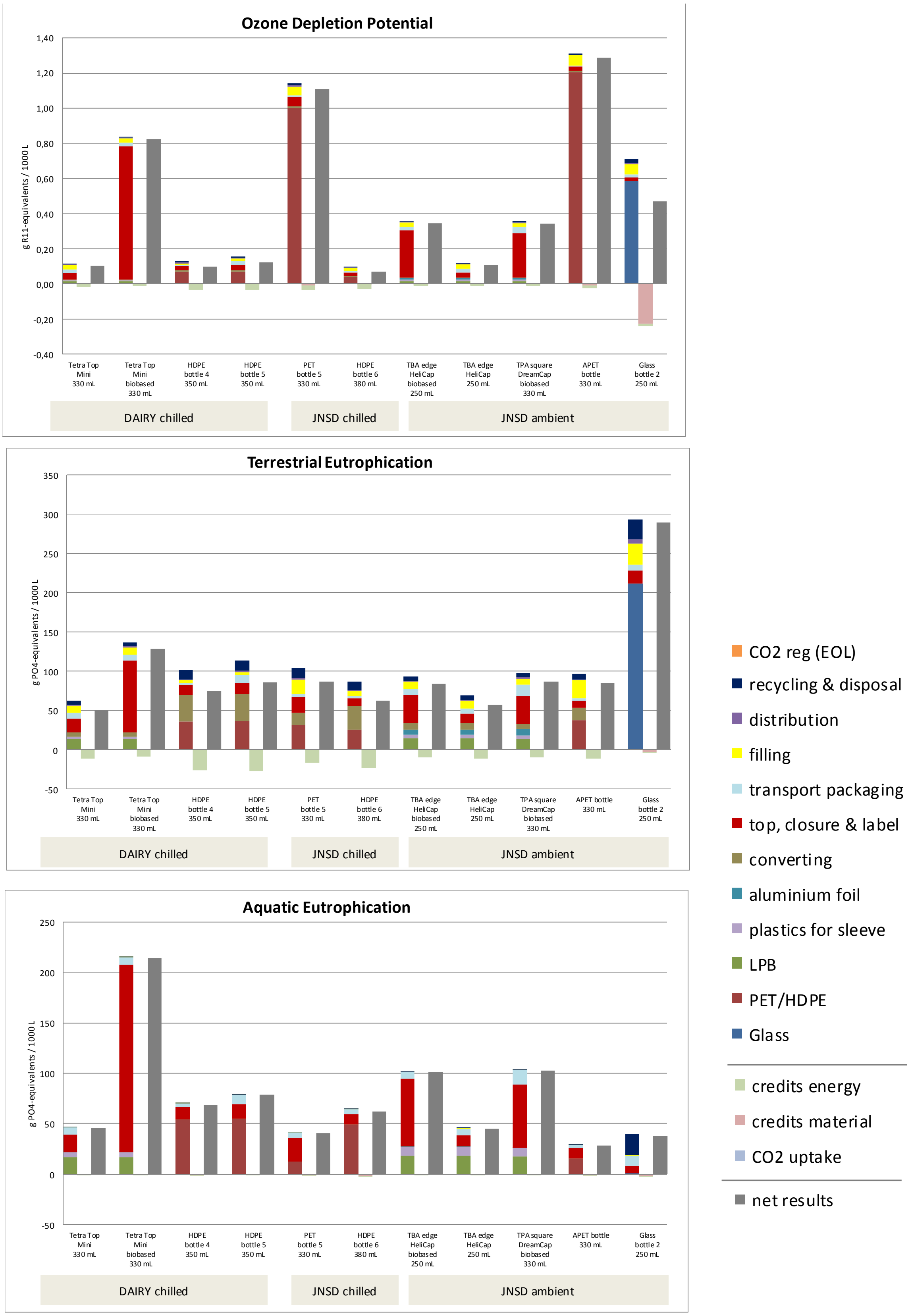


Figure 67: Indicator results for base scenarios of **segment Grab & Go, Finland**, allocation factor 50% (Part 2)

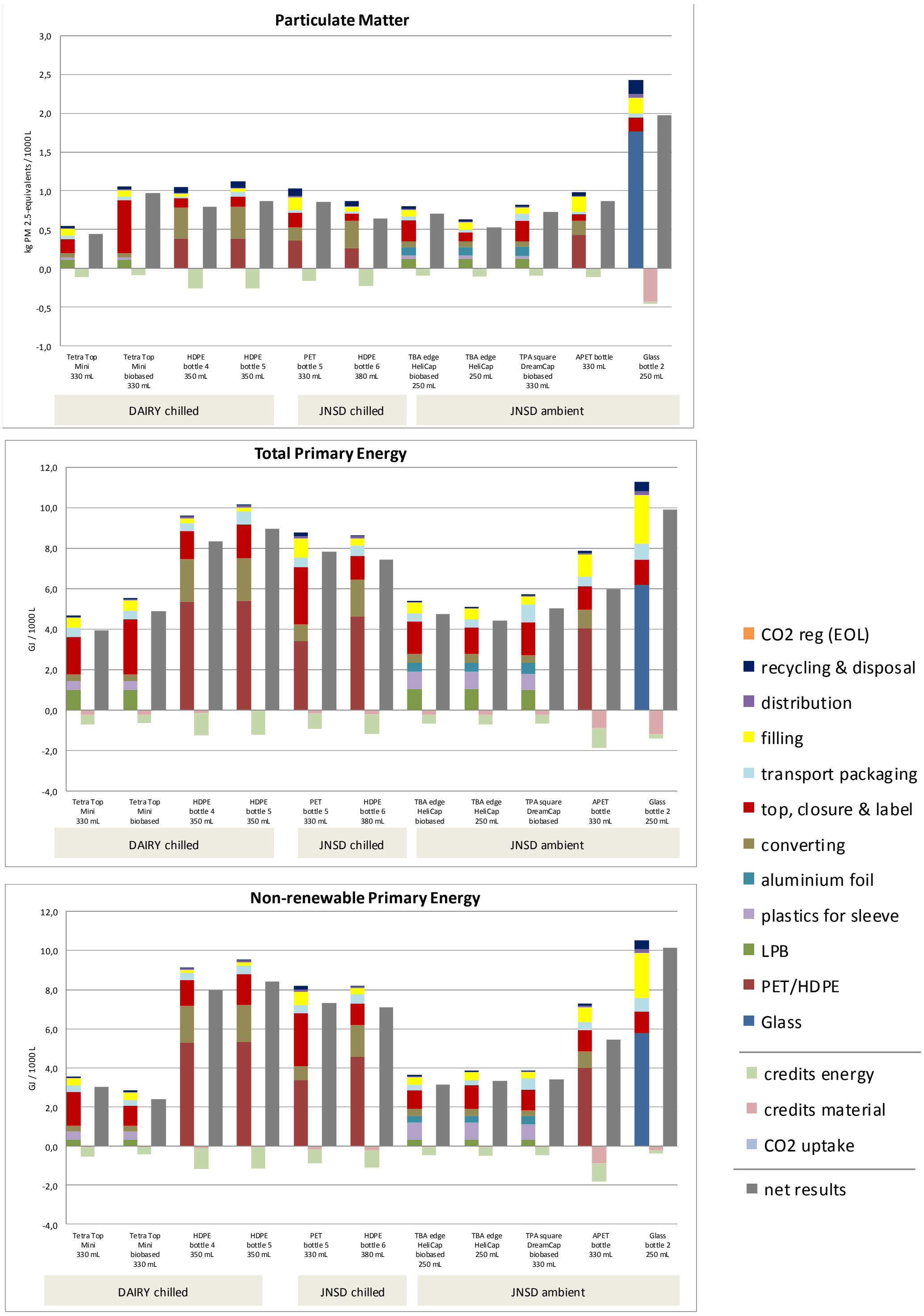


Figure 68: Indicator results for base scenarios of **segment Grab & Go, Finland**, allocation factor 50% (Part 3)

Figure 69: Indicator results for base scenarios of **segment segment Grab & Go, Finland**, allocation factor 50% (Part 4)

Table 64: Category indicator results per impact category for base scenarios of segment Grab & Go, Dairy chilled, Finland- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, Dairy chilled Finland, allocation factor 50 %		Tetra Top Mini 330 mL Dairy chilled	Tetra Top Mini biobased 330 mL Dairy chilled	HDPE bottle 4 350 mL Dairy chilled	HDPE bottle 5 350 mL Dairy chilled
Climate change [kg CO_2-equivalents]	Burdens	174.15	163.22	406.13	435.73
	CO2 (reg)	18.15	39.42	0.03	3.55
	Credits	-31.14	-25.89	-66.81	-66.62
	CO_2 uptake	-43.39	-91.25	-4.94	-4.94
	Net results (∑)	117.76	85.51	334.41	367.72
Acidification [kg SO_2-equivalents]	Burdens	0.53	1.06	1.14	1.21
	Credits	-0.07	-0.06	-0.13	-0.12
	Net results (∑)	0.45	1.00	1.02	1.09
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.29	9.68	10.31	11.41
	Credits	-0.85	-0.73	-1.30	-1.24
	Net results (∑)	6.44	8.95	9.01	10.17
Ozone Depletion [g R-11-equivalents]	Burdens	0.12	0.84	0.13	0.16
	Credits	-0.02	-0.01	-0.03	-0.03
	Net results (∑)	0.10	0.83	0.10	0.13
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	59.53	133.92	103.33	114.28
	Credits	-6.56	-5.63	-12.07	-11.94
	Net results (∑)	52.97	128.29	91.26	102.34
Aquatic eutrophication [g PO_4-equivalents]	Burdens	48.28	217.23	73.59	82.58
	Credits	-2.36	-2.36	-1.57	-0.43
	Net results (∑)	45.92	214.88	72.02	82.15
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.51	1.02	1.05	1.12
	Credits	-0.06	-0.06	-0.12	-0.11
	Net results (∑)	0.44	0.96	0.93	1.01
Total Primary Energy [GJ]	Burdens	4.68	5.54	9.61	10.18
	Credits	-0.73	-0.64	-1.27	-1.21
	Net results (∑)	3.95	4.90	8.34	8.97
Non-renewable primary energy [GJ]	Burdens	3.56	2.83	9.14	9.56
	Credits	-0.53	-0.44	-1.19	-1.13
	Net results (∑)	3.03	2.39	7.95	8.43
Use of Nature [m^2-equivalents*year]	Burdens	27.03	49.12	0.60	2.41
	Credits	-3.19	-3.18	-0.16	-0.16
	Net results (∑)	23.84	45.94	0.43	2.25
Water use [m^3]	Water cool	3.36	2.68	3.68	3.94
	Water process	2.73	3.09	1.18	1.20
	Water unspec	0.52	47.68	2.58	2.58

Table 65: Category indicator results per impact category for base scenarios of segment Grab & Go, JNSD chilled, Finland- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, JNSD chilled Finland, allocation factor 50 %		PET bottle 5 330 mL	HDPE bottle 6 380 mL
Climate change [kg CO_2-equivalents]	Burdens	377.15	353.31
	CO2 (reg)	1.34	0.02
	Credits	-45.41	-59.89
	CO_2 uptake	0.00	-4.94
	Net results (∑)	333.08	288.50
Acidification [kg SO_2-equivalents]	Burdens	1.04	0.92
	Credits	-0.09	-0.11
	Net results (∑)	0.95	0.81
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	12.36	8.52
	Credits	-1.15	-1.20
	Net results (∑)	11.21	7.32
Ozone Depletion [g R-11-equivalents]	Burdens	1.14	0.10
	Credits	-0.03	-0.03
	Net results (∑)	1.11	0.07
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	100.37	86.13
	Credits	-8.68	-10.88
	Net results (∑)	91.68	75.25
Aquatic eutrophication [g PO_4-equivalents]	Burdens	45.84	67.16
	Credits	-1.59	-2.17
	Net results (∑)	44.26	64.99
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.97	0.86
	Credits	-0.08	-0.10
	Net results (∑)	0.89	0.75
Total Primary Energy [GJ]	Burdens	8.80	8.62
	Credits	-0.94	-1.18
	Net results (∑)	7.86	7.45
Non-renewable primary energy [GJ]	Burdens	8.18	8.19
	Credits	-0.87	-1.11
	Net results (∑)	7.31	7.09
Use of Nature [m^2-equivalents*year]	Burdens	1.47	0.54
	Credits	-0.15	-0.14
	Net results (∑)	1.32	0.40
Water use [m^3]	Water cool	5.51	3.26
	Water process	0.92	1.06
	Water unspec	0.44	16.03

Table 66: Category indicator results per impact category for base scenarios of **segment Grab & Go, JNSD ambient, Finland**- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, JNSD ambient Finland, allocation factor 50 %		TBA edge HeliCap biobased 250 mL	TBA edge HeliCap 250 mL	TPA square DreamCap biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate change [kg CO_2-equivalents]	Burdens	190.08	193.40	210.70	337.99	678.74
	CO2 (reg)	25.25	18.61	26.52	0.43	1.47
	Credits	-27.23	-29.98	-28.25	-32.10	-120.18
	CO_2 uptake	-61.23	-45.36	-58.34	0.00	-10.51
	Net results (∑)	126.88	136.67	150.63	306.32	549.51
Acidification [kg SO_2-equivalents]	Burdens	0.80	0.62	0.84	0.99	1.95
	Credits	-0.06	-0.07	-0.07	-0.06	-0.35
	Net results (∑)	0.73	0.55	0.77	0.92	1.59
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	8.76	7.96	9.57	10.88	35.09
	Credits	-0.76	-0.83	-0.79	-0.83	-4.34
	Net results (∑)	8.00	7.13	8.78	10.05	30.75
Ozone Depletion [g R-11-equivalents]	Burdens	0.36	0.12	0.36	1.31	0.71
	Credits	-0.01	-0.01	-0.01	-0.03	-0.24
	Net results (∑)	0.35	0.11	0.34	1.29	0.47
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	90.46	65.85	96.28	90.28	275.37
	Credits	-5.90	-6.39	-6.13	-6.25	-2.13
	Net results (∑)	84.56	59.46	90.15	84.03	273.24
Aquatic eutrophication [g PO_4-equivalents]	Burdens	103.69	47.56	106.07	32.42	41.39
	Credits	-2.42	-2.42	-2.52	-1.49	-1.96
	Net results (∑)	101.27	45.14	103.56	30.93	39.43
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.76	0.60	0.80	0.90	2.24
	Credits	-0.06	-0.06	-0.06	-0.06	-0.44
	Net results (∑)	0.70	0.53	0.74	0.84	1.80
Total Primary Energy [GJ]	Burdens	5.41	5.13	5.74	7.89	11.29
	Credits	-0.67	-0.72	-0.69	-1.89	-1.39
	Net results (∑)	4.75	4.41	5.04	6.00	9.90
Non-renewable primary energy [GJ]	Burdens	3.62	3.86	3.88	7.29	10.53
	Credits	-0.46	-0.51	-0.48	-1.84	-0.40
	Net results (∑)	3.16	3.35	3.40	5.45	10.13
Use of Nature [m^2-equivalents*year]	Burdens	35.24	27.91	35.41	0.48	2.68
	Credits	-3.28	-3.28	-3.43	-0.01	-0.07
	Net results (∑)	31.96	24.63	31.98	0.48	2.61
Water use [m^3]	Water cool	2.64	2.83	2.74	4.66	0.60
	Water process	3.47	3.35	3.65	0.75	1.27
	Water unspec	16.23	0.58	14.85	0.22	0.13

7.3.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the Grab & Go segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories 'Aquatic Eutrophication' and 'Use of Nature'. It is also relevant regarding 'Photo-Oxidant Formation' 'Acidification', 'Terrestrial Eutrophication', 'Particulate Matter' and the consumption of 'Total Primary Energy' and 'Non-renewable Primary Energy'.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category 'Non-renewable Primary Energy', where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories 'Climate Change', 'Acidification' and 'Particulate Matter' as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the top and closures is higher for the two Tetra Top packagings systems than for the TBA edge and TBA square cartons as more plastic is used for the top element of those packaging systems.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

Especially if bio-based plastics are used for top and/or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category for most packaging systems.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. For the 'Tetra Top Mini bio-based' the CO2 reg (EOL) emissions are significantly higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Finland 38% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category 'Use of Nature'. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 Grab & Go 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. Exceptions are the 'Ozone Depletion Potential' of the HDPE bottles as well as 'Use of Nature' of all regarded plastic bottles.

For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for the HDPE bottles than for the PET bottles with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from ‘Ozone Depletion Potential’, ‘Aquatic Eutrophication’ and ‘Use of Nature’.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the ‘Aquatic Eutrophication Potential’. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category. An exception is the sector filling for the PET bottles, because the filling process includes the stretch blowing of the preforms to bottles as this takes place at the filling plant.

The impact of the plastic bottles’ recycling & disposal sector is most significant regarding ‘Climate Change’. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the plastic bottles are not collected for recycling in Finland the amount of bottle waste incinerated is very high.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants.

Glass bottle

Even more than for the other regarded packaging systems, the production of the base material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results in all categories apart from ‘Aquatic Eutrophication’ and ‘Use of Nature’.

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact category ‘Climate Change’, the sector top, closure & label 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’.

Please note that the categories ‘Water Use’ and ‘Use of Nature’ do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

7.3.3 Comparison between packaging systems

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

DAIRY chilled

Table 67: Comparison of net results **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Finland**

segment Grab & Go DAIRY chilled, Finland	The net results of **Tetra Top Mini 330 mL** are lower (green)/ higher (orange) than those of		
	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	38%	-65%	-68%
Acidification	-55%	-55%	-58%
Summer Smog	-28%	-28%	-37%
Ozone Depletion Potential	-88%	3%	-19%
Terrestrial Eutrophication	-59%	-42%	-48%
Aquatic Eutrophication	-79%	-36%	-44%
Human Toxicity: PM 2.5	-54%	-52%	-56%
Total Primary Energy	-19%	-53%	-56%
Non-renewable Primary Energy	27%	-62%	-64%

Table 68: Comparison of net results **Tetra Top Mini biobased 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Finland**

segment Grab & Go DAIRY chilled, Finland	The net results of **Tetra Top Mini biobased 330 mL** are lower (green)/ higher (orange) than those of		
	Tetra Top Mini 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	-27%	-74%	-77%
Acidification	120%	-2%	-8%
Summer Smog	39%	-1%	-12%
Ozone Depletion Potential	717%	744%	560%
Terrestrial Eutrophication	142%	41%	25%
Aquatic Eutrophication	368%	198%	162%
Human Toxicity: PM 2.5	116%	3%	-5%
Total Primary Energy	24%	-41%	-45%
Non-renewable Primary Energy	-21%	-70%	-72%

JNSD ambient

Table 69: Comparison of net results **Tetra Brik Aseptic Edge HeliCap biobased 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Finland**

segment Grab & Go JNSD ambient, Finland	The net results of **TBA edge HeliCap biobased 250 mL** are lower (green)/ higher (orange) than those of				
	TBA edge HeliCap 250 mL	TPA square DreamCap biobased 330 mL	HDPE bottle 6 380 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	-7%	-16%	-56%	-59%	-77%
Acidification	33%	-5%	-9%	-21%	-54%
Photo-Oxidant Formation	12%	-9%	9%	-20%	-74%
Ozone Depletion Potential	228%	1%	384%	-73%	-26%
Terrestrial Eutrophication	42%	-6%	12%	1%	-69%
Aquatic Eutrophication	124%	-2%	56%	227%	157%
Particulate Matter	32%	-5%	-7%	-17%	-61%
Total Primary Energy	8%	-6%	-36%	-21%	-52%
Non-renewable Primary Energy	-6%	-7%	-55%	-42%	-69%

Table 70: Comparison of net results **Tetra Brik Aseptic Edge HeliCap 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Finland**

segment Grab & Go JNSD ambient, Finland	The net results of **TBA edge HeliCap250 mL** are lower (green)/ higher (orange) than those of				
	TBA edge HeliCap biobased 250 mL	TPA square DreamCap biobased 330 mL	HDPE bottle 6 380 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	8%	-9%	-53%	-55%	-75%
Acidification	-25%	-28%	-32%	-40%	-65%
Photo-Oxidant Formation	-11%	-19%	-3%	-29%	-77%
Ozone Depletion Potential	-69%	-69%	48%	-92%	-78%
Terrestrial Eutrophication	-30%	-34%	-21%	-29%	-78%
Aquatic Eutrophication	-55%	-56%	-31%	46%	14%
Particulate Matter	-24%	-28%	-29%	-37%	-70%
Total Primary Energy	-7%	-13%	-41%	-26%	-55%
Non-renewable Primary Energy	6%	-1%	-53%	-39%	-67%

Table 71: Comparison of net results **Tetra Prisma Aseptic square DreamCap biobased 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Finland**

segment Grab & Go JNSD ambient, Finland	The net results of **TPA squareDreamCapbiobased330 mL** are lower (green)/ higher (orange) than those of				
	TBA edge HeliCap biobased 250 mL	TBA edge HeliCap 250 mL	HDPE bottle 6 380 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	19%	10%	-48%	-51%	-73%
Acidification	5%	40%	-5%	-17%	-52%
Photo-Oxidant Formation	10%	23%	20%	-13%	-71%
Ozone Depletion Potential	-1%	225%	379%	-73%	-27%
Terrestrial Eutrophication	7%	52%	20%	7%	-67%
Aquatic Eutrophication	2%	129%	59%	235%	163%
Particulate Matter	5%	39%	-2%	-12%	-59%
Total Primary Energy	6%	14%	-32%	-16%	-49%
Non-renewable Primary Energy	8%	1%	-52%	-38%	-66%

8 Sensitivity Analyses Finland

8.1 Dairy

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 subjective 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%.

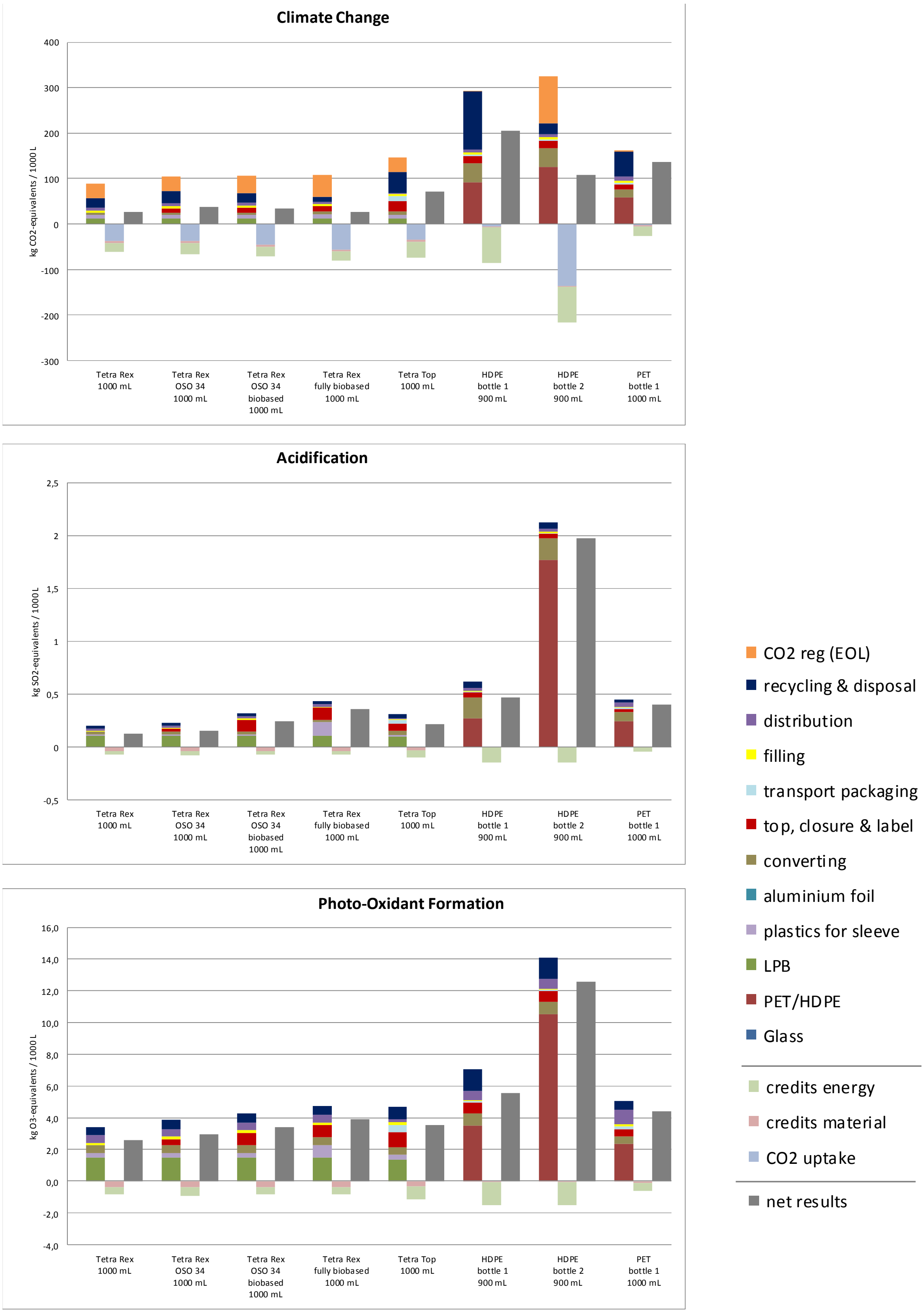


Figure 70: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Finland, allocation factor 100% (Part 1)

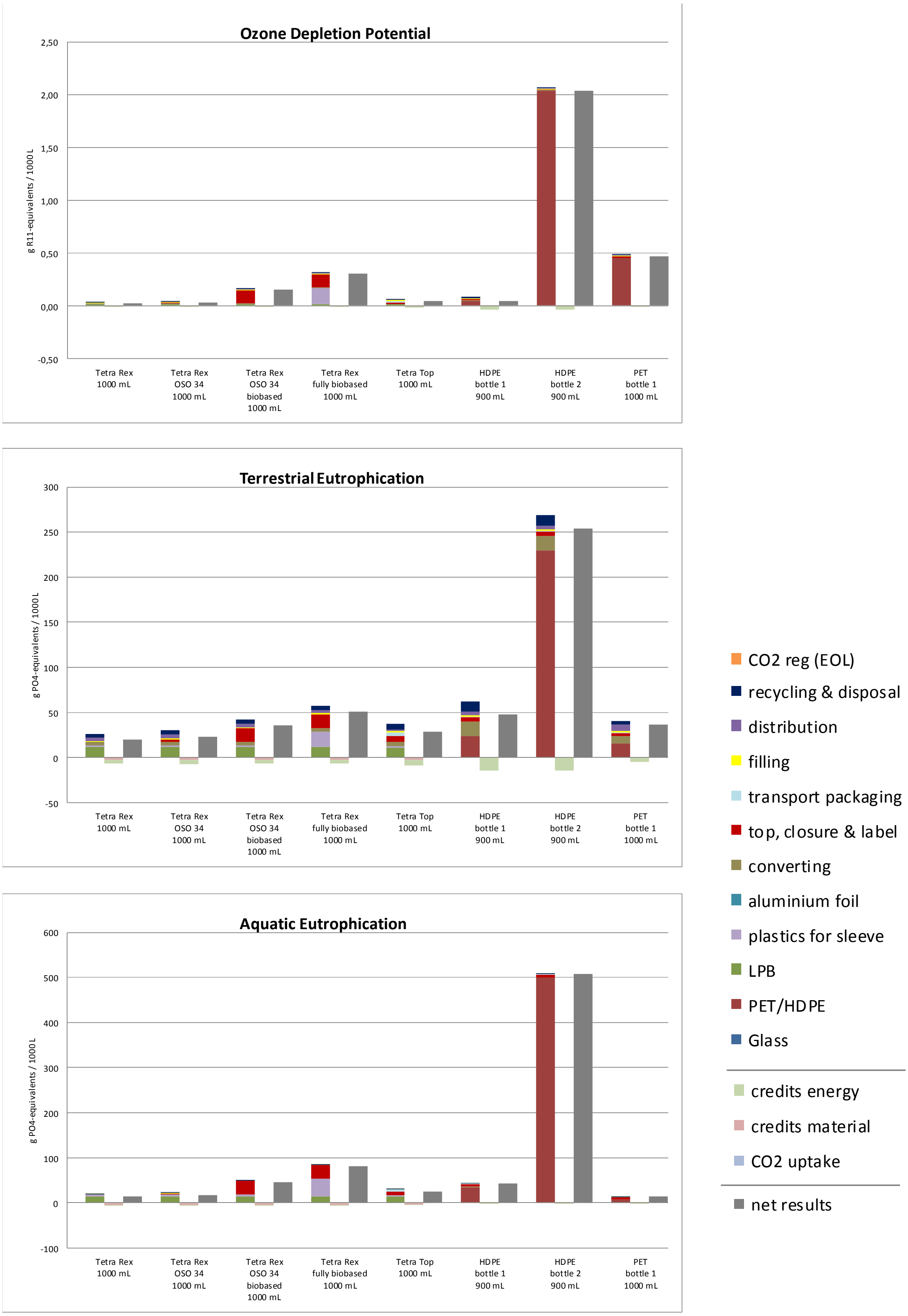


Figure 71: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Finland** , allocation factor 100% (Part 2)

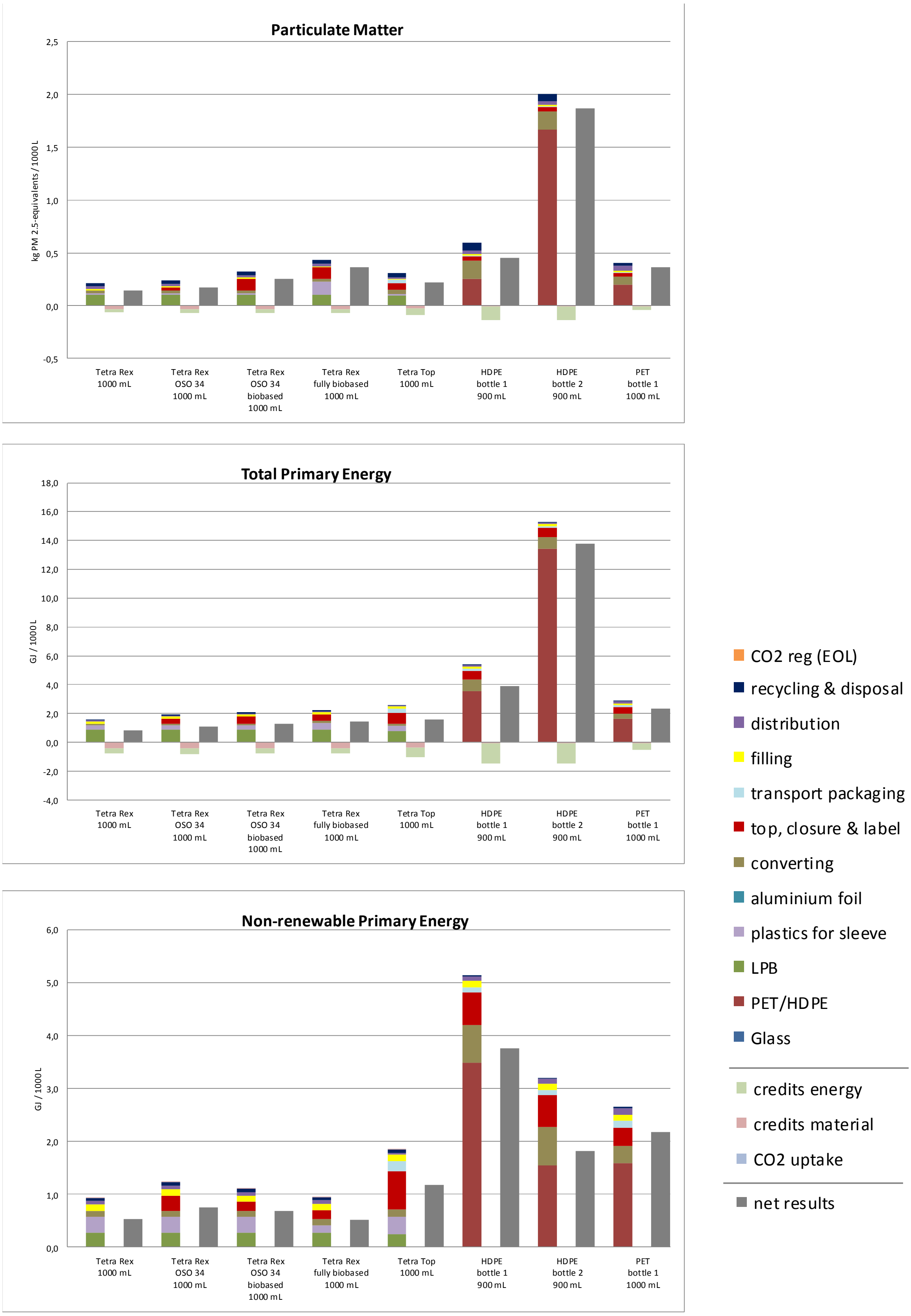


Figure 72: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Norway**, allocation factor 100% (Part 3)

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all systems examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the application of an allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Finnish market the electricity credited is the Finnish grid mix with its relatively low share of fossil energy sources.

8.1.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

8.1.3 Sensitivity analysis regarding plastic bottle weights DAIRY Finland

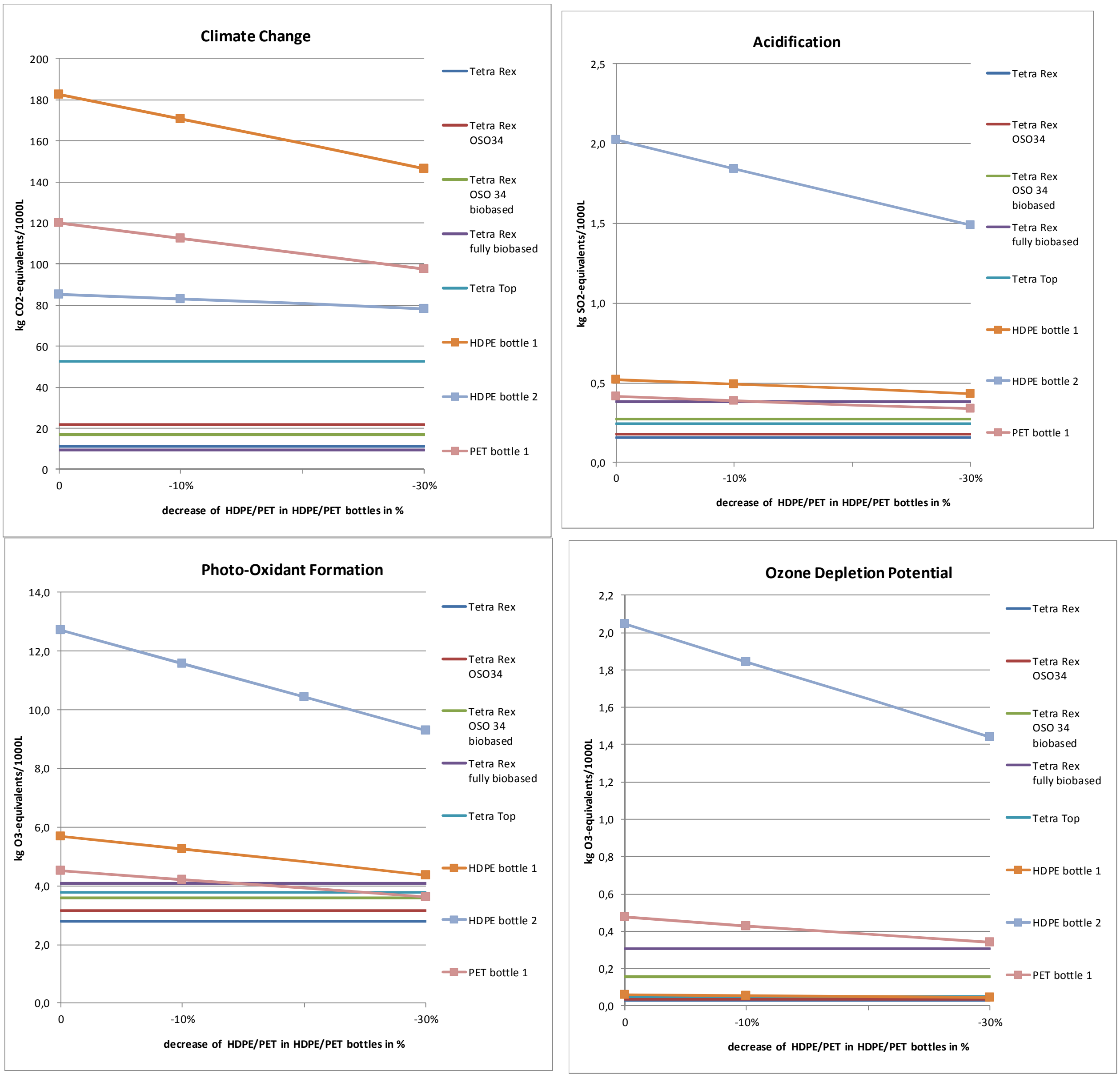
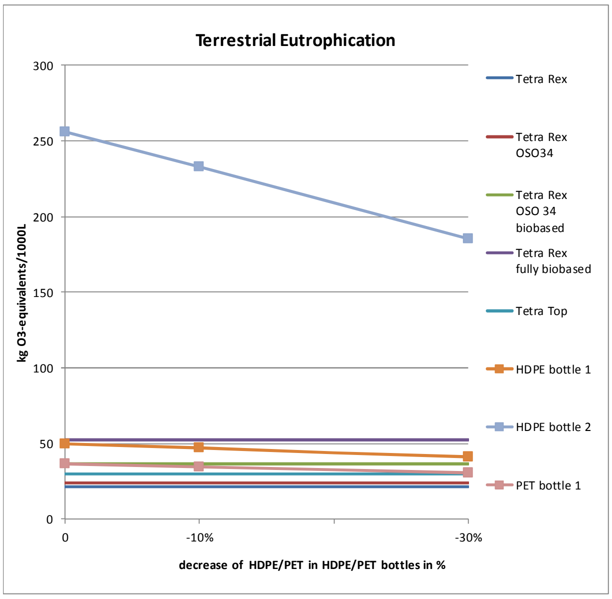
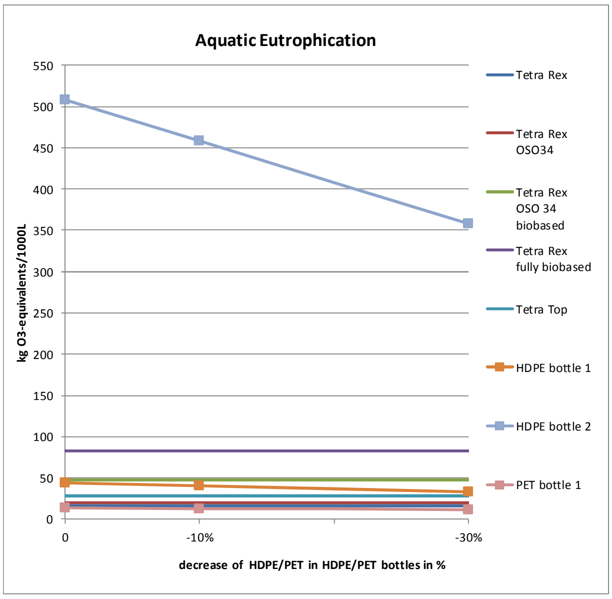
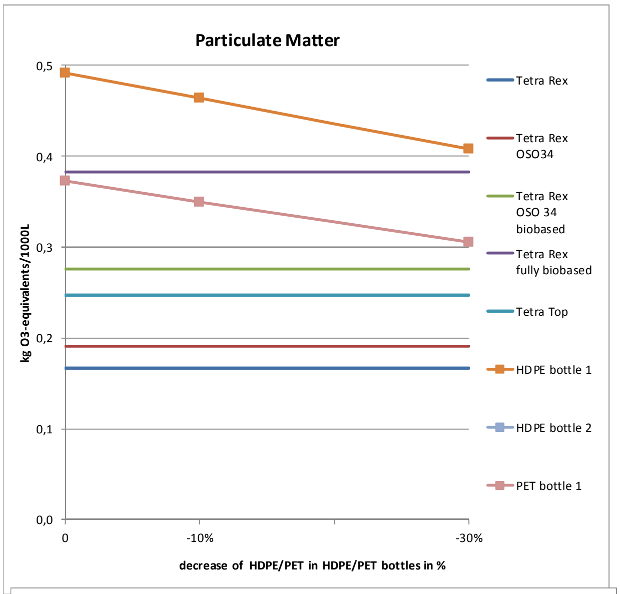
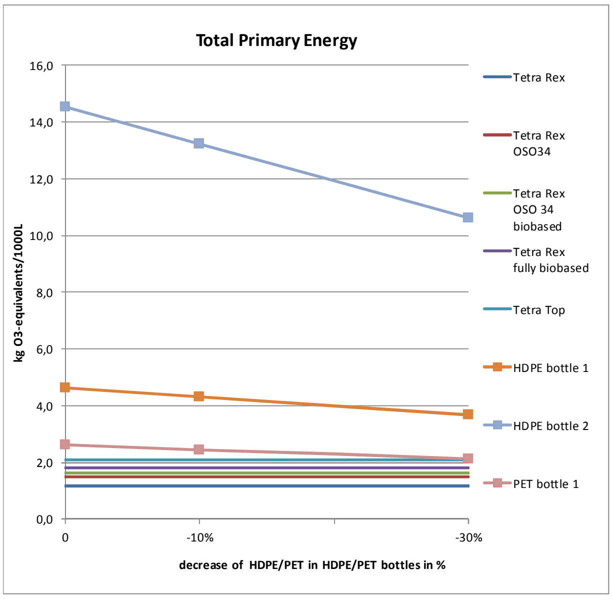


Figure 73: Indicator results for sensitivity analysis on plastic bottle weights of **segment DAIRY, Finland**, allocation factor 50% (Part 1)









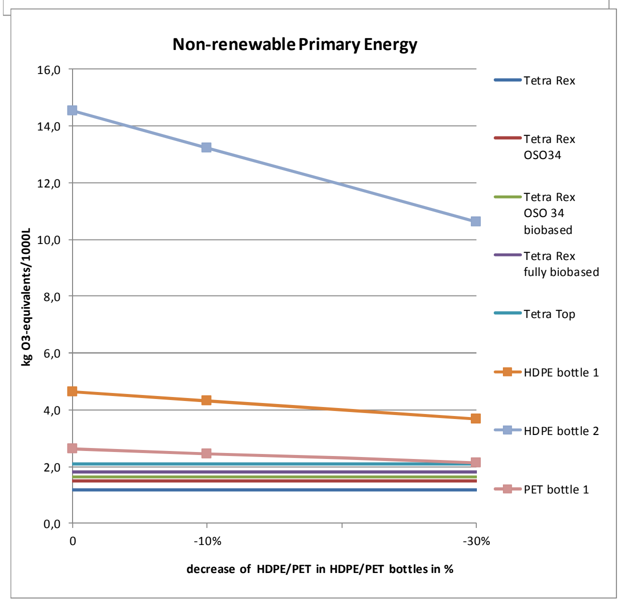


Figure 74: Indicator results for sensitivity analysis on plastic bottle weights of **segment DAIRY, Finland**, allocation factor 50% (Part 2)

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In most cases though, even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of beverage cartons is met.

A lightweight 'HDPE bottle 1' does not break even with any beverage carton that showed lower results in the base scenarios.

A lightweight 'HDPE bottle 2' would never achieve lower results than any of the beverage cartons in any impact category even with a weight reduction of 30%.

A lightweight version of the 'PET bottle 1' reaches break-even with 'Tetra Rex fully bio-based' in the categories 'Acidification' (at ca. 15%) and 'Photo-Oxidant Formation (at ca. 15%). It also breaks even with 'Tetra Top' in 'Terrestrial Eutrophication' at about 25% weight reduction.

For the impact category 'Climate Change' and in the inventory categories related to primary energy demand none of the lightweight bottles achieves lower results than any of the beverage cartons.

8.1.4 Sensitivity analysis regarding inventory dataset for Bio-PE DAIRY Finland

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

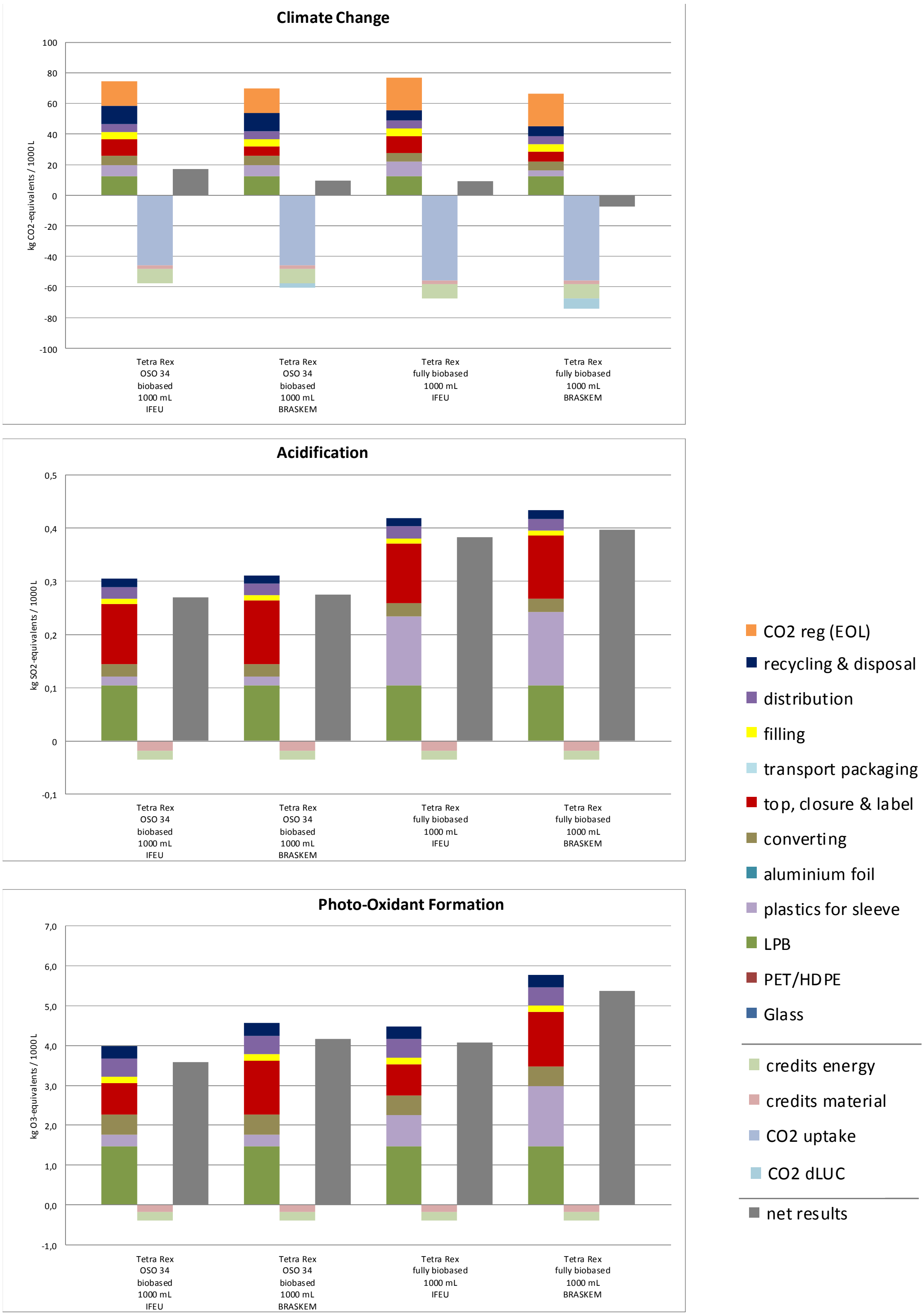


Figure 75: Indicator results for sensitivity analysis on Bio-PE of **segment DAIRY,** Finland, allocation factor 50% (Part 1)

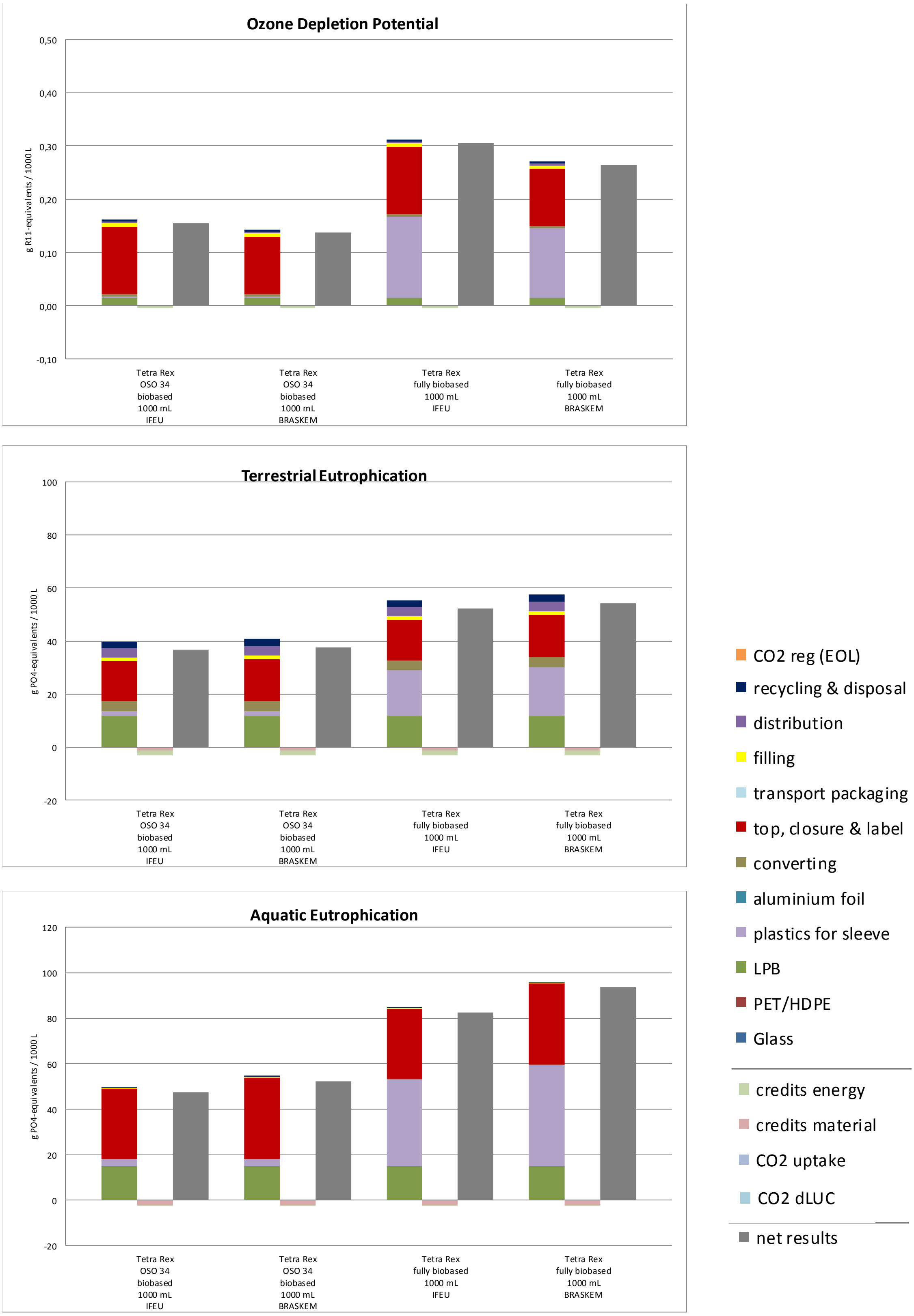


Figure 76: Indicator results for sensitivity analysis on Bio-PE of segment DAIRY, Finland, allocation factor 50% (Part 2)

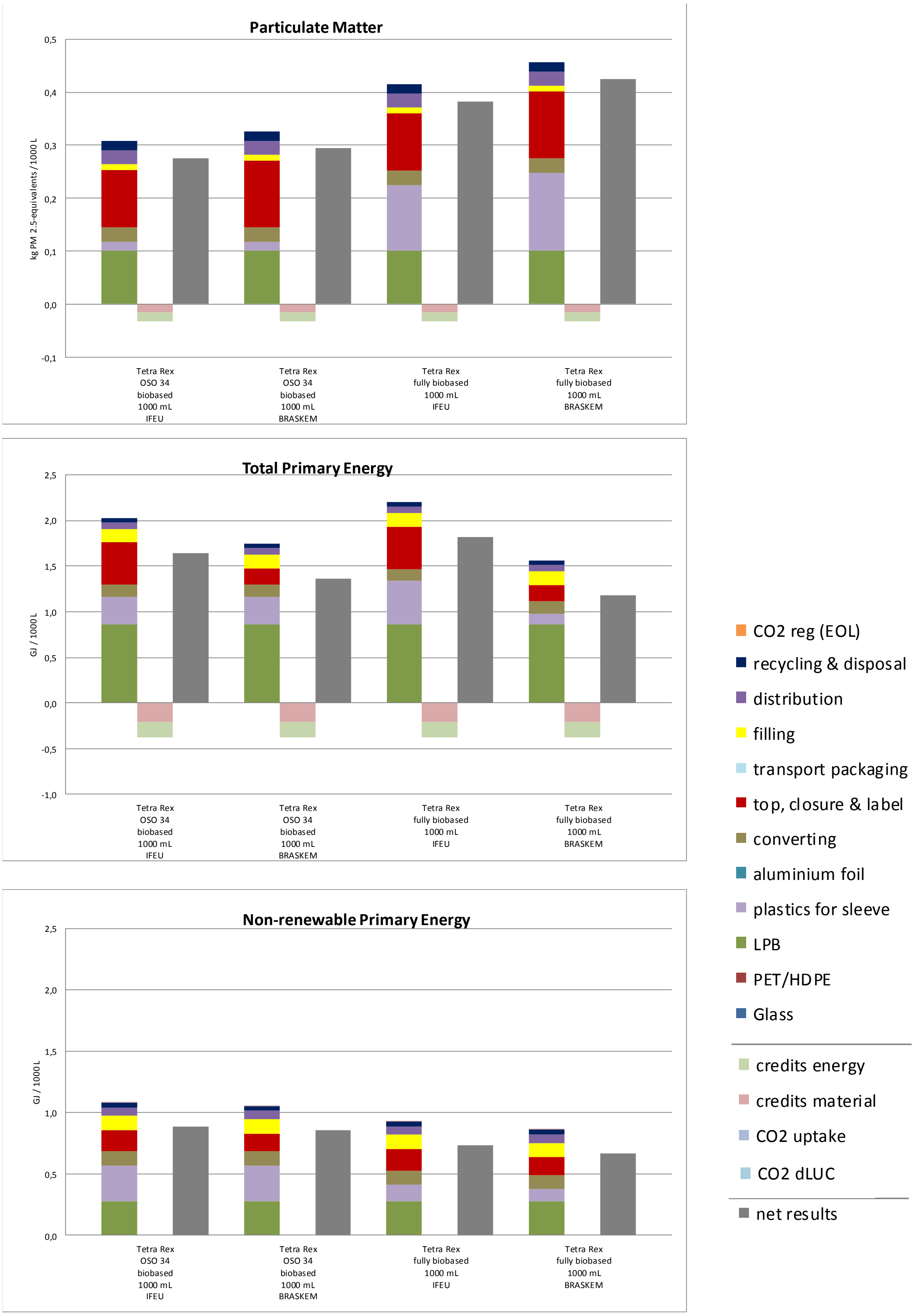


Figure 77: Indicator results for sensitivity analysis on Bio-PE of segment DAIRY, Finland, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the Tetra Rex cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower' Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of dairy packaging on the Finnish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

8.2 JNSD

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 subjective 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 78: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Finland**, allocation factor 100% (Part 1)

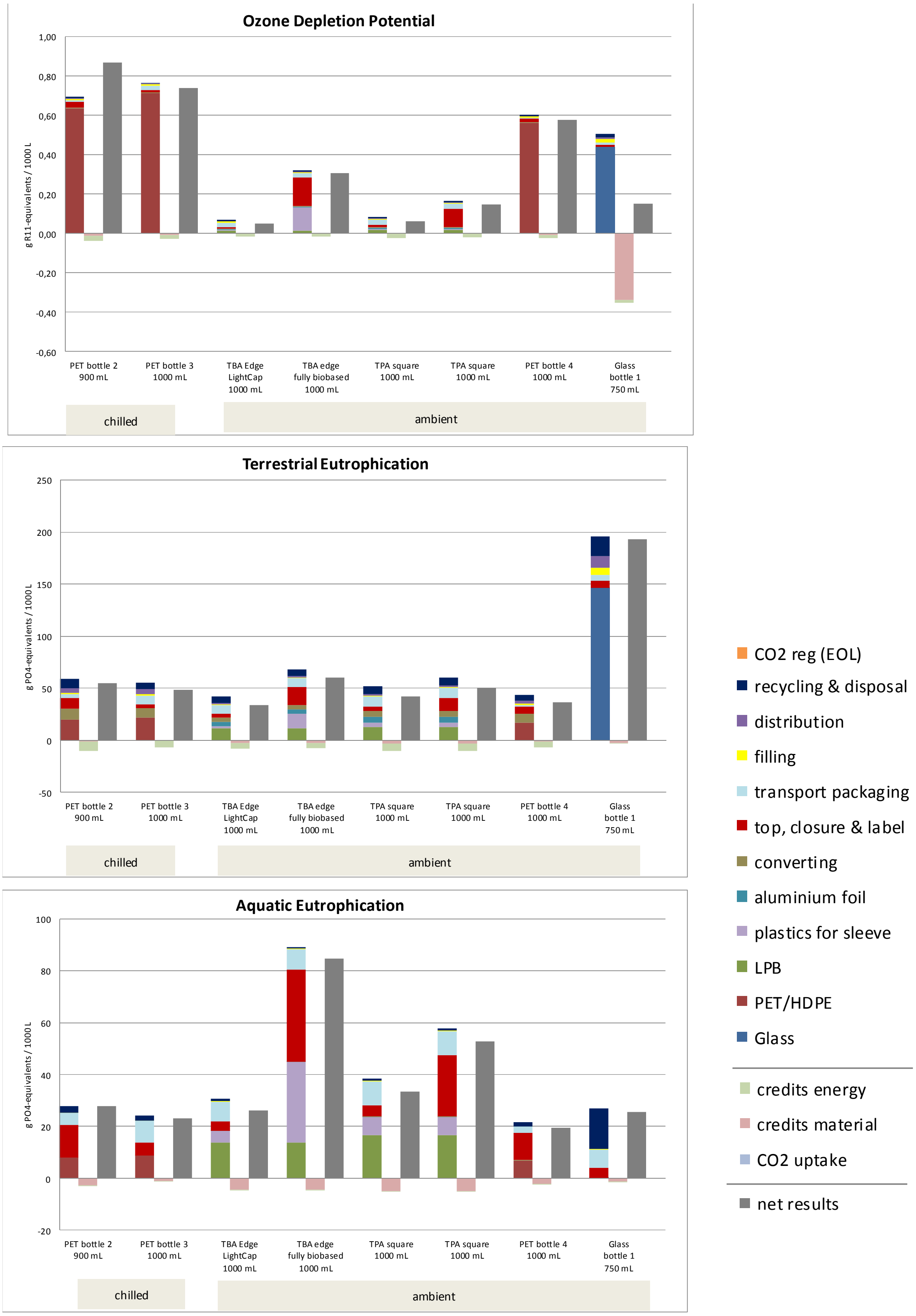


Figure 79: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Finland**, allocation factor 100% (Part 2)

Figure 80: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Finland**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category ‘Climate Change’ are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the application of an allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Finnish market the electricity credited is the Finnish grid mix with its relatively low share of fossil energy sources.

8.2.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

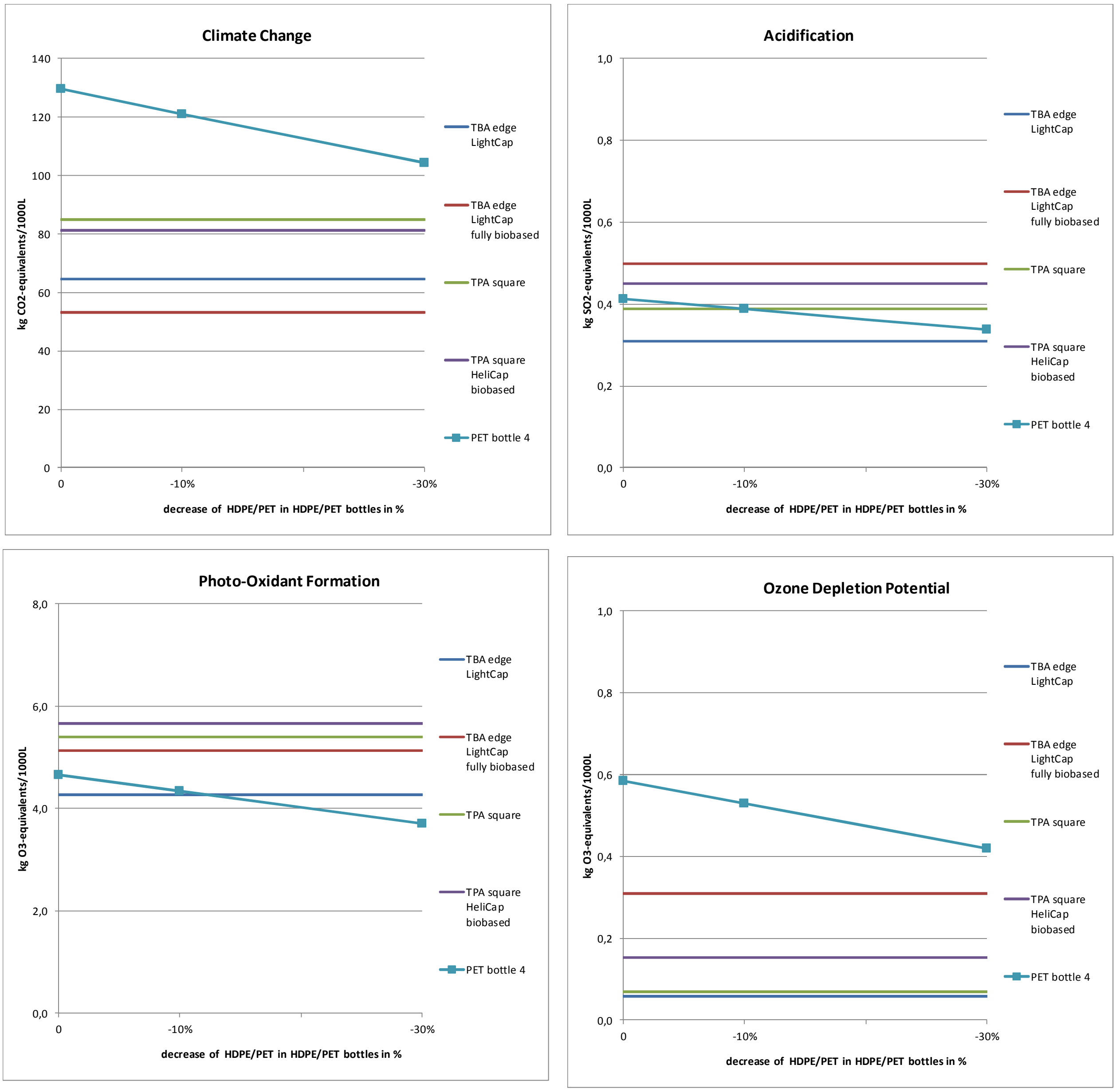
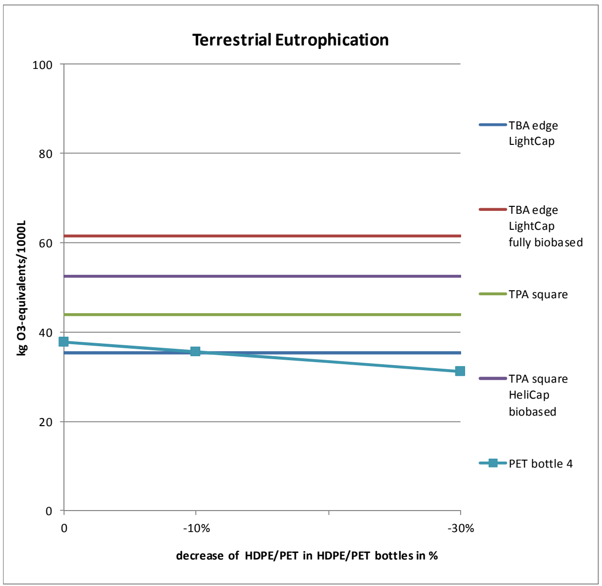
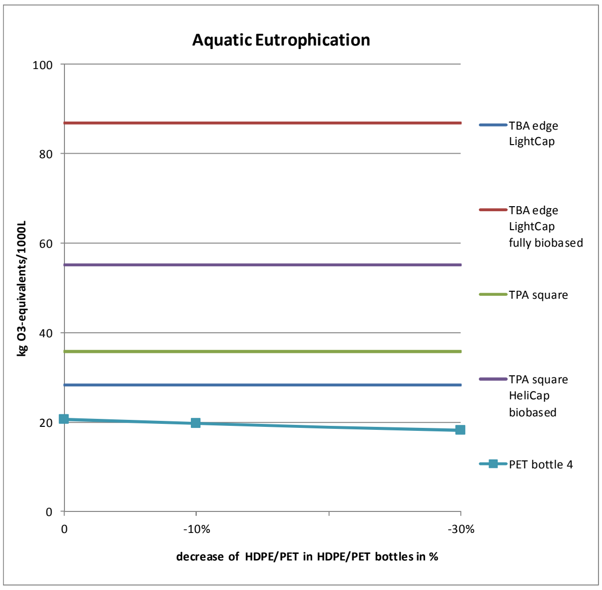
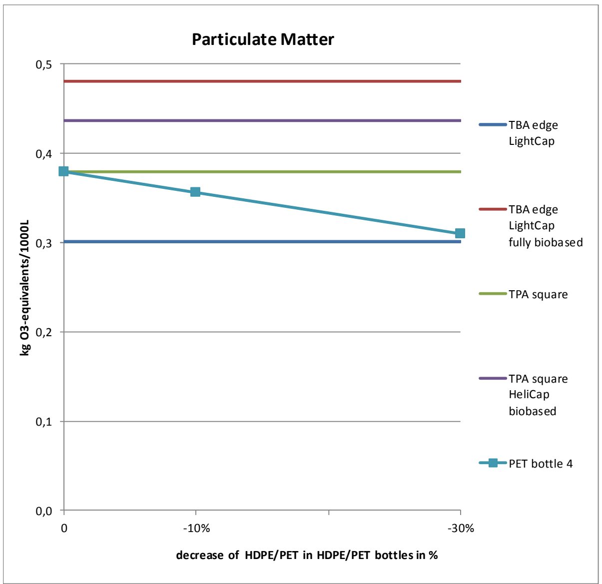
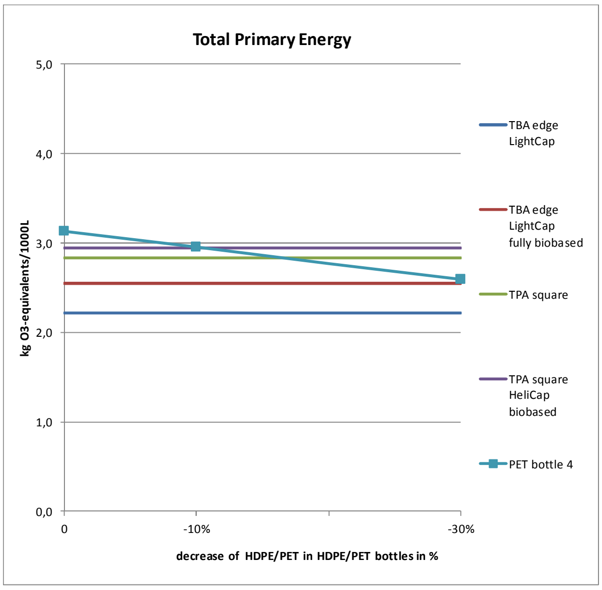


Figure 81: Indicator results for sensitivity analysis on plastic bottle weights of **segment JNSD, Finland**, allocation factor 50% (Part 1)









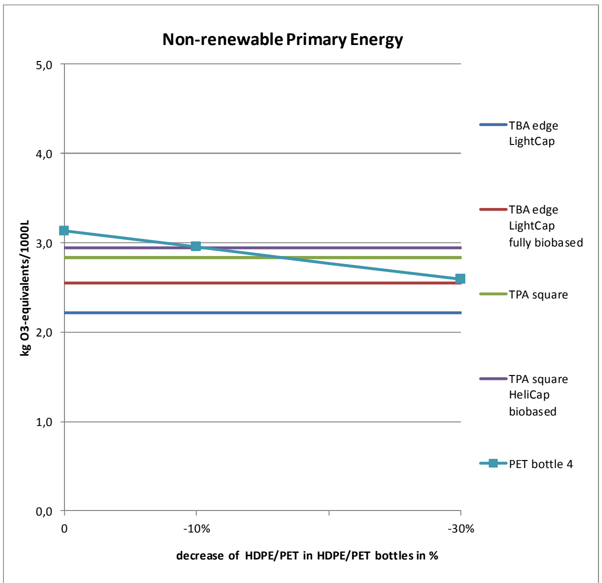


Figure 82: Indicator results for sensitivity analysis on plastic bottle weights **segment JNSD, Finland**, allocation factor 50% (Part 2)

Description and Interpretation

For the JNSD segment only the ‘PET bottle 4’ is recalculated with reduced weight, as the plastic bottles ‘PET bottle 2’ and ‘PE bottle 3’ are for chilled JNSD, for which no beverage carton has been examined.

