



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, May 2019





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Heidelberg, May 2019



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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), grab & go and still water on the four Nordic markets.

The study covers the market situation of the Swedish, Norwegian, Finish and Danish market. 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.

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.

Segment Grab & Go

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 *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' 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 *JNSD ambient* 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.

Segment Water

In the segment water no unambiguous result can be observed. While all examined beverage cartons show lower 'Climate Change' results than all the examined PET bottles,

in other categories, the beverage cartons often show higher impacts. Especially beverage cartons with a high share of biobased polyethylene show higher results than the PET bottles in the categories 'Acidification', 'Photo-Oxidant Formation', 'Terrestrial and Aquatic Eutrophication'

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 the segments Dairy, JNSD and Grab & Go in all 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 CO₂ 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.

Regarding the segment water, no unambiguous conclusion can be drawn. PET bottles used for water tend to be lighter than those used for milk or JNSD. Besides their low weight, their high recycling rate, due to the deposit system applied, leads to relatively low results in many categories. The comparison of the different beverage cartons with the water bottles shows an inconclusive result.

Also the use of bio-based polyethylene does not deliver 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.

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
NM VOC	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

Preface

In 2017 ifeu conducted a Life Cycle Assessment for Tetra Pak with the same title as the present study [ifeu 2017]. As for the present study a critical review was conducted by a critical review panel consisting of Håkan Stripple, Ph.D. Alessandra Zamagni and Prof. Dr. Birgit Grahl.

The study from 2017 examined packaging systems in the liquid food segments dairy and juice (including grab&go sized packs) on the Nordic market. For the present study, water packaging solutions were added. In the course of this widening of the scope, it was decided to update the underlying data and recalculate and reassess the packaging systems of the 2017 study as well. The most important updates concern background data like transport and electricity production, end-of-life parameters and process data for the production of base materials used in the production of beverage cartons and bottles, including an updated dataset for biobased polyethylene. The objectives of the study, as well as the other elements of the scope remain the same. Therefore the present study report effectively replaces its predecessor. The study report from 2017 should not be considered valid anymore.

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 (CO₂). 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 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, water 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, water 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 CO₂ reduction per gram of raw material or relevant environmental information.
- (4) to provide knowledge regarding the environmental performance of carton packaging systems compared to optimized weights of PET bottles.
- (5) to provide knowledge regarding the environmental performance of carton packaging systems compared to PET bottles for water with optimized shares of recycled content.

As the **results of this study for the scopes (1), (2), (3), (4) and (5) shall be used for internal and external communication**, the study will be critically reviewed according to ISO 14040/14044.

1.2 Organisation of the study

This study was commissioned by Tetra Pak in 2018. 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
- **ifeu:** Samuel Schlecht, Frank Wellenreuther

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, Integrah, 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:

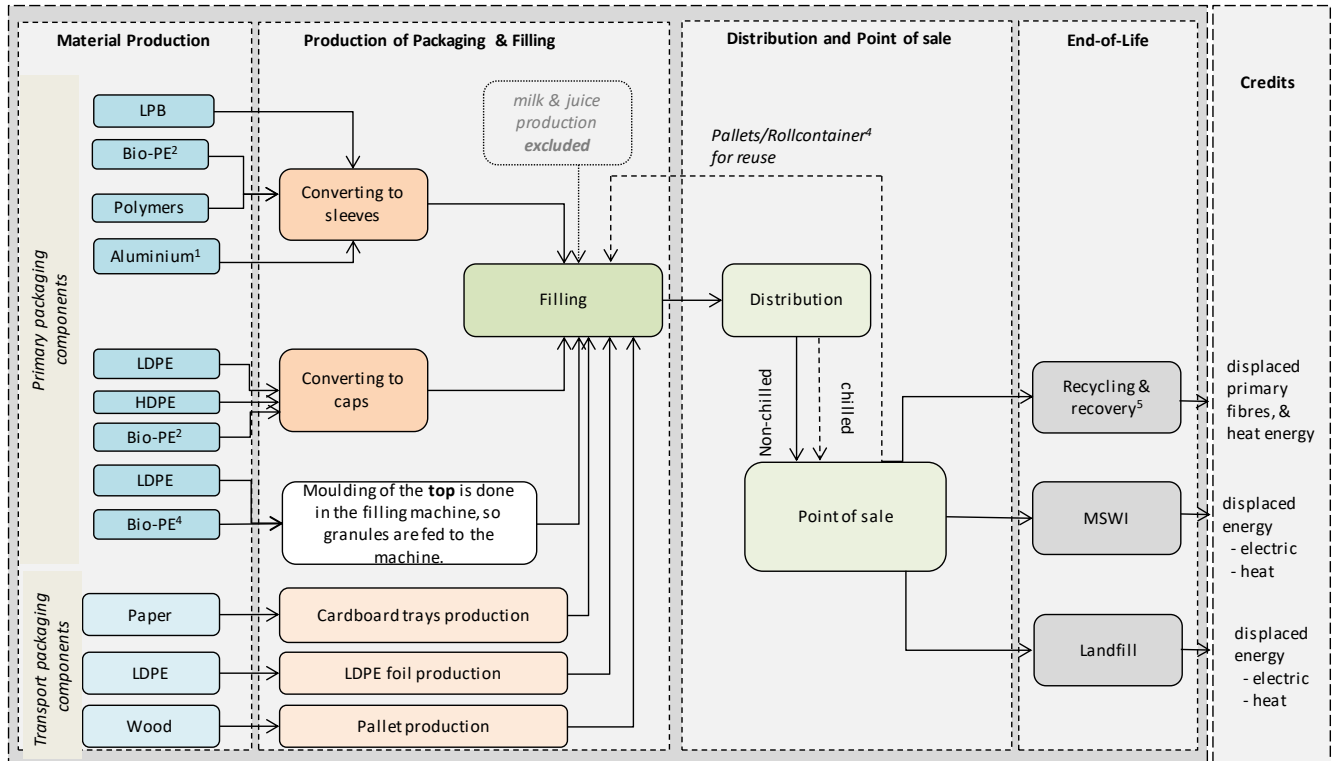
- production, converting, recycling and final disposal of the primary base materials used in the primary packaging elements from the studied systems (incl. closures)
- production, converting, recycling and final disposal of primary packaging elements and related transports
- production, recycling and 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 roll container is excluded
 ⁵ no material recycling of beverage cartons in Denmark

Figure 1: System boundaries of beverage cartons

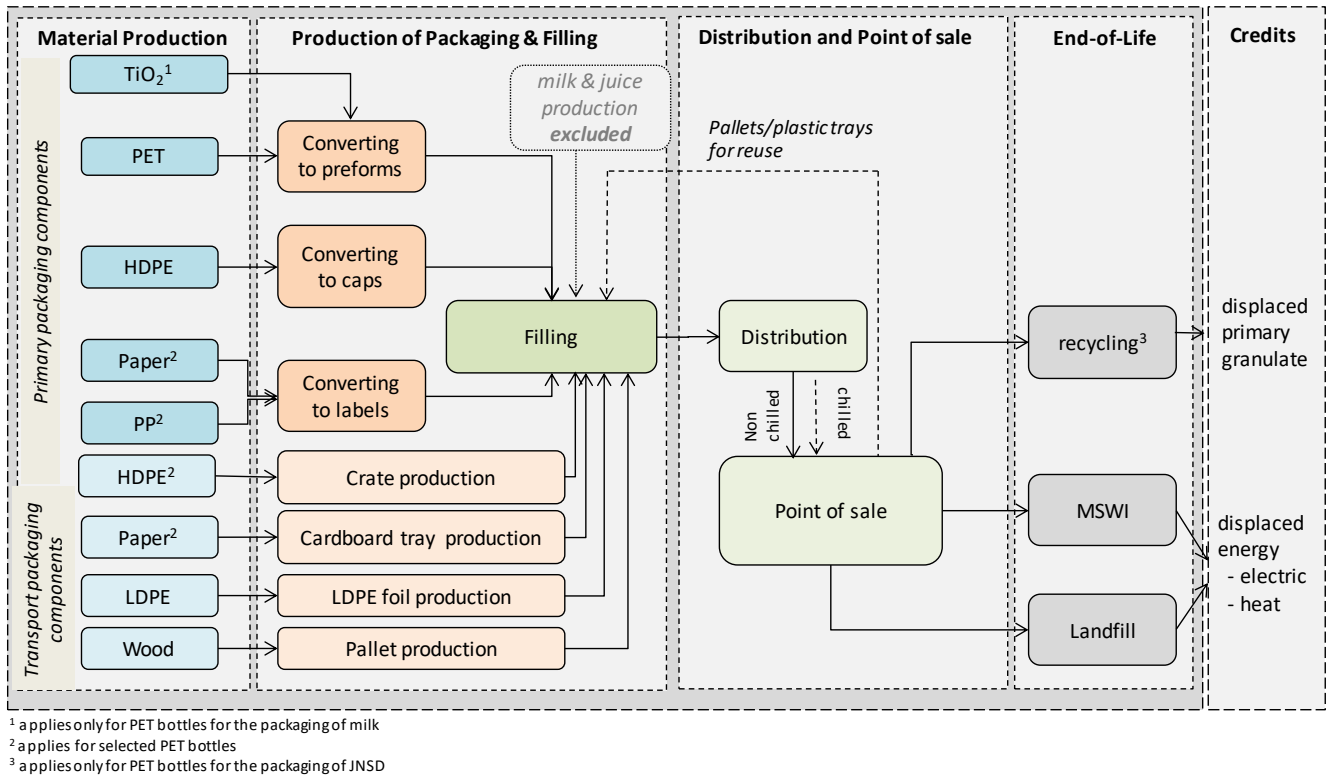


Figure 2: System boundaries of PET bottles

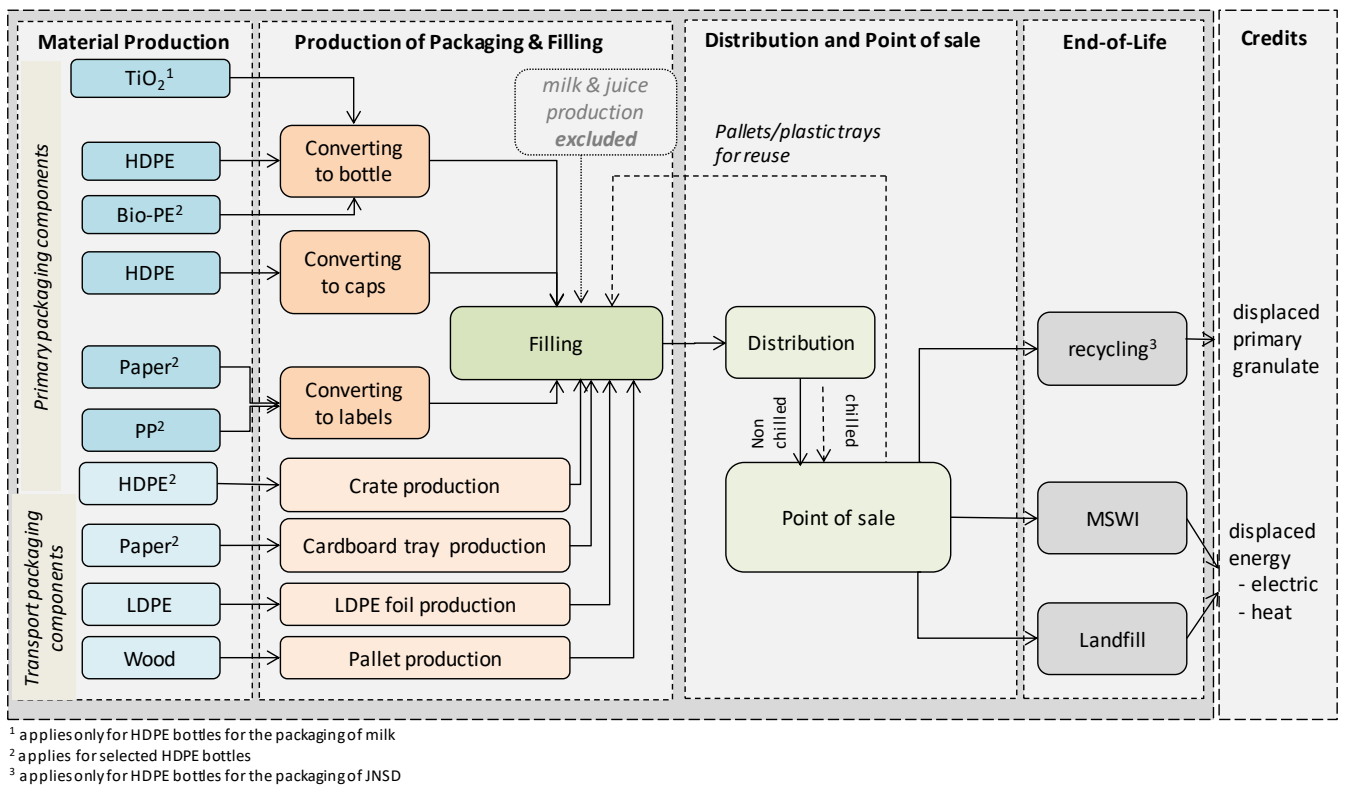


Figure 3: System boundaries of HDPE bottles

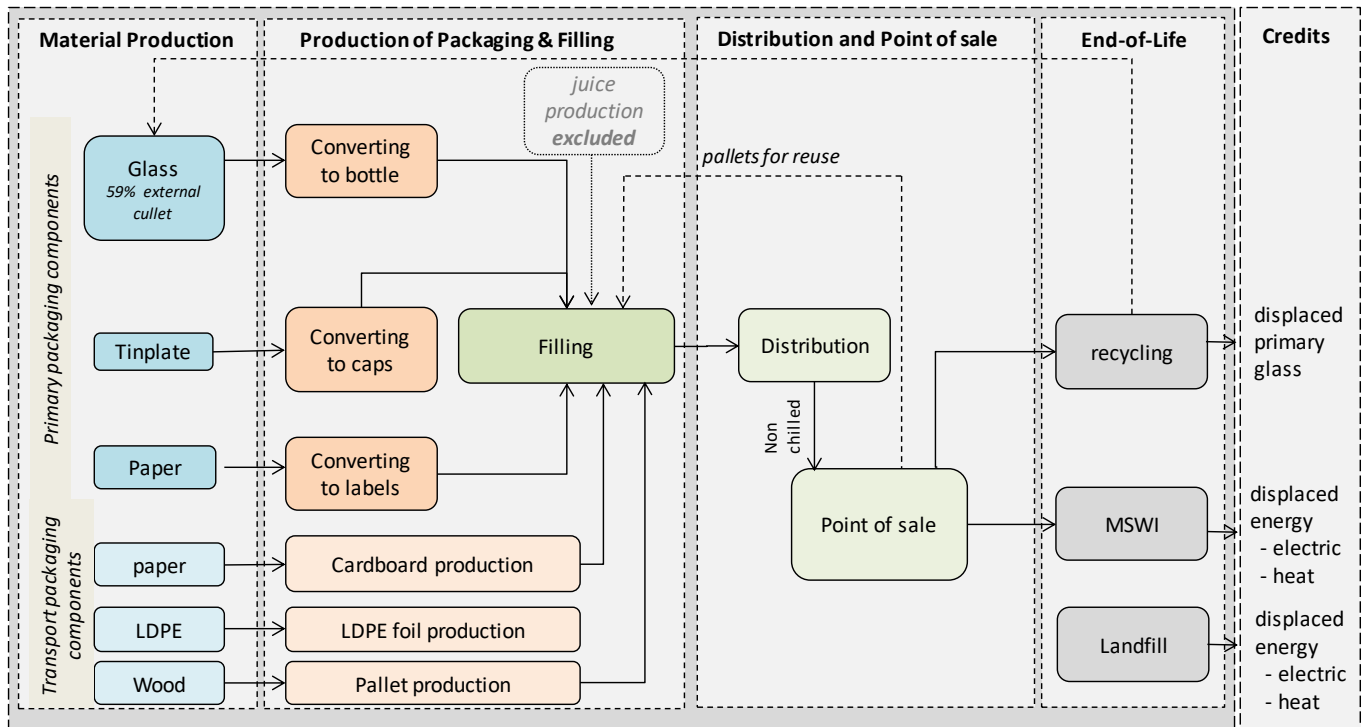


Figure 4: System boundaries of glass bottles

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 2018. 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 2018. The process-specific data, such as filling data refer to 2016-2018. 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 fossil plastic production originates from the Plastics Europe datasets and refer to 2011 and 2015.

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 $\leq 10\%$ 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 6 and 7. 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 5 (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 5. 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 Figures 5 to Figure 7

The following graphs (Figures 5 to 7) 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], [Klöppfer 1996] and [Kim et al. 1997]. According to [Klöppfer 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

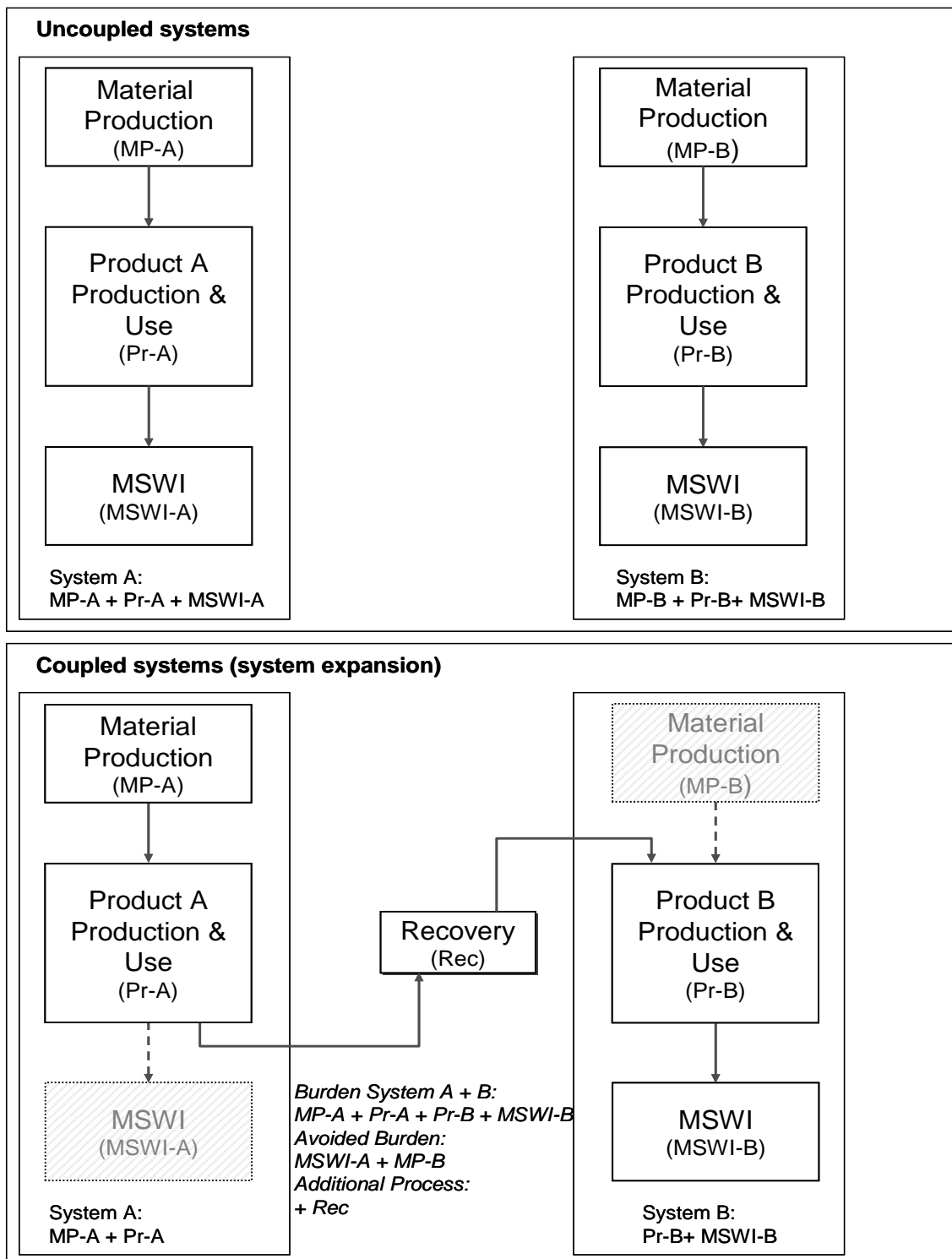


Figure 5: Additional system benefit/burden through recycling (schematic flow chart)

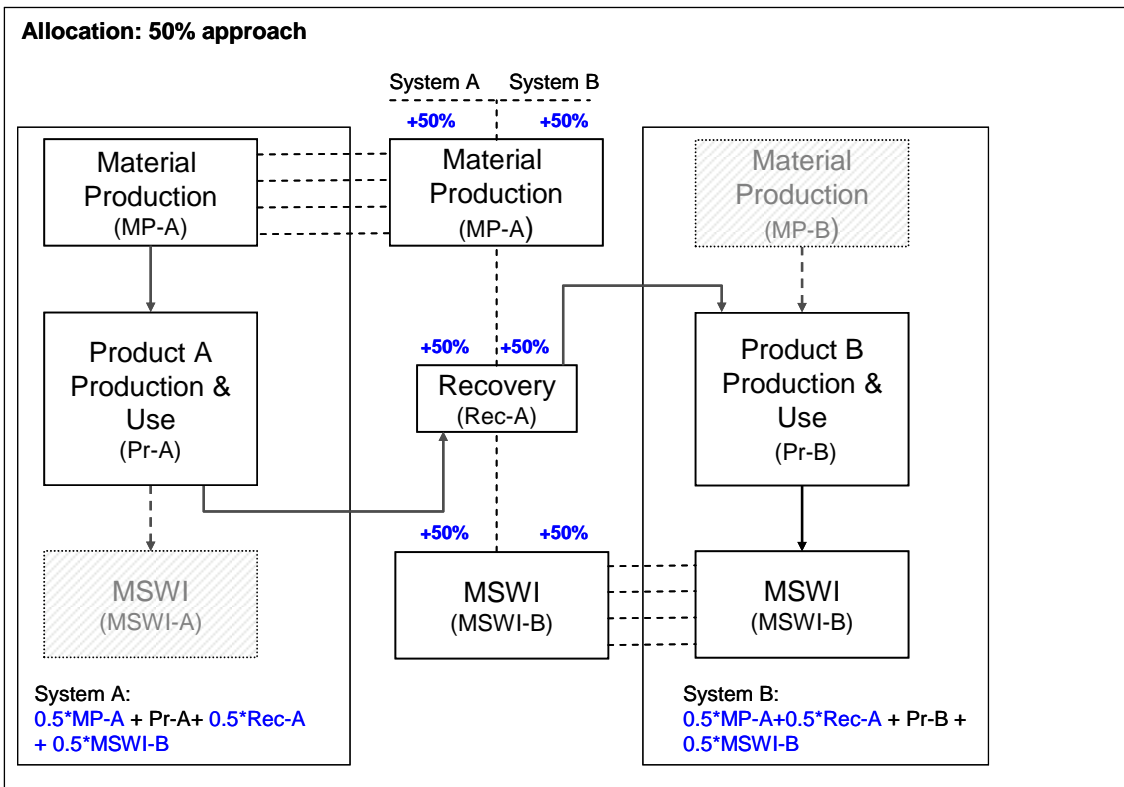


Figure 6: Principles of 50% allocation (schematic flow chart)

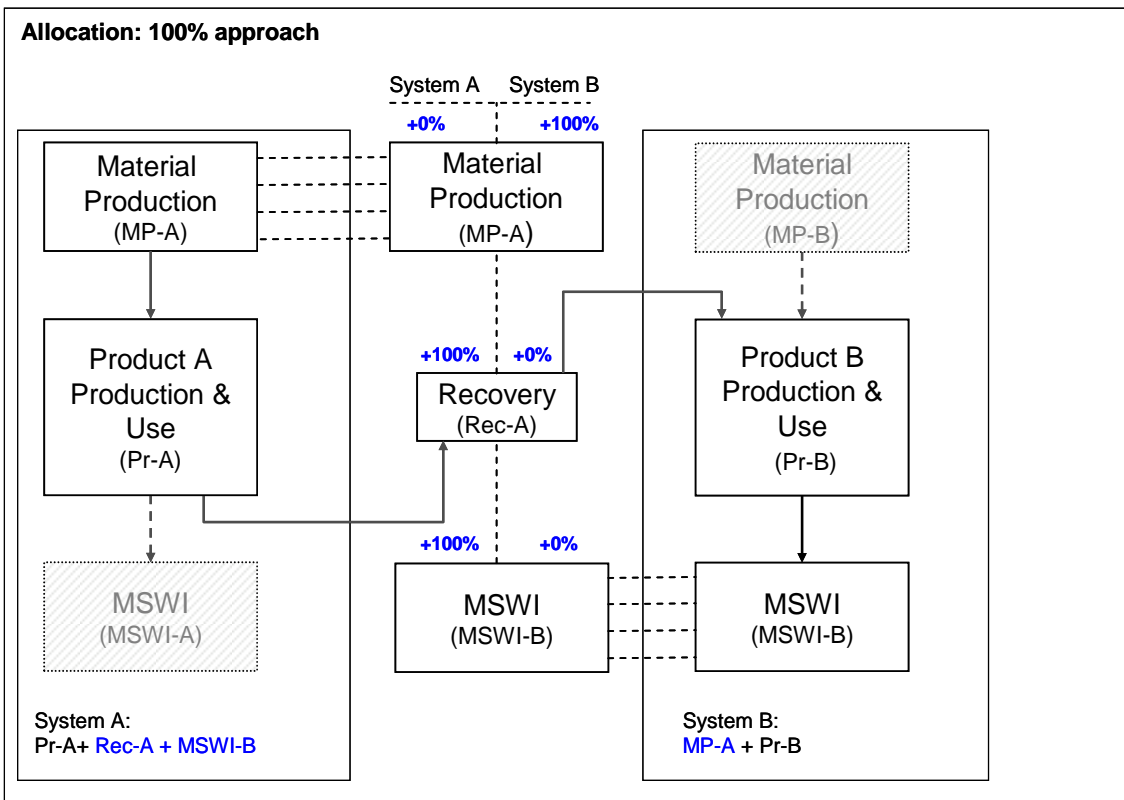


Figure 7: Principles of 100% allocation (schematic flow chart)

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 CO₂-e per functional unit.

Note on biogenic carbon: At the impact assessment level, it must be decided how to model and calculate CO₂-based GWP. In the present study the non-fossil CO₂ 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 CO₂ 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 CO₂ 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 O₃-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 NO_x. The 'Nitrogen-Maximum Incremental Reactivity' (NMIR) for NO_x 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 NO_x 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 NO_x 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 NO_x
- 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 O₃-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 SO₂-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 SO₂-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 primarily 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 primarily 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 & Jansson 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 phosphorus 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 (GSD²):

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 GSD². 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 ₂ O	C ₂ F ₂ H ₄	CF ₄	CCl ₄	C ₂ F ₆	R22	kg CO ₂ -e
Stratospheric Ozone Depletion	CFC-11	N ₂ O	HBFC-123	HCFC-22	Halon-1211	Methyl Bromide	Methyl Chloride	Tetrachlor-methane	kg CFC-11-e
Photo-Oxidant Formation	CH ₄	NMVOc	Benzene	Formaldehyde	Ethyl acetate	VOC	TOC	Ethanol	kg O ₃ -e
Acidification	NO _x	NH ₃	SO ₂	TRS***	HCl	H ₂ S	HF		kg SO ₂ -e
Terrestrial Eutrophication	NO _x	NH ₃							kg PO ₄ -e
Aquatic Eutrophication	COD	N	NH ₄ ⁺	NO ₃ ⁻	NO ₂ ⁻	P			kg PO ₄ -e
Particulate Matter	PM _{2,5}	SO ₂	NO _x	NH ₃	NMVOc				kg PM _{2,5} -e

* CO₂ fossil and biogenic / ** CH₄ fossil and CH₄ 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 crucial information, the impact category use of nature is addressed in this study by the category indicator 'Distance-to-Nature-Potential' (DNP) ($m^2 \cdot e \cdot 1a$) 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 $m^2 \cdot e \cdot 1a / fu$.

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 m³.

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), JNSD (Juice, Nectars & Still Drinks) (ambient and chilled) and water 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 are included there 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. Some of them were gathered for the related previous LCA [IVL 2009] and confirmed to be valid for the time scope 2018 as well.

The specifications of the competing packaging systems were determined by Tetra Pak 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 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, water versus water). 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			

Packages Dairy

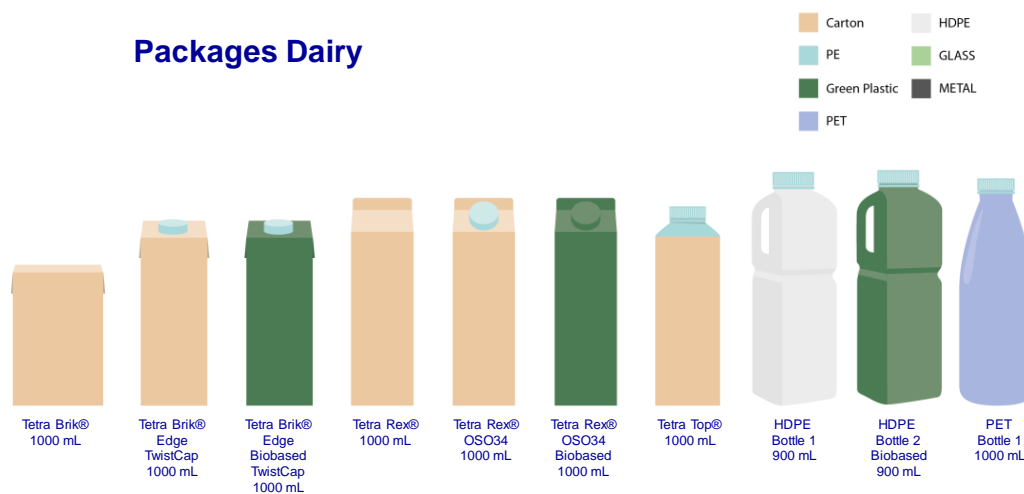


Figure 9: Pictures of analysed packaging systems in the segment dairy (Source: Tetra Pak©)

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			

Packages JNSD

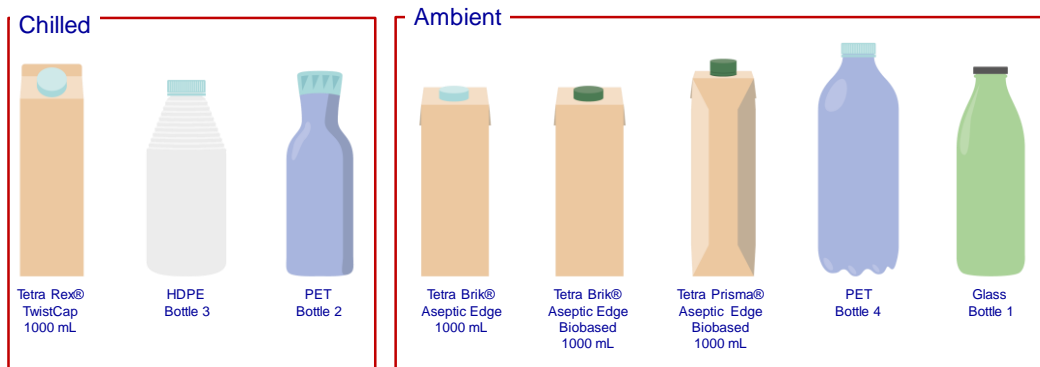
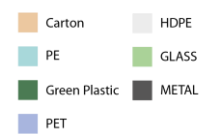


Figure 10: Pictures of analysed packaging systems in the segment JNSD (Source: Tetra Pak©)

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			

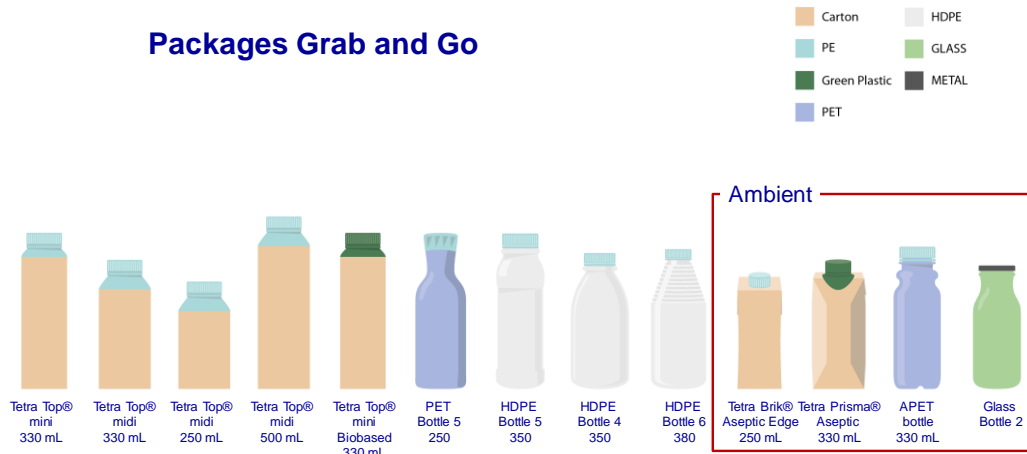


Figure 11: Pictures of analysed packaging systems in the segment Grab & Go (Source: Tetra Pak©)

Table 9: List of beverage containers in segment **water**

Carton based packaging systems	chilled (C) / ambient (A)	Geographic scope	Competing packaging systems	chilled (C) / ambient (A)	Geographic scope
Tetra Prisma Aseptic DC26 Bio-based cap & sleeve 330 ml	A	SE, DK, FI, NO	PET bottle 11 - 14 500 ml	A	SE
Tetra Prisma Aseptic DC26 Bio-based cap 330 ml	A	SE, DK, FI, NO	PET bottle 29 - 31	A	SE
Tetra Prisma Aseptic Square DC26 Fossil cap & sleeve 330 ml	A	SE, DK, FI, NO	PET bottle 15 - 19 500 ml	A	FI
Tetra Prisma Aseptic Edge DC26 Bio-based cap & sleeve 500 ml	A	SE, DK, FI, NO	PET bottle 20, 21 , 23, 24 500 ml	A	DK
Tetra Prisma Aseptic Edge DC26 Bio-based cap 500 ml	A	SE, DK, FI, NO	PET bottle 22 300 ml	A	DK
Tetra Prisma Aseptic Edge DC26 fossil cap & sleeve 500 ml	A	SE, DK, FI, NO	PET bottle 25 600 ml	A	NO
Tetra Top Midi Eifel C38 Bio-based cap, top & sleeve 500 ml	A	SE, DK, FI, NO	PET bottle 26 - 27 500 ml	A	NO
Tetra Top Midi Eifel C38 Bio-based cap & top 500 ml	A	SE, DK, FI, NO	PET bottle 28 300 ml	A	NO

Table 10: 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	39.39	39.39	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	25.17
- liquid packaging board	g	22.72	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	g										4.45
Polymers	g										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										15
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 11: 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	32.13	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	24.22	21.60	21.60	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 12: 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	16.67
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	8.79
- Polymers	g	1.80	1.93	2.23	1.80	2.57	2.57	3.20
- Aluminium	g					0.59	0.59	0.93
Top		2.90	3.71	3.68	2.90			
Polymers	g	2.90	3.71	3.68				
Bio polymers	g				2.90			
closure	g	3.30	3.30	3.30	3.30	2.70	2.70	3.75
- 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 13: Packaging specifications for regarded carton systems for the packaging of water in Sweden (SE), Denmark (DK), Norway (NO) and Finland (FI): components and masses [g/piece] - as applied in the model