A lightweight ‘PET bottle 4’ does not achieve lower results than any of the regarded beverage cartons in the impact categories ‘Climate Change’ and ‘Ozone Depletion Potential’, even if its weight is reduced by 30%.

It reaches break-even though with ‘TPA square’ in ‘Acidification’ at about 10% weight reduction and with ‘TPA square HeliCap bio-based’ in ‘Photo-Oxidant Formation’ and ‘Terrestrial Eutrophication’ at about 12% weight reduction.

8.2.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu’s own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

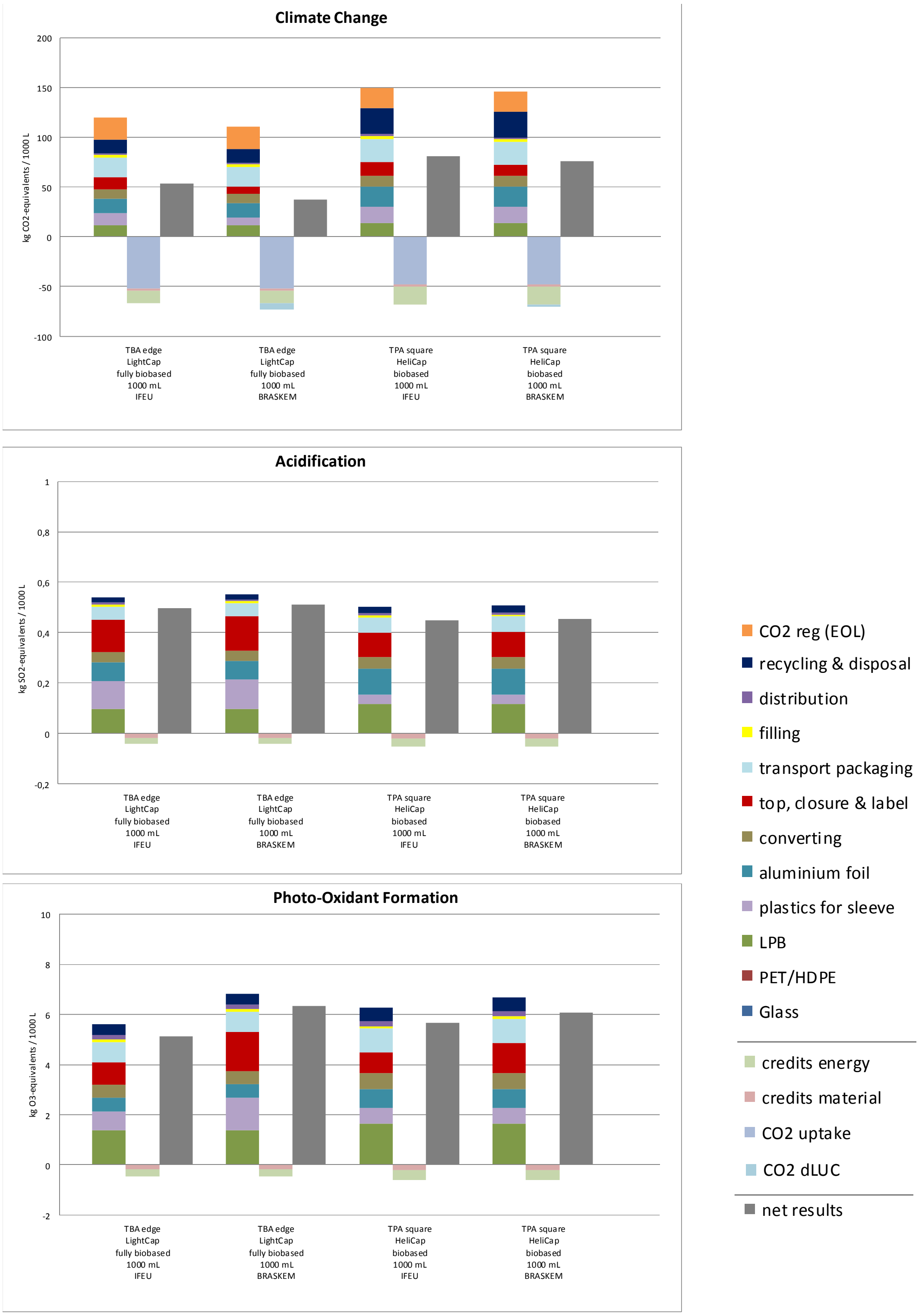


Figure 83: Indicator results for sensitivity analysis on Bio-PE of segment JNSD, Finland, allocation factor 50% (Part 1)

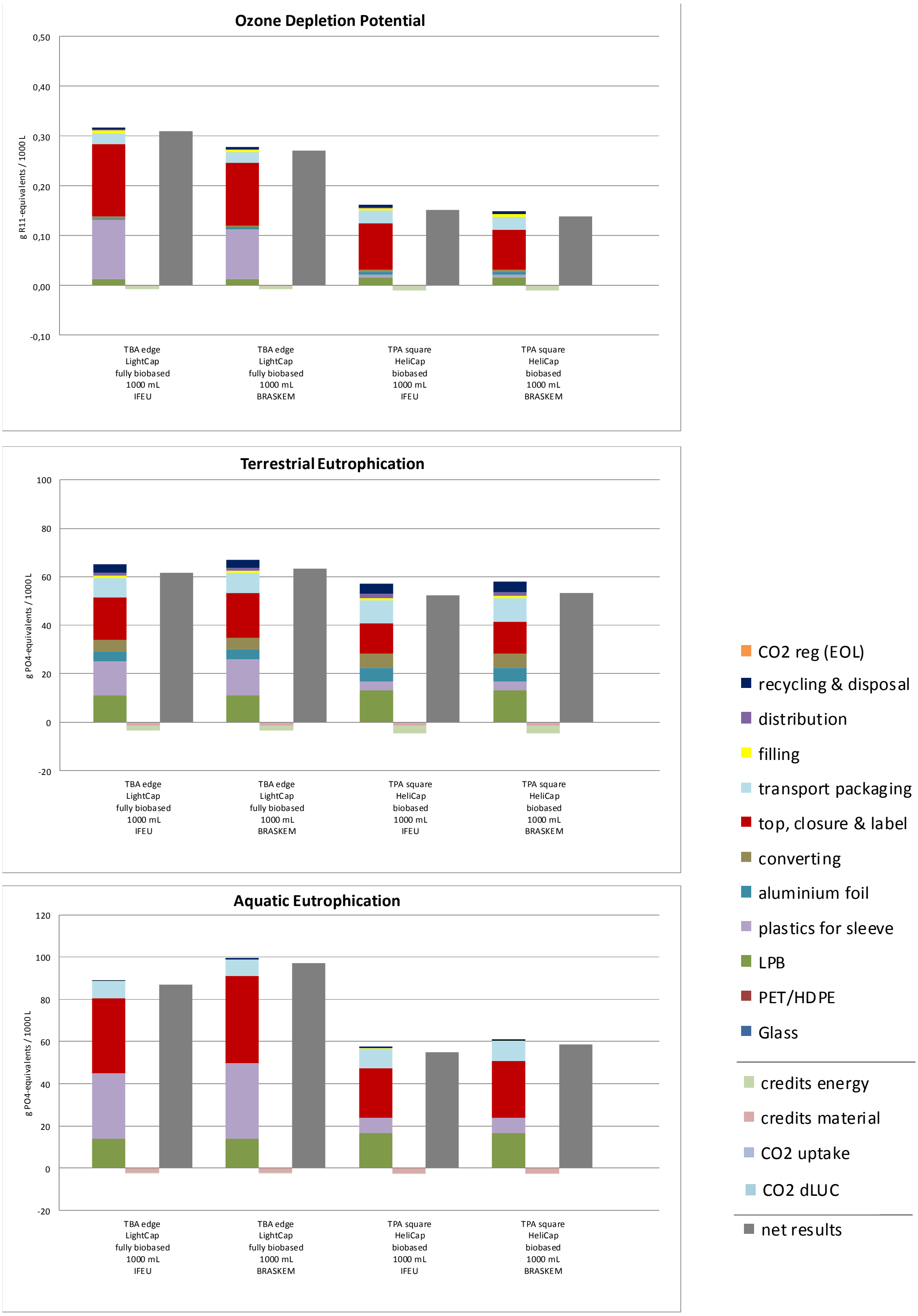


Figure 84: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Finland**, allocation factor 50% (Part 2)

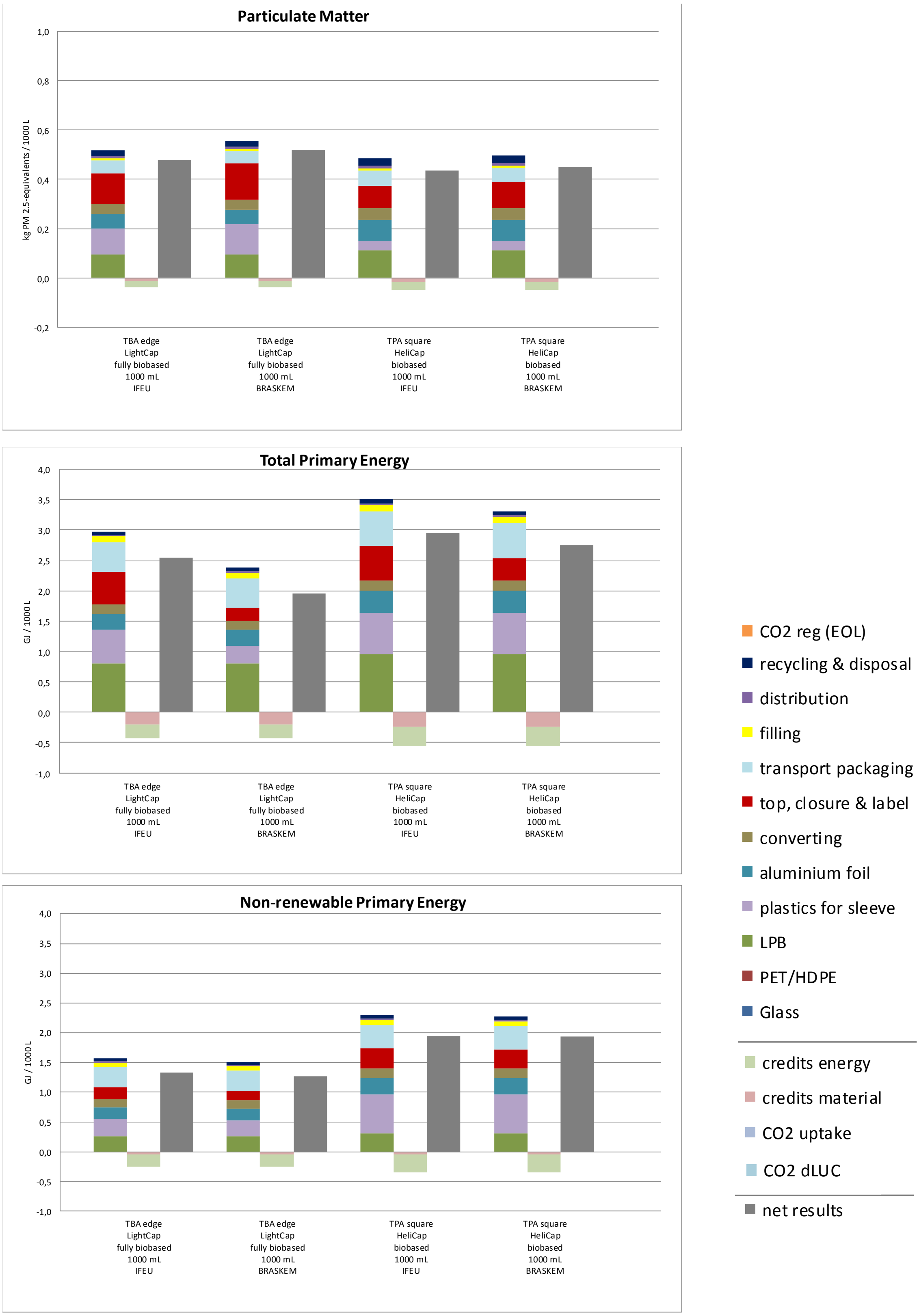


Figure 85: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Finland**, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the TBA edge and TPA square cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower 'Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of JNSD packaging on the Finnish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

8.3 Grab & Go

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 subjective 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%.

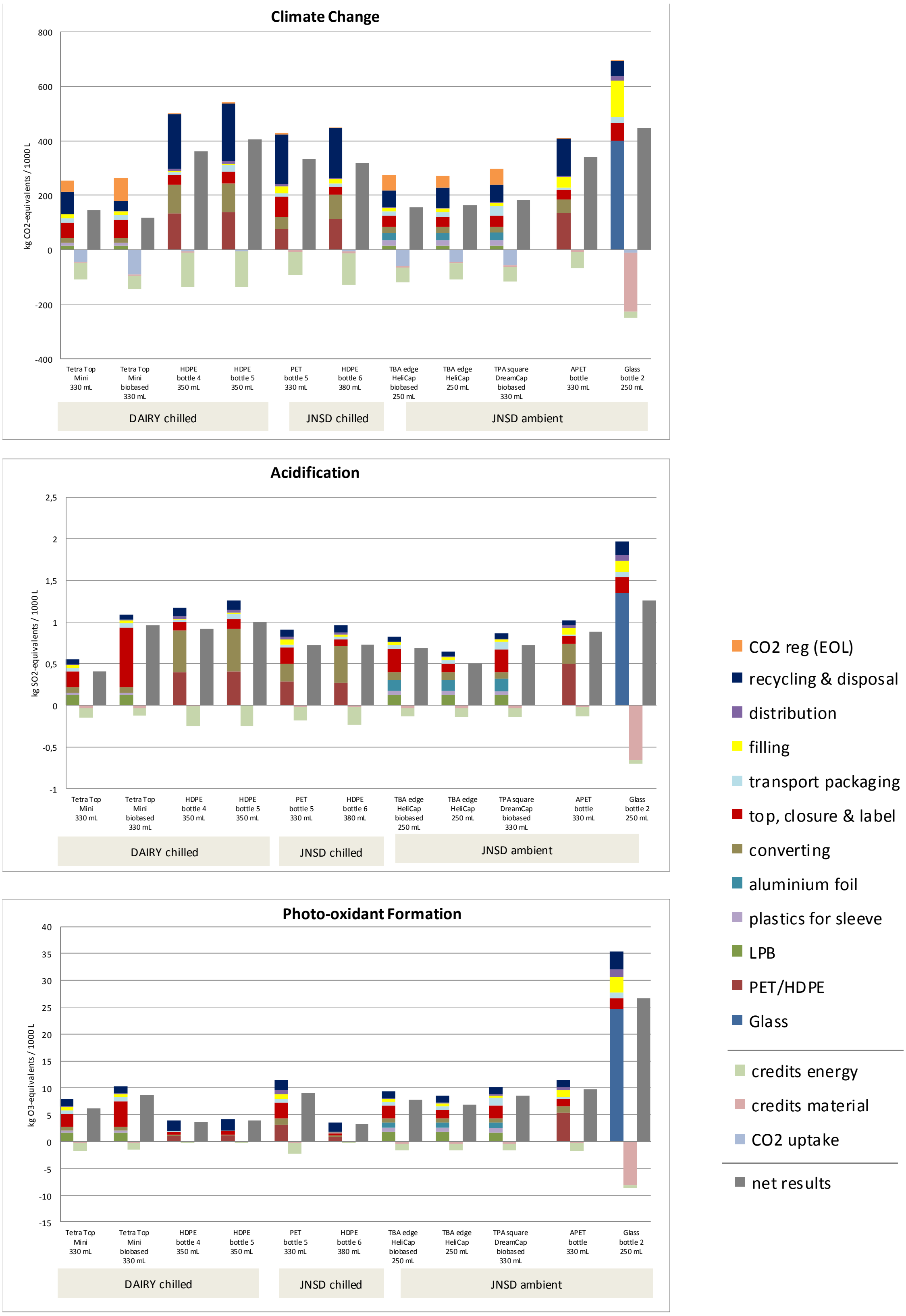


Figure 86: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Finland**, allocation factor 100% (Part 1)

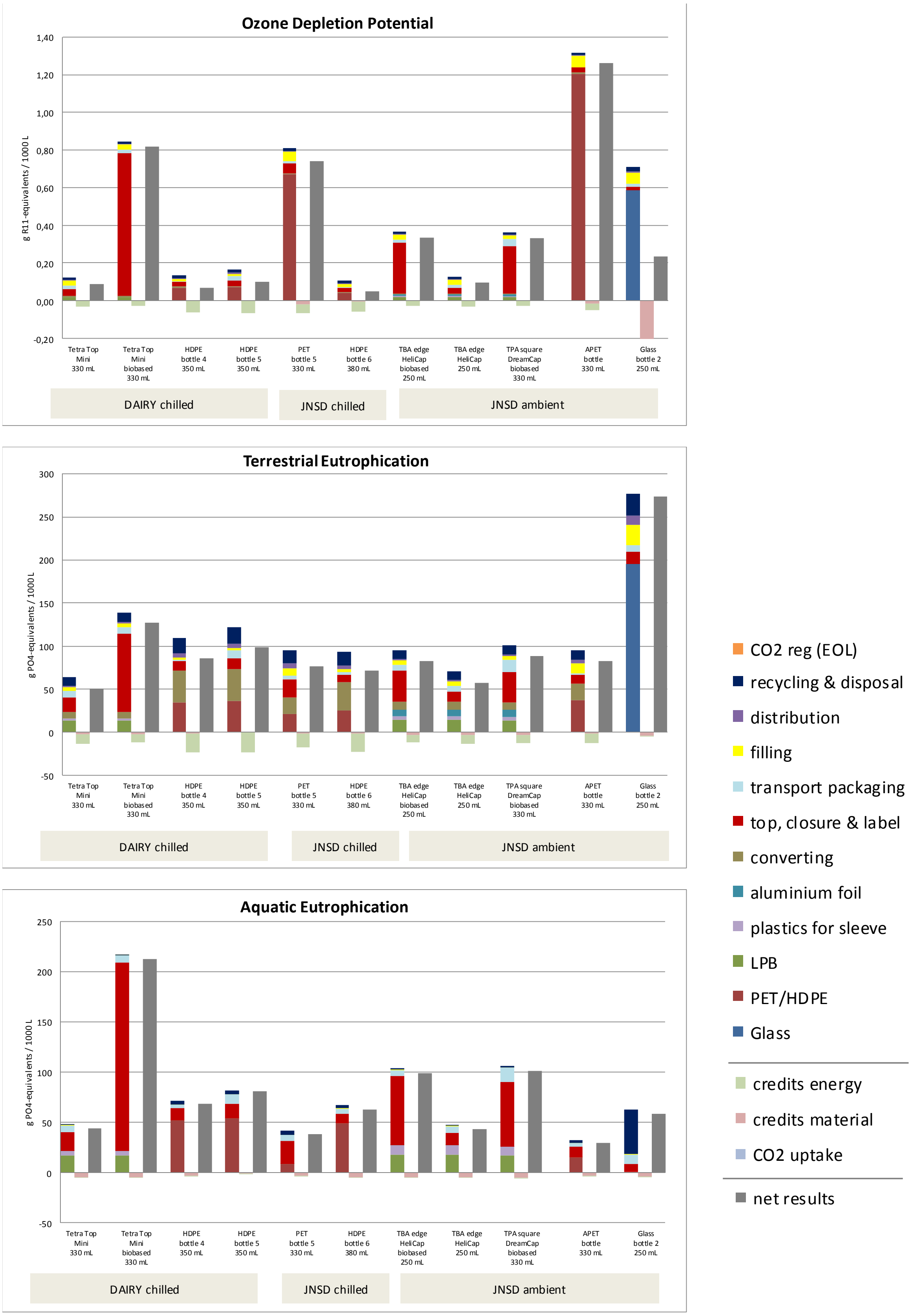


Figure 87: Indicator results for sensitivity analysis on system allocation of segment JNSD, Finland, allocation factor 100% (Part 2)

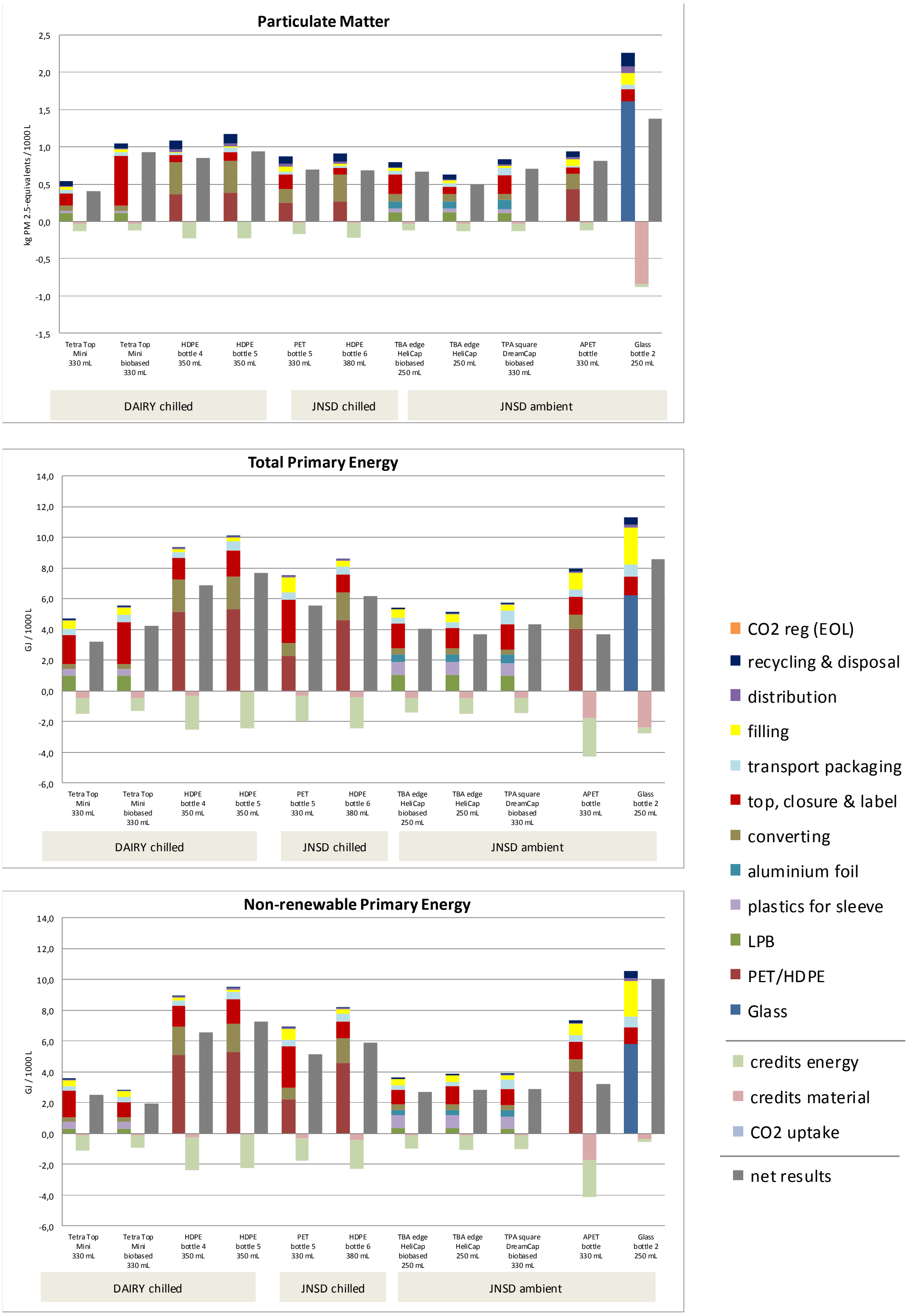


Figure 88: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Finland** allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios. In that case, the application of an allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Finnish market the electricity credited is the Finnish grid mix with its relatively low share of fossil energy sources.

8.3.2 Sensitivity analysis regarding plastic bottle weights Grab & Go Finland

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are be analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

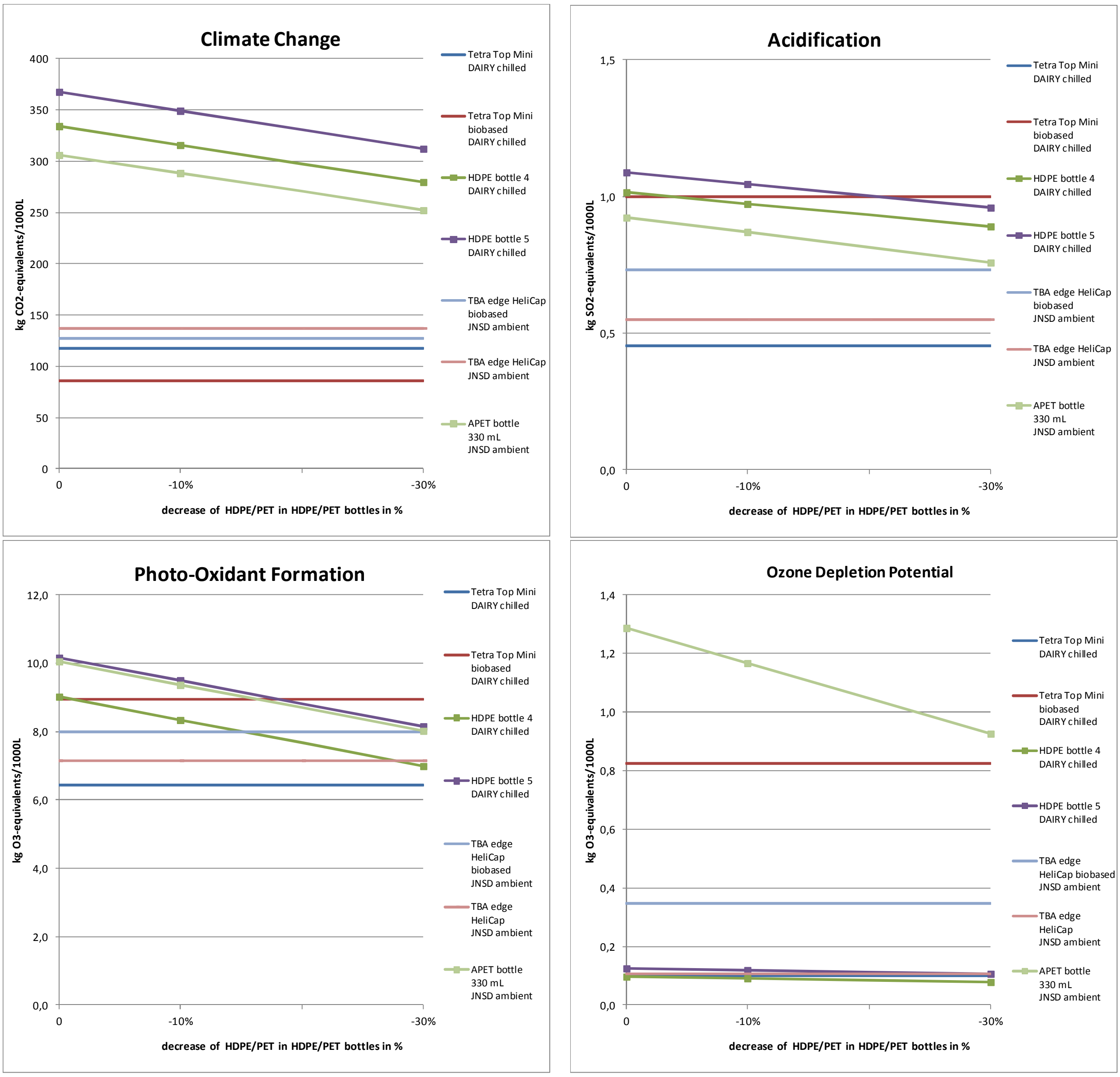


Figure 89: Indicator results for sensitivity analysis on plastic bottle weights of **segment Grab & Go, Finland**, allocation factor 50% (Part 1)

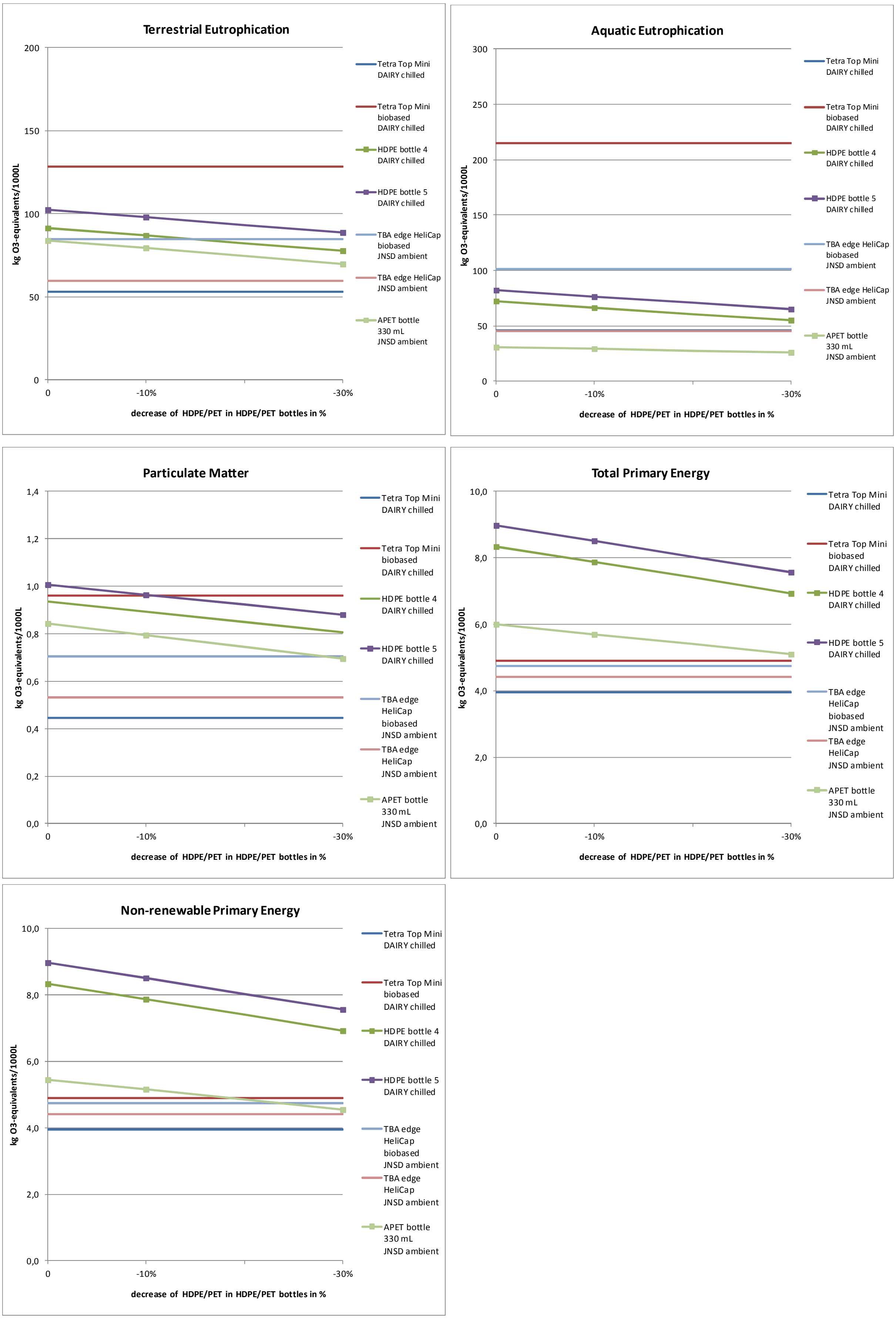


Figure 90: Indicator results for sensitivity analysis on plastic bottle weights **segment Grab & Go, Finland**, allocation factor 50% (Part 2)

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In many cases though, even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of a beverage carton is met.

No lightweight bottle achieves a new ‘rank’ when compared to beverage cartons in the categories ‘Climate Change’, ‘Ozone Depletion Potential’ and ‘Aquatic Eutrophication’.

In the category ‘Acidification’ the ‘HDPE bottle 4’ and HDPE bottle 5’ each reach break-even with the ‘Tetra Top mini bio-based’ at about 5% and 20& weight reduction respectively.

In the category ‘Photo-Oxidant Formation’ all recalculated lightweight bottles reach break-even with the respective next-in-rank beverage carton at about 15-20% weight reduction. The ‘HDPE bottle 4’ even reaches break-even with the ‘TBA egde HeliCap bio-based’ at about 28% weight reduction.

In ‘Terrestrial Eutrophication’ break-even with ‘TBA edge HeliCap bio-based’ is achieved by the ‘HDPE bottle 4’ at about 15% weight reduction.

In ‘Particulate Matter’ the ‘HDPE bottle 5’ reaches lower results than the ‘Tetra Top mini bio-based’ at about 10% weight reduction and the ‘APET bottle’ reached break-even with ‘TBA edge HeliCap bio-based’ at about 28% weight reduction.

8.3.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu’s own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

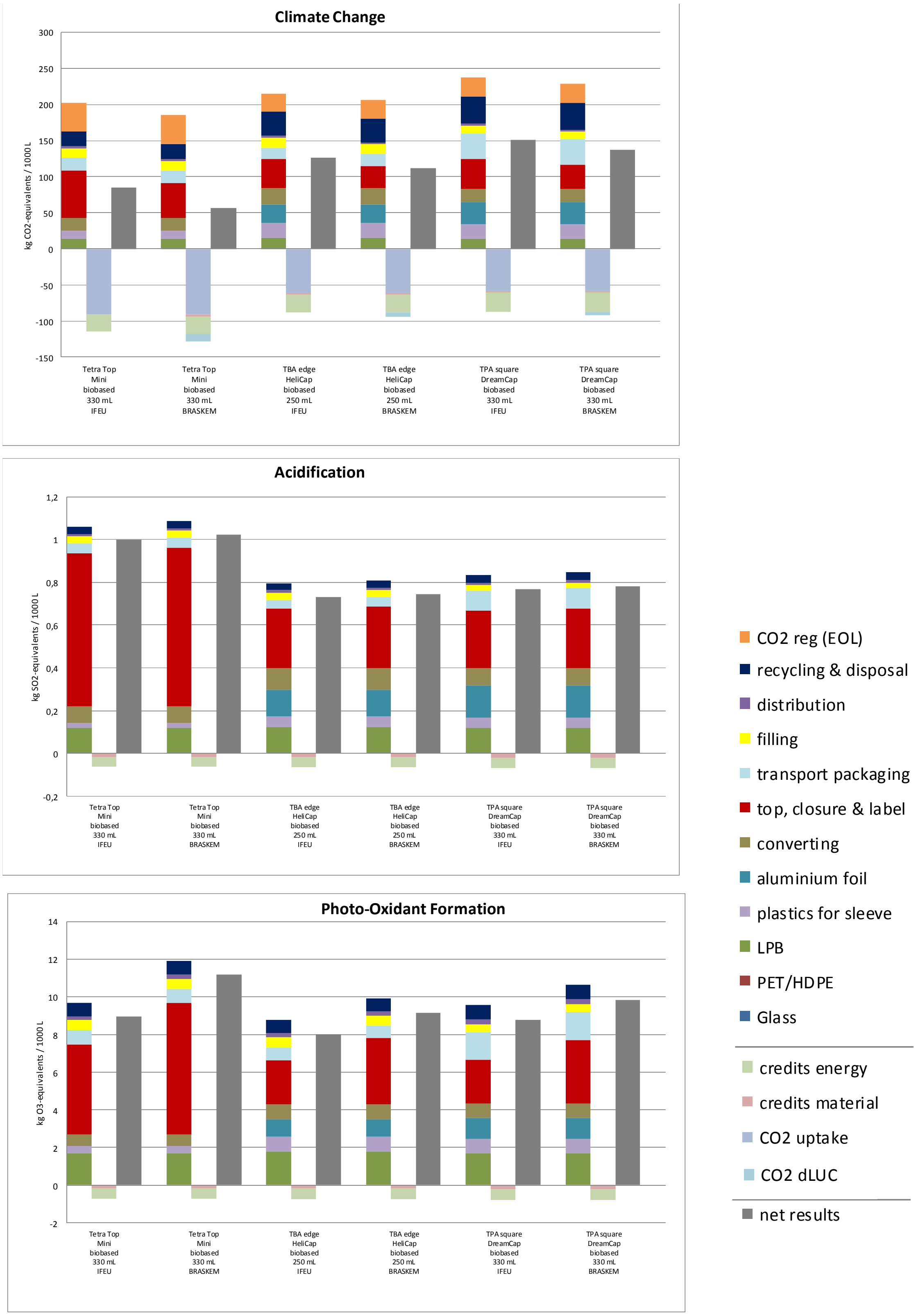


Figure 91: Indicator results for sensitivity analysis on Bio-PE of **segment Grab & Go Finland**, allocation factor 50% (Part 1)

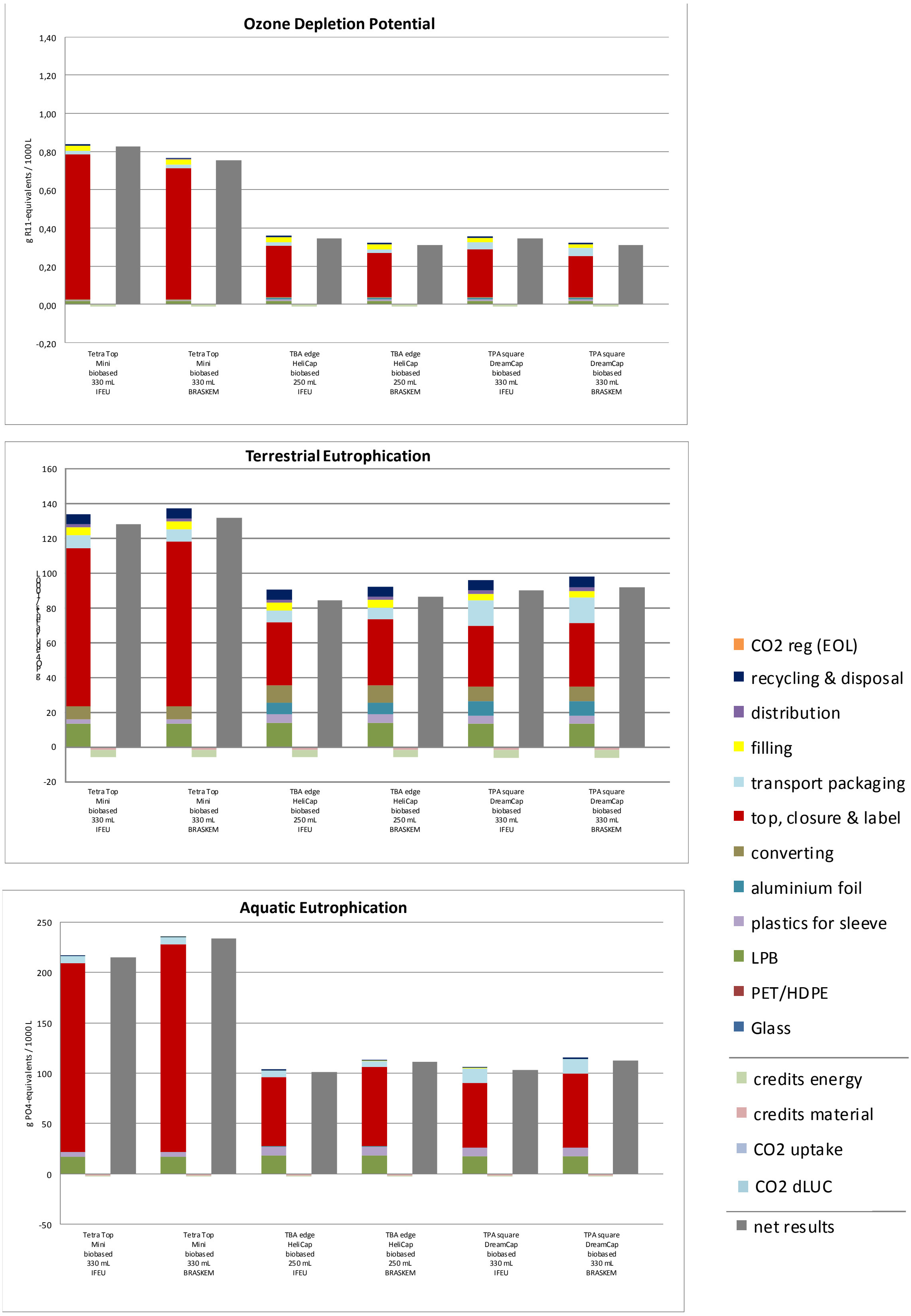


Figure 92: Indicator results for sensitivity analysis on Bio-PE of segment Grab & Go, Finland, allocation factor 50% (Part 2)

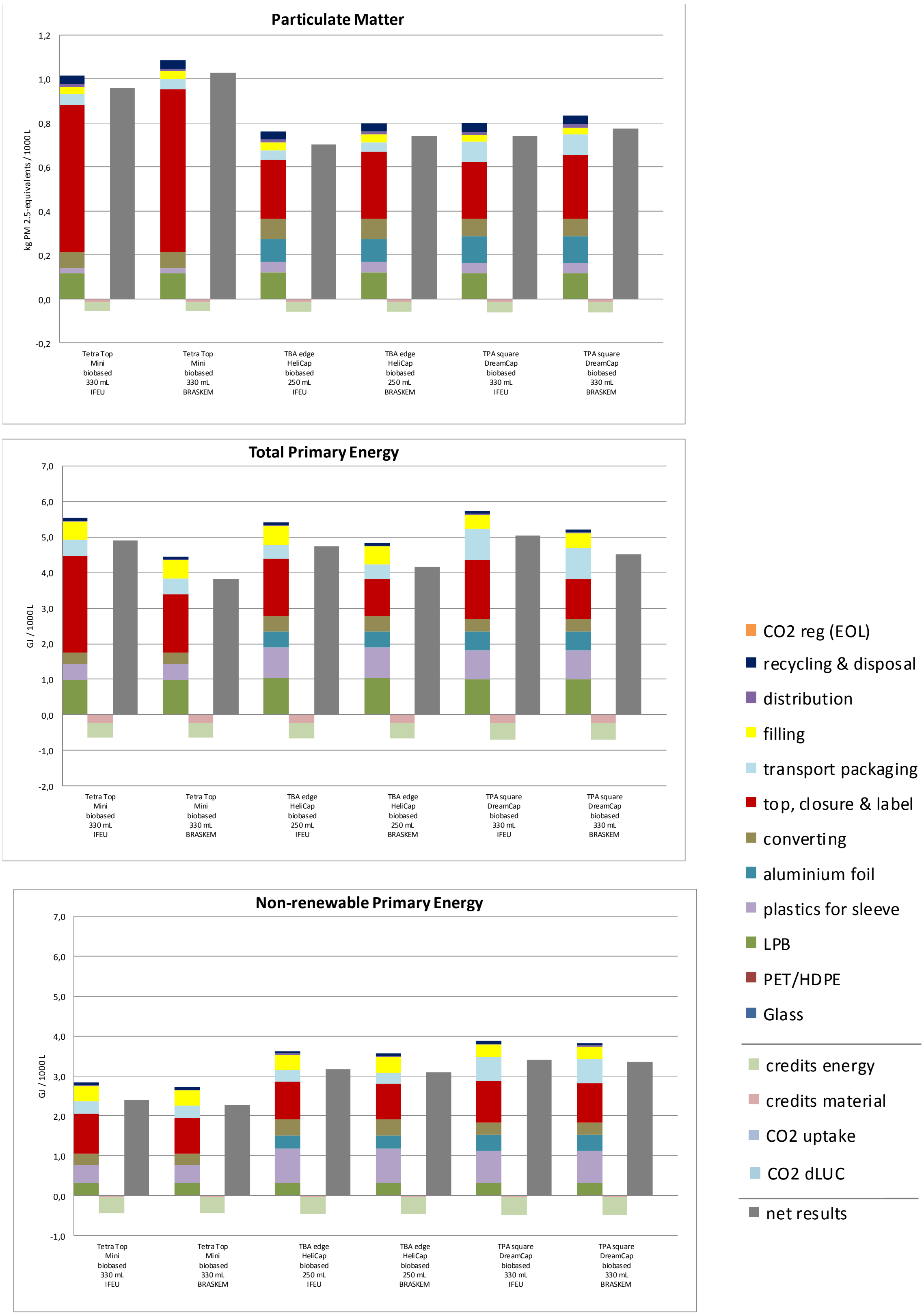


Figure 93: Indicator results for sensitivity analysis on Bio-PE of **segment Grab & Go, Finland**, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the beverage cartons with bio-based plastics of the Grab & go segment modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower' Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of grab & go packaging on the Finnish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

9 Conclusions Finland

9.1 Dairy Finland

In general the examined beverage carton systems show lower burdens in all of the impact categories than their competing systems. An exception to this occurs in some categories if the carton contains a high share of bio-based polyethylene.

This is especially true in the base scenarios where an allocation factor of 50% is applied. This is due to the fact that only half of the regenerative CO_2-emissions of end-of-life are accounted to the beverage carton. With an allocation factor of 100%, therefore the results are higher, but still lower than the competing bottles in most of impact categories.

A considerable role for these generally low environmental impacts of beverage cartons plays the renewability of their paperboard components and a high use of renewable energies.

Apart from the ‘Tetra Top’ the carton systems also benefit from the use of multi-use roll containers instead of one-way transport packaging.

Lowest results are shown by those beverage carton systems without a separate closure system.

In the environmental impact category ‘Climate Change’ the cartons furthermore benefit from the use of bio-based polyethylene for sleeve and/or closure. However, a higher share of Bio-PE leads to higher environmental impacts in all other impact categories examined. In case of the substitution of fossil based polyethylene by bio-based polyethylene in the sleeve and closure the respective beverage cartons may lose their environmental advantage against the competing bottles in some impact categories.

The sensitivity analysis on plastic bottle weights shows, that reducing the weight of plastic bottles will lead to lower environmental impacts. When compared to the unaltered beverage cartons the results of the potential fossil-based lightweight bottles calculated may lead to a change in the overall ranking in some cases, especially in regard to the fully bio-based cartons. In the category ‘Climate Change’ however none of the potential lightweight bottles achieve lower results than any of the beverage cartons.

9.2 JNSD Finland

In the segment JNSD ambient the use of aluminium foil for ambient packaging increases the overall burdens of the beverage cartons. However the cartons without bio-based polyethylene still show lower or similar results than the bottles examined in most of the impact categories.

With an increased share of bio-based polyethylene 'Climate Change' results of beverage cartons improve. Results in all other impact categories however increase to an extent that compared to the PET bottle the carton loses its overall environmental advantage.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

9.3 Grab & Go Finland

The examined beverage carton systems without biobased polyethylene for Grab and Go in the sub-segment Dairy chilled show lower burdens in all of the impact categories than their competing systems.

As the share of plastics in a small volume Tetra Top packaging is higher than other beverage cartons of bigger volumes, the choice of plastic material type, e.g. fossil or bio-based, plays a decisive role for the environmental performance. In case of the 'Tetra Top Mini biobased 330 mL' the impact results are significantly lower only in the impact category 'Climate Change' than those of the 'HDPE bottle 4'.

In the sub-segment JNSD ambient the beverage carton can be considered the packaging of choice when compared to the glass bottle from an environmental viewpoint. Compared to the APET bottle, though, no unambiguous conclusion can be drawn; at least not for the biobased cartons. From the environmental viewpoint generally the 'TBA edge HeliCap 250 mL' seems to be the best choice.

Again volume size of the examined packaging systems in both sub-segments has an influence on their results: The higher the volume the lower are the impacts according to the functional unit of 1000 L beverage.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

10 Norway

In this section, the results of the examined packaging systems for Norway are presented separately for the different segments. The following individual life cycle elements are illustrated in sectoral (stacked) bar charts:

- Production and transport of glass including converting to bottle (**'glass'**)
- production and transport of HDPE/PET for bottles including additives, e.g. TiO_2 ('**HDPE/PET for bottle**')
- production and transport of liquid packaging board ('**liquid packaging board**')
- production and transport of plastics and additives for beverage carton ('**plastics for sleeve**')
- production and transport of aluminium & converting to foil ('**aluminium foil for sleeve**')
- production and transport of base materials for closure, top and label and related converting for cartons and plastic bottles ('**top closure&label**')
- converting processes of cartons and plastic bottles and transport to filler ('**converting**')
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays ('**transport packaging**')
- filling process including packaging handling ('**filling**')
- retail of the packages from filler to the point-of-sale ('**distribution**')
- sorting, recycling and disposal processes – all emissions except regenerative CO_2 ('**recycling/disposal**')
- CO_2 emissions from incineration of biobased and renewable materials **('CO2 reg. (EOL)'**; in the following also the term regenerative CO2 emissions is used

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 section 1.8) 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 energy recovery (replacing e.g. grid electricity) (‘**credits energy**’)
- credits for material recycling (‘**credits material**’)
- uptake of athmospheric CO_2 during the plant growth phase (‘**CO_2-uptake’**)

For the sensitivity analysis including the BRASKEM bio-PE dataset the sector ‘**CO_2 – direct land use change**’ (dLUC) is introduced. This sector shows changes in soil organic carbon and above and below ground carbon stocks from conversion of land to sugarcane cultivation. The BRASKEM dataset accounts a negative CO2 value for dLUC.

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

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

- sectoral results of the packaging system itself (stacked bar ‘environmental burdens’)
- credits given for secondary products leaving the system (negative stacked bar ‘credits’)
- 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 (i.e. milk, JNSD) to the point of sale including the end-of-life of the packaging materials.

10.1 Results DAIRY Norway

10.1.1 Presentation of results DAIRY Norway

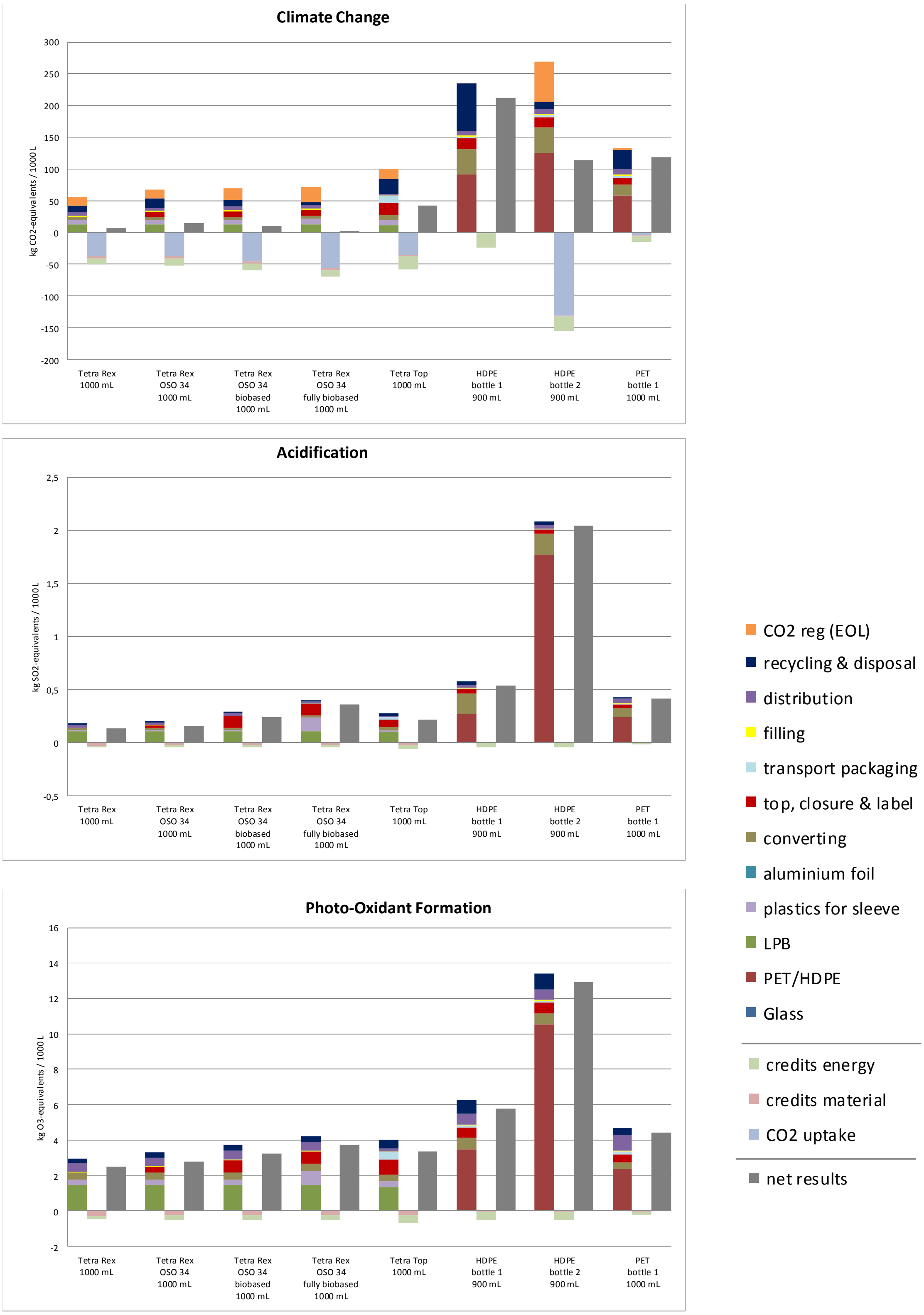


Figure 94: Indicator results for base scenarios of **segment Dairy, Norway**, allocation factor 50% (Part 1)

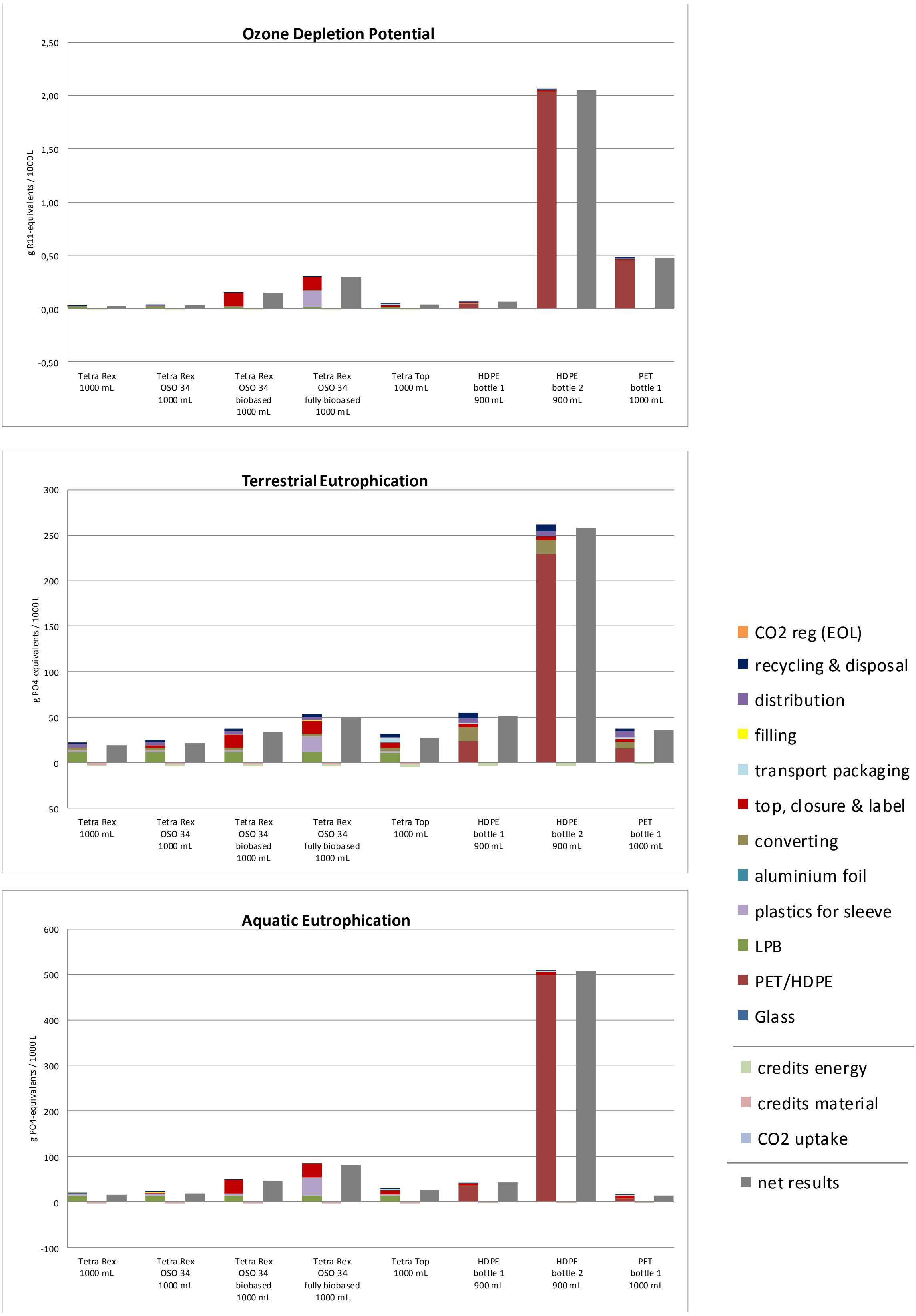


Figure 95 Indicator results for base scenarios of **segment Dairy, Norway**, allocation factor 50% (Part 2)

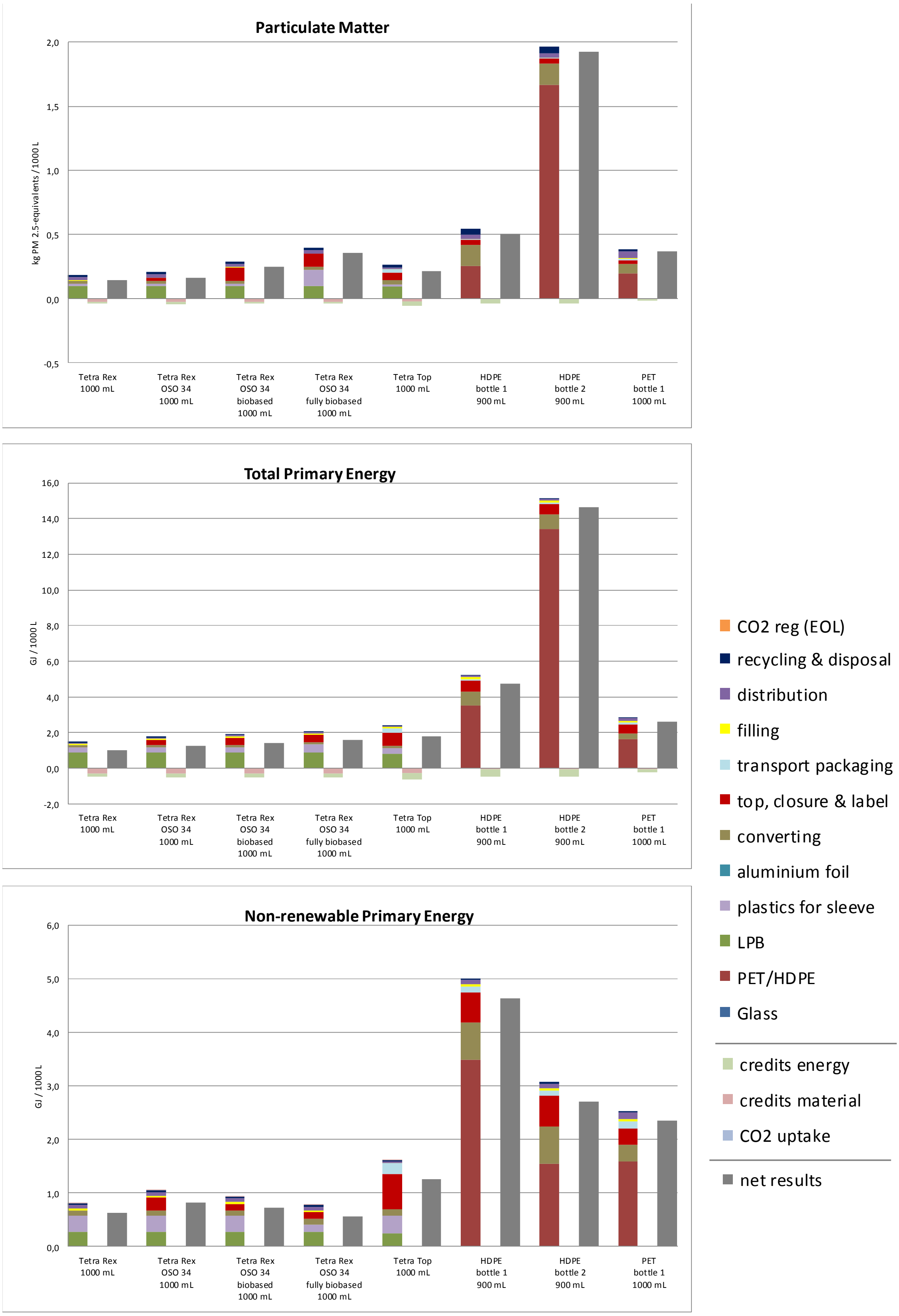


Figure 96: Indicator results for base scenarios of **segment Dairy, Norway**, allocation factor 50% (Part 3)

Figure 97: Indicator results for base scenarios of **segment dairy, Norway**, allocation factor 50% (Part 4)

Table 72: Category indicator results per impact category for base scenarios of segment DAIRY, Norway- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Norway, allocation factor 50 %		Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	42.09	53.64	51.37	47.95	84.96
	CO2 (reg)	14.02	14.22	18.14	23.83	15.12
	Credits	-11.60	-14.90	-13.74	-13.74	-23.34
	CO_2 uptake	-37.99	-37.99	-45.86	-55.84	-34.94
	Net results (∑)	6.53	14.98	9.91	2.21	41.81
Acidification [kg SO_2-equivalents]	Burdens	0.18	0.20	0.29	0.40	0.27
	Credits	-0.04	-0.05	-0.05	-0.05	-0.06
	Net results (∑)	0.13	0.15	0.24	0.36	0.21
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	2.95	3.31	3.71	4.20	4.00
	Credits	-0.46	-0.52	-0.49	-0.49	-0.66
	Net results (∑)	2.50	2.80	3.22	3.71	3.34
Ozone Depletion [g R-11-equivalents]	Burdens	0.03	0.03	0.15	0.30	0.05
	Credits	0.00	-0.01	-0.01	-0.01	-0.01
	Net results (∑)	0.02	0.03	0.15	0.30	0.04
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	22.59	25.25	37.47	53.03	31.75
	Credits	-3.51	-3.96	-3.78	-3.78	-5.04
	Net results (∑)	19.08	21.29	33.68	49.25	26.71
Aquatic eutrophication [g PO_4-equivalents]	Burdens	18.63	21.46	49.31	84.43	29.23
	Credits	-3.47	-3.36	-3.36	-3.36	-2.93
	Net results (∑)	15.17	18.11	45.96	81.07	26.30
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.18	0.21	0.29	0.40	0.27
	Credits	-0.04	-0.04	-0.04	-0.04	-0.05
	Net results (∑)	0.15	0.17	0.25	0.36	0.22
Total Primary Energy [GJ]	Burdens	1.49	1.77	1.91	2.08	2.40
	Credits	-0.47	-0.52	-0.50	-0.50	-0.62
	Net results (∑)	1.02	1.25	1.41	1.59	1.79
Non-renewable primary energy [GJ]	Burdens	0.81	1.05	0.93	0.78	1.62
	Credits	-0.18	-0.23	-0.21	-0.21	-0.36
	Net results (∑)	0.63	0.82	0.72	0.56	1.26
Use of Nature [m^2-equivalents*year]	Burdens	21.33	21.46	25.10	29.70	20.82
	Credits	-5.04	-4.86	-4.86	-4.86	-4.11
	Net results (∑)	16.29	16.60	20.24	24.84	16.72
Water use [m^3]	Water cool	1.00	1.15	1.05	0.88	1.61
	Water process	2.00	2.04	2.10	2.17	1.94
	Water unspec	0.26	0.30	8.07	17.89	0.34

Table 73: Category indicator results per impact category for base scenarios of segment DAIRY, Norway- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Norway, allocation factor 50 %		HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	235.32	205.61	130.53
	CO2 (reg)	0.04	63.46	2.49
	Credits	-23.60	-23.52	-10.20
	CO_2 uptake	0.00	-131.34	-4.54
	Net results (∑)	211.75	114.21	118.29
Acidification [kg SO_2-equivalents]	Burdens	0.58	2.09	0.43
	Credits	-0.04	-0.04	-0.02
	Net results (∑)	0.54	2.04	0.41
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	6.28	13.41	4.65
	Credits	-0.50	-0.50	-0.23
	Net results (∑)	5.78	12.91	4.42
Ozone Depletion [g R-11-equivalents]	Burdens	0.07	2.06	0.47
	Credits	-0.01	-0.01	0.00
	Net results (∑)	0.06	2.05	0.47
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	55.13	261.92	37.64
	Credits	-3.75	-3.74	-1.68
	Net results (∑)	51.38	258.18	35.96
Aquatic eutrophication [g PO_4-equivalents]	Burdens	42.54	507.21	15.12
	Credits	-0.41	-0.41	-0.52
	Net results (∑)	42.13	506.80	14.60
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.54	1.96	0.38
	Credits	-0.04	-0.04	-0.02
	Net results (∑)	0.51	1.93	0.37
Total Primary Energy [GJ]	Burdens	5.22	15.13	2.82
	Credits	-0.48	-0.48	-0.22
	Net results (∑)	4.75	14.64	2.60
Non-renewable primary energy [GJ]	Burdens	5.01	3.07	2.53
	Credits	-0.37	-0.37	-0.18
	Net results (∑)	4.64	2.70	2.35
Use of Nature [m^2-equivalents*year]	Burdens	0.29	60.98	0.94
	Credits	-0.15	-0.15	-0.10
	Net results (∑)	0.14	60.83	0.84
Water use [m^3]	Water cool	2.03	1.07	2.40
	Water process	7.20	8.28	6.93
	Water unspec	0.72	130.18	0.06

10.1.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the dairy segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. It is also relevant regarding ‘Photo-Oxidant Formation’ ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’ and the consumption of ‘Total Primary Energy’ and ‘Non-renewable Primary Energy’.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category ‘Non-renewable Primary Energy’, where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the ‘Tetra Rex fully bio-based’ due to the production of bio-based PE and relatively lower for ‘Tetra Top’ where the plastics of top and closure show the highest burdens.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from ‘Climate Change’ are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sector top, closure & label plays a role in almost all impact categories. The one exception obviously being the ‘Tetra Rex’ without a separate closure. The impacts of the production of plastics for the closures is higher for ‘Tetra Rex OSO 34 bio-based’ and ‘Tetra Rex fully bio-based’ than for the ‘Tetra Rex OSO 34’ with a fossil-based closure in all categories apart from ‘Non-renewable Primary Energy’. The sector is especially important for ‘Tetra Top’ as its combined Top and Cap uses about three times more plastic than the ‘OSO’ closure of the other beverage cartons.

The sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories ‘Climate Change’, ‘Photo-Oxidant Formation’, ‘Terrestrial Eutrophication‘ and to a lower extent ‘Acidification’. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories ‘Acidification’, and ‘Terrestrial eutrophication’ are mainly caused by NO_2 emissions from incineration plants.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging’s end-of-life. For the different Tetra Rex packaging systems the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal. It’s the other way around for the ‘Tetra Top’ as the higher share of fossil-based plastics in that packaging system leads to more non-regenerative CO_2 emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Norway 61% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category Use of Nature. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 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. Exceptions are the 'Ozone Depletion Potential' of the 'HDPE bottle 1' and the 'Aquatic Eutrophication' of 'PET bottle 1' as well as 'Use of Nature' of both these fossil-based plastic bottles.

For the three regarded bottles three different plastics are used: Fossil-based HDPE for the 'HDPE bottle 1'm bio-based PE for the 'HDPE bottle 2' and fossil-based PET for the 'PET bottle 1'. The closures of all three of them are made from HDPE. Therefore the impacts of plastics production on different categories vary accordingly. For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for both HDPE bottles than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide. The even higher burdens of bio-based PE of the 'HDPE bottle 2' originate from field emissions of N_2O from the use of nitrogen fertilisers on sugarcane fields. The agricultural background of the 'HDPE bottle 2' also means that for 'Use of Nature' the production of Bio-PE is the main contributor to this category.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the ‘Aquatic Eutrophication Potential’. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the fossil-based plastic bottles’ recycling & disposal sector is most significant regarding ‘Climate Change’. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the white opaque plastic bottles do not undergo a material recycling, the amount of bottle waste incinerated is relatively high. The regenerative CO_2 emissions from the bio-based ‘HDPE bottle 2’ are of course similarly high, but they are attributed to the sector CO_2 reg (EOL).

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the white plastic bottle waste is incinerated in MSWIs, the received material credits are insignificant compared to the credits for energy.

Please note that the categories ‘Water Use’ and ‘Use of Nature’ do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

10.1.3 Comparison between packaging systems

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

Table 74: Comparison of net results **Tetra Rex 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

segment DAIRY (chilled), Norway	The net results of **Tetra Rex 1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-56%	195%	-84%	-97%	-94%	-94%
Acidification	-12%	-62%	-37%	-75%	-93%	-67%
Photo-Oxidant Formation	-11%	-33%	-25%	-57%	-81%	-44%
Ozone Depletion Potential	-14%	-92%	-40%	-64%	-99%	-95%
Terrestrial Eutrophication	-10%	-61%	-29%	-63%	-93%	-47%
Aquatic Eutrophication	-16%	-81%	-42%	-64%	-97%	4%
Human Toxicity: PM 2.5	-11%	-59%	-32%	-71%	-92%	-60%
Total Primary Energy	-19%	-36%	-43%	-79%	-93%	-61%
Non-renewable Primary Energy	-24%	11%	-50%	-86%	-77%	-73%

Table 75: Comparison of net results **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

segment DAIRY (chilled), Norway	The net results of **Tetra Rex OSO 34 1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	129%	577%	-64%	-93%	-87%	-87%
Acidification	14%	-57%	-28%	-71%	-93%	-63%
Photo-Oxidant Formation	12%	-25%	-16%	-52%	-78%	-37%
Ozone Depletion Potential	16%	-91%	-30%	-58%	-99%	-94%
Terrestrial Eutrophication	12%	-57%	-20%	-59%	-92%	-41%
Aquatic Eutrophication	19%	-78%	-31%	-57%	-96%	24%
Human Toxicity: PM 2.5	13%	-54%	-23%	-67%	-91%	-55%
Total Primary Energy	23%	-21%	-30%	-74%	-91%	-52%
Non-renewable Primary Energy	31%	45%	-35%	-82%	-70%	-65%

Table 76: Comparison of net results **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

segment DAIRY (chilled), Norway	The net results of **Tetra Rex OSO 34 biobased 1000 mL** are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000 mL	Tetra Rex OSO 34 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	52%	-34%	348%	-76%	-95%	-91%	-92%
Acidification	80%	58%	-32%	13%	-55%	-88%	-41%
Photo-Oxidant Formation	29%	15%	-13%	-4%	-44%	-75%	-27%
Ozone Depletion Potential	540%	450%	-51%	283%	133%	-93%	-69%
Terrestrial Eutrophication	77%	58%	-32%	26%	-34%	-87%	-6%
Aquatic Eutrophication	203%	154%	-43%	75%	9%	-91%	215%
Human Toxicity: PM 2.5	70%	51%	-30%	16%	-51%	-87%	-32%
Total Primary Energy	39%	13%	-11%	-21%	-70%	-90%	-46%
Non-renewable Primary Energy	15%	-12%	28%	-43%	-84%	-73%	-69%

Table 77: Comparison of net results **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

segment DAIRY (chilled), Norway	The net results of **Tetra Rex OSO 34 fully biobased 1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-66%	-78%	-95%	-99%	-98%	-98%
Acidification	165%	47%	67%	-34%	-83%	-13%
Photo-Oxidant Formation	48%	15%	11%	-36%	-71%	-16%
Ozone Depletion Potential	1202%	104%	680%	375%	-86%	-37%
Terrestrial Eutrophication	158%	46%	84%	-4%	-81%	37%
Aquatic Eutrophication	435%	76%	208%	92%	-84%	455%
Human Toxicity: PM 2.5	143%	43%	66%	-30%	-81%	-3%
Total Primary Energy	56%	12%	-11%	-67%	-89%	-39%
Non-renewable Primary Energy	-10%	-22%	-55%	-88%	-79%	-76%

Table 78: Comparison of net results **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

segment DAIRY (chilled), Norway	The net results of **Tetra Top1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex OSO 34 fully biobased 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	540%	322%	1791%	-80%	-63%	-65%
Acidification	59%	-12%	-40%	-60%	-90%	-48%
Photo-Oxidant Formation	34%	4%	-10%	-42%	-74%	-24%
Ozone Depletion Potential	67%	-74%	-87%	-39%	-98%	-92%
Terrestrial Eutrophication	40%	-21%	-46%	-48%	-90%	-26%
Aquatic Eutrophication	73%	-43%	-68%	-38%	-95%	80%
Human Toxicity: PM 2.5	47%	-14%	-40%	-58%	-89%	-41%
Total Primary Energy	75%	26%	12%	-62%	-88%	-31%
Non-renewable Primary Energy	100%	75%	123%	-73%	-53%	-46%

10.2 Results JNSD Norway

10.2.1 Presentation of results JNSD Norway

Figure 98: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 1)

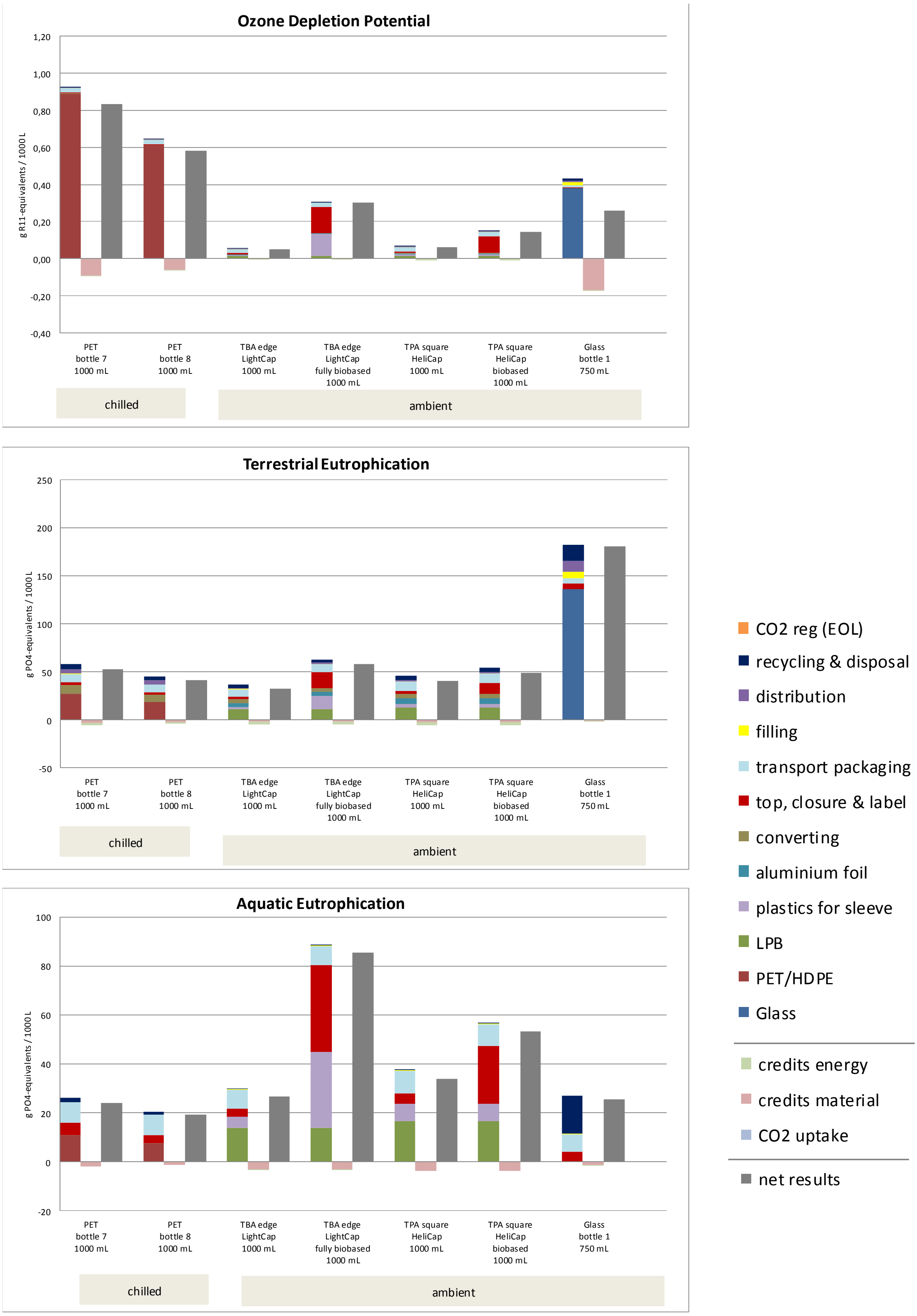


Figure 99: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 2)

Figure 100: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 3)

Figure 101: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 4)

Table 79: Category indicator results per impact category for base scenarios of segment JNSD chilled, Norway- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD chilled Norway, allocation factor 50 %		PET bottle 7 1000 mL	PET bottle 8 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	215.69	163.16
	CO2 (reg)	3.46	3.46
	Credits	-29.29	-21.24
	CO_2 uptake	0.00	0.00
	Net results (∑)	189.86	145.38
Acidification [kg SO_2-equivalents]	Burdens	0.62	0.47
	Credits	-0.07	-0.05
	Net results (∑)	0.55	0.42
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.27	5.47
	Credits	-0.81	-0.59
	Net results (∑)	6.46	4.88
Ozone Depletion [g R-11-equivalents]	Burdens	0.93	0.65
	Credits	-0.10	-0.07
	Net results (∑)	0.83	0.58
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	58.29	45.55
	Credits	-5.75	-4.15
	Net results (∑)	52.54	41.40
Aquatic eutrophication [g PO_4-equivalents]	Burdens	26.02	20.58
	Credits	-1.86	-1.45
	Net results (∑)	24.15	19.13
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.57	0.43
	Credits	-0.06	-0.05
	Net results (∑)	0.50	0.39
Total Primary Energy [GJ]	Burdens	4.70	3.56
	Credits	-0.69	-0.50
	Net results (∑)	4.01	3.06
Non-renewable primary energy [GJ]	Burdens	4.38	3.26
	Credits	-0.63	-0.46
	Net results (∑)	3.75	2.81
Use of Nature [m^2-equivalents*year]	Burdens	1.78	1.77
	Credits	-0.03	-0.03
	Net results (∑)	1.76	1.74
Water use [m^3]	Water cool	2.68	1.92
	Water process	6.59	6.50
	Water unspec	0.09	0.07

Table 80: Category indicator results per impact category for base scenarios of segment JNSD ambient, Norway- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD ambient Norway, allocation factor 50 %		TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square HeliCap 1000 mL	TPA square HeliCap biobased 1000 mL	Glass bottle 1 750 mL
Climate change [kg CO_2-equivalents]	Burdens	89.35	89.05	122.87	120.84	400.71
	CO2 (reg)	18.69	25.00	19.46	22.18	1.27
	Credits	-19.41	-18.07	-26.30	-25.49	-84.68
	CO_2 uptake	-35.55	-52.18	-42.28	-47.73	-6.22
	Net results (∑)	53.08	43.80	73.75	69.79	311.07
Acidification [kg SO_2-equivalents]	Burdens	0.33	0.52	0.43	0.48	1.27
	Credits	-0.05	-0.05	-0.07	-0.07	-0.25
	Net results (∑)	0.28	0.47	0.36	0.42	1.02
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	0.49	5.33	5.72	5.98	23.34
	Credits	-0.05	-0.57	-0.76	-0.75	-3.12
	Net results (∑)	0.44	4.76	4.96	5.23	20.21
Ozone Depletion [g R-11-equivalents]	Burdens	0.06	0.31	0.07	0.15	0.43
	Credits	-0.01	-0.01	-0.01	-0.01	-0.18
	Net results (∑)	0.05	0.30	0.06	0.14	0.26
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	36.98	62.90	46.36	54.72	182.37
	Credits	-4.56	-4.35	-5.84	-5.71	-1.19
	Net results (∑)	32.42	58.55	40.52	49.00	181.18
Aquatic eutrophication [g PO_4-equivalents]	Burdens	29.81	88.57	37.60	56.87	27.06
	Credits	-3.19	-3.19	-3.61	-3.61	-1.38
	Net results (∑)	26.62	85.39	33.99	53.25	25.68
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.32	0.50	0.41	0.47	1.49
	Credits	-0.05	-0.05	-0.06	-0.06	-0.32
	Net results (∑)	0.27	0.45	0.35	0.40	1.17
Total Primary Energy [GJ]	Burdens	2.56	2.86	3.28	3.37	6.36
	Credits	-0.58	-0.55	-0.72	-0.71	-0.97
	Net results (∑)	1.99	2.31	2.55	2.66	5.40
Non-renewable primary energy [GJ]	Burdens	1.68	1.42	2.21	2.13	5.64
	Credits	-0.30	-0.28	-0.41	-0.39	-0.32
	Net results (∑)	1.37	1.14	1.81	1.73	5.33
Use of Nature [m^2-equivalents*year]	Burdens	21.80	29.49	25.95	28.46	1.15
	Credits	-4.52	-4.52	-5.12	-5.12	-0.03
	Net results (∑)	17.29	24.97	20.83	23.34	1.12
Water use [m^3]	Water cool	1.19	0.99	1.60	1.51	0.00
	Water process	2.36	2.50	2.85	2.89	0.00
	Water unspec	0.31	16.70	0.40	5.77	0.00

10.2.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the JNSD segment, in most impact categories one of the biggest parts 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 considerable share of the burdens of the impact categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. It is also significantly relevant regarding ‘Photo-Oxidant Formation’ ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’ and the consumption of ‘Total Primary Energy’ and to a lower extent ‘Non-renewable Primary Energy’.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category ‘Non-renewable Primary Energy’, where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the ‘TBA edge LightCap fully bio-based’ due to the production of bio-based PE.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories ‘Climate

Change', 'Acidification' and 'Particulate Matter' as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the closures are higher for 'TBA edge LightCap fully bio-based' and 'TPA square HeliCap bio-based' than for the beverage cartons with a fossil-based closure in all categories apart from 'Non-renewable Primary Energy'.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sector transport packaging plays a more important role for almost all categories than for the beverage cartons used for the packaging of dairy. This is because the JNSD cartons use one-way secondary packaging (cardboard trays) instead of roll containers.

The sectors filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. Especially for the 'TBA edge LightCap fully bio-based' the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Norway 61% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category Use of Nature. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 JNSD 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 regarded plastic bottles for the JNSD segment are made from PET. The closures of both of them are made from HDPE. For the impact categories 'Climate Change', 'Acidification', 'Photo-Oxidant Formation', 'Ozone Depletion Potential', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Particulate Matter' the burdens from PET production (sector PET/HDPE in the graphs) are the highest single contributor to the overall burdens.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from fossil-based HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the PET bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the recycling rate of PET bottles in Norway is relatively low (22.3%) the amount of bottle waste incinerated is high.

For the regarded plastic bottles a similar amount of energy recovery is given than material credits. The energy credits mainly originate from the incineration plants. The received material credits originate from the substitution of primary plastics due to the recycling of bottles.

Glass bottle

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

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact categories 'Climate Change', 'Aquatic Eutrophication' and 'Use of Nature' 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'.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

10.2.3 Comparison between packaging systems

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

Table 81: Comparison of net results **Tetra Brik Aseptic Edge LightCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Norway**

segment JNSD (ambient), Norway	The net results of **TBA edgeLightCap1000 mL** are lower (green)/ higher (orange) than those of			
	TBA edge LightCap fully biobased 1000 mL	TPA square HeliCap 1000 mL	TPA square HeliCap biobased 1000 mL	Glass bottle 1 750 mL
Climate Change	21%	-28%	-24%	-83%
Acidification	-41%	-21%	-33%	-73%
Photo-Oxidant Formation	-91%	-91%	-92%	-98%
Ozone Depletion Potential	-84%	-19%	-66%	-81%
Terrestrial Eutrophication	-45%	-20%	-34%	-82%
Aquatic Eutrophication	-69%	-22%	-50%	4%
Particulate Matter	-40%	-21%	-32%	-77%
Total Primary Energy	-14%	-22%	-25%	-63%
Non-renewable Primary Energy	20%	-24%	-21%	-74%

Table 82: Comparison of net results **Tetra Brik Aseptic Edge LightCap fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Norway**

segment JNSD (ambient), Norway	The net results of **TBA edge LightCap fully biobased 1000 mL** are lower (green)/ higher (orange) than those of			
	TBA edge LightCap 1000 mL	TPA square HeliCap 1000 mL	TPA square HeliCap biobased 1000 mL	Glass bottle 1 750 mL
Climate Change	-17%	-41%	-37%	-86%
Acidification	68%	32%	13%	-54%
Photo-Oxidant Formation	990%	-4%	-9%	-76%
Ozone Depletion Potential	514%	396%	111%	17%
Terrestrial Eutrophication	81%	45%	19%	-68%
Aquatic Eutrophication	221%	151%	60%	233%
Particulate Matter	65%	31%	12%	-61%
Total Primary Energy	16%	-10%	-13%	-57%
Non-renewable Primary Energy	-17%	-37%	-34%	-79%

Table 83: Comparison of net results **Tetra Prisma Aseptic square HeliCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Norway**

segment JNSD (ambient), Norway	The net results of **TPA square HeliCap 1000 mL** are lower (green)/ higher (orange) than those of			
	TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square HeliCap biobased 1000 mL	Glass bottle 1 750 mL
Climate Change	39%	68%	6%	-76%
Acidification	27%	-24%	-14%	-65%
Photo-Oxidant Formation	1034%	4%	-5%	-75%
Ozone Depletion Potential	24%	-80%	-58%	-76%
Terrestrial Eutrophication	25%	-31%	-17%	-78%
Aquatic Eutrophication	28%	-60%	-36%	32%
Particulate Matter	27%	-23%	-14%	-70%
Total Primary Energy	29%	11%	-4%	-53%
Non-renewable Primary Energy	32%	58%	4%	-66%

Table 84: Comparison of net results **Tetra Prisma Aseptic square HeliCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Norway**

segment JNSD (ambient), Norway	The net results of **TPA squareHeliCap biobased 1000 mL** are lower (green)/ higher (orange) than those of			
	TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square HeliCap 1000 mL	Glass bottle 1 750 mL
Climate Change	31%	59%	-5%	-78%
Acidification	49%	-12%	17%	-59%
Photo-Oxidant Formation	1097%	10%	6%	-74%
Ozone Depletion Potential	191%	-53%	136%	-44%
Terrestrial Eutrophication	51%	-16%	21%	-73%
Aquatic Eutrophication	100%	-38%	57%	107%
Particulate Matter	48%	-11%	16%	-65%
Total Primary Energy	34%	15%	4%	-51%
Non-renewable Primary Energy	26%	52%	-4%	-67%

10.3 Results Grab & Go Norway

10.3.1 Presentation of results Grab & Go Norway

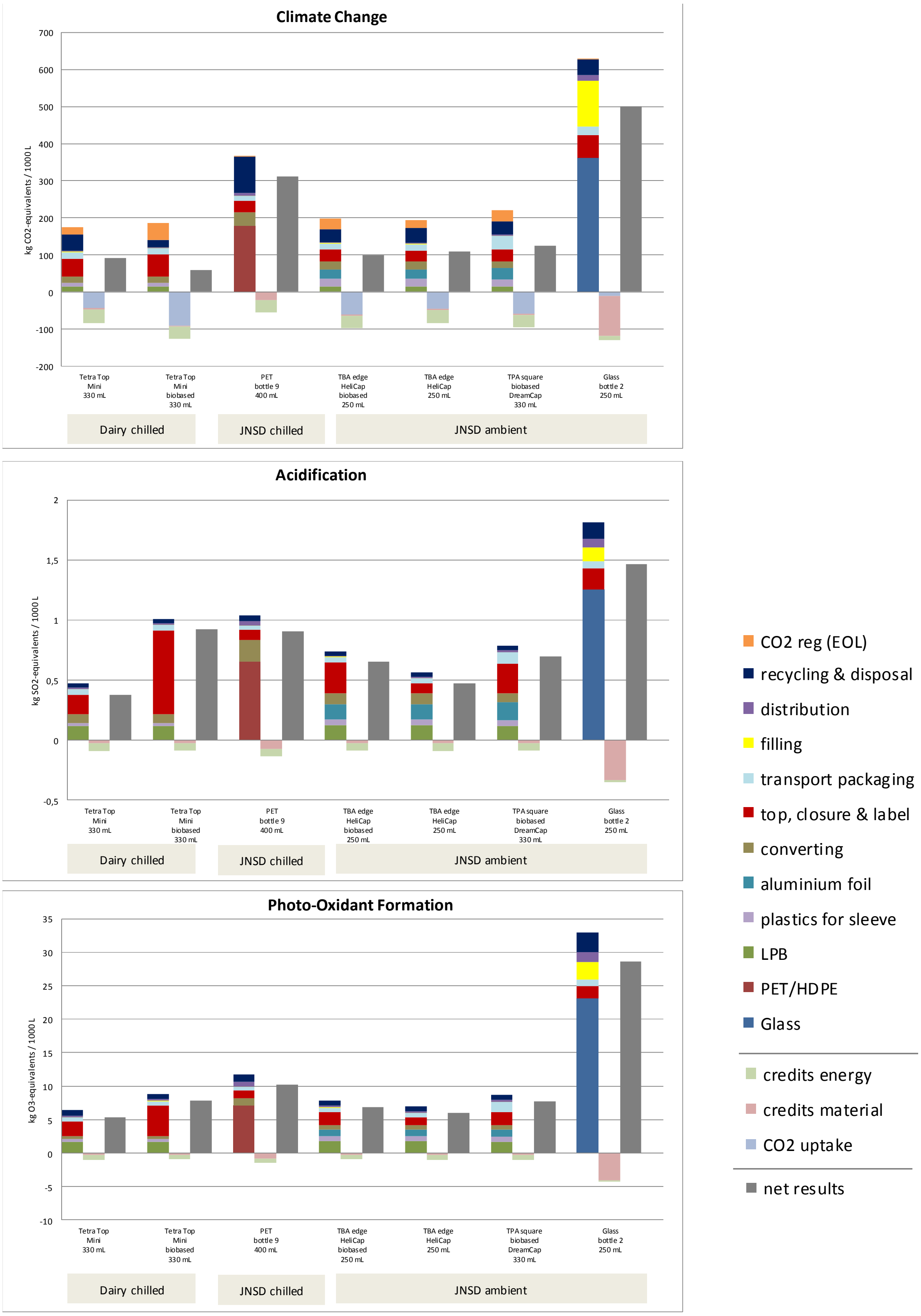


Figure 102: Indicator results for base scenarios of **segment Grab & Go, Norway**, allocation factor 50% (Part 1)

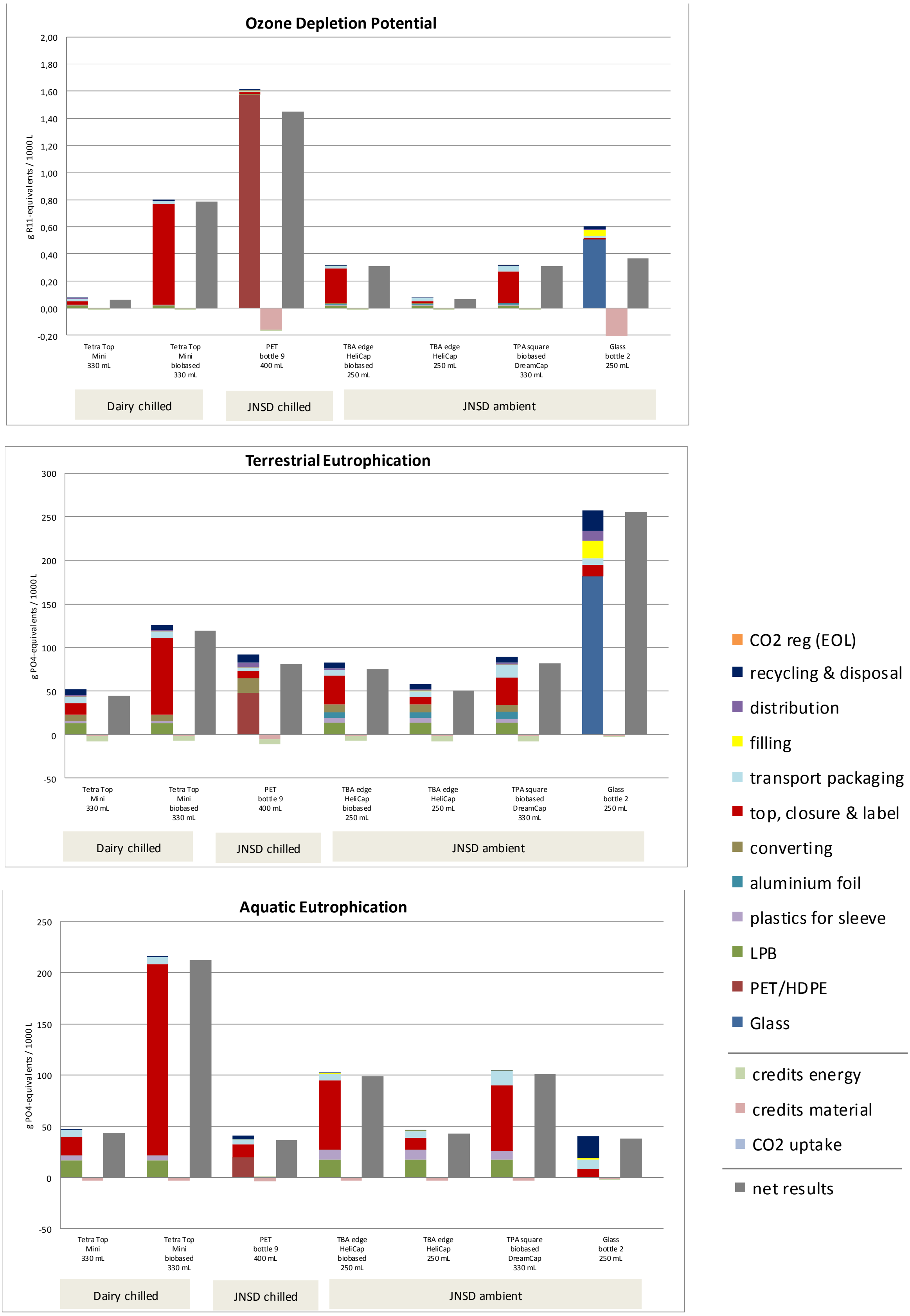


Figure 103: Indicator results for base scenarios of segment Grab & Go, Norway, allocation factor 50% (Part 2)

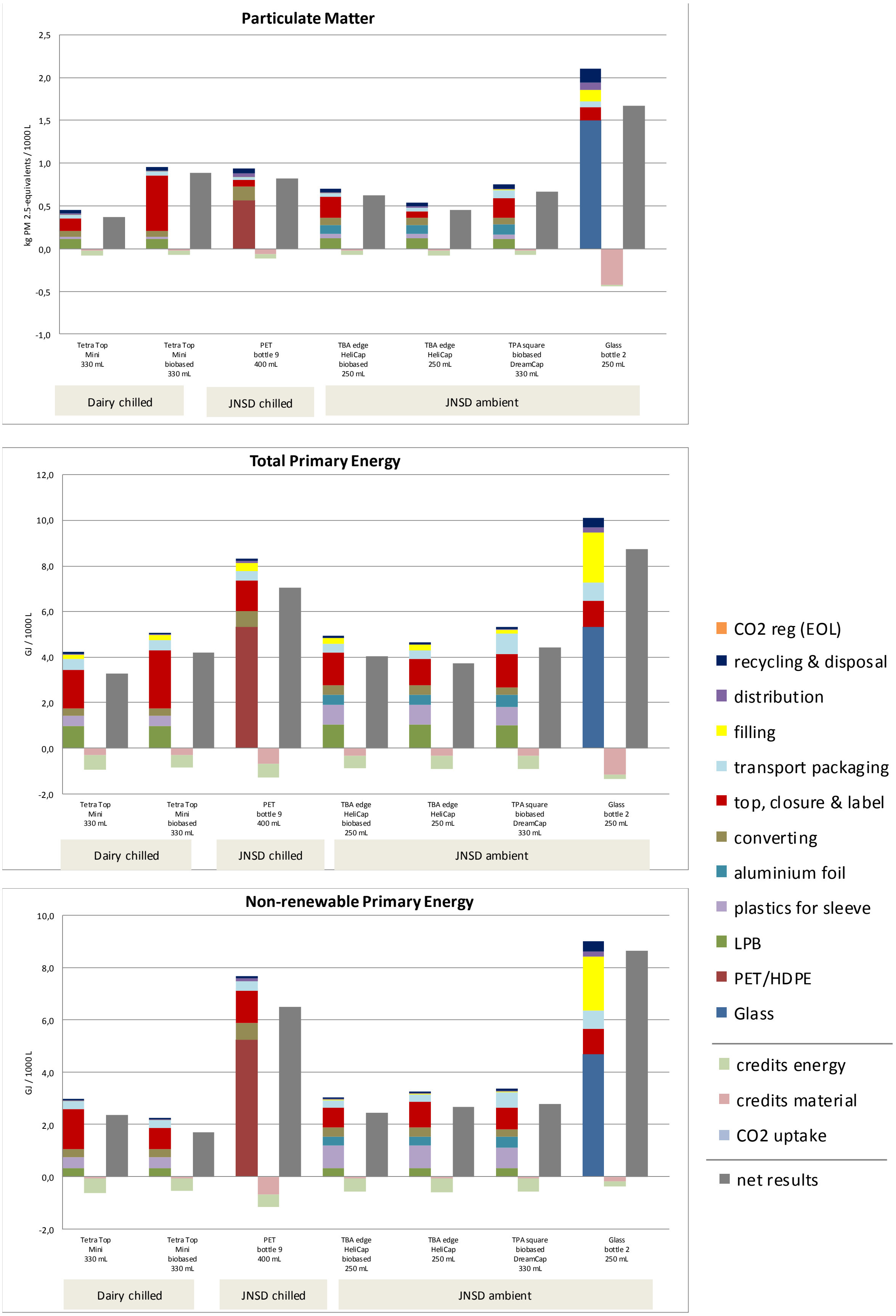


Figure 104: Indicator results for base scenarios of **segment Grab & Go, Norway**, allocation factor 50% (Part 3)

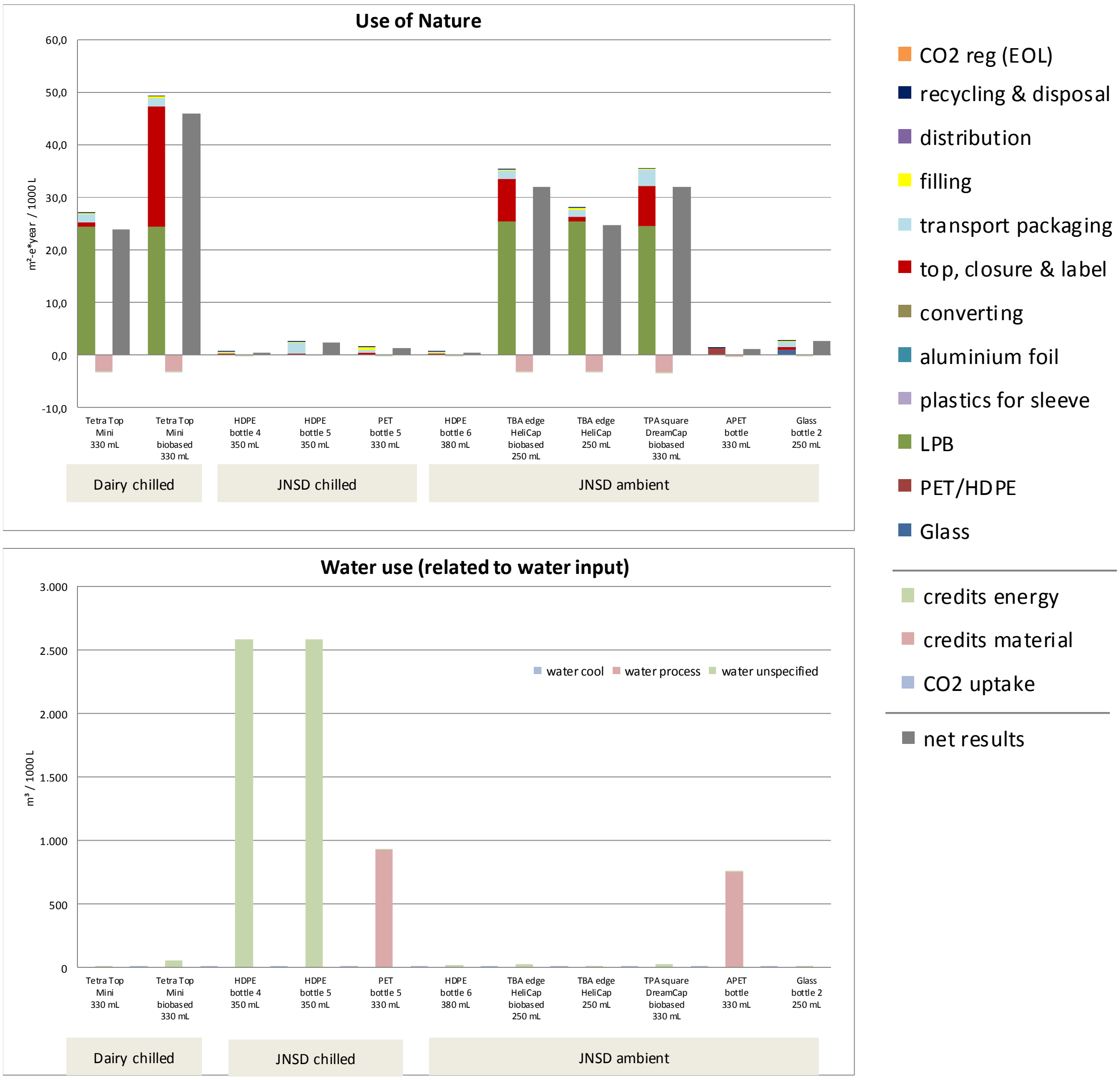


Figure 105: Indicator results for base scenarios of **segment Grab & Go, Norway**, allocation factor 50% (Part 4)

Table 85: Category indicator results per impact category for base scenarios of segment Grab & Go, Dairy chilled, Norway- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, Dairy chilled, JNSD chilled Norway, allocation factor 50 %		Tetra Top Mini 330 mL Dairy chilled	Tetra Top Mini biobased 330 mL Dairy chilled	PET bottle 9 400 mL JNSD chilled
Climate change [kg CO_2-equivalents]	Burdens	155.47	140.73	364.82
	CO2 (reg)	19.99	45.08	1.30
	Credits	-40.50	-36.04	-54.59
	CO_2 uptake	-43.39	-91.25	0.00
	Net results (∑)	91.57	58.53	311.53
Acidification [kg SO_2-equivalents]	Burdens	0.47	1.01	1.04
	Credits	-0.09	-0.08	-0.13
	Net results (∑)	0.38	0.92	0.91
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	6.41	8.80	11.73
	Credits	-1.03	-0.94	-1.51
	Net results (∑)	5.37	7.86	10.22
Ozone Depletion [g R-11-equivalents]	Burdens	0.08	0.80	1.62
	Credits	-0.01	-0.01	-0.17
	Net results (∑)	0.06	0.79	1.45
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	52.09	126.48	91.62
	Credits	-7.86	-7.16	-10.66
	Net results (∑)	44.23	119.32	80.96
Aquatic eutrophication [g PO_4-equivalents]	Burdens	46.90	215.85	40.61
	Credits	-3.28	-3.28	-3.74
	Net results (∑)	43.62	212.57	36.87
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.45	0.96	0.94
	Credits	-0.08	-0.07	-0.12
	Net results (∑)	0.37	0.88	0.82
Total Primary Energy [GJ]	Burdens	4.22	5.07	8.33
	Credits	-0.93	-0.85	-1.29
	Net results (∑)	3.29	4.22	7.04
Non-renewable primary energy [GJ]	Burdens	2.98	2.25	7.68
	Credits	-0.62	-0.56	-1.17
	Net results (∑)	2.36	1.70	6.50
Use of Nature [m^2-equivalents*year]	Burdens	26.57	48.66	0.79
	Credits	-4.50	-4.50	-0.03
	Net results (∑)	22.07	44.16	0.76
Water use [m^3]	Water cool	2.72	2.04	4.72
	Water process	2.66	3.02	1.45
	Water unspec	0.51	47.67	0.23

Table 86: Category indicator results per impact category for base scenarios of **segment Grab & Go, JNSD ambient, Norway**- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go, JNSD ambient Norway, allocation factor 50 %		TBA edge HeliCap biobased 250 mL	TBA edge HeliCap 250 mL	TPA square biobased DreamCap 330 mL	Glass bottle 2 250 mL
Climate change [kg CO_2-equivalents]	Burdens	168.92	173.49	190.39	627.81
	CO2 (reg)	28.40	19.91	29.64	1.87
	Credits	-36.36	-38.70	-37.51	-119.49
	CO_2 uptake	-61.23	-45.36	-58.34	-10.51
	Net results (∑)	99.73	109.35	124.18	499.68
Acidification [kg SO_2-equivalents]	Burdens	0.74	0.56	0.79	1.82
	Credits	-0.09	-0.09	-0.09	-0.35
	Net results (∑)	0.65	0.47	0.70	1.47
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.82	7.01	8.74	32.94
	Credits	-0.95	-1.00	-0.98	-4.28
	Net results (∑)	6.86	6.01	7.76	28.66
Ozone Depletion [g R-11-equivalents]	Burdens	0.32	0.08	0.32	0.60
	Credits	-0.01	-0.01	-0.01	-0.24
	Net results (∑)	0.31	0.07	0.31	0.37
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	82.52	57.90	89.30	257.23
	Credits	-7.28	-7.64	-7.48	-1.83
	Net results (∑)	75.24	50.26	81.82	255.40
Aquatic eutrophication [g PO_4-equivalents]	Burdens	102.31	46.18	104.58	39.87
	Credits	-3.41	-3.41	-3.44	-1.95
	Net results (∑)	98.90	42.78	101.13	37.92
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.70	0.53	0.75	2.10
	Credits	-0.08	-0.08	-0.08	-0.44
	Net results (∑)	0.63	0.46	0.67	1.67
Total Primary Energy [GJ]	Burdens	4.93	4.64	5.31	10.11
	Credits	-0.87	-0.91	-0.89	-1.36
	Net results (∑)	4.06	3.73	4.42	8.74
Non-renewable primary energy [GJ]	Burdens	3.02	3.26	3.36	9.03
	Credits	-0.56	-0.60	-0.58	-0.38
	Net results (∑)	2.46	2.66	2.78	8.65
Use of Nature [m^2-equivalents*year]	Burdens	34.76	27.43	34.97	1.69
	Credits	-4.69	-4.69	-4.75	-0.03
	Net results (∑)	30.07	22.75	30.22	1.66
Water use [m^3]	Water cool	1.95	2.14	2.01	0.58
	Water process	3.39	3.27	3.57	1.27
	Water unspec	16.22	0.57	14.84	0.13

10.3.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the Grab & Go segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories 'Aquatic Eutrophication' and 'Use of Nature'. It is also relevant regarding 'Photo-Oxidant Formation' 'Acidification', 'Terrestrial Eutrophication', 'Particulate Matter' and the consumption of 'Total Primary Energy' and 'Non-renewable Primary Energy'.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category 'Non-renewable Primary Energy', where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories 'Climate Change', 'Acidification' and 'Particulate Matter' as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the top and closures is higher for the two Tetra Top packaging systems than for the TBA edge and TBA square cartons as more plastic is used for the top element of those packaging systems.

Especially if bio-based plastics are used for top and/or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category for most packaging systems.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. A share of the greenhouse gases is generated from the energy production required in the respective recycling and disposal processes. When the packaging materials are incinerated in MSWI facilities, this also leads to GHG emissions. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. For the 'Tetra Top Mini bio-based' the CO2 reg (EOL) emissions are significantly higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Norway 61% of used beverage cartons are recycled, the credits given for the substitution of primary paper production are low apart from the category Use of Nature. This is due the relatively low burdens of paper production and the application of the allocation factor of 50%.The energy credits arise from incineration plants, where energy recovery takes place.

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

In the regarded plastic bottle system in the Grab & Go segment, the biggest part of the environmental burdens is also caused by the production of the base materials of the bottle in most impact and inventory categories. An exception is 'Use of Nature'.

A distinct share of the eutrophying emissions in the PET inventory dataset originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the plastic bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the overall Norwegian incineration rate of PET bottles is 73.8% the amount of bottle waste incinerated is very high.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants.

Glass bottle

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

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact category 'Climate Change', the sector top, closure & label 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'.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

10.3.3 Comparison between packaging systems

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

DAIRY chilled

Table 87: Comparison of net results **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, DAIRY, chilled, Norway**

segment Grab & Go DAIRY chilled, Norway	The net results of **Tetra Top Mini 330 mL** are lower (green)/ higher (orange) than those of
	Tetra Top Mini biobased 330 mL
Climate Change	56%
Acidification	-59%
Summer Smog	-32%
Ozone Depletion Potential	-92%
Terrestrial Eutrophication	-63%
Aquatic Eutrophication	-79%
Human Toxicity: PM 2.5	-58%
Total Primary Energy	-22%
Non-renewable Primary Energy	39%

JNSD ambient

Table 88: Comparison of net results **Tetra Brik Aseptic Edge HeliCap 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Norway**

segment Grab & Go JNSD ambient, Norway	The net results of **TBA edge HeliCap 250 mL** are lower (green)/ higher (orange) than those of		
	TBA edge HeliCap biobased 250 mL	TPA square biobased DreamCap 330 mL	Glass bottle 2 250 mL
Climate Change	10%	-12%	-78%
Acidification	-27%	-32%	-68%
Photo-Oxidant Formation	-12%	-23%	-79%
Ozone Depletion Potential	-78%	-78%	-82%
Terrestrial Eutrophication	-33%	-39%	-80%
Aquatic Eutrophication	-57%	-58%	13%
Particulate Matter	-27%	-32%	-73%
Total Primary Energy	-8%	-16%	-57%
Non-renewable Primary Energy	8%	-4%	-69%

Table 89: Comparison of net results **Tetra Brik Aseptic Edge HeliCap biobased 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Norway**

segment Grab & Go JNSD ambient, Norway	The net results of **TBA edge HeliCap biobased 250 mL** are lower (green)/ higher (orange) than those of		
	TBA edge HeliCap 250 mL	TPA square biobased DreamCap 330 mL	Glass bottle 2 250 mL
Climate Change	-9%	-20%	-80%
Acidification	38%	-6%	-55%
Photo-Oxidant Formation	14%	-12%	-76%
Ozone Depletion Potential	359%	-1%	-16%
Terrestrial Eutrophication	50%	-8%	-71%
Aquatic Eutrophication	131%	-2%	161%
Particulate Matter	37%	-7%	-62%
Total Primary Energy	9%	-8%	-54%
Non-renewable Primary Energy	-8%	-12%	-72%

Table 90: Comparison of net results **Tetra Prisma Aseptic Square DreamCap 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Norway**

segment Grab & Go JNSD ambient, Norway	The net results of **TPA square biobased DreamCap 330 mL** are lower (green)/ higher (orange) than those of		
	TBA edge HeliCap biobased 250 mL	TBA edge HeliCap 250 mL	Glass bottle 2 250 mL
Climate Change	25%	14%	-75%
Acidification	7%	47%	-52%
Photo-Oxidant Formation	13%	29%	-73%
Ozone Depletion Potential	1%	363%	-16%
Terrestrial Eutrophication	9%	63%	-68%
Aquatic Eutrophication	2%	136%	167%
Particulate Matter	7%	47%	-60%
Total Primary Energy	9%	18%	-49%
Non-renewable Primary Energy	13%	4%	-68%

11 Sensitivity Analyses Norway

11.1 DAIRY

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 subjective 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%.

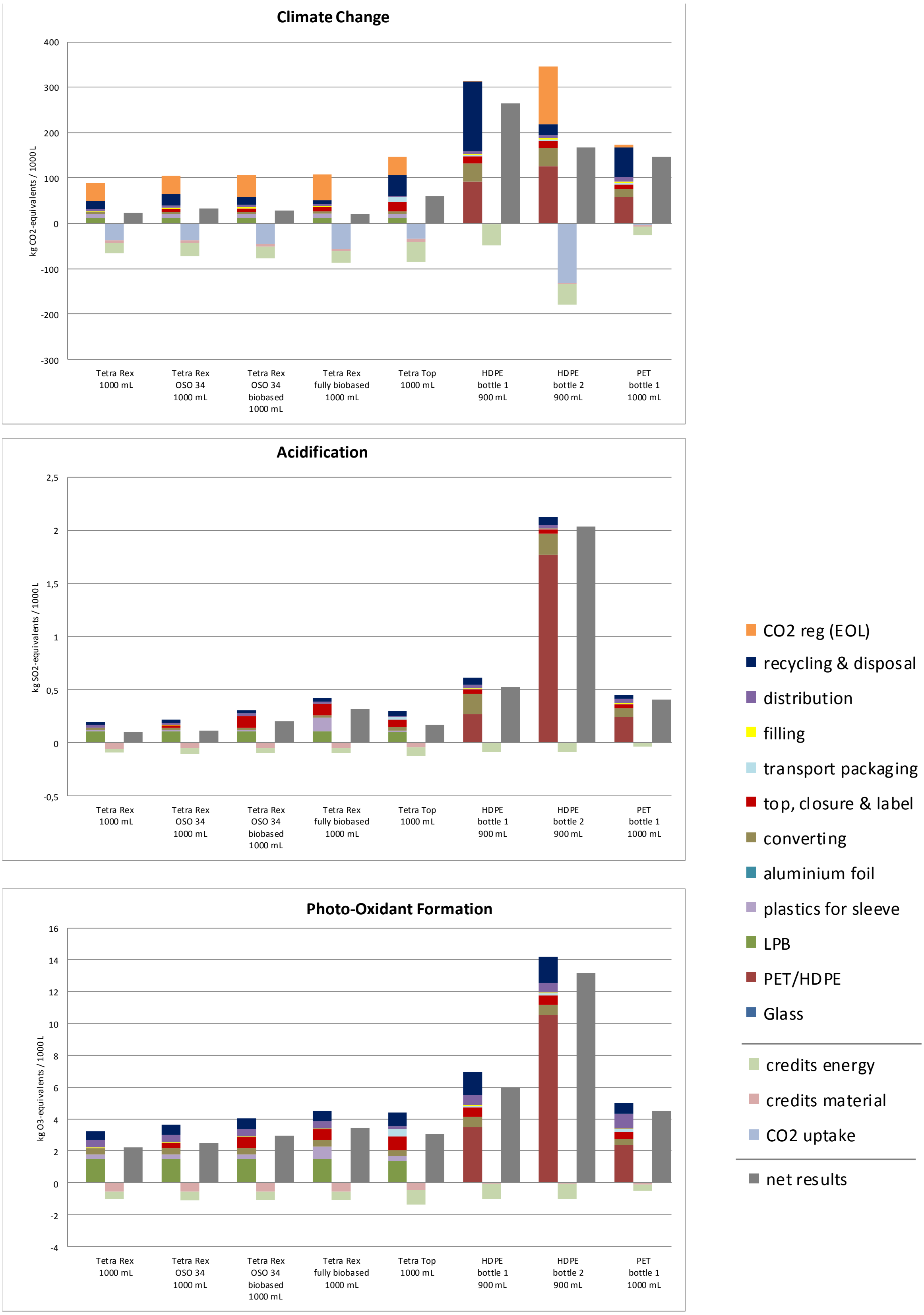


Figure 106: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Norway**, allocation factor 100% (Part 1)

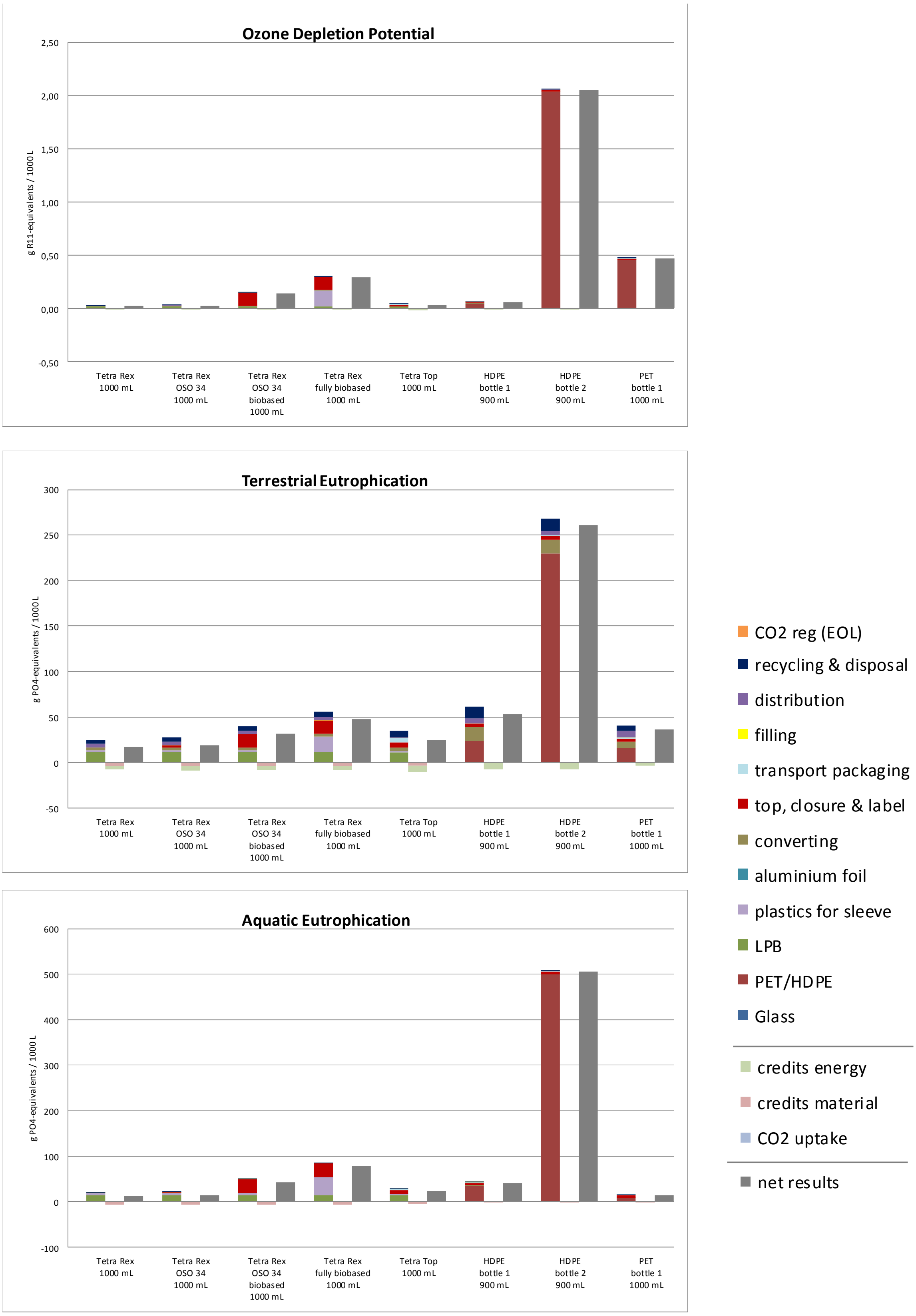


Figure 107: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Norway, allocation factor 100% (Part 2)

Figure 108: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Norway**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all systems examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the application of an allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Norwegian market the electricity credited is the Norwegian grid mix with its relatively low share of fossil energy sources.

11.1.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

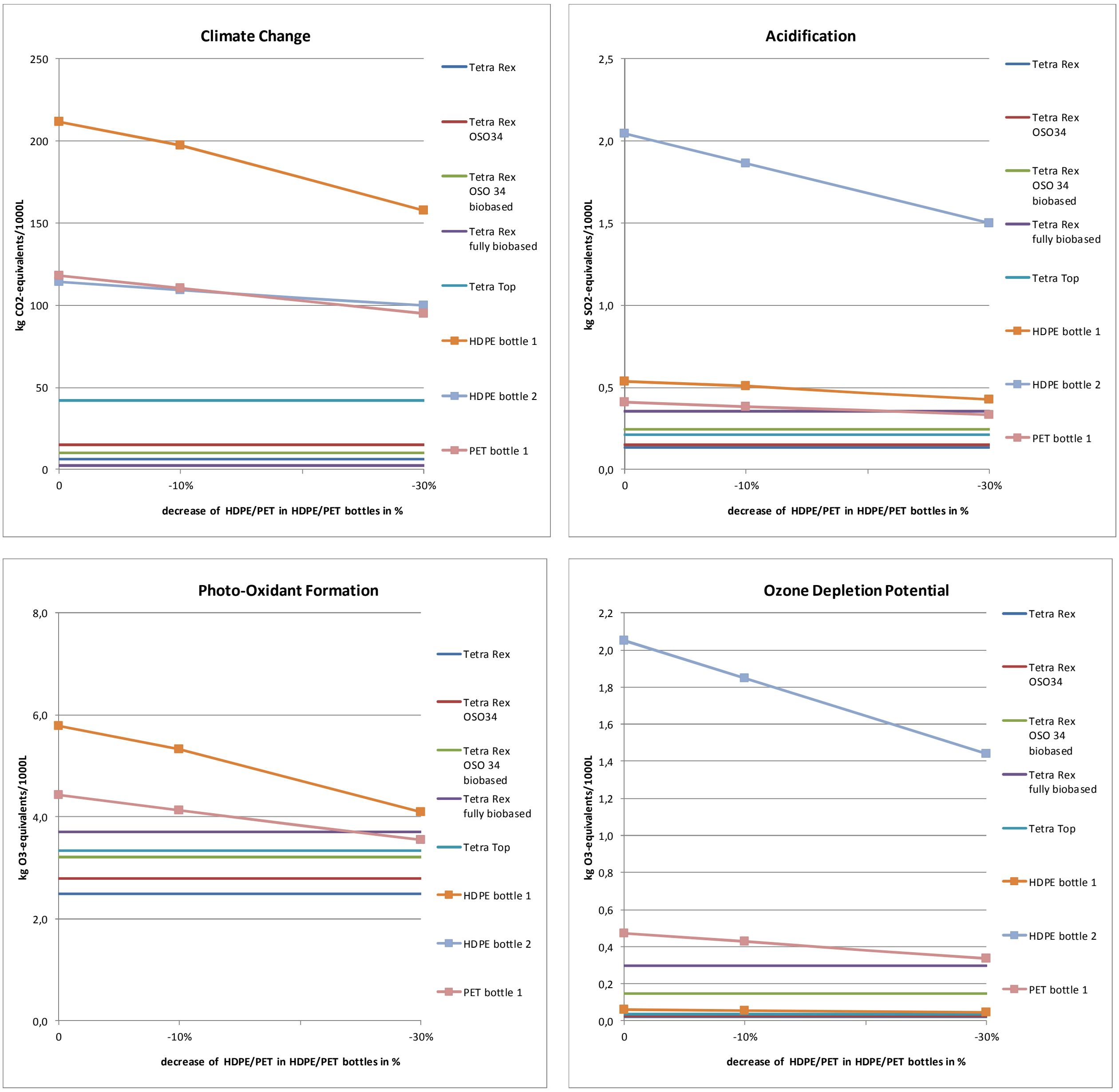


Figure 109: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Norway, allocation factor 50% (Part 1)

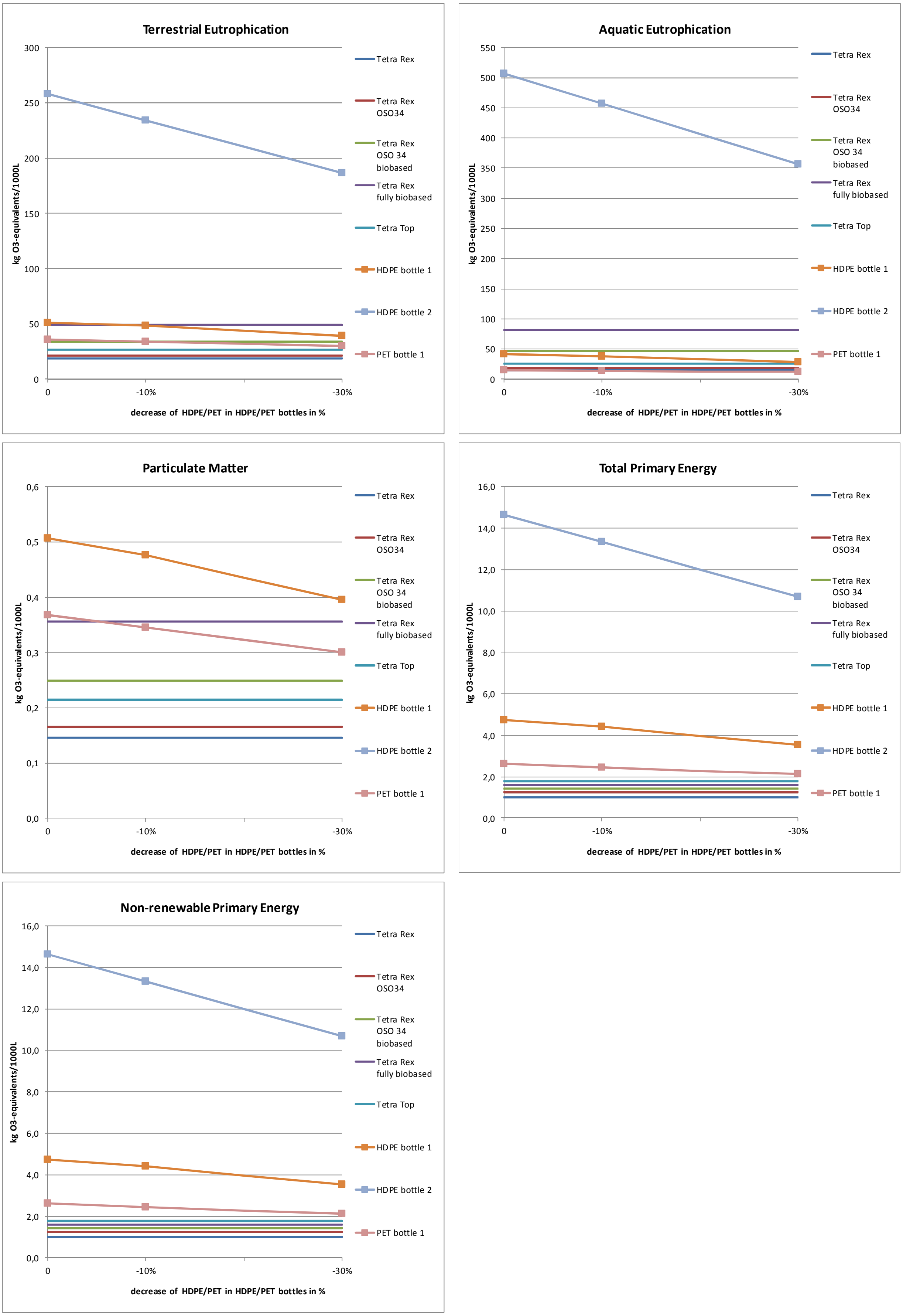


Figure 110: Indicator results for sensitivity analysis on plastic bottle weights of **segment DAIRY, Norway**, allocation factor 50% (Part 2)

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In most cases though, even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of beverage cartons is met.

A lightweight 'HDPE bottle 1' shows a lower result than the 'Tetra Rex fully bio-based' in the categories 'Terrestrial Eutrophication' from a break-even point of around 5% weight reduction. It also breaks even with 'Tetra Top' in the category 'Aquatic Eutrophication' at about 30% weight reduction.

A lightweight 'HDPE bottle 2' would never achieve lower results than any of the beverage cartons in any impact category even with a weight reduction of 30%.

A lightweight version of the 'PET bottle 1' reaches break-even with 'Tetra Rex fully bio-based' in the categories 'Acidification' (at ca. 20%), 'Photo-Oxidant Formation (at ca. 25%) and 'Particulate Matter' at about 5% weight reduction. It also breaks even with "Tetra Rex OSO bio-based' in 'terrestrial Eutrophication' at about 10% weight reduction.

For the impact category 'Climate Change' and in the inventory categories related to primary energy demand none of the lightweight bottles achieves lower results than any of the beverage cartons.

11.1.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

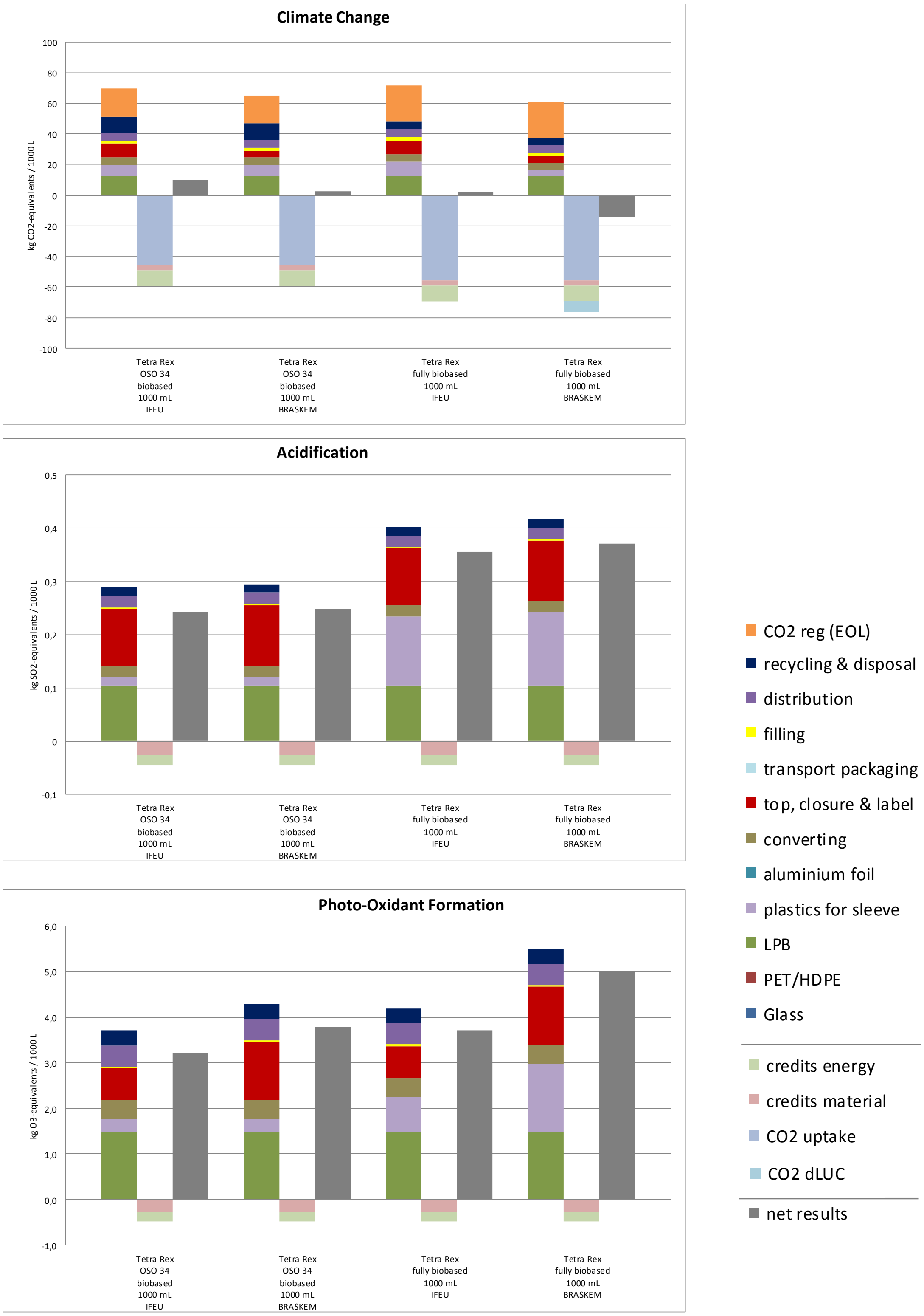


Figure 111: Indicator results for sensitivity analysis on Bio-PE of **segment DAIRY, Norway**, allocation factor 50% (Part 1)

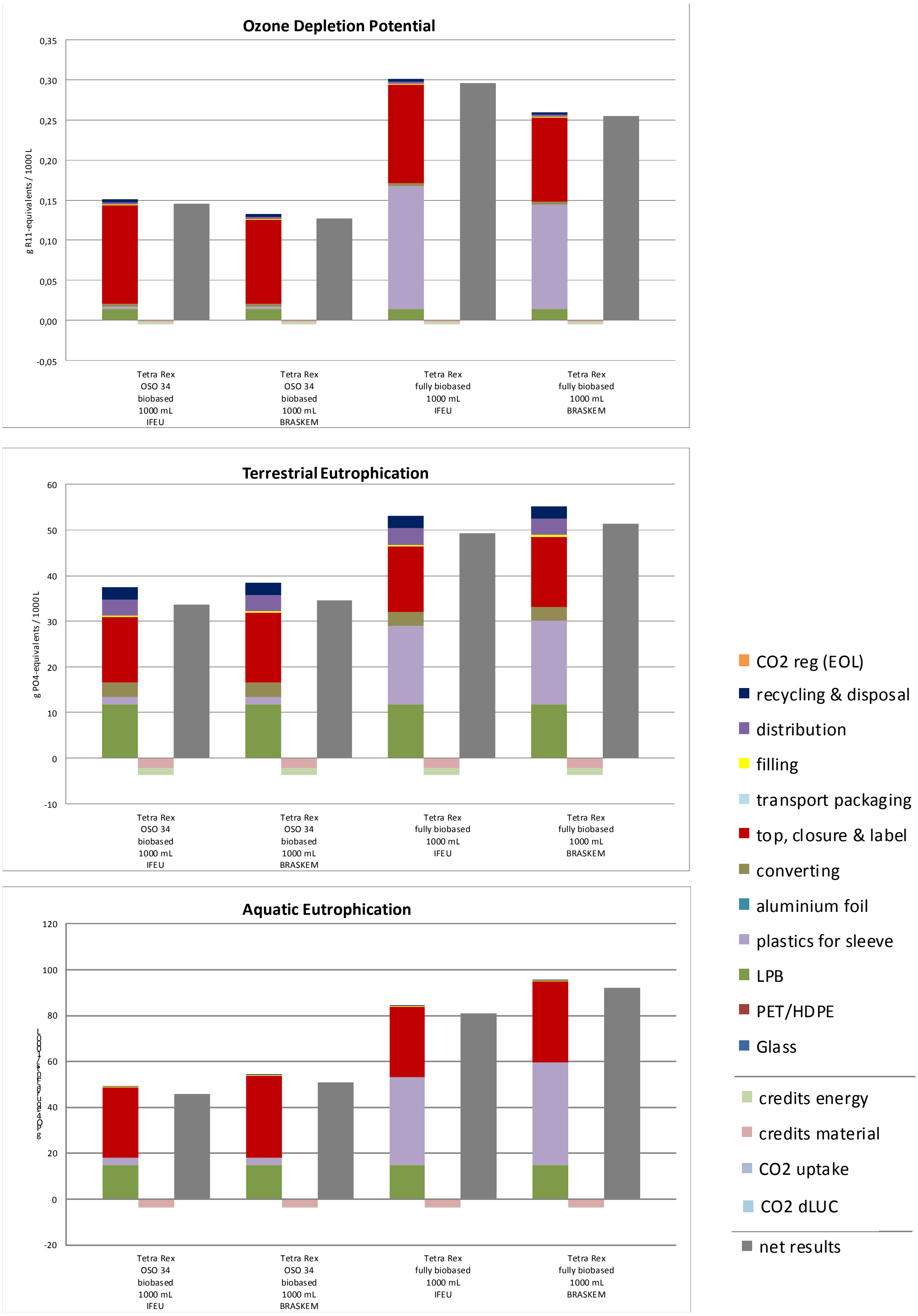


Figure 112: Indicator results for sensitivity analysis on Bio-PE of segment DAIRY, Norway, allocation factor 50% (Part 2)

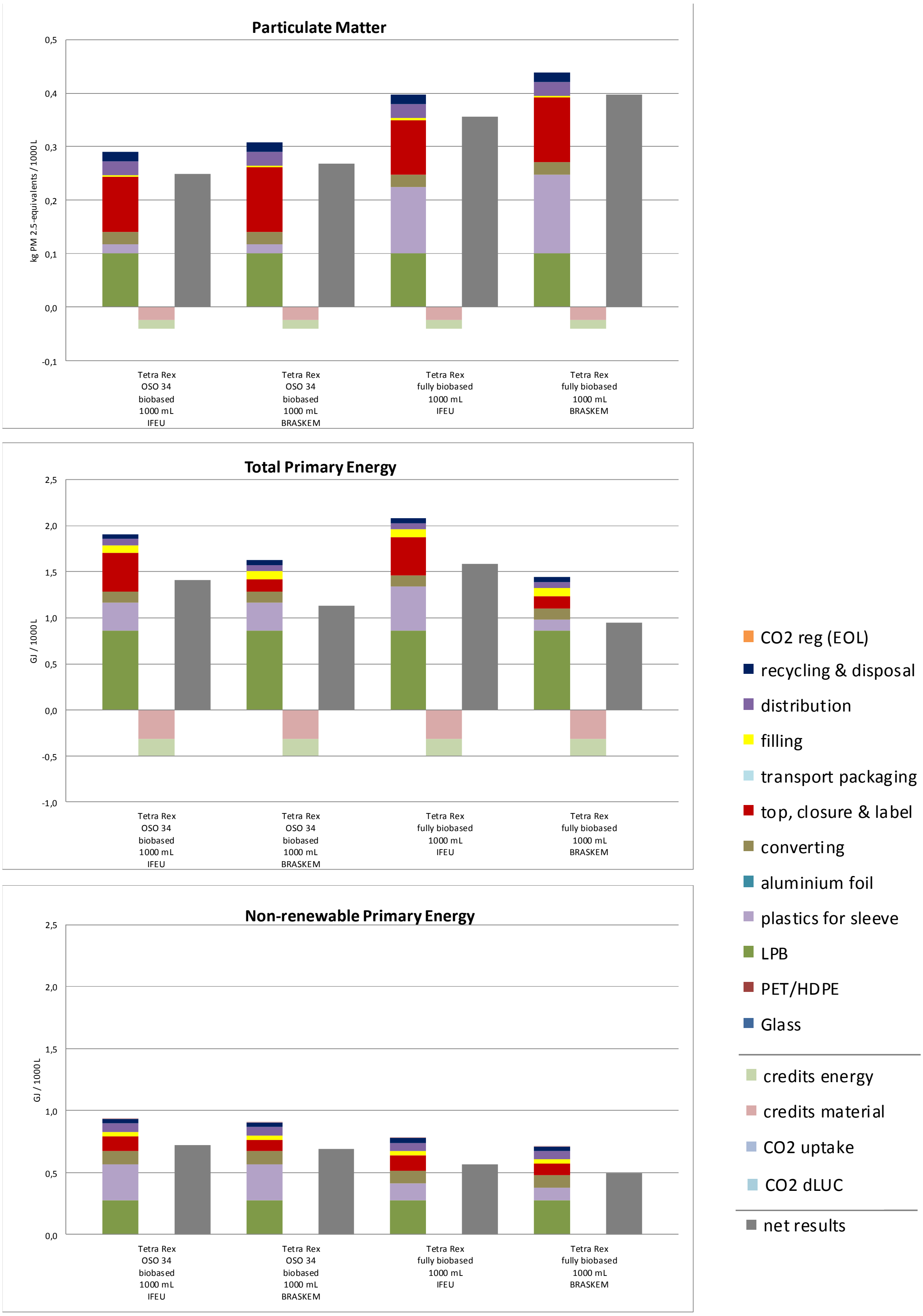


Figure 113: Indicator results for sensitivity analysis on Bio-PE of **segment DAIRY, Norway**, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the Tetra Rex cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category ‘Climate Change’ the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category ‘Photo-Oxidant Formation’.