		WATER							
Packaging components	Unit	TPA Square DC26 bb cap&sleeve	TPA Square DC26 bb cap	TPA Square DC26 fossil cap&sleeve	TPA Edge DC26 bb cap&sleeve	TPA Edge DC26 bb cap	TPA Edge DC26 fossil cap&sleeve	TT Midi Eifel C38 bb cap, top & sleeve	TT Midi Eifel C38 bb cap, top
Volume [ml]		330	330	330	500	500	500	500	500
Geographic Scope		SE, FI, DK, NO							
Chilled / ambient		ambient							
primary packaging (sum)	g	16.67	16.67	16.67	22.09	22.09	22.09	21.72	21.72
composite material (sleeve)	g	12.92	12.92	12.92	18.34	18.34	18.34	14.96	14.96
- liquid packaging board	g	8.79	8.79	8.79	13.20	13.20	13.20	11.56	11.56
- aluminium	g	0.93	0.93	0.93	1.19	1.19	1.19	0.73	0.73
- Polymers	g	1.63	3.20	3.20	1.94	3.95	3.95	1.30	2.67
- Bio polymers	g	1.57			2.01			1.37	
Top	g							3.87	3.87
- Polymers	g							0.47	0.47
- Bio polymers	g							3.40	3.40
Closure	g	3.75	3.75	3.75	3.75	3.75	3.75	2.90	2.90
- Polymers	g	2.18	2.18	3.75	2.18	2.18	3.75		
- Bio polymers	g	1.58	1.58		1.58	1.58		2.90	2.90
secondary packaging (sum)	g	182.50	182.50	182.50	202.78	202.78	202.78	110.54	110.54
tray (corr.cardboard)	g	182.50	182.50	182.50	202.78	202.78	202.78	110.54	110.54
tertiary packaging (sum)	g	25170	25170	25170	25170	25170	25170	25170	25170
pallet	g	25000	25000	25000	25000	25000	25000	25000	25000
type of pallet	-	EURO	EURO	EURO	EURO	EURO	EURO	EURO	EURO
number of use cycles	-	25	25	25	25	25	25	25	25
stretch foil (per pallet) (LDPE)	g	170	170	170	170	170	170	170	170
pallet configuration									
cartons per tray	pc	12	12	12	12	12	12	12	12
trays / per layer	pc	19	19	19	14	14	14	19	19
layers per pallet	pc	8	8	8	6	6	6	6	6
cartons per pallet	pc	1824	1824	1824	1008	1108	1008	1368	1368

Table 14: 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	g		37.87	
-TiO2	g	1.99	1.99	1.20
Trip rate of bottle		1	1	1
Label				
paper	g			1.67
PP	g	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 15: 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	g	2.13	1.99	2.68				2.54
PP	g				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 16: 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	g	1.18	1.19					
- Glass	g							160.51
Recycled content	%			25				
Trip rate of bottle		1	1	1	1	1	1	1
Label								
paper	g				1.34			1.43
PP	g	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	5	5	5	5	4	6
bottles per pallet	pc	1296	1200	1200	1200	1400	960	1296

Table 17: Packaging specifications for regarded alternative systems in the segment WATER in Sweden (SE), components and masses [g/piece] – as applied in the model

WATER					
Packing components	Unit	PET bottle 11	PET bottle 12	PET bottle 13	PET bottle 14
Volume [ml]		500	500	500	500
Geographic scope		SE			
Chilled/ambient		ambient			
primary packaging (sum)	g	26.43	40.25	33.04	27.63
bottle	g	22.96	34.43	29.37	24.74
- PET	g	22.96	34.43	29.37	24.74
- PA	g				
- carbon black	g				
- TiO2	g				
Recycled content ¹	%	0%	0%	0%	0%
bio-based content	%	0%	0%	0%	0%
trip rate of bottle		1	1	1	1
Label	g	0.98	2.31	1.63	0.62
- paper	g			1.63	0.62
- PP	g	0.98	2.31		
closure	g	2.48	3.50	2.03	2.27
- HDPE	g	2.48	3.50	2.03	2.27
secondary packaging (sum)	g	7.93	150.85	77.19	7.93
tray (corr. cardboard)	g	0.00	121.85	61.33	0.00
shrink foil per tray (LDPE)	g	7.93	29	15.86	7.93
tertiary packaging (sum)	g	27721	25480	25480	27721
pallet	g	25000	25000	25000	25000
type of pallet	-	EURO	EURO	EURO	EURO
number of use cycles	-	25	25	25	25
stretch foil (per pallet) (LDPE)	g	346	346	346	346
cardboard layer (per pallet)	g	2375.00			2375.00
pallet configuration					
bottles per tray	pc	6	20	12	6
trays / shrink packs per layer	pc	43	10	20	43
layers per pallet	pc	6	6	6	6
bottles per pallet	pc	1584	1200	1200	1584

Table 18: Packaging specifications for regarded alternative systems in the segment WATER in Finland (FI): components and masses [g/piece] – as applied in the model

WATER						
Packing components	Unit	PET bottle 15	PET bottle 16	PET bottle 17	PET bottle 18	PET bottle 19
Volume [ml]		500	500	500	500	500
Geographic scope		FI				
Chilled/ambient		ambient				
primary packaging (sum)	g	24.42	20.96	20.10	26.69	24.79
bottle	g	20.83	18.62	17.24	22.96	22.54
- PET	g	20.83	18.62	17.24	22.96	22.54
- PA	g					
- carbon black	g					
- TiO2	g					
Recycled content ¹	%	0%	0%	0%	0%	0%
trip rate of bottle		1	1	1	1	1
Label	g	0.66	0.27	0.57	1.25	0.29
- paper	g					
- PP	g	0.66	0.27	0.57	1.25	0.29
closure	g	2.94	2.06	2.29	2.48	1.96
- HDPE	g	2.94	2.06	2.29	2.48	1.96
secondary packaging (sum)	g	7.93	7.93	7.93	7.93	7.93
tray (corr. cardboard)	g	0.00	0.00	0.00	0.00	0.00
shrink foil per tray (LDPE)	g	7.93	7.93	7.93	7.93	7.93
tertiary packaging (sum)	g	27721	27721	27721	27721	27721
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	346	346	346	346	346
cardboard layer (per pallet)	g	2375.00	2375.00	2375.00	2375.00	2375.00
pallet configuration						
bottles per tray	pc	6	6	6	6	6
trays / shrink packs per layer	pc	43	43	43	43	43

layers per pallet	pc	6	6	6	6	6
bottles per pallet	pc	1584	1584	1584	1584	1584

Table 19: Packaging specifications for regarded alternative systems in the segment WATER in Denmark (DK; components and masses [g/piece] – as applied in the model

WATER						
Packing components	Unit	PET bottle 20	PET bottle 21	PET bottle 22	PET bottle 23	PET bottle 24
Volume [ml]		500	500	300	500	500
Geographic scope		DK				
Chilled/ambient		ambient				
primary packaging (sum)	g	17.09	22.13	14.72	13.66	20.73
bottle	g	14.66	20.13	12.92	12.02	18.49
- PET	g	14.66	20.13	12.92	12.02	18.49
- PA	g					
- carbon black	g					
- TiO2	g					
Recycled content ¹	%	0%	50%	50%	50%	0%
trip rate of bottle		1	1	1	1	1
Label	g	0.44	0.54	0.41	0.25	0.26
- paper	g					
- PP	g	0.44	0.54	0.41	0.25	0.26
closure	g	2.00	1.46	1.39	1.38	1.98
- HDPE	g	2.00	1.46	1.39	1.38	1.98
secondary packaging (sum)	g	6.48	7.93	6.01	12.94	7.93
tray (corr. cardboard)	g	0.00	0.00	0.00	0.00	0.00
shrink foil per tray (LDPE)	g	6.46	7.93	6.01	12.94	7.93
tertiary packaging (sum)	g	27721	27721	27721	27721	27721
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	346	346	346	346	346
cardboard layer (per pallet)	g	2375.00	2375.00	2375.00	2375.00	2375.00

pallet configuration						
bottles per tray	pc	6	6	6	9	6
trays / shrink packs per layer	pc	43	43	43	24	43
layers per pallet	pc	6	6	6	6	6
bottles per pallet	pc	1584	1584	1584	1296	1584

Table 9: Packaging specifications for regarded alternative systems in the segment WATER in Norway (NO); components and masses [g/piece] – as applied in the model

WATER					
Packing components	Unit	PET bottle 25	PET bottle 26	PET bottle 27	PET bottle 28
Volume [ml]		600	500	500	300
Geographic scope		NO			
Chilled/ambient		ambient			
primary packaging (sum)	g	27.21	26.66	27.62	22.64
bottle	g	24.70	23.88	24.70	17.12
- PET	g	24.70	23.88	24.70	17.12
- PA	g				
- carbon black	g				
- TiO2	g				
recycled content ¹	%	0%	0%	0%	0%
bio-based content	%	0%	0%	0%	0%
trip rate of bottle		1	1	1	1
Label	g	0.93	0.32	0.65	0.51
- paper	g			0.65	0.51
- PP	g	0.93	0.32		
closure	g	1.57	2.46	2.27	5.01
- HDPE	g	1.57	2.46	2.27	5.01
secondary packaging (sum)	g	7.93	7.93	7.93	7.93
tray (corr. cardboard)	g	0.00	0.00	0.00	0.00
shrink foil per tray (LDPE)	g	7.93	7.93	7.93	7.93
tertiary packaging (sum)	g	27721	27721	27721	27721
pallet	g	25000	25000	25000	25000
type of pallet	-	EURO	EURO	EURO	EURO
number of use cycles	-	25	25	25	25
stretch foil (per pallet) (LDPE)	g	346	346	346	346
cardboard layer (per pallet)	g	2375.00	2375.00	2375.00	2375.00

pallet configuration					
bottles per tray	pc	6	6	6	6
trays / shrink packs per layer	pc	43	43	43	43
layers per pallet	pc	6	6	6	6
bottles per pallet	pc	1584	1584	1584	1584

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 Tables 21 and 22.

Table 21: 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% ^R	2015	[Tetra Pak 2016]
	Plastic bottles	40.4% ^R	2017	[FTI 2019]
	deposit PET bottles for water	84.1% ^R	2018	[Tetra Pak 2018]
	Glass bottles	93.6% ^C	2015	[Ferver 2019]
Finland	Beverage carton	21.0% ^R	2018	[Tetra Pak 2019]
	Plastic bottles	0.0% ¹	2014	[TemaNord 2014]
	deposit PET bottles for water	91.0% ^R	2018	[Tetra Pak 2018]
	Glass bottles	78.4% ^C	2015	[Ferver 2019]
Norway	Beverage carton	61.7% ^R	2016	[ACE 2018]
	Plastic bottles	22.3% ^R	2015 ²	(https://www.grontpunkt.no/gjenvinning/forbruker/plastemballasje ; accessed July 2016)
	deposit PET bottles for water	96.8% ^R	2018	[Tetra Pak 2018]
	Glass bottles	86.8% ^C	2015	[Ferver 2019]
Denmark	Beverage carton	0.0%	2016	[ACE 2018],[Tetra Pak 2018]
	PET bottles	0.0%	2014	[TemaNord 2014]
	deposit PET bottles for water	90.0% ^R	2018	[Tetra Pak 2018]
	HDPE bottles	15.0% ^R	2014	[TemaNord 2014]
	Glass bottles	84.9% ^C	2014	[Ferver 2019]

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 .

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

Country	MSWI/Landfill	Quota	Reference year	Source
Sweden	MSWI	99.2%	2017	calculated based on [Eurostat 2019]
	Landfill	0.8%		
Finland	MSWI	98.4%		
	Landfill	1.6%		
Norway	MSWI	93.5%		
	Landfill	6.5%		
Denmark	MSWI	98.4%		
	Landfill	1.6%		

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.

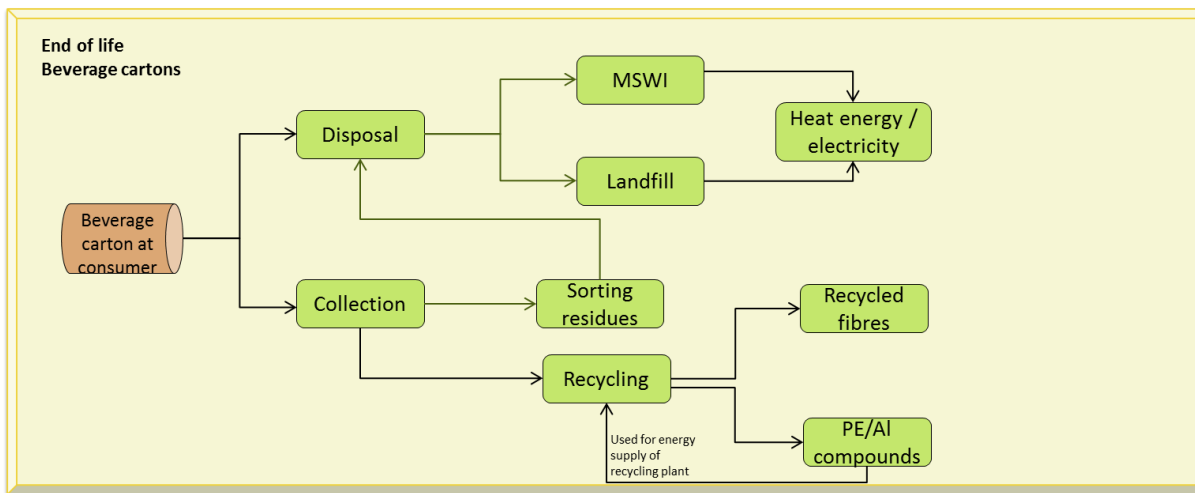


Figure 12: End-of-life model of beverage carton

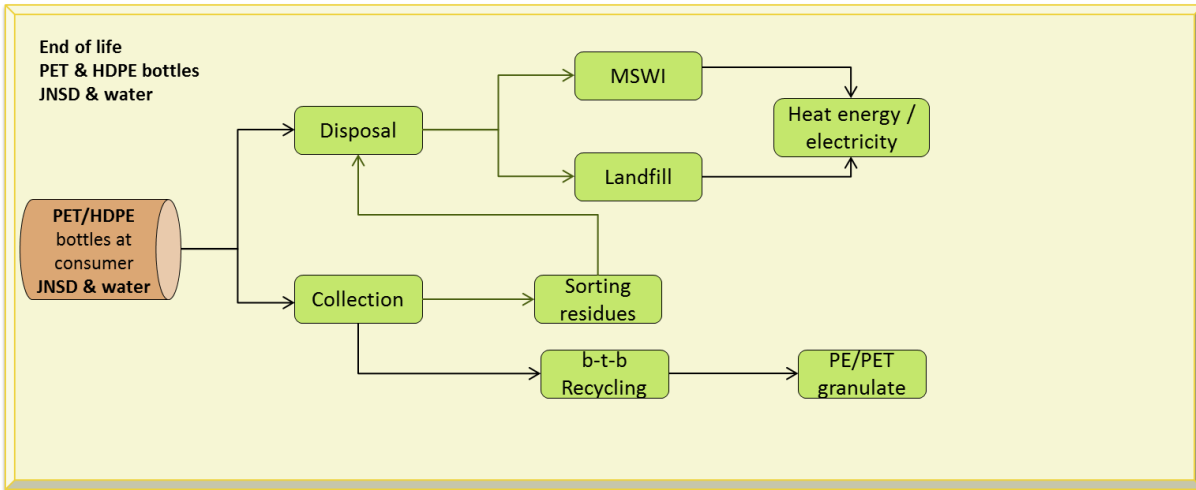


Figure 13: End-of-life model of water and JNSD plastic bottles

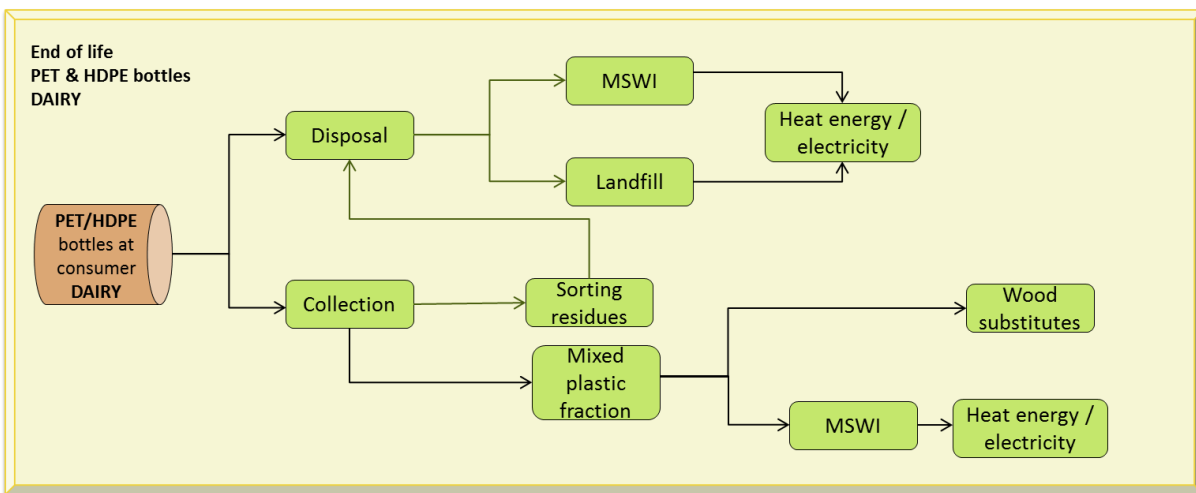


Figure 14: End-of-life model of dairy plastic bottles

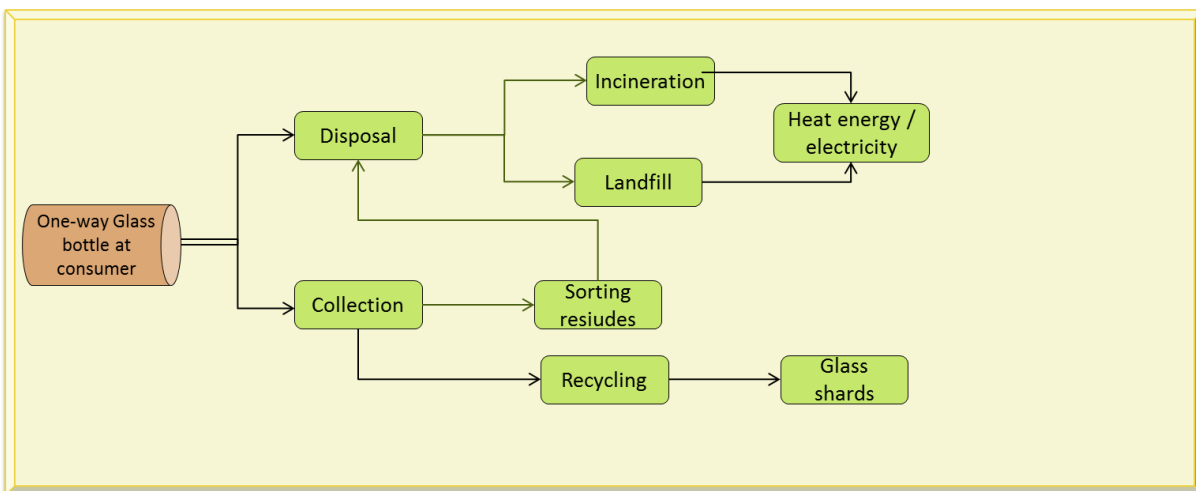


Figure 15: End-of-life model of glass bottles.

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 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 with a minimum PET weight of 10 grams. 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
 - Water: PET bottle 17 – 20.10 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%.

2.4.4 Sensitivity analysis regarding recycled content of plastic bottles

To consider potential future developments in terms of recycled content of plastic bottles additional scenarios with higher shares of recycled PET content are analysed and illustrated in break-even graphs.

Each of the plastic bottles will be additionally calculated with 50% and 100% recycled PET content.

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

Table 23: 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	[Braskem 2018]	2017
PET	Plastics Europe, published online June 2017	2015
Titanium dioxide	Ecoinvent V.3.4	2017
Tinplate	[APEAL 2015]	2012/2013
Aluminium	EAA Environmental Profile report 2013 [EAA 2013]	2010
Corrugated cardboard	[FEFCO 2015]	2014
Liquid packaging board	ifeu data, obtained from ACE [ACE 2012]	2009
Production		
BC converting	Tetra Pak	2009
Glass bottle converting including glass production	UBA 2000 (bottle glass); energy prechains 2012	2000/2012
Preform production	Data provided by Tetra Pak, gathered in 2009, updated in 2016	2016
HDPE bottle production	Data provided by Tetra Pak, gathered in 2009, updated in 2016	2016
Filling		
Filling of beverage cartons	Data provided by Tetra Pak	2016-2018
Filling plastic bottles	Data provided by Tetra Pak, gathered in 2009, updated in 2016	2016

Material / Process step	Source	Reference period
	SBM is included in data for PET bottles	
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	2015
Municipal waste incineration	ifeu database, based on statistics and incineration plant models	2008
Landfill	ifeu database, based on statistics and incineration plant models	2008
lorry transport	ifeu database, based on statistics and transport models, emission factors based on HBEFA 3.1 [INFRAS 2017].	2016
rail transport	[EcoTransIT 2016]	2016
sea ship transport	[EcoTransIT 2016]	2016

3.1 Plastics

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

- Polypropylene (PP)
- High density polyethylene (HDPE)
- Low density polyethylene (LDPE)
- Linear Low density polyethylene (LLDPE)
- Bio-based Polyethylene (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)

The bio-based PE used by Tetra Pak in the regarded beverage carton systems is supplied by Braskem in Brazil. The PE is produced from ethanol based on sugar cane. This study uses two LCA datasets provided by Braskem, one for bio-based HDPE and one for bio-based LDPE [Braskem 2018]. In order to address co-products in the bio-based PE production, the LCA datasets used in this study use the approach of economical allocation. Credits for land use change have been excluded from the datasets as underlying assumptions and models are not known.

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

3.2 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 refer to the year 2012 and are published by APEAL [APEAL 2015]. The data set is based on a weighted average site-specific data (gate-to-gate) of European steel producers whereas the electricity grid mix included in the data is country-specific. According to APEAL the dataset represent about 95% of the annual European supply or production volume.

3.4 Glass and glass bottles

The data used for the manufacture 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 Ecolnvent 2.2 (same datasets as in Ecolnvent 3.1), including a forestry model to calculate inventories for this sub-system. Energy required is supplied by electricity as well as by on-site energy production by incineration of wood and bark. The specific energy sources were taken into account.

3.6 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2015 [FEFCO 2015] were used. More specifically, the data sets for the manufacture of 'Kraftliners' (predominantly based on primary fibres), 'Testliners' and 'Wellenstoff' (both based on waste paper) as well as for corrugated cardboard packaging were used. The data sets represent weighted average values from European locations recorded in the FEFCO data set. They refer to the year 2014. All corrugated board and cardboard trays are assumed to be sourced from European production.

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

3.7 Titanium dioxide

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

The data used in this study is taken from ecoinvent database 3.4. The data refers to the years 1997 – 2017 and is representative for Europe.

3.8 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 and 2018, 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 and 2018. 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 2018, as filling machines and technologies have not changed since then.

3.11 Transport settings

Table 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 24: 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

shows the applied distribution distances. Distribution centers are the places where the products are temporarily stored and then distributed to the different point of sales (i.e.

supermarkets). Distances have been calculated as average distances from representative filling plants to one representative distribution center in each country. The applied distances from distribution centers to point of sales are educated estimates. For each country the same distribution model is applied for all packages.

It is assumed that not the full return distance is driven with an empty load, as lorries load other goods (outside the system boundaries of this study) for at least part of their journey. As these other goods usually cannot be loaded at the final point of the beverage packaging delivery it is assumed that a certain part of the return trip is made without any load and so has to be allocated to the distribution system. No First hand data is available on average empty return distances. For this reason an estimation of 33% based on expert judgement of the delivery distance is calculated as an empty return trip.

Table 25: Distribution distances in km for the examined packaging systems in Sweden, Finland, Norway and Denmark

country	Distribution distance [km] as applied in this study			
	Distribution Step 1		Distribution step 2	
	filler > warehouse (delivery)	warehouse > filler (return trip)	warehouse > POS (delivery)	POS > warehouse (return trip)
Sweden	288	95	144	144
Finland	288	95	144	144
Norway	288	95	144	144
Denmark	215	71	71	71

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.

In all of the four countries PET bottles for water are deposit bottles. These bottles are modelled with considerably higher collection rates, which were obtained from Tetra Pak.

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 Austrian, German, French, Norwegian, Swedish and Swiss Environment Agencies in the 'Handbook of emission factors' [INFRAS 2017]. The 'Handbook' is a database application referring to the year 2017 and giving as a result the transport distance related fuel consumption and the emissions differentiated into lorry size classes and road categories. Data are based on average fleet compositions within several lorry size classes. The emission factors used in this study refer to the year 2016.

Based on the above-mentioned parameters – lorry size class and road category – the fuel consumption and emissions as a function of the transport load and distance were determined. Wherever cooling during transport is required, additional fuel consumption is modelled accordingly based on data from ifeu's internal database.

Ship transport

The data used for the present study represent freight transport with an overseas container ship (10.5 t/TEU¹) and a utilisation of capacity by 70%. Energy use is based on an average fleet composition of this ship category with data taken from [EcoTransIT World 2016]. The Ecological Transport Information Tool (EcoTransIT) calculates environmental impacts of any freight transport. Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on [EcoTransIT World 2016]. For the consideration of well-to-tank emissions data were taken from IFEU's internal database.

¹ Twenty-foot Equivalent Unit

Rail transport

The data used for rail transport for the present study also is based on data from [EcoTransIT World 2016]. Emission factors and fuel consumption have been applied for direct emissions based on [EcoTransIT World 2016]. The needed electricity is modelled with the electricity mix of the country the train is operating (see also section 3.14.2)

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 2015 for the production of paperboard and the market related mix of energy suppliers in the year 2015 for all other processes depending on their location (e.g. energy for filling process: either Sweden, Finland, Norway, Denmark; energy for corrugated cardboard production: European). The applied shares of energy sources to the related market are given in Table 26.

¹ <http://www.iea.org/statistics/>

Table 26: Share of energy source to specific energy mix, reference year 2015.

country	EU 28	Sweden	Finland	Denmark	Norway
Energy source					
Hard coal	14.11%	0.23%	7.34%	23.79%	0.03%
Brown coal	10.32%	0.00%	0.00%	0.00%	0.00%
Fuel oil	1.65%	0.15%	0.30%	0.54%	0.02%
Natural gas	16.51%	0.67%	12.65%	6.59%	1.77%
Nuclear energy	26.70%	33.85%	33.66%	0.00%	0.00%
Hydropower/Wind/Solar	24.50%	57.99%	29.14%	52.48%	97.91%
<i>Hydropower</i>	45.74%	82.15%	87.77%	0.12%	98.21%
<i>Windpower</i>	40.42%	17.75%	12.18%	95.98%	1.79%
<i>Solar energy</i>	13.01%	0.10%	0.04%	3.89%	0.00%
Geothermal energy	0.83%	0.00%	0.00%	0.00%	0.00%
Biomass energy	4.84%	5.34%	15.69%	11.01%	0.01%
Waste	1.35%	1.75%	1.23%	5.59%	0.26%

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.

Table 27: 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.

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

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 1997], 30% of paper is decomposed anaerobically on landfills.

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

4 Results 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'**)
- CO₂ 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 1.7) 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 atmospheric CO₂ during the plant growth phase (**'CO₂-uptake'**)

The LCA results are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

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

- sectoral results of the packaging system itself (stacked bar 'environmental burdens')
- credits given for secondary products leaving the system (negative stacked bar 'credits')
- net results as a results of the subtraction 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.

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

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 $\leq 10\%$ 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)

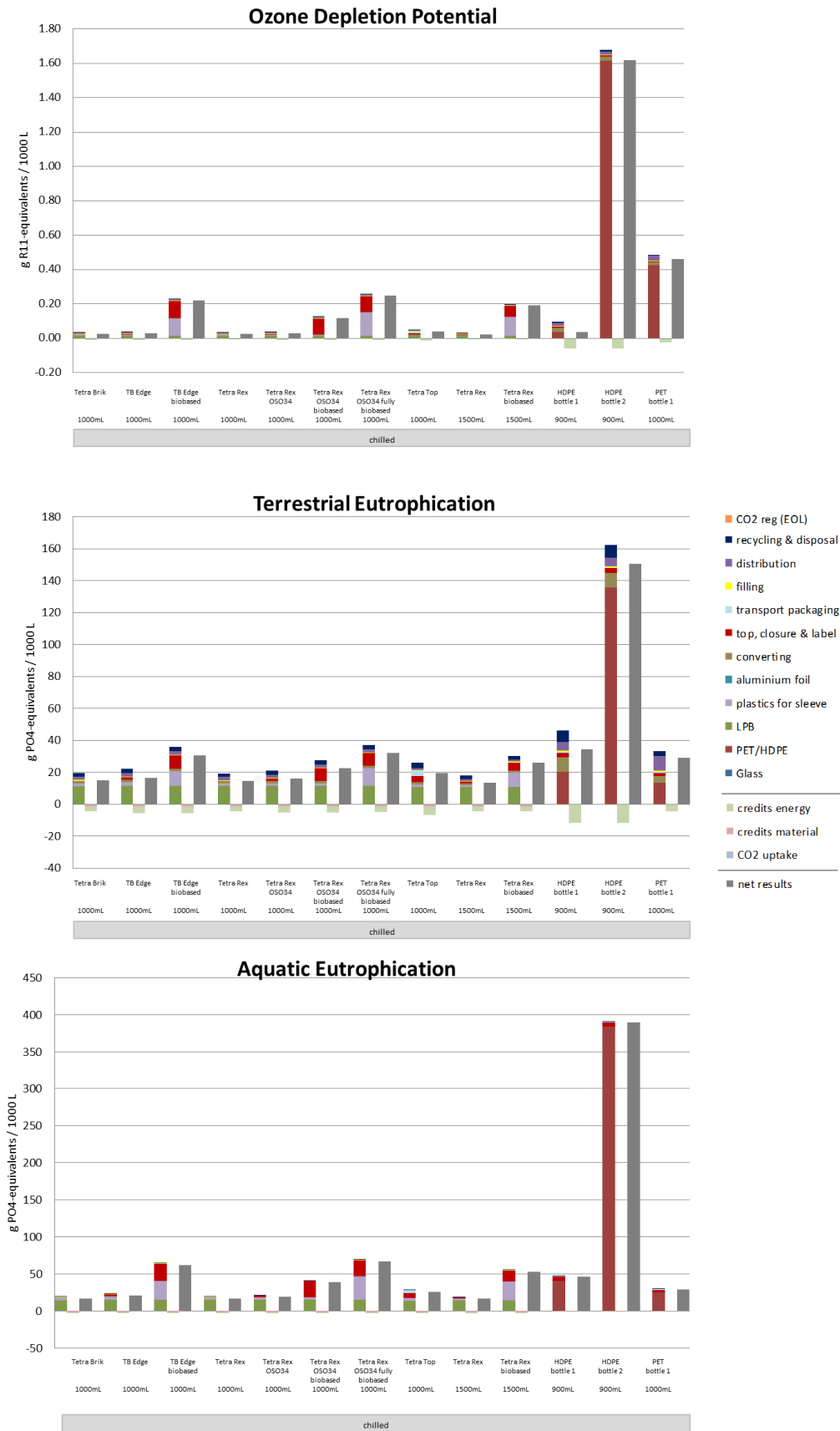


Figure 17 Indicator results for base scenarios of segment Dairy, Sweden, allocation factor 50% (Part 2)

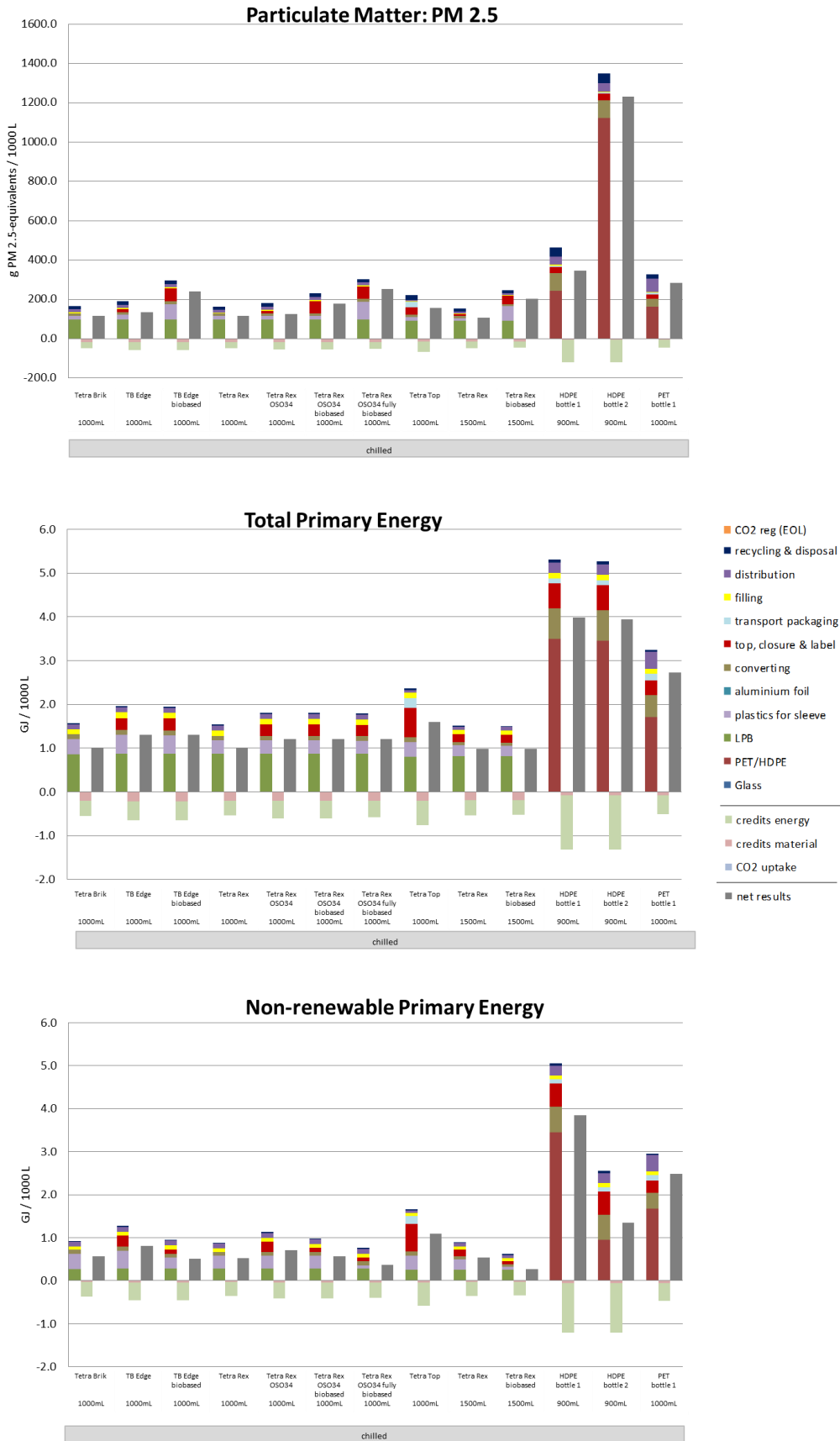


Figure 18: Indicator results for base scenarios of segment Dairy, Sweden, allocation factor 50% (Part 3)



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

Table 28: Category indicator results per impact category for base scenarios of **segment DAIRY, Sweden-** burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	45.45	59.28	53.68	43.30	53.19	50.58	46.61	77.27	41.81	36.82	239.59	193.38	142.99
	CO ₂ (reg)	18.11	18.55	26.87	18.38	18.42	22.35	28.13	19.97	17.20	24.55	2.13	67.14	4.14
	Credits	-22.51	-28.02	-27.42	-21.72	-25.40	-25.19	-24.01	-34.91	-22.06	-21.19	-73.65	-73.67	-27.45
	CO ₂ uptake net results	-37.69	-38.58	-55.44	-38.24	-38.31	-46.26	-57.90	-41.02	-35.79	-50.61	-4.27	-135.64	-8.34
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.17	0.19	0.26	0.16	0.18	0.22	0.27	0.23	0.16	0.22	0.50	1.09	0.35
	Credits	-0.05	-0.06	-0.06	-0.05	-0.06	-0.06	-0.06	-0.08	-0.05	-0.05	-0.14	-0.14	-0.05
	Net results	0.11	0.13	0.20	0.11	0.12	0.16	0.21	0.15	0.10	0.17	0.36	0.95	0.30
	Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	2.53	2.93	4.32	2.51	2.77	3.44	4.38	3.37	2.36	3.58	6.39	18.40
Ozone Depletion [g R11/1000 L]	Burdens	-0.61	-0.73	-0.71	-0.59	-0.67	-0.67	-0.64	-0.86	-0.59	-0.57	-1.47	-1.47	-0.57
	Credits	1.92	2.20	3.60	1.91	2.10	2.77	3.74	2.50	1.77	3.01	4.92	16.93	3.85
	Net results	0.03	0.04	0.23	0.03	0.04	0.13	0.26	0.05	0.03	0.20	0.10	1.68	0.49
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.06	-0.06
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	19.44	22.20	36.00	19.27	21.09	27.61	37.13	26.15	18.09	30.22	46.25	162.19	33.37
	Credits	-4.66	-5.58	-5.49	-4.55	-5.14	-5.11	-4.92	-6.61	-4.54	-4.40	-11.80	-11.81	-4.47
	Net results	14.77	16.62	30.51	14.72	15.95	22.50	32.21	19.54	13.56	25.83	34.45	150.38	28.90
	Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	19.18	23.11	64.31	18.86	21.29	40.74	69.17	28.31	18.75	54.98	47.08	390.29
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	-2.16	-2.23	-2.23	-2.18	-2.20	-2.20	-2.20	-2.15	-2.05	-2.05	-0.59	-0.59	-0.62
	Credits	17.02	20.88	62.08	16.68	19.09	38.54	66.98	26.16	16.71	52.93	46.49	389.70	28.98
	Net results	165.55	191.59	298.11	163.57	180.48	230.53	304.37	223.46	154.31	248.07	465.42	1349.19	327.61
	Credits	-48.12	-57.34	-56.38	-47.00	-52.93	-52.61	-50.70	-67.54	-46.77	-45.37	-117.79	-117.82	-44.63
Total Primary Energy [GJ]	Burdens	117.43	134.24	241.73	116.57	127.55	177.93	253.66	155.93	107.54	202.70	347.63	1231.37	282.98
	Credits	1.57	1.96	1.95	1.54	1.81	1.81	1.79	2.37	1.52	1.51	5.30	5.26	3.24
	Net results	-0.56	-0.66	-0.65	-0.54	-0.61	-0.60	-0.58	-0.77	-0.54	-0.52	-1.32	-1.32	-0.52
	Credits	1.02	1.30	1.30	1.00	1.20	1.20	1.21	1.60	0.98	0.98	3.98	3.94	2.72
Non-renewable Primary Energy [GJ]	Burdens	0.93	1.27	0.96	0.89	1.13	0.98	0.76	1.66	0.90	0.62	5.05	2.55	2.95
	Credits	-0.37	-0.46	-0.45	-0.36	-0.42	-0.41	-0.39	-0.58	-0.36	-0.35	-1.20	-1.20	-0.47
	Net results	0.56	0.81	0.51	0.53	0.72	0.57	0.37	1.09	0.54	0.27	3.85	1.35	2.49
	Credits	21.25	21.81	34.08	21.56	21.65	27.44	35.91	21.89	20.19	30.98	0.51	100.03	0.54
Use of Nature [m ² /year]	Burdens	-3.13	-3.22	-3.22	-3.17	-3.17	-3.17	-3.17	-2.96	-2.96	-2.96	-0.34	-0.34	-0.18
	Credits	18.12	18.59	30.86	18.39	18.48	24.27	32.74	18.93	17.22	28.01	0.17	0.00	0.00
	Net results	1.12	1.41	1.45	1.18	1.40	1.43	1.45	1.69	1.16	1.19	3.03	3.88	3.02
	water cool	2.05	2.29	2.28	2.06	2.07	2.07	2.06	1.75	1.90	1.89	0.17	0.23	0.24
Water use [m ³ /1000 L]	water process	0.19	0.24	0.36	0.20	0.24	0.30	0.38	0.48	0.20	0.31	1.02	2.43	0.80
	water unspecified													

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 CO₂ emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Sweden 35.5% 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 CO₂ 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 CO₂.