The main reason for the lower’ Climate Change’ result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of dairy packaging on the Norwegian market. It is relevant though for the environmental impact categories ‘Climate Change’ and Photo-Oxidant Formation’.

11.2 JNSD

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 subjective 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%.

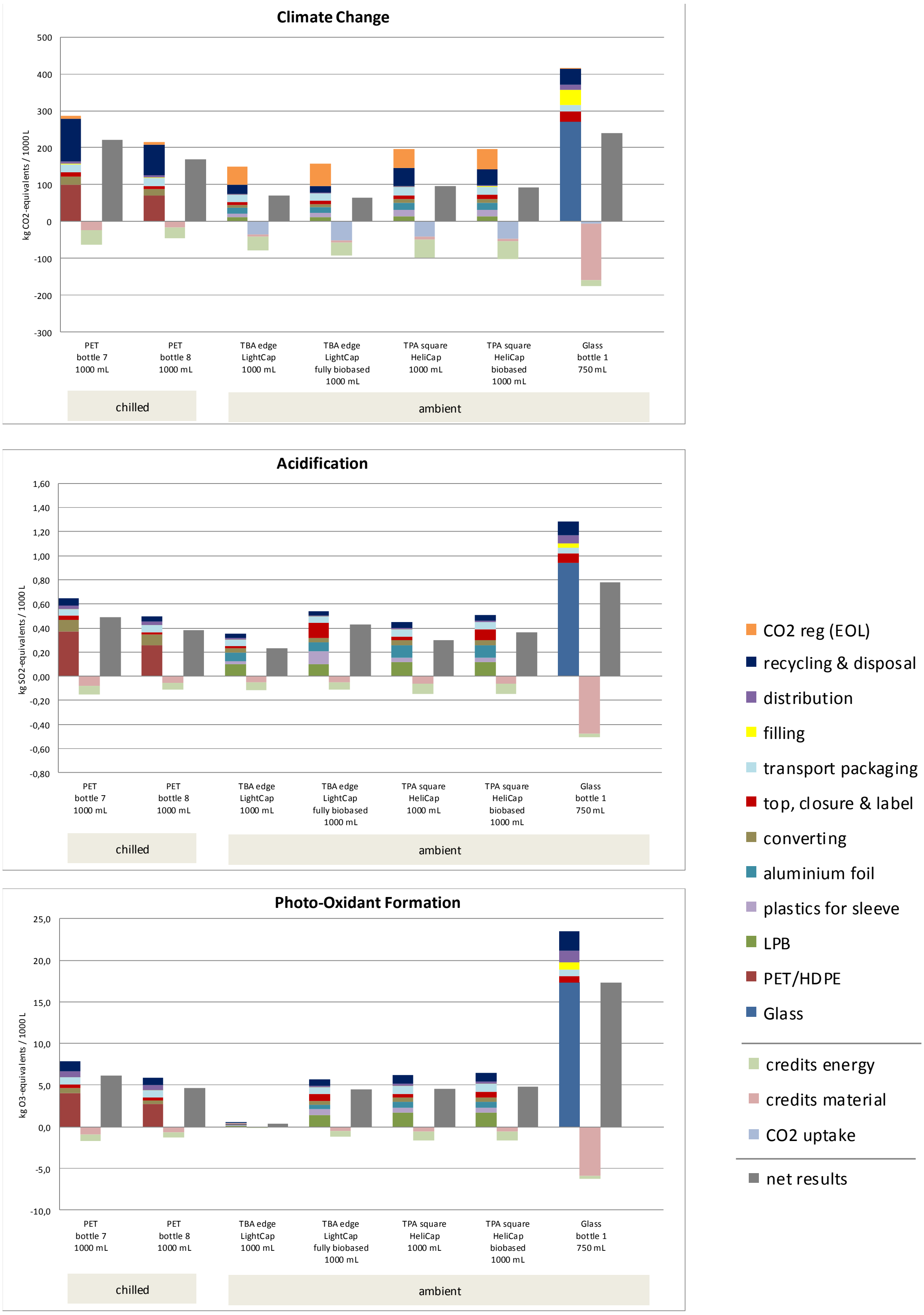


Figure 114: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Norway**, allocation factor 100% (Part 1)

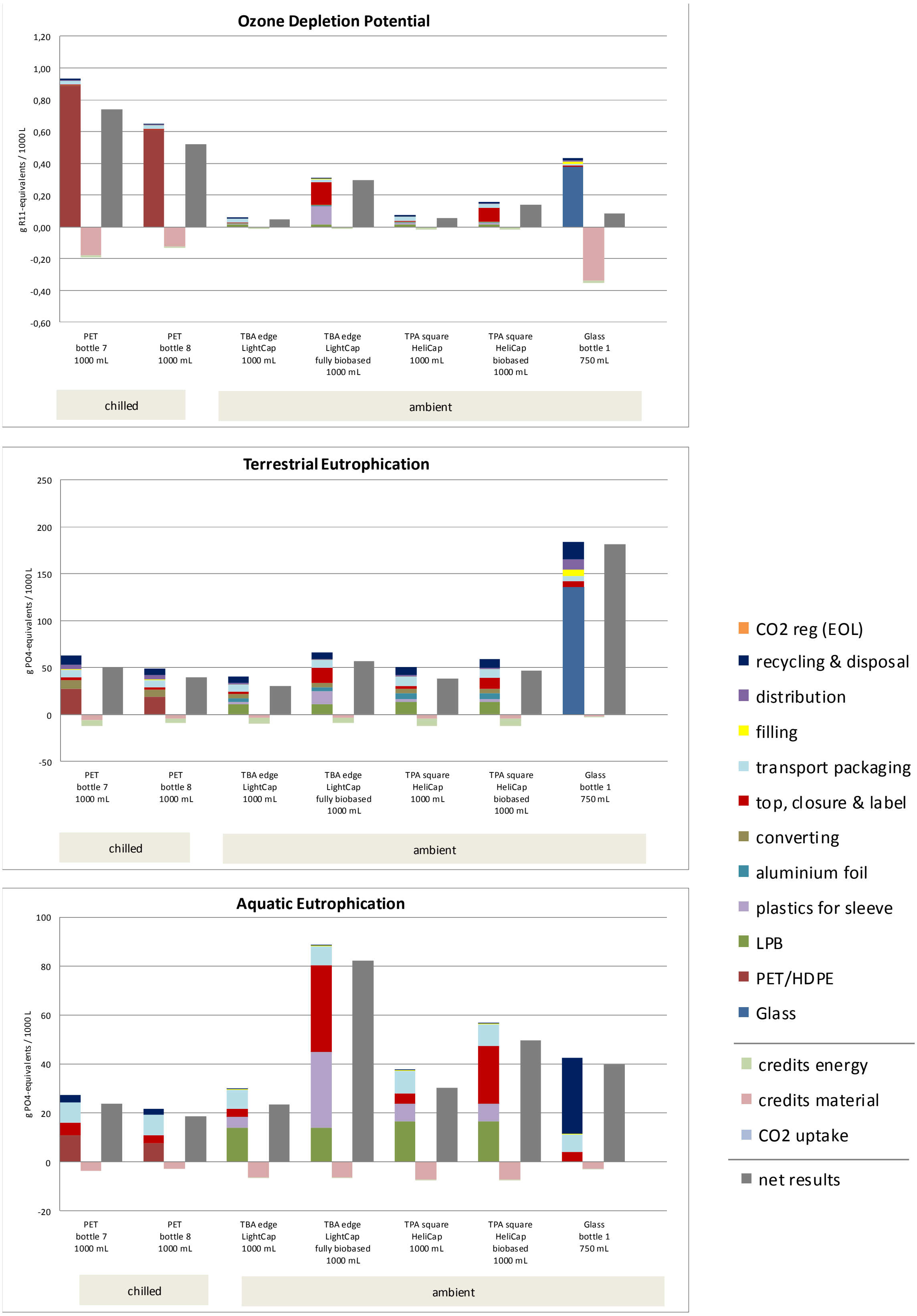


Figure 115: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Norway**, allocation factor 100% (Part 2)

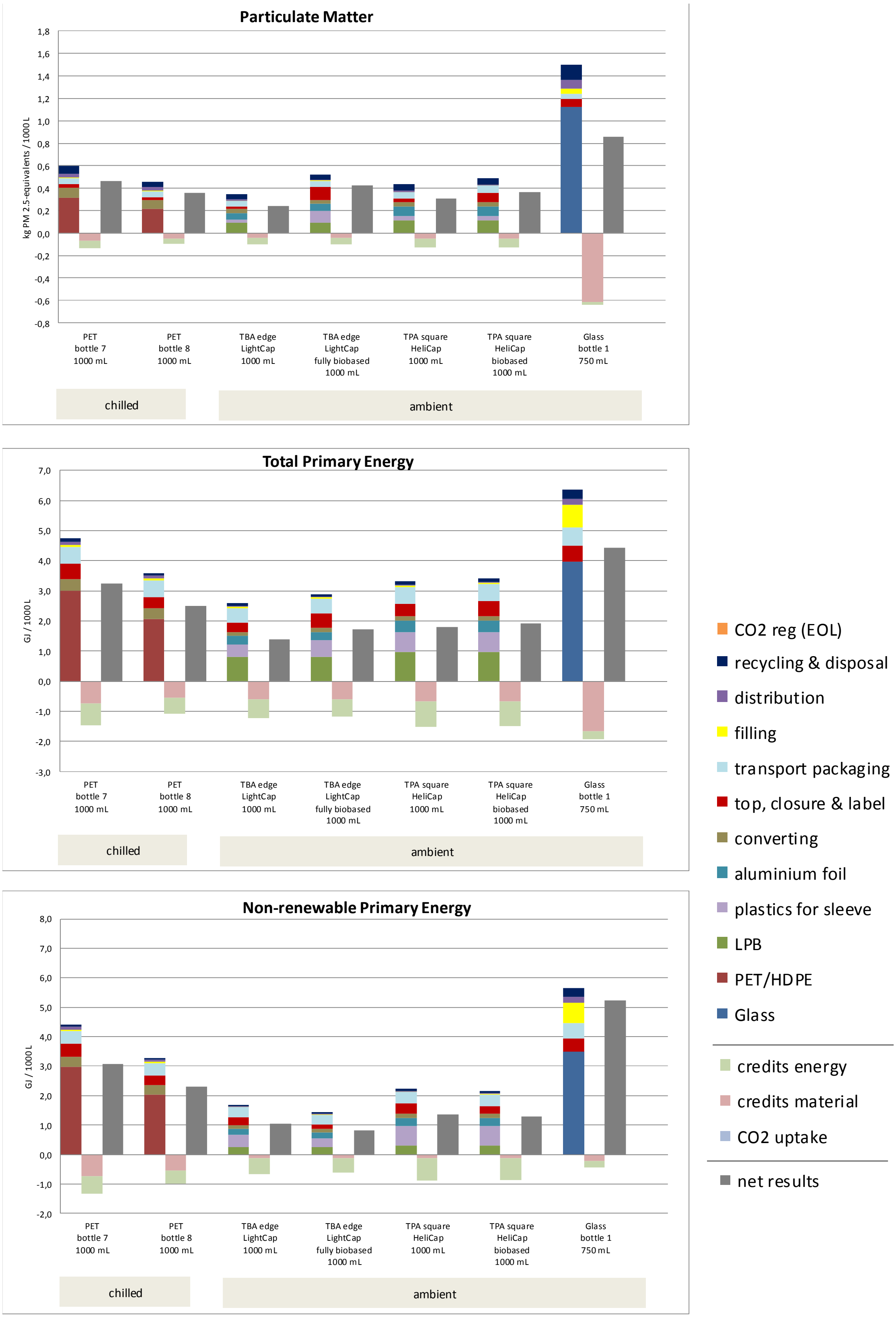


Figure 116: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Norway**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Norwegian market the electricity credited is the Norwegian grid mix with its relatively low share of fossil energy sources.

11.2.2 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

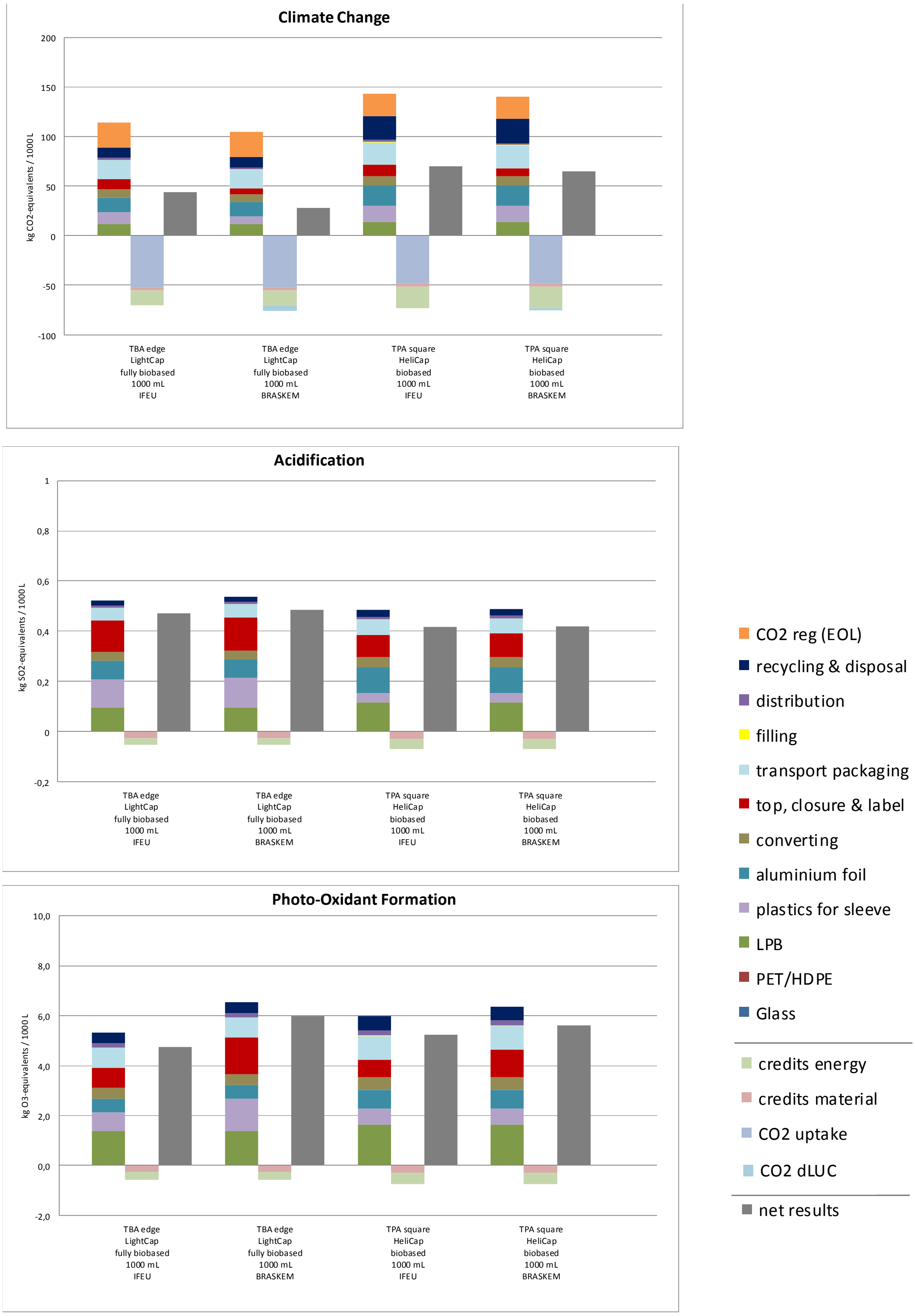


Figure 117: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Norway**, allocation factor 50% (Part 1)

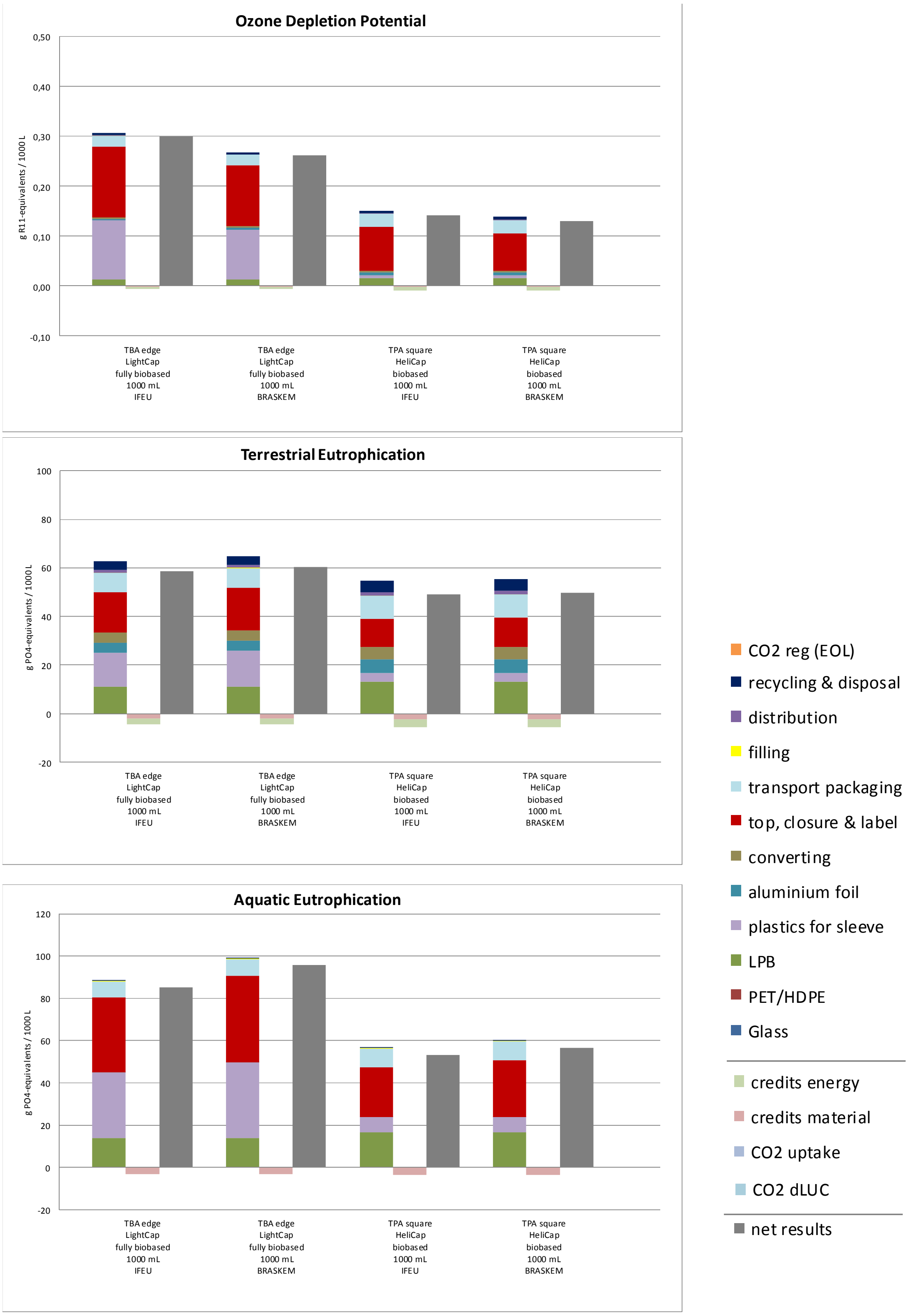


Figure 118: Indicator results for sensitivity analysis on Bio-PE of **segment JNSD, Norway**, allocation factor 50% (Part 2)

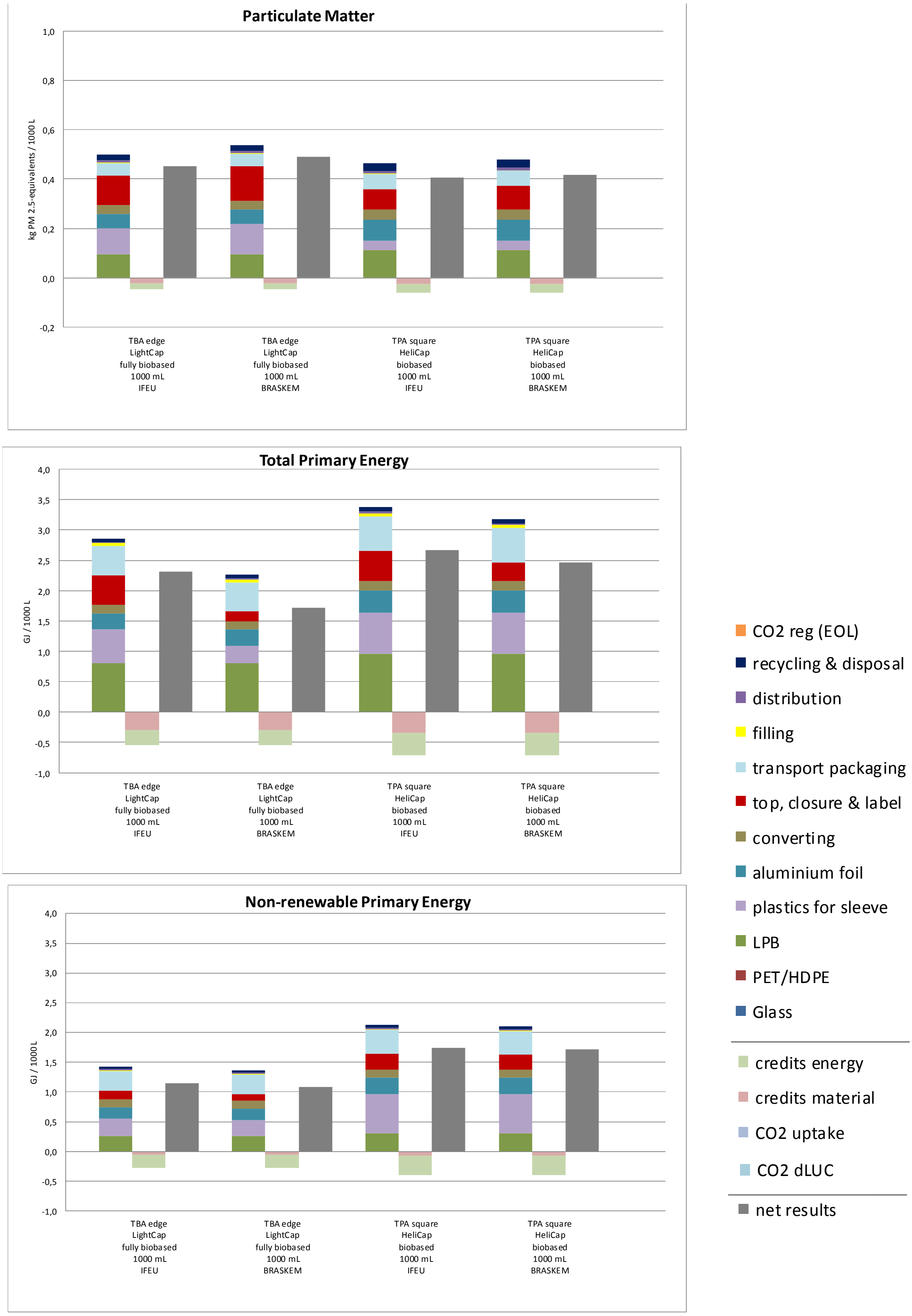


Figure 119: Indicator results for sensitivity analysis on Bio-PE of segment JNSD, Norway, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the TBA edge and TPA square cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower 'Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of JNSD packaging on the Norwegian market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

11.3 Grab & Go

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 subjective 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%.

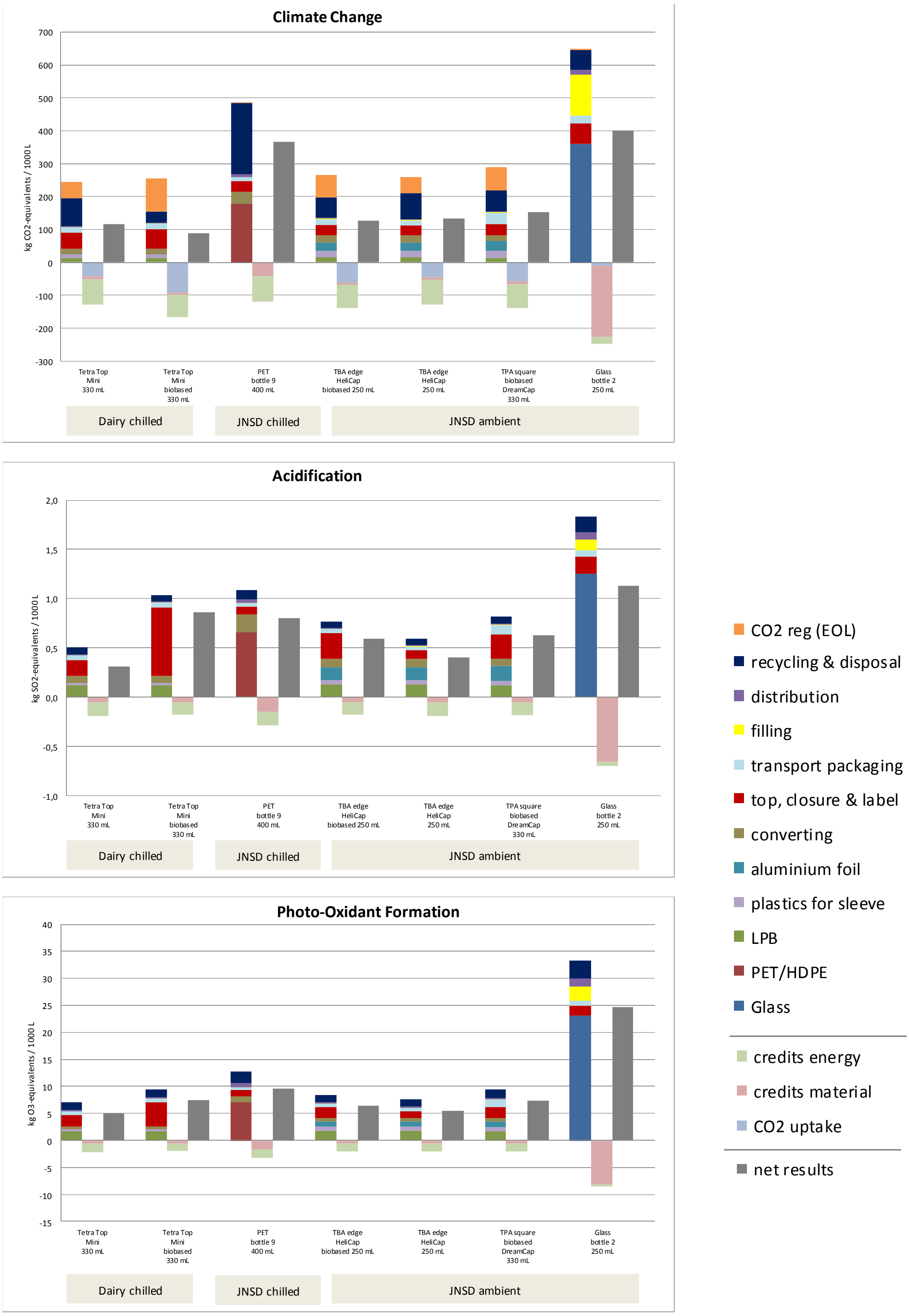


Figure 120: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Norway**, allocation factor 100% (Part 1)

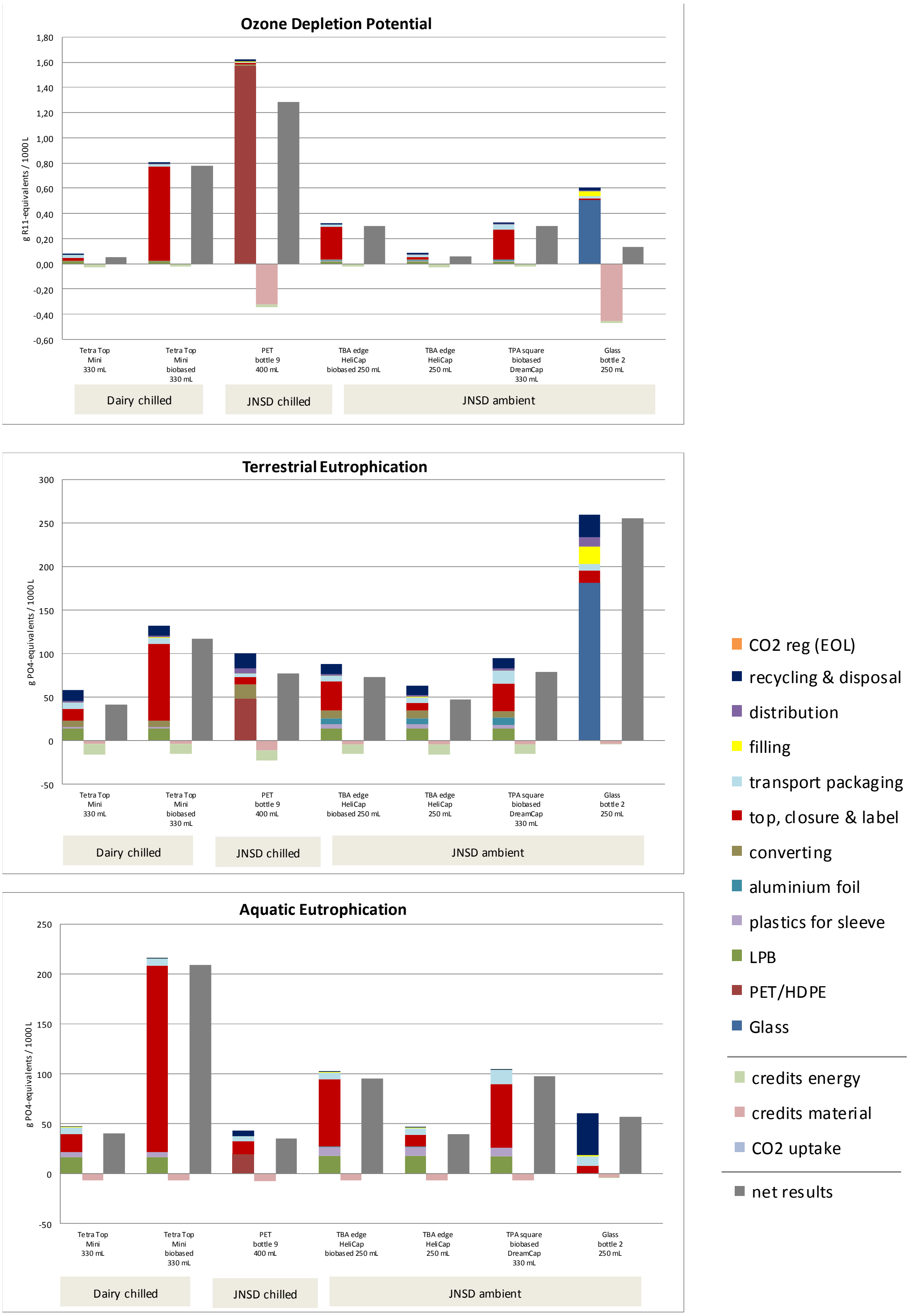


Figure 121: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Norway**, allocation factor 100% (Part 2)

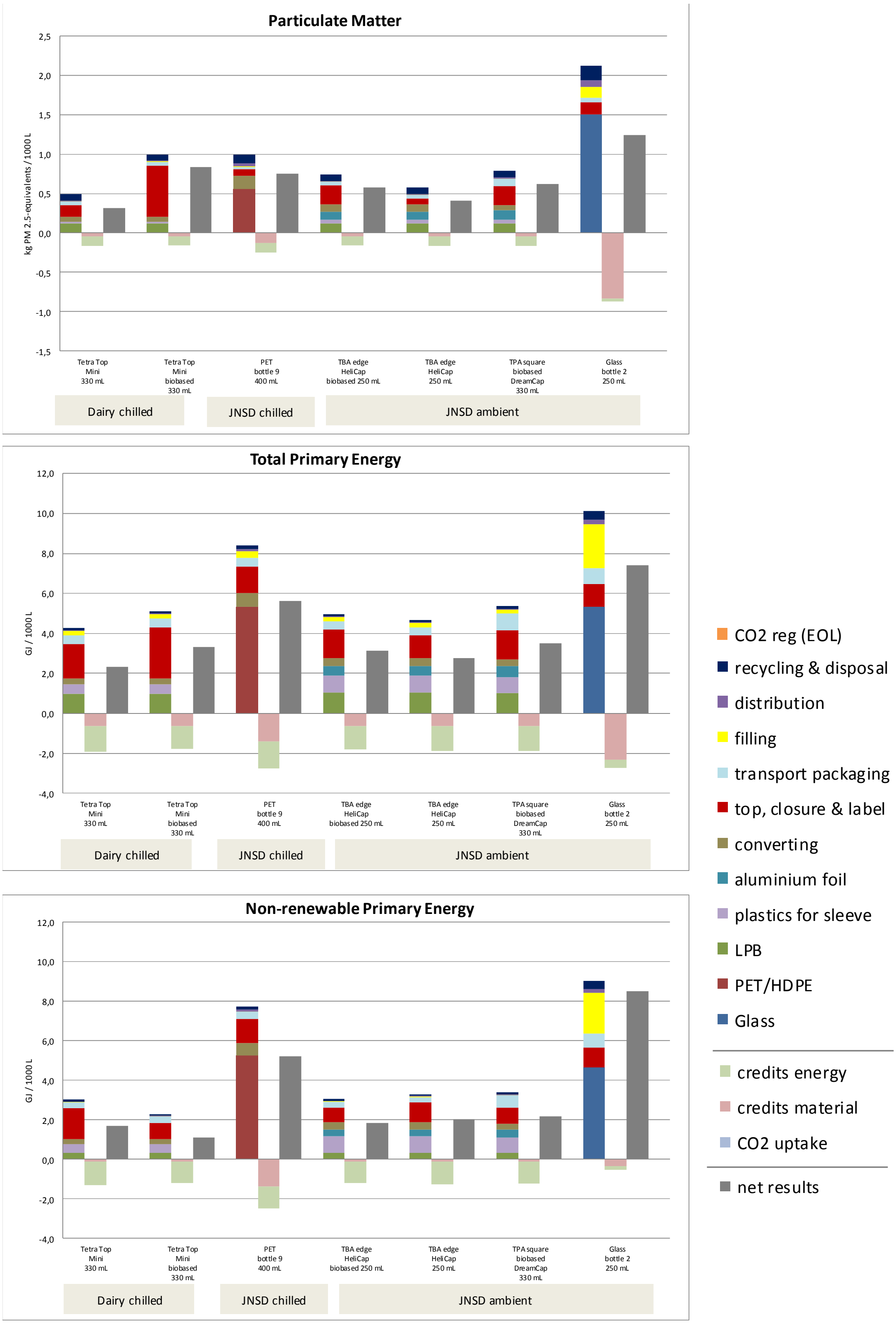


Figure 122: Indicator results for sensitivity analysis on system allocation of **segment JNSD, Norway**, allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Norwegian market the electricity credited is the Norwegian grid mix with its relatively low share of fossil energy sources.

11.3.2 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

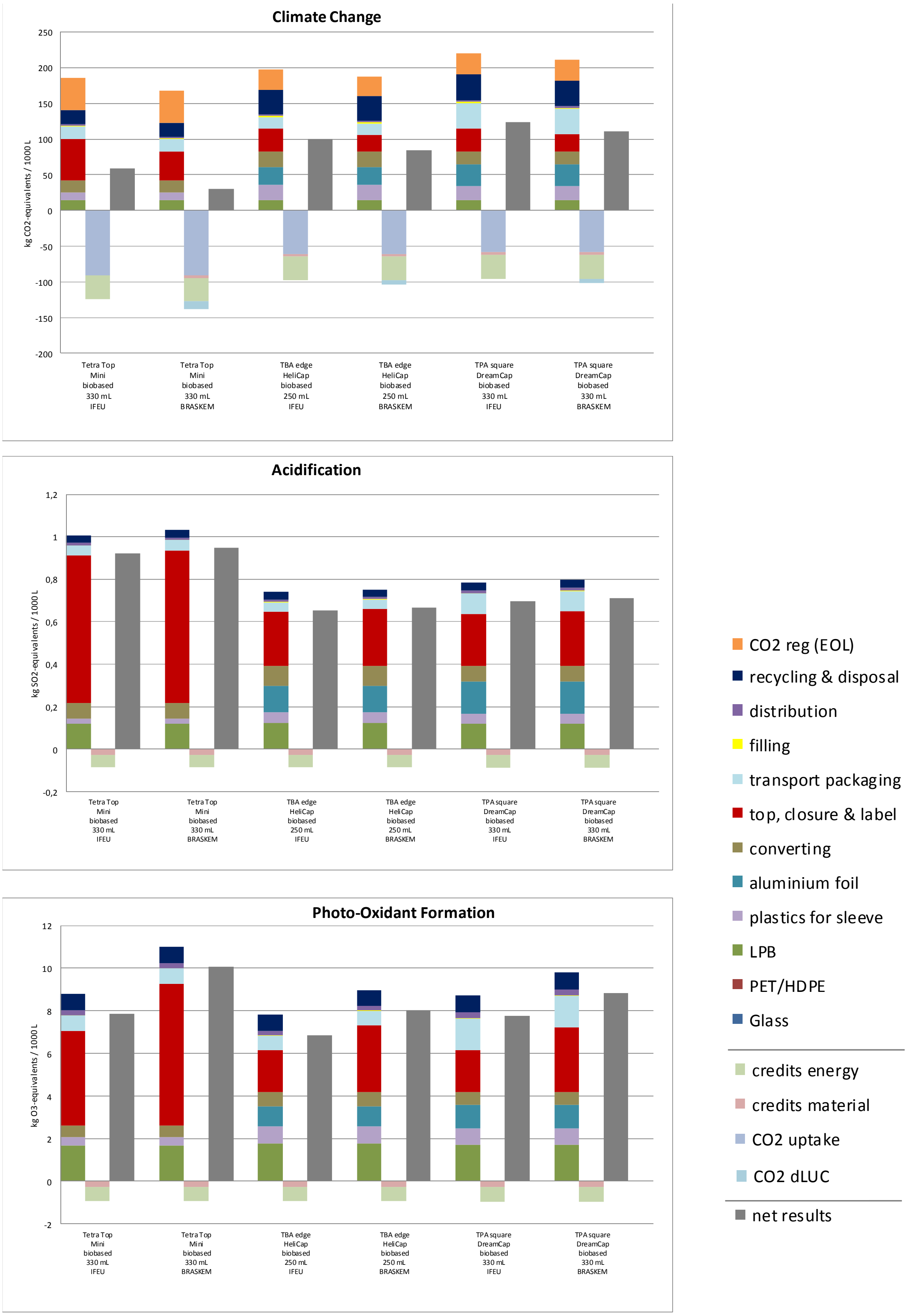


Figure 123: Indicator results for sensitivity analysis on Bio-PE of **segment Grab & Go, Norway**, allocation factor 50% (Part 1)

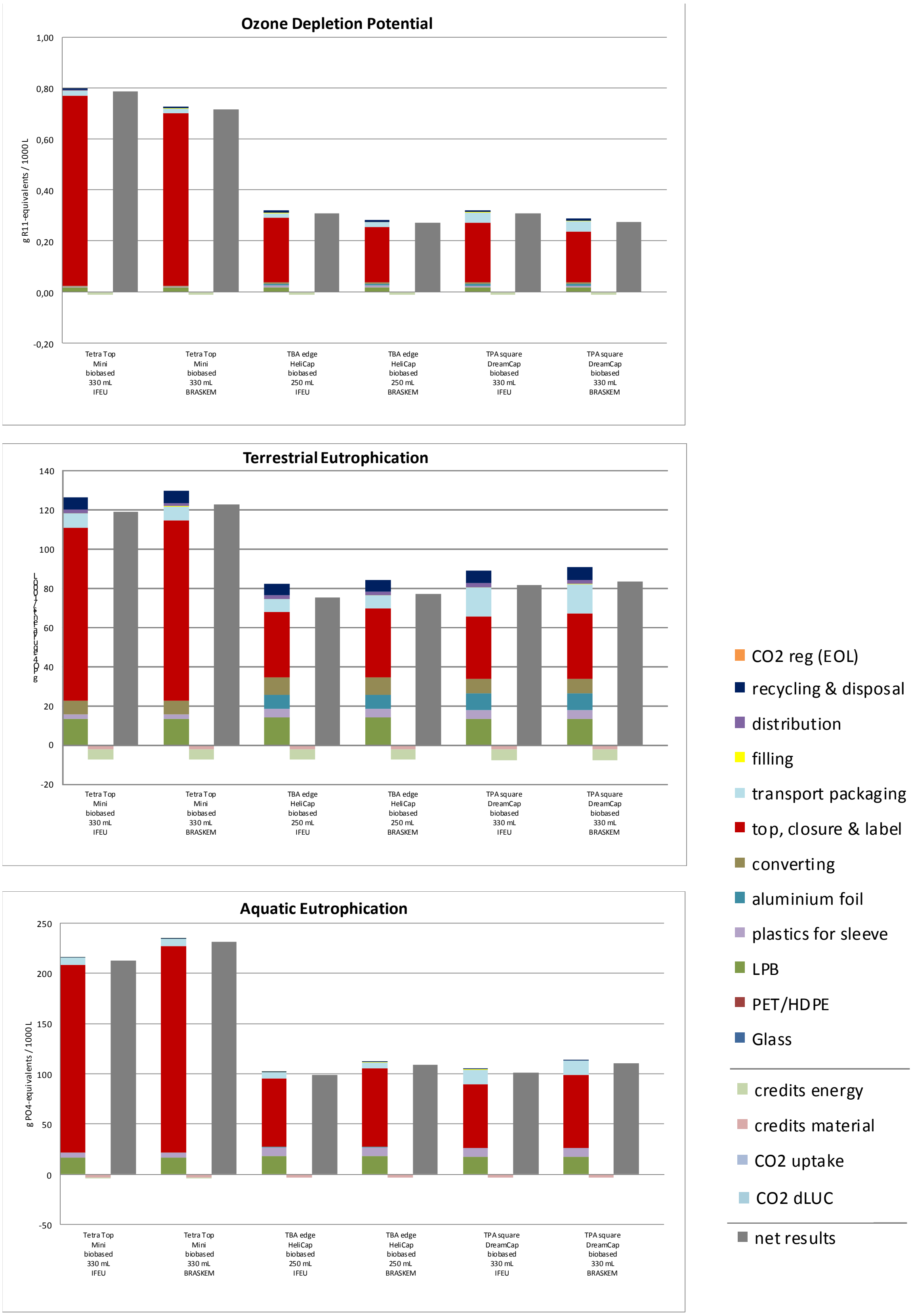


Figure 124: Indicator results for sensitivity analysis on Bio-PE of segment Grab & Go, Norway, allocation factor 50% (Part 2)

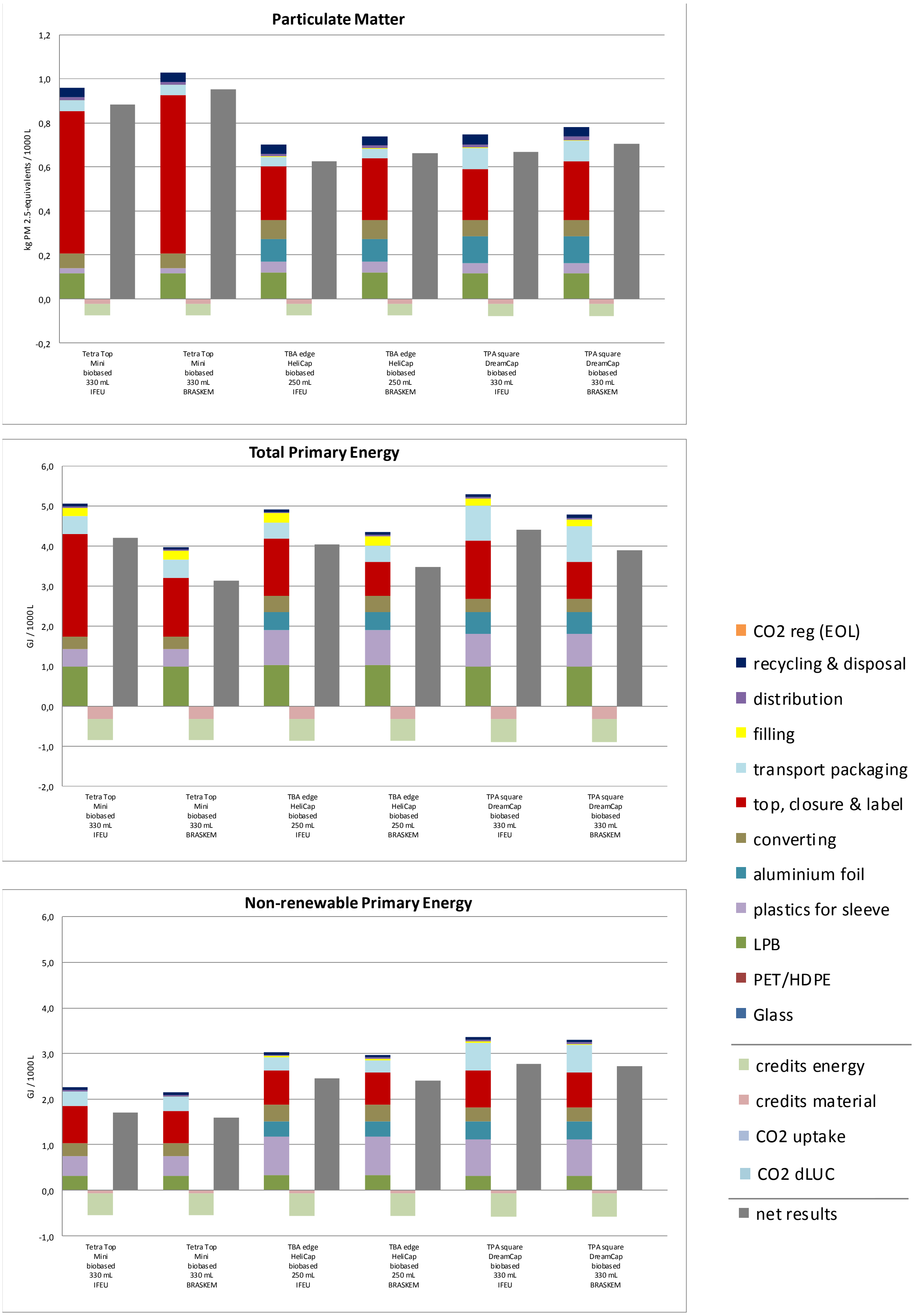


Figure 125: Indicator results for sensitivity analysis on Bio-PE of **segment Grab & Go, Norway**, allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the beverage cartons with bio-based plastics of the Grab & go segment modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower' Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of the dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of grab & go packaging on the Norwegian market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

12 Conclusions Norway

12.1 Dairy Norway

In general the examined beverage carton systems show lower burdens in all of the impact categories than their competing systems. An exception to this occurs in some categories if the carton contains a high share of biobased polyethylene.

This is especially true in the base scenarios where an allocation factor of 50% is applied. This is due to the fact that only half of the regenerative CO_2-emissions of end-of-life are accounted to the beverage carton. With an allocation factor of 100%, therefore the results are higher, but still lower than the competing bottles in most of impact categories.

A considerable role for these generally low environmental impacts of beverage cartons plays the renewability of their paperboard components and a high use of renewable energies.

Apart from the 'Tetra Top' the carton systems also benefit from the use of multi-use roll containers instead of one-way transport packaging.

Lowest results are shown by those beverage carton systems without a separate closure system.

In the environmental impact category 'Climate Change' the cartons furthermore benefit from the use of bio-based polyethylene for sleeve and/or closure. However, a higher share of Bio-PE leads to higher environmental impacts in all other impact categories examined. In case of the substitution of fossil based polyethylene by bio-based polyethylene in the sleeve and closure the respective beverage cartons may lose their environmental advantage against the competing bottles in some impact categories.

The sensitivity analysis on plastic bottle weights shows, that reducing the weight of plastic bottles will lead to lower environmental impacts. When compared to the unaltered beverage cartons the results of the potential fossil-based lightweight bottles calculated may lead to a change in the overall ranking in some cases, especially in regard to the fully bio-based cartons. In the category 'Climate Change' however none of the potential lightweight bottles achieve lower results than any of the beverage cartons.

12.2 JNSD Norway

In the segment JNSD ambient the use of aluminium foil for ambient packaging increases the overall burdens of the beverage cartons. In this segment in Norway are only compared to the glass bottle. Compared to this packaging system the beverage cartons perform very favourably in all categories apart from 'Aquatic Eutrophication'.

Again the substitution of fossil based plastics by bio-based polyethylene in the same type of beverage carton leads to lower results 'Climate Change' and higher results in all other impact categories.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

12.3 Grab & Go Norway

The examined beverage carton 'Tetra Top Mini 330 mL' without bio-based polyethylene for Grab and Go in the sub-segment Dairy chilled show lower burdens in all of the impact categories apart from 'Climate Change' than the 'Tetra Top Mini 330 mL' containing bio-based polyethylene.

As the share of plastics in a small volume Tetra Top packaging is higher than other beverage cartons of bigger volumes, the choice of plastic material type, e.g. fossil or bio-based, plays a decisive role for the environmental performance.

In the sub-segment JNSD ambient the beverage cartons show lower results than the glass bottle in most categories. Of the three regarded beverage cartons the 'TBA edge HeliCap 250 mL' shows a more favourable environmental performance when compared to its carton based competitors.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

13 Denmark

In this section, the results of the examined packaging systems for Denmark are presented separately for the different segments. The following individual life cycle elements are illustrated in sectoral (stacked) bar charts:

- Production and transport of glass including converting to bottle (**'glass'**)
- production and transport of HDPE/PET for bottles including additives, e.g. TiO_2 ('**HDPE/PET for bottle**')
- production and transport of liquid packaging board ('**liquid packaging board**')
- production and transport of plastics and additives for beverage carton ('**plastics for sleeve**')
- production and transport of aluminium & converting to foil ('**aluminium foil for sleeve**')
- production and transport of base materials for closure, top and label and related converting for cartons and plastic bottles ('**top closure&label**')
- converting processes of cartons and plastic bottles and transport to filler ('**converting**')
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays ('**transport packaging**')
- filling process including packaging handling ('**filling**')
- retail of the packages from filler to the point-of-sale ('**distribution**')
- sorting, recycling and disposal processes – all emissions except regenerative CO_2 ('**recycling/disposal**')
- CO_2 emissions from incineration of biobased and renewable materials **('CO2 reg. (EOL)'**; in the following also the term regenerative CO2 emissions is used

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 section 1.8) 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 energy recovery (replacing e.g. grid electricity) (‘**credits energy**’)
- credits for material recycling (‘**credits material**’)
- uptake of athmospheric CO_2 during the plant growth phase (‘**CO_2-uptake’**)

For the sensitivity analysis including the BRASKEM bio-PE dataset the sector ‘**CO_2 – direct land use change**’ (dLUC) is introduced. This sector shows changes in soil organic carbon and above and below ground carbon stocks from conversion of land to sugarcane cultivation. The BRASKEM dataset accounts a negative CO2 value for dLUC.

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

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

- sectoral results of the packaging system itself (stacked bar ‘environmental burdens’)
- credits given for secondary products leaving the system (negative stacked bar ‘credits’)
- 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 (i.e. milk, JNSD) to the point of sale including the end-of-life of the packaging materials.

13.1 Results Dairy Denmark

13.1.1 Presentation of results DAIRY Denmark

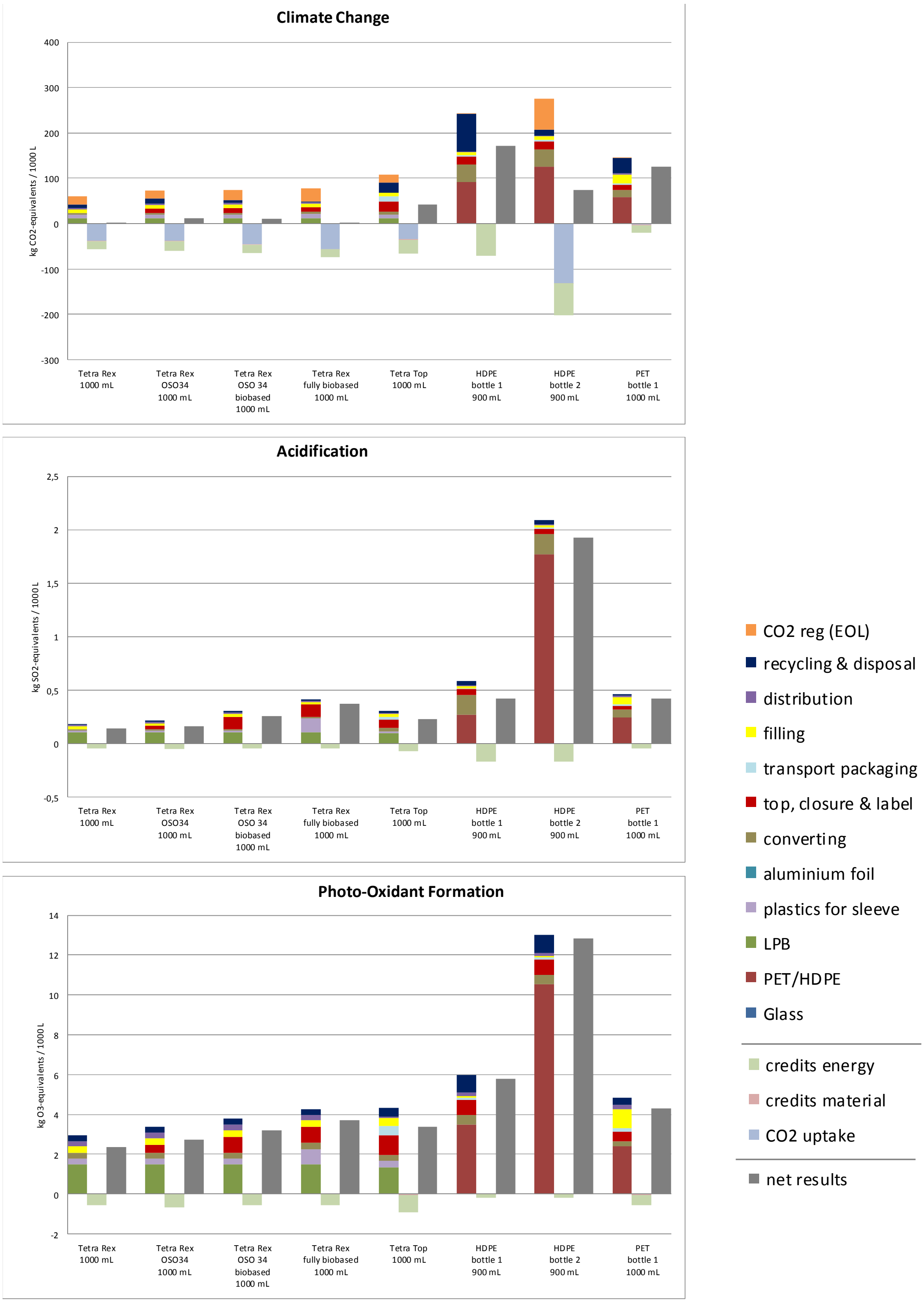


Figure 126: Indicator results for base scenarios of **segment Dairy, Denmark**, allocation factor 50% (Part 1)

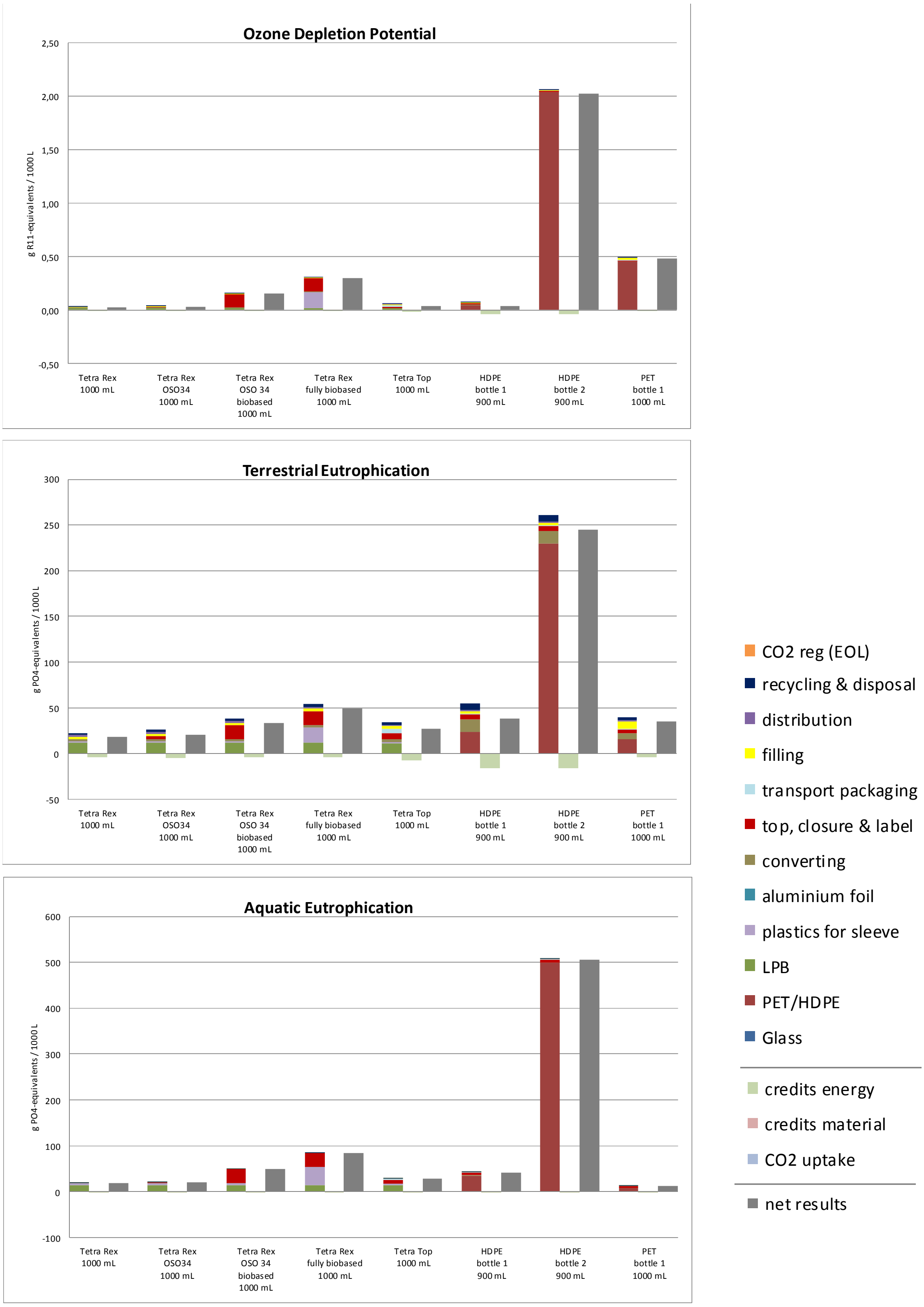


Figure 127 Indicator results for base scenarios of **segment Dairy, Denmark**, allocation factor 50% (Part 2)

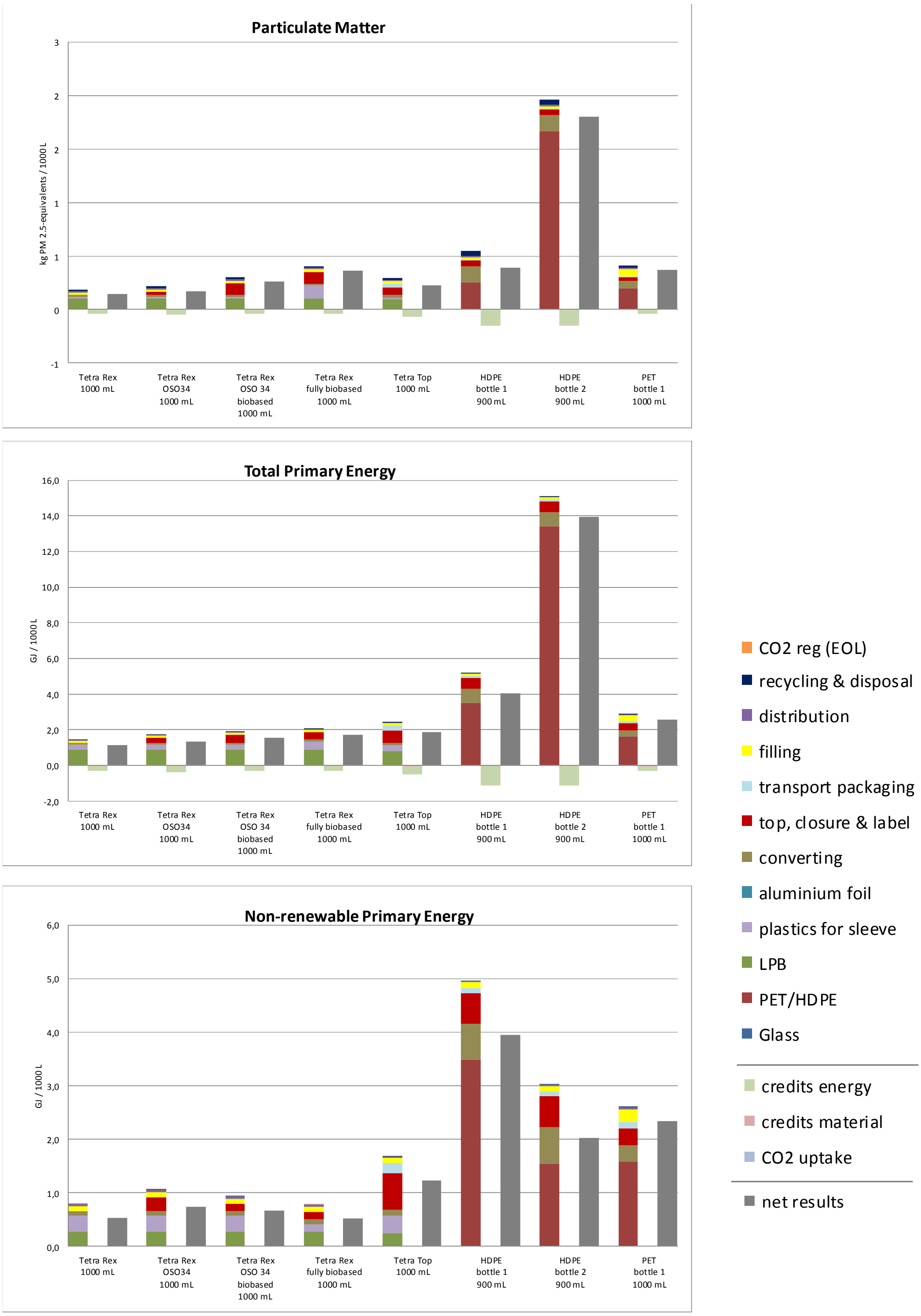


Figure 128: Indicator results for base scenarios of **segment Dairy, Denmark**, allocation factor 50% (Part 3)

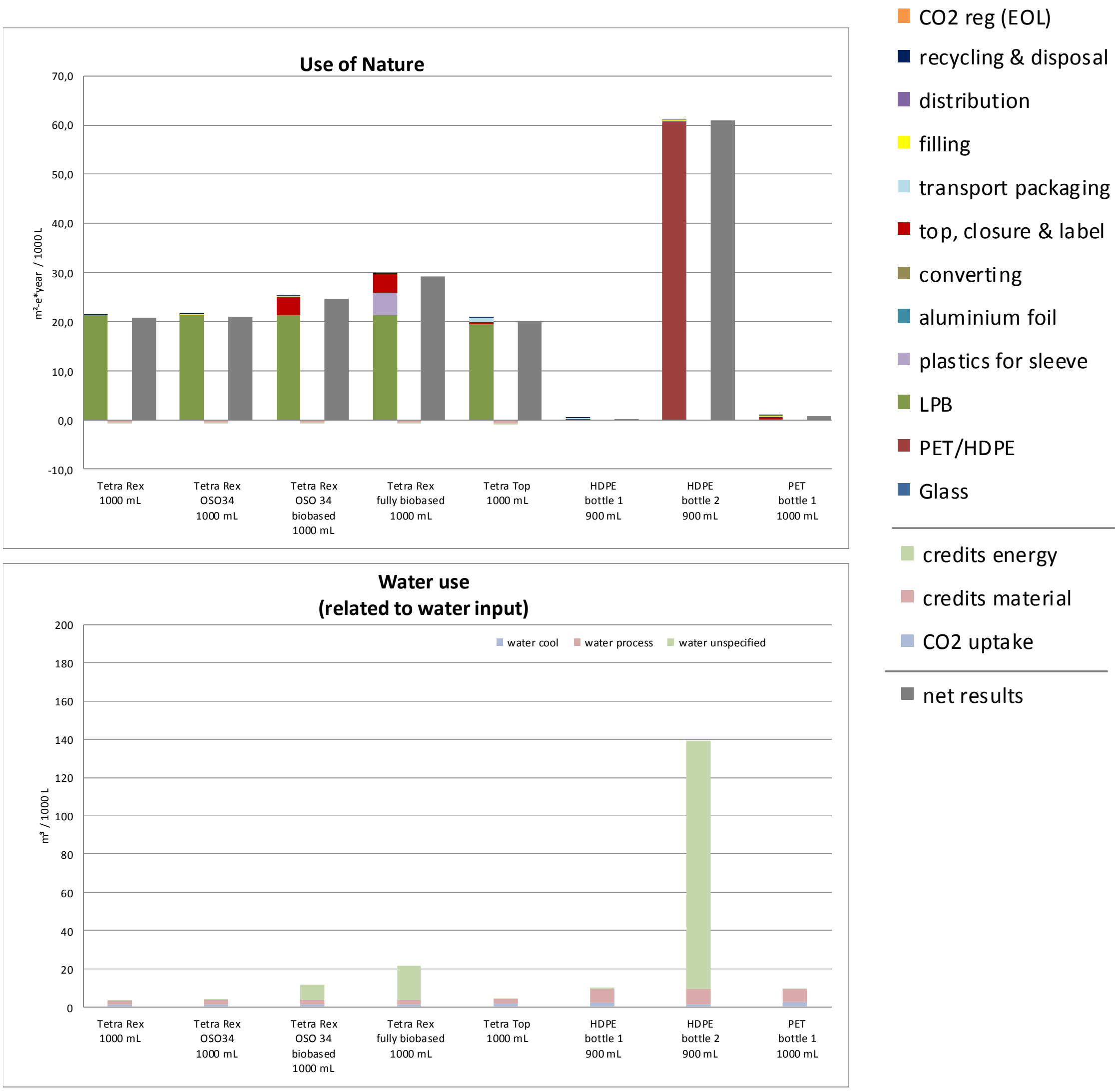


Figure 129: Indicator results for base scenarios of **segment Dairy, Denmark**, allocation factor 50% (Part 4)

Table 91: Category indicator results per impact category for base scenarios of **segment DAIRY, Denmark**- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Denmark, allocation factor 50 %		Tetra Rex 1000 mL	Tetra Rex OSO34 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex fully biobased 1000 mL	Tetra Top 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	41.63	55.05	52.77	49.38	90.07
	CO2 (reg)	18.11	18.14	22.07	27.74	18.29
	Credits	-18.94	-22.54	-19.02	-19.02	-31.12
	CO_2 uptake	-37.99	-37.99	-45.86	-55.84	-34.94
	Net results (∑)	2.82	12.67	9.97	2.27	42.29
Acidification [kg SO_2-equivalents]	Burdens	0.18	0.22	0.30	0.42	0.30
	Credits	-0.05	-0.05	-0.05	-0.05	-0.07
	Net results (∑)	0.14	0.16	0.26	0.37	0.23
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	2.93	3.39	3.79	4.27	4.32
	Credits	-0.57	-0.67	-0.57	-0.57	-0.93
	Net results (∑)	2.36	2.71	3.22	3.70	3.39
Ozone Depletion [g R-11-equivalents]	Burdens	0.03	0.04	0.16	0.31	0.06
	Credits	-0.01	-0.01	-0.01	-0.01	-0.02
	Net results (∑)	0.02	0.03	0.15	0.30	0.04
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	22.54	25.97	38.19	53.75	34.36
	Credits	-4.45	-5.28	-4.47	-4.47	-7.28
	Net results (∑)	18.09	20.69	33.72	49.28	27.08
Aquatic eutrophication [g PO_4-equivalents]	Burdens	18.59	21.24	49.09	84.21	28.96
	Credits	-0.37	-0.39	-0.39	-0.39	-0.56
	Net results (∑)	18.23	20.86	48.71	83.82	28.40
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.19	0.22	0.30	0.41	0.29
	Credits	-0.04	-0.05	-0.04	-0.04	-0.07
	Net results (∑)	0.15	0.17	0.26	0.37	0.23
Total Primary Energy [GJ]	Burdens	1.45	1.73	1.87	2.05	2.41
	Credits	-0.32	-0.38	-0.33	-0.33	-0.53
	Net results (∑)	1.12	1.35	1.55	1.72	1.88
Non-renewable primary energy [GJ]	Burdens	0.80	1.06	0.94	0.79	1.68
	Credits	-0.27	-0.32	-0.27	-0.27	-0.44
	Net results (∑)	0.53	0.74	0.67	0.52	1.23
Use of Nature [m^2-equivalents*year]	Burdens	21.37	21.49	25.12	29.73	20.86
	Credits	-0.55	-0.57	-0.56	-0.56	-0.70
	Net results (∑)	20.81	20.92	24.56	29.17	20.16
Water use [m^3]	Water cool	1.01	1.25	1.16	0.98	1.73
	Water process	2.18	2.20	2.26	2.34	2.07
	Water unspec	0.27	0.30	8.07	17.89	0.35

Table 92: Category indicator results per impact category for base scenarios of segment DAIRY, Denmark- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios DAIRY Denmark, allocation factor 50 %		HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	242.01	207.58	144.31
	CO2 (reg)	0.25	68.64	1.59
	Credits	-71.22	-71.22	-17.67
	CO_2 uptake	0.00	-131.34	-2.66
	Net results (∑)	171.04	73.65	125.57
Acidification [kg SO_2-equivalents]	Burdens	0.59	2.09	0.46
	Credits	-0.17	-0.17	-0.04
	Net results (∑)	0.42	1.92	0.42
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	5.98	13.01	4.84
	Credits	-0.18	-0.18	-0.55
	Net results (∑)	5.79	12.83	4.30
Ozone Depletion [g R-11-equivalents]	Burdens	0.08	2.07	0.49
	Credits	-0.04	-0.04	-0.01
	Net results (∑)	0.04	2.02	0.48
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	54.90	260.96	39.48
	Credits	-16.37	-16.37	-4.20
	Net results (∑)	38.53	244.58	35.28
Aquatic eutrophication [g PO_4-equivalents]	Burdens	42.29	506.96	13.33
	Credits	-0.42	-0.42	-0.52
	Net results (∑)	41.87	506.54	12.81
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.55	1.96	0.41
	Credits	-0.15	-0.15	-0.04
	Net results (∑)	0.39	1.81	0.37
Total Primary Energy [GJ]	Burdens	5.18	15.09	2.88
	Credits	-1.13	-1.13	-0.31
	Net results (∑)	4.05	13.96	2.57
Non-renewable primary energy [GJ]	Burdens	4.97	3.03	2.61
	Credits	-1.01	-1.01	-0.27
	Net results (∑)	3.95	2.02	2.33
Use of Nature [m^2-equivalents*year]	Burdens	0.36	61.04	0.86
	Credits	-0.18	-0.18	-0.07
	Net results (∑)	0.18	60.86	0.79
Water use [m^3]	Water cool	1.99	1.02	2.45
	Water process	7.20	8.28	6.87
	Water unspec	0.71	130.18	0.06

13.1.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the dairy segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories 'Aquatic Eutrophication' and 'Use of Nature'. It is also relevant regarding 'Photo-Oxidant Formation' 'Acidification', 'Terrestrial Eutrophication', 'Particulate Matter' and the consumption of 'Total Primary Energy' and 'Non-renewable Primary Energy'.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category 'Non-renewable Primary Energy', where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the 'Tetra Rex fully bio-based' due to the production of bio-based PE and relatively lower for 'Tetra Top' where the plastics of top and closure show the highest burdens.

The sector top, closure & label plays a role in almost all impact categories. The one exception obviously being the 'Tetra Rex' without a separate closure. The impacts of the production of plastics for the closures is higher for 'Tetra Rex OSO 34 bio-based' and 'Tetra Rex fully bio-based' than for the 'Tetra Rex OSO 34' with a fossil-based closure in all categories apart from 'Non-renewable Primary Energy'. The sector is especially important for 'Tetra Top' as its combined Top and Cap uses about three times more plastic than the 'OSO' closure of the other beverage cartons.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. As beverage cartons do not undergo a material recycling in Denmark, the greenhouse gases are generated due to the incineration in MSWI facilities. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants as well.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. For the different Tetra Rex packaging systems the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal. It's the other way around for the 'Tetra Top' as the higher share of fossil-based plastics in that packaging system leads to more non-regenerative CO_2 emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits do not play a role as in Denmark beverage cartons are not collected for recycling.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 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. Exceptions are the 'Ozone Depletion Potential' of the 'HDPE bottle 1' and the 'Aquatic Eutrophication' of 'PET bottle 1' as well as 'Use of Nature' of both these fossil-based plastic bottles.

For the three regarded bottles three different plastics are used: Fossil-based HDPE for the 'HDPE bottle 1'm bio-based PE for the 'HDPE bottle 2' and fossil-based PET for the 'PET bottle 1'. The closures of all three of them are made from HDPE. Therefore the impacts of plastics production on different categories vary accordingly. For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for both HDPE bottles than for the PET bottle with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide. The even higher burdens of bio-based PE of the 'HDPE bottle 2' originate from field emissions of N_2O from the use of nitrogen fertilisers on sugarcane fields. The agricultural background of the 'HDPE bottle 2' also means that for 'Use of Nature' the production of Bio-PE is the main contributor to this category.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the ‘Aquatic Eutrophication Potential’. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The impact of the fossil-based plastic bottles’ recycling & disposal sector is most significant regarding ‘Climate Change’. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the white opaque plastic bottles do not undergo a material recycling, the amount of bottle waste incinerated is relatively high. The regenerative CO_2 emissions from the bio-based ‘HDPE bottle 2’ are of course similarly high, but they are attributed to the sector CO_2 reg (EOL).

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the plastic bottle waste is incinerated in MSWIs, the received material credits are insignificant compared to the credits for energy.

Please note that the categories ‘Water Use’ and ‘Use of Nature’ do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

13.1.3 Comparison between packaging systems

The following tables show the net results of the regarded beverage cartons systems for all impact categories and the inventory categories regarding total energy demand compared to those of the other regarded packaging systems in the same segment. Differences lower than 10% are considered to be insignificant and are coloured in grey (please see section 1.6 on Precision and uncertainty).

Table 93: Comparison of net results **Tetra Rex 1000 mL mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

segment DAIRY (chilled), Denmark	The net results of **Tetra Rex1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex OSO34 1000 mL	Tetra Rex fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-78%	24%	-93%	-98%	-96%	-98%
Acidification	-14%	-63%	-39%	-67%	-93%	-67%
Photo-Oxidant Formation	-13%	-36%	-30%	-59%	-82%	-45%
Ozone Depletion Potential	-20%	-93%	-47%	-42%	-99%	-96%
Terrestrial Eutrophication	-13%	-63%	-33%	-53%	-93%	-49%
Aquatic Eutrophication	-13%	-78%	-36%	-56%	-96%	42%
Particulate Matter	-14%	-60%	-36%	-63%	-92%	-61%
Total Primary Energy	-17%	-35%	-40%	-72%	-92%	-56%
Non-renewable Primary Energy	-28%	3%	-57%	-87%	-74%	-77%

Table 94: Comparison of net results **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

segment DAIRY (chilled), Denmark	The net results of **Tetra Rex OSO34 1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex 1000 mL	Tetra Rex fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	350%	459%	-70%	-93%	-83%	-90%
Acidification	17%	-56%	-29%	-62%	-92%	-62%
Photo-Oxidant Formation	15%	-27%	-20%	-53%	-79%	-37%
Ozone Depletion Potential	26%	-91%	-34%	-27%	-99%	-95%
Terrestrial Eutrophication	14%	-58%	-24%	-46%	-92%	-41%
Aquatic Eutrophication	14%	-75%	-27%	-50%	-96%	63%
Particulate Matter	16%	-54%	-25%	-57%	-91%	-55%
Total Primary Energy	20%	-22%	-28%	-67%	-90%	-48%
Non-renewable Primary Energy	39%	44%	-40%	-81%	-63%	-68%

Table 95: Comparison of net results **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

segment DAIRY (chilled), Denmark	The net results of **Tetra Rex OSO 34 biobased 1000 mL** are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000 mL	Tetra Rex OSO34 1000 mL	Tetra Rex fully biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	254%	-21%	340%	-76%	-94%	-86%	-92%
Acidification	86%	59%	-31%	12%	-39%	-87%	-39%
Photo-Oxidant Formation	36%	18%	-13%	-5%	-45%	-75%	-25%
Ozone Depletion Potential	612%	466%	-50%	275%	311%	-93%	-69%
Terrestrial Eutrophication	86%	63%	-32%	25%	-12%	-86%	-4%
Aquatic Eutrophication	167%	134%	-42%	72%	16%	-90%	280%
Particulate Matter	78%	54%	-29%	15%	-34%	-86%	-30%
Total Primary Energy	38%	15%	-10%	-18%	-62%	-89%	-40%
Non-renewable Primary Energy	26%	-9%	30%	-45%	-83%	-67%	-71%

Table 96: Comparison of net results **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

segment DAIRY (chilled), Denmark	The net results of **Tetra Rexfully biobased1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Top 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	-20%	-77%	-95%	-99%	-97%	-98%
Acidification	168%	44%	62%	-12%	-81%	-12%
Photo-Oxidant Formation	57%	15%	9%	-36%	-71%	-14%
Ozone Depletion Potential	1317%	99%	647%	719%	-85%	-38%
Terrestrial Eutrophication	172%	46%	82%	28%	-80%	40%
Aquatic Eutrophication	360%	72%	195%	100%	-83%	554%
Particulate Matter	151%	41%	62%	-7%	-80%	-1%
Total Primary Energy	53%	11%	-9%	-58%	-88%	-33%
Non-renewable Primary Energy	-3%	-23%	-58%	-87%	-74%	-78%

Table 97: Comparison of net results **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

segment DAIRY (chilled), Denmark	The net results of **Tetra Top1000 mL** are lower (green)/ higher (orange) than those of					
	Tetra Rex 1000 mL	Tetra Rex OSO 34 biobased 1000 mL	Tetra Rex fully biobased 1000 mL	HDPE bottle 1 900 mL	HDPE bottle 2 900 mL	PET bottle 1 1000 mL
Climate Change	1402%	324%	1767%	-75%	-43%	-66%
Acidification	65%	-11%	-38%	-46%	-88%	-46%
Photo-Oxidant Formation	43%	5%	-9%	-42%	-74%	-21%
Ozone Depletion Potential	90%	-73%	-87%	10%	-98%	-92%
Terrestrial Eutrophication	50%	-20%	-45%	-30%	-89%	-23%
Aquatic Eutrophication	56%	-42%	-66%	-32%	-94%	122%
Particulate Matter	55%	-13%	-38%	-43%	-88%	-39%
Total Primary Energy	68%	22%	9%	-54%	-87%	-27%
Non-renewable Primary Energy	132%	83%	138%	-69%	-39%	-47%

13.2 Results JNSD Denmark

13.2.1 Presentation of results JNSD Denmark

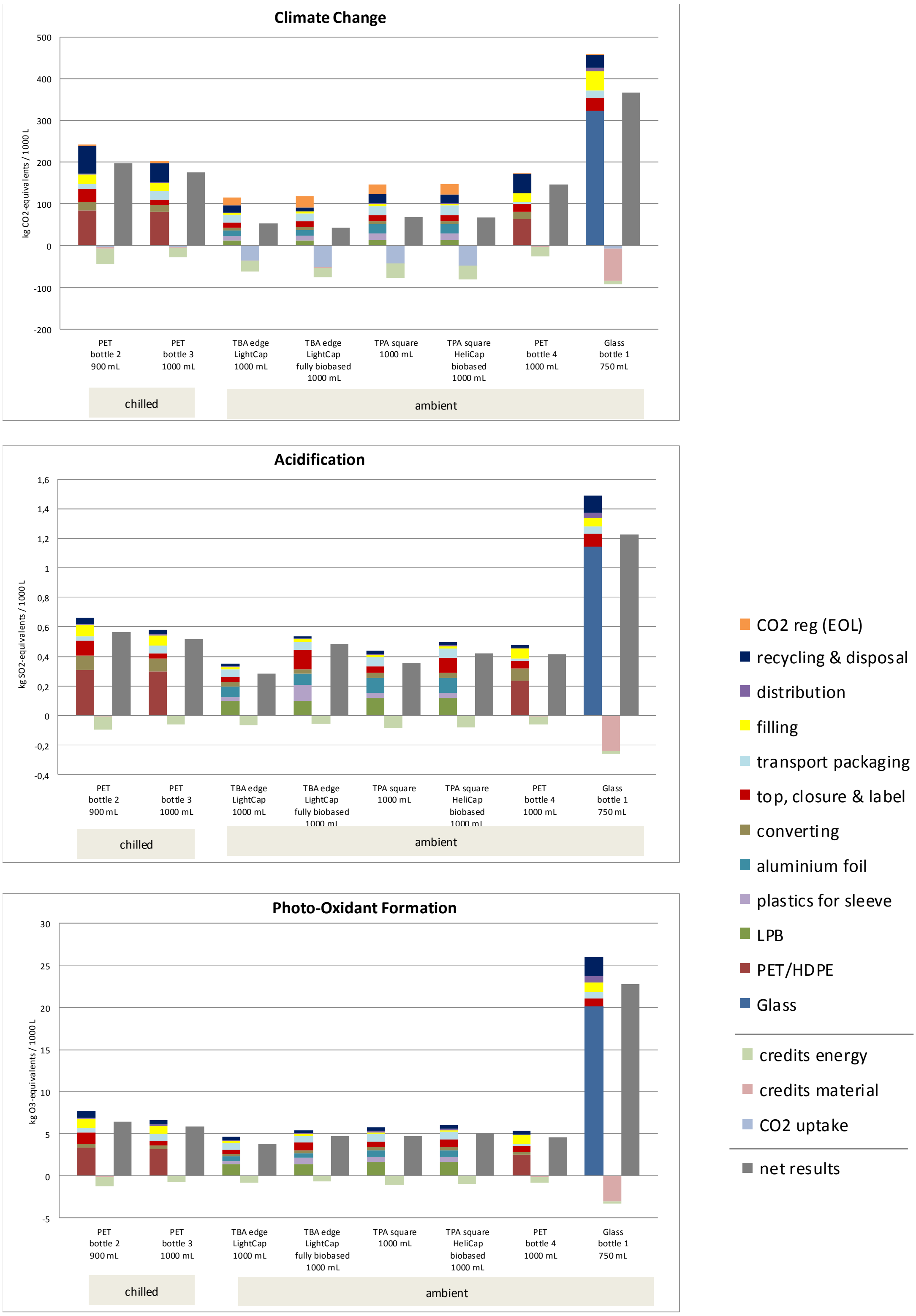


Figure 130: Indicator results for base scenarios of **segment JNSD, Denmark**, allocation factor 50% (Part 1)

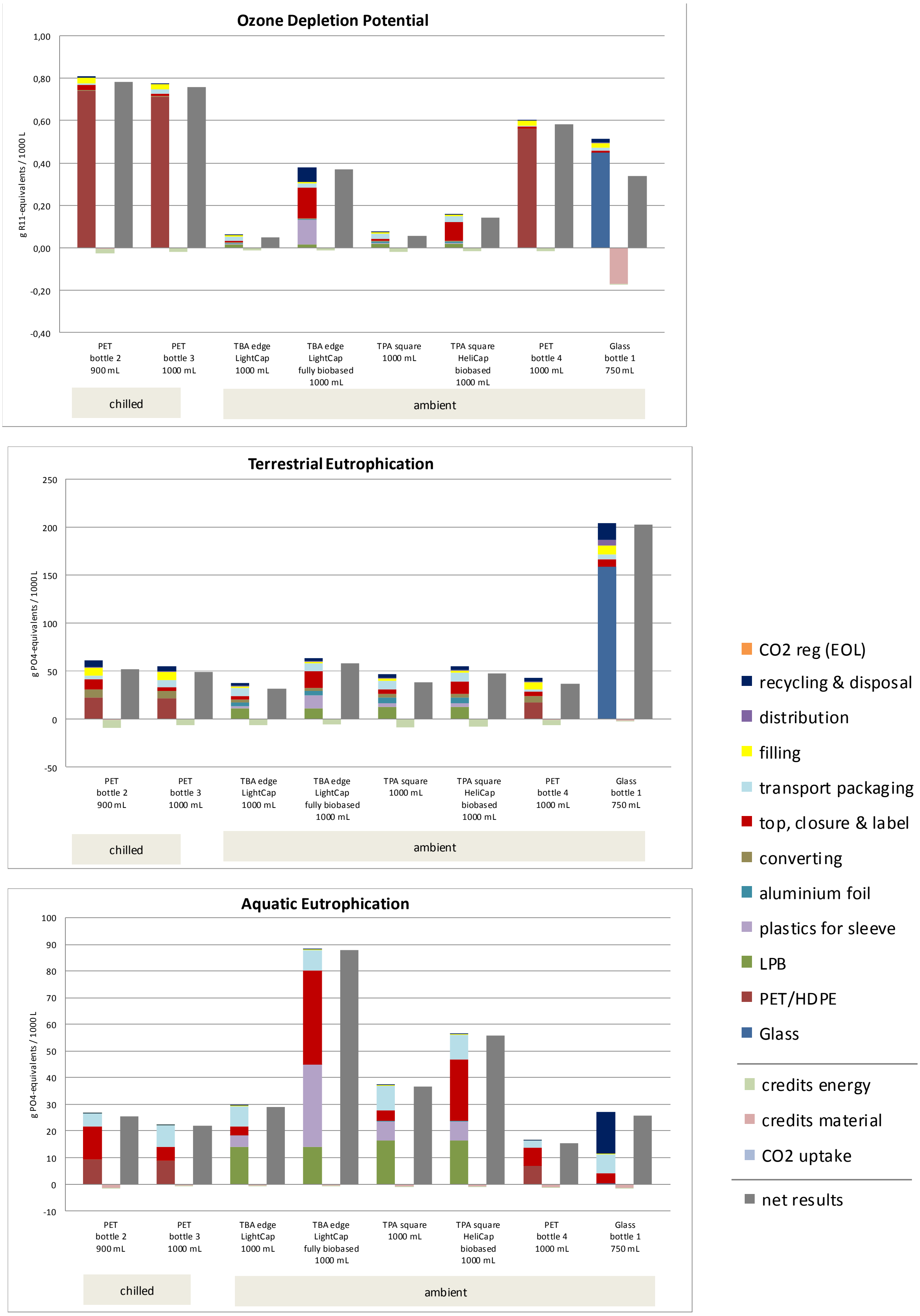


Figure 131 Indicator results for base scenarios of **segment JNSD, Denmark**, allocation factor 50% (Part 2)

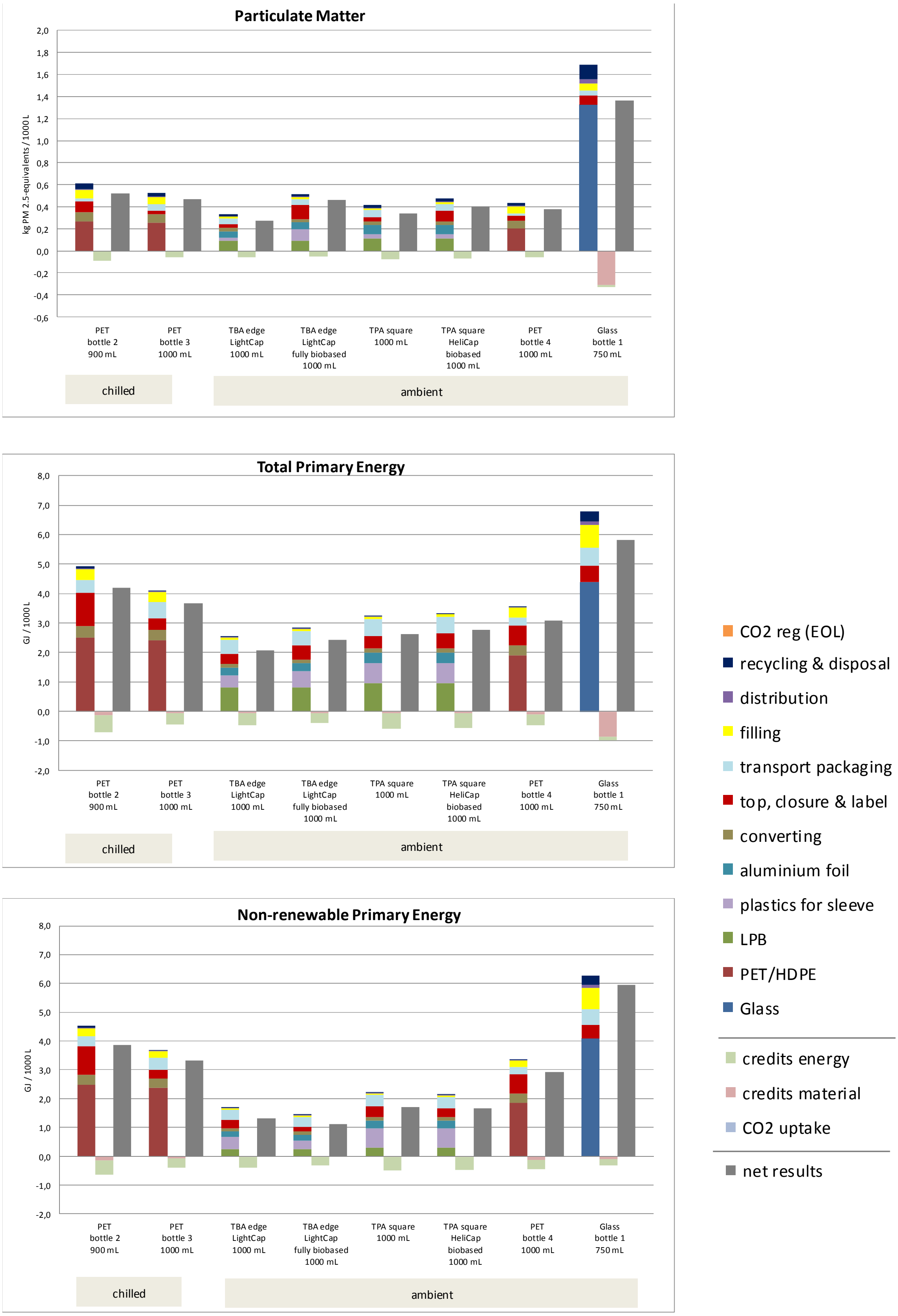


Figure 132: Indicator results for base scenarios of **segment JNSD, Denmark**, allocation factor 50% (Part 3)

Figure 133: Indicator results for base scenarios of **segment JNSD, Denmark**, allocation factor 50% (Part 4)

Table 98: Category indicator results per impact category for base scenarios of **segment JNSD chilled, Denmark**- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD chilled Denmark, allocation factor 50 %		PET bottle 2 900 mL	PET bottle 3 1000 mL
Climate change [kg CO_2-equivalents]	Burdens	239.87	198.22
	CO2 (reg)	3.08	4.81
	Credits	-40.74	-25.44
	CO_2 uptake	-4.21	-2.85
	Net results (∑)	198.00	174.74
Acidification [kg SO_2-equivalents]	Burdens	0.66	0.58
	Credits	-0.10	-0.06
	Net results (∑)	0.57	0.52
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.73	6.65
	Credits	-1.26	-0.79
	Net results (∑)	6.48	5.87
Ozone Depletion [g R-11-equivalents]	Burdens	0.81	0.78
	Credits	-0.03	-0.02
	Net results (∑)	0.78	0.76
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	61.48	54.81
	Credits	-9.62	-6.08
	Net results (∑)	51.86	48.73
Aquatic eutrophication [g PO_4-equivalents]	Burdens	26.92	22.39
	Credits	-1.35	-0.58
	Net results (∑)	25.57	21.82
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.61	0.53
	Credits	-0.09	-0.06
	Net results (∑)	0.52	0.47
Total Primary Energy [GJ]	Burdens	4.92	4.11
	Credits	-0.72	-0.44
	Net results (∑)	4.20	3.67
Non-renewable primary energy [GJ]	Burdens	4.52	3.70
	Credits	-0.65	-0.39
	Net results (∑)	3.87	3.31
Use of Nature [m^2-equivalents*year]	Burdens	1.39	2.28
	Credits	-0.12	-0.08
	Net results (∑)	1.28	2.20
Water use [m^3]	Water cool	2.86	2.86
	Water process	7.20	7.20
	Water unspec	0.18	0.18

Table 99: Category indicator results per impact category for base scenarios of segment JNSD ambient, Denmark- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios JNSD ambient Denmark, allocation factor 50 %		TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate change [kg CO_2-equivalents]	Burdens	95.57	90.37	123.53	121.50	171.91	458.14
	CO2 (reg)	19.63	28.44	23.36	26.07	0.23	1.30
	Credits	-26.97	-22.91	-35.30	-32.86	-26.17	-86.11
	CO_2 uptake	-35.55	-52.18	-42.28	-47.73	0.00	-6.22
	Net results (∑)	52.67	43.73	69.31	66.98	145.97	367.10
Acidification [kg SO_2-equivalents]	Burdens	0.35	0.54	0.44	0.50	0.48	1.49
	Credits	-0.07	-0.06	-0.08	-0.08	-0.06	-0.26
	Net results (∑)	0.29	0.48	0.35	0.42	0.42	1.23
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	4.61	5.43	5.79	6.05	5.35	26.07
	Credits	-0.81	-0.69	-1.06	-0.99	-0.82	-3.28
	Net results (∑)	3.79	4.74	4.73	5.06	4.53	22.78
Ozone Depletion [g R-11-equivalents]	Burdens	0.06	0.38	0.08	0.16	0.60	0.51
	Credits	-0.02	-0.01	-0.02	-0.02	-0.02	-0.18
	Net results (∑)	0.05	0.37	0.06	0.14	0.58	0.34
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	37.95	63.88	47.03	55.39	42.93	204.73
	Credits	-6.36	-5.43	-8.30	-7.74	-6.24	-1.90
	Net results (∑)	31.59	58.45	38.73	47.65	36.69	202.83
Aquatic eutrophication [g PO_4-equivalents]	Burdens	29.63	88.38	37.28	56.55	16.56	27.00
	Credits	-0.63	-0.62	-0.72	-0.72	-1.12	-1.38
	Net results (∑)	29.00	87.76	36.56	55.83	15.44	25.62
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.34	0.51	0.42	0.48	0.44	1.69
	Credits	-0.06	-0.05	-0.08	-0.07	-0.06	-0.33
	Net results (∑)	0.27	0.46	0.34	0.40	0.38	1.36
Total Primary Energy [GJ]	Burdens	2.54	2.83	3.24	3.33	3.55	6.78
	Credits	-0.47	-0.40	-0.60	-0.57	-0.48	-0.97
	Net results (∑)	2.07	2.43	2.63	2.77	3.08	5.81
Non-renewable primary energy [GJ]	Burdens	1.69	1.44	2.22	2.14	3.35	6.26
	Credits	-0.38	-0.33	-0.50	-0.47	-0.43	-0.31
	Net results (∑)	1.31	1.11	1.72	1.67	2.92	5.95
Use of Nature [m^2-equivalents*year]	Burdens	21.82	29.50	25.96	28.47	0.37	1.75
	Credits	-0.82	-0.81	-0.96	-0.96	-0.08	-0.06
	Net results (∑)	21.00	28.69	25.00	27.52	0.29	1.69
Water use [m^3]	Water cool	1.36	1.11	1.75	1.66	2.86	0.00
	Water process	2.51	2.64	3.01	3.02	7.20	0.00
	Water unspec	0.31	16.70	0.40	5.77	0.18	0.00

13.2.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the JNSD segment, in most impact categories one of the biggest parts 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 considerable share of the burdens of the impact categories 'Aquatic Eutrophication' and 'Use of Nature'. It is also significantly relevant regarding 'Photo-Oxidant Formation' 'Acidification', 'Terrestrial Eutrophication', 'Particulate Matter' and the consumption of 'Total Primary Energy' and to a lower extent 'Non-renewable Primary Energy'.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category 'Non-renewable Primary Energy', where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics. It is considerably higher for the 'TBA edge LightCap fully bio-based' due to the production of bio-based PE.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories 'Climate

Change', 'Acidification' and 'Particulate Matter' as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the closures is higher for 'TBA edge LightCap fully bio-based' and 'TPA square HeliCap bio-based' than for the beverage cartons with a fossil-based closure in all categories apart from 'Non-renewable Primary Energy'.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sector transport packaging plays a more important role for almost all categories than for the beverage cartons used for the packaging of dairy. This is because the JNSD cartons use one-way secondary packaging (cardboard trays) instead of roll containers.

The sectors filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. As beverage cartons do not undergo a material recycling in Denmark, the greenhouse gases are generated due to the incineration in MSWI facilities. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants as well.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. Especially for the 'TBA edge LightCap fully bio-based' the CO2 reg (EOL) emissions are higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits do not play a role as in Denmark beverage cartons are not collected for recycling.

The energy credits arise from incineration plants, where energy recovery takes place.

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

All regarded plastic bottles for chilled and ambient JNSD segment alike are made from PET. The closures of all three of them are made from HDPE. For the impact categories 'Climate Change', 'Acidification', 'Photo-Oxidant Formation', 'Ozone Depletion Potential', 'Terrestrial Eutrophication', 'Aquatic Eutrophication' and 'Particulate Matter' the burdens from PET production (sector PET/HDPE in the graphs) are the highest single contributor to the overall burdens.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from fossil-based HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category.

The filling process of PET bottles though shows a certain share of the burdens in all categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’.

The impact of the PET bottles’ recycling & disposal sector is most significant regarding ‘Climate Change’. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the collection rate of PET bottles in Denmark is 0% the amount of bottle waste incinerated is relatively high.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants. Since no primary granulate is credited as the plastic bottle waste is incinerated in MSWIs, the received material credits are insignificant compared to the credits for energy.

Glass bottle

Even more than for the other regarded packaging systems, the production of the base material is the main contributor to the overall burdens for the glass bottle. The production of glass clearly dominates the results in all categories apart from ‘Aquatic Eutrophication’ and ‘Use of Nature’.

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact categories ‘Climate Change’, ‘Aquatic Eutrophication’ and ‘Use of Nature’ 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’.

Please note that the categories ‘Water Use’ and ‘Use of Nature’ do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

13.2.3 Comparison between packaging systems

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

Table 100: Comparison of net results **Tetra Brik Aseptic Edge LightCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

segment JNSD (ambient), Denmark	The net results of **TBA edge LightCap 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA edge LightCap fully biobased 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	20%	-24%	-21%	-64%	-86%
Acidification	-41%	-19%	-32%	-31%	-77%
Photo-Oxidant Formation	-20%	-20%	-25%	-16%	-83%
Ozone Depletion Potential	-87%	-16%	-66%	-92%	-86%
Terrestrial Eutrophication	-46%	-18%	-34%	-14%	-84%
Aquatic Eutrophication	-67%	-21%	-48%	88%	13%
Particulate Matter	-40%	-19%	-32%	-27%	-80%
Total Primary Energy	-15%	-21%	-25%	-33%	-64%
Non-renewable Primary Energy	18%	-24%	-22%	-55%	-78%

Table 101: Comparison of net results **Tetra Brik Aseptic Edge LightCap fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

segment JNSD (ambient), Denmark	The net results of **TBA edge LightCap fully biobased 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA edge LightCap 1000 mL	TPA square 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	-17%	-37%	-35%	-70%	-88%
Acidification	69%	36%	15%	16%	-61%
Photo-Oxidant Formation	25%	0%	-6%	5%	-79%
Ozone Depletion Potential	673%	547%	161%	-37%	9%
Terrestrial Eutrophication	85%	51%	23%	59%	-71%
Aquatic Eutrophication	203%	140%	57%	468%	243%
Particulate Matter	67%	35%	14%	22%	-66%
Total Primary Energy	17%	-8%	-12%	-21%	-58%
Non-renewable Primary Energy	-15%	-35%	-33%	-62%	-81%

Table 102: Comparison of net results **TPA square 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

segment JNSD (ambient), Denmark	The net results of **TPA square1000 mL** are lower (green)/ higher (orange) than those of				
	TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square HeliCap biobased 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	32%	58%	3%	-53%	-81%
Acidification	24%	-26%	-15%	-15%	-71%
Photo-Oxidant Formation	25%	0%	-7%	4%	-79%
Ozone Depletion Potential	19%	-85%	-60%	-90%	-83%
Terrestrial Eutrophication	23%	-34%	-19%	6%	-81%
Aquatic Eutrophication	26%	-58%	-35%	137%	43%
Particulate Matter	24%	-26%	-15%	-10%	-75%
Total Primary Energy	27%	8%	-5%	-14%	-55%
Non-renewable Primary Energy	31%	55%	3%	-41%	-71%

Table 103: Comparison of net results **Tetra Prisma Aseptic square HeliCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

segment JNSD (ambient), Denmark	The net results of **TPA square HeliCap biobased 1000 mL** are lower (green)/ higher (orange) than those of				
	TBA edge LightCap 1000 mL	TBA edge LightCap fully biobased 1000 mL	TPA square 1000 mL	PET bottle 4 1000 mL	Glass bottle 1 750 mL
Climate Change	27%	53%	-3%	-54%	-82%
Acidification	47%	-13%	18%	1%	-66%
Photo-Oxidant Formation	33%	7%	7%	12%	-78%
Ozone Depletion Potential	196%	-62%	148%	-76%	-58%
Terrestrial Eutrophication	51%	-18%	23%	30%	-77%
Aquatic Eutrophication	92%	-36%	53%	261%	118%
Particulate Matter	46%	-13%	18%	7%	-70%
Total Primary Energy	34%	14%	5%	-10%	-52%
Non-renewable Primary Energy	27%	50%	-3%	-43%	-72%

13.3 Results Grab & Go Denmark

13.3.1 Presentation of results Grab & Go Denmark

Figure 134: Indicator results for base scenarios of segment Grab & Go, Denmark, allocation factor 50% (Part 1)

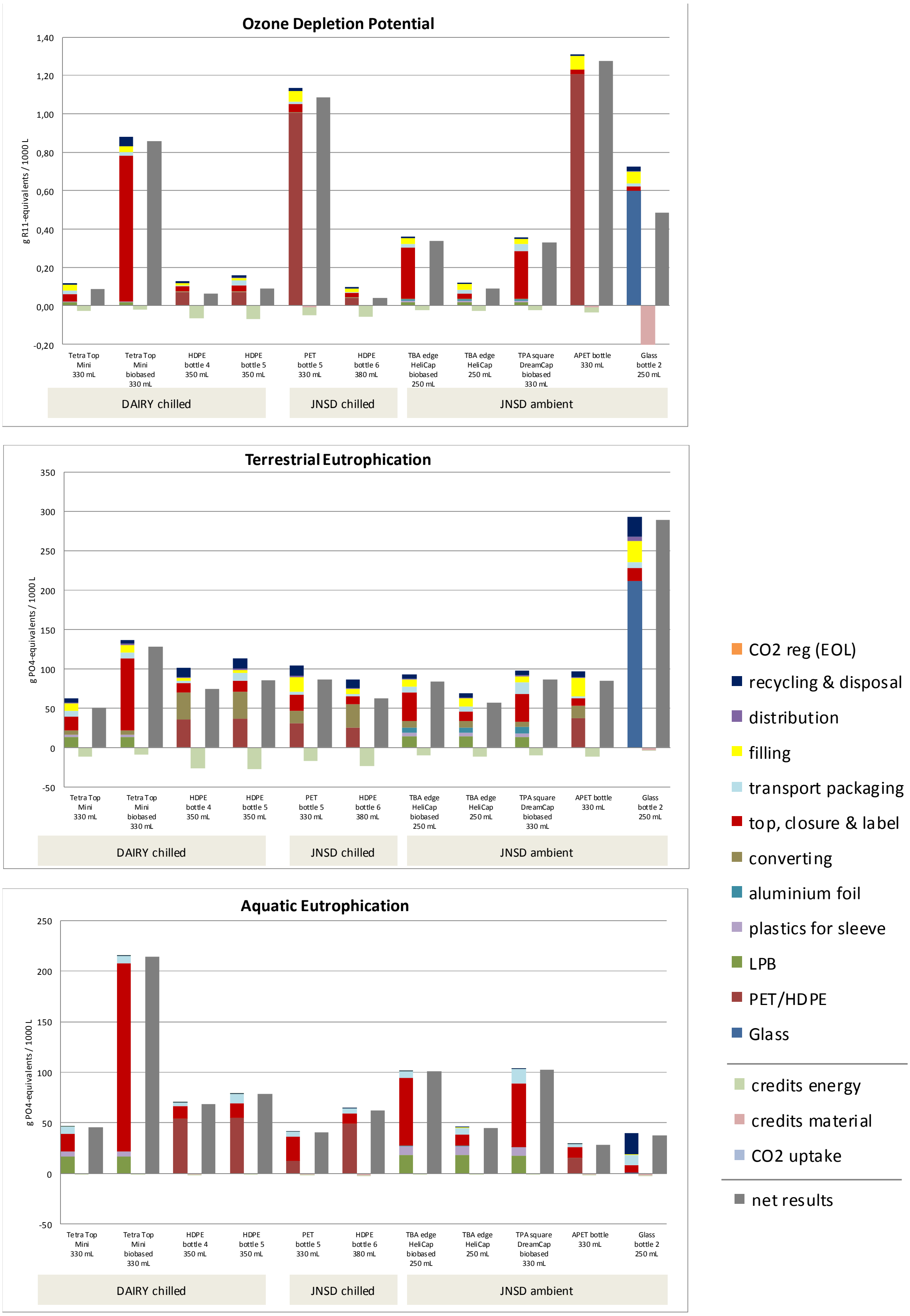


Figure 135 Indicator results for base scenarios of **segment Grab & Go, Denmark**, allocation factor 50% (Part 2)

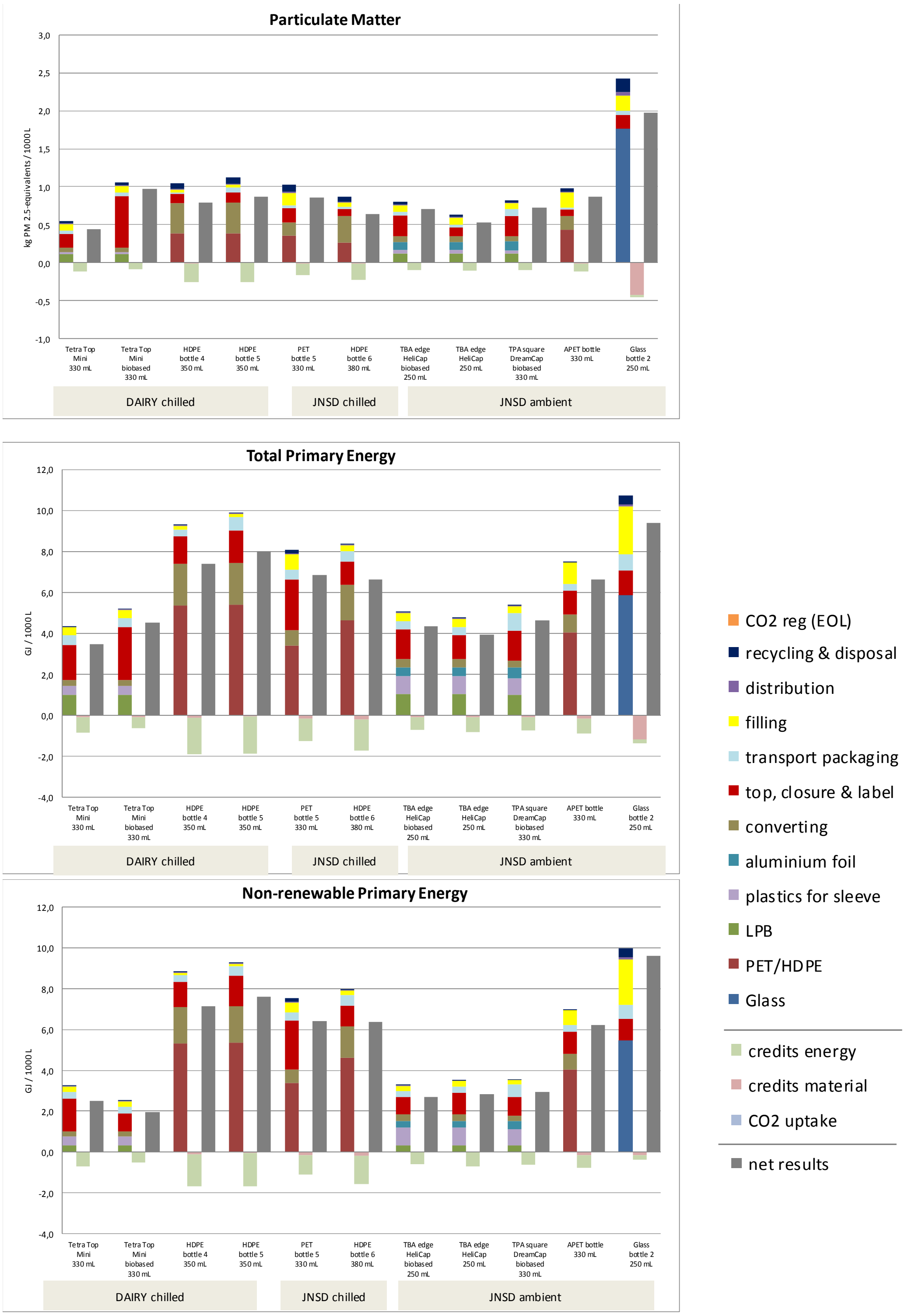


Figure 136: Indicator results for base scenarios of **segment Grab & Go, Denmark**, allocation factor 50% (Part 3)

Figure 137: Indicator results for base scenarios of **segment Grab & Go, Denmark**, allocation factor 50% (Part 4)

Table 104: Category indicator results per impact category for base scenarios of **segment Grab & Go DAIRY chilled, Denmark**- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go DAIRY chilled Denmark, allocation factor 50 %		Tetra Top Mini 330 mL	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate change [kg CO_2-equivalents]	Burdens	179.07	164.34	431.72	460.40
	CO2 (reg)	23.32	48.40	0.23	4.10
	Credits	-50.98	-37.43	-116.98	-119.13
	CO_2 uptake	-43.39	-91.25	0.00	0.00
	Net results (∑)	108.02	84.07	314.97	345.37
Acidification [kg SO_2-equivalents]	Burdens	0.58	1.11	1.15	1.22
	Credits	-0.12	-0.09	-0.27	-0.28
	Net results (∑)	0.45	1.02	0.87	0.95
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	7.70	10.09	9.78	10.95
	Credits	-1.52	-1.12	-1.91	-1.89
	Net results (∑)	6.18	8.97	7.87	9.05
Ozone Depletion [g R-11-equivalents]	Burdens	0.12	0.88	0.13	0.16
	Credits	-0.03	-0.02	-0.07	-0.07
	Net results (∑)	0.09	0.86	0.06	0.09
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	62.61	137.04	101.69	113.12
	Credits	-11.89	-8.78	-26.90	-27.43
	Net results (∑)	50.72	128.26	74.79	85.70
Aquatic eutrophication [g PO_4-equivalents]	Burdens	46.17	215.16	70.02	79.12
	Credits	-0.80	-0.80	-1.41	-0.41
	Net results (∑)	45.37	214.36	68.61	78.71
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.55	1.06	1.05	1.12
	Credits	-0.11	-0.08	-0.25	-0.26
	Net results (∑)	0.44	0.97	0.79	0.86
Total Primary Energy [GJ]	Burdens	4.34	5.19	9.31	9.91
	Credits	-0.85	-0.64	-1.90	-1.87
	Net results (∑)	3.49	4.55	7.41	8.04
Non-renewable primary energy [GJ]	Burdens	3.24	2.51	8.84	9.28
	Credits	-0.72	-0.54	-1.71	-1.68
	Net results (∑)	2.51	1.97	7.13	7.60
Use of Nature [m^2-equivalents*year]	Burdens	26.70	48.78	0.49	2.36
	Credits	-0.98	-0.95	-0.28	-0.28
	Net results (∑)	25.72	47.84	0.22	2.08
Water use [m^3]	Water cool	3.09	2.42	3.38	3.62
	Water process	2.78	3.14	2.58	2.58
	Water unspec	0.51	47.67	1.17	1.19

Table 105: Category indicator results per impact category for base scenarios of **segment Grab & Go JNSD chilled, Denmark**- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go JNSD chilled ambient Denmark, allocation factor 50 %		PET bottle 5 330 mL	HDPE bottle 6 380 mL
Climate change [kg CO_2-equivalents]	Burdens	409.37	379.30
	CO2 (reg)	1.19	0.23
	Credits	-73.40	-104.40
	CO_2 uptake	0.00	0.00
	Net results (∑)	337.16	275.13
Acidification [kg SO_2-equivalents]	Burdens	1.11	0.94
	Credits	-0.18	-0.24
	Net results (∑)	0.94	0.70
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	12.81	8.17
	Credits	-2.24	-1.76
	Net results (∑)	10.57	6.42
Ozone Depletion [g R-11-equivalents]	Burdens	1.14	0.10
	Credits	-0.05	-0.06
	Net results (∑)	1.08	0.04
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	104.02	86.13
	Credits	-17.32	-23.97
	Net results (∑)	86.70	62.16
Aquatic eutrophication [g PO_4-equivalents]	Burdens	42.14	64.45
	Credits	-1.57	-2.15
	Net results (∑)	40.57	62.30
Particulate matter [kg PM 2,5- equivalents]	Burdens	1.03	0.87
	Credits	-0.16	-0.23
	Net results (∑)	0.86	0.64
Total Primary Energy [GJ]	Burdens	8.10	8.38
	Credits	-1.24	-1.74
	Net results (∑)	6.86	6.63
Non-renewable primary energy [GJ]	Burdens	7.54	7.95
	Credits	-1.12	-1.58
	Net results (∑)	6.43	6.37
Use of Nature [m^2-equivalents*year]	Burdens	1.21	0.49
	Credits	-0.19	-0.25
	Net results (∑)	1.02	0.24
Water use [m^3]	Water cool	2.46	3.02
	Water process	6.87	16.03
	Water unspec	0.06	1.06

Table 106: Category indicator results per impact category for base scenarios of segment Grab & Go JNSD ambient, Denmark- burdens, credits and net results per functional unit of 1000 L (All figures are rounded to two decimal places.)

Base scenarios Grab & Go JNSD ambient ambient Denmark, allocation factor 50 %		TBA edge HeliCap biobased 250 mL	TBA edge HeliCap 250 mL	TPA square DreamCap biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate change [kg CO_2-equivalents]	Burdens	193.02	197.61	208.44	370.68	716.28
	CO2 (reg)	31.96	24.04	33.06	0.23	1.92
	Credits	-41.92	-49.02	-43.77	-50.16	-121.44
	CO_2 uptake	-61.23	-45.36	-58.34	0.00	-10.51
	Net results (∑)	121.83	127.28	139.39	320.75	586.25
Acidification [kg SO_2-equivalents]	Burdens	0.84	0.67	0.87	1.08	2.15
	Credits	-0.10	-0.12	-0.11	-0.12	-0.37
	Net results (∑)	0.74	0.55	0.76	0.96	1.78
Photo-Oxidant Formation [kg O_3-equivalents]	Burdens	9.13	8.32	9.71	11.67	37.31
	Credits	-1.25	-1.46	-1.32	-1.55	-4.51
	Net results (∑)	7.87	6.86	8.39	10.12	32.79
Ozone Depletion [g R-11-equivalents]	Burdens	0.36	0.12	0.35	1.31	0.72
	Credits	-0.02	-0.03	-0.02	-0.04	-0.24
	Net results (∑)	0.34	0.09	0.33	1.27	0.49
Terrestrial eutrophication [g PO_4-equivalents]	Burdens	93.17	68.56	97.22	96.54	292.84
	Credits	-9.80	-11.43	-10.30	-11.92	-2.94
	Net results (∑)	83.38	57.13	86.92	84.62	289.90
Aquatic eutrophication [g PO_4-equivalents]	Burdens	101.51	45.39	103.73	29.51	39.79
	Credits	-0.76	-0.76	-0.95	-1.47	-1.95
	Net results (∑)	100.76	44.63	102.78	28.04	37.84
Particulate matter [kg PM 2,5- equivalents]	Burdens	0.80	0.63	0.82	0.98	2.42
	Credits	-0.09	-0.11	-0.10	-0.11	-0.45
	Net results (∑)	0.71	0.53	0.73	0.87	1.97
Total Primary Energy [GJ]	Burdens	5.05	4.76	5.38	7.51	10.76
	Credits	-0.71	-0.82	-0.75	-0.87	-1.37
	Net results (∑)	4.34	3.94	4.63	6.64	9.39
Non-renewable primary energy [GJ]	Burdens	3.28	3.52	3.55	7.00	9.99
	Credits	-0.60	-0.70	-0.62	-0.79	-0.37
	Net results (∑)	2.68	2.82	2.93	6.21	9.61
Use of Nature [m^2-equivalents*year]	Burdens	34.88	27.56	35.05	0.71	2.59
	Credits	-0.90	-0.92	-1.20	-0.14	-0.08
	Net results (∑)	33.99	26.64	33.85	0.57	2.51
Water use [m^3]	Water cool	2.35	2.54	2.44	4.12	0.00
	Water process	3.52	3.40	3.69	0.75	0.00
	Water unspec	16.22	0.57	14.84	0.21	0.00

13.3.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the Grab & Go segment, in most impact categories one of the biggest parts 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 significant share of the burdens of the impact categories ‘Aquatic Eutrophication’ and ‘Use of Nature’. It is also relevant regarding ‘Photo-Oxidant Formation’ ‘Acidification’, ‘Terrestrial Eutrophication’, ‘Particulate Matter’ and the consumption of ‘Total Primary Energy’ and ‘Non-renewable Primary Energy’.

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 significantly to the acidifying potential.

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

The production of plastics for the sleeves of the beverage carton systems shows significant 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 only exception is the inventory category ‘Non-renewable Primary Energy’, where it makes up about half of the total burdens in the beverage cartons with fossil-based plastics.

The beverage cartons used for the packaging of ambient JNSD also contain aluminium foil. The production of aluminium contributes mainly to the impact categories ‘Climate Change’, ‘Acidification’ and ‘Particulate Matter’ as well as to the inventory categories regarding primary energy.

The sector top, closure & label plays a role in almost all impact categories. The impacts of the production of plastics for the top and closures is higher for the two Tetra Top packagings systems than for the TBA edge and TBA square cartons as more plastic is used for the top element of those packaging systems.

Especially if bio-based plastics are used for sleeve or closure the burdens of all impact categories apart from 'Climate Change' are heavily influenced if not dominated by the provision of bioplastics. One reason for the big influence on most impact categories is the high energy demand, the use of mainly fossil fuels 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 and the related use of mainly fossil fuels are reflected in the indicators Particulate Matter, Total primary energy, terrestrial eutrophication and acidification. By burning bagasse on the field a considerable contribution is observed in Particulate Matter. The emissions of the polymerisation process play a considerable role in Climate Change and Photo-Oxidant Formation.

The converting process generally plays a minor role. 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 sectors transport packaging, filling and distribution show small burdens for all beverage carton systems in most impact categories. None of these sectors, though, plays an important role on the overall results in any category for most packaging systems.

The sector recycling & disposal of the regarded beverage cartons is most relevant in the impact categories 'Climate Change', 'Photo-Oxidant Formation', 'Terrestrial Eutrophication' and to a lower extent 'Acidification'. As beverage cartons do not undergo a material recycling in Denmark, the greenhouse gases are generated due to the incineration in MSWI facilities. The contributions to the impact categories 'Acidification', and 'Terrestrial eutrophication' are mainly caused by NO_2 emissions from incineration plants as well.

Emissions of regenerative CO_2 (CO2 reg (EOL)) from incineration plants play a significant 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 sector recycling & disposal they represent the total CO_2 emissions from the packaging's end-of-life. For the 'Tetra Top Mini bio-based' the CO2 reg (EOL) emissions are significantly higher than the fossil-based of recycling & disposal.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits do not play a role as in Denmark beverage cartons are not collected for recycling.

The energy credits arise from incineration plants, where energy recovery takes place.

The uptake of CO_2 by the trees harvested for the production of paperboard plays a significant role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. 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 Grab & Go 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. Exceptions are the 'Ozone Depletion Potential' of the HDPE bottles as well as 'Use of Nature' of all regarded plastic bottles.

For most impact categories the burdens from plastic production (sector PET/HDPE in the graphs) are higher for the HDPE bottles than for the PET bottles with the exception of 'Ozone Depletion Potential' where fossil-based HDPE shows only a low result whereas the production of terephtalic acid (PTA) for PET leads to high emissions of methyl bromide.

A distinct share of the eutrophying emissions in the PET and HDPE inventory datasets originate from phosphate emissions. They are caused by the production of antimony. In the applied datasets from PlasticsEurope, the production of antimony is represented by an Ecoinvent dataset. According to the methodology of Ecoinvent long-term emissions are generally considered. In this case, phosphate emissions originating from tailings are included into the datasets for a period of 100 years and lead to a dominating share on the eutrophying emissions. This aspect as well has to be considered in further interpretations and conclusions.

The energy-intensive converting process of all regarded bottles shows a considerable impact in all categories apart from 'Ozone Depletion Potential', 'Aquatic Eutrophication' and 'Use of Nature'.

The closures made from HDPE originate from crude oil. The extraction of crude oil is the main contributor to the 'Aquatic Eutrophication Potential'. Half of the emissions are caused by the COD and phosphate emissions.

The sectors transport packaging, filling and distribution show small burdens for all bottles in most impact categories. None of these sectors, though, plays an important role on the overall results in any category. An exception is the sector filling for the PET bottles, because the filling process includes the stretch blowing of the preforms to bottles as this takes place at the filling plant.

The impact of the plastic bottles' recycling & disposal sector is most significant regarding 'Climate Change'. The incineration of plastic bottles in MSWIs causes high greenhouse gas emissions. As the PET bottles are not collected for recycling in Denmark and the HDPE bottles's recycling rate is relatively low (15%) the amount of bottle waste incinerated is very high.

For the regarded plastic bottles more credits for energy recovery are given than for material recycling. The energy credits mainly originate from the incineration plants.

Glass bottle

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

All other life cycle sectors play only a minor role compared to the glass production. Exceptions to a certain extent are the filling step and recycling & disposal. For the impact category 'Climate Change', the sector top, closure & label 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'.

Please note that the categories 'Water Use' and 'Use of Nature' do not deliver robust enough data to take them into account further on in this study (please see details in section 1.8). Therefore these categories will not feature in the comparison and sensitivity sections, nor will they be considered for the final conclusions. The graphs of the base results were included anyhow to give an indication about the importance of these categories.

13.3.3 Comparison between packaging systems

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

Table 107: Comparison of net results **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, DAIRY chilled, Denmark**

segment Grab & Go DAIRY chilled, Denmark	The net results of **Tetra Top Mini 330 mL** are lower (green)/ higher (orange) than those of		
	Tetra Top Mini biobased 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	28%	-66%	-69%
Acidification	-56%	-48%	-52%
Photo-Oxidant Formation	-31%	-21%	-32%
Ozone Depletion Potential	-90%	39%	-3%
Terrestrial Eutrophication	-60%	-32%	-41%
Aquatic Eutrophication	-79%	-34%	-42%
Particulate Matter	-55%	-45%	-49%
Total Primary Energy	-23%	-53%	-57%
Non-renewable Primary Energy	27%	-65%	-67%

Table 108: Comparison of net results **Tetra Top Mini biobased 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, DAIRY chilled, Denmark**

segment Grab & Go DAIRY chilled, Denmark	The net results of **Tetra Top Mini biobased 330 mL** are lower (green)/ higher (orange) than those of		
	Tetra Top Mini 330 mL	HDPE bottle 4 350 mL	HDPE bottle 5 350 mL
Climate Change	-22%	-73%	-76%
Acidification	125%	17%	8%
Photo-Oxidant Formation	45%	14%	-1%
Ozone Depletion Potential	894%	1281%	867%
Terrestrial Eutrophication	153%	71%	50%
Aquatic Eutrophication	373%	212%	172%
Particulate Matter	122%	23%	13%
Total Primary Energy	31%	-39%	-43%
Non-renewable Primary Energy	-22%	-72%	-74%

JNSD chilled

In this segment no beverage cartons were examined for the Danish market.

JNSD ambient

Table 109: Comparison of net results **TBA edge HeliCap biobased 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Denmark**

segment Grab & Go JNSD ambient, Denmark	The net results of **TBA edge HeliCap biobased 250 mL** are lower (green)/ higher (orange) than those of			
	TBA edge Helicap 250 mL	TPA square DreamCap biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	-4%	-13%	-62%	-79%
Acidification	35%	-2%	-22%	-58%
Summer Smog	15%	-6%	-22%	-76%
Ozone Depletion Potential	269%	2%	-74%	-31%
Terrestrial Eutrophication	46%	-4%	-1%	-71%
Aquatic Eutrophication	126%	-2%	259%	166%
Human Toxicity: PM 2.5	35%	-3%	-18%	-64%
Total Primary Energy	10%	-6%	-35%	-54%
Non-renewable Primary Energy	-5%	-8%	-57%	-72%

Table 110: Comparison of net results **TBA edge HeliCap 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Denmark**

segment Grab & Go JNSD ambient, Denmark	The net results of **TBA edge Helicap 250 mL** are lower (green)/ higher (orange) than those of			
	TBA edge HeliCap biobased 250 mL	TPA square DreamCap biobased 330 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	4%	-9%	-60%	-78%
Acidification	-26%	-28%	-42%	-69%
Summer Smog	-13%	-18%	-32%	-79%
Ozone Depletion Potential	-73%	-72%	-93%	-81%
Terrestrial Eutrophication	-31%	-34%	-32%	-80%
Aquatic Eutrophication	-56%	-57%	59%	18%
Human Toxicity: PM 2.5	-26%	-28%	-39%	-73%
Total Primary Energy	-9%	-15%	-41%	-58%
Non-renewable Primary Energy	5%	-4%	-55%	-71%

Table 111: Comparison of net results **TPA square DreamCap biobased 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Denmark**

segment Grab & Go JNSD ambient, Denmark	The net results of **TPA square DreamCap biobased 330 mL** are lower (green)/ higher (orange) than those of			
	TBA edge Helicap 250 mL	TBA edge HeliCap biobased 250 mL	APET bottle 330 mL	Glass bottle 2 250 mL
Climate Change	10%	14%	-57%	-76%
Acidification	38%	2%	-20%	-57%
Summer Smog	22%	7%	-17%	-74%
Ozone Depletion Potential	263%	-2%	-74%	-32%
Terrestrial Eutrophication	52%	4%	3%	-70%
Aquatic Eutrophication	130%	2%	267%	172%
Human Toxicity: PM 2.5	38%	3%	-16%	-63%
Total Primary Energy	17%	7%	-30%	-51%
Non-renewable Primary Energy	4%	9%	-53%	-70%

14 Sensitivity Analyses Denmark

14.1 Dairy

14.1.1 Sensitivity analysis on system allocation Dairy Denmark

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 subjective 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%.

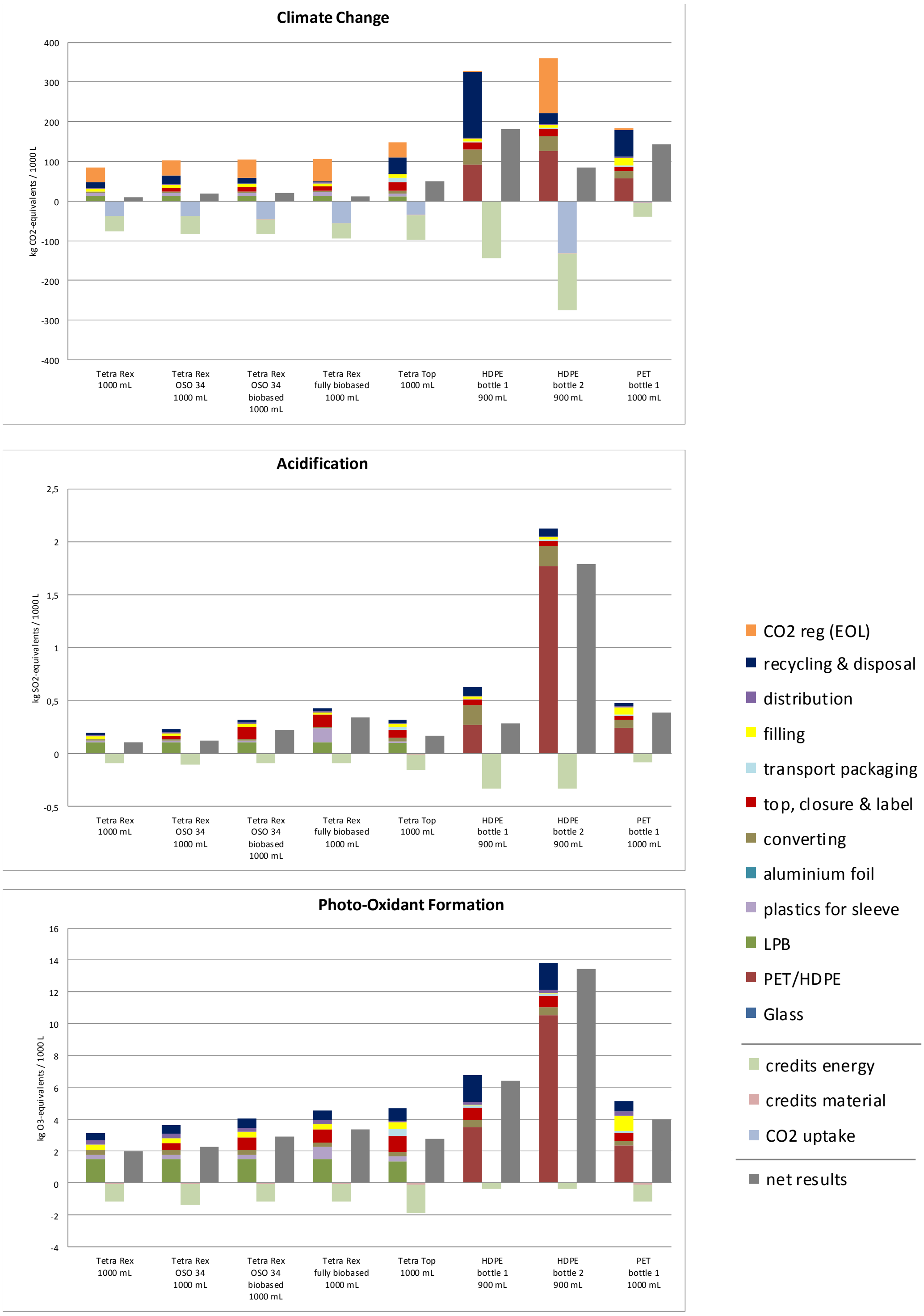


Figure 138: Indicator results for sensitivity analysison on system allocation; **segment DAIRY, Denmark**, Allocation factor 100% (Part 1)

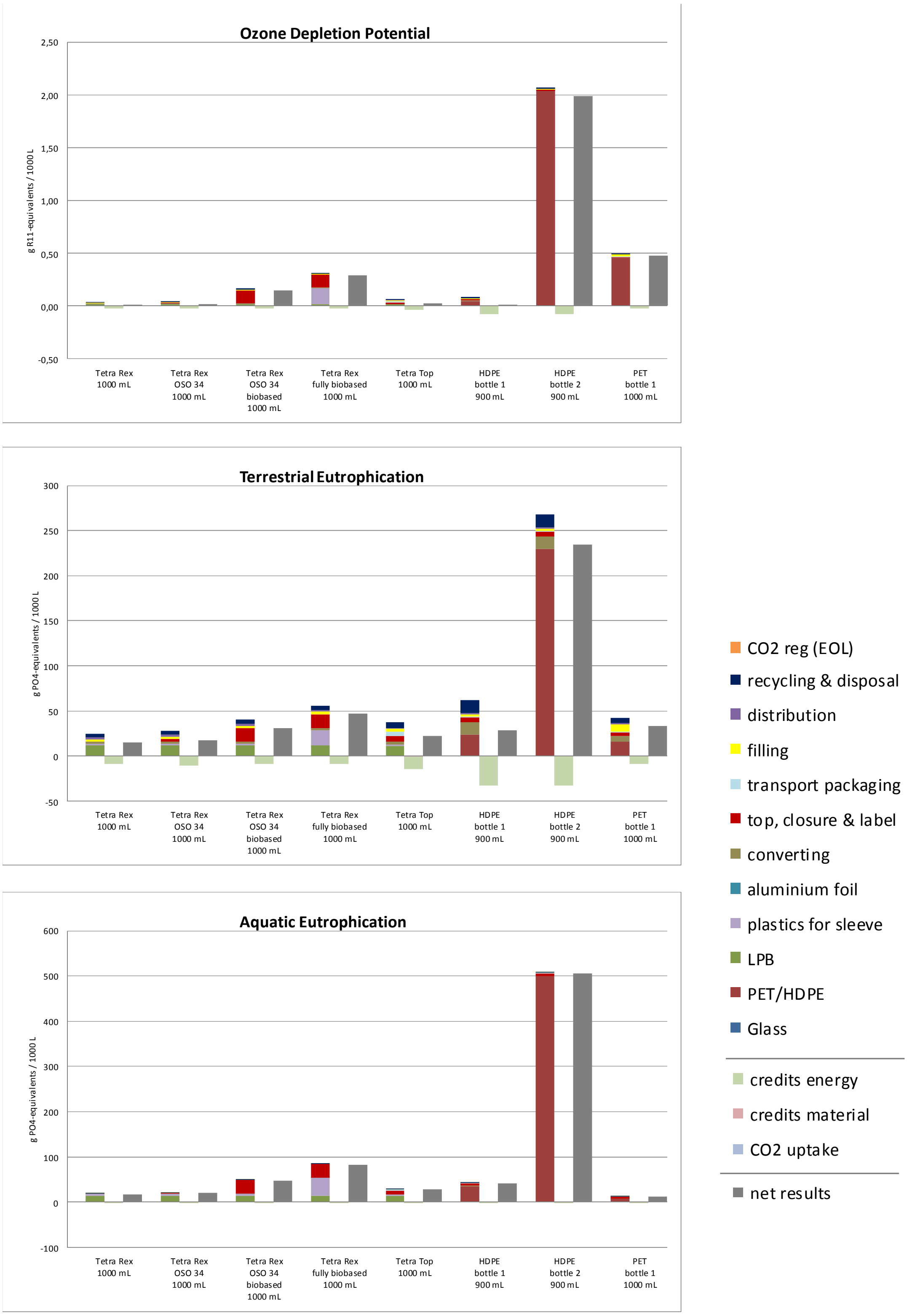


Figure 139: Indicator results for sensitivity analysison on system allocation; **segment DAIRY, Denmark**, Allocation factor 100% (Part 2)

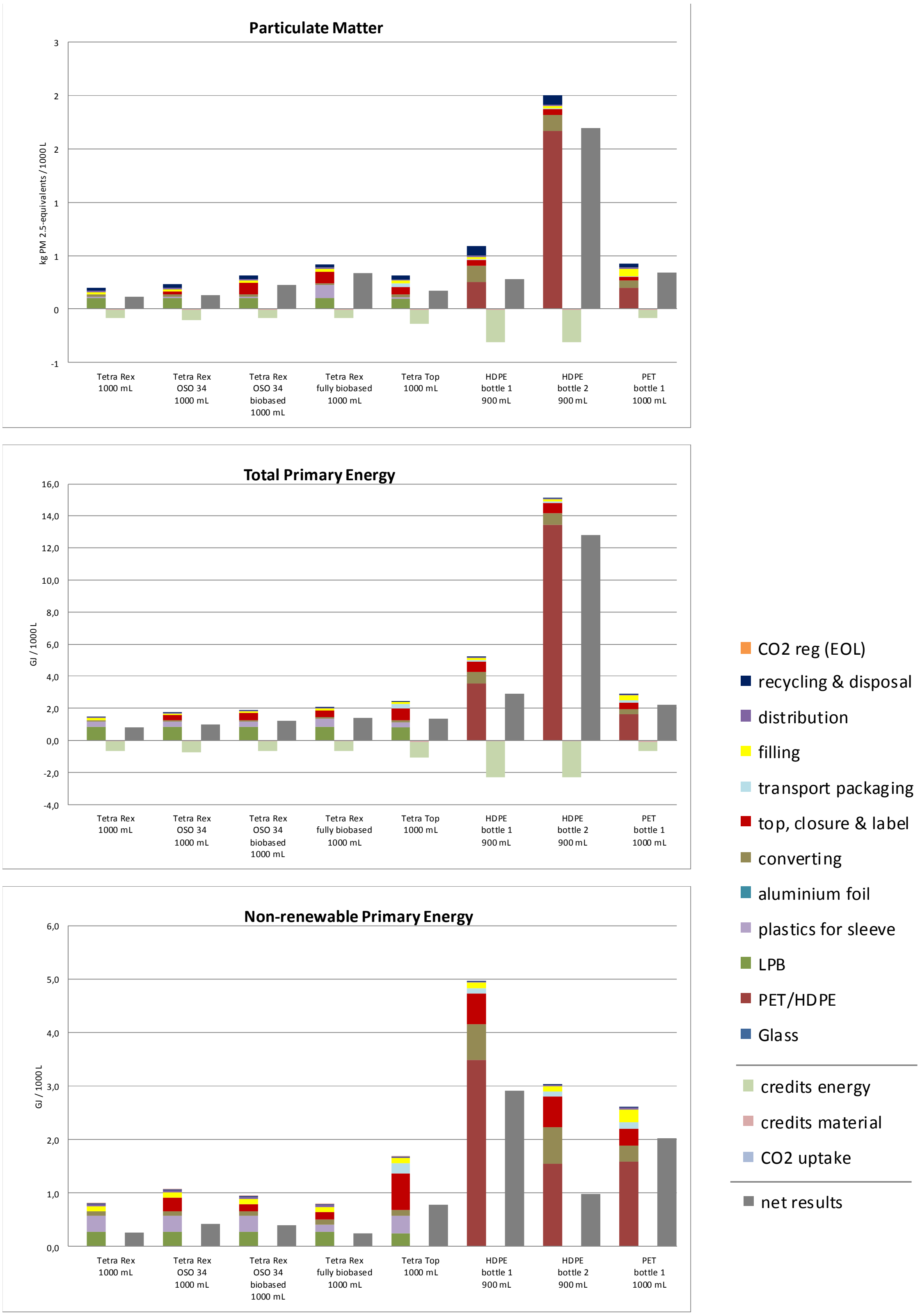


Figure 140: Indicator results for sensitivity analysison on system allocation; **segment DAIRY, Denmark**, Allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all systems examined, the net results of the impact category ‘Climate Change’ are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Danish market the electricity credited is the Danish grid mix with its relatively low share of fossil energy sources.