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', 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 terephthalic 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 N₂O 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 CO₂ emissions from the bio-based 'HDPE bottle 2' are of course similarly high, but they are attributed to the sector CO₂ 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹. In cases where positive net results are compared to negative ones, and the other way around, no meaningful percentage numbers could be calculated. In these cases the tables just show by their colour code, if the net results are lower or higher than those of the packaging systems the respective beverage carton is compared to.

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

DAIRY (chilled), Sweden	The net results of Tetra Brik 1000mL are lower (green)/ higher (orange) than those of											
	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-70%		97%	-57%	129%		-84%	191%		-98%	-93%	-97%
Acidification	-12%	-44%	1%	-8%	-28%	-46%	-27%	9%	-33%	-69%	-88%	-63%
Photo-Oxidant Formation	-13%	-47%	0%	-9%	-31%	-49%	-23%	9%	-36%	-61%	-89%	-50%
Ozone Depletion Potential	-13%	-88%	-1%	-10%	-78%	-89%	-34%	11%	-86%	-30%	-98%	-94%
Terrestrial Eutrophication	-11%	-52%	0%	-7%	-34%	-54%	-24%	9%	-43%	-57%	-90%	-49%
Aquatic Eutrophication	-18%	-73%	2%	-11%	-56%	-75%	-35%	2%	-68%	-63%	-96%	-41%
Particulate Matter	-13%	-51%	1%	-8%	-34%	-54%	-25%	9%	-42%	-66%	-90%	-59%
Total Primary Energy	-22%	-22%	2%	-15%	-15%	-16%	-37%	4%	3%	-74%	-74%	-63%
Non-renewable Primary Energy	-31%	11%	6%	-22%	-2%	52%	-48%	5%	107%	-85%	-58%	-77%

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

DAIRY (chilled), Sweden	The net results of TB Edge 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	234%		558%	42%	666%		-47%	871%		-93%	-78%	-90%
Acidification	14%	-37%	15%	5%	-18%	-39%	-17%	24%	-24%	-65%	-87%	-58%
Photo-Oxidant Formation	14%	-39%	15%	5%	-21%	-41%	-12%	24%	-27%	-55%	-87%	-43%
Ozone Depletion Potential	15%	-86%	14%	3%	-74%	-88%	-24%	28%	-84%	-20%	-98%	-93%
Terrestrial Eutrophication	12%	-46%	13%	4%	-26%	-48%	-15%	23%	-36%	-52%	-89%	-42%
Aquatic Eutrophication	23%	-66%	25%	9%	-46%	-69%	-20%	25%	-61%	-55%	-95%	-28%
Particulate Matter	14%	-44%	15%	5%	-25%	-47%	-14%	25%	-34%	-61%	-89%	-53%
Total Primary Energy	28%	0%	31%	9%	8%	8%	-19%	33%	33%	-67%	-67%	-52%
Non-renewable Primary Energy	45%	61%	53%	14%	42%	120%	-25%	52%	200%	-79%	-40%	-67%

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

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

DAIRY (chilled), Sweden	The net results of TB Edge biobased 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change						68%			78%			
Acidification	80%	58%	81%	65%	29%	-4%	32%	96%	20%	-45%	-79%	-33%
Photo-Oxidant Formation	87%	64%	88%	71%	30%	-4%	44%	103%	20%	-27%	-79%	-6%
Ozone Depletion Potential	733%	624%	726%	648%	85%	-12%	452%	827%	15%	482%	-86%	-52%
Terrestrial Eutrophication	107%	84%	107%	91%	36%	-5%	56%	125%	18%	-11%	-80%	6%
Aquatic Eutrophication	265%	197%	272%	225%	61%	-7%	137%	272%	17%	34%	-84%	114%
Particulate Matter	106%	80%	107%	90%	36%	-5%	55%	125%	19%	-30%	-80%	-15%
Total Primary Energy	28%	0%	31%	9%	8%	8%	-19%	33%	32%	-67%	-67%	-52%
Non-renewable Primary Energy	-10%	-38%	-5%	-29%	-11%	37%	-53%	-5%	87%	-87%	-62%	-80%

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

DAIRY (chilled), Sweden	The net results of Tetra Rex 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-49%	-85%		-78%	16%		-92%	48%		-99%	-97%	-98%
Acidification	-1%	-13%	-45%	-9%	-29%	-47%	9%	-34%	-69%	-88%	-63%	-63%
Photo-Oxidant Formation	0%	-13%	-47%	-9%	-31%	-49%	-23%	8%	-36%	-61%	-89%	-50%
Ozone Depletion Potential	1%	-12%	-88%	-9%	-78%	-89%	-33%	12%	-86%	-30%	-98%	-94%
Terrestrial Eutrophication	0%	-11%	-52%	-8%	-35%	-54%	-25%	9%	-43%	-57%	-90%	-49%
Aquatic Eutrophication	-2%	-20%	-73%	-13%	-57%	-75%	-36%	0%	-68%	-64%	-96%	-42%
Particulate Matter	-1%	-13%	-52%	-9%	-34%	-54%	-25%	8%	-42%	-66%	-91%	-59%
Total Primary Energy	-2%	-23%	-23%	-17%	-17%	-18%	-38%	2%	1%	-75%	-75%	-63%
Non-renewable Primary Energy	-5%	-35%	5%	-26%	-7%	44%	-51%	-1%	96%	-86%	-61%	-79%

Table 33: Comparison of net results: **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

DAIRY (chilled), Sweden	The net results of Tetra Rex OSO34 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	135%	-30%		363%	439%		-63%	583%		-95%	-85%	-93%
Acidification	9%	-4%	-39%	9%	-22%	-42%	-20%	19%	-28%	-66%	-87%	-60%
Photo-Oxidant Formation	9%	-4%	-42%	10%	-24%	-44%	-16%	19%	-30%	-57%	-88%	-45%
Ozone Depletion Potential	11%	-3%	-87%	10%	-75%	-88%	-26%	24%	-85%	-22%	-98%	-94%
Terrestrial Eutrophication	8%	-4%	-48%	8%	-29%	-50%	-18%	18%	-38%	-54%	-89%	-45%
Aquatic Eutrophication	12%	-9%	-69%	14%	-50%	-71%	-27%	14%	-64%	-59%	-95%	-34%
Particulate Matter	9%	-5%	-47%	9%	-28%	-50%	-18%	19%	-37%	-63%	-90%	-55%
Total Primary Energy	18%	-8%	-8%	20%	0%	-1%	-25%	23%	22%	-70%	-70%	-56%
Non-renewable Primary Energy	28%	-12%	41%	35%	25%	94%	-34%	34%	164%	-81%	-47%	-71%

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

DAIRY (chilled), Sweden	The net results of Tetra Rex OSO34 biobased 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-56%	-87%		-14%	-81%		-93%	27%		-99%	-97%	-99%
Acidification	39%	22%	-22%	40%	28%	-25%	2%	52%	-7%	-57%	-84%	-48%
Photo-Oxidant Formation	44%	26%	-23%	45%	32%	-26%	11%	56%	-8%	-44%	-84%	-28%
Ozone Depletion Potential	350%	291%	-46%	346%	304%	-52%	198%	401%	-38%	214%	-93%	-74%
Terrestrial Eutrophication	52%	35%	-26%	53%	41%	-30%	15%	66%	-13%	-35%	-85%	-22%
Aquatic Eutrophication	126%	85%	-38%	131%	102%	-42%	47%	131%	-27%	-17%	-90%	33%
Particulate Matter	52%	33%	-26%	53%	39%	-30%	14%	65%	-12%	-49%	-86%	-37%
Total Primary Energy	18%	-8%	-8%	20%	0%	-1%	-25%	23%	22%	-70%	-70%	-56%
Non-renewable Primary Energy	2%	-30%	13%	7%	-20%	55%	-48%	7%	111%	-85%	-58%	-77%

Table 35: Comparison of net results: **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

DAIRY (chilled), Sweden	The net results of Tetra Rex OSO34 fully biobased 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change			-212%						31%			
Acidification	86%	64%	4%	88%	71%	34%	37%	104%	24%	-42%	-78%	-31%
Photo-Oxidant Formation	95%	70%	4%	96%	78%	35%	50%	111%	24%	-24%	-78%	-3%
Ozone Depletion Potential	847%	723%	14%	839%	750%	110%	527%	953%	31%	561%	-85%	-46%
Terrestrial Eutrophication	118%	94%	6%	119%	102%	43%	65%	138%	25%	-7%	-79%	11%
Aquatic Eutrophication	294%	221%	8%	302%	251%	74%	156%	301%	27%	44%	-83%	131%
Particulate Matter	116%	89%	5%	118%	99%	43%	63%	136%	25%	-27%	-79%	-10%
Total Primary Energy	19%	-7%	-7%	21%	1%	1%	-24%	24%	23%	-70%	-69%	-56%
Non-renewable Primary Energy	-34%	-55%	-27%	-31%	-48%	-35%	-66%	-31%	36%	-90%	-73%	-85%

Table 36: Comparison of net results: **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

DAIRY (chilled), Sweden	The net results of Tetra Top 1000mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	533%	90%		1147%	169%	1351%		1740%		-87%	-58%	-81%
Acidification	36%	20%	-24%	37%	25%	-2%	-27%	49%	-9%	-58%	-84%	-50%
Photo-Oxidant Formation	30%	14%	-31%	31%	19%	-10%	-33%	41%	-17%	-49%	-85%	-35%
Ozone Depletion Potential	51%	31%	-82%	50%	36%	-66%	-84%	68%	-79%	5%	-98%	-91%
Terrestrial Eutrophication	32%	18%	-36%	33%	22%	-13%	-39%	44%	-24%	-43%	-87%	-32%
Aquatic Eutrophication	54%	25%	-58%	57%	37%	-32%	-61%	57%	-51%	-44%	-93%	-10%
Particulate Matter	33%	16%	-35%	34%	22%	-12%	-39%	45%	-23%	-55%	-87%	-45%
Total Primary Energy	58%	23%	23%	60%	33%	33%	32%	64%	63%	-60%	-59%	-41%
Non-renewable Primary Energy	94%	34%	115%	105%	52%	91%	195%	103%	302%	-72%	-19%	-56%

Table 37: Comparison of net results: **Tetra Rex 1500 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

DAIRY (chilled), Sweden	The net results of Tetra Rex 1500mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-66%	-90%		-32%	-85%	-21%		-95%		-99%	-98%	-99%
Acidification	-9%	-20%	-49%	-8%	-16%	-34%	-51%	-33%	-39%	-72%	-89%	-66%
Photo-Oxidant Formation	-8%	-19%	-51%	-7%	-16%	-36%	-53%	-29%	-41%	-64%	-90%	-54%
Ozone Depletion Potential	-10%	-22%	-89%	-11%	-19%	-80%	-91%	-40%	-88%	-37%	-99%	-95%
Terrestrial Eutrophication	-8%	-18%	-56%	-8%	-15%	-40%	-58%	-31%	-48%	-61%	-91%	-53%
Aquatic Eutrophication	-2%	-20%	-73%	0%	-12%	-57%	-75%	-36%	-68%	-64%	-96%	-42%
Particulate Matter	-8%	-20%	-56%	-8%	-16%	-40%	-58%	-31%	-47%	-69%	-91%	-62%
Total Primary Energy	-4%	-25%	-25%	-2%	-18%	-19%	-19%	-39%	0%	-75%	-75%	-64%
Non-renewable Primary Energy	-5%	-34%	6%	1%	-25%	-6%	45%	-51%	98%	-86%	-60%	-78%

Table 38: Comparison of net results: **Tetra Rex biobased 1500 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Sweden**

DAIRY (chilled), Sweden	The net results of Tetra Rex biobased 1500mL are lower (green)/ higher (orange) than those of											
	Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change			-353%					-45%				
Acidification	50%	32%	-16%	51%	38%	8%	-20%	10%	64%	-54%	-82%	-44%
Photo-Oxidant Formation	56%	37%	-16%	57%	43%	9%	-20%	20%	70%	-39%	-82%	-22%
Ozone Depletion Potential	622%	528%	-13%	616%	548%	60%	-24%	378%	703%	404%	-88%	-59%
Terrestrial Eutrophication	75%	55%	-15%	75%	62%	15%	-20%	32%	90%	-25%	-83%	-11%
Aquatic Eutrophication	211%	154%	-15%	217%	177%	37%	-21%	102%	217%	14%	-86%	83%
Particulate Matter	73%	51%	-16%	74%	59%	14%	-20%	30%	88%	-42%	-84%	-28%
Total Primary Energy	-3%	-25%	-25%	-1%	-18%	-18%	-19%	-39%	0%	-75%	-75%	-64%
Non-renewable Primary Energy	-52%	-67%	-47%	-49%	-62%	-53%	-27%	-75%	-49%	-93%	-80%	-89%

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)

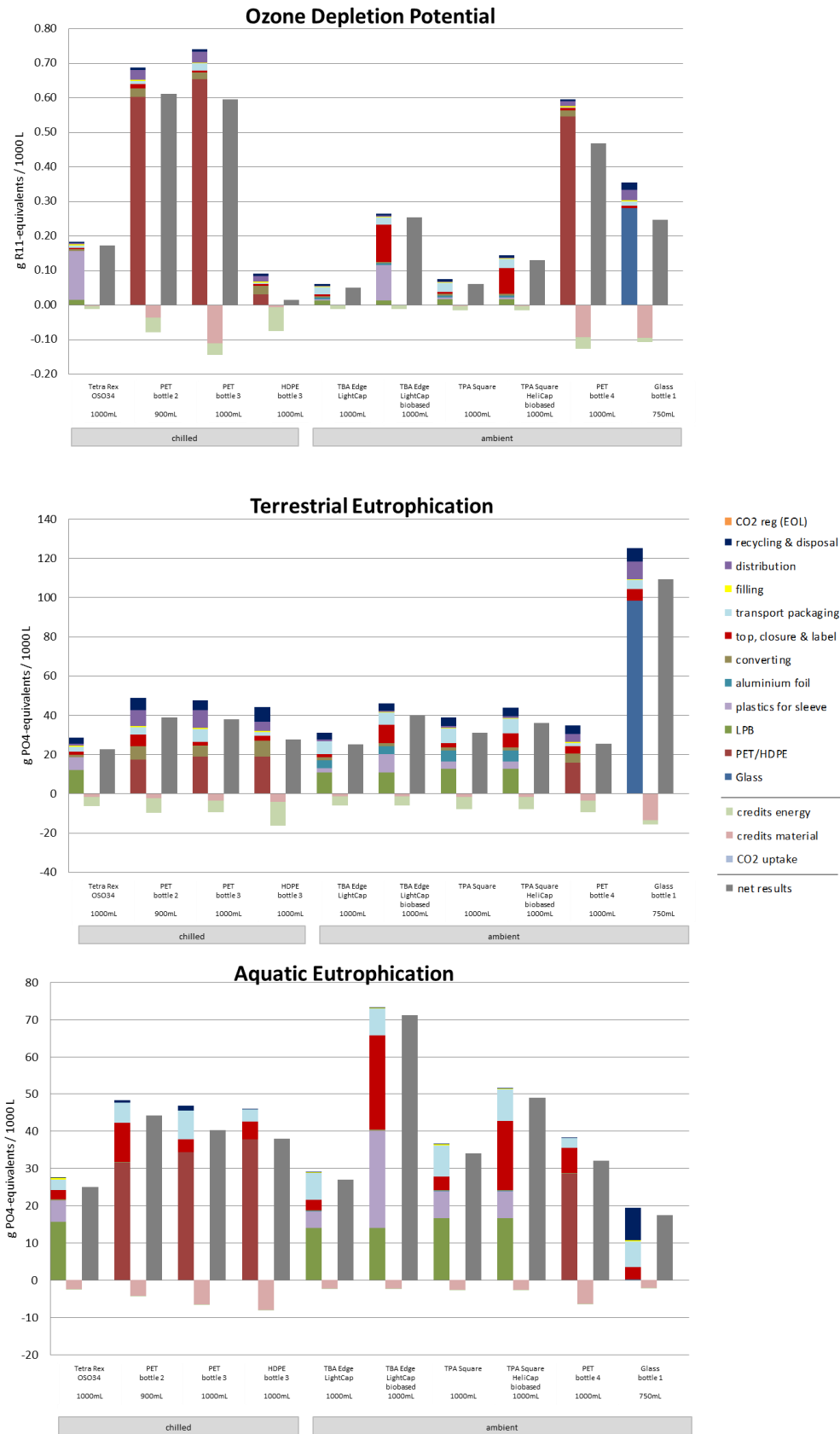


Figure 21: Indicator results for base scenarios of segment JNSD, Sweden, allocation factor 50% (Part 2)

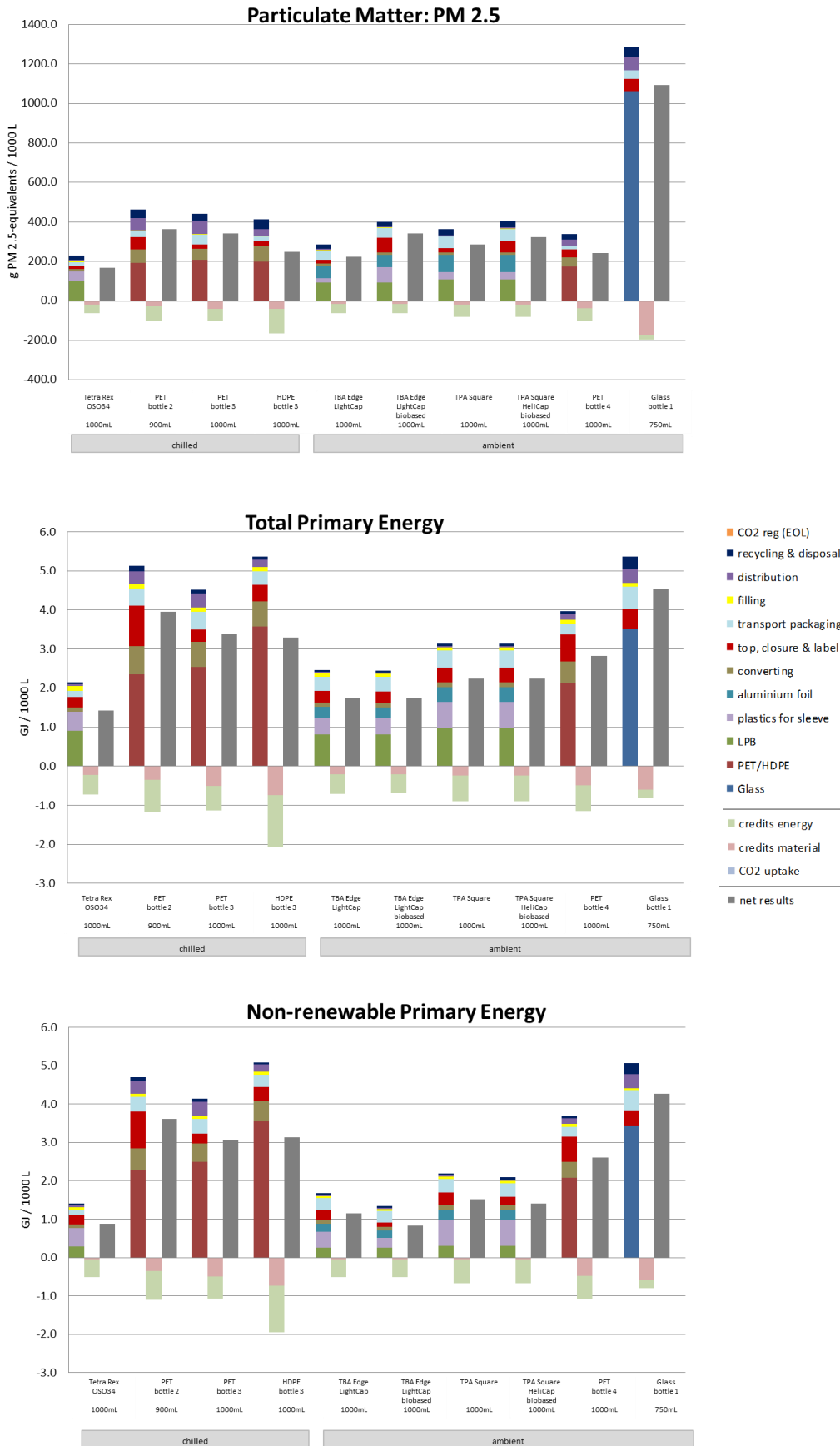


Figure 22: Indicator results for base scenarios of segment JNSD, Sweden, allocation factor 50% (Part 3)

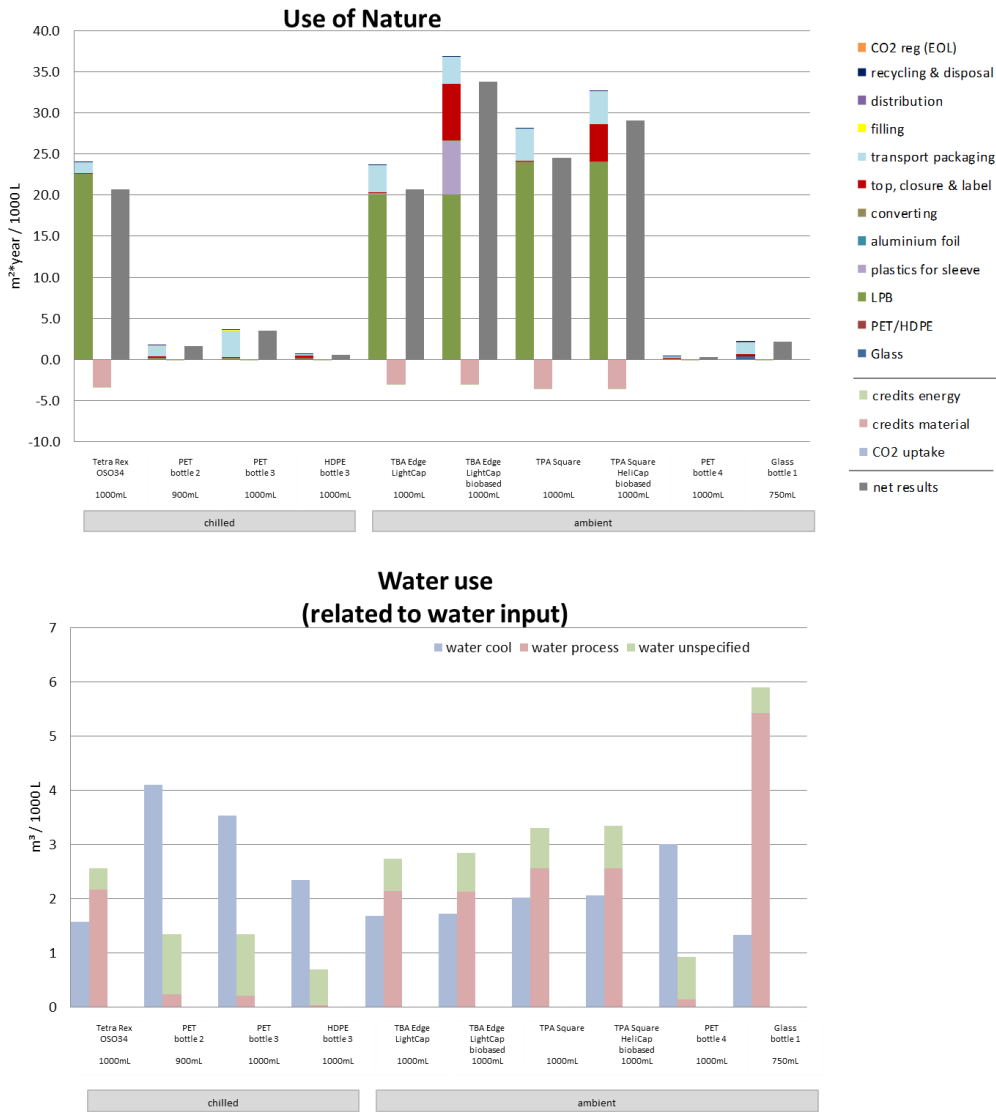


Figure 23: Indicator results for base scenarios of segment JNSD, Sweden, allocation factor 50% (Part 4)

Table 39: Category indicator results per impact category for base scenarios of segment **JNSD, Sweden**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.) **Description and interpretation**

		Tetra Rex OSO34 1000mL	PET bottle 2 900mL	PET bottle 3 1000mL	HDPE bottle 3 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	71.12	219.81	201.38	233.83	88.53	82.51	115.58	113.63	166.45	372.43
	CO ₂ (reg)	21.81	6.35	7.77	4.32	21.19	30.12	25.16	28.18	1.91	6.22
	Credits	-31.08	-57.08	-52.27	-95.11	-31.47	-30.71	-40.96	-40.98	-52.66	-60.18
	CO ₂ uptake net results	-44.98	-12.81	-15.69	-8.71	-43.32	-61.39	-51.41	-57.56	-3.84	-12.47
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.24	0.49	0.47	0.42	0.31	0.39	0.39	0.42	0.36	1.30
	Credits	-0.07	-0.11	-0.11	-0.19	-0.07	-0.07	-0.09	-0.09	-0.11	-0.16
	Net results	0.17	0.37	0.36	0.23	0.24	0.32	0.30	0.33	0.25	1.14
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	3.45	6.50	6.14	6.17	3.93	5.42	4.95	5.47	4.74	15.89
	Credits	-0.80	-1.27	-1.24	-2.15	-0.79	-0.78	-1.02	-1.02	-1.25	-1.96
	Net results	2.65	5.23	4.90	4.03	3.14	4.64	3.93	4.45	3.49	13.94
Ozone Depletion [g R11/1000 L]	Burdens	0.18	0.69	0.74	0.09	0.06	0.26	0.08	0.14	0.60	0.36
	Credits	-0.01	-0.08	-0.14	-0.08	-0.01	-0.01	-0.01	-0.01	-0.13	-0.11
	Net results	0.17	0.61	0.60	0.02	0.05	0.25	0.06	0.13	0.47	0.25
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	28.78	48.78	47.64	44.18	31.14	45.93	38.98	44.02	34.88	125.07
	Credits	-6.12	-9.77	-9.52	-16.35	-6.07	-5.95	-7.79	-7.80	-9.50	-15.61
	Net results	22.66	39.01	38.12	27.83	25.07	39.98	31.18	36.23	25.38	109.46
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	27.51	48.36	46.89	45.96	29.10	73.26	36.58	51.63	38.38	19.51
	Credits	-2.40	-4.17	-6.58	-7.97	-2.16	-2.16	-2.56	-2.56	-6.27	-2.01
	Net results	25.10	44.18	40.31	37.99	26.94	71.11	34.02	49.07	32.11	17.49
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	230.76	462.72	441.96	412.32	287.59	401.83	365.14	403.58	340.35	1287.57
	Credits	-62.81	-98.68	-98.24	-163.70	-62.17	-60.96	-79.63	-79.65	-97.55	-194.73
	Net results	167.95	364.05	343.72	248.62	225.42	340.87	285.51	323.93	242.80	1092.84
Total Primary Energy [GJ]	Burdens	2.14	5.12	4.52	5.36	2.46	2.45	3.14	3.14	3.96	5.36
	Credits	-0.72	-1.17	-1.14	-2.06	-0.71	-0.69	-0.90	-0.90	-1.15	-0.82
	Net results	1.42	3.95	3.38	3.29	1.75	1.76	2.24	2.24	2.82	4.54
Non-renewable Primary Energy [GJ]	Burdens	1.40	4.70	4.13	5.08	1.68	1.34	2.20	2.09	3.68	5.06
	Credits	-0.51	-1.10	-1.08	-1.95	-0.52	-0.51	-0.67	-0.67	-1.09	-0.79
	Net results	0.88	3.61	3.05	3.13	1.16	0.83	1.52	1.41	2.60	4.27
Use of Nature [m ² ·year]	Burdens	24.02	1.71	3.58	0.68	23.68	36.83	28.14	32.62	0.38	2.24
	Credits	-3.34	-0.08	-0.07	-0.11	-3.01	-3.01	-3.58	-3.58	-0.06	-0.05
	Net results	20.69	1.63	3.51	0.57	20.67	33.82	24.56	29.04	0.32	2.19
Water use [m ³ /1000 L]	water cool	1.57	4.10	3.53	2.34	1.68	1.72	2.01	2.05	3.00	1.33
	water process	2.17	0.24	0.21	0.03	2.14	2.12	2.56	2.56	0.14	5.42
	water unspecified	0.39	1.11	1.14	0.66	0.59	0.72	0.74	0.78	0.78	0.47

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 35.5% 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 CO₂ 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 CO₂.