14.1.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are be analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

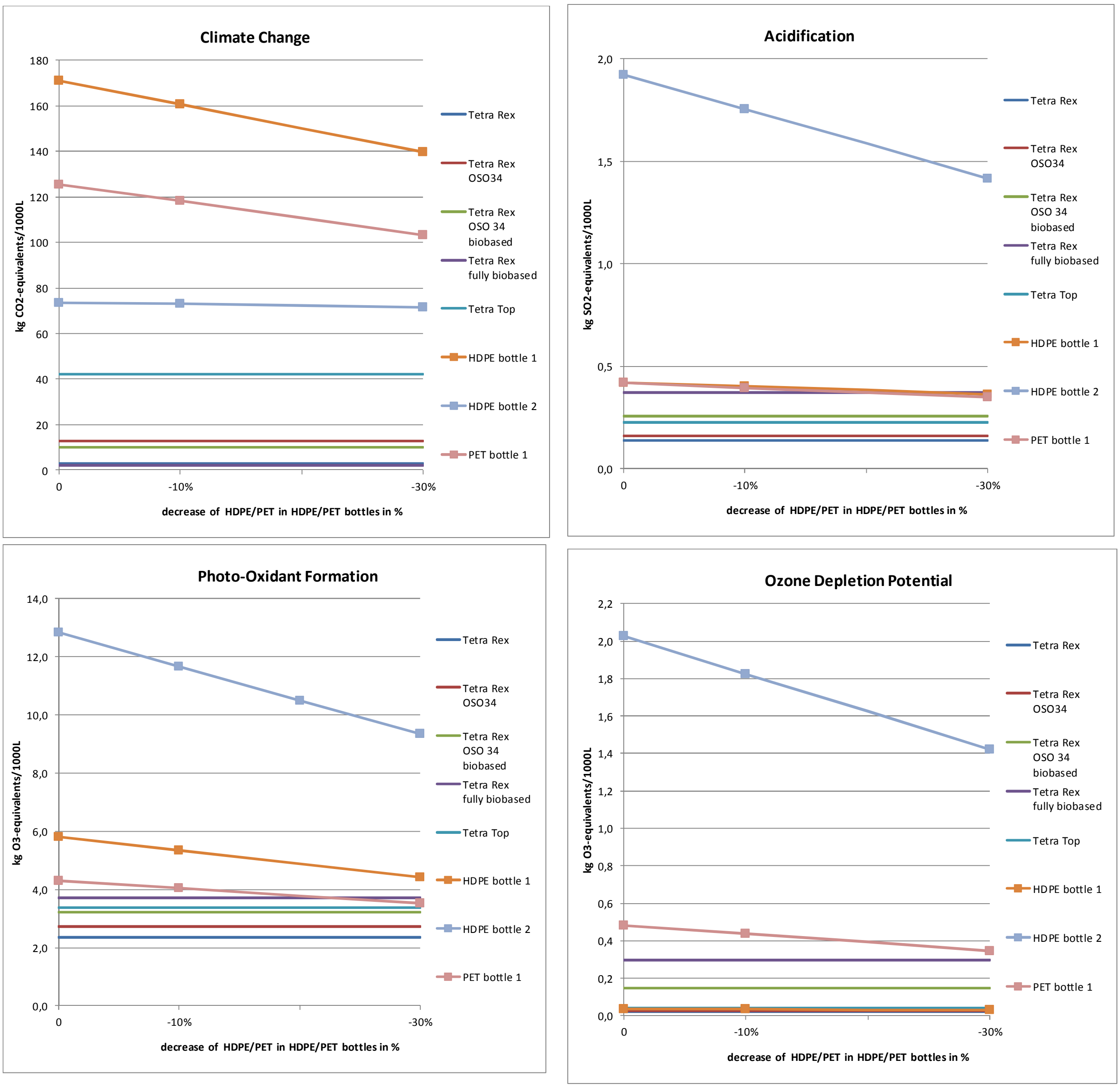


Figure 141: Indicator results for sensitivity analysison on plastic bottle weights; **segment DAIRY, Denmark**, Allocation factor 50% (Part 1)

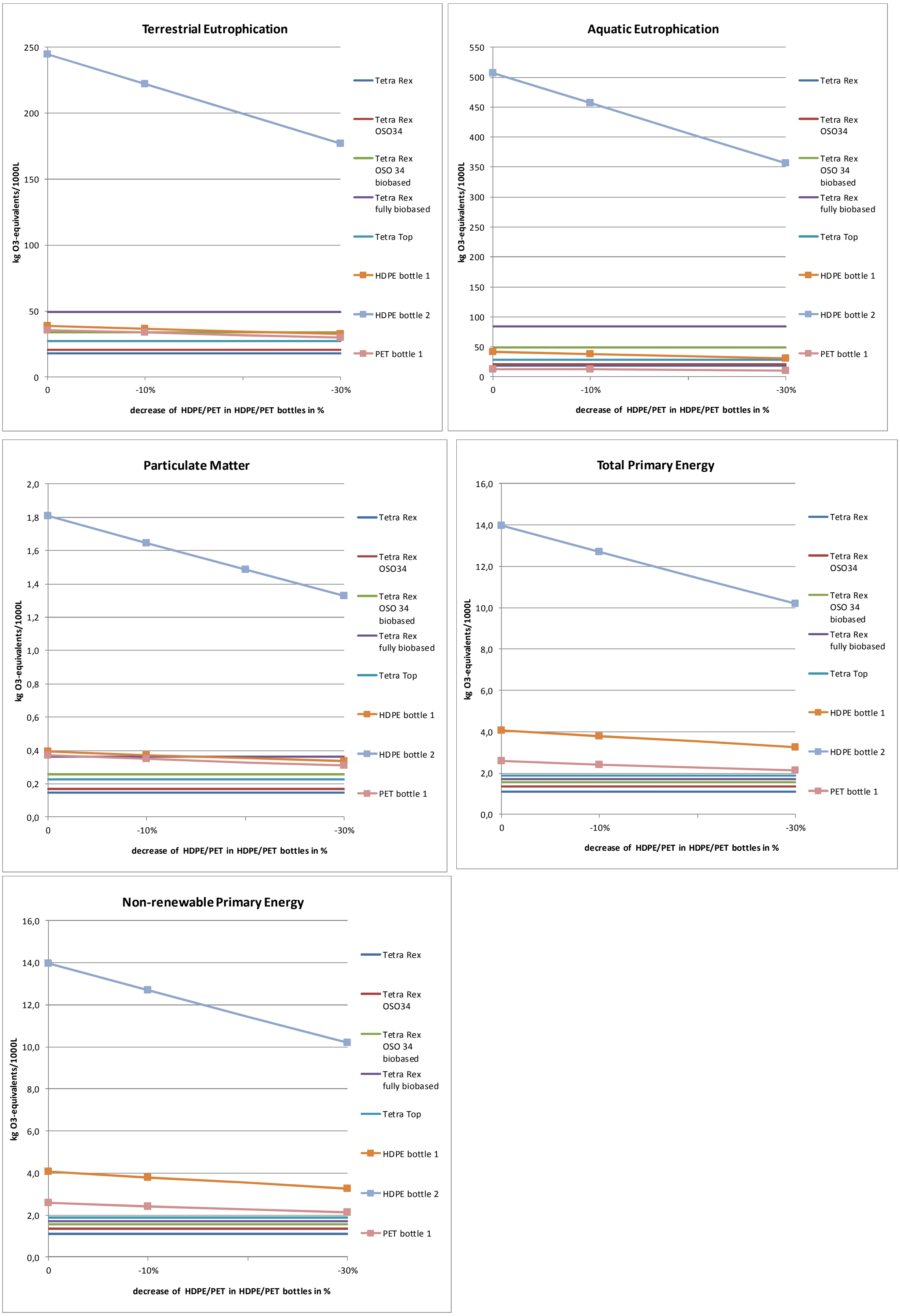


Figure 142: Indicator results for sensitivity analysison on plastic bottle weights; **segment DAIRY, Denmark**, Allocation factor 50% (Part 2)

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In most cases though, even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of beverage cartons is met.

A lightweight 'HDPE bottle 1' shows a lower result than the 'Tetra Rex fully bio-based' in the categories Acidification from a break-even point of around 20% weight reduction. It also breaks even with 'Tetra Rex OSO 34 bio-based in the category 'Terrestrial Eutrophication' at about 20% weight reduction and with ''Tetra Rex fully bio-based' in the category 'Particulate Matter' at about 15% weight reduction.

A lightweight 'HDPE bottle 2' would never achieve lower results than any of the beverage cartons in any impact category even with a weight reduction of 30%.

A lightweight version of the 'PET bottle 1' reaches break-even with 'Tetra Rex fully bio-based' in the categories 'Acidification' (at ca. 20%), 'Photo-Oxidant Formation (at ca. 25%), 'Ozone Depletion Potential' (at ca. 3%) and 'Particulate Matter' at about 5% weight reduction.

For the impact category 'Climate Change' and in the inventory categories related to primary energy demand none of the lightweight bottles achieves lower results than any of the beverage cartons.

14.1.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

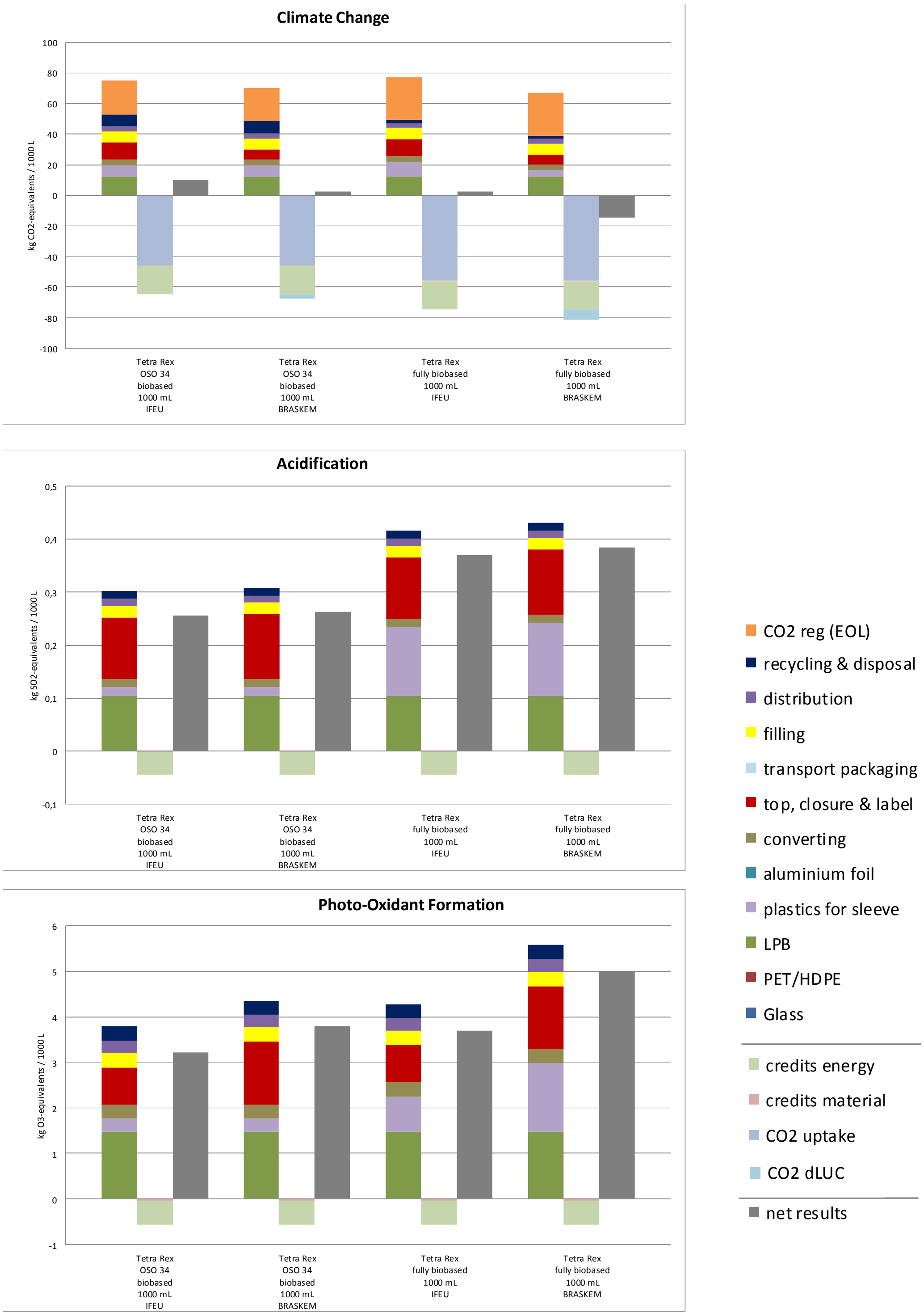


Figure 143: Indicator results for sensitivity analysis on Bio-PE dataset; **segment DAIRY, Denmark**, Allocation factor 50% (Part 1)

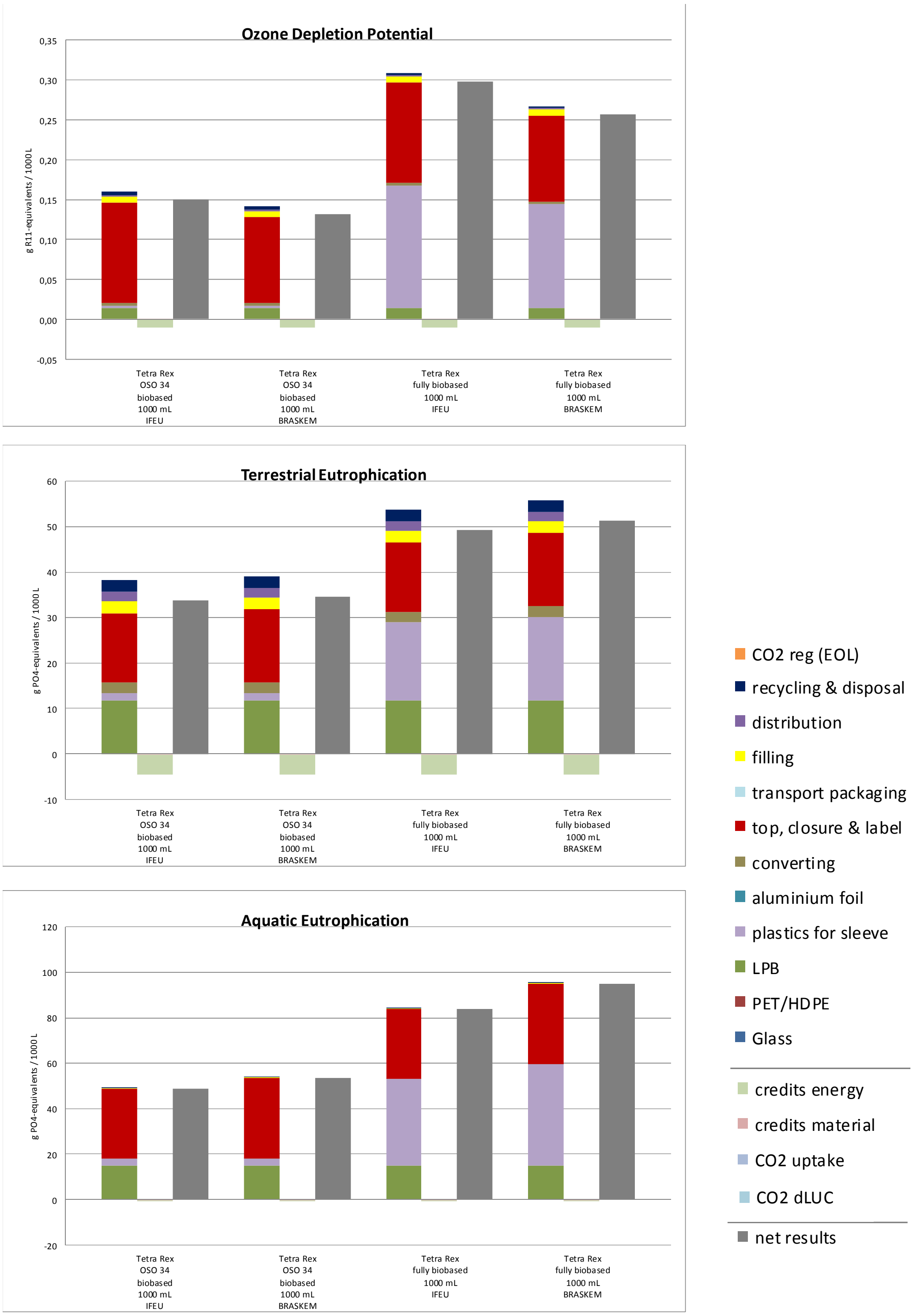


Figure 144: Indicator results for sensitivity analysis on Bio-PE dataset; **segment DAIRY, Denmark**, Allocation factor 50% (Part 2)

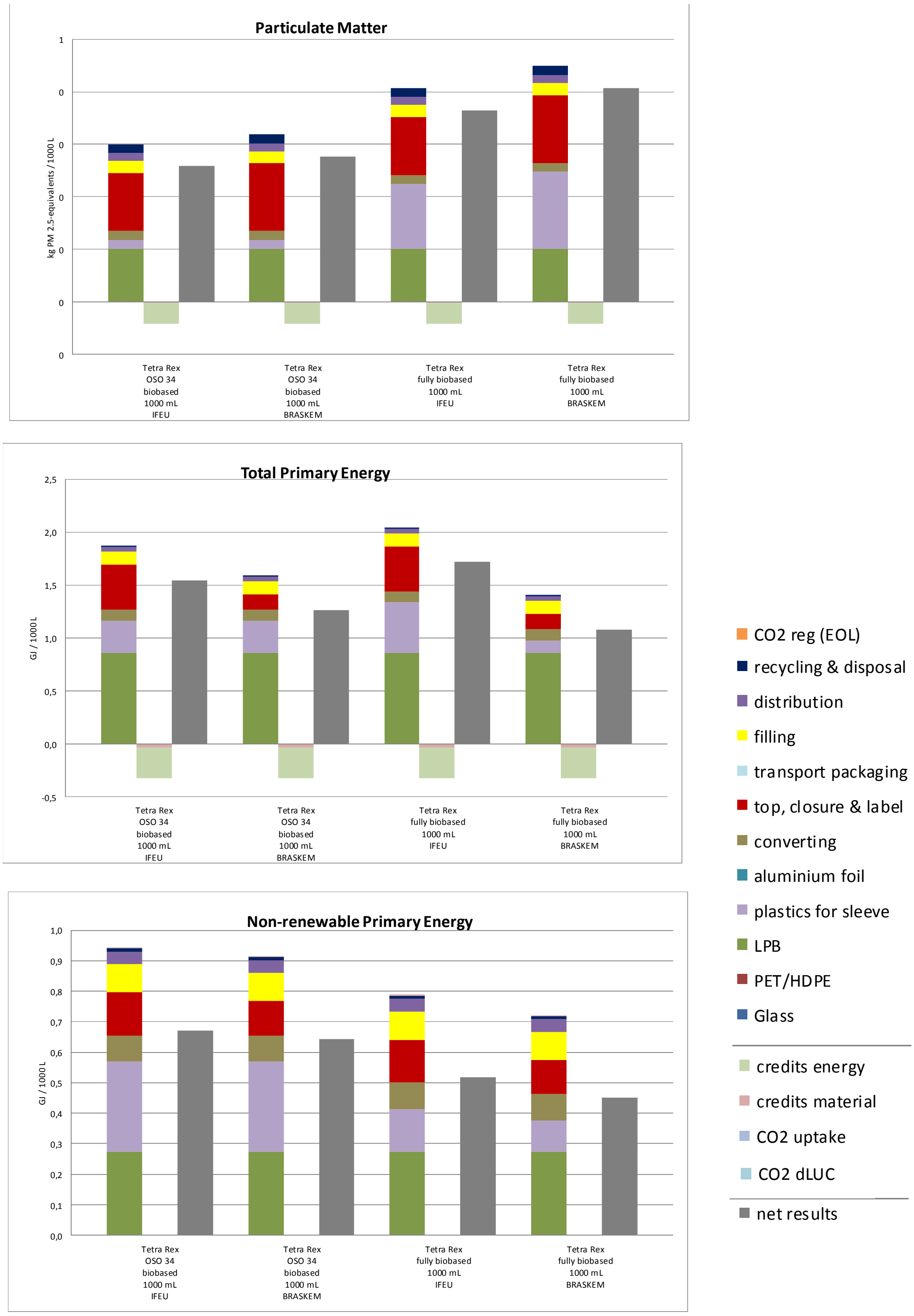


Figure 145: Indicator results for sensitivity analysis on Bio-PE dataset; **segment DAIRY, Denmark**, Allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the Tetra Rex cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower' Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of dairy packaging on the Danish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

14.2 JNSD

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 norm's recommendation on subjective 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%.

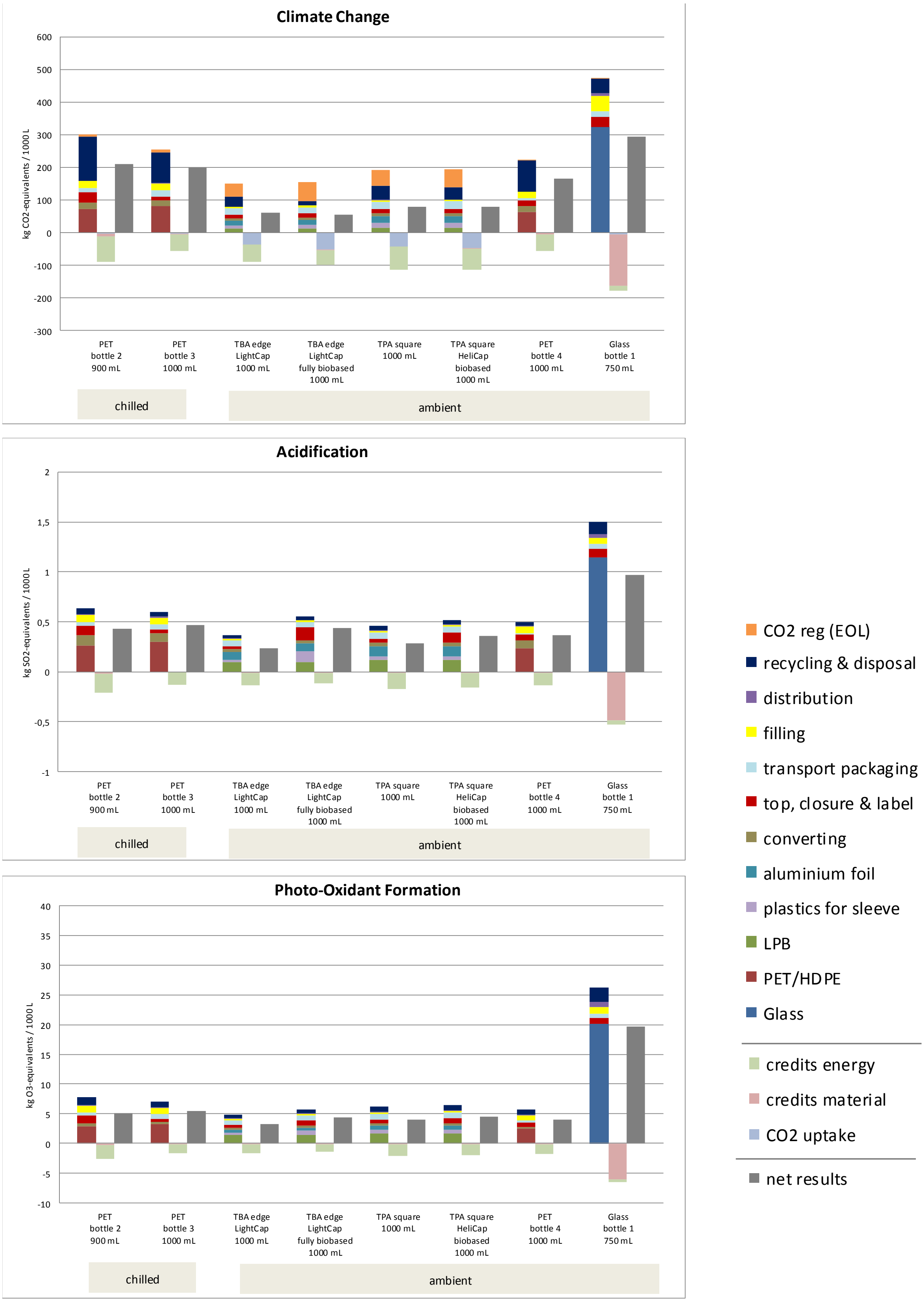


Figure 146: Indicator results for sensitivity analysison on system allocation; **segment JNSD, Denmark**, Allocation factor 100% (Part 1)

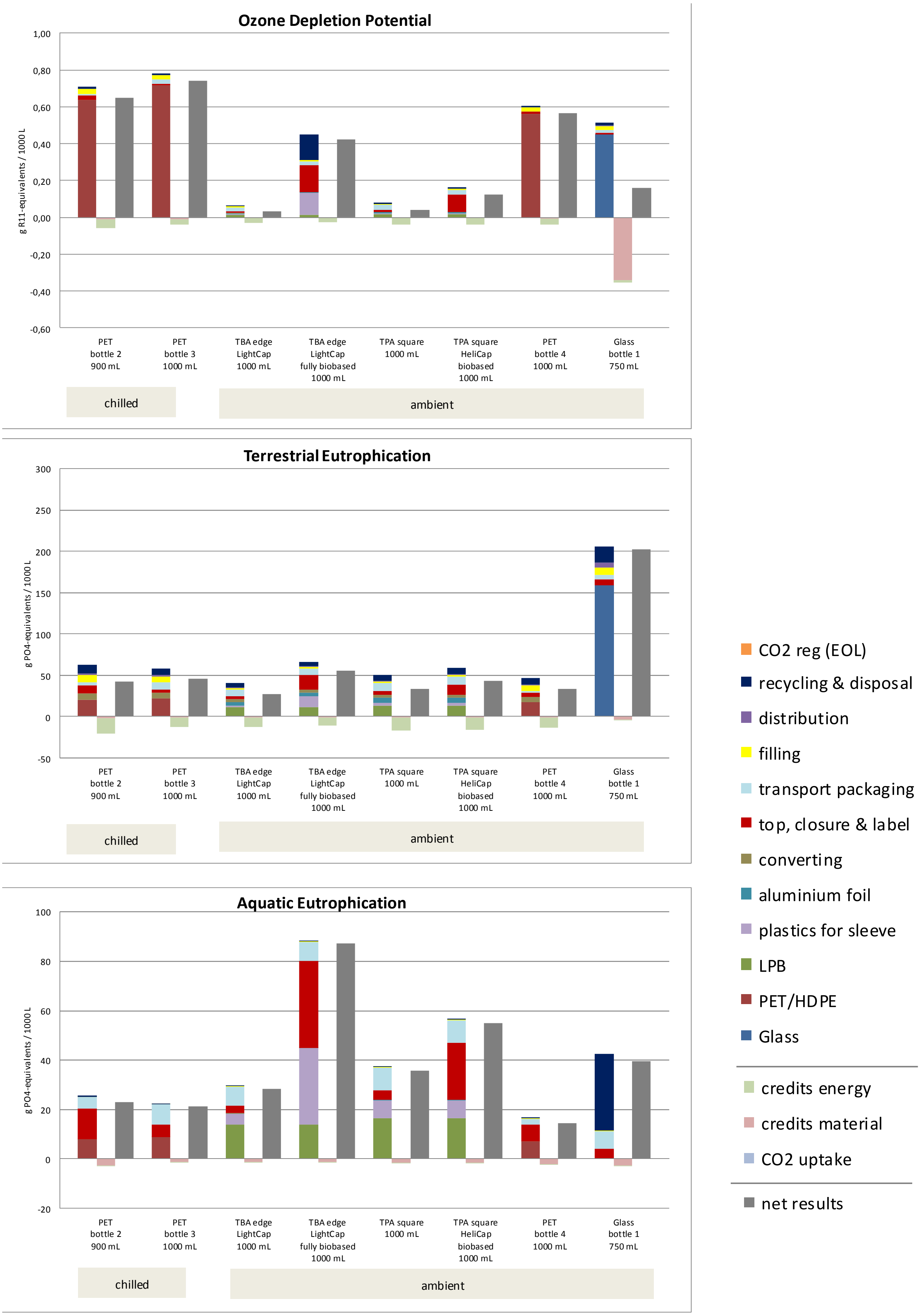


Figure 147: Indicator results for sensitivity analysison on system allocation; **segment JNSD, Denmark**, Allocation factor 100% (Part 2)

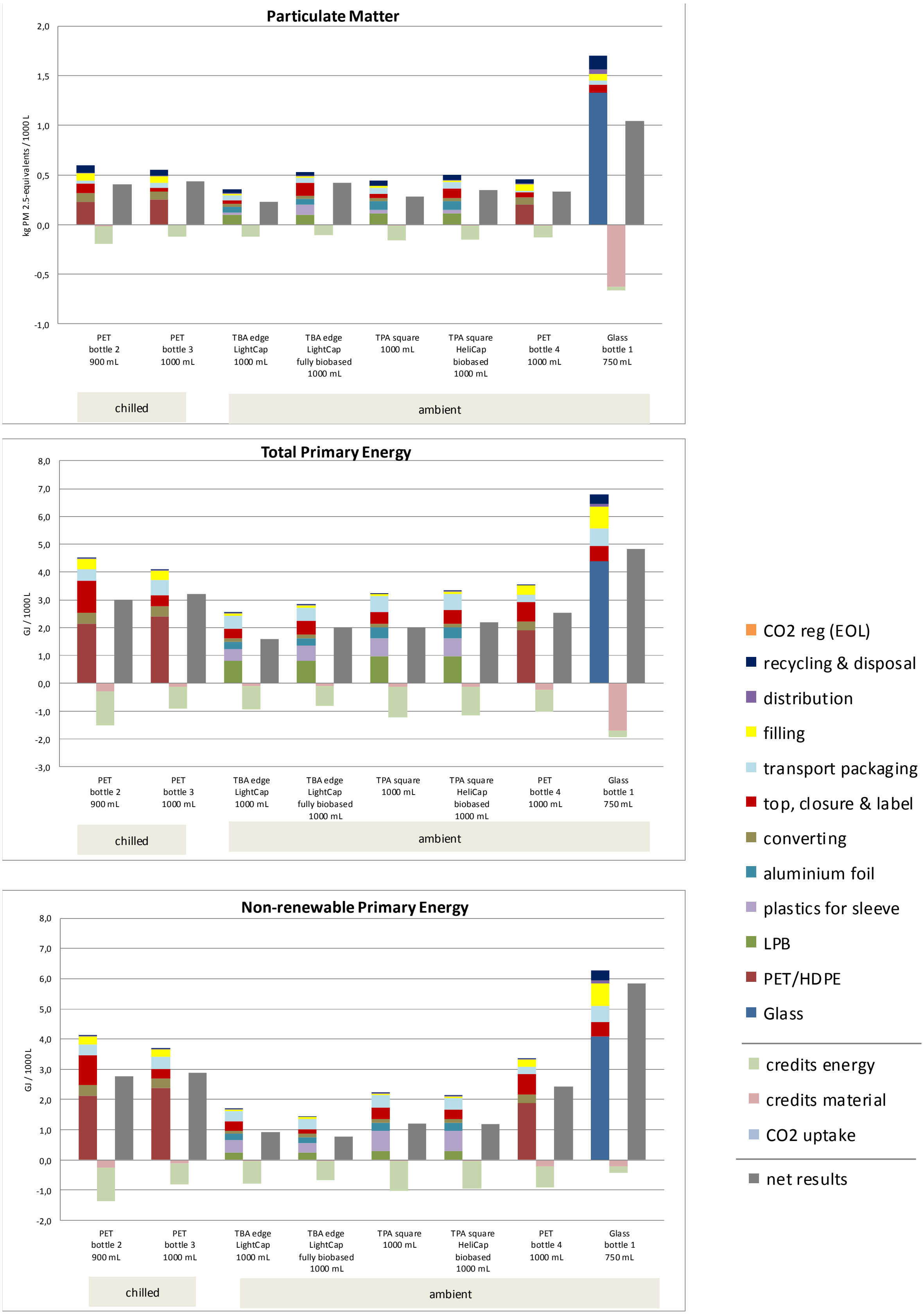


Figure 148: Indicator results for sensitivity analysison on system allocation; **segment JNSD, Denmark**, Allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Danish market the electricity credited is the Danish grid mix with its relatively low share of fossil energy sources.

14.2.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are be analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

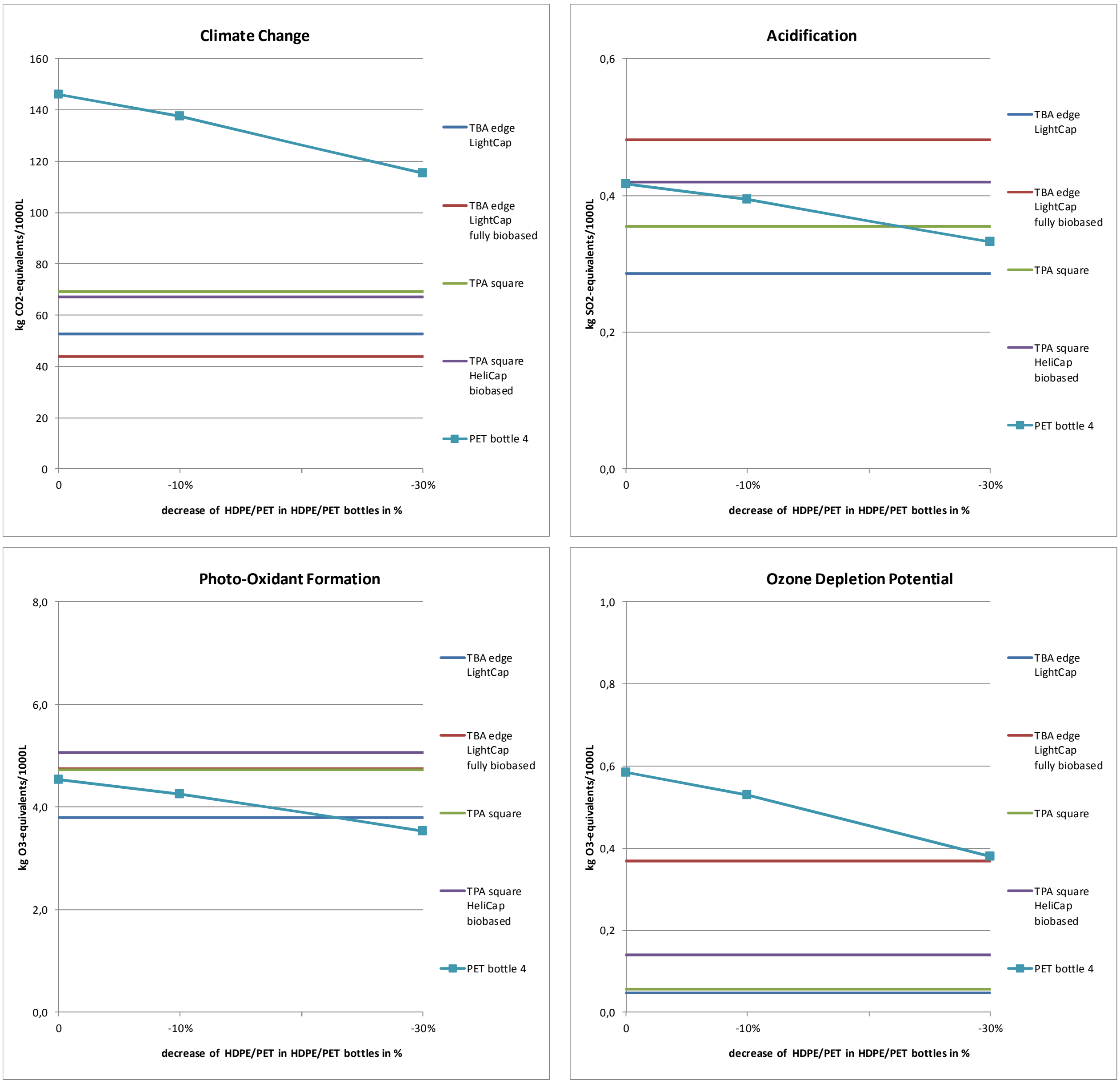


Figure 149: Indicator results for sensitivity analysis on bottle weights, segment **JNSD, Denmark**, Allocation factor 50% (Part 1)

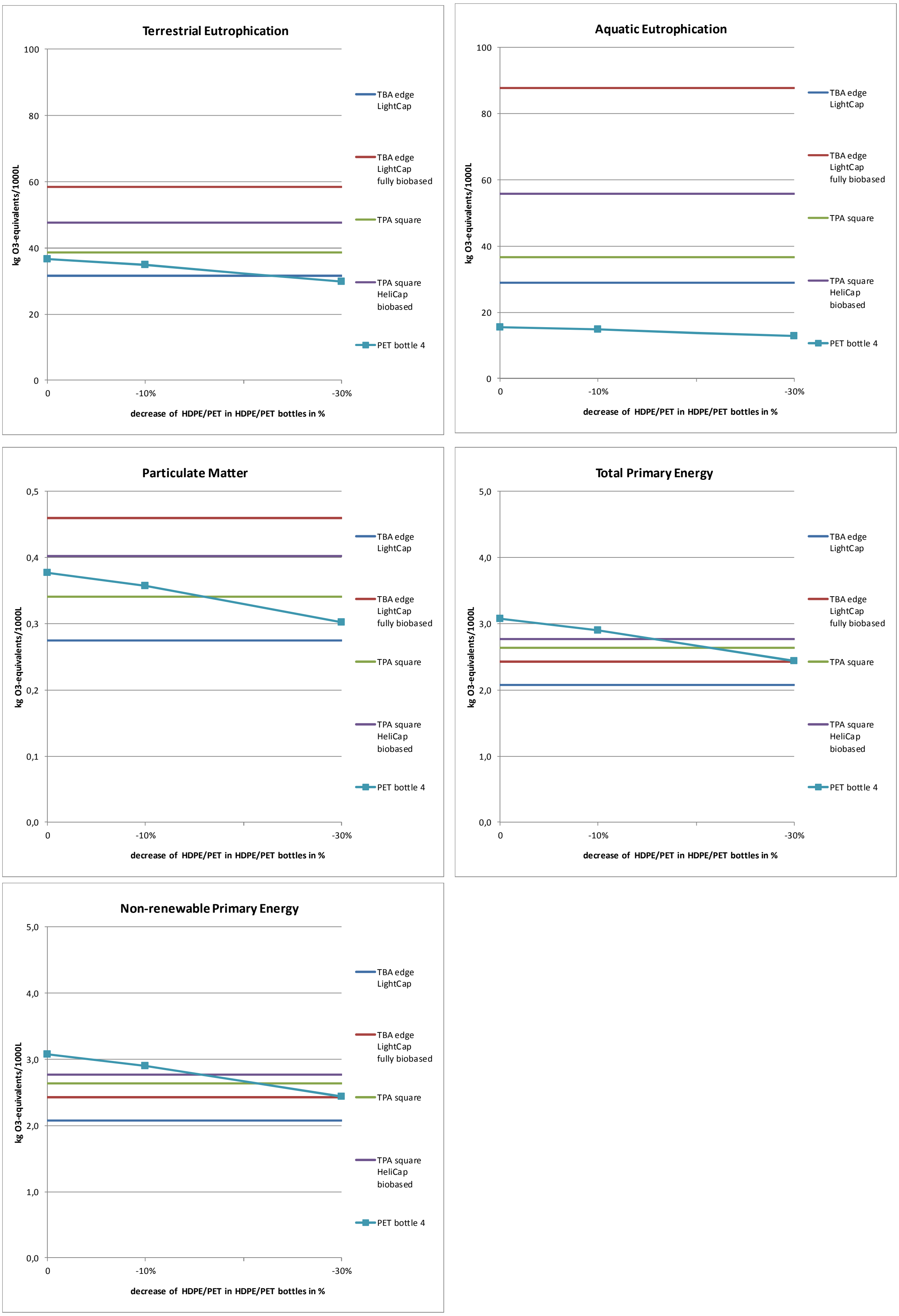


Figure 150: Indicator results for sensitivity analysis on bottle weights, segment **JNSD, Denmark**, Allocation factor 50% (Part 2)

Description and Interpretation

For the JNSD segment only the 'PET bottle 4' is recalculated with reduced weight, as the plastic bottles 'PET bottle 2' and 'PE bottle 3' are for chilled JNSD, for which no beverage carton has been examined.

A lightweight 'PET bottle 4' does not achieve lower results than any of the regarded beverage cartons in the impact categories 'Climate Change' and 'Ozone Depletion Potential', even if its weight is reduced by 30%.

It reaches break-even though with 'TPA square' in 'Acidification' at about 20% weight reduction and 'Particulate Matter' at ca. 15%, as well as with 'TBA edge LightCap' in 'Photo-Oxidant Formation' and 'Terrestrial Eutrophication' at about 25% weight reduction.

14.2.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu's own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

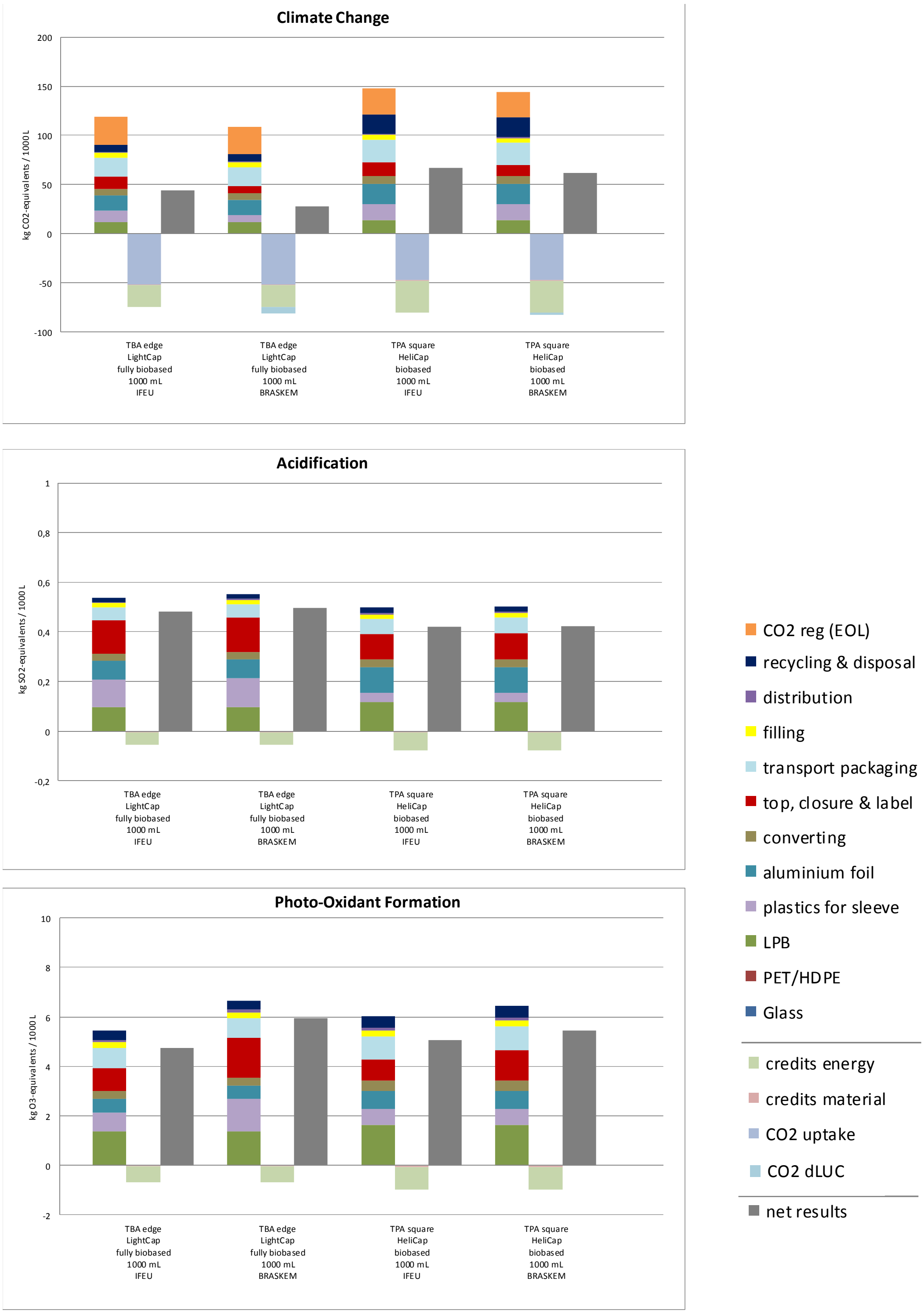


Figure 151: Indicator results for sensitivity analysis on Bio-PE dataset segment JNSD, Denmark, Allocation factor 50% (Part 1)

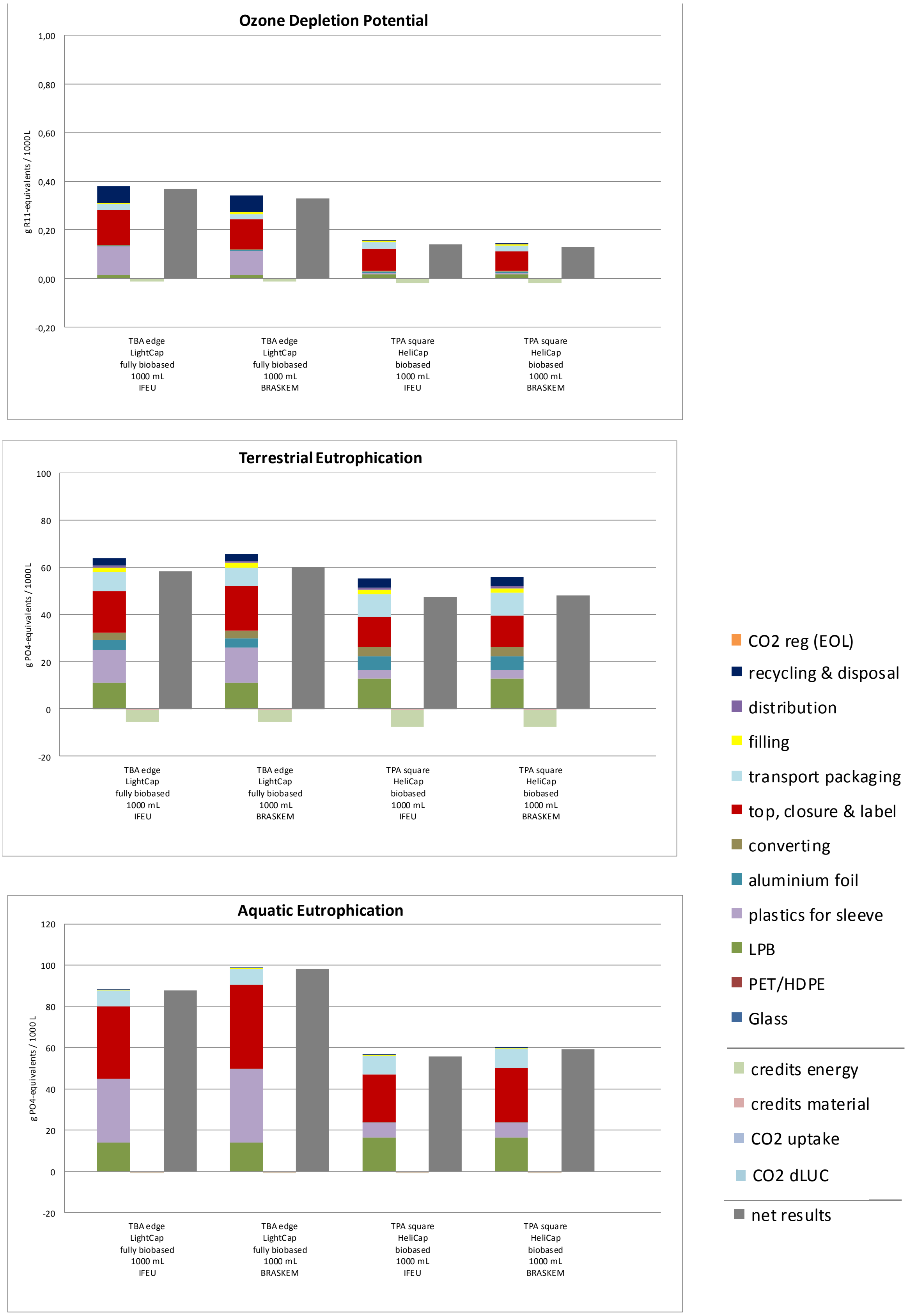


Figure 152: Indicator results for sensitivity analysis on Bio-PE dataset **segment JNSD, Denmark**, Allocation factor 50% (Part 2)

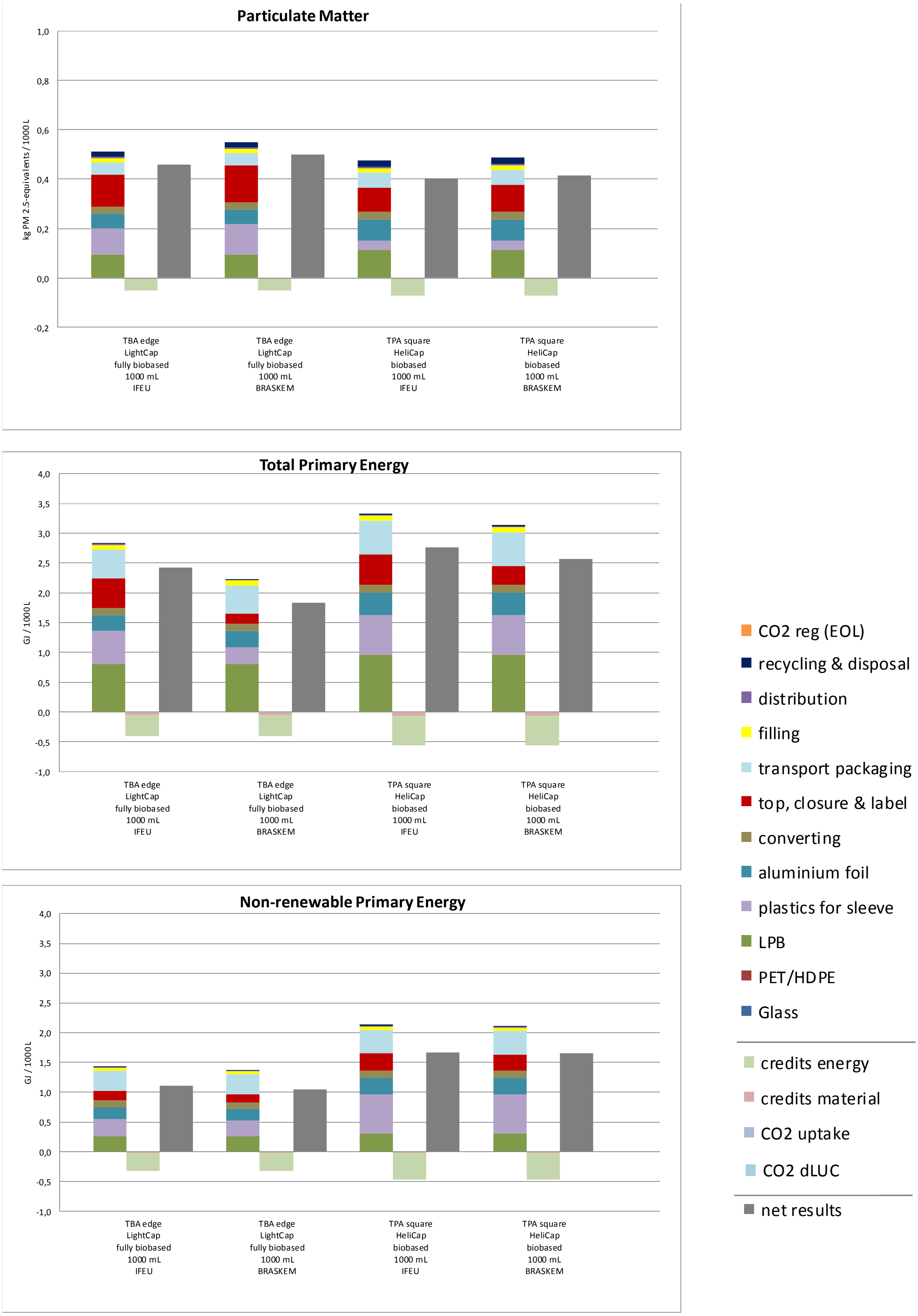


Figure 153: Indicator results for sensitivity analysis on Bio-PE dataset **segment JNSD, Denmark**, Allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the TBA edge and TPA square cartons with bio-based plastics modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category 'Climate Change' the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category 'Photo-Oxidant Formation'.

The main reason for the lower 'Climate Change' result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of JNSD packaging on the Danish market. It is relevant though for the environmental impact categories 'Climate Change' and Photo-Oxidant Formation'.

14.3 Grab & Go

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 norm's recommendation on subjective 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%.

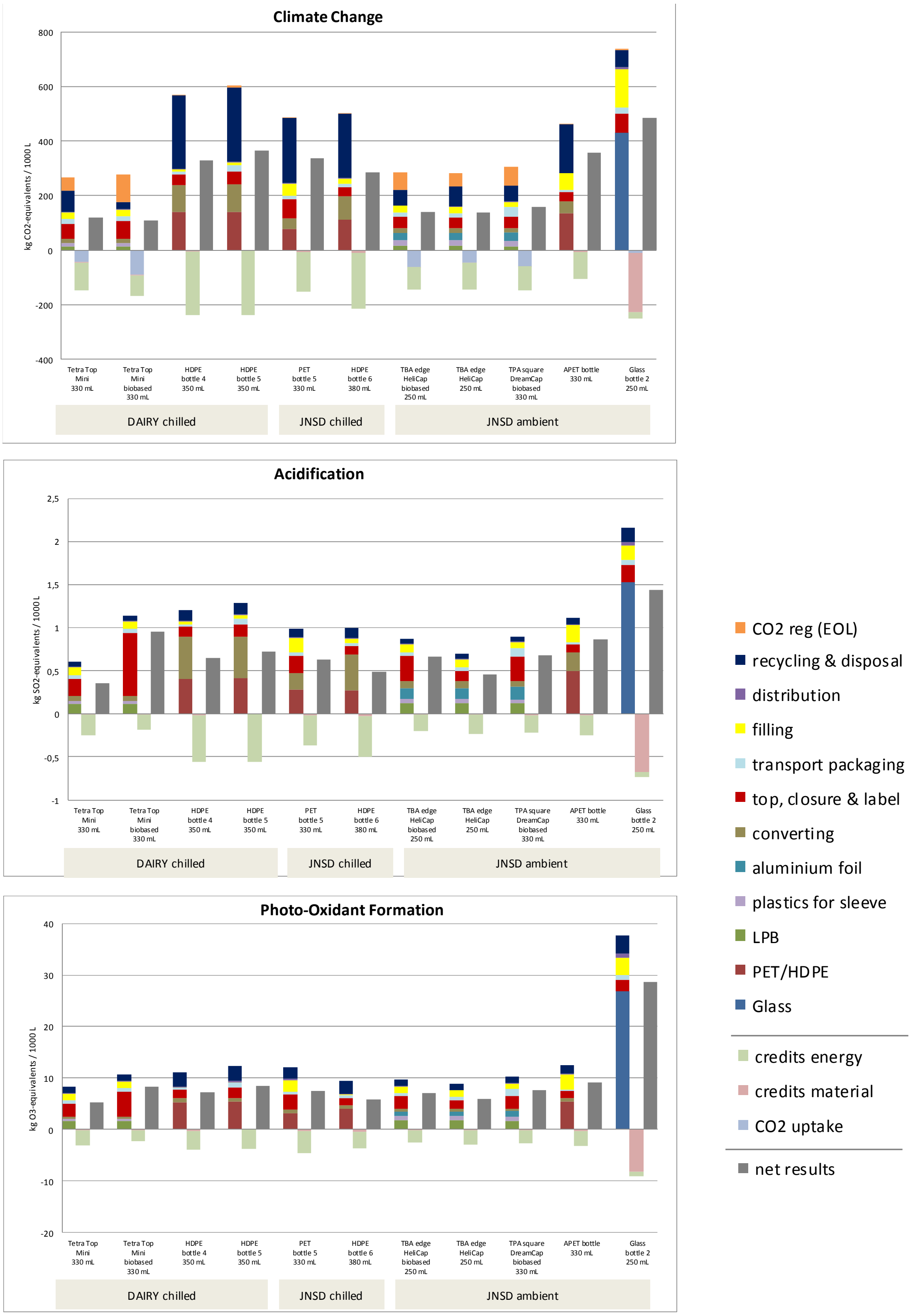


Figure 154: Indicator results for sensitivity analysis on system allocation; **segment Grab & Go, Denmark**, Allocation factor 100% (Part 1)

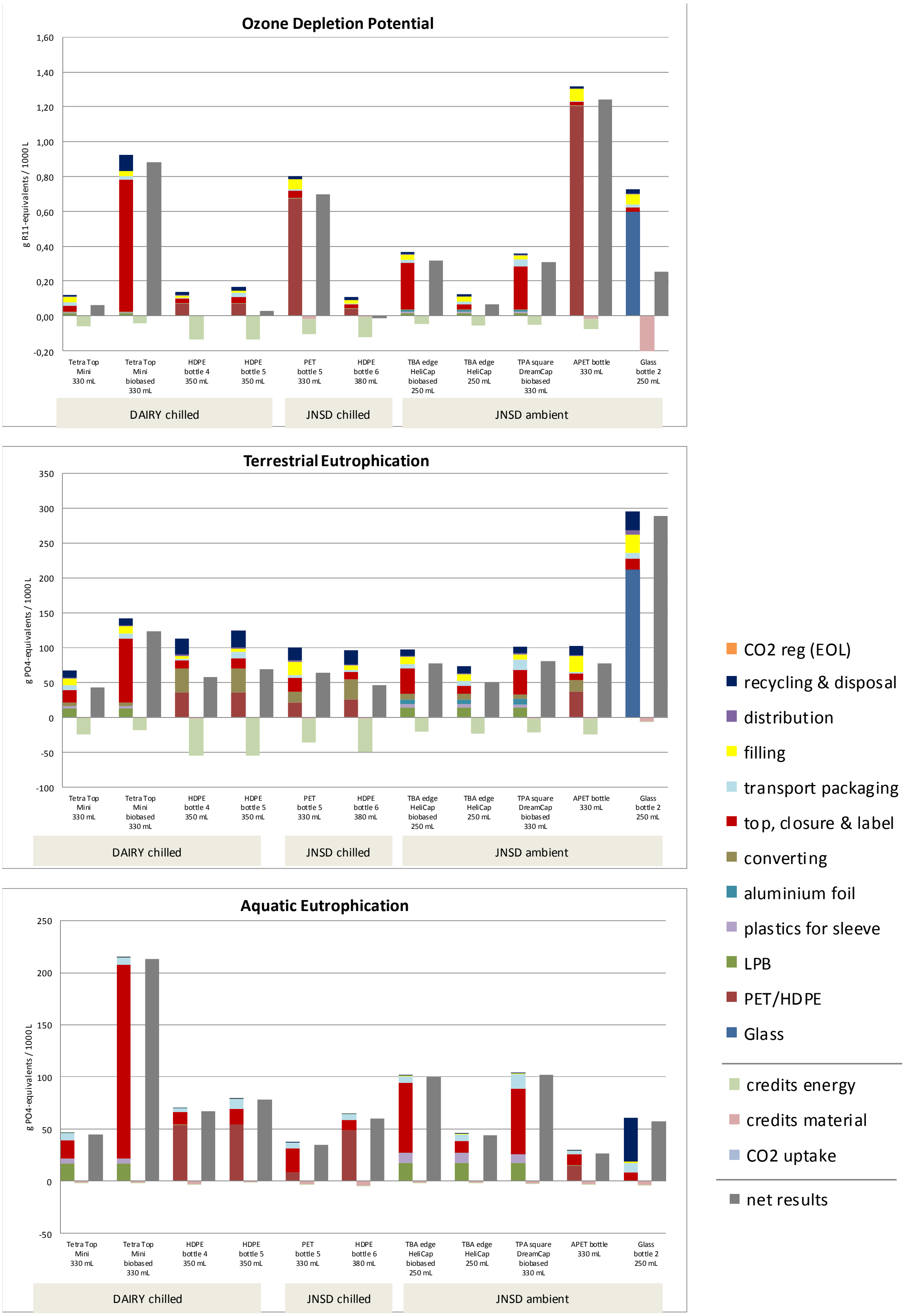


Figure 155: Indicator results for sensitivity analysis on system allocation; **segment Grab & Go, Denmark**, Allocation factor 100% (Part 2)

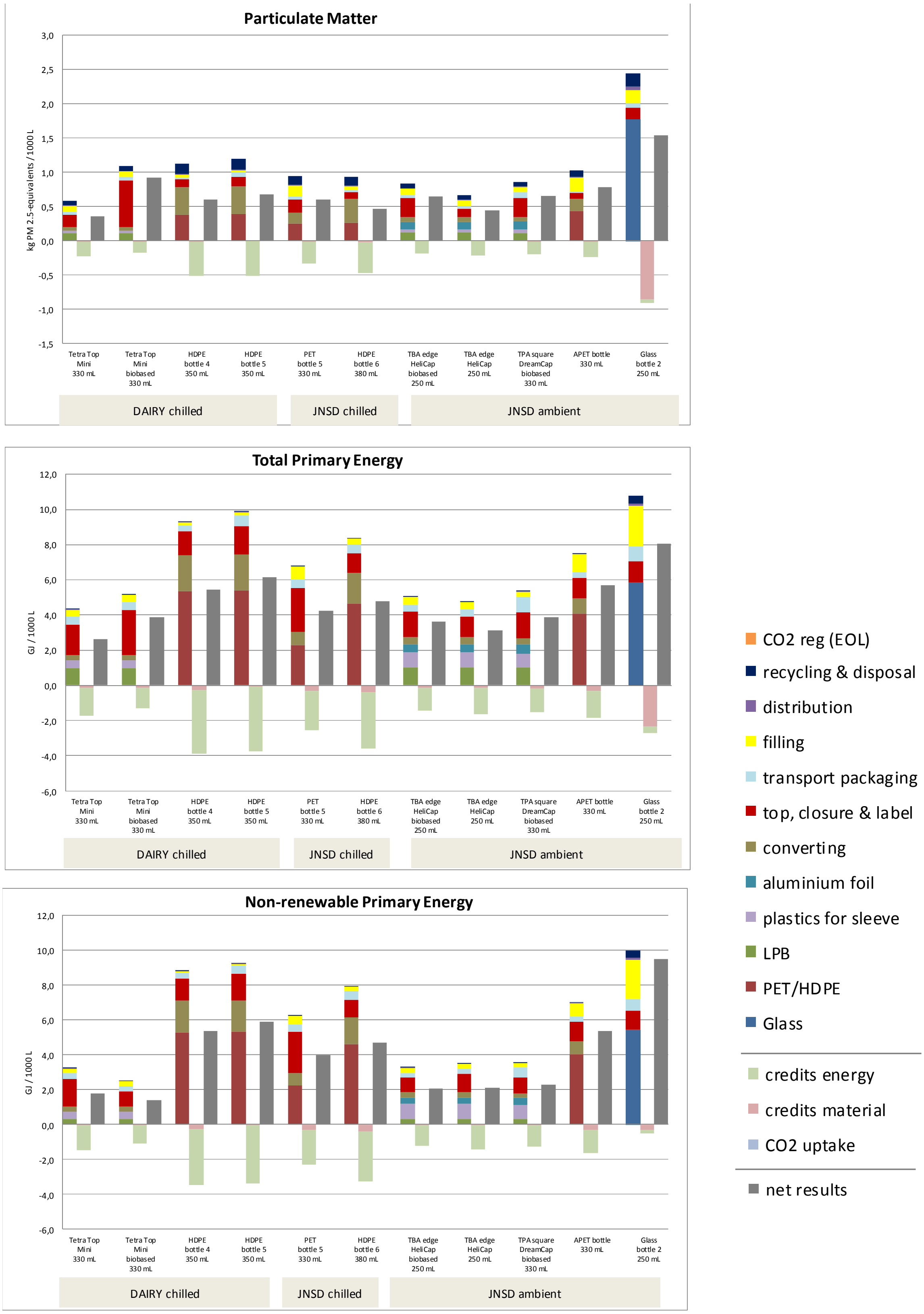


Figure 156: Indicator results for sensitivity analysis on system allocation; **segment Grab & Go, Denmark**, Allocation factor 100% (Part 3)

Description and interpretation

In general, the application of a higher allocation factor leads to lower net results for all examined systems in almost all regarded impact and inventory categories.

A higher allocation factor means the allocation of more burdens from the end-of-life processes (i.e. emissions from incineration, emissions from the production of electricity for recycling processes). It also means the allocation of more credits for the substitution of other processes (i.e. avoided electricity generation due to energy recovery at MSWIs).

In most cases, the benefits from the additional allocation of credits are higher than the additional burdens. That means the net results are lower with an applied allocation factor of 100 %.

There is one exception though: For all beverage cartons and plastic bottles examined, the net results of the impact category 'Climate Change' are higher with an allocation factor of 100 % instead of the allocation factor of 50 % of the base scenarios.

In that case, the allocation factor of 100 % means that all the emissions of the incineration are allocated to the system. This is of course also true for the energy credits for the energy recovery at the MSWI. These energy credits are relatively low though, as on the Danish market the electricity credited is the Danish grid mix with its relatively low share of fossil energy sources.

14.3.2 Sensitivity analysis regarding plastic bottle weights

To consider potential future developments in terms of weight of the plastic bottles, two additional weights of plastic bottles are be analysed and illustrated in this sensitivity analysis (for details please see section 2.4.4). Results are shown in the following break even graphs.