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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

Table 40 Comparison of net results: **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD chilled, Sweden**

<i>JNSD (chilled), Sweden</i>	The net results of Tetra Rex OSO34 1000mL are lower (green)/ higher (orange) than those of		
	PET bottle 2 900mL	PET bottle 3 1000mL	HDPE bottle 3 1000mL
Climate Change	-89%	-88%	-87%
Acidification	-56%	-53%	-29%
Photo-Oxidant Formation	-49%	-46%	-34%
Ozone Depletion Potential	-72%	-71%	1025%
Terrestrial Eutrophication	-42%	-41%	-19%
Aquatic Eutrophication	-43%	-38%	-34%
Particulate Matter	-54%	-51%	-32%
Total Primary Energy	-64%	-58%	-57%
Non-renewable Primary Energy	-75%	-71%	-72%

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

Table 41: 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**

<i>JNSD (ambient), Sweden</i>	The net results of TBA Edge LightCap 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	56%	-34%	-26%	-71%	-90%
Acidification	-20%	-16%	-23%	2%	-78%
Photo-Oxidant Formation	-26%	-12%	-22%	-1%	-75%
Ozone Depletion Potential	-64%	51%	-29%	-80%	-63%
Terrestrial Eutrophication	-30%	-10%	-22%	11%	-74%
Aquatic Eutrophication	-49%	6%	-27%	12%	106%
Particulate Matter	-27%	-13%	-23%	3%	-77%
Total Primary Energy	0%	-22%	-22%	-38%	-61%
Non-renewable Primary Energy	32%	-28%	-23%	-58%	-74%

Table 42: Comparison of net results: **Tetra Brik Edge LightCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

<i>JNSD (ambient), Sweden</i>	The net results of TBA Edge LightCap biobased 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	-36%	-58%	-53%	-82%	-93%
Acidification	25%	5%	-3%	28%	-72%
Photo-Oxidant Formation	34%	18%	4%	33%	-67%
Ozone Depletion Potential	176%	317%	95%	-46%	2%
Terrestrial Eutrophication	42%	28%	10%	58%	-63%
Aquatic Eutrophication	98%	109%	45%	121%	306%
Particulate Matter	37%	19%	5%	40%	-69%
Total Primary Energy	0%	-22%	-22%	-38%	-61%
Non-renewable Primary Energy	-24%	-45%	-41%	-68%	-81%

Table 43: Comparison of net results: **TPA square 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

<i>JNSD (ambient), Sweden</i>	The net results of TPA Square 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	51%	136%	12%	-57%	-84%
Acidification	19%	-5%	-8%	22%	-73%
Photo-Oxidant Formation	14%	-15%	-12%	13%	-72%
Ozone Depletion Potential	-34%	-76%	-53%	-87%	-75%
Terrestrial Eutrophication	11%	-22%	-14%	23%	-72%
Aquatic Eutrophication	-6%	-52%	-31%	6%	94%
Particulate Matter	15%	-16%	-12%	18%	-74%
Total Primary Energy	27%	28%	0%	-21%	-51%
Non-renewable Primary Energy	39%	83%	8%	-41%	-64%

Table 44: Comparison of net results: **TPA square HeliCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Sweden**

<i>JNSD (ambient), Sweden</i>	The net results of TPA Square HeliCap biobased 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	35%	111%	-11%	-61%	-86%
Acidification	29%	4%	8%	32%	-71%
Photo-Oxidant Formation	29%	-4%	13%	28%	-68%
Ozone Depletion Potential	42%	-49%	114%	-72%	-48%
Terrestrial Eutrophication	29%	-9%	16%	43%	-67%
Aquatic Eutrophication	36%	-31%	44%	53%	180%
Particulate Matter	30%	-5%	13%	33%	-70%
Total Primary Energy	27%	28%	0%	-21%	-51%
Non-renewable Primary Energy	29%	70%	-7%	-46%	-67%

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)

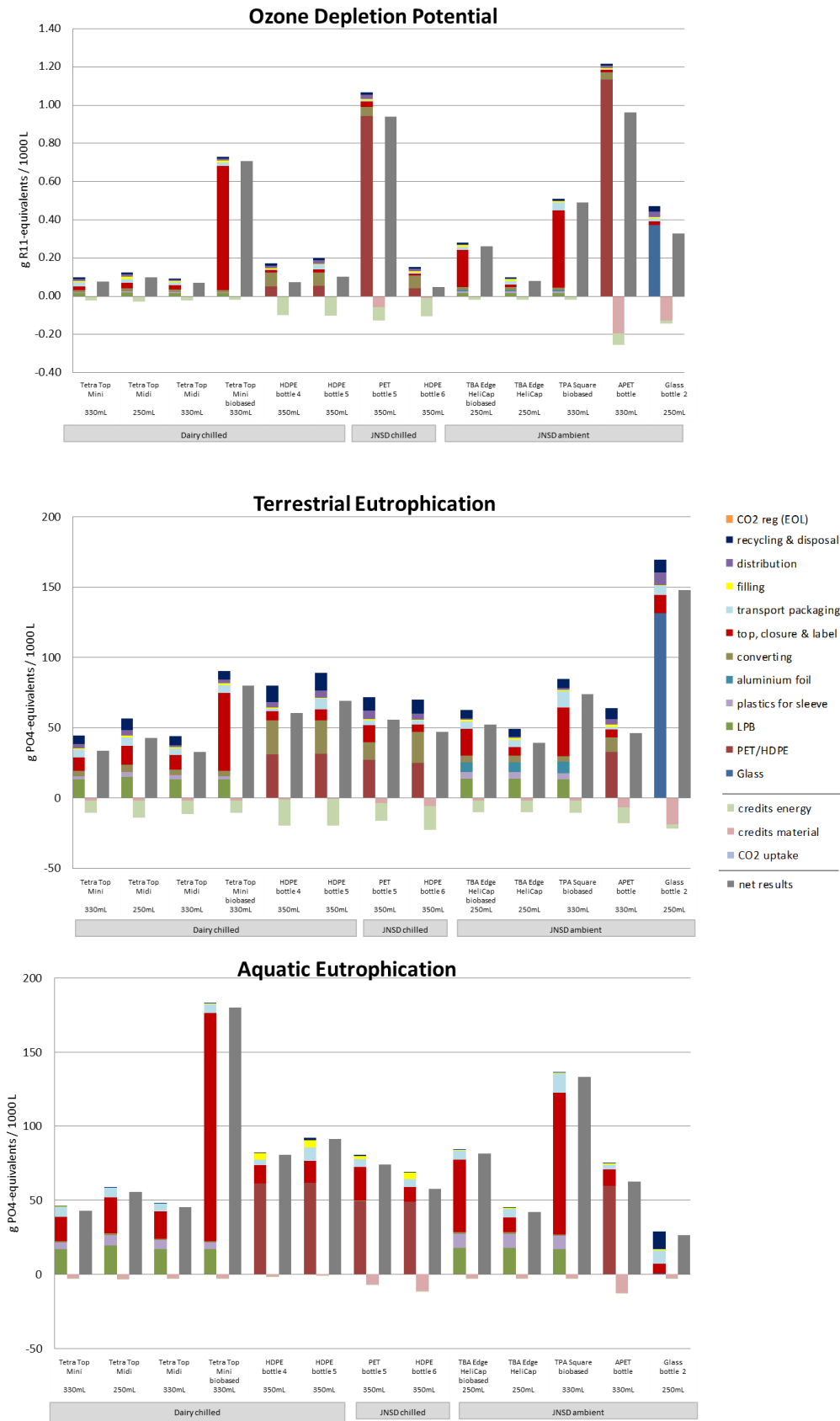


Figure 25: Indicator results for base scenarios of segment Grab & Go, Sweden, allocation factor 50% (Part 2)

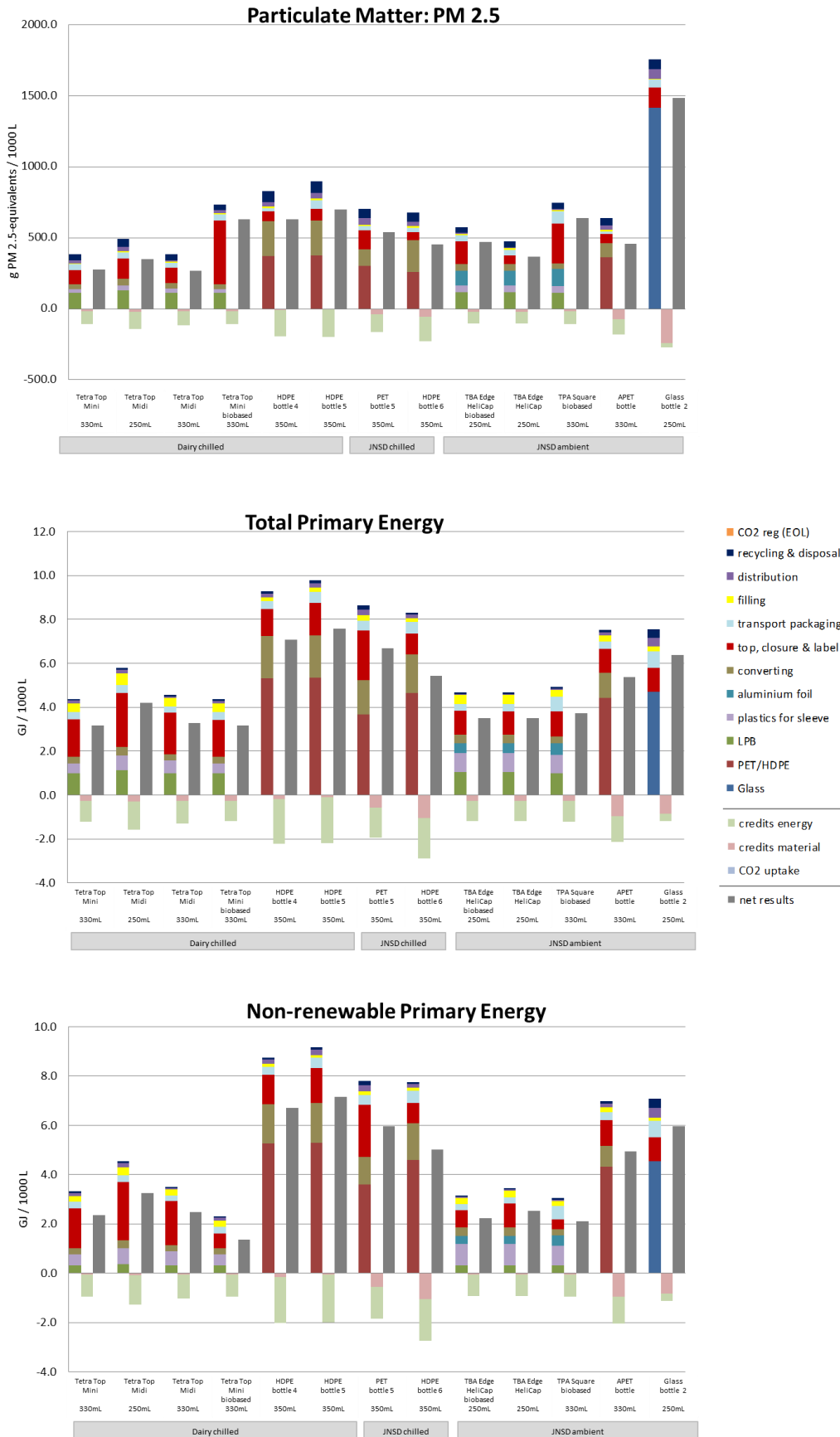


Figure 26: Indicator results for base scenarios of segment Grab & Go, Sweden, allocation factor 50% (Part 3)



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

Table 45: 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, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Midi 250mL	Tetra Top Midi 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL	PET bottle 5 350mL	HDPE bottle 6 350mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	148.89	201.44	154.17	131.16	410.17	438.19	339.00	357.18	157.88	163.01	173.71	312.64	514.98
	CO ₂ (reg)	25.58	28.83	24.84	52.50	1.90	6.21	6.13	4.95	33.82	25.91	45.23	1.87	8.58
	Credits	-58.17	-77.70	-62.85	-57.04	-121.77	-123.68	-95.56	-132.30	-55.74	-55.63	-57.68	-97.10	-87.23
	CO ₂ uptake	-52.32	-58.99	-50.87	-106.74	-3.81	-12.54	-12.37	-9.99	-69.09	-53.07	-91.67	-3.75	-17.21
	net results	63.97	93.59	65.29	19.89	286.49	308.18	237.19	219.84	66.87	80.22	69.80	213.66	419.12
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.39	0.50	0.39	0.63	0.89	0.96	0.74	0.70	0.57	0.50	0.72	0.68	1.79
	Credits	-0.12	-0.16	-0.13	-0.12	-0.23	-0.23	-0.19	-0.26	-0.12	-0.12	-0.12	-0.21	-0.23
	Net results	0.27	0.34	0.26	0.51	0.66	0.73	0.55	0.44	0.45	0.39	0.60	0.47	1.56
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	5.76	7.49	5.83	10.53	11.00	11.94	9.69	9.65	7.86	6.50	10.11	8.70	21.59
	Credits	-1.39	-1.82	-1.48	-1.36	-2.46	-2.46	-2.11	-3.00	-1.34	-1.34	-1.38	-2.33	-2.73
	Net results	4.37	5.67	4.34	9.17	8.54	9.49	7.58	6.66	6.52	5.16	8.73	6.38	18.86
Ozone Depletion [g R11/1000 L]	Burdens	0.10	0.13	0.09	0.73	0.17	0.20	1.07	0.15	0.28	0.10	0.51	1.22	0.47
	Credits	-0.02	-0.03	-0.02	-0.02	-0.10	-0.10	-0.13	-0.11	-0.02	-0.02	-0.02	-0.25	-0.14
	Net results	0.08	0.10	0.07	0.71	0.07	0.10	0.94	0.05	0.26	0.08	0.49	0.96	0.33
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	44.46	56.55	43.96	90.52	79.93	89.09	71.89	69.98	62.53	49.38	84.57	63.97	169.72
	Credits	-10.61	-13.93	-11.36	-10.43	-19.62	-19.77	-16.30	-22.77	-10.26	-10.24	-10.53	-17.71	-21.81
	Net results	33.85	42.62	32.61	80.10	60.30	69.33	55.60	47.21	52.27	39.14	74.04	46.25	147.90
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	45.75	58.70	48.06	182.84	82.16	91.98	80.73	68.79	84.15	44.92	136.09	75.12	29.10
	Credits	-2.73	-3.13	-2.71	-2.73	-1.65	-0.65	-6.68	-11.25	-2.81	-2.81	-2.72	-12.57	-2.75
	Net results	43.02	55.56	45.35	180.11	80.51	91.33	74.05	57.53	81.34	42.11	133.37	62.55	26.35
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	383.84	491.57	383.70	734.91	827.59	898.32	703.87	679.03	573.01	472.81	747.42	639.02	1757.24
	Credits	-107.85	-141.30	-115.30	-106.02	-195.82	-197.27	-164.57	-227.97	-104.40	-104.22	-107.02	-182.51	-271.84
	Net results	275.99	350.27	268.39	628.89	631.78	701.05	539.30	451.06	468.61	368.58	640.40	456.51	1485.40
Total Primary Energy [GJ]	Burdens	4.37	5.79	4.55	4.36	9.28	9.77	8.64	8.30	4.67	4.67	4.93	7.53	7.56
	Credits	-1.21	-1.58	-1.29	-1.19	-2.22	-2.20	-1.95	-2.88	-1.17	-1.17	-1.20	-2.15	-1.17
	Net results	3.16	4.21	3.27	3.17	7.06	7.58	6.69	5.42	3.50	3.50	3.73	5.38	6.39
Non-renewable Primary Energy [GJ]	Burdens	3.31	4.54	3.51	2.30	8.74	9.16	7.79	7.75	3.16	3.45	3.06	6.98	7.09
	Credits	-0.96	-1.28	-1.04	-0.94	-2.02	-2.00	-1.83	-2.73	-0.92	-0.92	-0.95	-2.04	-1.13
	Net results	2.35	3.26	2.47	1.36	6.71	7.16	5.96	5.02	2.24	2.53	2.10	4.95	5.95
Use of Nature [m ² /year]	Burdens	28.42	32.14	27.85	68.74	0.91	4.60	1.89	1.10	40.90	29.23	56.89	0.59	3.27
	Credits	-3.69	-4.21	-3.68	-3.69	-0.53	-0.55	-0.11	-0.15	-3.81	-3.81	-3.68	-0.09	-0.06
	Net results	24.73	27.93	24.17	65.06	0.38	4.05	1.78	0.95	37.09	25.42	53.21	0.00	0.00
Water use [m ³ /1000 L]	water cool	3.49	4.84	3.82	3.85	7.39	7.55	7.91	6.14	4.19	4.09	4.08	6.24	2.18
	water process	2.23	2.58	2.24	2.21	2.87	2.88	1.57	2.45	2.97	2.99	2.89	0.79	12.78
	water unspecified	0.84	1.11	0.90	1.29	1.69	2.11	1.77	0.98	0.96	0.86	1.41	1.56	0.95

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 35.5% 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 CO₂ 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 CO₂.

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 terephthalic 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

Table 46: Comparison of net results: **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in segment **Grab & Go, Dairy chilled, Sweden**

<i>Grab & Go DAIRY (chilled), Sweden</i>	The net results of Tetra Top Mini 330mL are lower (green)/ higher (orange) than those of				
	Tetra Top Midi 250mL	Tetra Top Midi 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	-32%	-2%	222%	-78%	-79%
Acidification	-21%	3%	-46%	-59%	-63%
Photo-Oxidant Formation	-23%	1%	-52%	-49%	-54%
Ozone Depletion Potential	-20%	9%	-89%	7%	-23%
Terrestrial Eutrophication	-21%	4%	-58%	-44%	-51%
Aquatic Eutrophication	-23%	-5%	-76%	-47%	-53%
Particulate Matter	-21%	3%	-56%	-56%	-61%
Total Primary Energy	-25%	-3%	-1%	-55%	-58%
Non-renewable Primary Energy	-28%	-5%	73%	-65%	-67%

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



Table 47: Comparison of net results: **Tetra Top Midi 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Sweden**

<i>Grab & Go DAIRY (chilled), Sweden</i>	The net results of Tetra Top Midi 250mL are lower (green)/ higher (orange) than those of				
	Tetra Top Mini 330mL	Tetra Top Midi 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	46%	43%	371%	-67%	-70%
Acidification	26%	30%	-33%	-48%	-53%
Photo-Oxidant Formation	30%	31%	-38%	-34%	-40%
Ozone Depletion Potential	26%	37%	-86%	34%	-3%
Terrestrial Eutrophication	26%	31%	-47%	-29%	-39%
Aquatic Eutrophication	29%	23%	-69%	-31%	-39%
Particulate Matter	27%	31%	-44%	-45%	-50%
Total Primary Energy	33%	29%	33%	-40%	-44%
Non-renewable Primary Energy	38%	32%	139%	-52%	-55%

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

<i>Grab & Go DAIRY (chilled), Sweden</i>	The net results of Tetra Top Midi 330mL are lower (green)/ higher (orange) than those of				
	Tetra Top Mini 330mL	Tetra Top Midi 250mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	2%	-30%	228%	-77%	-79%
Acidification	-3%	-23%	-48%	-60%	-64%
Photo-Oxidant Formation	-1%	-23%	-53%	-49%	-54%
Ozone Depletion Potential	-8%	-27%	-90%	-2%	-29%
Terrestrial Eutrophication	-4%	-23%	-59%	-46%	-53%
Aquatic Eutrophication	5%	-18%	-75%	-44%	-50%
Particulate Matter	-3%	-23%	-57%	-58%	-62%
Total Primary Energy	3%	-22%	3%	-54%	-57%
Non-renewable Primary Energy	5%	-24%	81%	-63%	-65%

Table 49: 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**

<i>Grab & Go DAIRY (chilled), Sweden</i>	The net results of Tetra Top Mini biobased 330mL are lower (green)/ higher (orange) than those of				
	Tetra Top Mini 330mL	Tetra Top Midi 250mL	Tetra Top Midi 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	-69%	-79%	-70%	-93%	-94%
Acidification	87%	48%	93%	-23%	-31%
Photo-Oxidant Formation	110%	62%	111%	7%	-3%
Ozone Depletion Potential	806%	621%	890%	867%	600%
Terrestrial Eutrophication	137%	88%	146%	33%	16%
Aquatic Eutrophication	319%	224%	297%	124%	97%
Particulate Matter	128%	80%	134%	0%	-10%
Total Primary Energy	1%	-25%	-3%	-55%	-58%
Non-renewable Primary Energy	-42%	-58%	-45%	-80%	-81%

Table 50: 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**

<i>Grab & Go JNSD (ambient), Sweden</i>	The net results of TBA Edge HeliCap biobased 250mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle 2 250mL
Climate Change	-17%	-4%	-69%	-84%
Acidification	17%	-24%	-4%	-71%
Photo-Oxidant Formation	26%	-25%	2%	-65%
Ozone Depletion Potential	223%	-47%	-73%	-21%
Terrestrial Eutrophication	34%	-29%	13%	-65%
Aquatic Eutrophication	93%	-39%	30%	209%
Particulate Matter	27%	-27%	3%	-68%
Total Primary Energy	0%	-6%	-35%	-45%
Non-renewable Primary Energy	-12%	6%	-55%	-62%

Table 51: 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**

<i>Grab & Go JNSD (ambient), Sweden</i>	The net results of TBA Edge HeliCap 250mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	20%	15%	-62%	-81%
Acidification	-15%	-35%	-18%	-75%
Photo-Oxidant Formation	-21%	-41%	-19%	-73%
Ozone Depletion Potential	-69%	-84%	-92%	-75%
Terrestrial Eutrophication	-25%	-47%	-15%	-74%
Aquatic Eutrophication	-48%	-68%	-33%	60%
Particulate Matter	-21%	-42%	-19%	-75%
Total Primary Energy	0%	-6%	-35%	-45%
Non-renewable Primary Energy	13%	20%	-49%	-57%

Table 52: 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**

<i>Grab & Go JNSD (ambient), Sweden</i>	The net results of TPA Square biobased 330mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	4%	-13%	-67%	-83%
Acidification	31%	54%	26%	-62%
Photo-Oxidant Formation	34%	69%	37%	-54%
Ozone Depletion Potential	88%	507%	-49%	49%
Terrestrial Eutrophication	42%	89%	60%	-50%
Aquatic Eutrophication	64%	217%	113%	406%
Particulate Matter	37%	74%	40%	-57%
Total Primary Energy	7%	7%	-31%	-42%
Non-renewable Primary Energy	-6%	-17%	-57%	-65%

4.4 Results base scenarios *water SWEDEN*

4.4.1 Presentation of results water Sweden

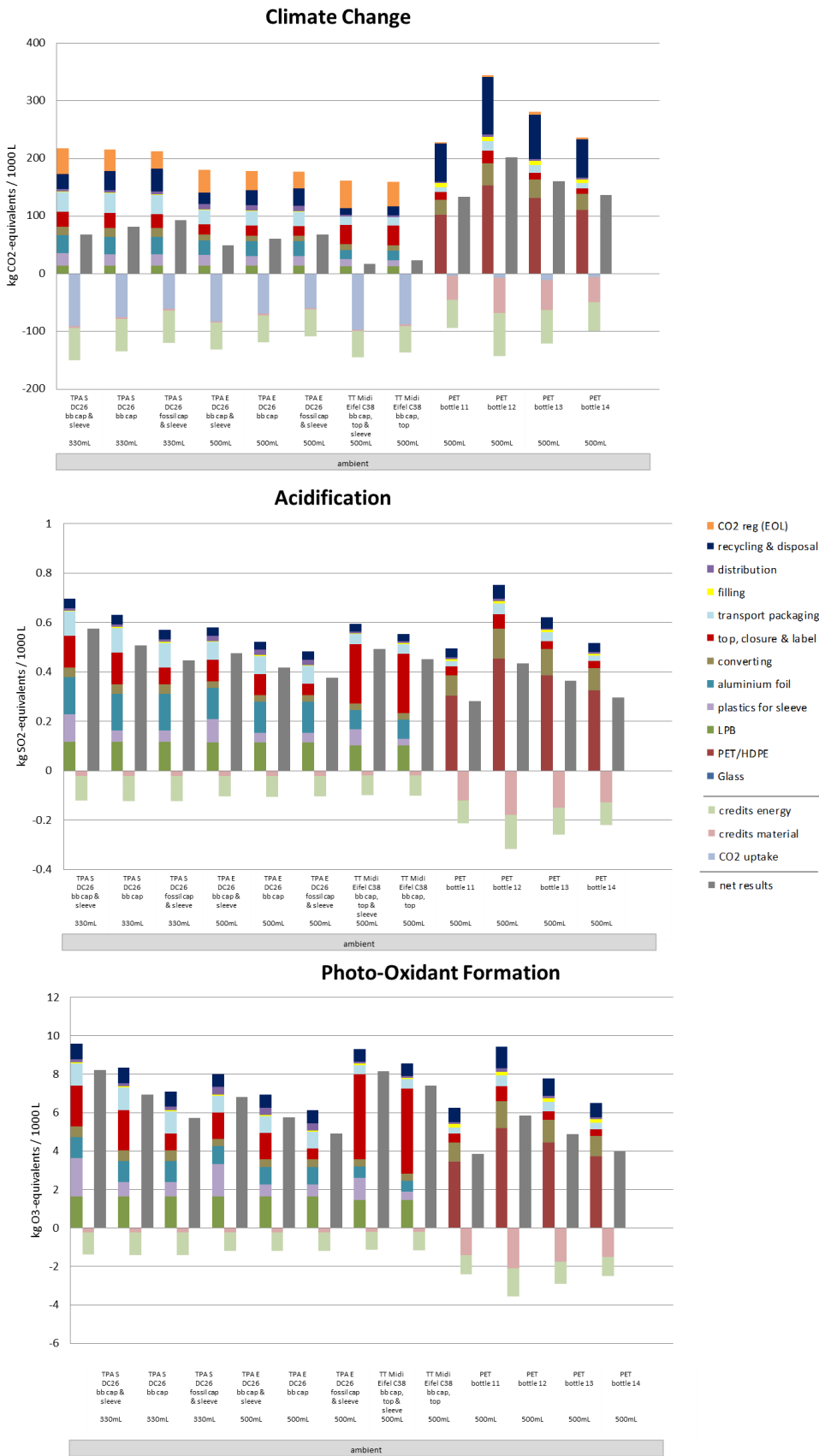


Figure 28: Indicator results for base scenarios of segment Water, Sweden, allocation factor 50% (Part 1)

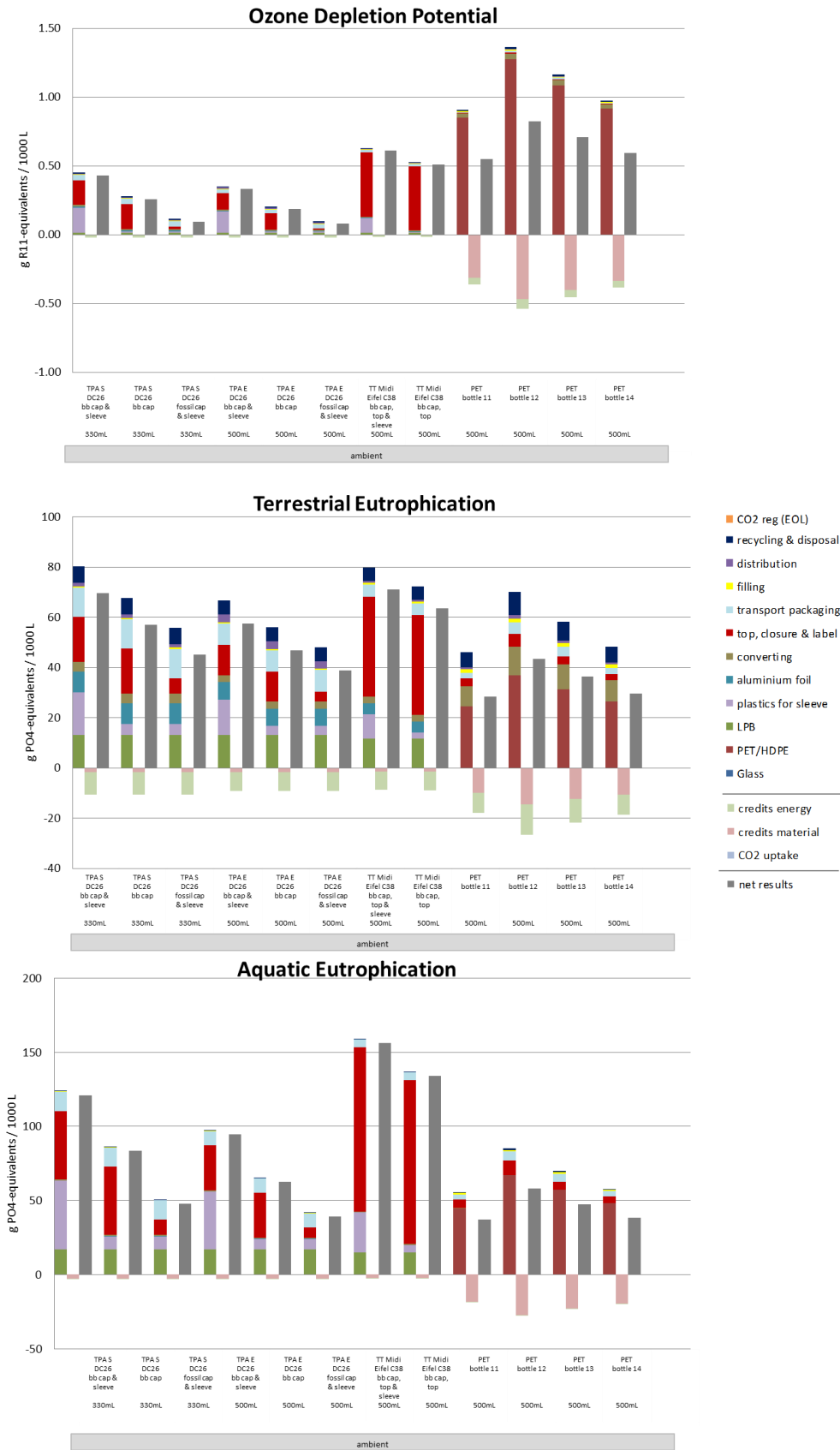


Figure 29: Indicator results for base scenarios of segment Water, Sweden, allocation factor 50% (Part 2)

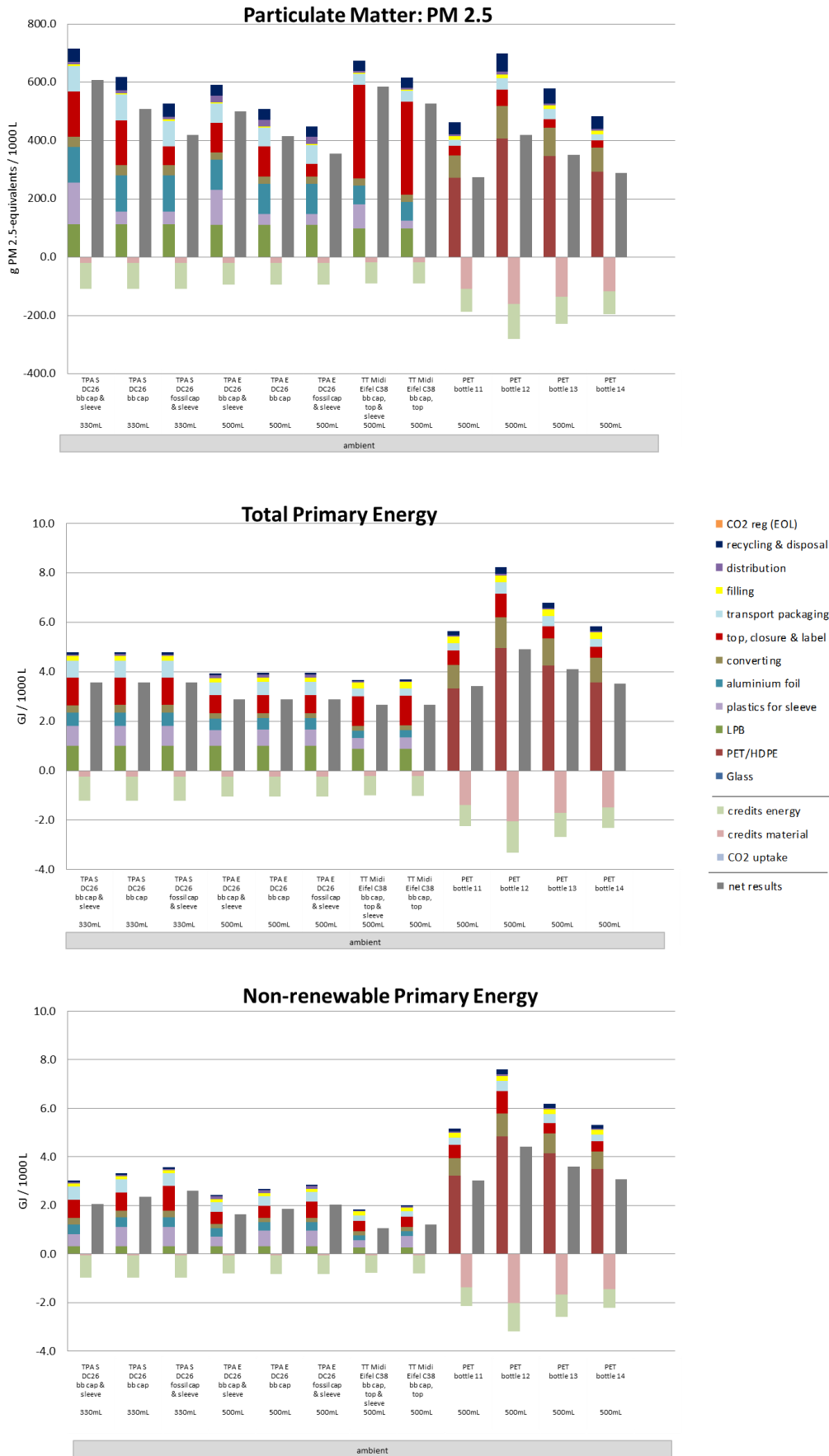


Figure 30: Indicator results for base scenarios of segment Water, Sweden, allocation factor 50% (Part 3)



Figure 31: Indicator results for base scenarios of segment Water, Sweden, allocation factor 50% (Part 4)

Table 53: Category indicator results per impact category for base scenarios of **segment Water** - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	173.08	178.31	182.99	140.44	144.86	147.95	113.66	116.72	226.21	341.42	275.95	233.42
	CO ₂ (reg)	44.96	37.31	30.10	40.41	33.92	29.17	47.69	43.21	1.56	3.20	5.50	2.63
	Credits	-58.56	-58.89	-58.79	-48.92	-49.32	-49.30	-47.31	-48.40	-91.08	-135.98	-109.51	-93.94
	CO ₂ uptake net results	-90.88	-75.46	-60.95	-82.01	-68.95	-59.35	-96.97	-87.94	-3.13	-6.45	-11.13	-5.31
Acidification [kg SO ₂ -e/1000 L]	Burdens	68.60	81.27	93.35	49.92	60.52	68.47	17.07	23.59	133.56	202.19	160.82	136.80
	Credits	0.70	0.63	0.57	0.58	0.52	0.48	0.59	0.55	0.49	0.75	0.62	0.52
	Net results	-0.12	-0.12	-0.12	-0.10	-0.10	-0.10	-0.10	-0.10	-0.21	-0.32	-0.26	-0.22
	Net results	0.58	0.51	0.45	0.47	0.42	0.38	0.49	0.45	0.28	0.43	0.36	0.30
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	9.60	8.34	7.11	8.00	6.94	6.12	9.30	8.56	6.26	9.42	7.77	6.51
	Credits	-1.39	-1.40	-1.40	-1.19	-1.20	-1.20	-1.14	-1.16	-2.40	-3.56	-2.90	-2.49
	Net results	8.20	6.94	5.71	6.81	5.74	4.92	8.16	7.40	3.86	5.86	4.87	4.02
	Burdens	0.45	0.28	0.12	0.35	0.21	0.10	0.63	0.53	0.91	1.36	1.16	0.98
Ozone Depletion [g R11/1000 L]	Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.36	-0.54	-0.45	-0.38
	Net results	0.43	0.26	0.10	0.34	0.19	0.08	0.62	0.51	0.55	0.83	0.71	0.59
	Burdens	80.32	67.71	55.81	66.60	55.91	48.04	79.71	72.33	46.20	70.02	58.12	48.22
	Net results	-10.65	-10.71	-10.69	-9.09	-9.16	-9.16	-8.72	-8.89	-17.90	-26.67	-21.66	-18.58
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	69.67	57.01	45.12	57.50	46.75	38.88	71.00	63.43	28.30	43.36	36.46	29.64
	Credits	-2.68	-2.68	-2.68	-2.65	-2.65	-2.65	-2.38	-2.38	-18.43	-27.14	-22.80	-19.60
	Net results	121.04	83.37	47.85	94.52	62.62	39.12	156.25	134.18	37.12	58.12	47.21	38.22
	Burdens	716.03	618.22	527.50	592.59	509.74	449.71	674.60	617.29	463.04	700.06	578.86	483.69
Aquatic Eutrophication [g PO ₄ /1000 L]	Credits	-108.26	-108.78	-108.62	-92.65	-93.30	-93.27	-88.72	-90.47	-187.63	-279.62	-227.66	-195.10
	Net results	607.78	509.45	418.88	499.94	416.44	356.44	585.88	526.82	275.40	420.44	351.19	288.59
	Burdens	4.77	4.79	4.79	3.93	3.95	3.94	3.67	3.68	5.65	8.22	6.79	5.83
	Credits	-1.21	-1.22	-1.22	-1.05	-1.05	-1.05	-1.00	-1.02	-2.23	-3.31	-2.70	-2.32
Total Primary Energy [GJ]	Net results	3.56	3.57	3.57	2.89	2.89	2.89	2.67	2.66	3.42	4.90	4.09	3.51
	Burdens	3.03	3.32	3.59	2.43	2.68	2.86	1.84	2.01	5.17	7.60	6.18	5.31
	Credits	-0.97	-0.97	-0.97	-0.81	-0.81	-0.81	-0.78	-0.80	-2.14	-3.18	-2.59	-2.23
	Net results	2.06	2.35	2.62	1.63	1.87	2.04	1.06	1.21	3.03	4.42	3.59	3.08
Use of Nature [m ² /year]	Burdens	53.38	42.15	31.59	46.16	36.66	29.66	60.34	53.77	0.86	2.16	2.07	0.96
	Credits	-3.65	-3.65	-3.65	-3.64	-3.64	-3.64	-3.29	-3.29	-0.06	-0.09	-0.07	-0.06
	Net results	49.73	38.50	27.94	42.52	33.02	26.03	57.05	50.48	0.80	2.06	2.00	0.90
	water cool	3.61	3.60	3.51	2.89	2.88	2.82	3.07	3.06	4.77	6.41	5.70	5.01
Water use [m ³ /1000 L]	water process	2.76	2.77	2.78	2.68	2.69	2.70	2.18	2.19	0.71	0.81	0.81	0.74
	water unspecified	1.37	1.28	1.16	1.06	0.96	0.90	1.13	1.06	0.93	1.51	1.21	0.97

4.4.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the water 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 SO₂, 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 water 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 shows visible impacts in almost all impact categories.

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 N₂O 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 water 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 35.5% 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 CO₂ 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 CO₂.

Plastic bottles

In the regarded plastic bottle systems in the water 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 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 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 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'.

For the regarded plastic bottles for water more material credits are given than for bottles in other beverage segments as the deposit system for water bottles leads to a high recycling rate.

4.4.3 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of each compared packaging system¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

Table 54: Comparison of net results: Tetra Prisma Aseptic Square bio-based cap & sleeve 330 mL versus competing carton based and alternative packaging systems in **segment Water,Sweden**

WATER (ambient), Sweden	The net results of TPA S DC26 bb cap & sleeve 330mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	-16%	-27%	37%	13%	0%	302%	191%	-49%	-66%	-57%	-50%
Acidification	13%	29%	21%	38%	53%	17%	27%	104%	33%	59%	94%
Photo-Oxidant Formation	18%	44%	20%	43%	67%	1%	11%	113%	40%	68%	104%
Ozone Depletion Potential	67%	349%	28%	128%	427%	-30%	-16%	-22%	-48%	-39%	-27%
Terrestrial Eutrophication	22%	54%	21%	49%	79%	-2%	10%	146%	61%	91%	135%
Aquatic Eutrophication	45%	153%	28%	93%	209%	-23%	-10%	226%	108%	156%	217%
Particulate Matter	19%	45%	22%	46%	71%	4%	15%	121%	45%	73%	111%
Total Primary Energy	0%	0%	23%	23%	23%	33%	34%	4%	-27%	-13%	2%
Non-renewable Primary Energy	-12%	-21%	27%	11%	1%	95%	71%	-32%	-53%	-43%	-33%

Table 55: Comparison of net results: Tetra Prisma Aseptic Square bio-based cap 330 mL versus competing carton based and alternative packaging systems in **segment Water,Sweden**

WATER (ambient), Sweden	The net results of TPA S DC26 bb cap 330mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	18%	-13%	63%	34%	19%	376%	245%	-39%	-60%	-49%	-41%
Acidification	-12%	13%	7%	22%	35%	3%	12%	80%	17%	40%	71%
Photo-Oxidant Formation	-15%	22%	2%	21%	41%	-15%	-6%	80%	19%	42%	73%
Ozone Depletion Potential	-40%	169%	-23%	37%	216%	-58%	-50%	-53%	-69%	-64%	-56%
Terrestrial Eutrophication	-18%	26%	-1%	22%	47%	-20%	-10%	101%	31%	56%	92%
Aquatic Eutrophication	-31%	74%	-12%	33%	113%	-47%	-38%	125%	43%	77%	118%
Particulate Matter	-16%	22%	2%	22%	43%	-13%	-3%	85%	21%	45%	77%
Total Primary Energy	0%	0%	24%	23%	23%	34%	34%	4%	-27%	-13%	2%
Non-renewable Primary Energy	14%	-10%	45%	26%	15%	123%	94%	-22%	-47%	-35%	-24%

Table 56: Comparison of net results: Tetra Prisma Aseptic Square fossil cap & sleeve 330 mL versus competing carton based and alternative packaging systems in **segment Water,Sweden**

WATER (ambient), Sweden	The net results of TPA S DC26 fossil cap & sleeve 330mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	36%	15%	87%	54%	36%	447%	296%	-30%	-54%	-42%	-32%
Acidification	-22%	-12%	-6%	7%	19%	-9%	-1%	59%	3%	23%	51%
Photo-Oxidant Formation	-30%	-18%	-16%	-1%	16%	-30%	-23%	48%	-3%	17%	42%
Ozone Depletion Potential	-78%	-63%	-71%	-49%	17%	-84%	-81%	-83%	-88%	-86%	-84%
Terrestrial Eutrophication	-35%	-21%	-22%	-4%	16%	-36%	-29%	59%	4%	24%	52%
Aquatic Eutrophication	-60%	-43%	-49%	-24%	22%	-69%	-64%	29%	-18%	1%	25%
Particulate Matter	-31%	-18%	-16%	1%	18%	-29%	-20%	52%	0%	19%	45%
Total Primary Energy	0%	0%	24%	23%	23%	34%	34%	4%	-27%	-13%	2%
Non-renewable Primary Energy	27%	11%	61%	40%	28%	148%	116%	-14%	-41%	-27%	-15%

Table 57: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap & sleeve 500 mL versus competing carton based and alternative packaging systems in **segment Water,Sweden**

WATER (ambient), Sweden	The net results of TPA E DC26 bb cap & sleeve 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	A50_SE_lms dal_500, Gut
Climate Change	-27%	-39%	-47%	-18%	-27%	192%	112%	-63%	-75%	-69%	-64%
Acidification	-18%	-7%	6%	14%	26%	-4%	5%	68%	9%	31%	60%
Photo-Oxidant Formation	-17%	-2%	19%	19%	38%	-16%	-8%	77%	16%	40%	69%
Ozone Depletion Potential	-22%	30%	249%	77%	310%	-45%	-34%	-39%	-59%	-53%	-43%
Terrestrial Eutrophication	-17%	1%	27%	23%	48%	-19%	-9%	103%	33%	58%	94%
Aquatic Eutrophication	-22%	13%	98%	51%	142%	-40%	-30%	155%	63%	100%	147%
Particulate Matter	-18%	-2%	19%	20%	40%	-15%	-5%	82%	19%	42%	73%
Total Primary Energy	-19%	-19%	-19%	0%	0%	8%	9%	-15%	-41%	-29%	-18%
Non-renewable Primary Energy	-21%	-31%	-38%	-13%	-20%	54%	34%	-46%	-63%	-55%	-47%

Table 58: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap 500 mL versus competing carton based and alternative packaging systems in **segment Water,Sweden**

WATER (ambient), Sweden	The net results of TPA E DC26 bb cap 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	-12%	-26%	-35%	21%	-12%	254%	157%	-55%	-70%	-62%	-56%
Acidification	-28%	-18%	-7%	-12%	11%	-15%	-8%	48%	-4%	15%	41%
Photo-Oxidant Formation	-30%	-17%	1%	-16%	17%	-30%	-22%	49%	-2%	18%	43%
Ozone Depletion Potential	-56%	-27%	97%	-44%	131%	-69%	-63%	-66%	-77%	-73%	-68%
Terrestrial Eutrophication	-33%	-18%	4%	-19%	20%	-34%	-26%	65%	8%	28%	58%
Aquatic Eutrophication	-48%	-25%	31%	-34%	60%	-60%	-53%	69%	8%	33%	64%
Particulate Matter	-31%	-18%	-1%	-17%	17%	-29%	-21%	51%	-1%	19%	44%
Total Primary Energy	-19%	-19%	-19%	0%	0%	8%	9%	-15%	-41%	-29%	-17%
Non-renewable Primary Energy	-10%	-21%	-29%	15%	-9%	77%	54%	-38%	-58%	-48%	-39%

Table 59: Comparison of net results: Tetra Prisma Aseptic Edge fossil cap & sleeve 500 mL versus competing carton based and alternative packaging systems in **segment Water,Sweden**

WATER (ambient), Sweden	The net results of TPA E DC26 fossil cap & sleeve 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	0%	-16%	-27%	37%	13%	301%	190%	-49%	-66%	-57%	-50%
Acidification	-34%	-26%	-16%	-21%	-10%	-24%	-17%	34%	-13%	4%	27%
Photo-Oxidant Formation	-40%	-29%	-14%	-28%	-14%	-40%	-33%	28%	-16%	1%	23%
Ozone Depletion Potential	-81%	-68%	-15%	-76%	-57%	-87%	-84%	-85%	-90%	-88%	-86%
Terrestrial Eutrophication	-44%	-32%	-14%	-32%	-17%	-45%	-39%	37%	-10%	7%	31%
Aquatic Eutrophication	-68%	-53%	-18%	-59%	-38%	-75%	-71%	5%	-33%	-17%	2%
Particulate Matter	-41%	-30%	-15%	-29%	-14%	-39%	-32%	29%	-15%	1%	24%
Total Primary Energy	-19%	-19%	-19%	0%	0%	8%	9%	-15%	-41%	-29%	-17%
Non-renewable Primary Energy	-1%	-13%	-22%	26%	9%	93%	69%	-33%	-54%	-43%	-34%

Table 60: Comparison of net results: **Tetra Top Midi Eifel C38 bio-based cap, top & sleeve 500 mL** versus competing carton based and alternative packaging systems in **segment Water, Sweden**

WATER (ambient), Sweden	The net results of TT Midi Eifel C38 bb cap, top & sleeve 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	-75%	-79%	-82%	-66%	-72%	-75%	-28%	-87%	-92%	-89%	-88%
Acidification	-14%	-3%	10%	4%	18%	31%	9%	75%	14%	36%	66%
Photo-Oxidant Formation	-1%	18%	43%	20%	42%	66%	10%	112%	39%	68%	103%
Ozone Depletion Potential	42%	137%	539%	83%	224%	650%	20%	12%	-26%	-13%	3%
Terrestrial Eutrophication	2%	25%	57%	23%	52%	83%	12%	151%	64%	95%	140%
Aquatic Eutrophication	29%	87%	227%	65%	150%	299%	16%	321%	169%	231%	309%
Particulate Matter	-4%	15%	40%	17%	41%	64%	11%	113%	39%	67%	103%
Total Primary Energy	-25%	-25%	-25%	-8%	-8%	-8%	0%	-22%	-46%	-35%	-24%
Non-renewable Primary Energy	-49%	-55%	-60%	-35%	-43%	-48%	-13%	-65%	-76%	-71%	-66%

Table 61: Comparison of net results: **Tetra Top Midi Eifel C38 bio-based cap & top 500 mL** versus competing carton based and alternative packaging systems in **segment Water, Sweden**

WATER (ambient), Sweden	The net results of TT Midi Eifel C38 bb cap, top 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change	-66%	-71%	-75%	-53%	-61%	-66%	-38%	-82%	-88%	-85%	-83%
Acidification	-21%	-11%	1%	-5%	8%	20%	-8%	60%	4%	25%	52%
Photo-Oxidant Formation	-10%	7%	30%	9%	29%	50%	-9%	92%	26%	52%	84%
Ozone Depletion Potential	19%	98%	433%	53%	170%	526%	-17%	-7%	-38%	-28%	-14%
Terrestrial Eutrophication	-9%	11%	41%	10%	36%	63%	-11%	124%	46%	74%	114%
Aquatic Eutrophication	11%	61%	180%	42%	114%	243%	-14%	261%	131%	184%	251%
Particulate Matter	-13%	3%	26%	5%	27%	48%	-10%	91%	25%	50%	83%
Total Primary Energy	-25%	-25%	-25%	-8%	-8%	-8%	0%	-22%	-46%	-35%	-24%
Non-renewable Primary Energy	-41%	-49%	-54%	-26%	-35%	-41%	15%	-60%	-73%	-66%	-61%

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%.

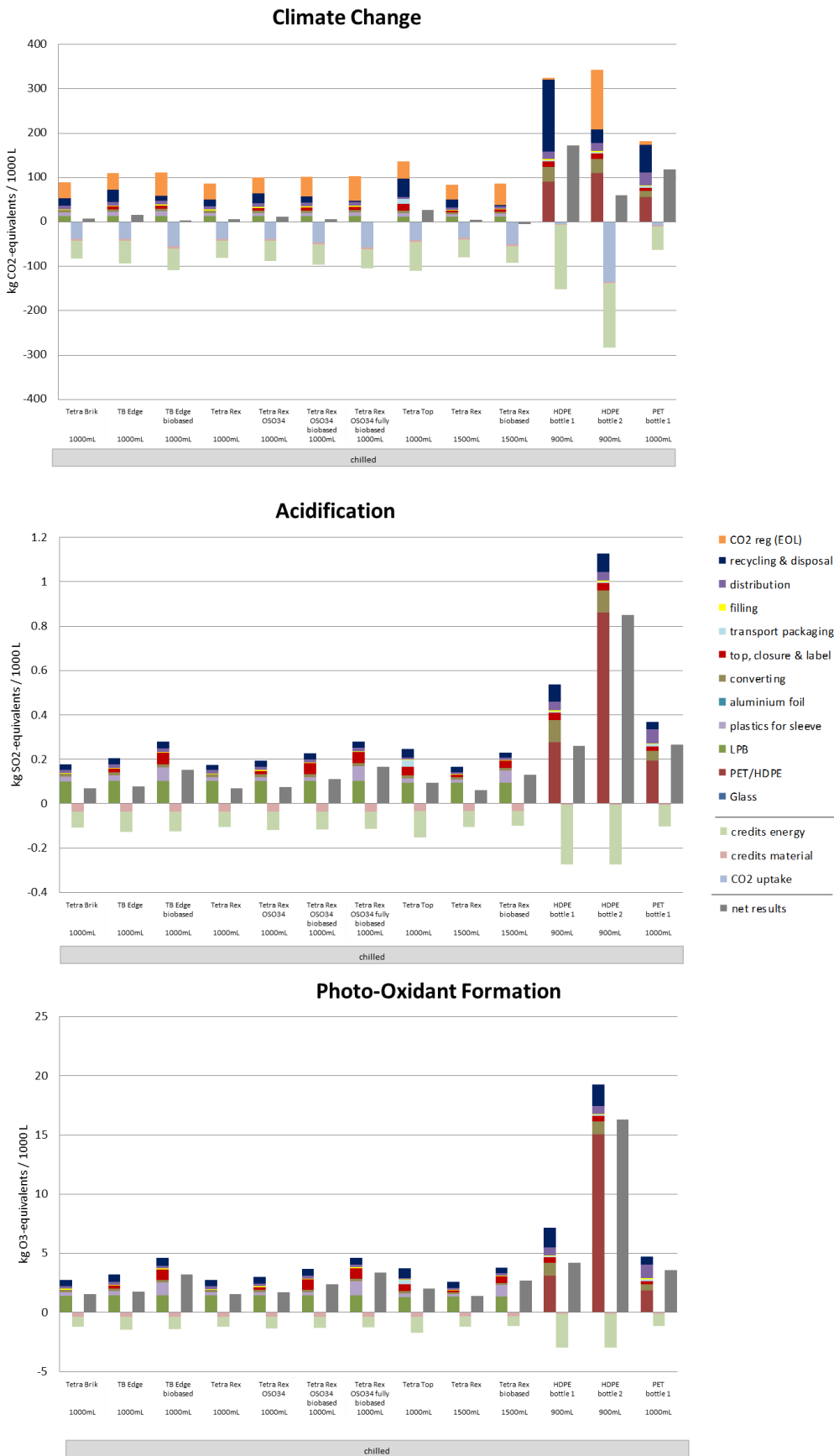


Figure 32: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Sweden, allocation factor 100% (Part 1)

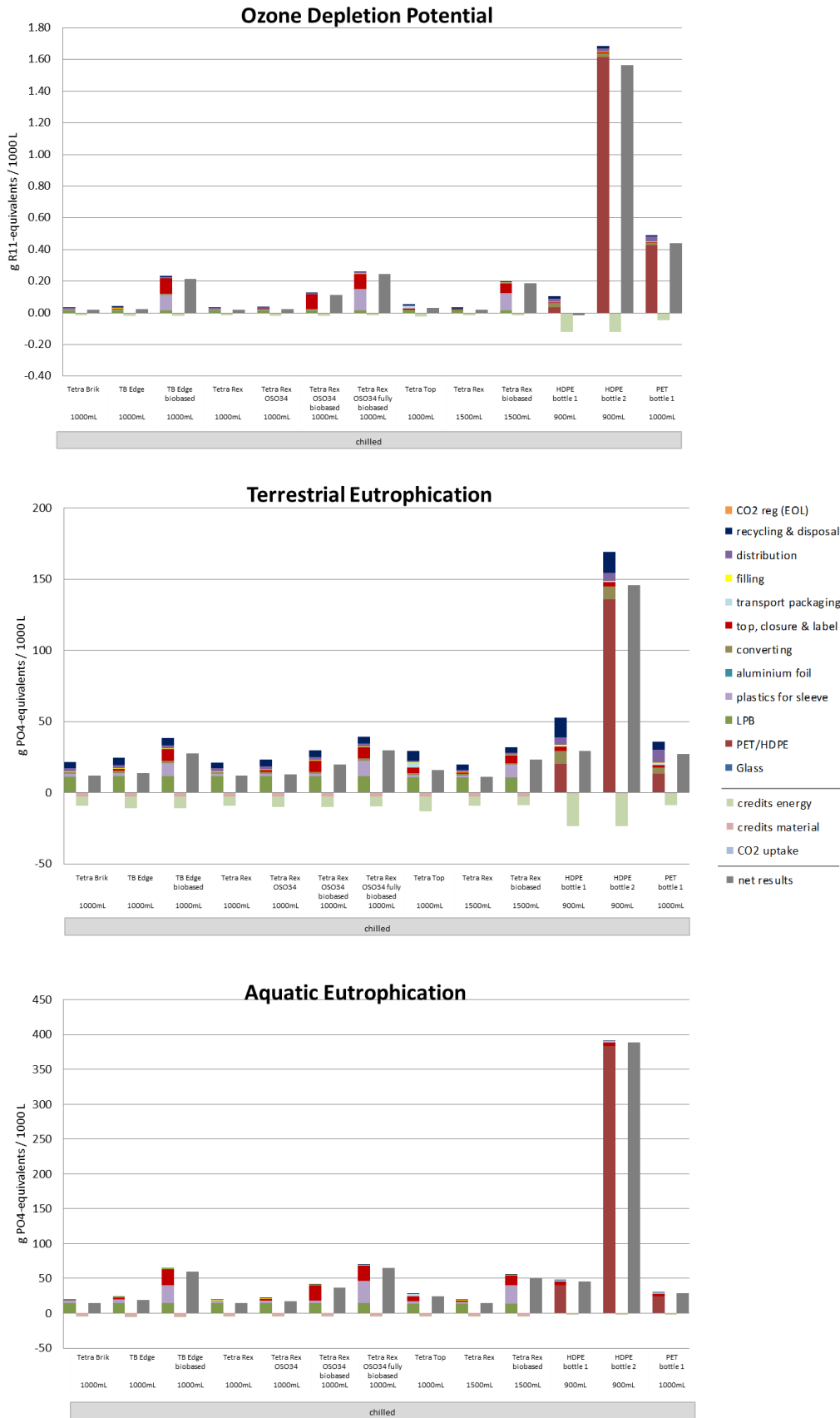


Figure 33: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Sweden, allocation factor 100% (Part 2)

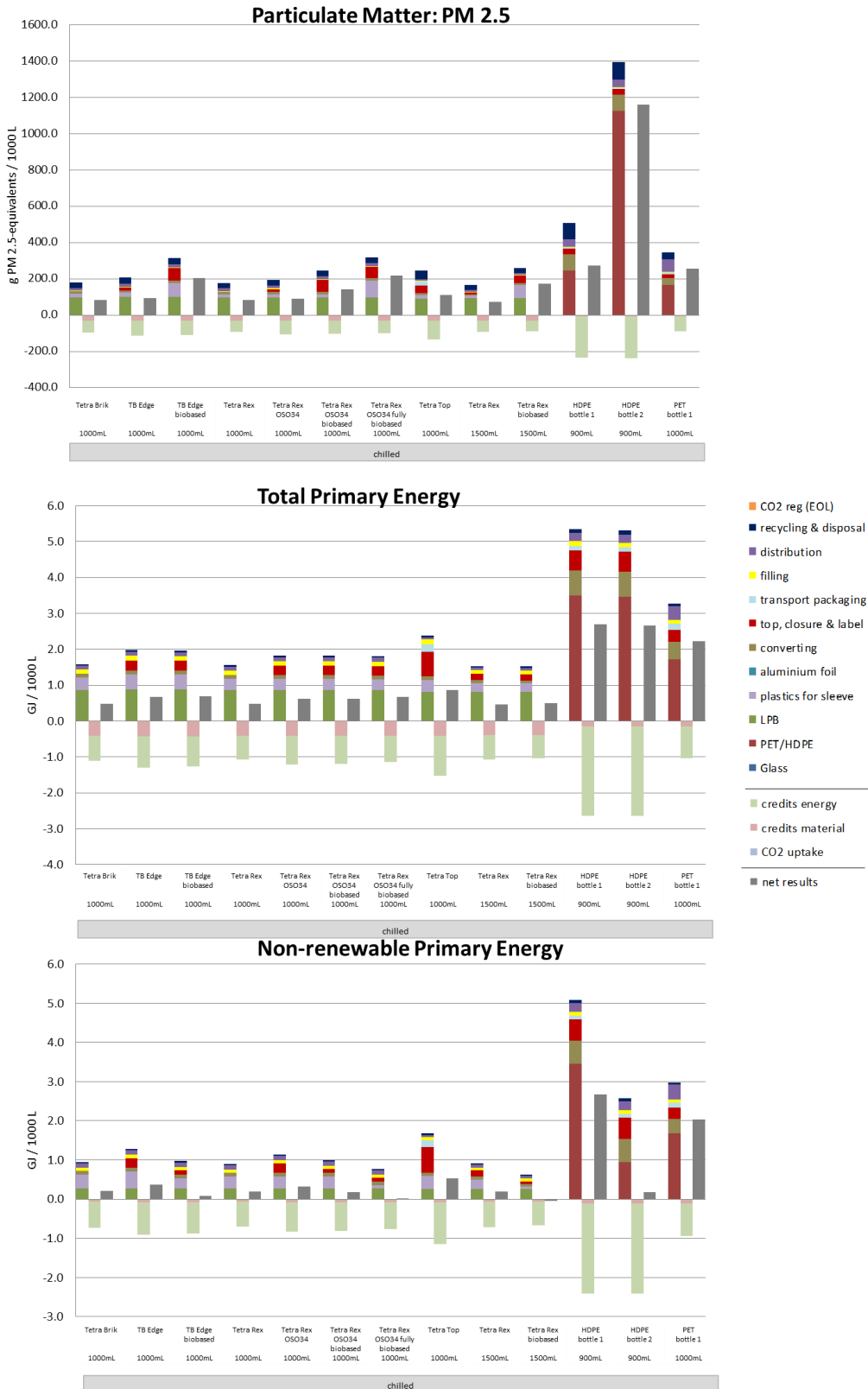


Figure 34: Indicator results for sensitivity analysis on system allocation of **segment DAIRY, Sweden**, allocation factor 100% (Part 3)

Table 10: Category indicator results per impact category for sensitivity analysis on system allocation scenarios of **segment DAIRY, Sweden**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Brik 1000mL	TB Edge 1000mL	TB Edge biobased 1000mL	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	Tetra Rex 1500mL	Tetra Rex biobased 1500mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	53.16	72.49	58.89	49.94	63.81	57.43	47.88	97.12	49.98	37.92	320.02	207.73	173.92
	CO ₂ (reg)	36.17	37.05	53.11	36.70	36.79	44.39	55.51	39.87	34.35	48.52	4.26	135.37	8.28
	Credits	-44.52	-55.52	-53.76	-42.93	-50.29	-49.65	-46.85	-69.36	-43.65	-41.39	-147.62	-147.65	-55.04
	CO ₂ uptake	-37.69	-38.58	-55.44	-38.24	-38.31	-46.26	-57.90	-41.02	-35.79	-50.61	-4.27	-135.64	-8.34
	net results	7.12	15.44	2.80	5.47	12.01	5.92	-1.36	26.60	4.89	-5.57	172.39	59.81	118.82
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.18	0.21	0.28	0.17	0.19	0.23	0.28	0.25	0.17	0.23	0.54	1.13	0.37
	Credits	-0.11	-0.13	-0.13	-0.11	-0.12	-0.12	-0.11	-0.15	-0.11	-0.10	-0.27	-0.27	-0.10
	Net results	0.07	0.08	0.15	0.07	0.08	0.11	0.17	0.09	0.06	0.13	0.26	0.85	0.27
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	2.76	3.22	4.60	2.73	3.04	3.70	4.64	3.73	2.59	3.81	7.17	19.24	4.72
	Credits	-1.20	-1.44	-1.41	-1.17	-1.33	-1.32	-1.28	-1.72	-1.17	-1.12	-2.95	-2.95	-1.13
	Net results	1.56	1.77	3.20	1.56	1.71	2.38	3.39	2.01	1.42	2.68	4.22	16.29	3.59
Ozone Depletion [g R11/1000 L]	Burdens	0.04	0.04	0.23	0.04	0.04	0.13	0.26	0.06	0.03	0.20	0.10	1.68	0.49
	Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.01	-0.12	-0.12	-0.05
	Net results	0.02	0.02	0.21	0.02	0.02	0.11	0.24	0.03	0.02	0.19	-0.02	1.56	0.44
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	21.36	24.62	38.40	21.12	23.29	29.79	39.29	29.21	19.99	32.10	52.81	169.25	35.99
	Credits	-9.25	-11.08	-10.80	-9.02	-10.21	-10.10	-9.65	-13.15	-9.00	-8.63	-23.66	-23.66	-8.96
	Net results	12.12	13.54	27.60	12.11	13.08	19.69	29.64	16.06	10.99	23.47	29.15	145.59	27.03
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	19.20	23.13	64.33	18.88	21.31	40.76	69.19	28.33	18.77	55.00	47.09	390.30	29.61
	Credits	-4.32	-4.47	-4.47	-4.37	-4.39	-4.39	-4.39	-4.29	-4.09	-4.09	-1.18	-1.19	-1.25
	Net results	14.88	18.67	59.86	14.51	16.91	36.36	64.80	24.03	14.68	50.90	45.91	389.11	28.36
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	178.29	207.55	313.94	175.84	194.95	244.96	318.66	243.59	166.87	260.49	507.68	1394.99	344.81
	Credits	-95.69	-114.13	-111.30	-93.43	-105.31	-104.28	-99.79	-134.58	-93.03	-89.40	-236.08	-236.13	-89.47
	Net results	82.60	93.42	202.65	82.41	89.64	140.68	218.88	109.01	73.84	171.10	271.59	1158.86	255.33
Total Primary Energy [GJ]	Burdens	1.59	1.98	1.96	1.56	1.82	1.82	1.81	2.38	1.53	1.52	5.34	5.30	3.26
	Credits	-1.10	-1.30	-1.27	-1.08	-1.21	-1.20	-1.15	-1.52	-1.03	-1.03	-2.65	-2.65	-1.03
	Net results	0.48	0.67	0.69	0.48	0.62	0.63	0.66	0.86	0.46	0.49	2.70	2.65	2.23
Non-renewable Primary Energy [GJ]	Burdens	0.94	1.28	0.97	0.90	1.14	0.99	0.77	1.68	0.91	0.63	5.08	2.58	2.97
	Credits	-0.73	-0.91	-0.88	-0.70	-0.82	-0.81	-0.77	-1.14	-0.71	-0.68	-2.41	-2.41	-0.94
	Net results	0.21	0.38	0.09	0.20	0.32	0.18	0.01	0.53	0.19	-0.05	2.67	0.17	2.03
Use of Nature [m ² /year]	Burdens	21.25	21.81	34.08	21.56	21.65	27.44	35.91	21.89	20.19	30.98	0.52	100.04	0.54
	Credits	-6.26	-6.44	-6.44	-6.33	-6.34	-6.34	-6.34	-5.92	-5.93	-5.93	-0.67	-0.67	-0.36
	Net results	14.99	15.37	27.64	15.23	15.31	21.10	29.57	15.97	14.26	25.06	-0.15	0.00	0.00
Water use [m ³ /1000 L]	water cool	0.95	1.21	1.26	1.02	1.22	1.25	1.27	1.45	1.00	1.04	1.29	2.14	2.40
	water process	1.92	2.16	2.15	1.94	1.95	1.94	1.93	1.63	1.79	1.78	0.04	0.10	0.20
	water unspecified	0.19	0.24	0.36	0.19	0.24	0.30	0.38	0.48	0.20	0.31	1.01	2.41	0.79

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 2.4.3). Results are shown in the following break even graphs.

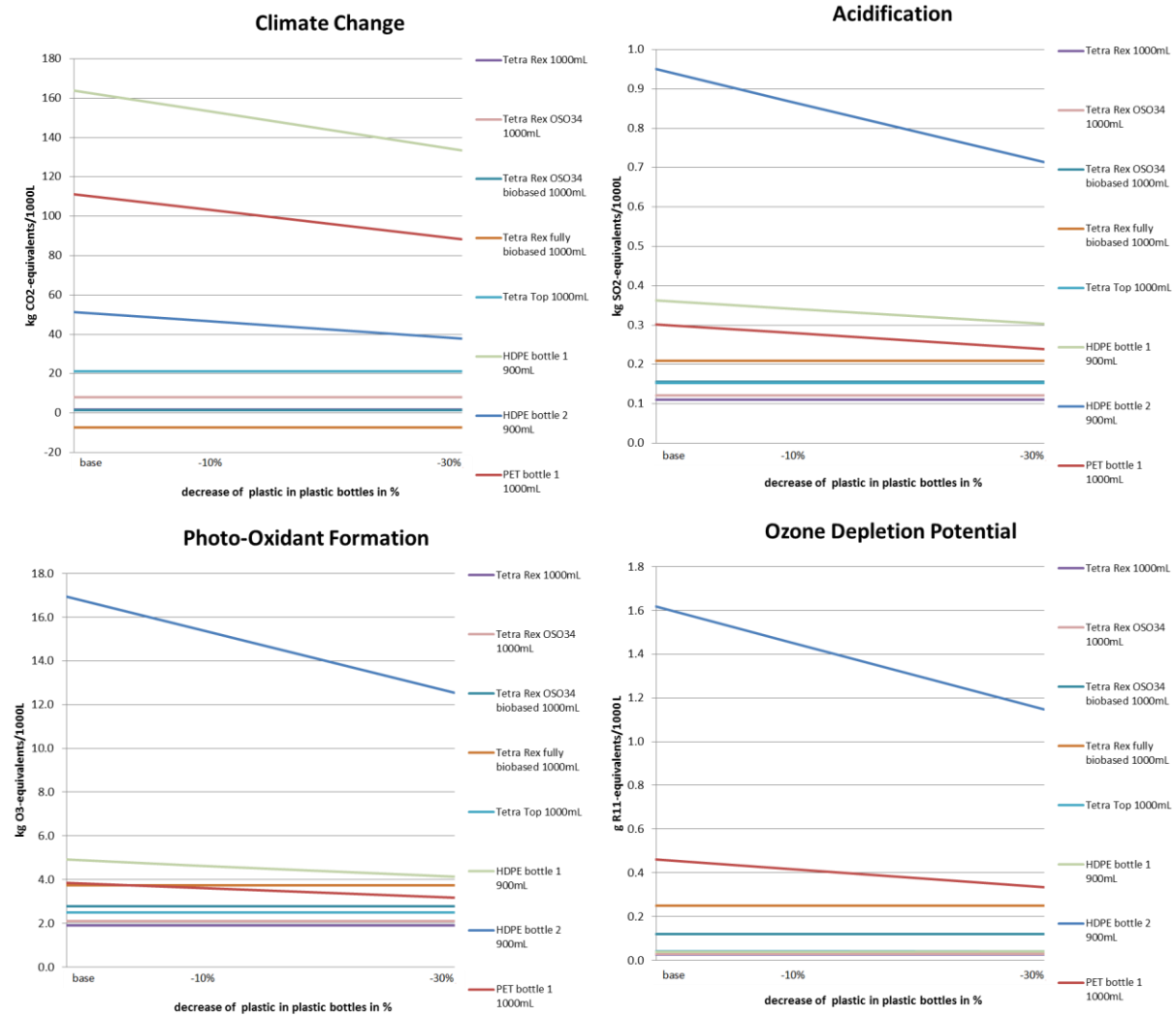


Figure 35: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Sweden, allocation factor 50% (Part 1)

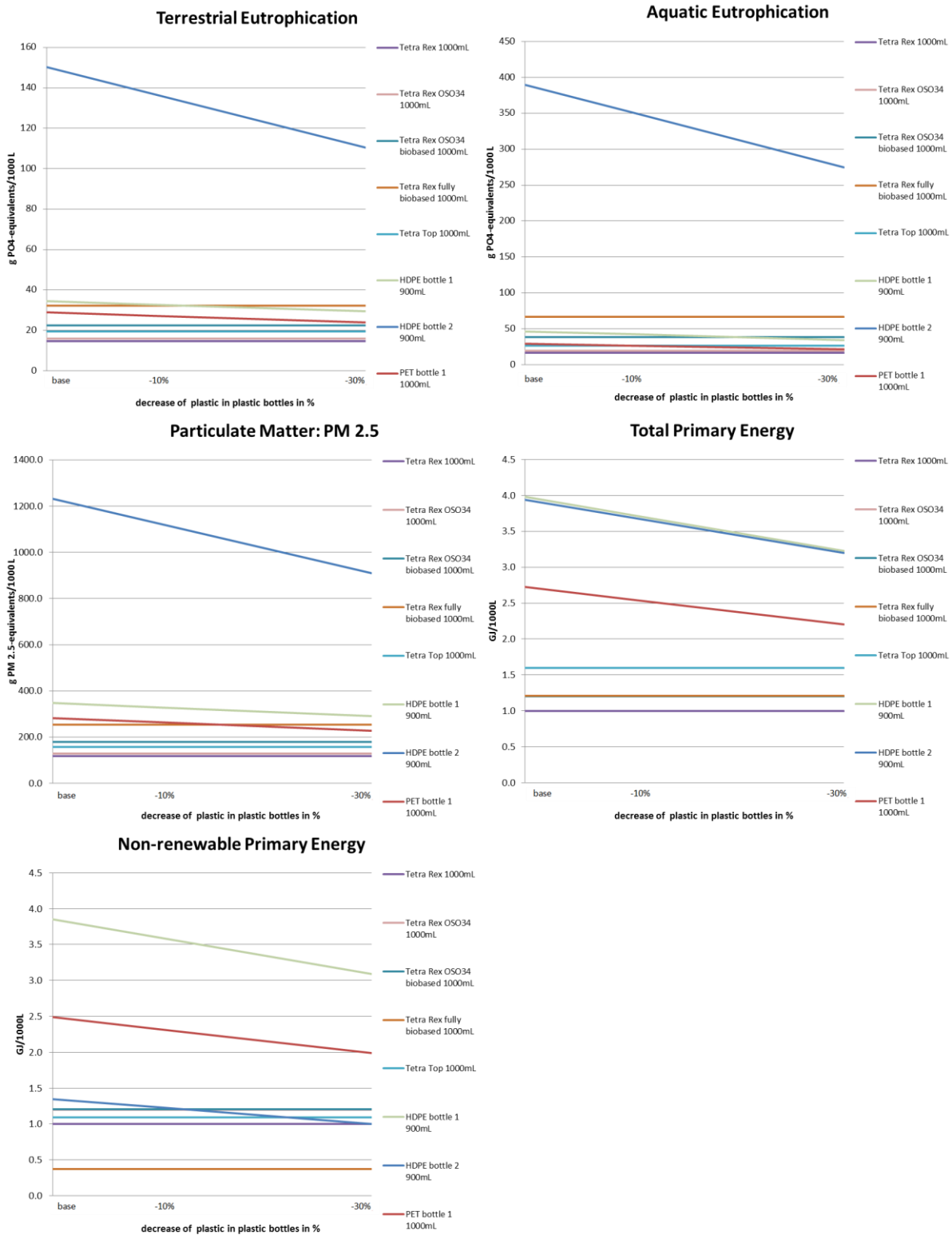


Figure 36: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Sweden, allocation factor 50% (Part 2)