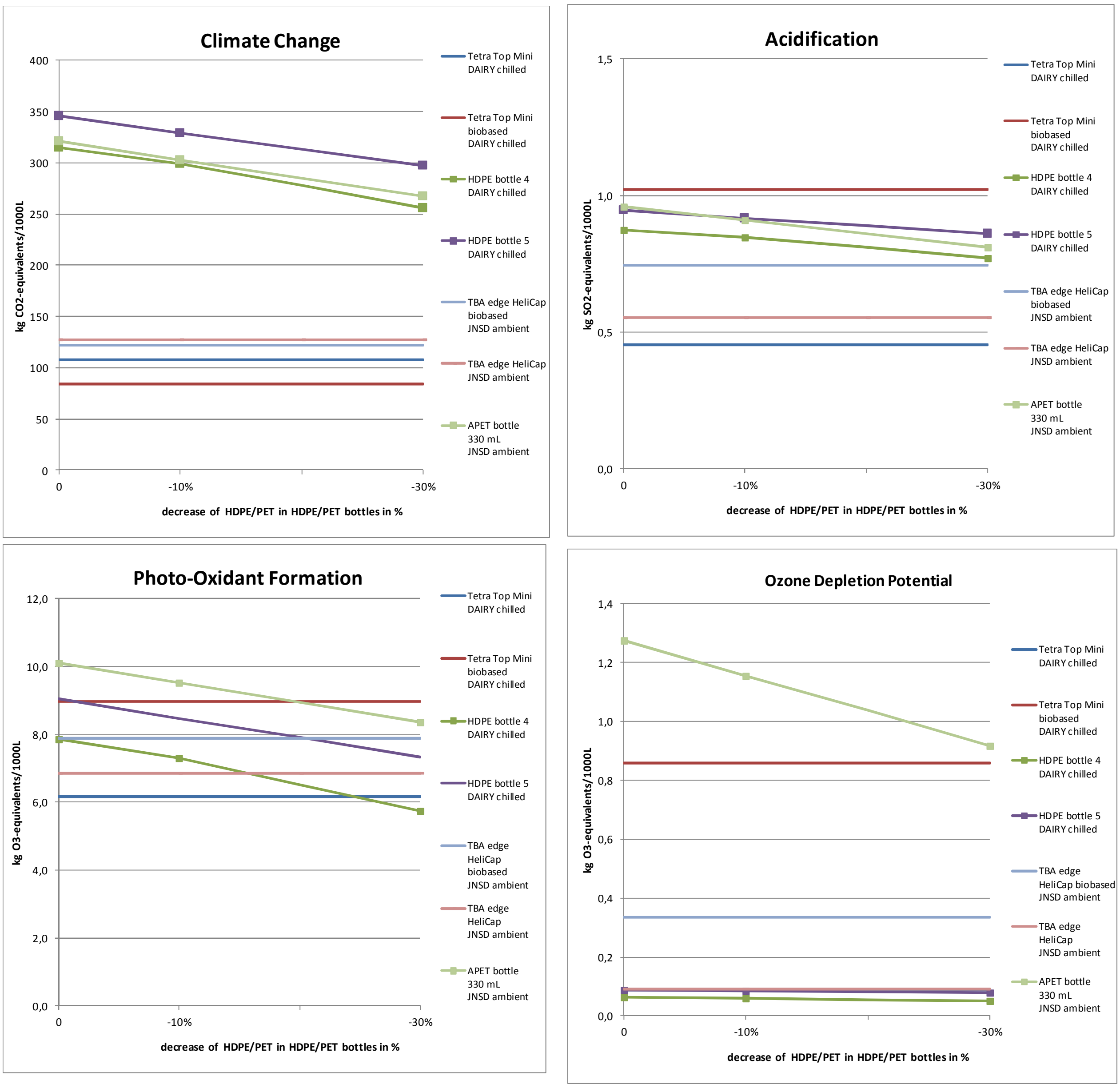


Figure 157: Indicator results for sensitivity analysis on plastic bottle weights; **segment Grab & Go, Denmark**, Allocation factor 50% (Part 1)

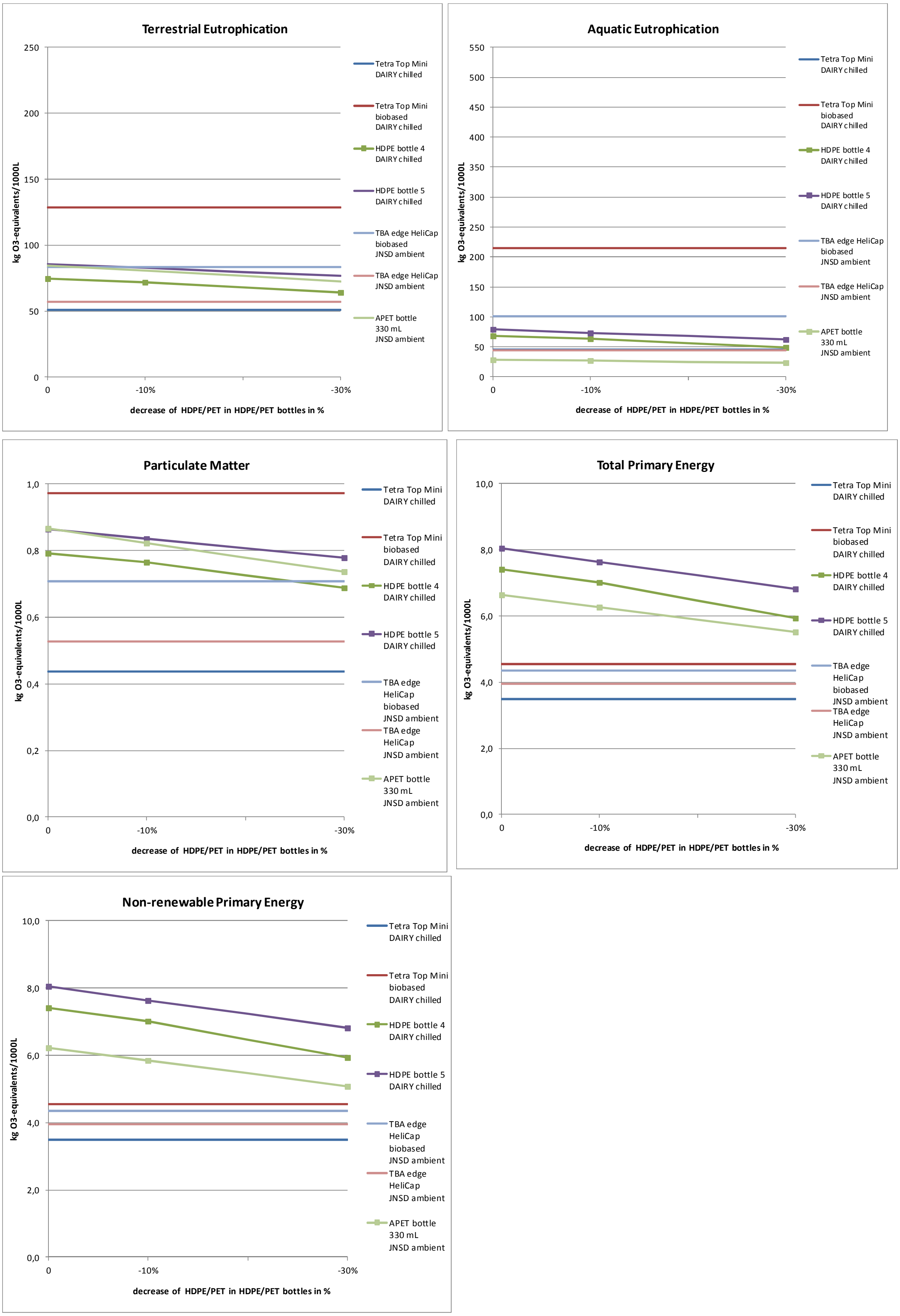


Figure 158: Indicator results for sensitivity analysis on plastic bottle weights; **segment Grab & Go, Denmark**, Allocation factor 50% (Part 2)

Description and Interpretation

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In many cases though even a weight reduction of 30% does not change the overall ranking of the examined packaging systems. In some cases a break-even with the results of a beverage carton is met.

No lightweight bottle achieves a new ‘rank’ when compared to beverage cartons in the categories ‘Climate Change’, ‘Acidification’, ‘Ozone Depletion Potential’ and ‘Aquatic Eutrophication’.

In the category ‘Photo-Oxidant Formation’ all recalculated lightweight bottles reach break-even with the respective next-in-rank beverage carton at about 15-20% weight reduction.

In ‘Terrestrial Eutrophication’ break-even is achieved by the ‘APET bottle’ and the ‘HDPE bottle 5’ at about 2-3% weight reduction.

A weight reduction of at least 25% for the ‘HDPE bottle 5’ would lead to a break-even point with the ‘TBA edge HeliCap bio-based’ although these two packaging systems should not really compared which each other as they are for chilled and ambient drinks respectively.

14.3.3 Sensitivity analysis regarding inventory dataset for Bio-PE

In the base scenarios of the study bio-PE for the modelling of bio-based plastics is modelled using ifeu’s own bio-PE dataset based on [MACEDO 2008] and [Chalmers 2009]. This is due to the fact that for the inventory dataset for Bio-PE published by Braskem the substitution approach was chosen to generate it. This fact and some intransparencies makes this dataset not suitable for the use in LCA (please see section 3.1.5). However, this sensitivity analysis applying the data of Braskem shows the differences in results in the following graphs.

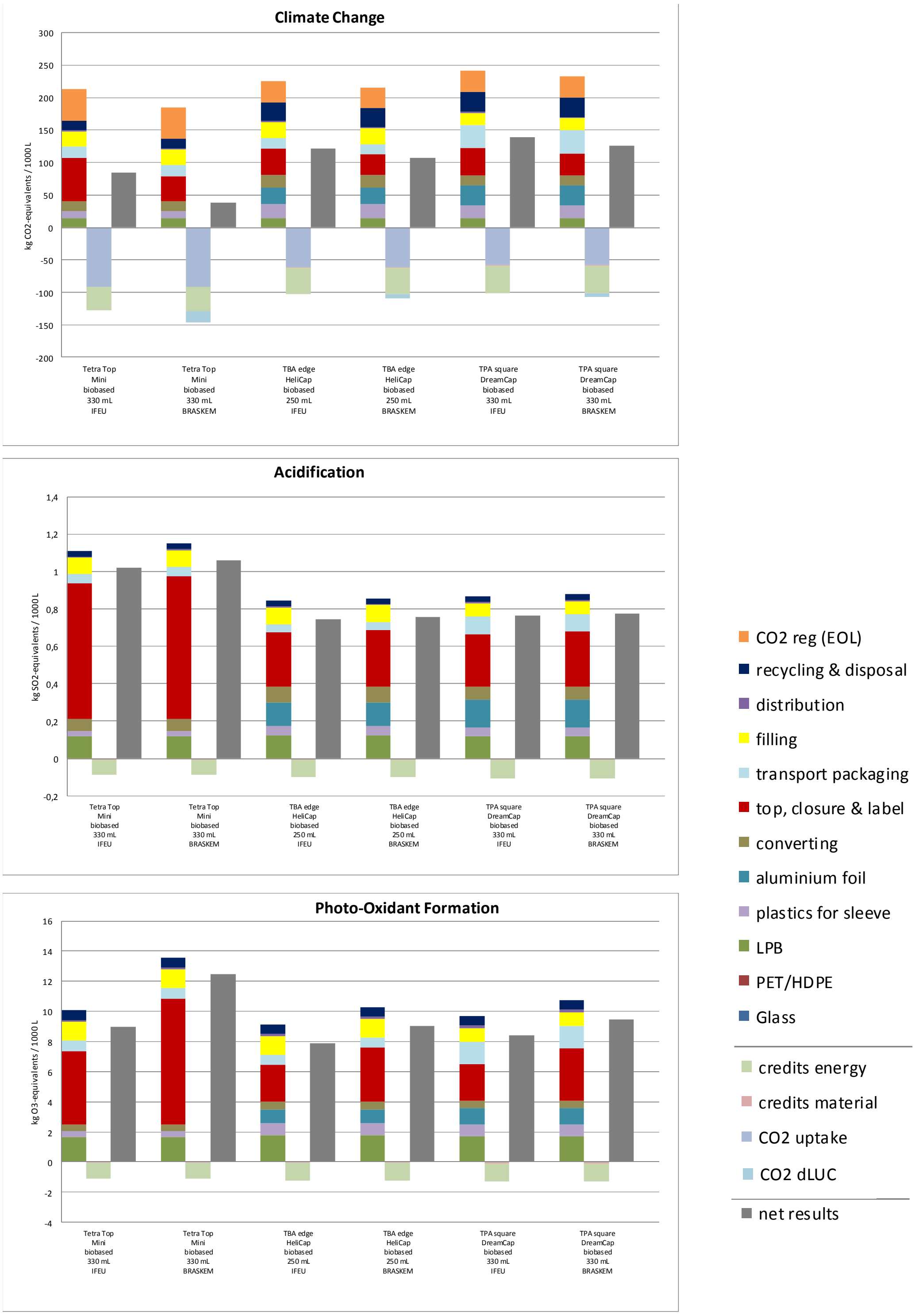


Figure 159: Indicator results for sensitivity analysis on Bio-PE dataset **segment Grab & Go, Denmark**, Allocation factor 50% (Part 1)

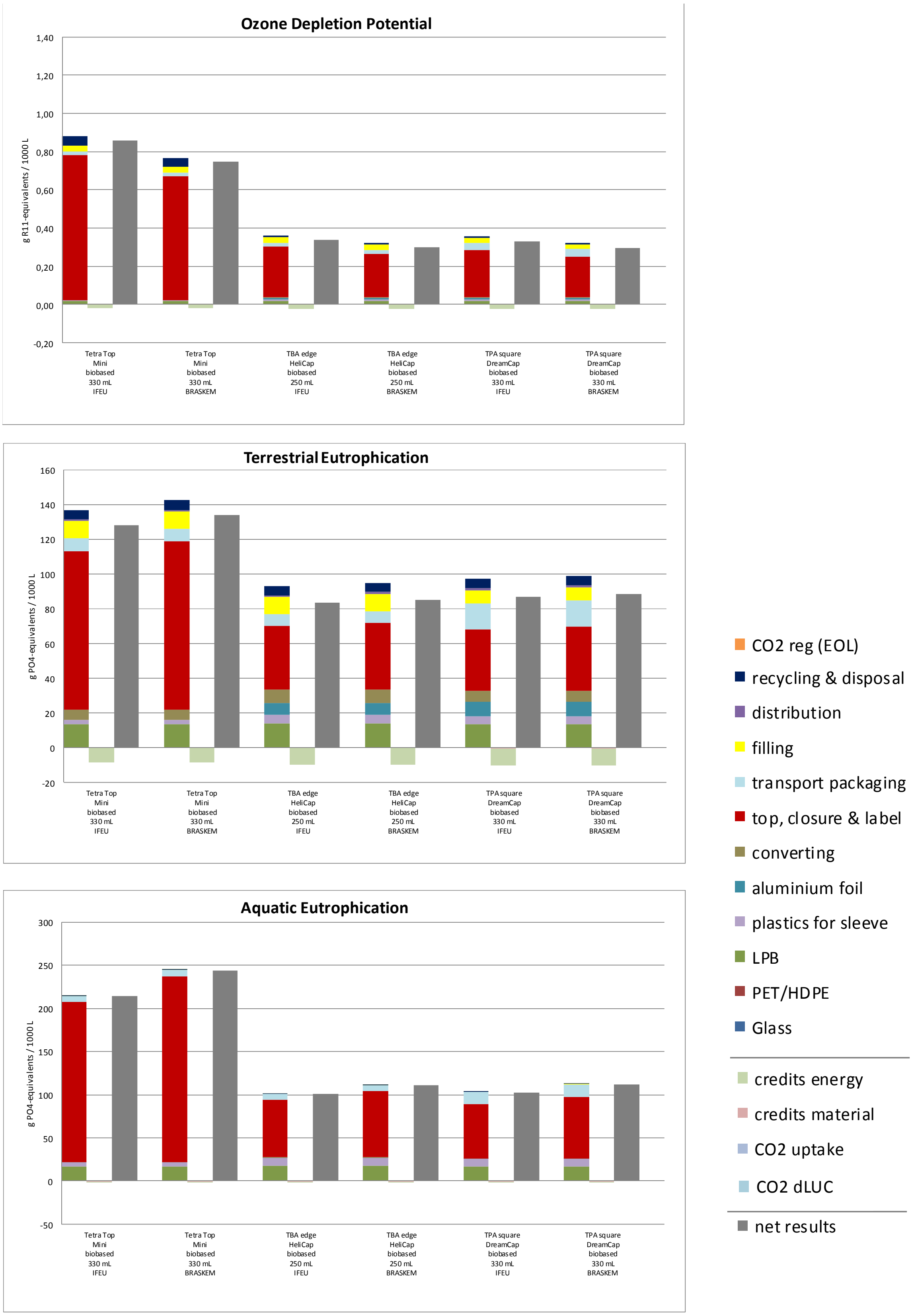


Figure 160: Indicator results for sensitivity analysis on Bio-PE dataset **segment Grab & Go, Denmark**, Allocation factor 50% (Part 2)

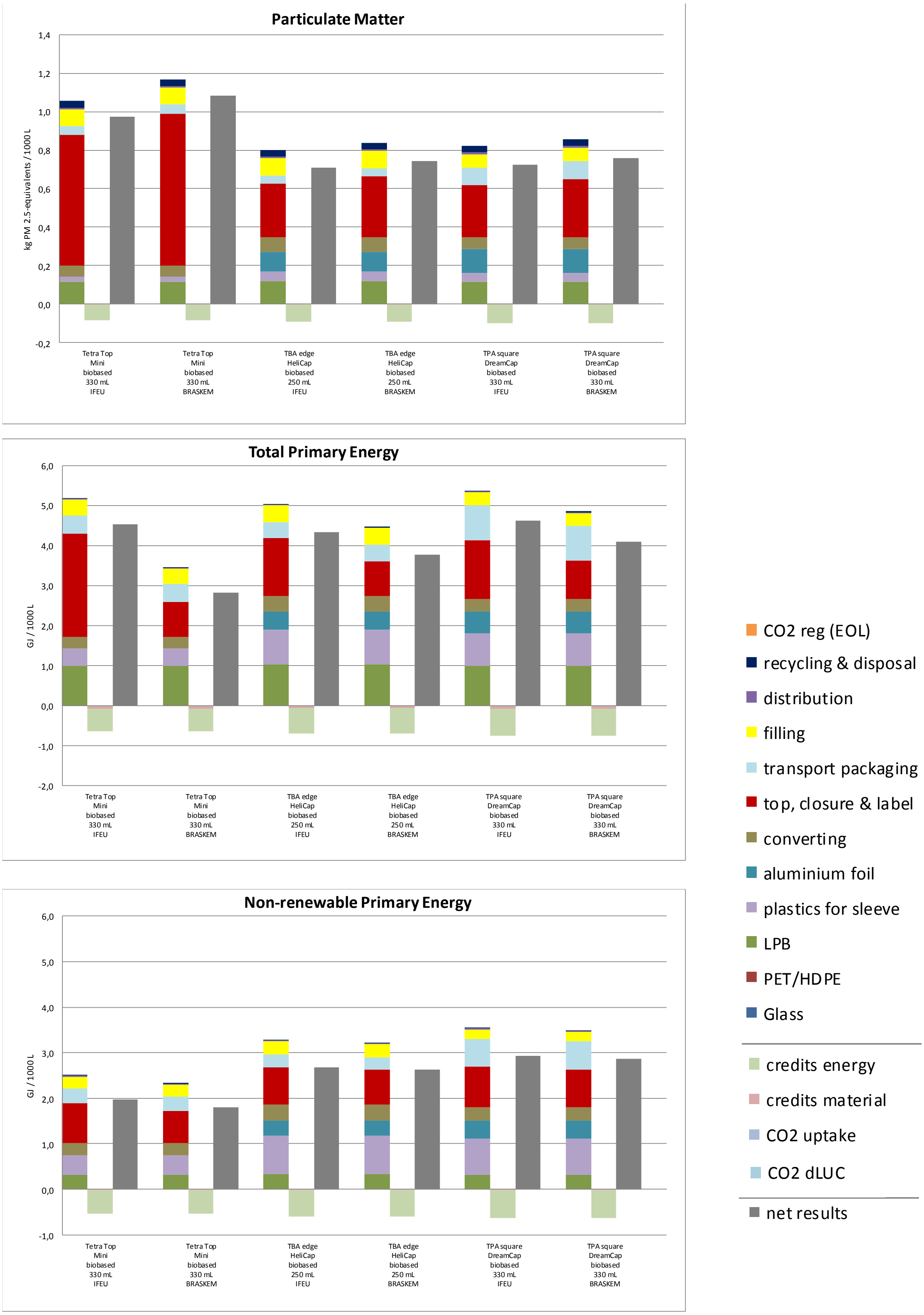


Figure 161: Indicator results for sensitivity analysis on Bio-PE dataset **segment Grab & Go, Denmark**, Allocation factor 50% (Part 3)

Description and interpretation

The sensitivity analysis comparing LCA results of the beverage cartons with bio-based plastics of the Grab & go segment modelled with the dataset for bio-based HDPE from the ifeu database and those of the same cartons modelled with the dataset published by bio-plastics producer Braskem shows several differences. In the impact category ‘Climate Change’ the cartons modelled with the Braskem data show lower net results than those modelled with ifeu data. In some of the other categories the cartons modelled with Braskem data show slightly higher results than those with modelled with ifeu data, but these differences are only significant in the category ‘Photo-Oxidant Formation’.

The main reason for the lower’ Climate Change’ result with Braskem data is the inclusion of benefits of land use change (CO_2 dLUC). Unfortunately the published dataset does not explain transparently where these benefits originate.

The sensitivity analysis therefore shows that the choice of dataset for the production of bio-based PE is not very relevant for the results of most categories of a full cradle-to-grave LCA of grab & go packaging on the Danish market. It is relevant though for the environmental impact categories ‘Climate Change’ and Photo-Oxidant Formation’.

15 Conclusions Denmark

15.1 Dairy Denmark

In general the examined beverage carton systems show lower burdens in all of the impact categories than their competing systems. An exception to this occurs in some categories if the carton contains a high share of biobased polyethylene.

This is especially true in the base scenarios where an allocation factor of 50% is applied. This is due to the fact that only half of the regenerative CO_2-emissions of end-of-life are accounted to the beverage carton. With an allocation factor of 100%, therefore the results are higher, but still lower than the competing bottles in most of impact categories.

A considerable role for these generally low environmental impacts of beverage cartons plays the renewability of their paperboard components and a high use of renewable energies.

Apart from the 'Tetra Top' the carton systems also benefit from the use of multi-use roll containers instead of one-way transport packaging.

Lowest results are shown by those beverage carton systems without a separate closure system.

In the environmental impact category 'Climate Change' the cartons furthermore benefit from the use of bio-based polyethylene for sleeve and/or closure. However, a higher share of Bio-PE leads to higher environmental impacts in all other impact categories examined. In case of the substitution of fossil based polyethylene by bio-based polyethylene in the sleeve and closure the respective beverage cartons may lose their environmental advantage against the competing bottles in some impact categories.

The sensitivity analysis on plastic bottle weights shows, that reducing the weight of plastic bottles will lead to lower environmental impacts. When compared to the unaltered beverage cartons the results of the potential fossil-based lightweight bottles calculated may lead to a change in the overall ranking in some cases, especially in regard to the fully bio-based cartons. In the category 'Climate Change' however none of the potential lightweight bottles achieve lower results than any of the beverage cartons.

15.2 JNSD Denmark

In the segment JNSD ambient the use of aluminium foil for ambient packaging increases the overall burdens of the beverage cartons. However the cartons without bio-based polyethylene still show lower or similar results than the bottles examined in most of the impact categories.

With an increased share of bio-based polyethylene ‘Climate Change’ results of beverage cartons improve. Results in all other impact categories however increase to an extent that compared to the PET bottle the carton loses its overall environmental advantage.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

15.3 Grab & Go Denmark

The examined beverage carton systems without biobased polyethylene for Grab and Go in the sub-segment Dairy chilled show lower burdens in all of the impact categories than their competing systems.

As the share of plastics in a small volume Tetra Top packaging is higher than other beverage cartons of bigger volumes, the choice of plastic material type, e.g. fossil or bio-based, plays a decisive role for the environmental performance. In case of the ‘Tetra Top Mini bio-based 330 mL’ the impact results are significantly lower only in the impact category ‘Climate Change’ than those of the ‘HDPE bottle 4’.

In the sub-segment JNSD ambient the beverage carton can be considered the packaging of choice when compared to the glass bottle from an environmental viewpoint. Compared to the APET bottle, though, no unambiguous conclusion can be drawn; at least not for the biobased cartons. From the environmental viewpoint generally the ‘TBA edge HeliCap 250 mL’ seems to be the best choice.

Again volume size of the examined packaging systems in both sub-segments has an influence on their results: The higher the volume the lower are the impacts according to the functional unit of 1000 L beverage.

The results of the applied sensitivity analysis do not deliver any other insights than those of the segment dairy.

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 (chilled and unchilled) and JNSD (chilled and unchilled). Even though carton packaging systems, plastic bottles and glass bottles are common in other market segments, other filling products create different requirements towards their packaging and thus certain characteristics may differ strongly, e.g. barrier functions.

Limitations concerning **selection of packaging systems**
The results are valid only for the exact packaging systems, that have been chosen by Tetra Pak. Even though this selection is based on market data it does not represent the whole Swedish, Finish, Danish or Norwegian market.

Limitations concerning **packaging system specifications**
The results are valid only for the examined packaging systems as defined by the specific system parameters, since any alternation of the latter may potentially change the overall environmental profile.

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

Each packaging system is defined by multiple system parameters which may potentially alter the overall environmental profile. All packaging specifications of the carton packaging systems were provided by Tetra Pak® and are to represent the typical packaging systems used in the analysed market segment. These data have been cross-checked by ifeu.

To some extent, there may be a certain variation of design (i.e. specifications) within a specific packaging system. Packaging specifications different from the ones used in this study cannot be compared directly with the results of this study.

Limitations concerning the chosen **environmental impact potentials** and applied **assessment 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 either Sweden, Denmark, Finland or Norway, 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

Beverage cartons show relatively low life cycle assessment results in most examined environmental impact categories compared to their competing packaging systems in all segments and countries regarded in this study. They benefit from the use of renewable materials and energies in the production processes. Especially the use of paperboard as the main component leads to low impacts in many categories compared to the use of plastics or glass for bottles. Regarding climate change mitigation the uptake of CO_2 leads to lower results in the respective impact category 'Climate Change', at least if half of the emissions originating from the incineration of used beverage cartons are allocated to the following system e.g. the Municipal Solid Waste Incinerators.

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 regarded.

From an overall environmental viewpoint, the use of bio-based plastics can therefore not be endorsed unreservedly. If there is a strong focus on climate change mitigation in Tetra Pak's environmental policy, though, the utilisation of bio-based polyethylene can be an applicable path to follow. In any case the consequences for the environmental performance in other impact categories should never be disregarded completely.

If the utilisation of bio-based polyethylene in beverage cartons remains part of Tetra Pak's environmental policy it is recommended to review the availability of other sources for bio-polymers, f.e. in regard to source material, to examine if lower environmental impacts can be achieved in other categories than climate change as well.

An example of the potential decrease of climate change impact by substitution of fossil-based polyethylene by bio-based polyethylene:

Comparison of the Tetra Rex OSO 34 1000mL with the Tetra Rex fully bio-based 1000 mL on the Finnish market for dairy packaging with an allocation factor of 50% (see section 6.1):

Climate change of Tetra Rex OSO 34:
21.84 kg CO_2-eq/FU

Climate change of Tetra Rex fully bio-based:
9.28 kg CO_2-eq/FU

That means a substitution of **6.17 kg of fossil PE** per 1000 packaging units by the same amount bio-based PE leads to a saving of **12.56 kg CO_2-eq**.

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Appendix A: Impact categories

The impact categories used in this study are introduced below and the corresponding characterisation factors are quantified. In each case, references are given for the origin of the methods that were used. The procedure for calculating the indicator result is given at the end of each sub-section.

A.1 Climate change

Climate Change is the impact of anthropogenic emissions on the radiative forcing of the atmosphere causing a temperature rise at the earth's surface. This could lead to adverse environmental effects on ecosystems and human health. This mechanism is described in detail in the relative references [IPCC 1995]. The category most used in life cycle assessments up to now is the radiative forcing [CML 2002, Klöpffer 1995] and is given as CO_2 equivalents. The characterisation method is a generally recognised method.

The Intergovernmental Panel on Climate Change (IPCC) is an international body of experts that computes and extrapolates methods and relevant parameters for all substances that influence climate change. The latest IPCC reports available at the time of LCA calculations commonly represent the scientific basis for quantifying climate change.

All carbon dioxide emissions, whether they are of regenerative or fossil origin, are accounted for with a characterisation factor of 1 CO_2 equivalent.

When calculating CO_2 equivalents, the gases' residence times in the troposphere is taken into account and the question arises as to what period of time should be used for the climate model calculations for the purposes of the product life cycle. Calculation models for 20, 50 and 100 years have been developed over the years, leading to different global warming potentials (GWPs). The models for 20 years are based on the most reliable prognosis; for longer time spans (500-year GWPs have been used at times), the uncertainties increase [CML 2002]. The Centre of Environmental Science – Leiden University (CML) as well as the German Environmental Agency both recommend modelling on a 100-year basis because it allows to better reflect the long-term impact of Climate Change. According to this recommendation, the 'characterisation factor' applied in the current study for assessing the impact on climate change is the *Global Warming Potential* for a 100-year time period based on IPCC 2013.

An excerpt of the most important substances taken into account when calculating the Climate Change are listed below along with the respective CO_2-equivalent factors – expressed as Global Warming Potential (GWP).

Greenhouse gas	CO_2 equivalents (GWP_i)[1]
Carbon dioxide (CO_2). fossil	1
Methane (CH_4)[2] fossil	30
Methane (CH_4) regenerative	28
Nitrous oxide (N_2O)	265
Tetrafluoromethane	6630
Hexafluoroethane	11100
Halon 1301	6290
R22	1810
Tetrachlormethane	1760
Trichlorethane	160
• Source: [IPCC 2013]	

Table A-1: Global warming potential for the most important substances taken into account in this study; CO_2 equivalent values for the 100-year perspective

Numerous other gases likely have an impact on GWP by IPCC. Those greenhouse gases are not represented in Table A-1 as they are not part of the inventory of this LCA study.

The contribution to the Climate Change is obtained by summing the products of the amount of each emitted harmful material (m_i) of relevance for Climate Change and the respective GWP (GWP_i) using the following equation:

$$GWP = \sum_i (m_i \times GWP_i)$$

Note on biogenic carbon:

At the impact assessment level, it must be decided how to model and calculate CO_2-based GWP. In this context, biogenic carbon (the carbon content of renewable biomass resources) plays a special role: as they grow, plants absorb carbon from the air, thus reducing the amounts of carbon dioxide in the atmosphere. The question is how this uptake should be valued in relation to the (re-)emission of CO_2 at the material's end of life, for example CO_2 fixation in biogenic materials such as growing trees versus the greenhouse gas's release from thermal treatment of cardboard waste.

In the life cycle community two approaches are common. CO_2 may be included at two points in the model, its uptake during the plant growth phase attributed with negative GWP values and the corresponding re-emissions at end of life with positive ones. 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] [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 operationalized by a multi-criteria assessment linking the use of land to different subjects of protection: Structure and functionality of ecosystems, biological diversity and different ecosystem services contributing to human wellbeing. In this sense hemeroby is understood as a mid-point indicator giving explicite information on naturalness and providing implicite information, at least partly, on biodiversity (number of species, number of rare or threathened species, diversity of structures), and soil quality (low impact.)

The system of hemeroby is subdivided in to seven classes (see Table 1). This system is appropriate to be applied on any type of land-use type accountable in LCA. Particularly production systems for biomass (wood from forests, all kinds of biomass from agriculture) are assessed in a differentiated way:

> To describe forest systems three criteria are defined: (1) natural character of the soil, (2) natural character of the forest vegetation, (3) natural character of the development conditions. The degree of performance is figured out by applying by 7 metrics for each criterion.
>
> Agricultural systems are assessed by four criteria: (1) diversity of weeds, (2) Diversity of structures, (3) Soil conservation, (4) Material input. Three metrics are used for each criterion to calculate the grade of hemeroby.

The approach includes the derivation of inventory results (x m^2 of area classified as class y) as well as the aggregation to the category indicator 'Distance-to-Nature-Potential' (DNP) (m^2-e * 1a) by characterization factors.

Class	Class name	Land-use type
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 characterized by factor 1. Each class ascending towards naturalness will be characterized by a factor half from the precedent. Therefore the maximum span from class VII to class II is 1 : 32, an span which corresponds with share of class VII area of entire area.[1] Table A-6.2 lists the characterisation factors for each class.

Class	Characterisation factor (DNP_i)
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])

A.8 References (for Appendix A)

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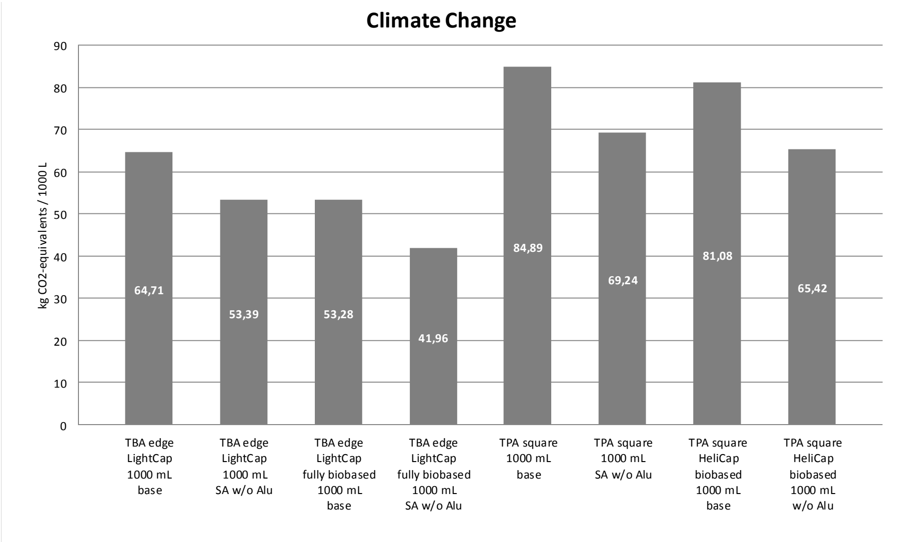
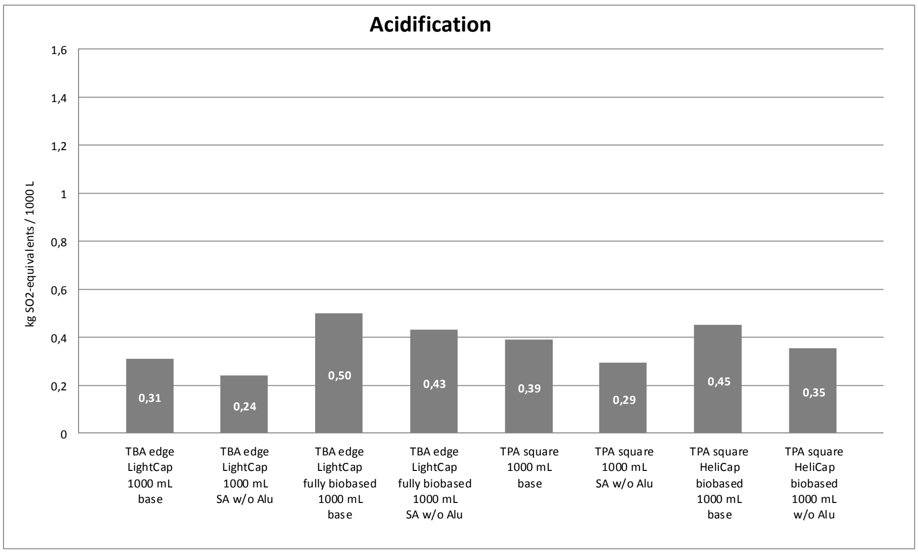
Appendix B:

Sensitivity analysis regarding the replacement of aluminum barrier with PE barrier

B1 Results Sweden

B1 a) Segment JNSD Sweden





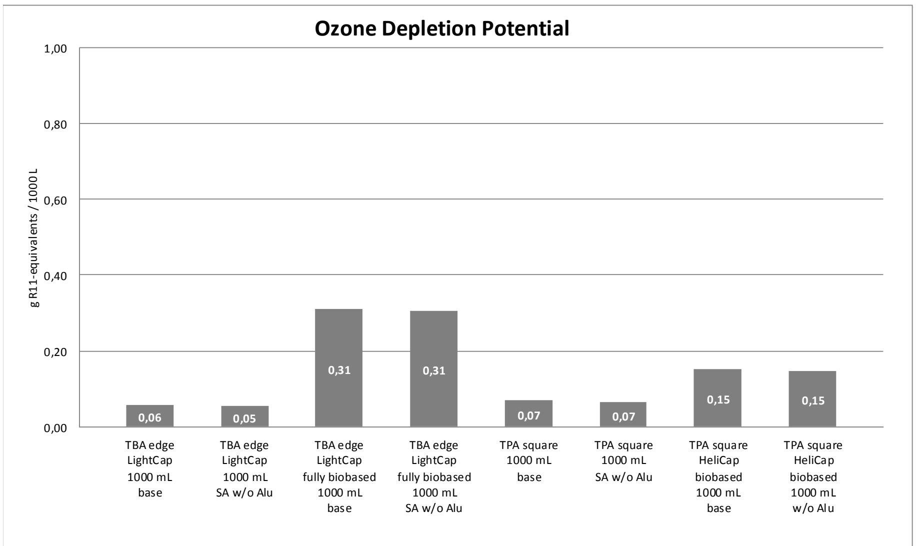
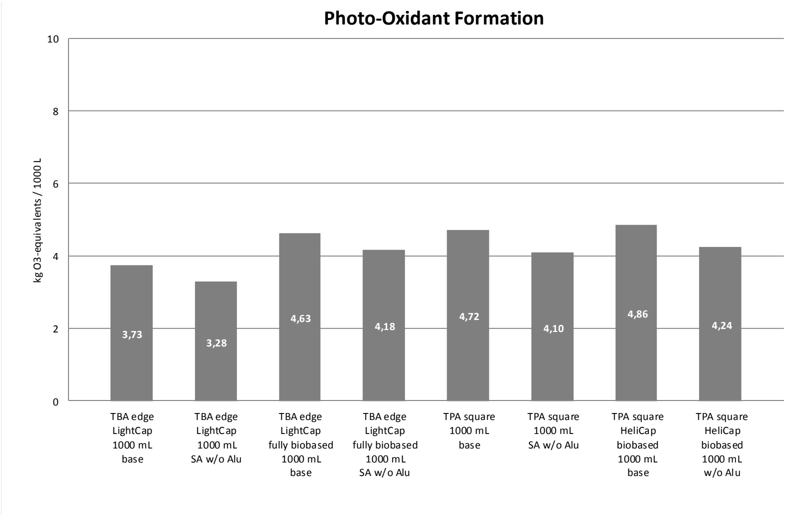
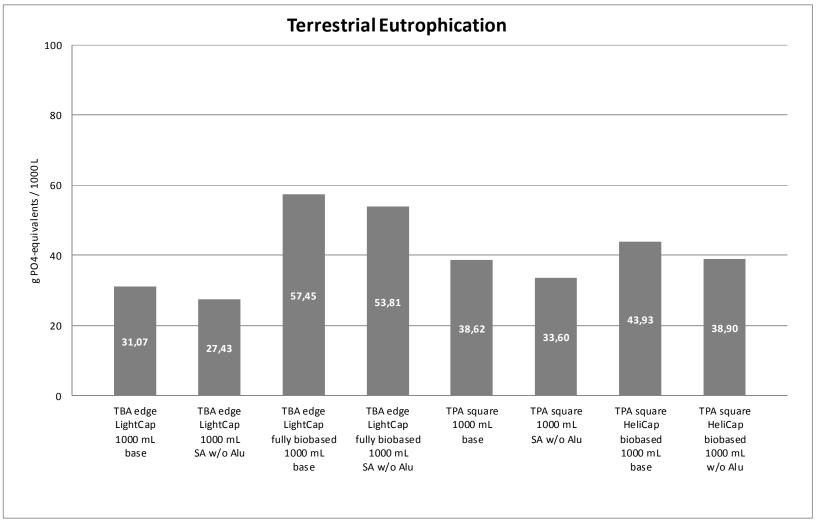


Figure 162: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Sweden**, Allocation factor 50% (Part 1)





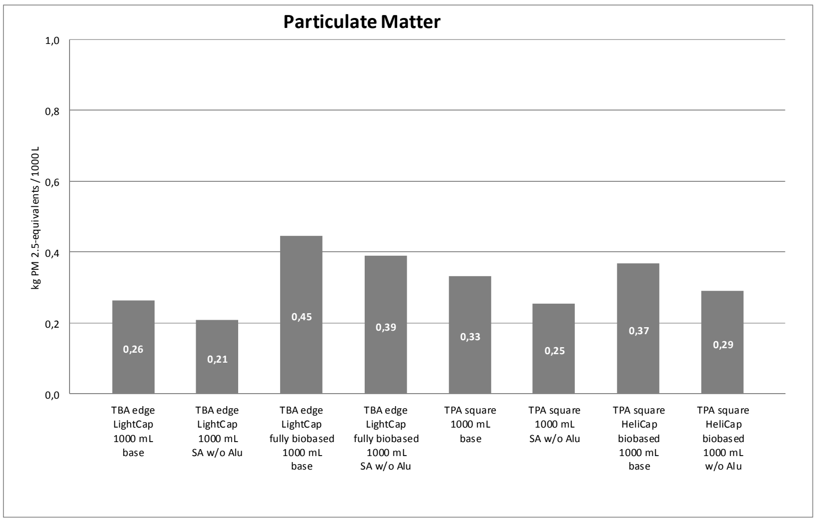
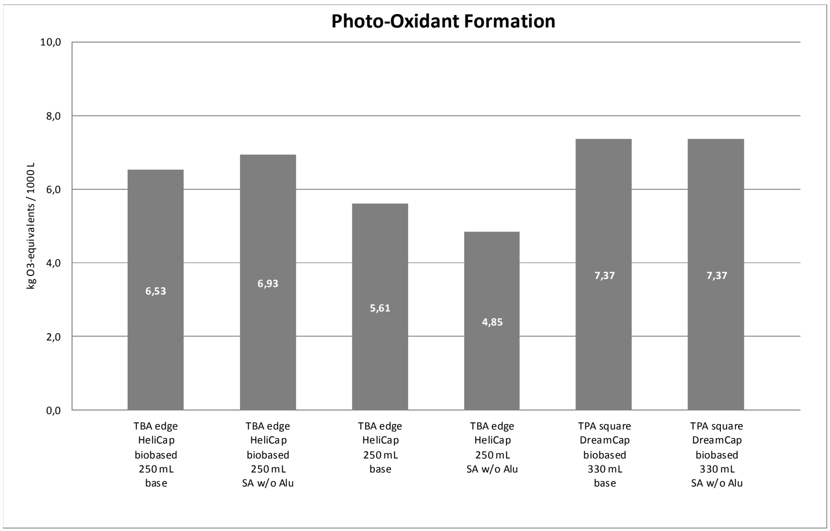


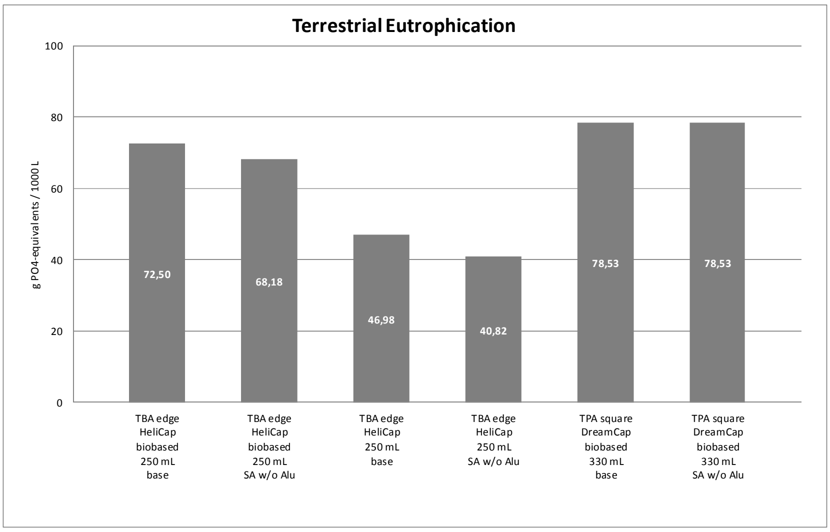
Figure 163: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Sweden**, Allocation factor 50% (Part 2)

Figure 164: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Sweden**, Allocation factor 50% (Part 3)

B2 a) Grab & Go Sweden

Figure 165: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Sweden**, Allocation factor 50% (Part 1)





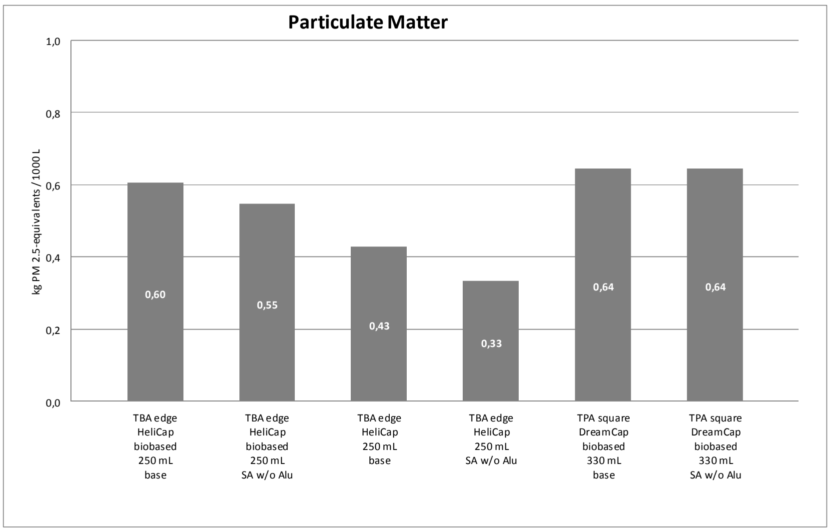


Figure 166: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Sweden**, Allocation factor 50% (Part 2)

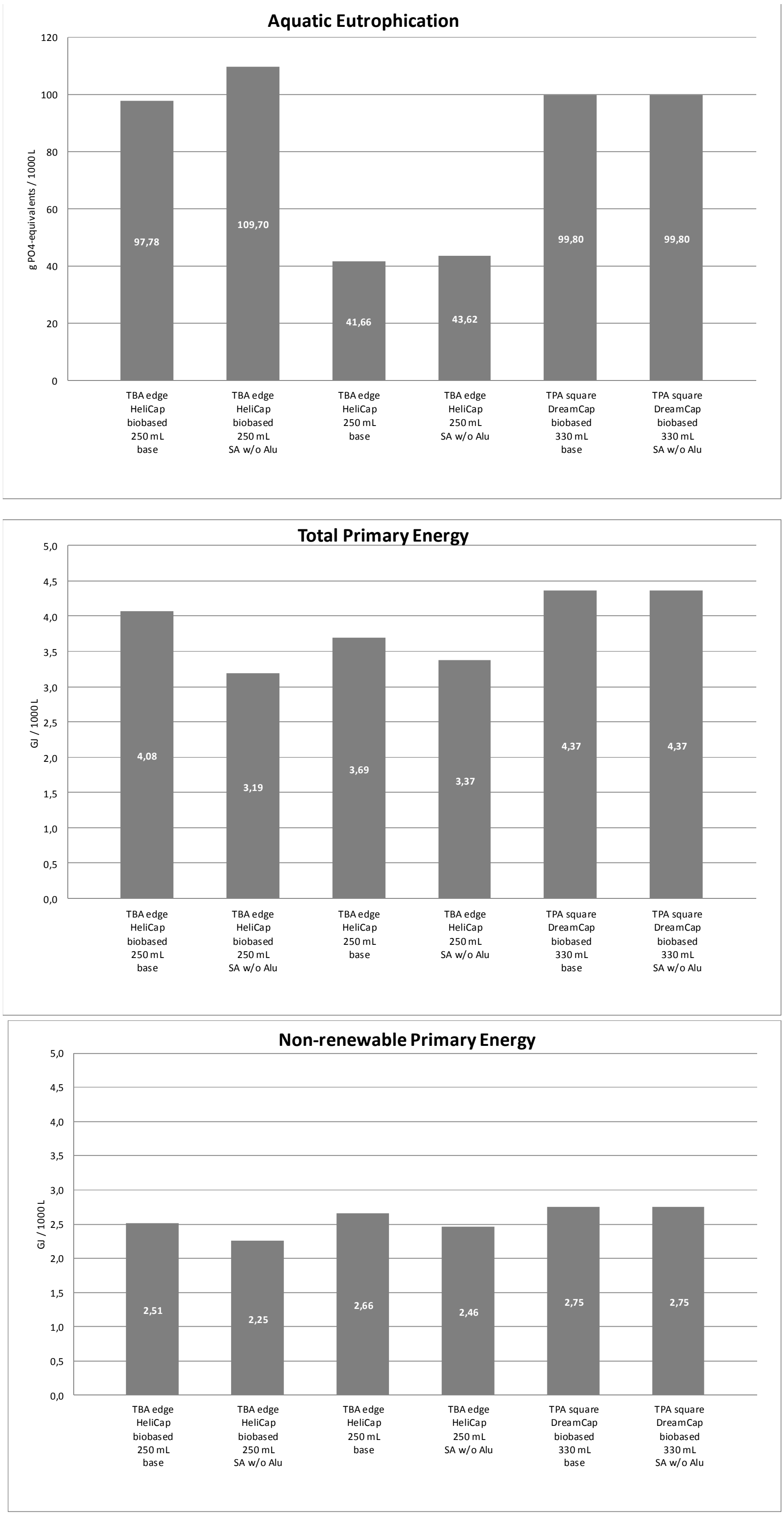


Figure 167: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Sweden**, Allocation factor 50% (Part 3)

B2 Results Finland

B2 a) JNSD Finland

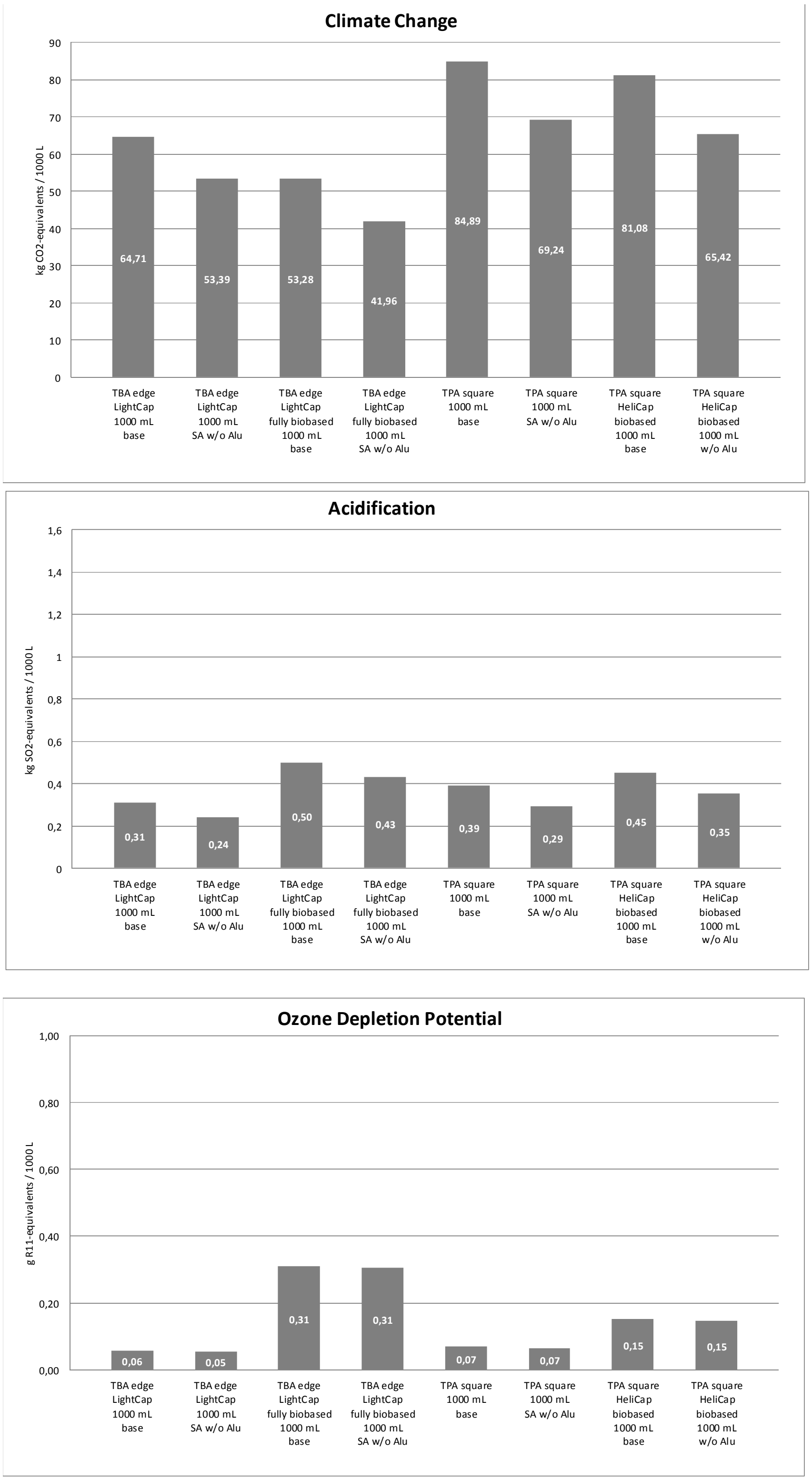
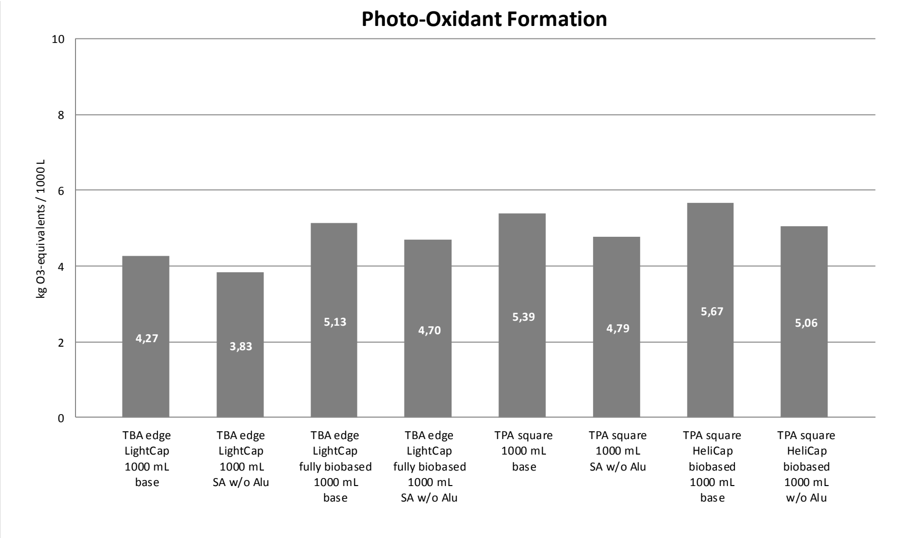
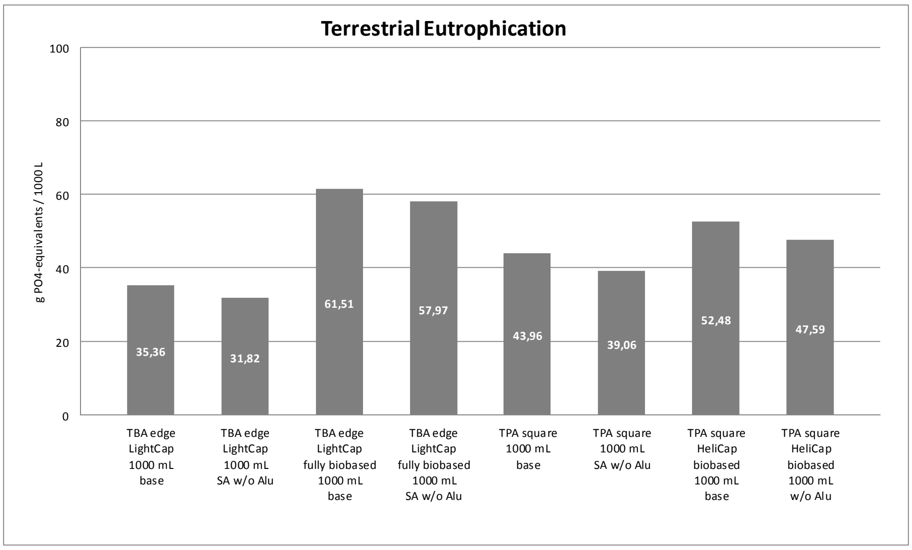


Figure 168: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Finland**, Allocation factor 50 (Part 1)





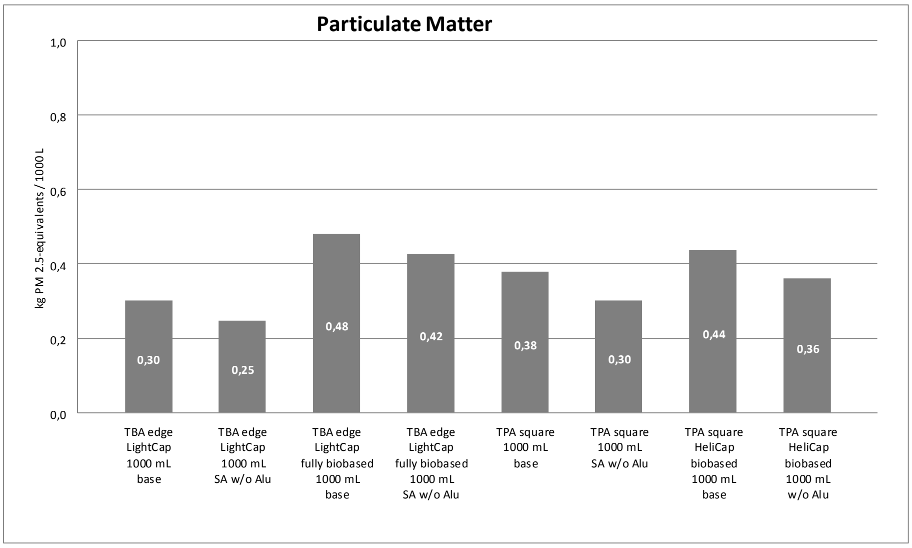


Figure 169: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Finland**, Allocation factor 50 (Part 2)

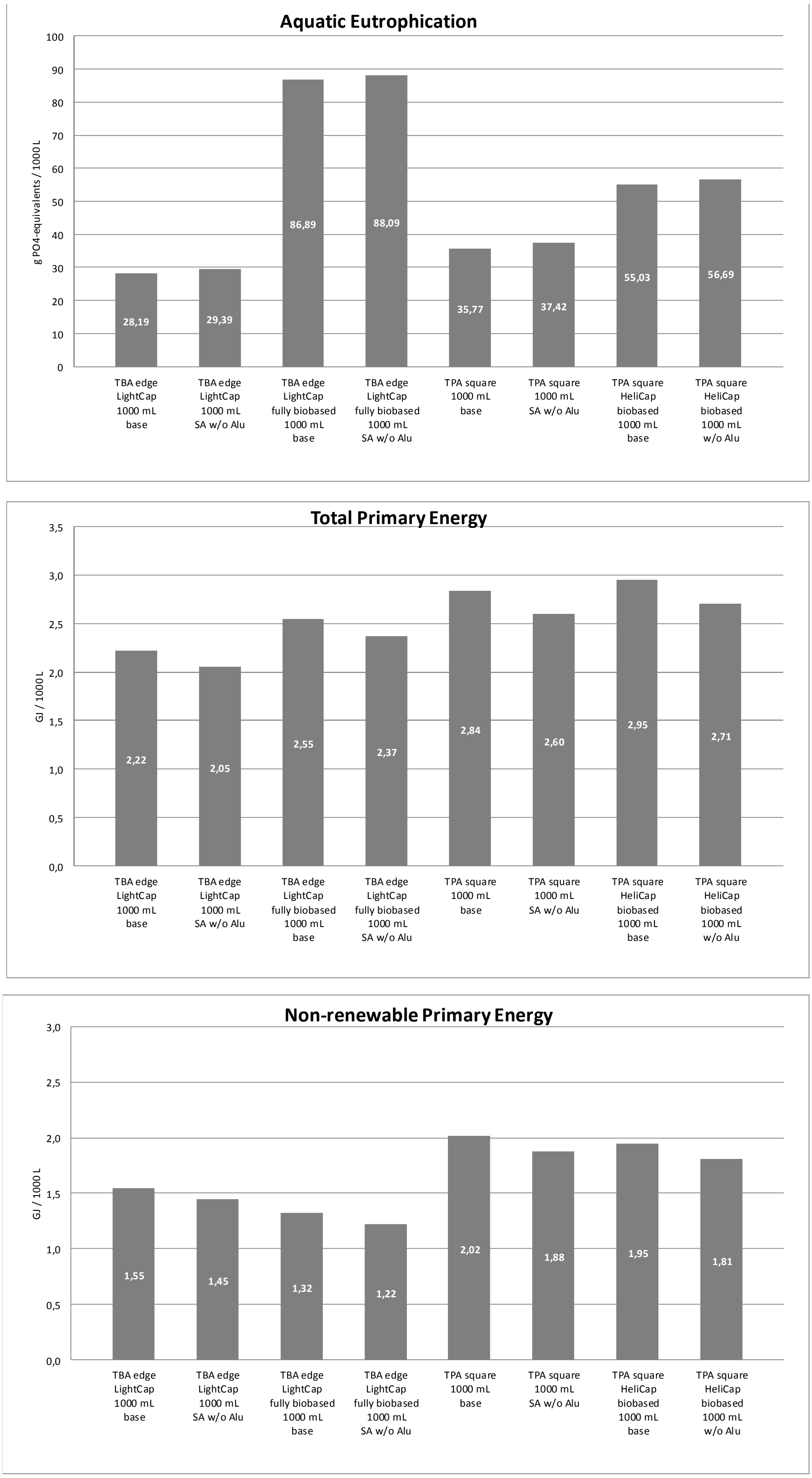
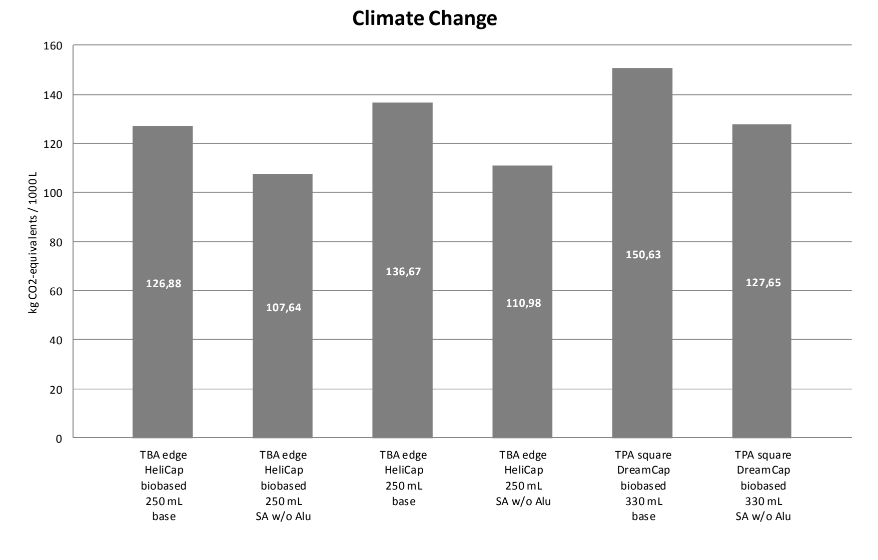
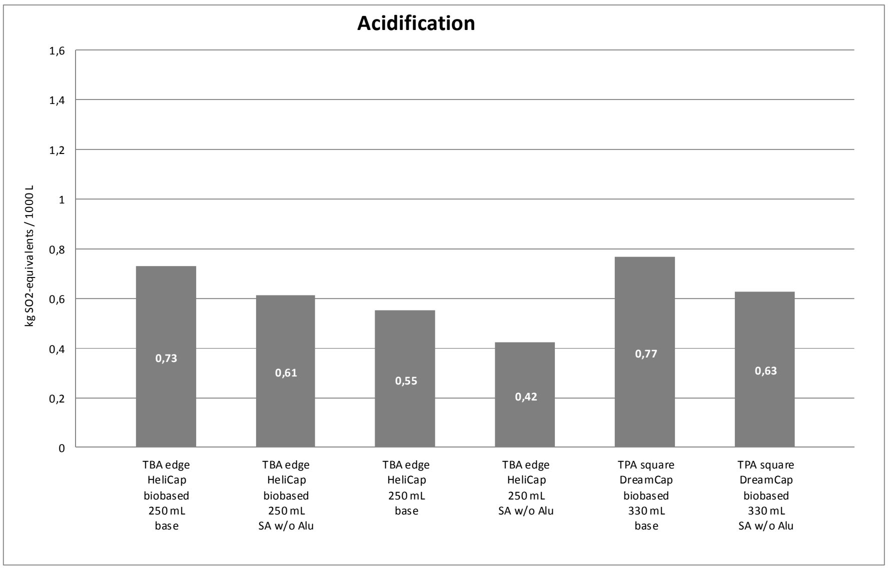


Figure 170: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Finland**, Allocation factor 50 (Part 3)

B2 b) Grab & Go Finland





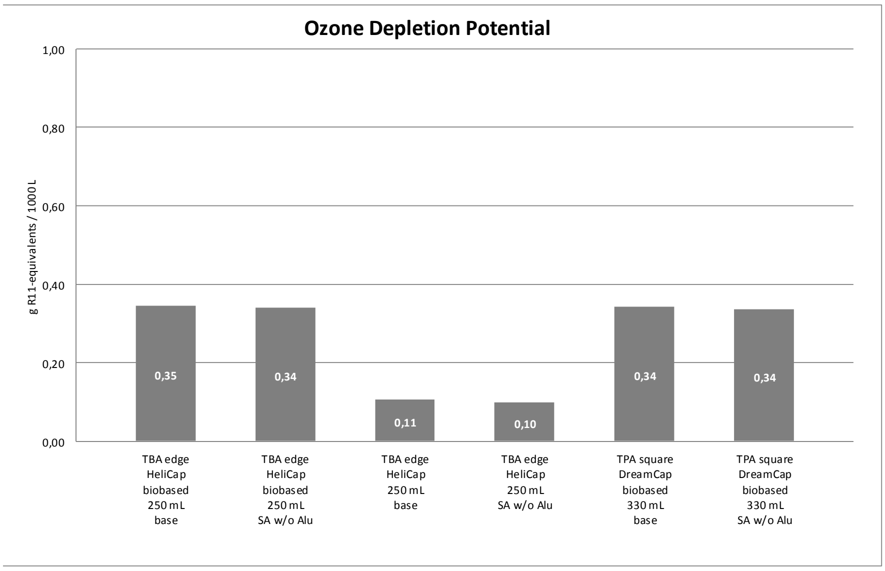
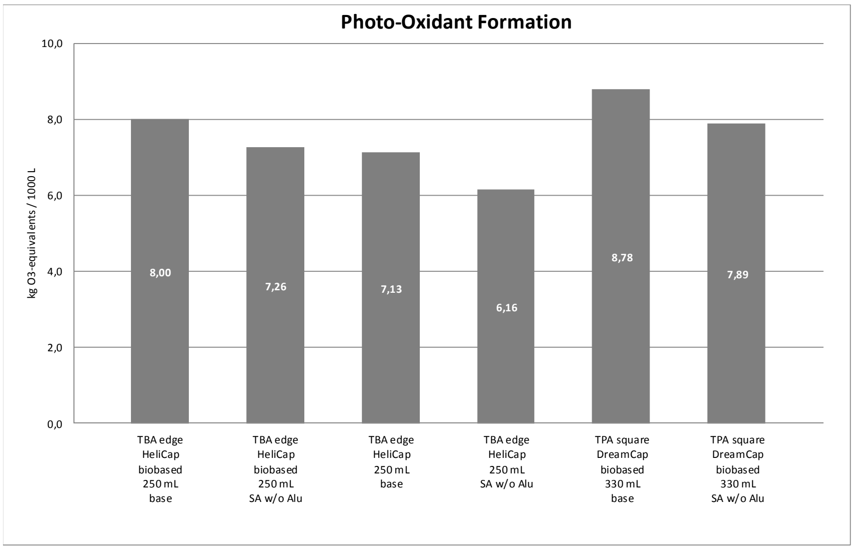
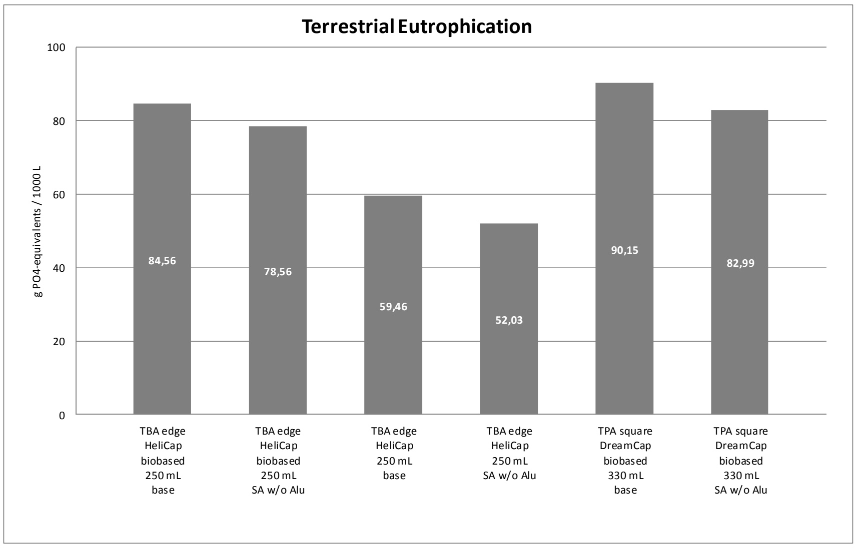


Figure 171: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Finland**, Allocation factor 50 (Part 1)