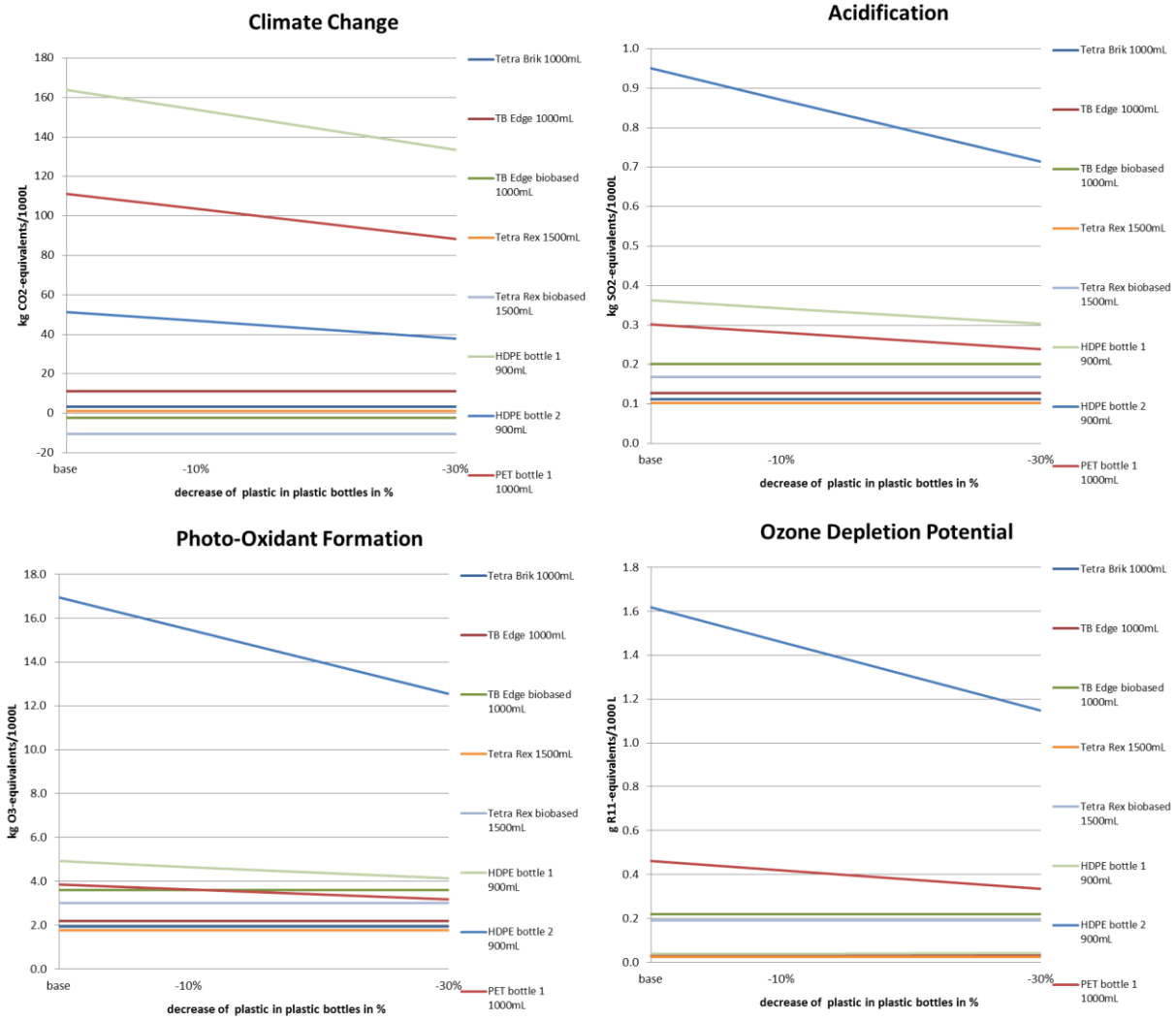


Figure 37: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Sweden, allocation factor 50% (Part 3)

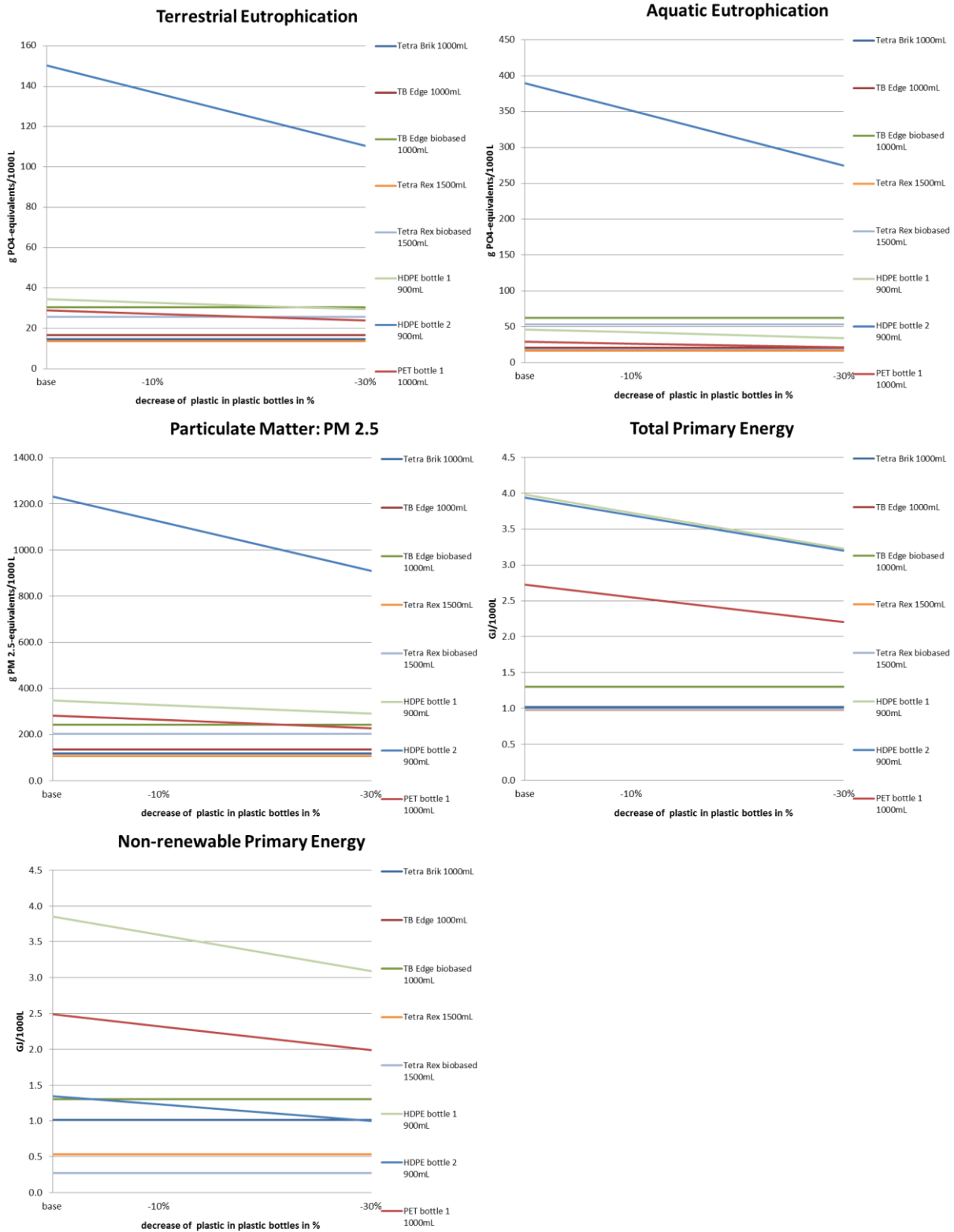


Figure 38: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Sweden, allocation factor 50% (Part 4)

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.

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

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

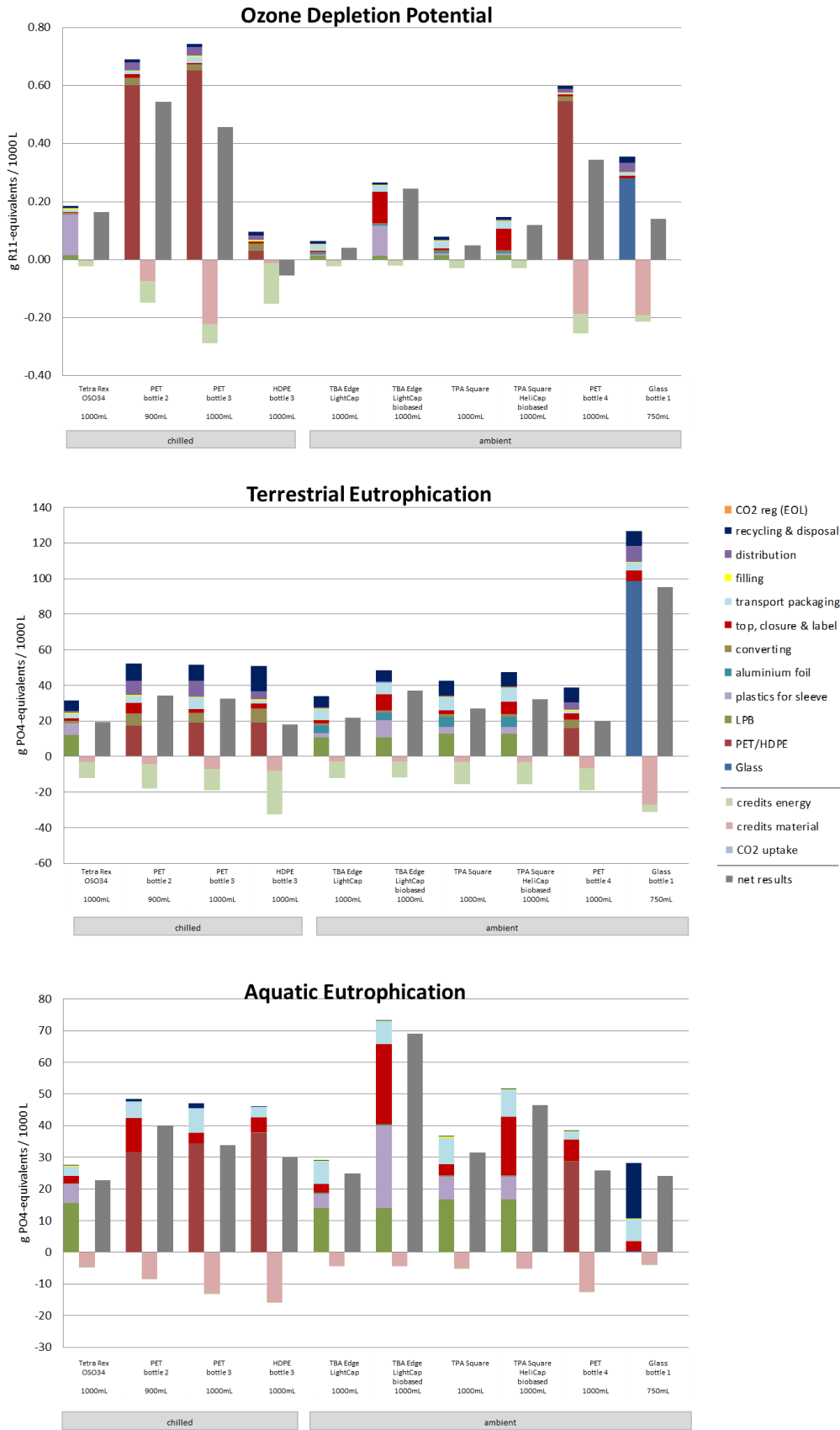


Figure 40: Indicator results for sensitivity analysis on system allocation of segment JNSD, Sweden, allocation factor 100% (Part 2)

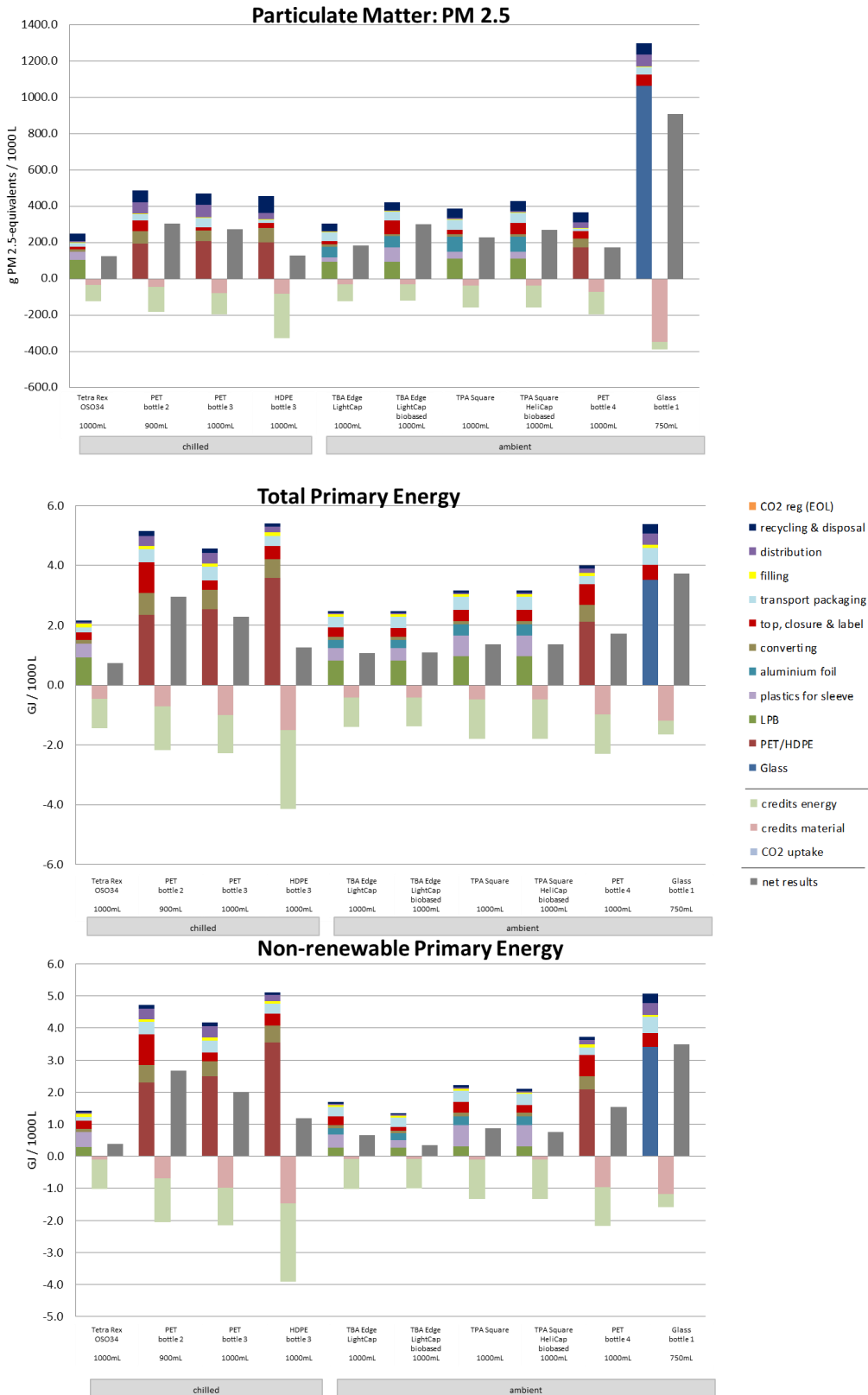


Figure 41: Indicator results for sensitivity analysis on system allocation of segment JNSD, Sweden, allocation factor 100% (Part 3)

Table 63: Category indicator results per impact category for sensitivity analysis on system allocation of **segment JNSD, Sweden**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Rex OSO34 1000mL	PET bottle 2 900mL	PET bottle 3 1000mL	HDPE bottle 3 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	85.03	263.30	245.58	316.37	103.31	88.71	136.74	131.92	214.64	383.17
	CO ₂ (reg)	43.54	11.50	15.53	8.64	42.31	59.54	50.22	56.07	3.83	12.44
	Credits	-61.63	-105.01	-104.61	-190.38	-62.47	-60.36	-81.37	-81.21	-105.43	-120.55
	CO ₂ uptake	-44.98	-11.60	-15.69	-8.71	-43.32	-61.39	-51.41	-57.56	-3.84	-12.47
	Net results	21.96	158.19	140.83	125.91	39.83	26.50	54.18	49.22	109.20	262.59
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.25	0.51	0.49	0.46	0.32	0.40	0.41	0.44	0.38	1.31
	Credits	-0.14	-0.21	-0.22	-0.37	-0.14	-0.14	-0.18	-0.18	-0.22	-0.32
	Net results	0.11	0.30	0.27	0.08	0.18	0.27	0.23	0.26	0.16	0.99
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	3.77	6.93	6.62	6.96	4.26	5.74	5.37	5.89	5.21	16.07
	Credits	-1.59	-2.36	-2.49	-4.30	-1.58	-1.53	-2.02	-2.02	-2.50	-3.92
	Net results	2.18	4.56	4.13	2.66	2.68	4.21	3.35	3.87	2.71	12.15
Ozone Depletion [g R11/1000 L]	Burdens	0.19	0.69	0.74	0.10	0.06	0.27	0.08	0.15	0.60	0.36
	Credits	-0.02	-0.15	-0.29	-0.15	-0.02	-0.02	-0.03	-0.03	-0.25	-0.21
	Net results	0.16	0.54	0.46	-0.06	0.04	0.25	0.05	0.12	0.35	0.14
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	31.43	52.38	51.62	50.84	33.86	48.63	42.51	47.55	38.84	126.55
	Credits	-12.16	-18.09	-19.04	-32.73	-12.07	-11.73	-15.50	-15.47	-19.02	-31.25
	Net results	19.27	34.30	32.58	18.11	21.79	36.89	27.01	32.08	19.82	95.31
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	27.53	48.38	47.00	45.98	29.12	73.28	36.60	51.65	38.48	28.21
	Credits	-4.80	-8.34	-13.15	-15.93	-4.32	-4.31	-5.12	-5.12	-12.54	-4.03
	Net results	22.72	40.04	33.85	30.05	24.80	68.97	31.48	46.53	25.93	24.19
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	248.24	486.28	468.61	455.11	305.51	419.61	388.41	426.83	366.70	1297.57
	Credits	-125.05	-182.85	-196.57	-327.65	-123.83	-120.44	-158.66	-158.40	-195.28	-389.76
	Net results	123.19	303.43	272.04	127.47	181.68	299.17	229.75	268.43	171.42	907.81
Total Primary Energy [GJ]	Burdens	2.16	5.14	4.57	5.39	2.48	2.47	3.16	3.16	4.01	5.37
	Credits	-1.43	-2.18	-2.28	-4.13	-1.41	-1.37	-1.80	-1.79	-2.30	-1.64
	Net results	0.73	2.96	2.29	1.26	1.07	1.10	1.37	1.37	1.71	3.73
Non-renewable Primary Energy [GJ]	Burdens	1.41	4.72	4.17	5.11	1.69	1.35	2.21	2.10	3.72	5.07
	Credits	-1.02	-2.05	-2.16	-3.91	-1.03	-1.00	-1.34	-1.34	-2.17	-1.59
	Net results	0.39	2.67	2.01	1.19	0.66	0.35	0.87	0.76	1.55	3.48
Use of Nature [m ² ·year]	Burdens	24.03	1.72	3.59	0.69	23.68	36.83	28.15	32.62	0.39	2.24
	Credits	-6.67	-0.15	-0.13	-0.23	-6.02	-6.02	-7.16	-7.16	-0.12	-0.10
	Net results	17.35	1.57	3.46	0.46	17.66	30.82	20.98	25.46	0.26	2.15
Water use [m ³ /1000 L]	water cool	1.34	3.07	2.41	0.50	1.46	1.51	1.73	1.78	1.87	0.93
	water process	2.04	0.17	0.13	-0.08	2.02	2.01	2.43	2.42	0.07	5.33
	water unspecified	0.39	1.02	0.97	0.51	0.59	0.72	0.74	0.78	0.63	0.43

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 2.4.3). Results are shown in the following break even graphs.

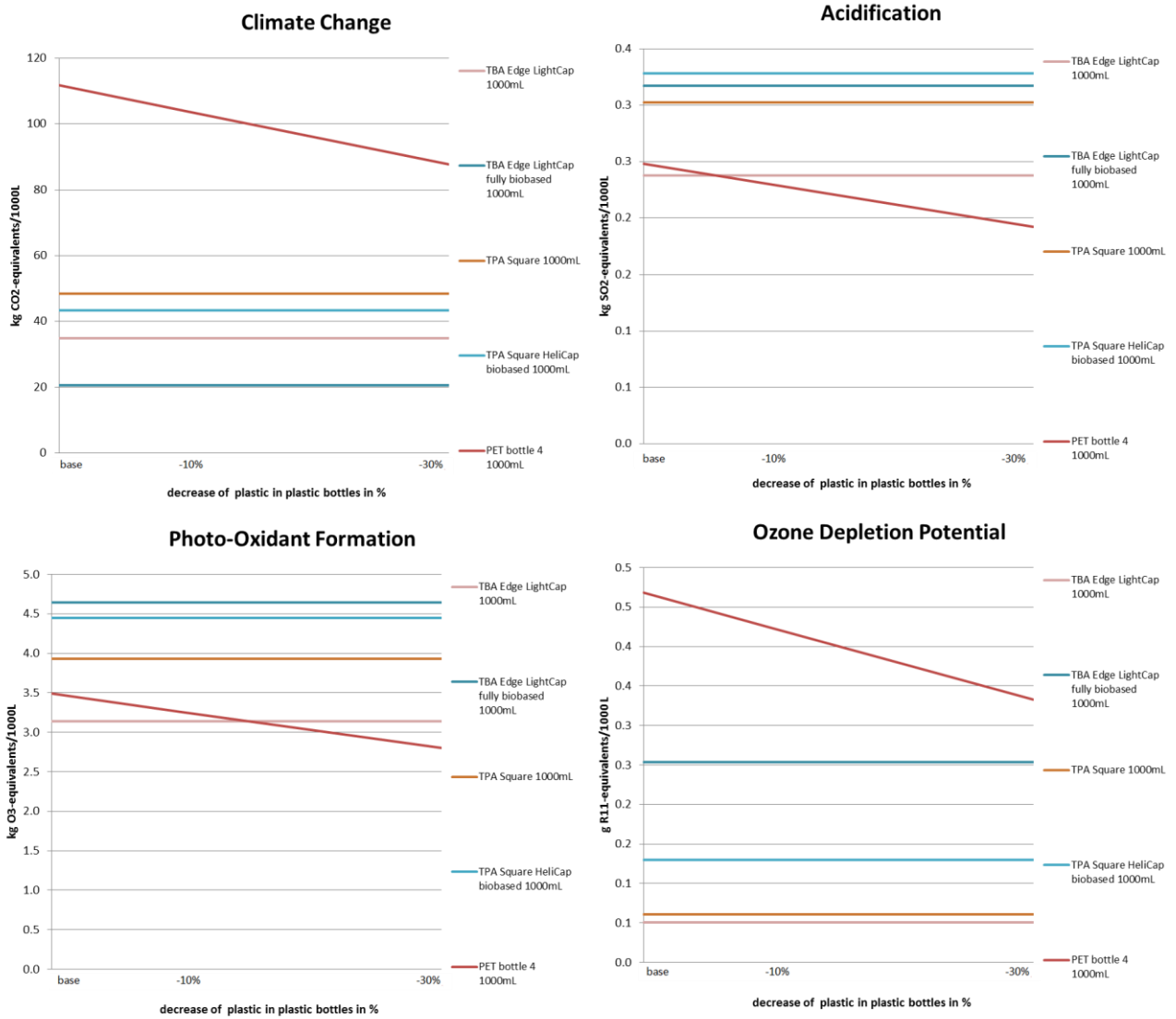


Figure 42: Indicator results for sensitivity analysis on plastic bottle weights of segment JNSD ambient, Sweden, allocation factor 50% (Part 1)

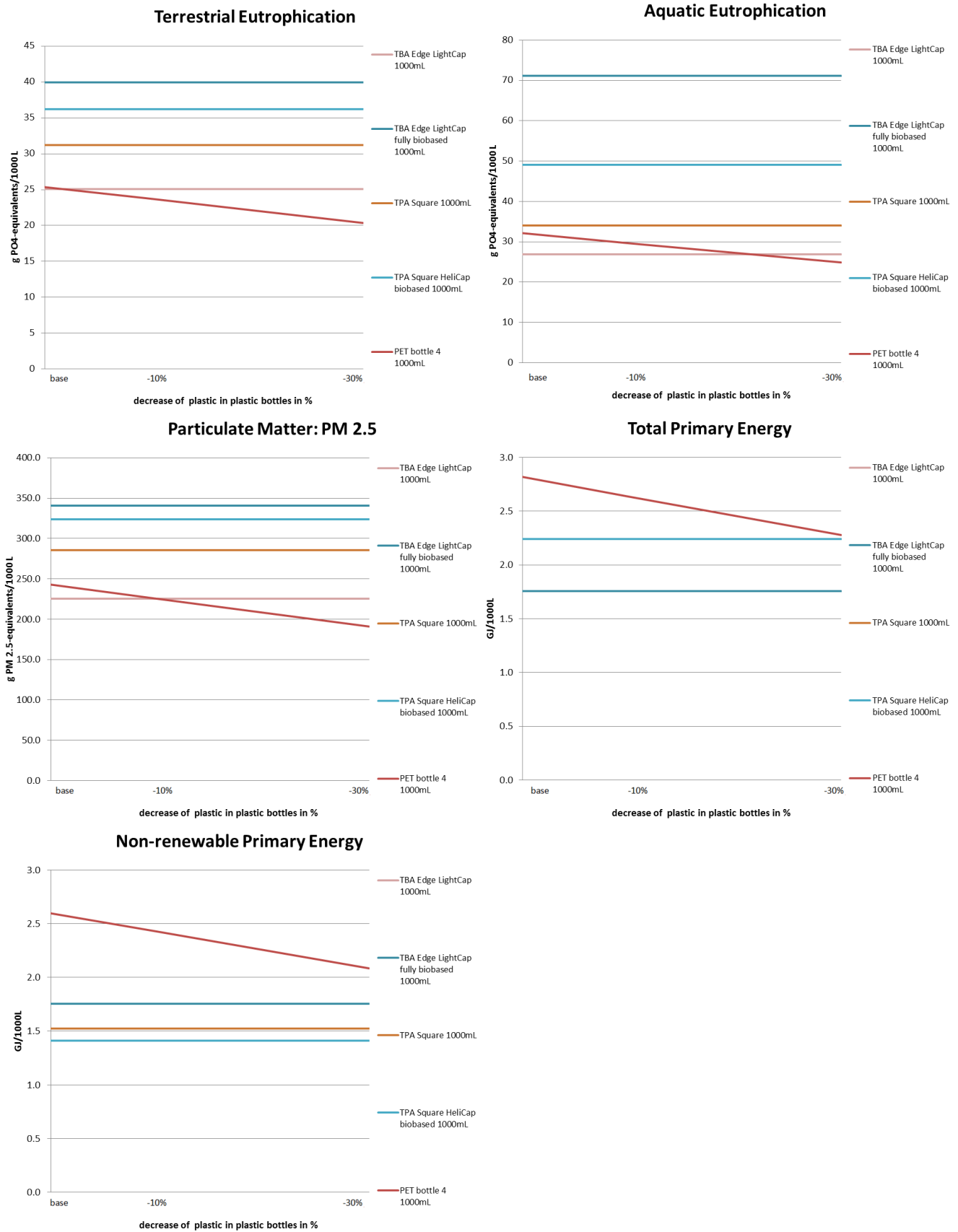


Figure 43: Indicator results for sensitivity analysis on plastic bottle weights of segment JNSD ambient, Sweden, allocation factor 50% (Part 2)

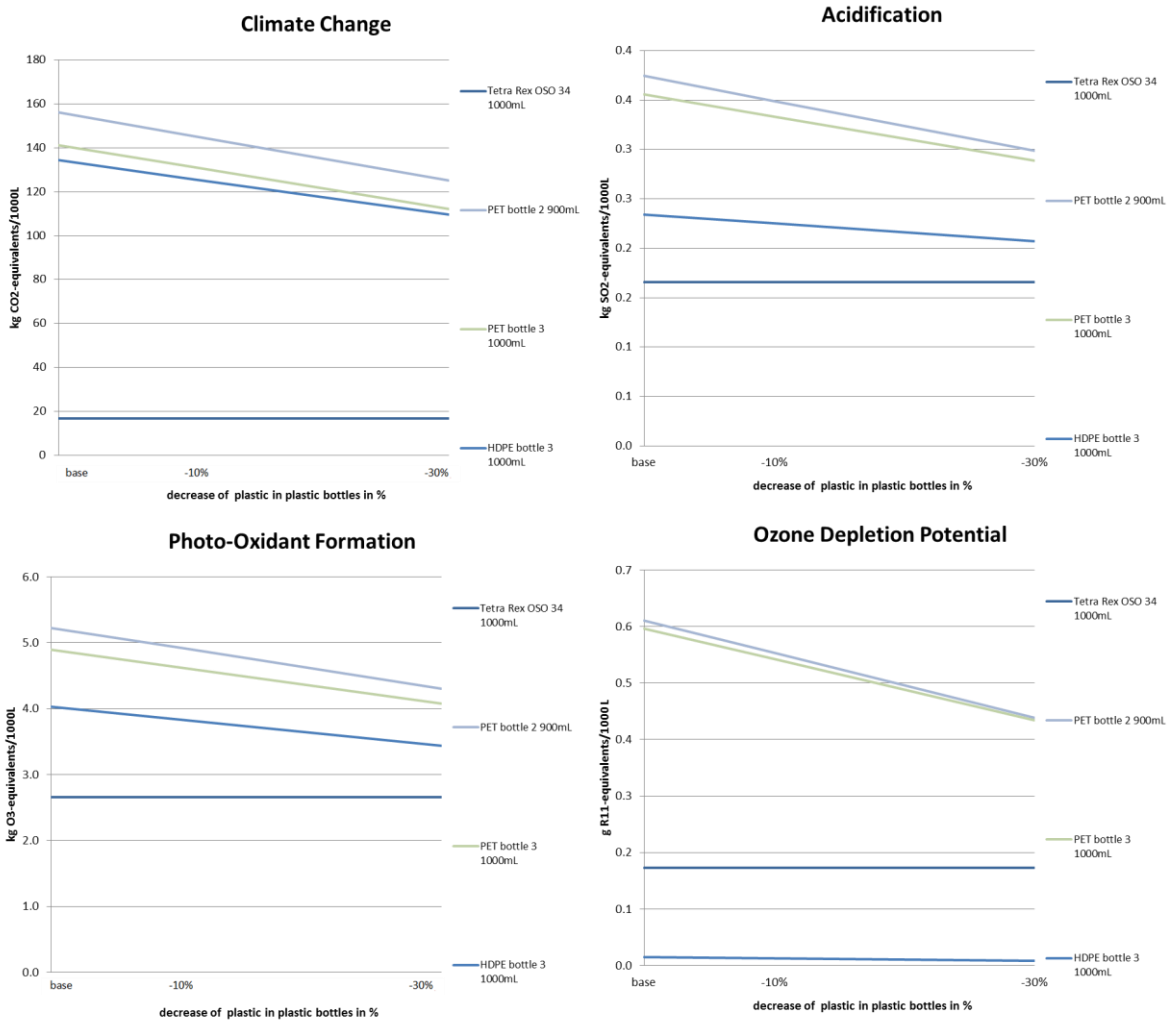


Figure 44:

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

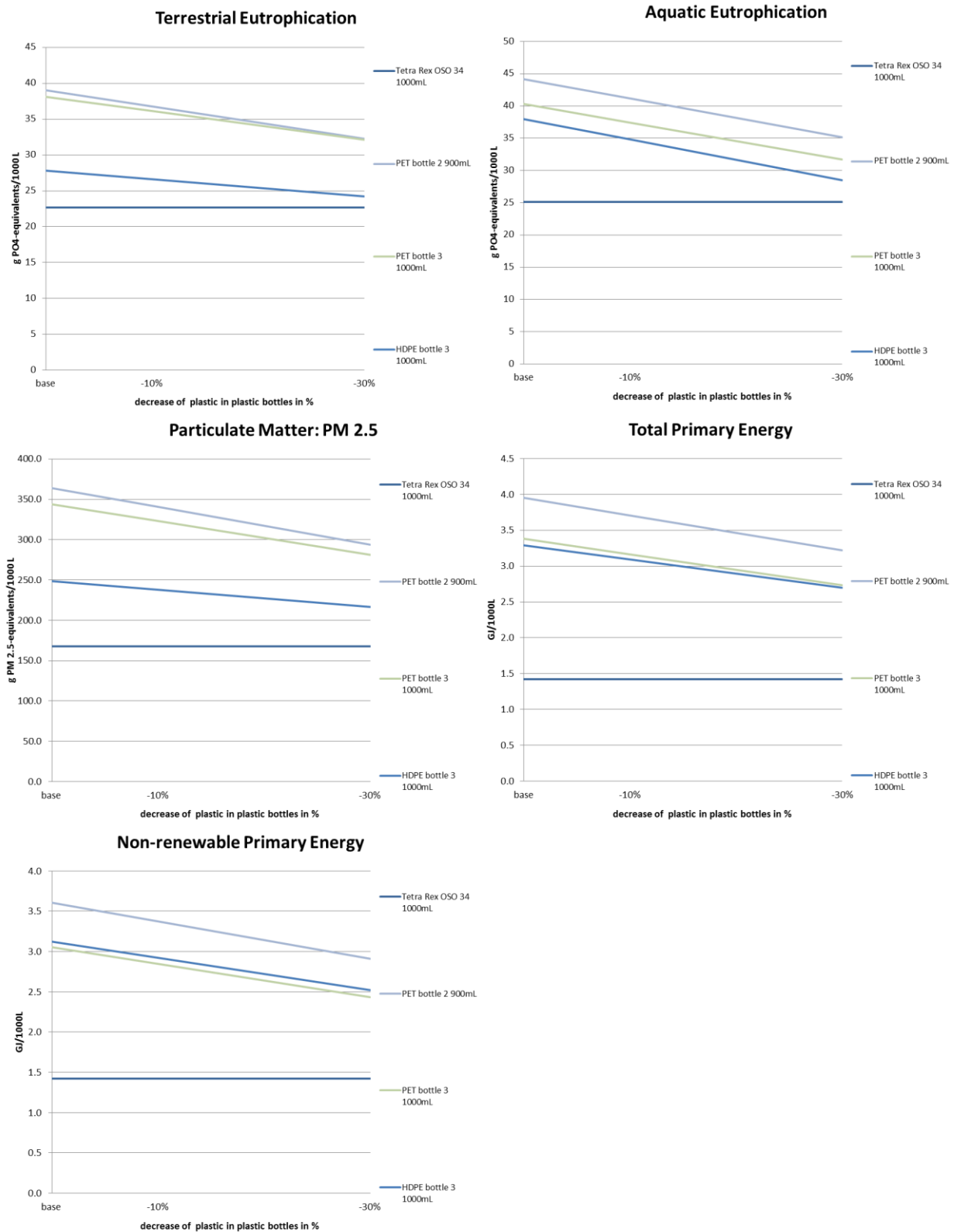


Figure 45: Indicator results for sensitivity analysis on plastic bottle weights of segment JNSD chilled, Sweden, allocation factor 50% (Part 2)

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' and 'Terrestrial Eutrophication' at about 2% weight reduction.

In the JNSD chilled segment none of the light weight bottles achieve a break-even with the only beverage carton in this segment, the 'Tetra Rex OSO 34'.

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

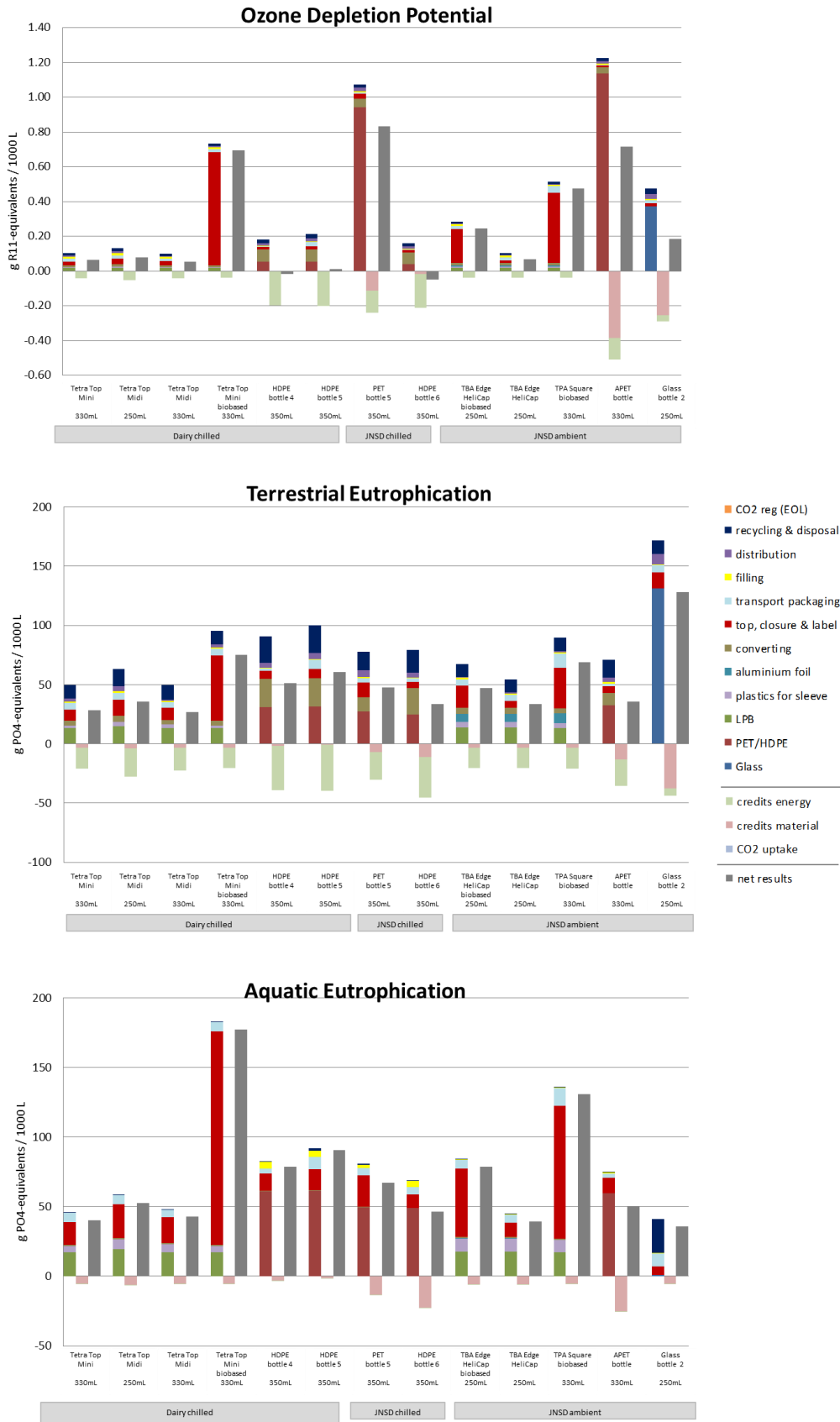


Figure 47: Indicator results for sensitivity analysis on system allocation of segment Grab & Go, Sweden , allocation factor 100% (Part 2)

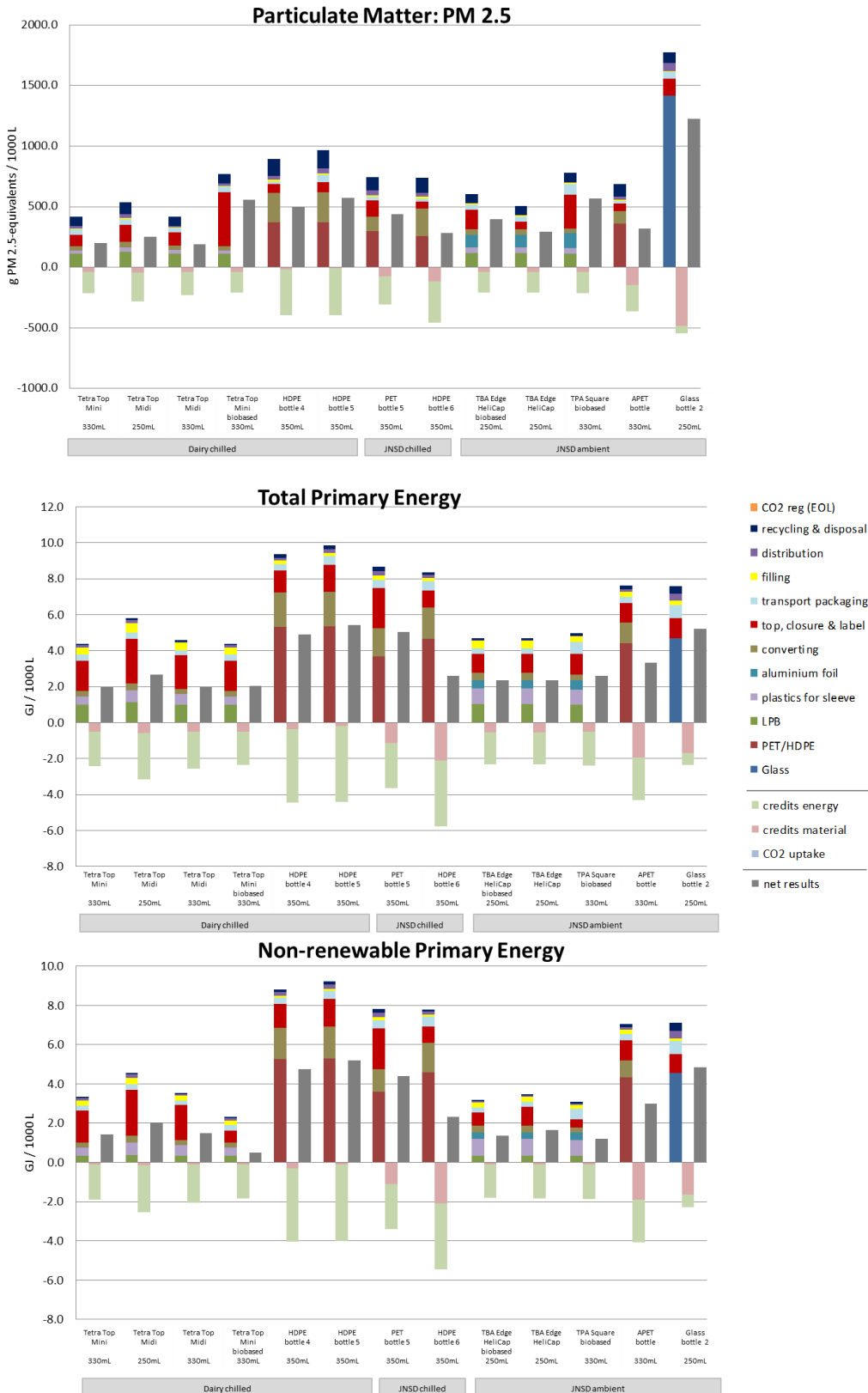


Figure 48: Indicator results for sensitivity analysis on system allocation of segment Grab & Go, Sweden, allocation factor 100% (Part 3)

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

		Tetra Top Mini 330mL	Tetra Top Midi 250mL	Tetra Top Midi 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL	PET bottle 5 350mL	HDPE bottle 6 350mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	188.56	258.77	199.26	145.14	542.86	572.74	415.27	472.55	185.75	198.39	193.56	402.03	531.20
	CO ₂ (reg)	51.07	57.57	49.59	103.02	3.80	12.42	10.92	9.90	67.06	51.73	89.29	3.74	17.17
	Credits	-115.79	-154.77	-125.14	-111.67	-244.11	-247.83	-175.87	-264.85	-110.42	-110.68	-113.76	-194.36	-174.70
	CO ₂ uptake	-52.32	-58.99	-50.87	-106.74	-3.82	-12.54	-11.02	-9.99	-69.09	-53.07	-91.67	-3.75	-17.21
	net results	71.52	102.59	72.84	29.76	298.74	324.79	239.30	207.60	73.31	86.38	77.42	207.66	356.46
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.42	0.54	0.42	0.66	0.95	1.02	0.78	0.75	0.60	0.53	0.74	0.72	1.80
	Credits	-0.24	-0.32	-0.26	-0.23	-0.46	-0.46	-0.35	-0.52	-0.23	-0.23	-0.24	-0.42	-0.46
	Net results	0.18	0.22	0.16	0.42	0.49	0.56	0.43	0.23	0.37	0.30	0.51	0.30	1.34
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	6.37	8.31	6.49	11.14	12.26	13.25	10.40	10.74	8.44	7.08	10.70	9.55	21.85
	Credits	-2.76	-3.63	-2.96	-2.68	-4.94	-4.92	-3.92	-6.00	-2.66	-2.67	-2.72	-4.66	-5.47
	Net results	3.61	4.68	3.53	8.46	7.32	8.33	6.48	4.74	5.78	4.41	7.98	4.89	16.38
Ozone Depletion [g R11/1000 L]	Burdens	0.10	0.13	0.10	0.73	0.18	0.21	1.07	0.16	0.28	0.10	0.51	1.22	0.47
	Credits	-0.04	-0.05	-0.04	-0.04	-0.20	-0.20	-0.24	-0.21	-0.04	-0.04	-0.04	-0.51	-0.29
	Net results	0.06	0.08	0.06	0.69	-0.02	0.01	0.83	-0.05	0.25	0.07	0.48	0.72	0.19
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	49.59	63.40	49.50	95.60	90.54	100.09	77.85	79.16	67.32	54.18	89.55	71.03	171.86
	Credits	-21.13	-27.76	-22.62	-20.47	-39.33	-39.60	-30.18	-45.58	-20.35	-20.39	-20.80	-35.45	-43.67
	Net results	28.46	35.64	26.88	75.13	51.21	60.49	47.67	33.58	46.97	33.79	68.75	35.58	128.20
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	45.78	58.73	48.08	182.87	82.18	92.00	80.77	68.82	84.18	44.95	136.12	75.32	41.15
	Credits	-5.46	-6.26	-5.41	-5.46	-3.29	-1.30	-13.36	-22.51	-5.63	-5.63	-5.43	-25.15	-5.50
	Net results	40.32	52.47	42.67	177.41	78.88	90.70	67.41	46.32	78.55	39.32	130.69	50.17	35.65
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	417.41	536.35	419.93	768.13	895.82	969.04	742.56	737.91	604.43	504.27	780.09	686.02	1771.68
	Credits	-215.09	-281.91	-230.00	-208.47	-392.53	-395.27	-304.96	-456.35	-207.39	-207.81	-211.76	-365.26	-544.05
	Net results	202.32	254.44	189.93	559.66	503.29	573.77	437.60	281.56	397.04	296.46	568.33	320.76	1227.63
Total Primary Energy [GJ]	Burdens	4.39	5.82	4.58	4.39	9.35	9.84	8.67	8.35	4.70	4.70	4.95	7.62	7.57
	Credits	-2.41	-3.14	-2.57	-2.34	-4.44	-4.41	-3.63	-5.76	-2.33	-2.33	-2.37	-4.30	-2.35
	Net results	1.98	2.68	2.01	2.05	4.90	5.44	5.04	2.58	2.37	2.36	2.58	3.32	5.22
Non-renewable Primary Energy [GJ]	Burdens	3.33	4.56	3.53	2.32	8.78	9.20	7.81	7.78	3.18	3.47	3.08	7.05	7.10
	Credits	-1.91	-2.55	-2.06	-1.84	-4.05	-4.00	-3.42	-5.46	-1.82	-1.83	-1.88	-4.08	-2.27
	Net results	1.42	2.01	1.47	0.48	4.73	5.20	4.39	2.32	1.36	1.64	1.20	2.98	4.83
Use of Nature [m ² /year]	Burdens	28.43	32.15	27.85	68.75	0.92	4.62	1.90	1.11	40.91	29.23	56.90	0.61	3.28
	Credits	-7.38	-8.42	-7.35	-7.37	-1.06	-1.09	-0.21	-0.30	-7.61	-7.61	-7.36	-0.19	-0.12
	Net results	21.05	23.73	20.50	61.38	-0.13	3.52	1.69	0.82	33.29	21.62	49.53	0.00	0.00
Water use [m ³ /1000 L]	water cool	3.11	4.34	3.41	3.48	4.54	4.61	6.18	3.59	3.83	3.72	3.71	4.19	1.60
	water process	2.09	2.42	2.10	2.07	2.66	2.66	1.46	2.29	2.83	2.84	2.75	0.66	12.65
	water unspecified	0.83	1.11	0.90	1.29	1.65	2.08	1.62	0.78	0.96	0.85	1.40	1.25	0.90

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 analysed and illustrated in this sensitivity analysis (for details please see section 2.4.3). Results are shown in the following break even graphs.

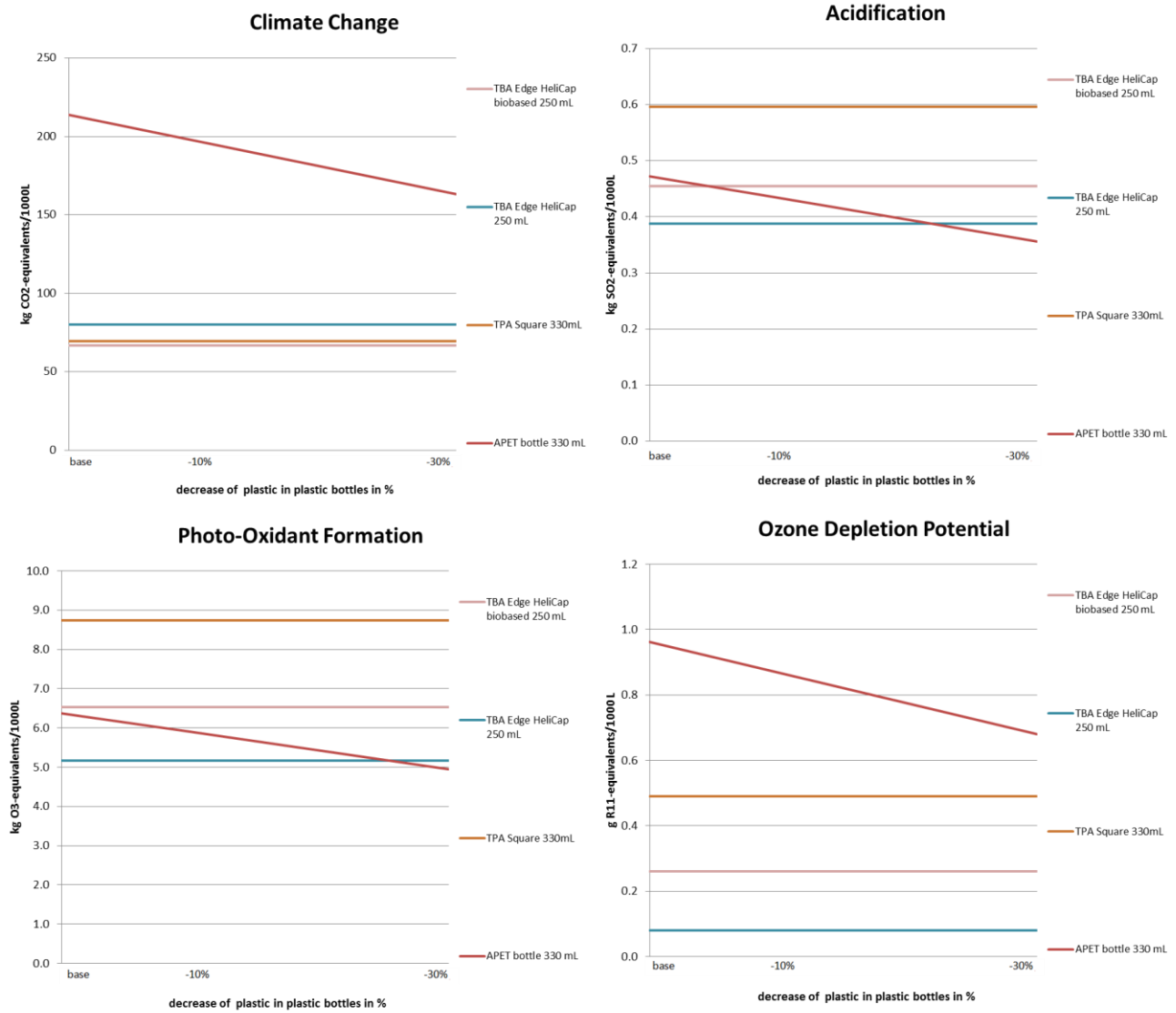


Figure 49: Indicator results for sensitivity analysis on plastic bottle weights of segment Grab & Go DAIRY chilled, Sweden, allocation factor 50% (Part 1)

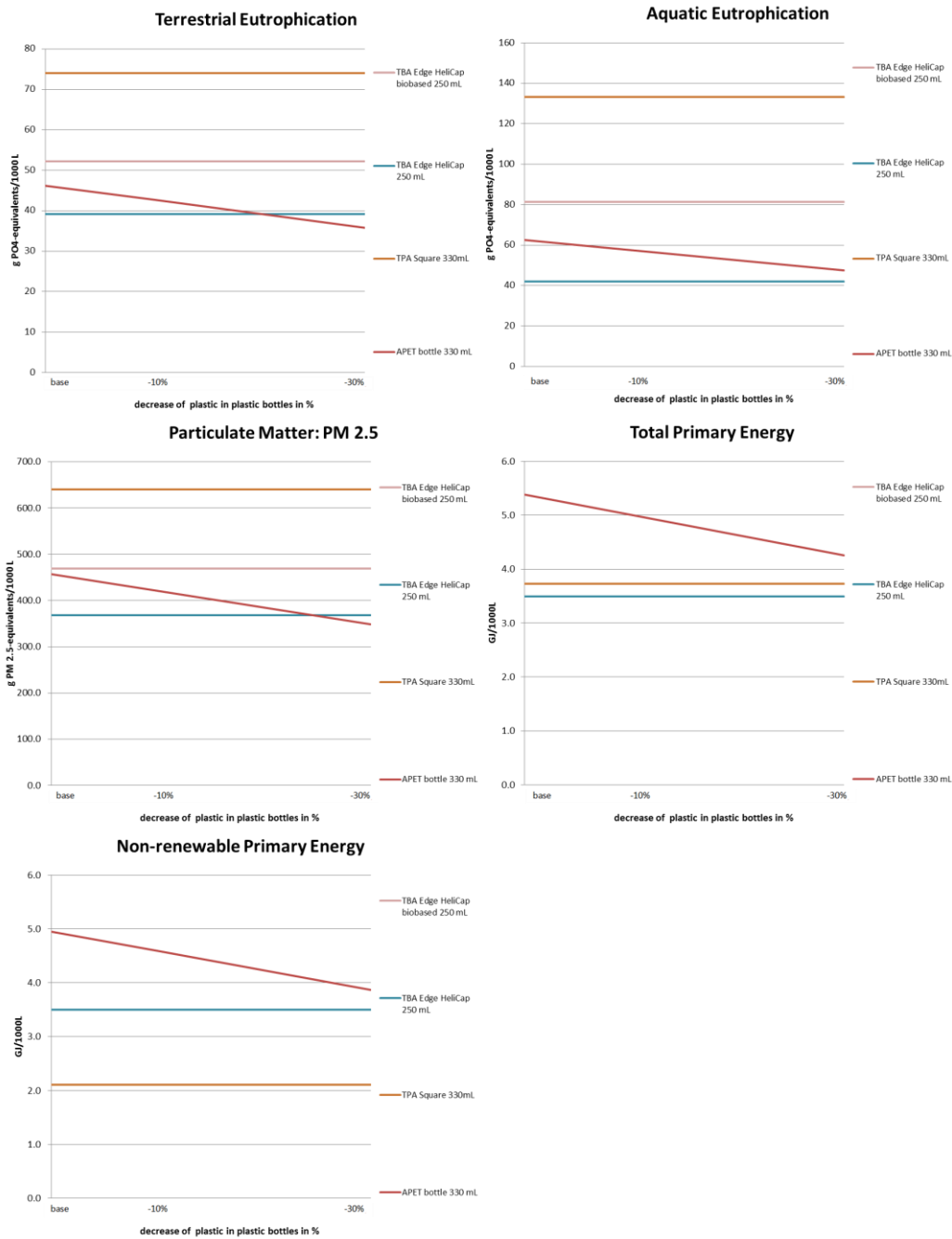


Figure 50: Indicator results for sensitivity analysis on plastic bottle weights of segment Grab & Go DAIRY chilled, Sweden, allocation factor 50% (Part 2)

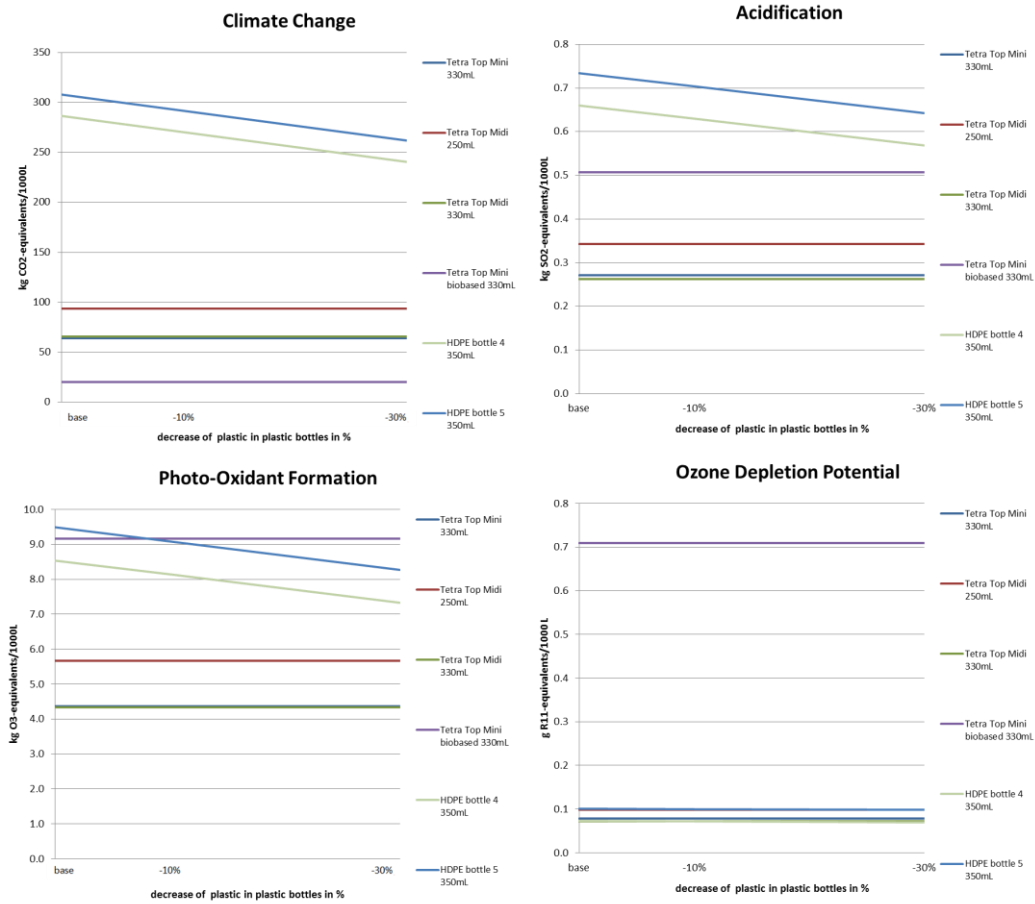


Figure 51: Indicator results for sensitivity analysis on plastic bottle weights of segment Grab & Go JNSD ambient, Sweden, allocation factor 50% (Part 1)

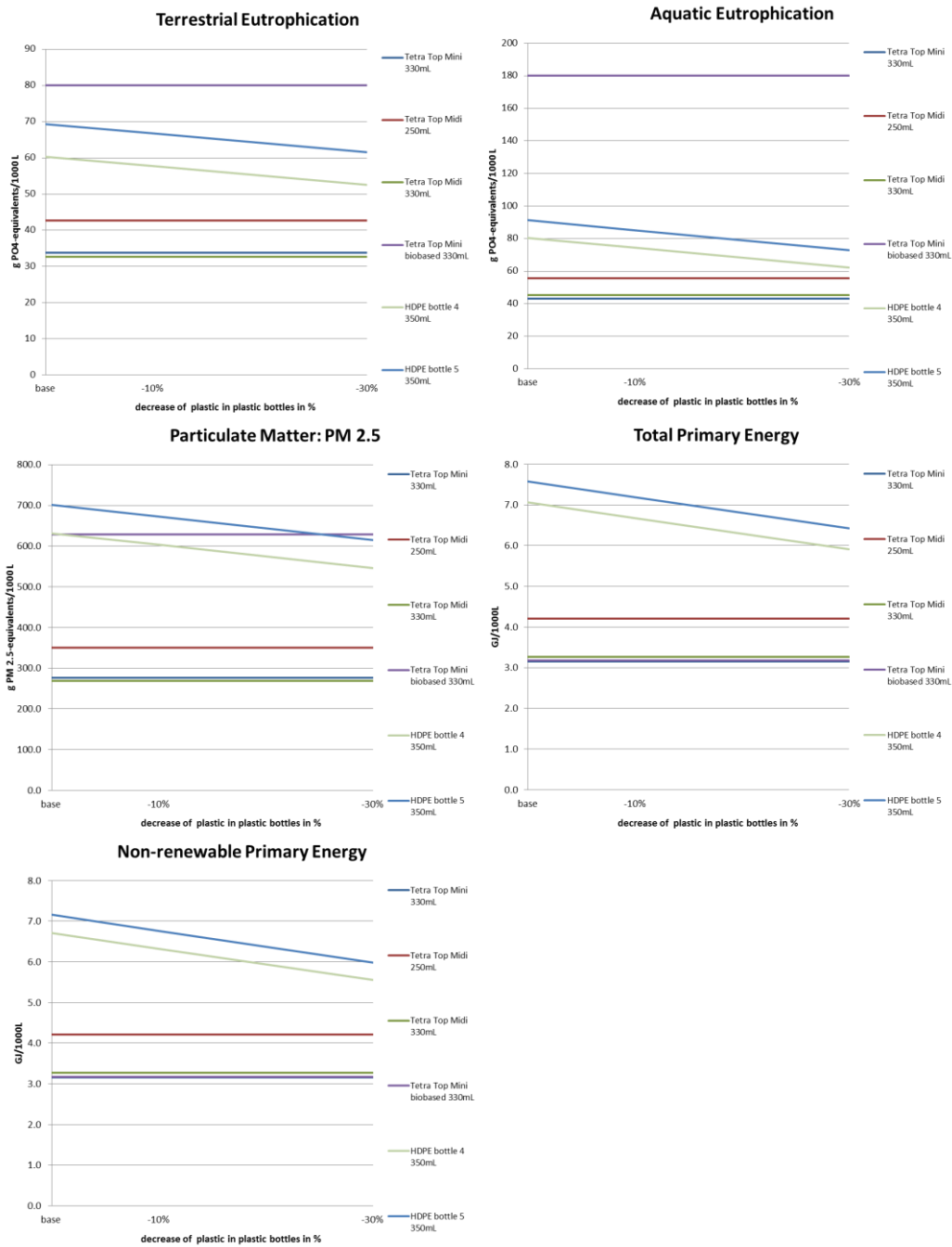


Figure 52: Indicator results for sensitivity analysis on plastic bottle weights of segment Grab & Go JNSD ambient, Sweden, allocation factor 50% (Part 2)

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.

The 'HDPE bottle 4' and 'HDPE bottle 5' as well as the 'APET bottle' breaks even with some beverage cartons in some categories.

5.4 Water Sweden

5.4.1 Sensitivity analysis on system allocation WATER 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 53: Indicator results for sensitivity analysis on system allocation of segment Water, Sweden, allocation factor 100% (Part 1)

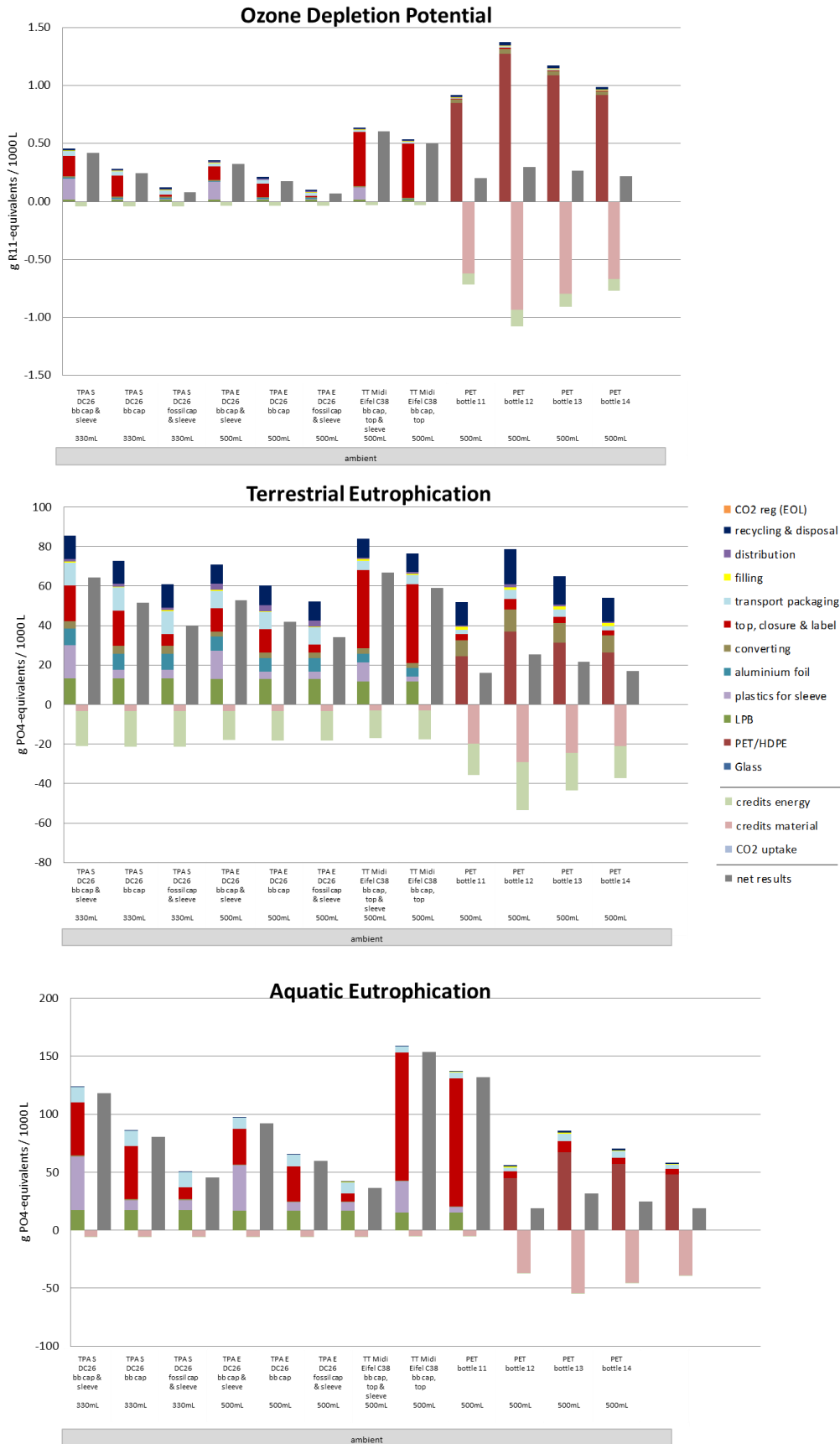


Figure 54: Indicator results for sensitivity analysis on system allocation of segment Water, Sweden, allocation factor 100% (Part 2)

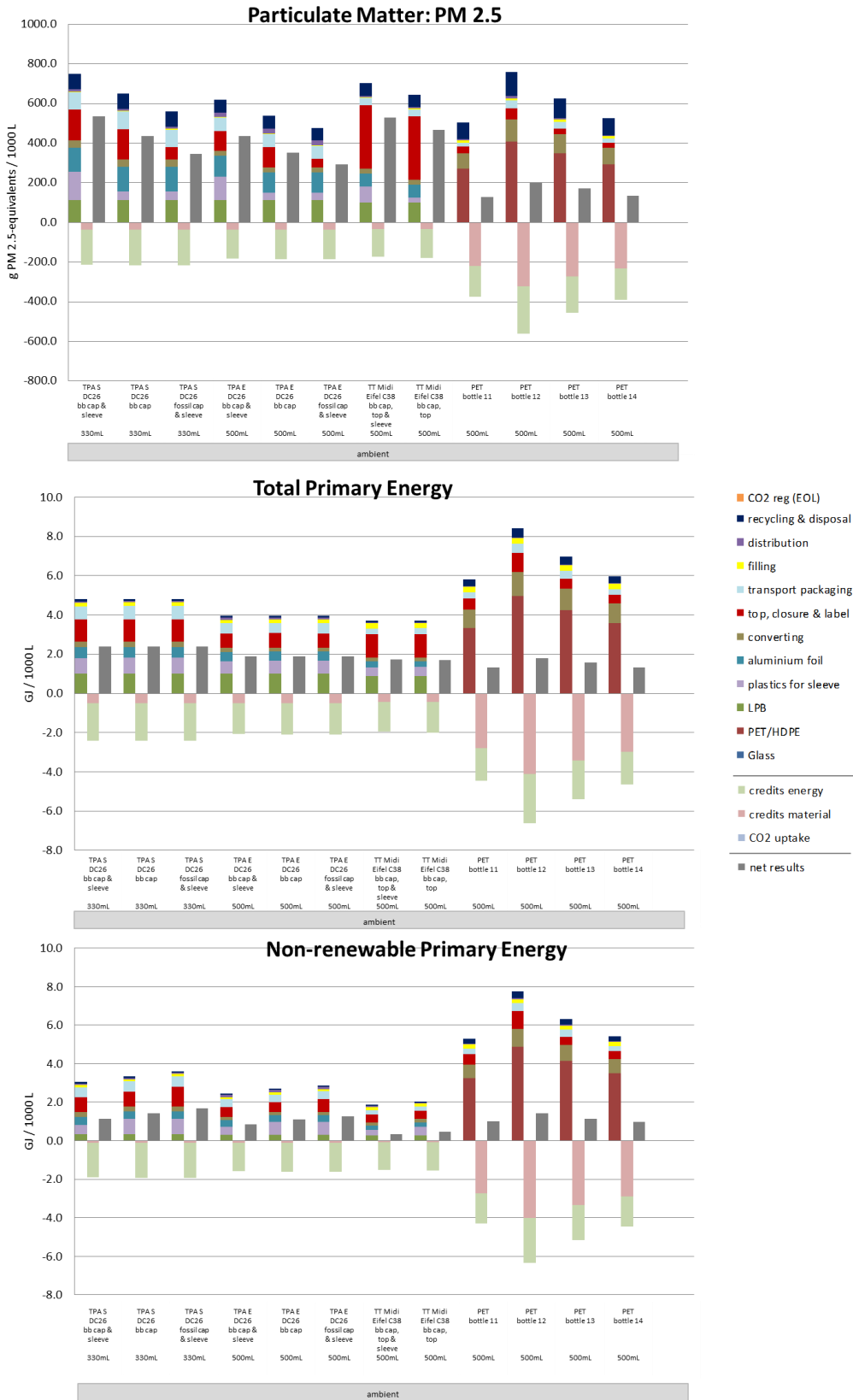


Figure 55: Indicator results for sensitivity analysis on system allocation of segment Water, Sweden, allocation factor 100% (Part 3)

Table 65: Category indicator results per impact category for sensitivity analysis on system allocation base scenarios of **segment Water, Sweden**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 11 500mL	PET bottle 12 500mL	PET bottle 13 500mL	PET bottle 14 500mL
Climate Change [kg CO2-e/1000 L]	Burdens	194.90	207.50	219.02	156.58	167.25	174.85	122.23	129.61	291.78	440.08	351.62	299.33
	CO2 (reg)	88.79	74.05	60.09	79.93	67.45	58.23	93.56	84.94	3.11	6.39	11.00	5.28
	Credits	-115.57	-116.77	-117.02	-96.51	-97.79	-98.04	-92.43	-94.95	-182.26	-272.06	-219.12	-187.97
	Net results	-90.88	-75.46	-60.95	-82.01	-68.95	-59.35	-96.97	-87.94	-3.13	-6.45	-11.13	-5.31
Acidification [kg SO2-e/1000 L]	Burdens	0.73	0.66	0.60	0.60	0.55	0.51	0.62	0.58	0.53	0.80	0.66	0.55
	Credits	-0.24	-0.24	-0.24	-0.21	-0.21	-0.21	-0.20	-0.20	-0.43	-0.63	-0.52	-0.44
	Net results	0.48	0.42	0.35	0.40	0.34	0.30	0.42	0.38	0.10	0.17	0.15	0.11
	Burdens	10.21	8.95	7.72	8.51	7.45	6.63	9.81	9.07	6.96	10.48	8.62	7.24
Photo-Oxidant Formation [kg O3 e/1000 L]	Credits	-2.75	-2.78	-2.78	-2.35	-2.38	-2.38	-2.23	-2.29	-4.80	-7.13	-5.80	-4.99
	Net results	7.45	6.17	4.94	6.16	5.07	4.25	7.57	6.79	2.16	3.35	2.82	2.25
	Burdens	0.46	0.28	0.12	0.36	0.21	0.10	0.64	0.53	0.92	1.38	1.17	0.99
	Credits	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03	-0.03	-0.03	-0.72	-1.08	-0.91	-0.77
Ozone Depletion [g R11/1000 L]	Net results	0.42	0.24	0.08	0.32	0.18	0.07	0.60	0.50	0.20	0.30	0.27	0.22
	Burdens	85.40	72.82	60.92	70.85	60.19	52.31	83.96	76.58	52.01	78.71	65.08	54.17
	Credits	-21.06	-21.25	-21.29	-17.98	-18.18	-18.22	-17.08	-17.49	-35.82	-53.35	-43.35	-37.18
	Net results	64.34	51.56	39.63	52.87	42.00	34.09	66.88	59.10	16.19	25.36	21.74	16.99
Aquatic Eutrophication [g PO4/1000 L]	Burdens	123.75	86.08	50.56	97.20	65.30	41.80	158.65	136.59	55.87	85.74	70.41	58.16
	Credits	-5.37	-5.37	-5.37	-5.31	-5.31	-5.31	-4.76	-4.76	-36.85	-54.28	-45.59	-39.20
	Net results	118.38	80.71	45.20	91.90	59.99	36.49	153.89	131.83	19.02	31.46	24.82	18.97
	Burdens	749.35	651.69	561.01	620.52	537.79	477.79	702.42	645.21	502.94	759.60	626.80	524.69
Particulate Matter [g PM 2.5-e/1000 L]	Credits	-214.31	-216.24	-216.64	-183.47	-185.54	-185.94	-174.17	-178.22	-375.42	-559.41	-455.49	-390.35
	Net results	535.04	435.45	344.37	437.04	352.25	291.85	528.25	466.99	127.52	200.20	171.32	134.34
	Burdens	4.80	4.81	4.81	3.96	3.97	3.97	3.69	3.70	5.79	8.43	6.97	5.98
	Credits	-2.40	-2.42	-2.43	-2.07	-2.09	-2.10	-1.96	-2.00	-4.47	-6.63	-5.39	-4.64
Total Primary Energy [GJ]	Net results	2.40	2.39	2.39	1.89	1.88	1.87	1.73	1.70	1.32	1.80	1.57	1.33
	Burdens	3.05	3.34	3.61	2.45	2.70	2.87	1.85	2.02	5.28	7.76	6.32	5.43
	Credits	-1.91	-1.93	-1.93	-1.59	-1.61	-1.62	-1.52	-1.56	-4.29	-6.35	-5.17	-4.45
	Net results	1.14	1.42	1.68	0.86	1.08	1.25	0.33	0.46	0.99	1.41	1.14	0.97
Use of Nature [m²/year]	Burdens	53.38	42.16	31.59	46.17	36.66	29.67	60.35	53.77	0.89	2.19	2.10	0.99
	Credits	-7.30	-7.30	-7.30	-7.27	-7.27	-7.27	-6.57	-6.57	-0.13	-0.18	-0.14	-0.13
	Net results	46.08	34.86	24.29	38.89	29.39	22.40	53.77	47.20	0.76	2.01	1.96	0.00
	water cool	3.23	3.22	3.12	2.56	2.55	2.49	2.77	2.75	3.05	3.82	3.63	3.25
Water use [m³/1000 L]	water process	2.62	2.63	2.64	2.54	2.55	2.56	2.06	2.06	0.61	0.66	0.69	0.64
	water unspecified	1.36	1.25	1.16	1.05	0.96	0.90	1.12	1.06	0.47	0.82	0.63	0.47

5.4.2 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 2.4.3). Results are shown in the following break even graphs.