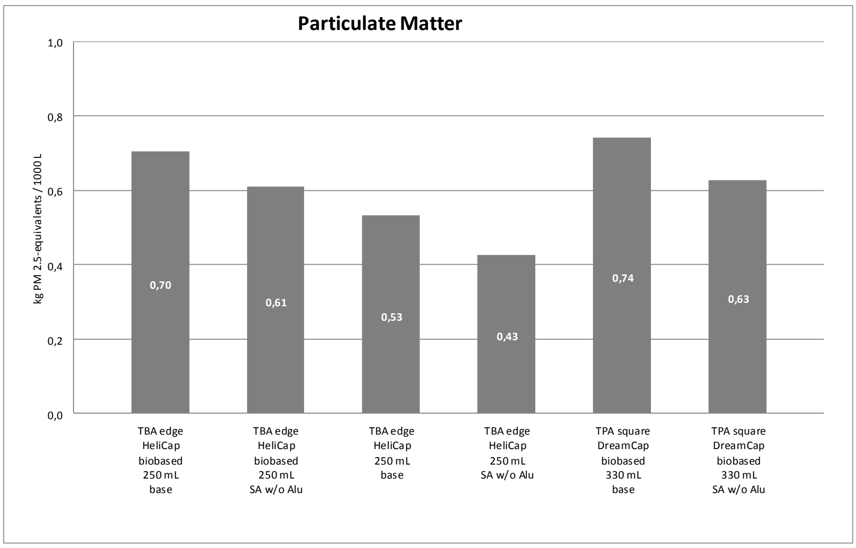
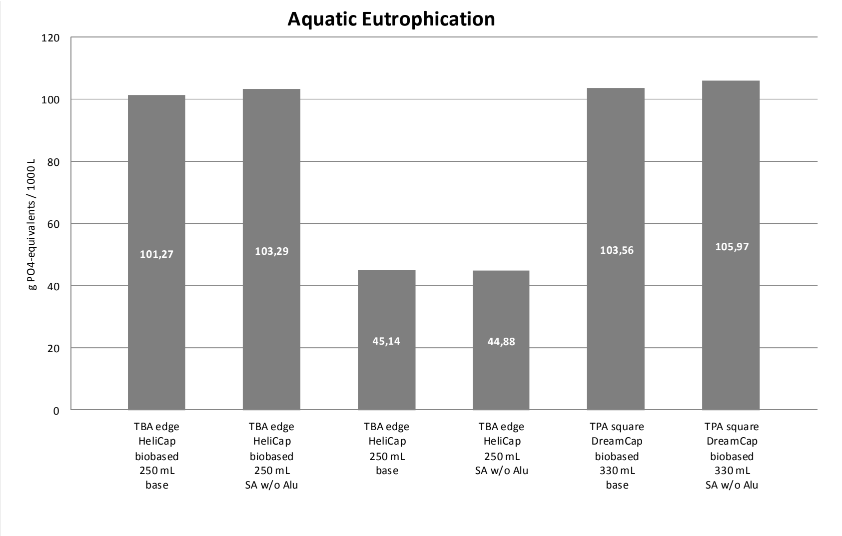
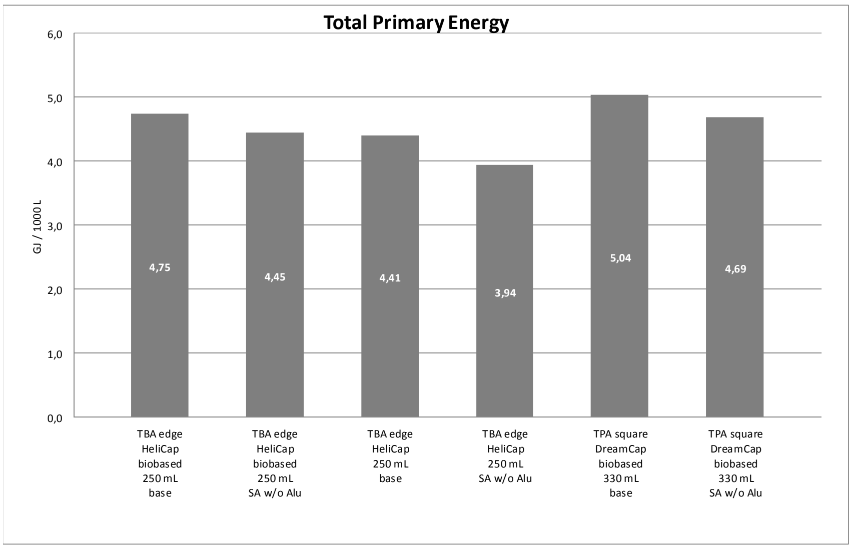


Figure 172: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Finland**, Allocation factor 50 (Part 2)





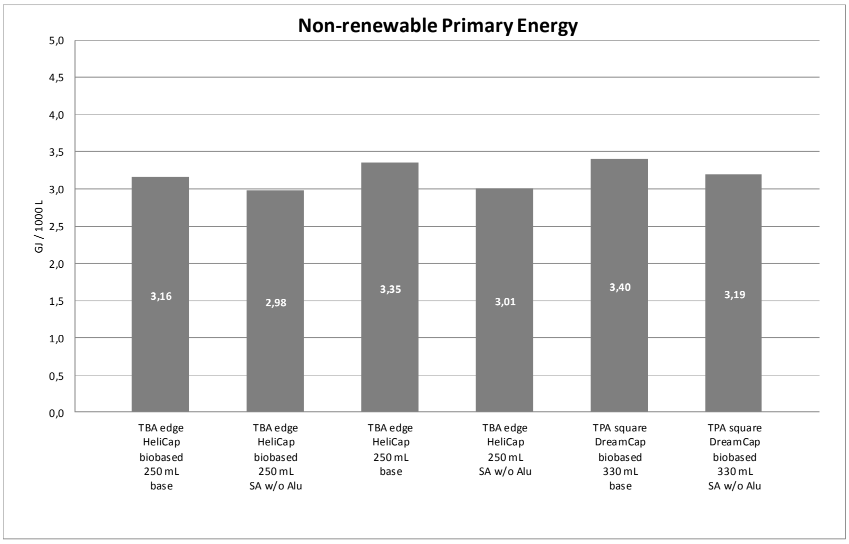


Figure 173: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Finland**, Allocation factor 50 (Part 3

B3 Results Norway

B3 a) JNSD Norway

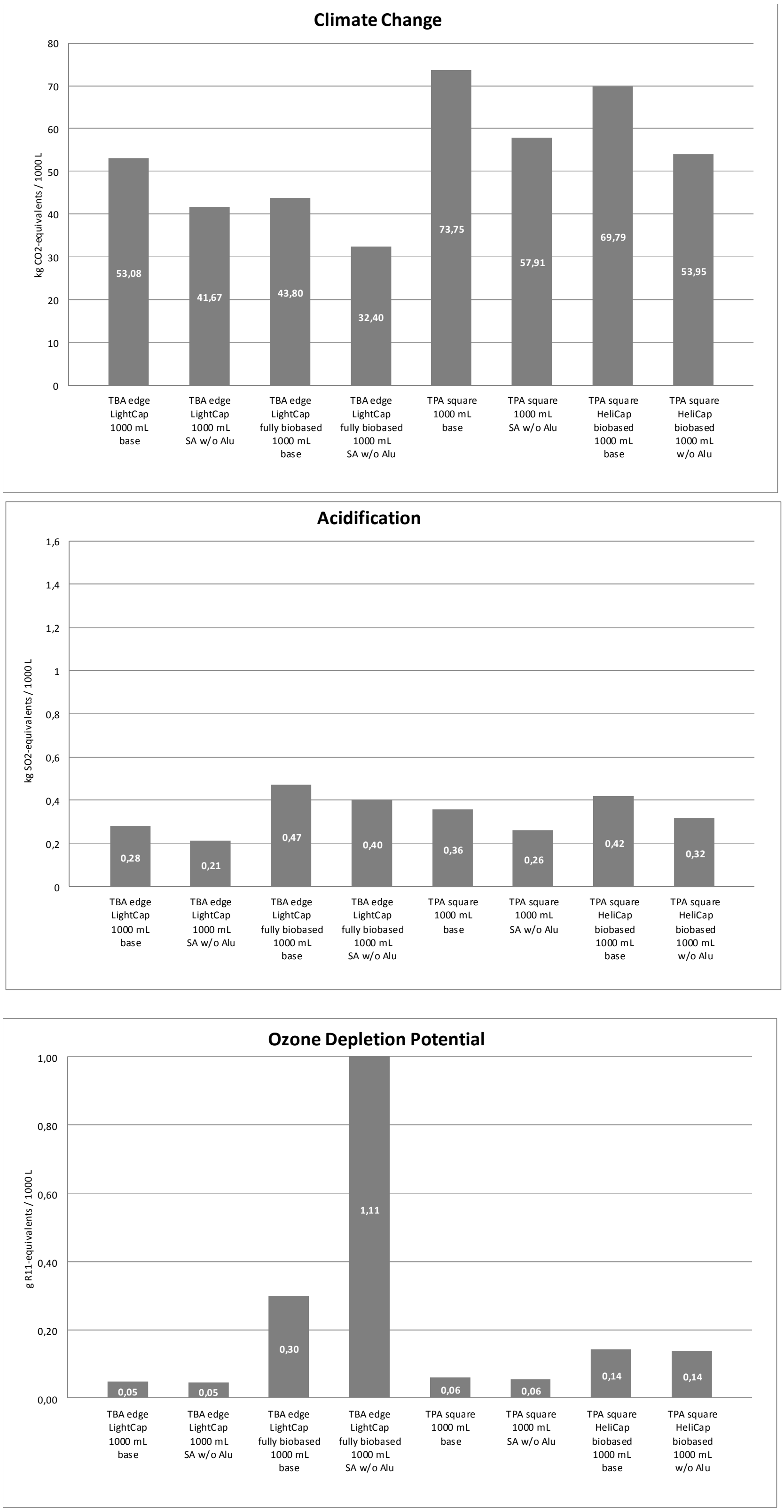
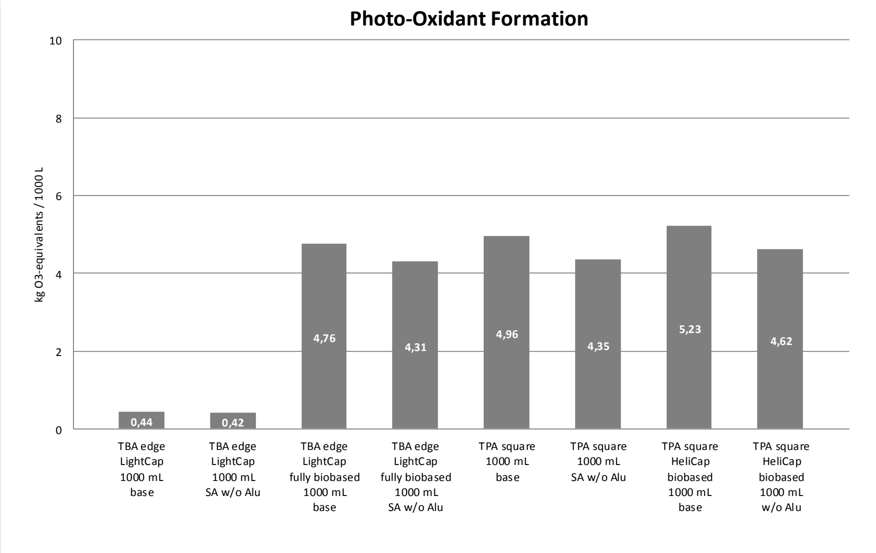
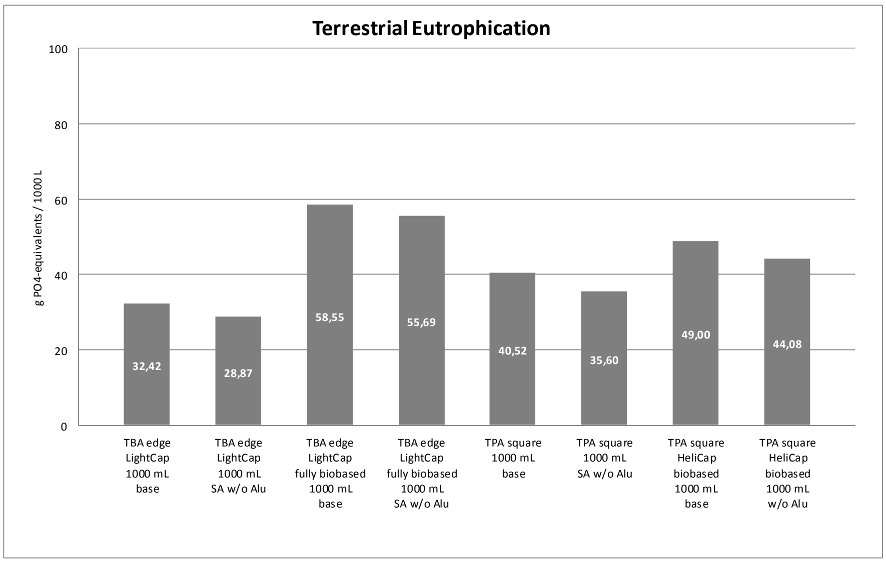


Figure 174: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Norway**, Allocation factor 50 (Part 1)





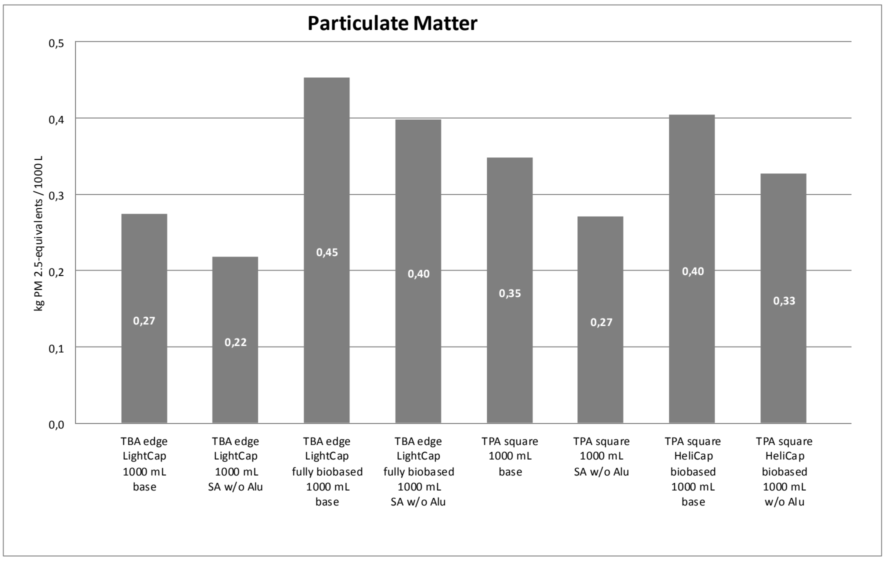


Figure 175: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Norway**, Allocation factor 50 (Part 2)

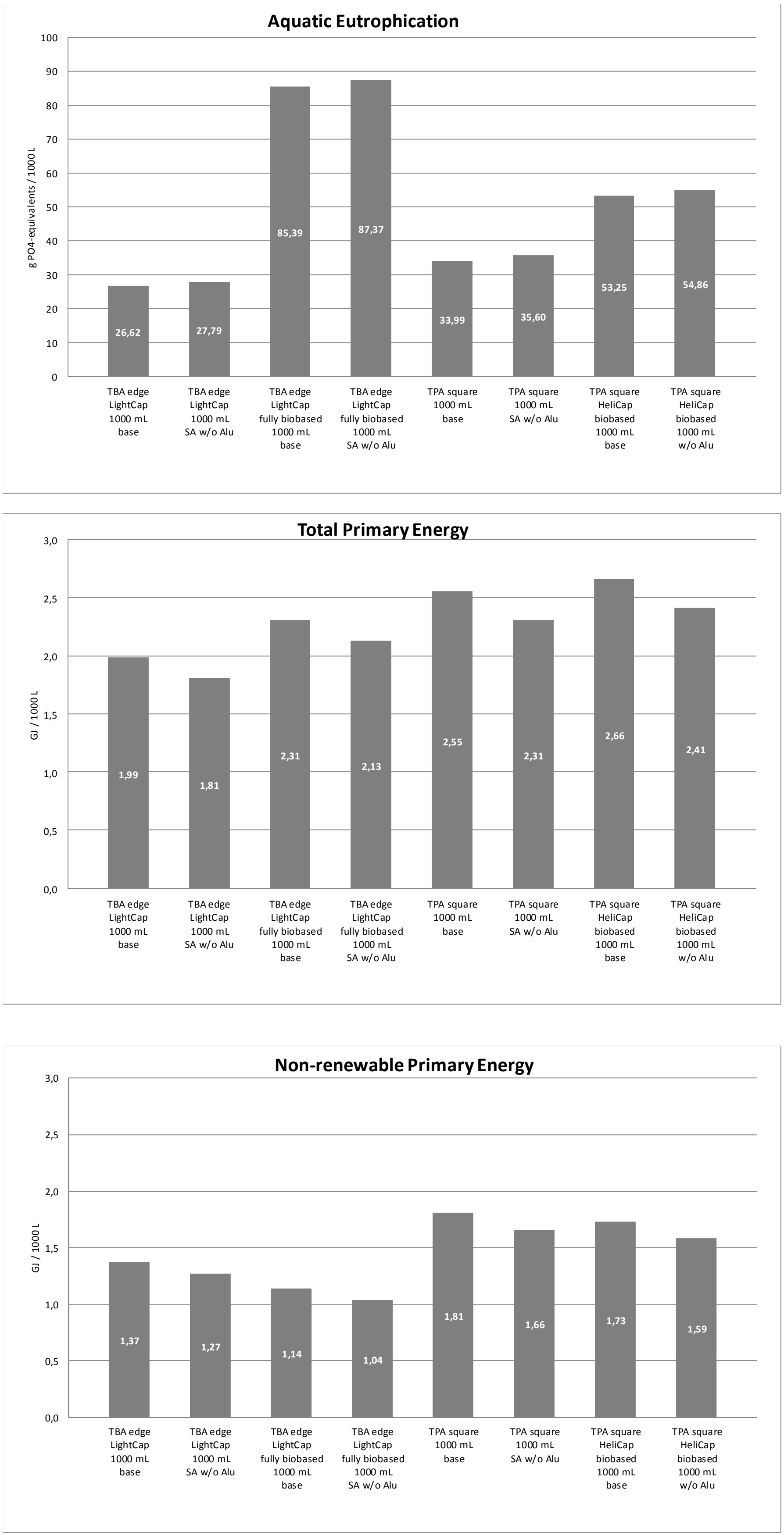


Figure 176: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Norway**, Allocation factor 50 (Part 3)

B3 b) Grab & Go Norway

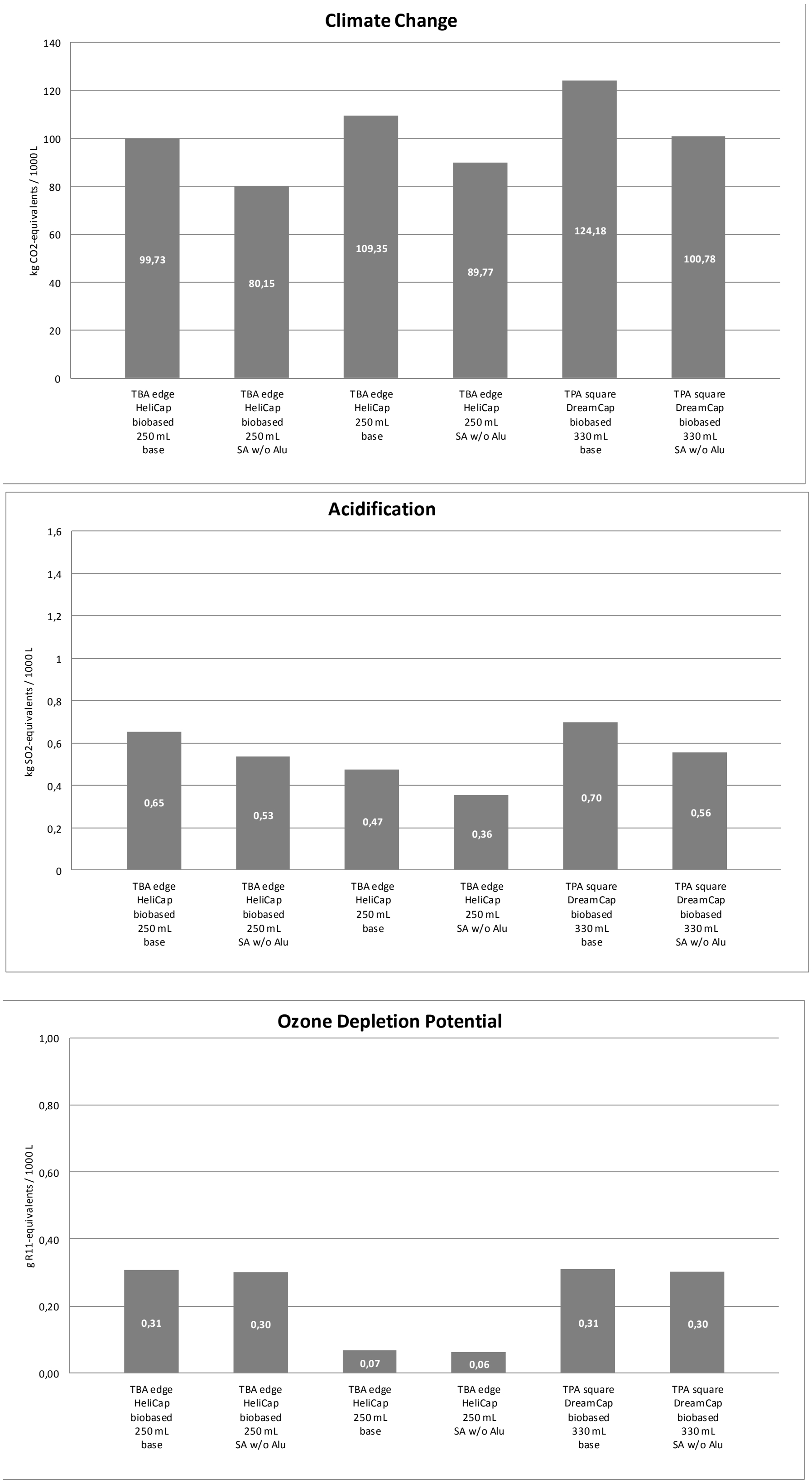
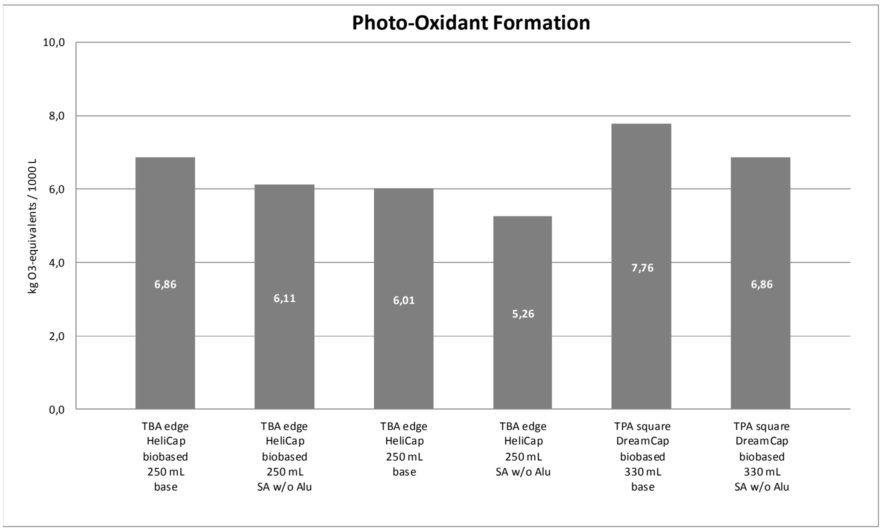
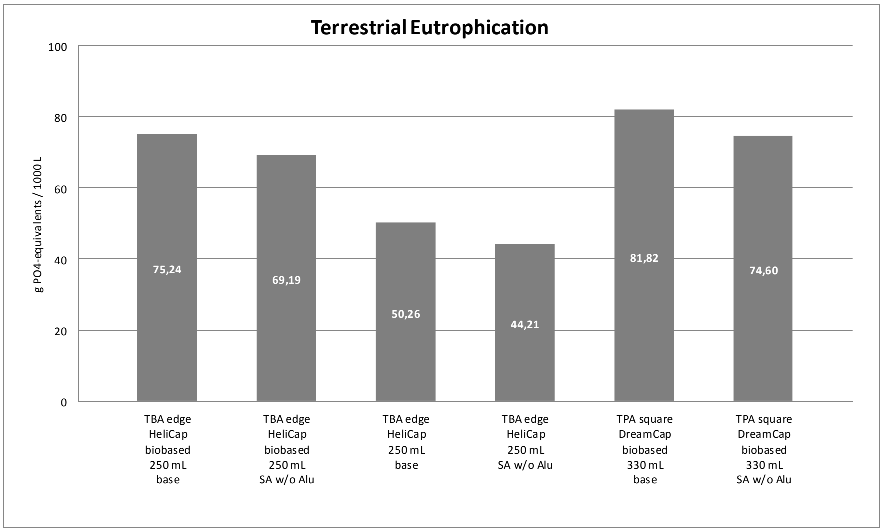


Figure 177: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Norway**, Allocation factor 50 (Part 1)





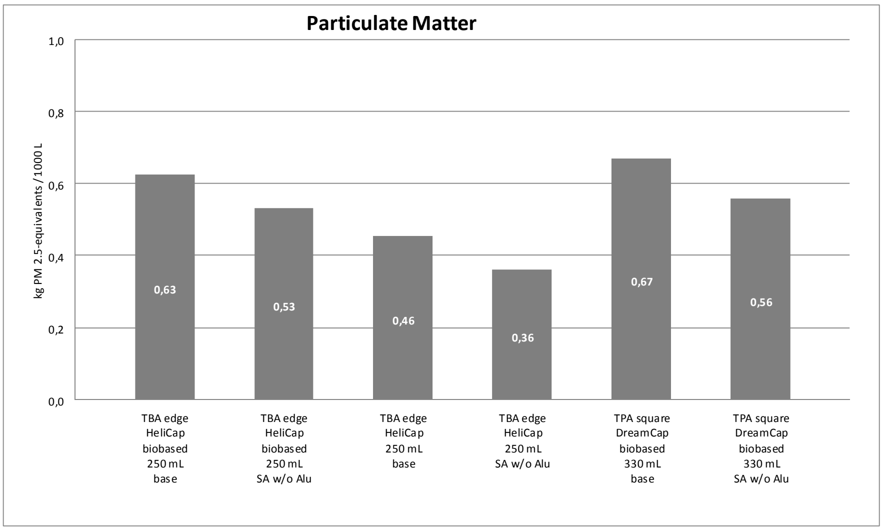
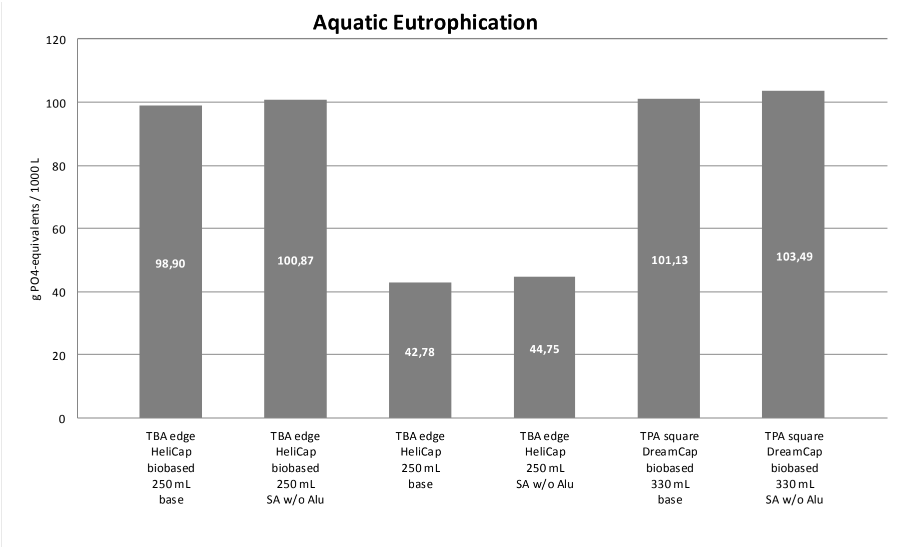
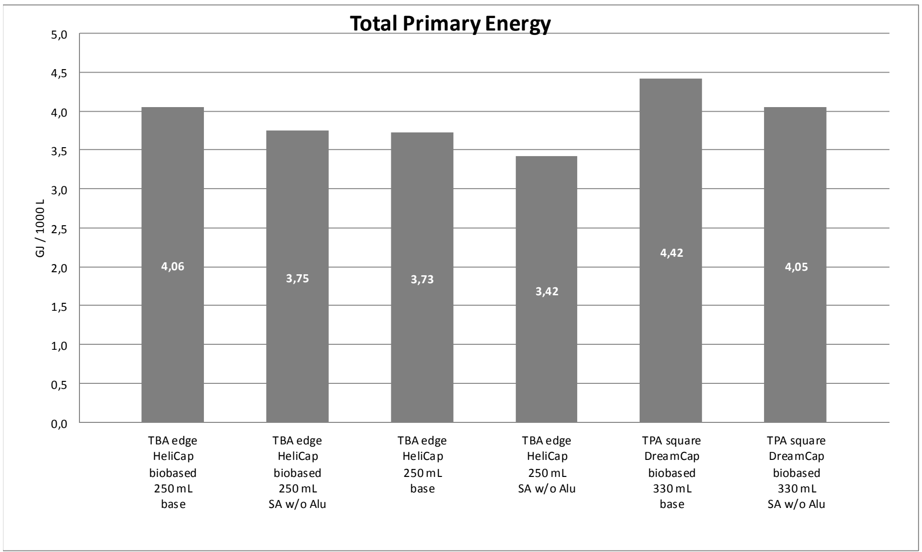


Figure 178: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Norway**, Allocation factor 50 (Part 2)





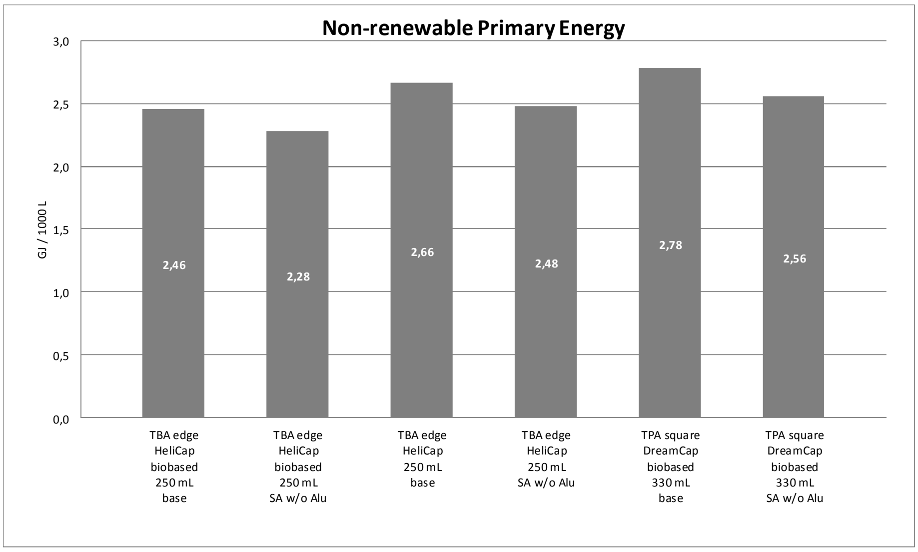


Figure 179: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Norway**, Allocation factor 50 (Part 3)

B4 Results Denmark

B4 a) JNSD Denmark

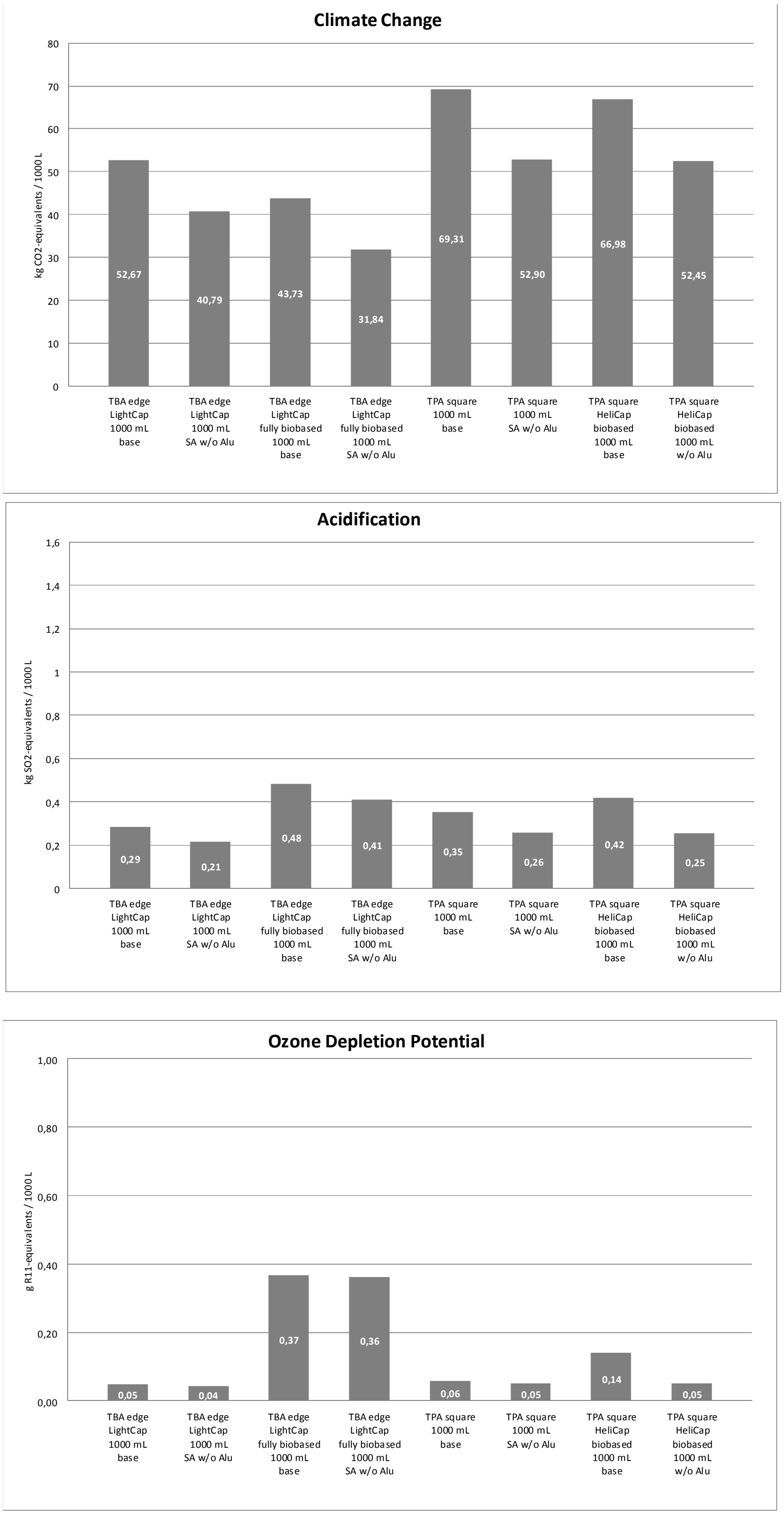
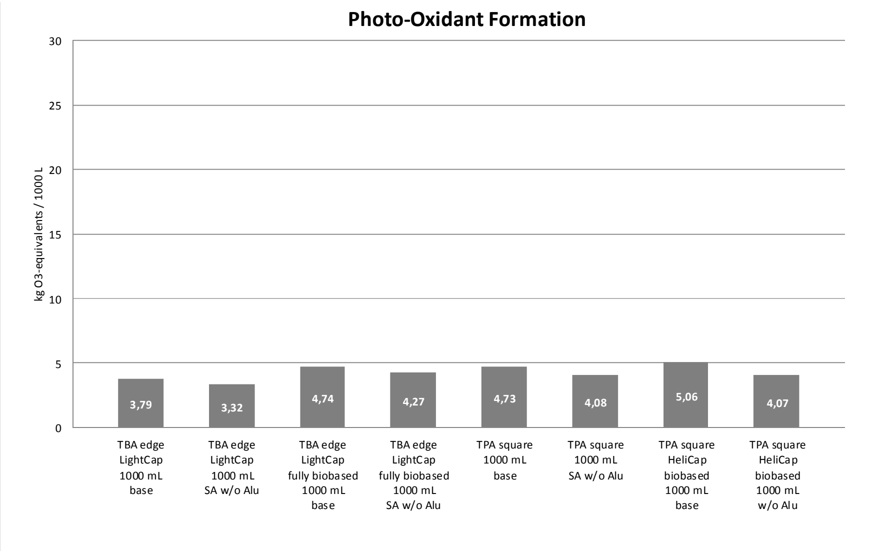
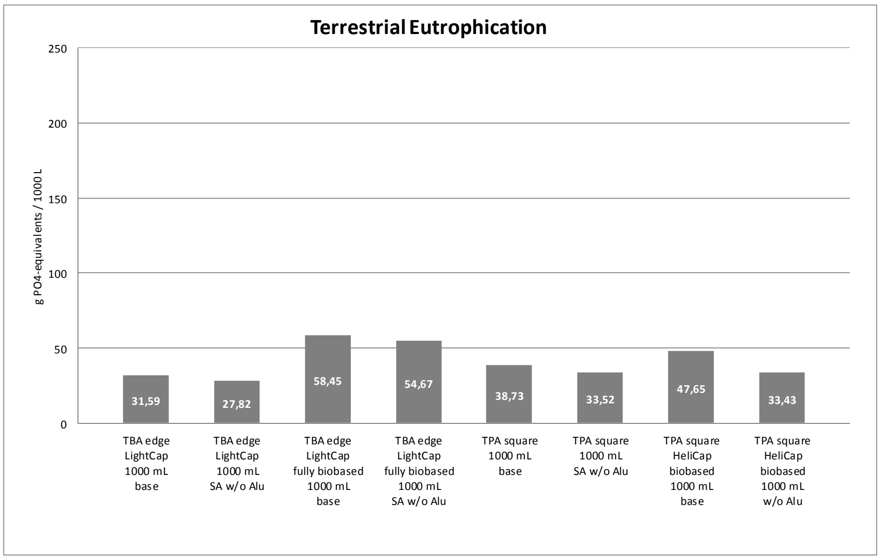


Figure 180: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Denmark**, Allocation factor 50 (Part 1)





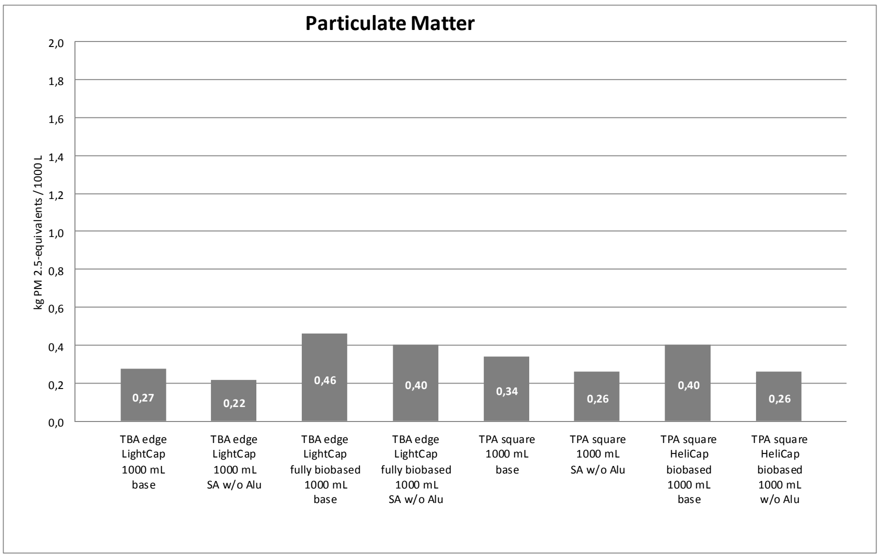
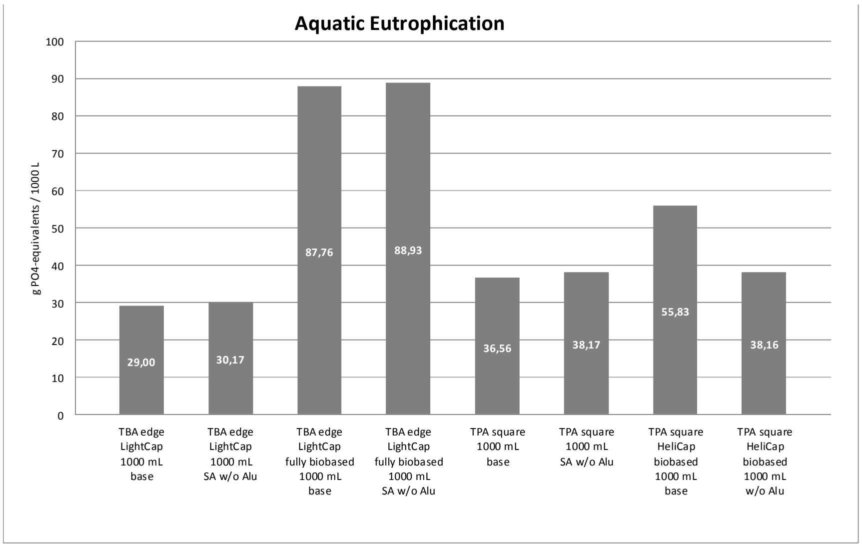
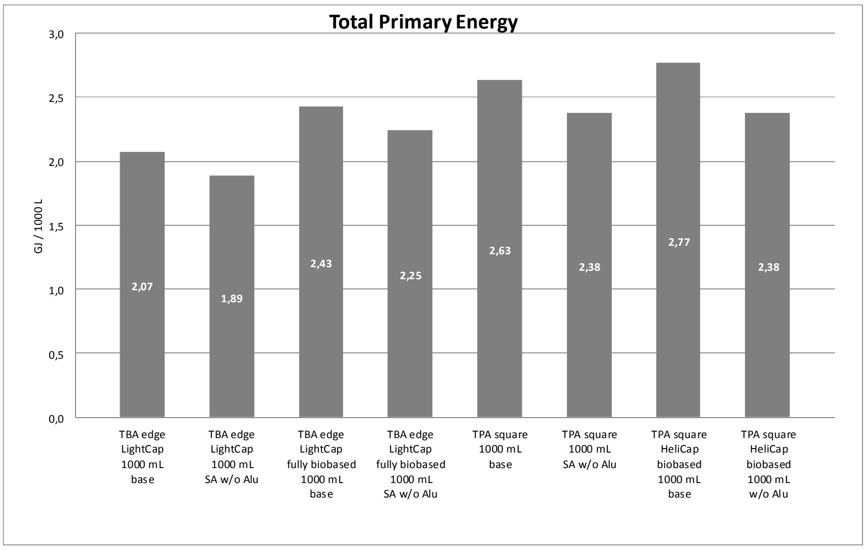


Figure 181: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Denmark**, Allocation factor 50 (Part 2)





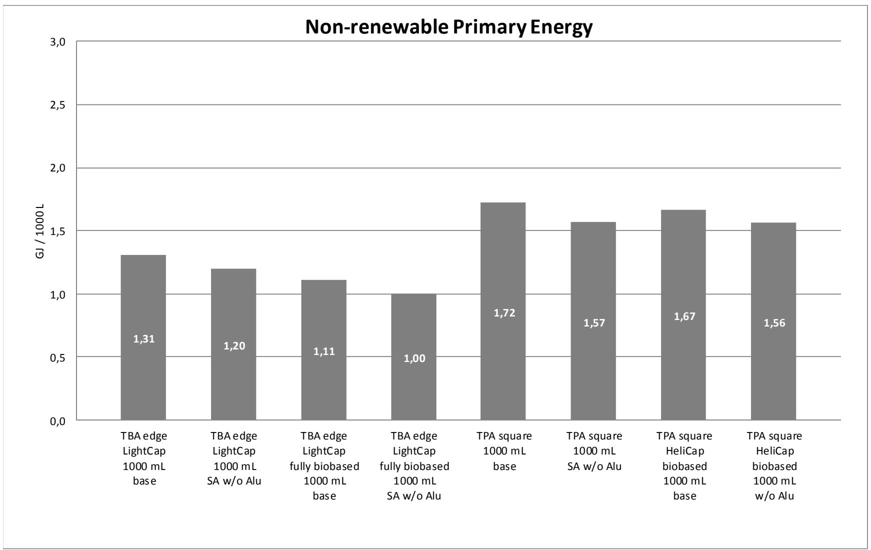
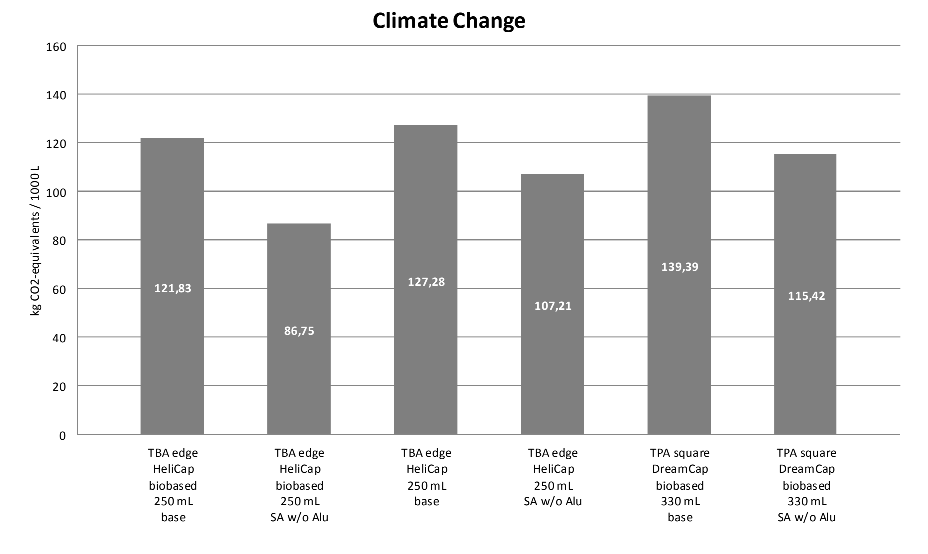
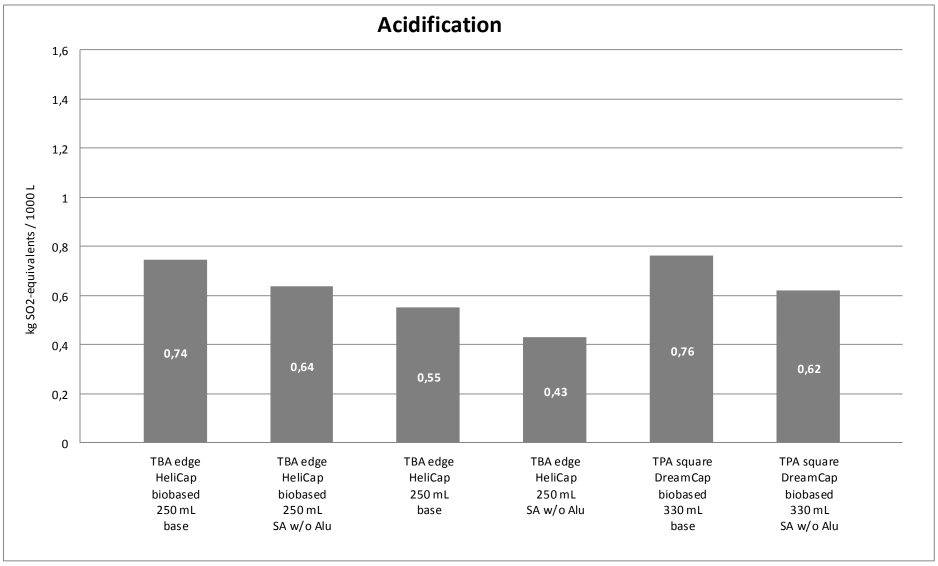


Figure 182: Indicator results for sensitivity analysis replacement of aluminium barrier **segment JNSD, Denmark**, Allocation factor 50 (Part 3)

B4 b) Grab & Go Denmark





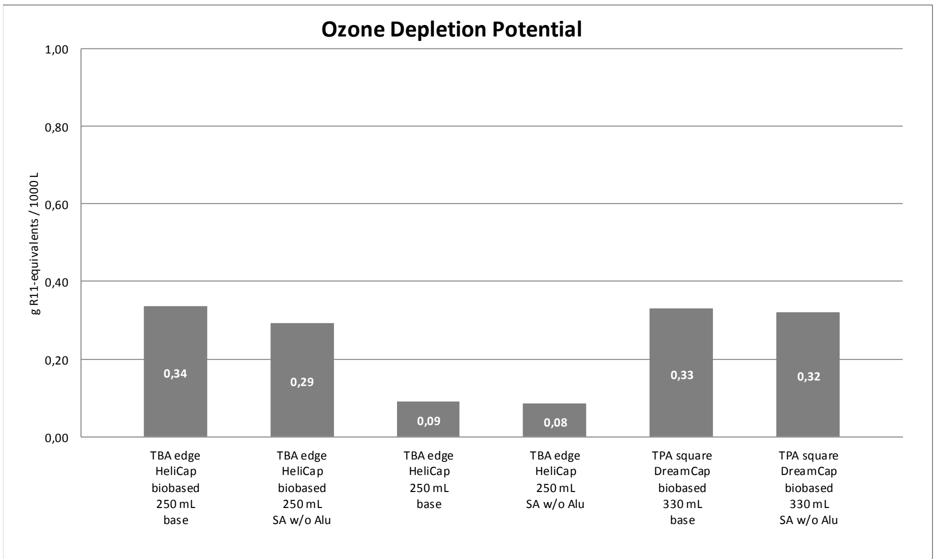
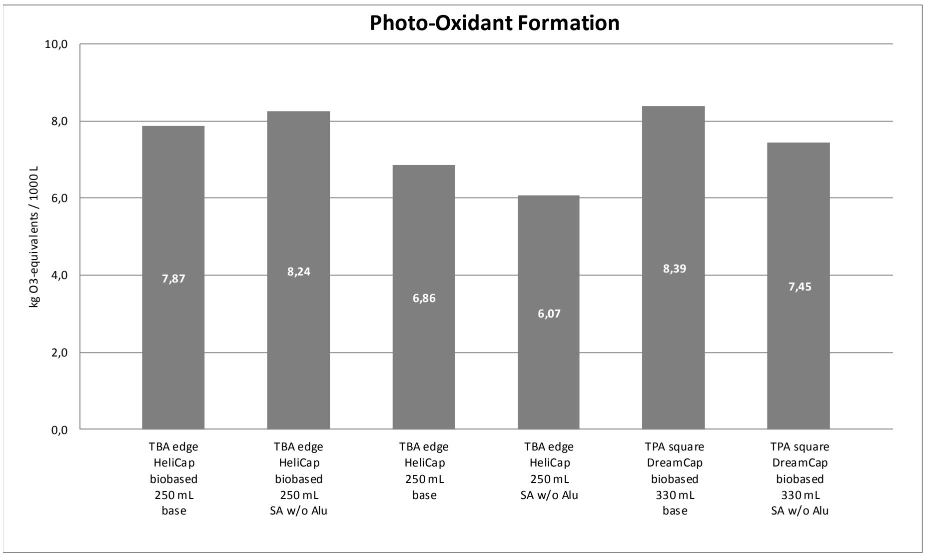
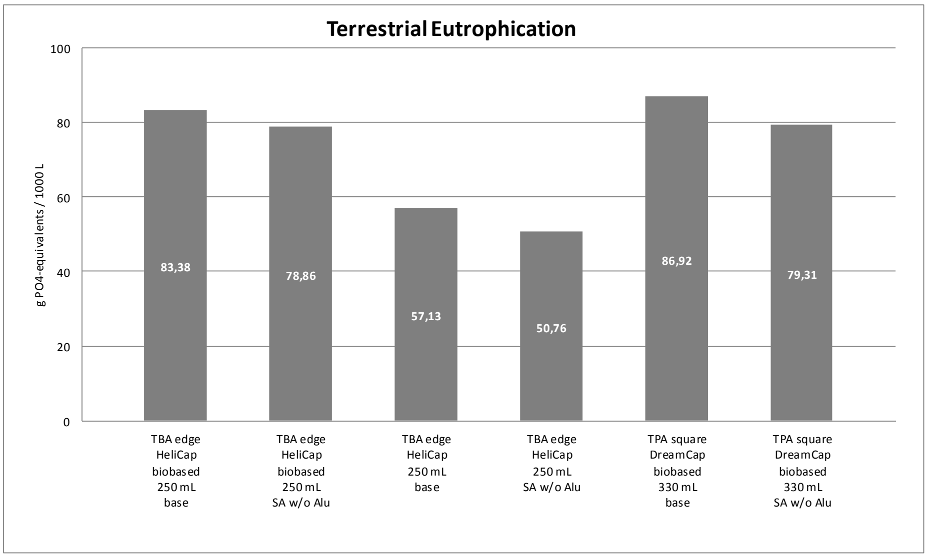


Figure 183: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Denmark**, Allocation factor 50 (Part 1)





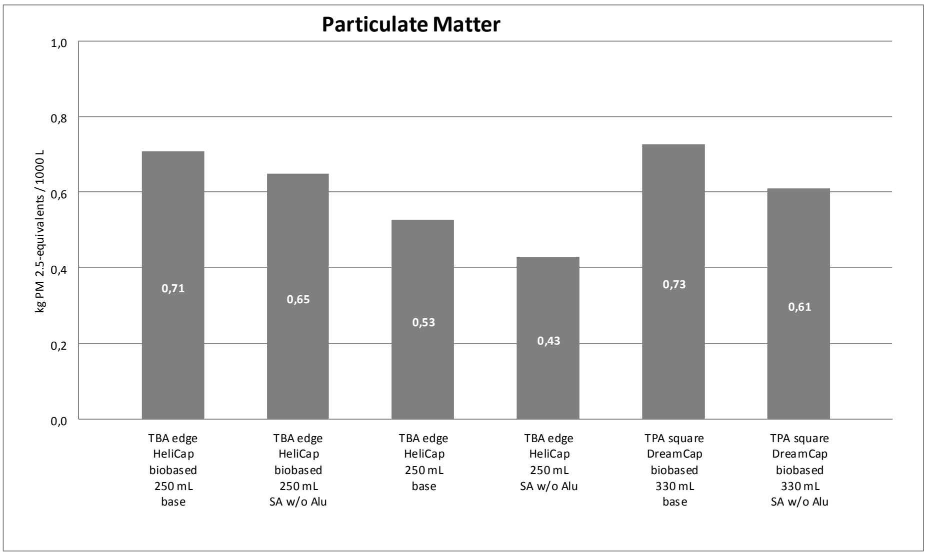


Figure 184: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Denmark**, Allocation factor 50 (Part 2)

Figure 185: Indicator results for sensitivity analysis replacement of aluminium barrier **segment Grab & Go, Denmark**, Allocation factor 50 (Part 3)

Appendix C:
Results for beverage cartons containing cream

Table 112: Packaging specifications of beverage cartons for the packaging of cream

Cream			
Packaging components	**Unit**	**Tetra Top Midi O38**	**Tetra Top Midi O38 biobased**
Volume [mL]		500	500
primary packaging (sum)	g	20.88	20.88
composite material (sleeve)	g	13.90	13.90
- liquid packaging board	g	11.56	11.56
- Polymers	g	2.34	2.34
Top		3.69	3.69
Polymers		3,69	
Bio-Polymers			3.69
Closure	g	3.30	3.30
- Polymers	g	3.30	
- Bio polymers	g		3.30
secondary packaging (sum)	g	**94.50**	**94.50**
tray (corr.cardboard)	g	94.50	94.50
tertiary packaging (sum)	g	**25170**	**25170**
pallet	g	25000	25000
type of pallet	-	EURO	EURO
number of use cycles	pc	25	25
stretch foil (per pallet) (LDPE)	g	170	170
pallet configuration			
cartons per tray /rollcontainer	pc	6	6
trays / shrink packs per layer	pc	24	24
layers per pallet/rollcontainer per lorry	pc	7	7

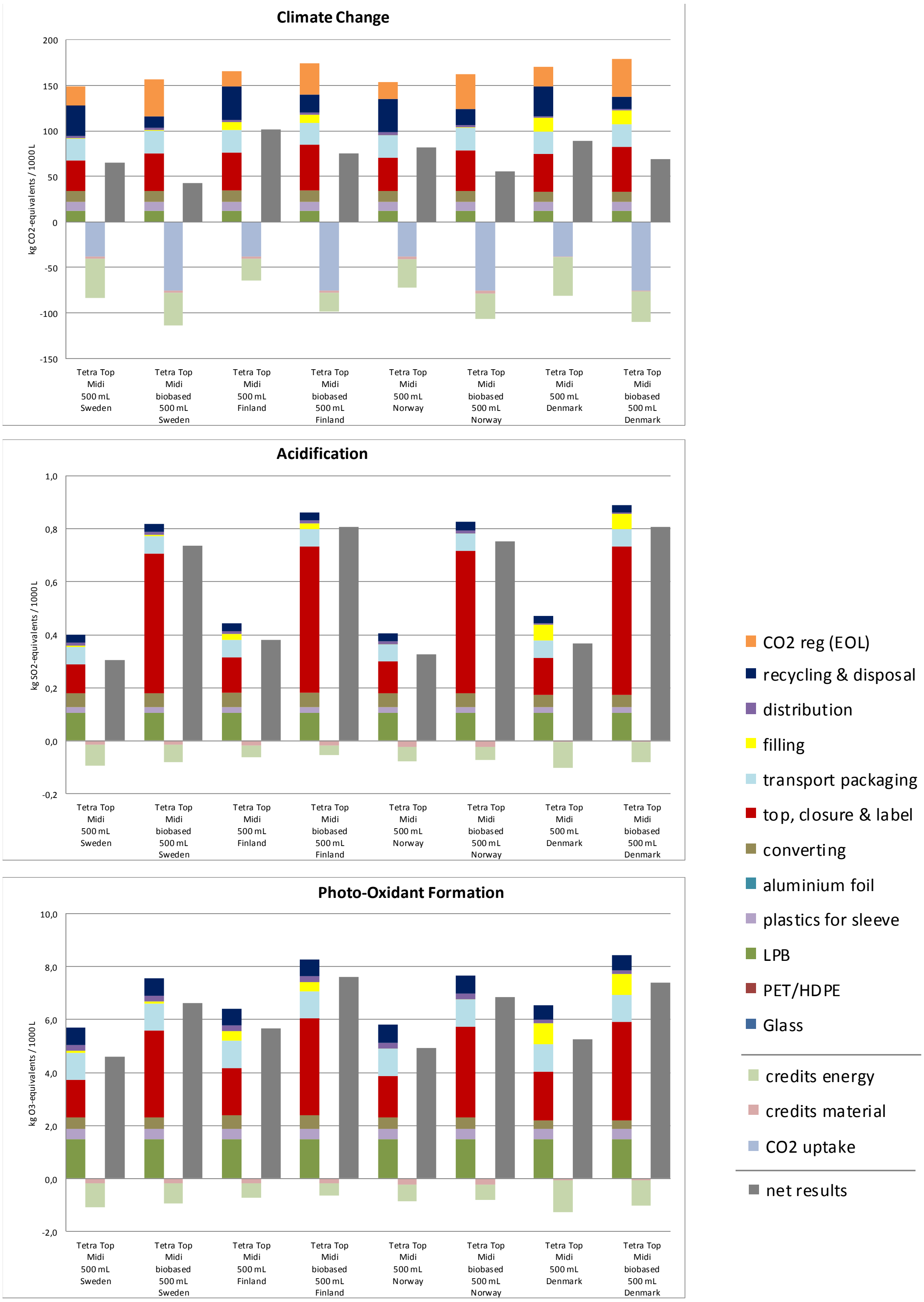


Figure 186: Indicator results for base scenarios of **segment Cream for Sweden, Norway, Finland and Denmark**, allocation factor 50% (Part 1)

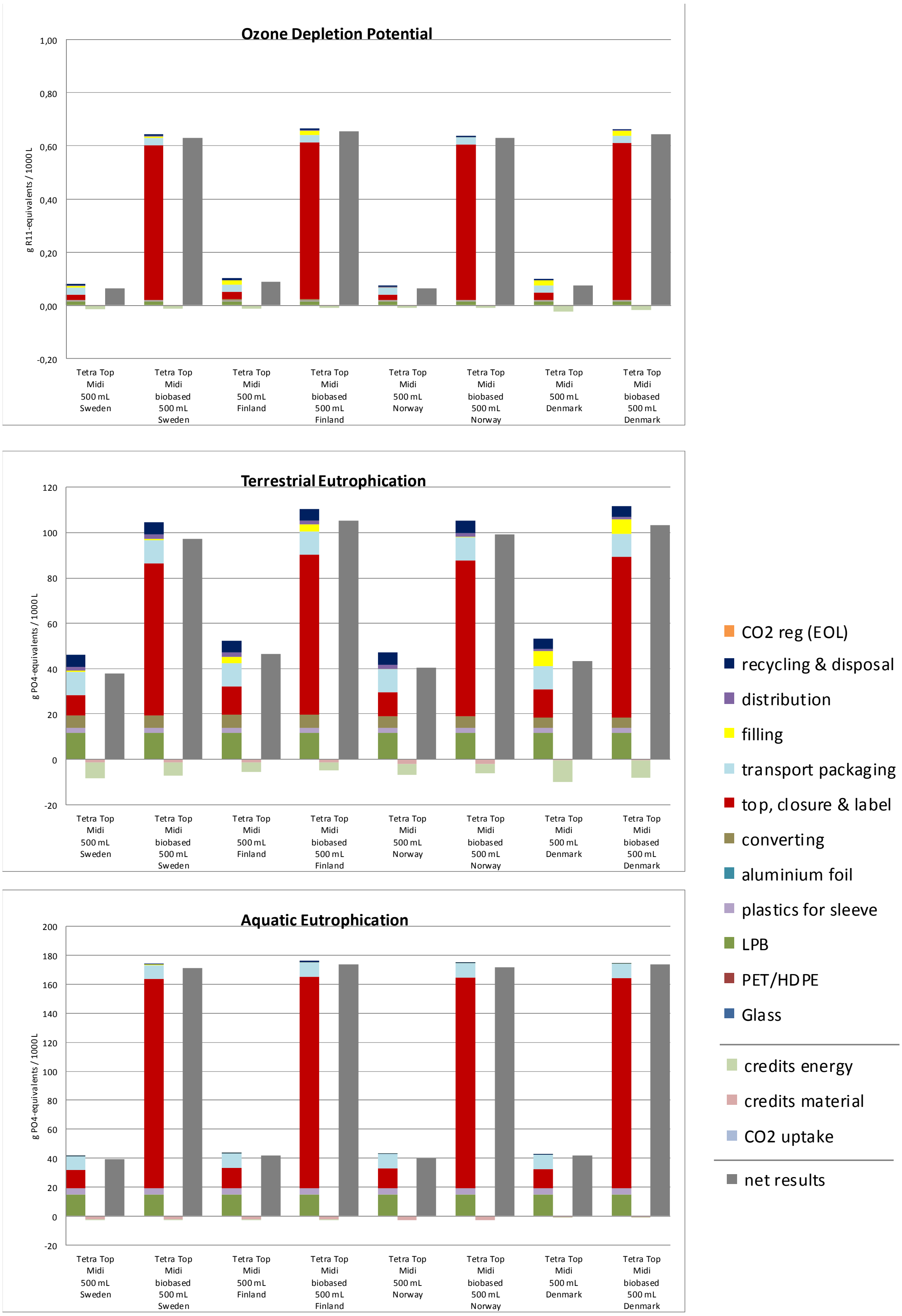


Figure 187: Indicator results for base scenarios of **segment Cream for Sweden, Norway, Finland and Denmark**, allocation factor 50% (Part 2)

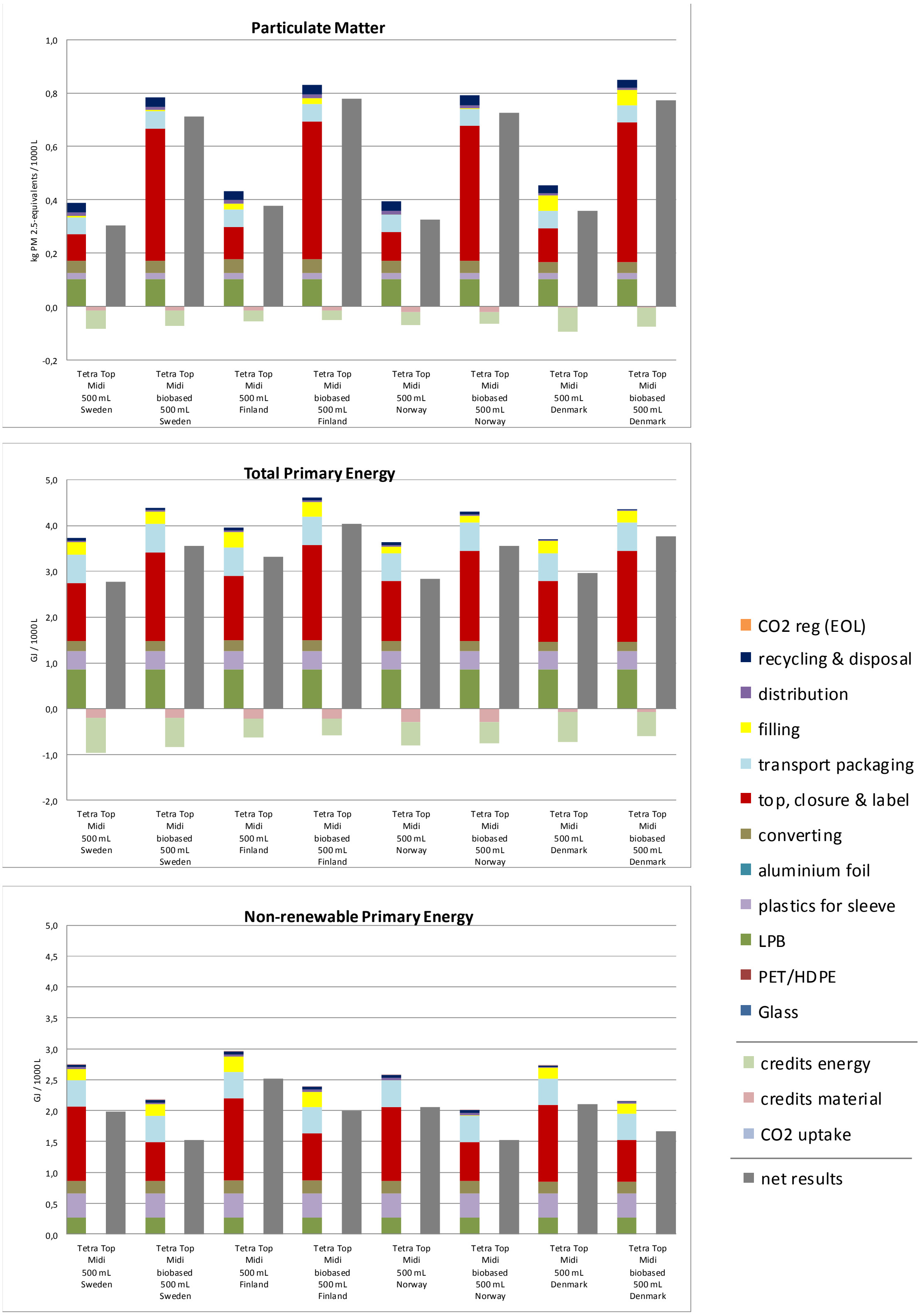


Figure 188: Indicator results for base scenarios of **segment Cream for Sweden, Norway, Finland and Denmark**, allocation factor 50% (Part 3)

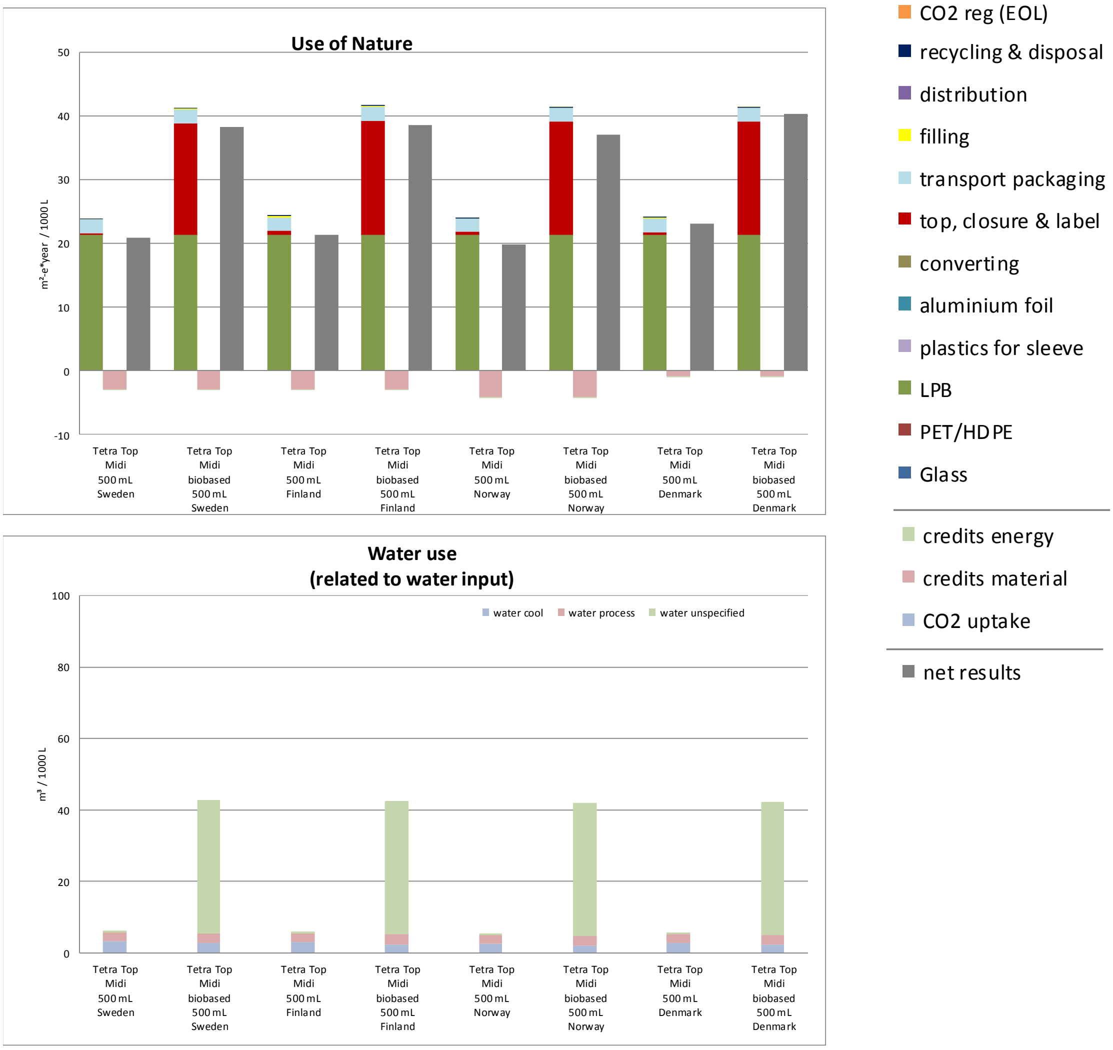


Figure 189: Indicator results for base scenarios of **segment Cream for Sweden, Norway, Finland and Denmark**, allocation factor 50% (Part 4)