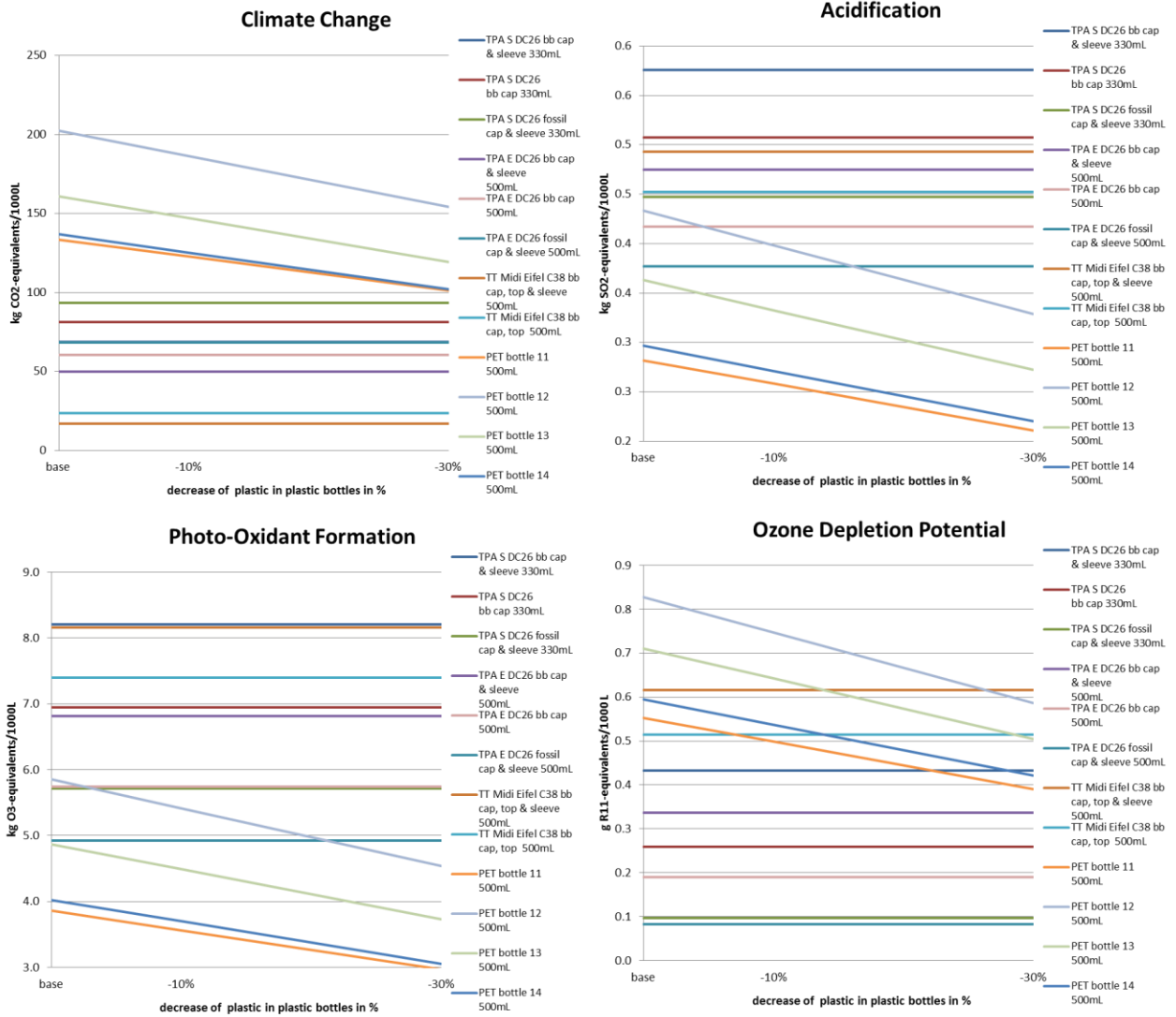


Figure 56: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Sweden, allocation factor 50% (Part 1)

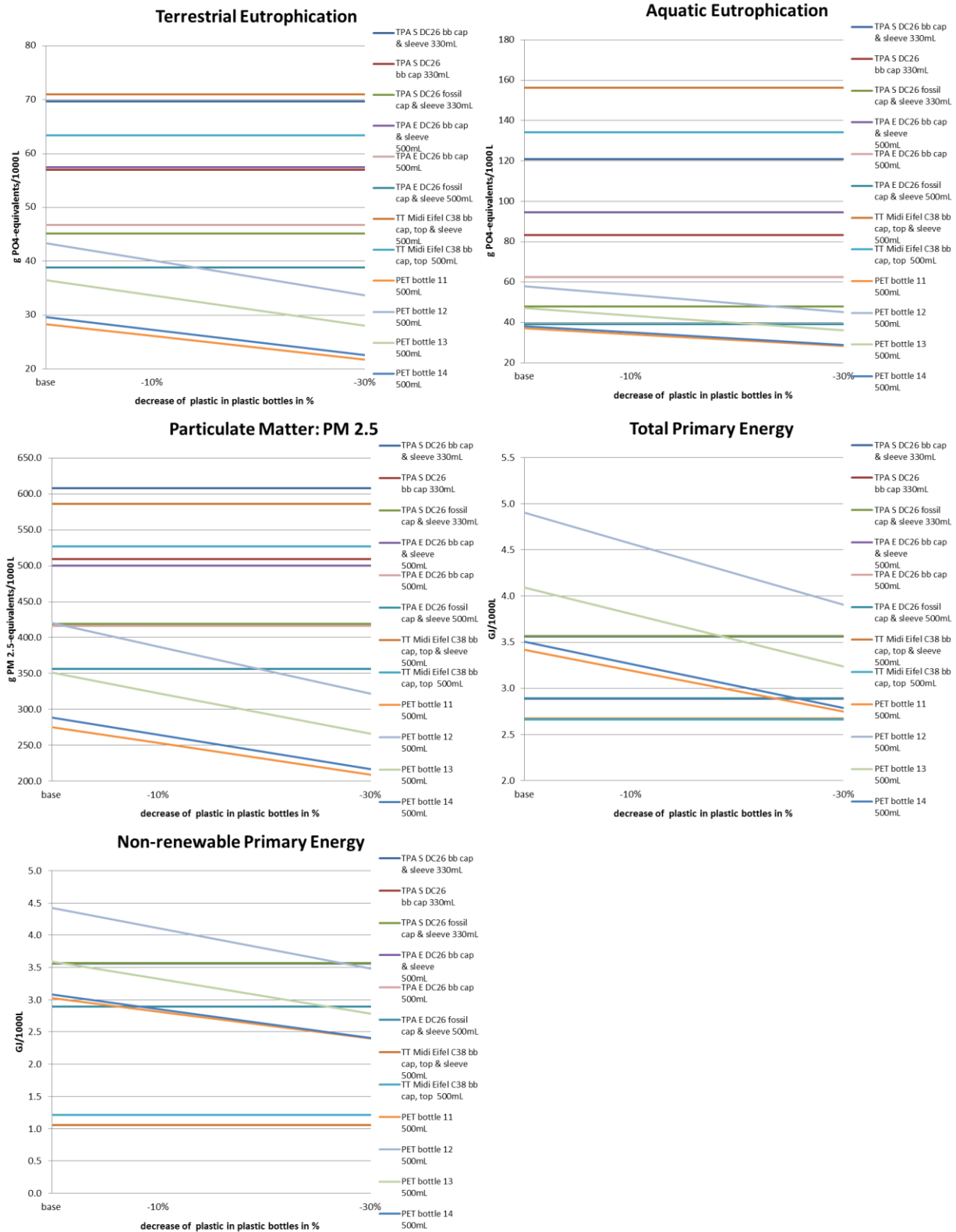


Figure 57: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Sweden, allocation factor 50% (Part 2)

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. No lightweight bottle achieves a new 'rank' when compared to beverage cartons in the categories 'Climate Change'.

In all other impact categories break even points are reached with various beverage cartons.

5.4.3 Sensitivity analysis regarding recycled PET in PET bottles

To consider potential future developments in terms of the share of recycle of the plastic bottles, two additional scenarios for plastic bottles with a recycled content of PET of 50% and 100% 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.

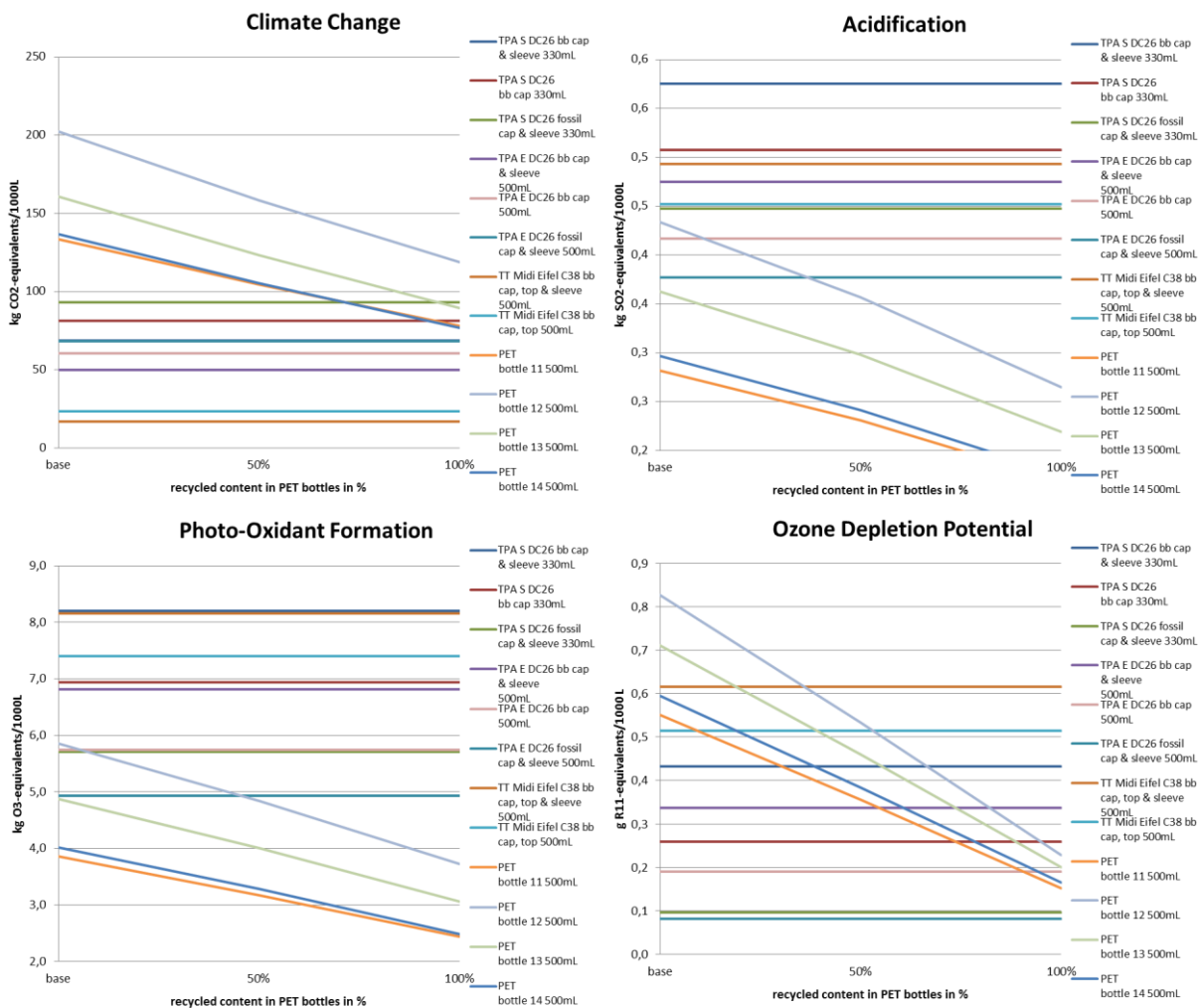


Figure 58: Indicator results for sensitivity analysis regarding recycled PET of segment Water, Sweden, allocation factor 50% (Part 1)

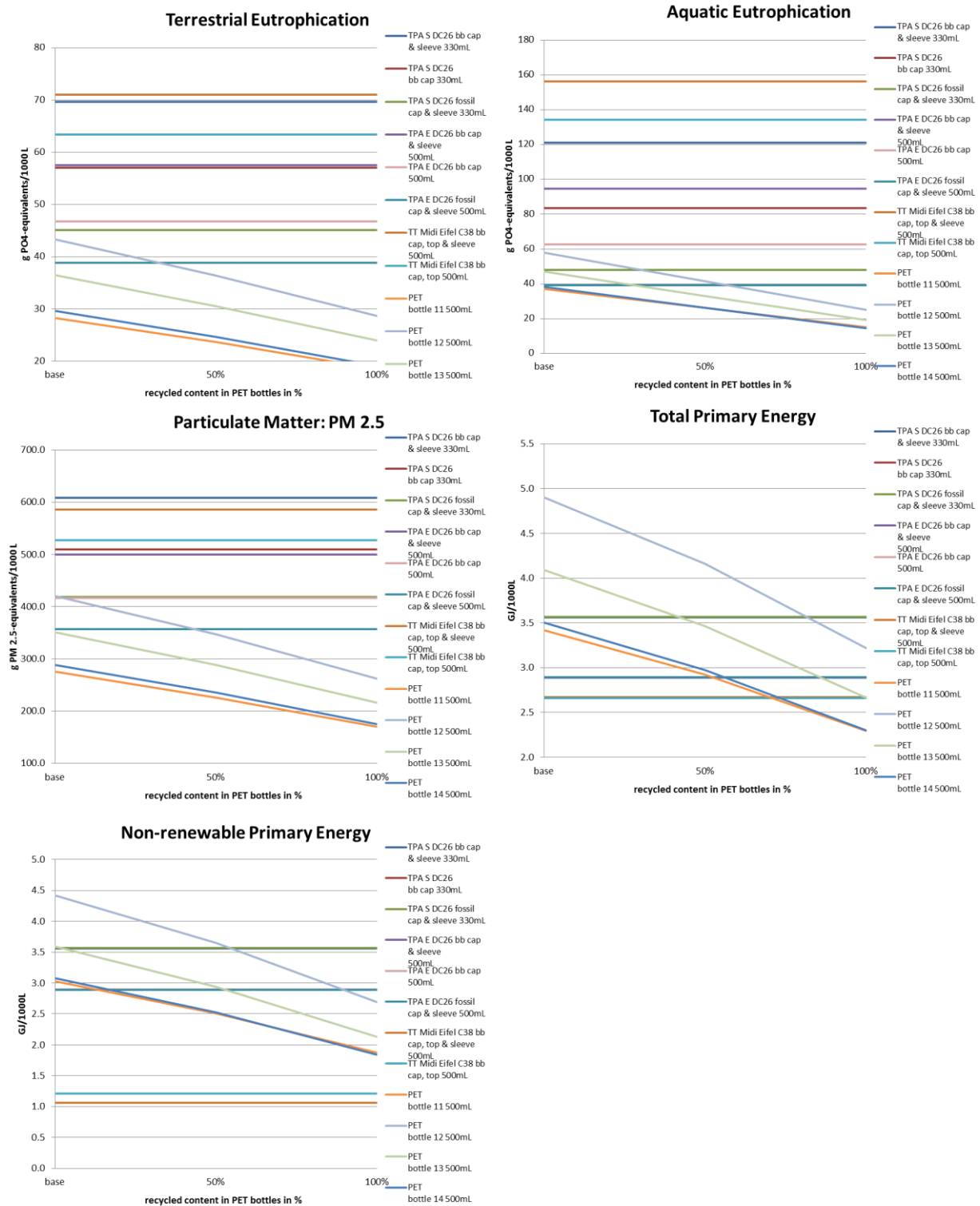


Figure 59: Indicator results for sensitivity analysis regarding recycled PET of segment Water, Sweden, allocation factor 50% (Part 2)

In all categories, including 'Climate Change', PET bottles with a higher recycled content will break even with at least some beverage cartons.

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 Edge biobased', '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 CO₂-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.

6.4 Water Sweden

In the segment water no unambiguous result can be observed. While all examined beverage cartons show lower 'Climate Change' results than all the examined PET bottles, in other categories the beverage cartons often show higher impacts. Especially beverage cartons with a high share of biobased polyethylene show higher results than the bottles in the categories 'Acidification', 'Photo-Oxidant Formation', 'Terrestrial and Aquatic Eutrophication'

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. TiO₂ (**'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 CO₂ (**'recycling/disposal'**)
- CO₂ 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 atmospheric CO₂ during the plant growth phase ('CO₂-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 subtraction 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.

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

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 $\leq 10\%$ are considered as insignificant.

7.1 Results Dairy Finland

7.1.1 Presentation of results DAIRY Finland



Figure 60: Indicator results for base scenarios of segment Dairy, Finland, allocation factor 50% (Part 1)

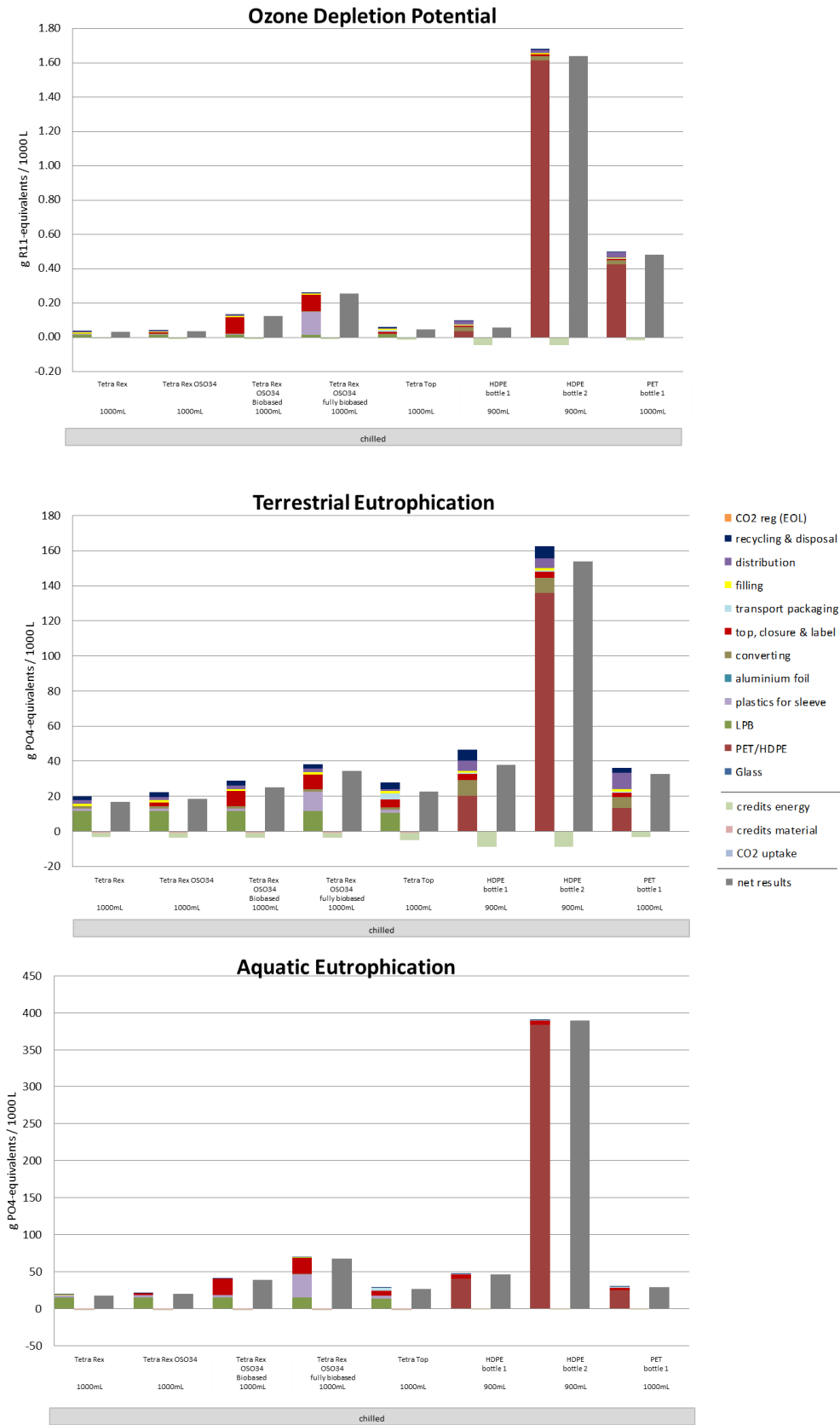


Figure 61 Indicator results for base scenarios of segment Dairy, Finland, allocation factor 50% (Part 2)



Figure 62: Indicator results for base scenarios of segment Dairy, Finland, allocation factor 50% (Part 3)

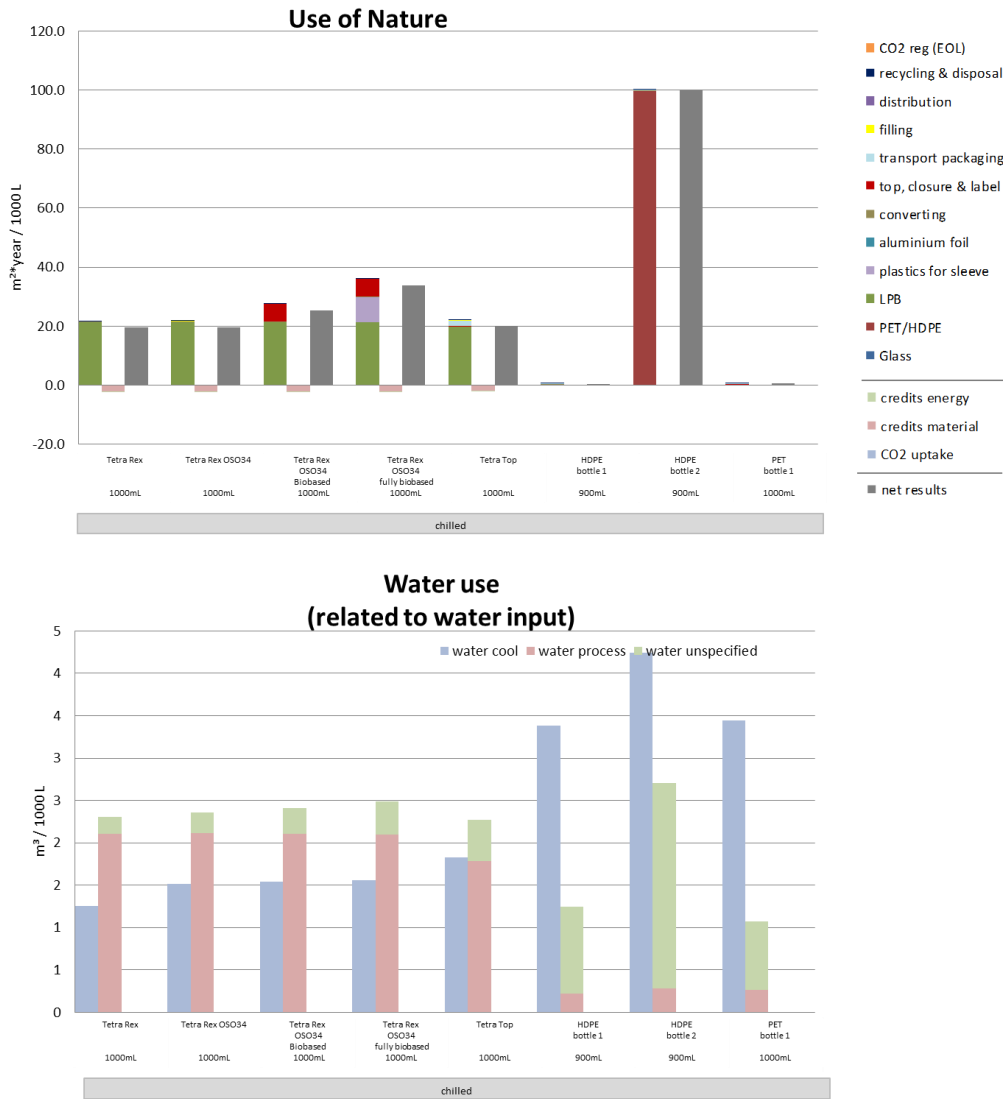


Figure 63: Indicator results for base scenarios of segment Dairy, Finland, allocation factor 50% (Part 4)

Table 66: Category indicator results per impact category for base scenarios of **segment DAIRY, Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	45.81	56.89	54.25	50.24	82.41	240.72	194.11	150.88
	CO ₂ (reg)	18.55	18.59	22.49	28.23	20.11	2.13	67.54	4.13
	Credits	-14.87	-17.38	-17.32	-16.81	-23.95	-48.52	-48.53	-18.37
	CO ₂ uptake	-38.24	-38.31	-46.26	-57.90	-41.02	-4.27	-135.64	-8.34
	net results	11.24	19.79	13.16	3.76	37.54	190.06	77.49	128.30
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.17	0.19	0.22	0.27	0.24	0.50	1.09	0.37
	Credits	-0.04	-0.04	-0.04	-0.04	-0.05	-0.09	-0.09	-0.04
	Net results	0.13	0.15	0.18	0.23	0.19	0.41	1.00	0.34
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	2.60	2.91	3.57	4.52	3.56	6.42	18.46	4.73
	Credits	-0.43	-0.49	-0.49	-0.47	-0.64	-1.09	-1.09	-0.43
	Net results	2.17	2.42	3.09	4.05	2.92	5.33	17.37	4.30
Ozone Depletion [g R11/1000 L]	Burdens	0.04	0.04	0.13	0.26	0.06	0.10	1.68	0.50
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01	-0.04	-0.04	-0.02
	Net results	0.03	0.04	0.13	0.26	0.05	0.06	1.64	0.48
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	20.04	22.25	28.76	38.27	27.77	46.52	162.71	36.01
	Credits	-3.33	-3.78	-3.77	-3.68	-4.92	-8.74	-8.74	-3.35
	Net results	16.71	18.47	24.99	34.59	22.85	37.78	153.97	32.67
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	18.87	21.30	40.75	69.19	28.33	47.13	390.34	29.63
	Credits	-1.44	-1.46	-1.46	-1.46	-1.47	-0.59	-0.59	-0.62
	Net results	17.43	19.84	39.29	67.73	26.86	46.54	389.75	29.00
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	169.86	189.92	239.95	313.73	236.63	468.50	1354.05	349.35
	Credits	-33.26	-37.61	-37.50	-36.63	-48.55	-83.88	-83.91	-32.30
	Net results	136.60	152.31	202.45	277.10	188.08	384.62	1270.14	317.05
Total Primary Energy [GJ]	Burdens	1.55	1.83	1.83	1.82	2.40	5.27	5.23	3.28
	Credits	-0.37	-0.42	-0.42	-0.41	-0.53	-0.89	-0.90	-0.36
	Net results	1.18	1.41	1.41	1.41	1.86	4.38	4.34	2.92
Non-renewable Primary Energy [GJ]	Burdens	0.91	1.16	1.02	0.79	1.71	5.05	2.55	3.02
	Credits	-0.25	-0.29	-0.29	-0.28	-0.40	-0.82	-0.82	-0.33
	Net results	0.66	0.87	0.73	0.51	1.31	4.23	1.73	2.69
Use of Nature [m ² ·year]	Burdens	21.60	21.70	27.49	35.96	21.96	0.55	100.07	0.67
	Credits	-2.10	-2.11	-2.11	-2.11	-2.00	-0.15	-0.16	-0.08
	Net results	19.49	19.59	25.38	33.86	19.97	0.39	99.92	0.59
Water use [m ³ /1000 L]	water cool	1.25	1.51	1.54	1.56	1.83	3.38	4.24	3.44
	water process	2.11	2.11	2.11	2.10	1.79	0.22	0.28	0.26
	water unspecified	0.20	0.25	0.30	0.38	0.49	1.02	2.43	0.81

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 CO₂ emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. While in Finland 21% 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 CO₂ 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 CO₂.

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', 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 terephthalic 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 N₂O 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 CO₂ emissions from the bio-based 'HDPE bottle 2' are of course similarly high, but they are attributed to the sector CO₂ 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

Table 67: Comparison of net results: **Tetra Rex 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

<i>DAIRY (chilled), Finland</i>	The net results of Tetra Rex 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-43%	-15%	199%	-70%	-94%	-85%	-91%
Acidification	-10%	-27%	-43%	-29%	-67%	-87%	-61%
Photo-Oxidant Formation	-11%	-30%	-46%	-26%	-59%	-88%	-50%
Ozone Depletion Potential	-13%	-75%	-88%	-36%	-45%	-98%	-94%
Terrestrial Eutrophication	-10%	-33%	-52%	-27%	-56%	-89%	-49%
Aquatic Eutrophication	-12%	-56%	-74%	-35%	-63%	-96%	-40%
Particulate Matter	-10%	-33%	-51%	-27%	-64%	-89%	-57%
Total Primary Energy	-16%	-16%	-16%	-37%	-73%	-73%	-60%
Non-renewable Primary Energy	-24%	-9%	28%	-49%	-84%	-62%	-75%

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

Table 68: Comparison of net results: **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

DAIRY (chilled), Finland	The net results of Tetra Rex OSO34 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	76%	50%	427%	-47%	-90%	-74%	-85%
Acidification	12%	-19%	-36%	-21%	-64%	-85%	-56%
Photo-Oxidant Formation	12%	-21%	-40%	-17%	-55%	-86%	-44%
Ozone Depletion Potential	15%	-71%	-86%	-26%	-37%	-98%	-93%
Terrestrial Eutrophication	11%	-26%	-47%	-19%	-51%	-88%	-43%
Aquatic Eutrophication	14%	-49%	-71%	-26%	-57%	-95%	-32%
Particulate Matter	12%	-25%	-45%	-19%	-60%	-88%	-52%
Total Primary Energy	20%	0%	0%	-24%	-68%	-67%	-52%
Non-renewable Primary Energy	32%	20%	70%	-33%	-79%	-49%	-68%

Table 69: Comparison of net results: **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

DAIRY (chilled), Finland	The net results of Tetra Rex OSO34 biobased 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	17%	-33%	250%	-65%	-93%	-83%	-90%
Acidification	37%	23%	-22%	-3%	-55%	-82%	-46%
Photo-Oxidant Formation	42%	27%	-24%	6%	-42%	-82%	-28%
Ozone Depletion Potential	302%	249%	-51%	158%	120%	-92%	-74%
Terrestrial Eutrophication	50%	35%	-28%	9%	-34%	-84%	-23%
Aquatic Eutrophication	125%	98%	-42%	46%	-16%	-90%	35%
Particulate Matter	48%	33%	-27%	8%	-47%	-84%	-36%
Total Primary Energy	19%	0%	0%	-24%	-68%	-68%	-52%
Non-renewable Primary Energy	10%	-17%	41%	-44%	-83%	-58%	-73%

Table 70: Comparison of net results: **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

DAIRY (chilled), Finland	The net results of Tetra Rex OSO34 fully biobased 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-67%	-81%	-71%	-90%	-98%	-95%	-97%
Acidification	76%	57%	28%	25%	-43%	-76%	-31%
Photo-Oxidant Formation	87%	67%	31%	38%	-24%	-77%	-6%
Ozone Depletion Potential	722%	614%	105%	427%	350%	-84%	-47%
Terrestrial Eutrophication	107%	87%	38%	51%	-8%	-78%	6%
Aquatic Eutrophication	289%	241%	72%	152%	46%	-83%	134%
Particulate Matter	103%	82%	37%	47%	-28%	-78%	-13%
Total Primary Energy	19%	0%	0%	-24%	-68%	-68%	-52%
Non-renewable Primary Energy	-22%	-41%	-29%	-61%	-88%	-70%	-81%

Table 71: Comparison of net results: **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Finland**

DAIRY (chilled), Finland	The net results of Tetra Top 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	234%	90%	185%	899%	-80%	-52%	-71%
Acidification	41%	26%	3%	-20%	-54%	-81%	-45%
Photo-Oxidant Formation	35%	21%	-5%	-28%	-45%	-83%	-32%
Ozone Depletion Potential	56%	36%	-61%	-81%	-15%	-97%	-90%
Terrestrial Eutrophication	37%	24%	-9%	-34%	-40%	-85%	-30%
Aquatic Eutrophication	54%	35%	-32%	-60%	-42%	-93%	-7%
Particulate Matter	38%	23%	-7%	-32%	-51%	-85%	-41%
Total Primary Energy	58%	32%	32%	32%	-57%	-57%	-36%
Non-renewable Primary Energy	98%	50%	80%	154%	-69%	-24%	-52%

7.2 Results JNSD Finland

7.2.1 Presentation of results JNSD Finland

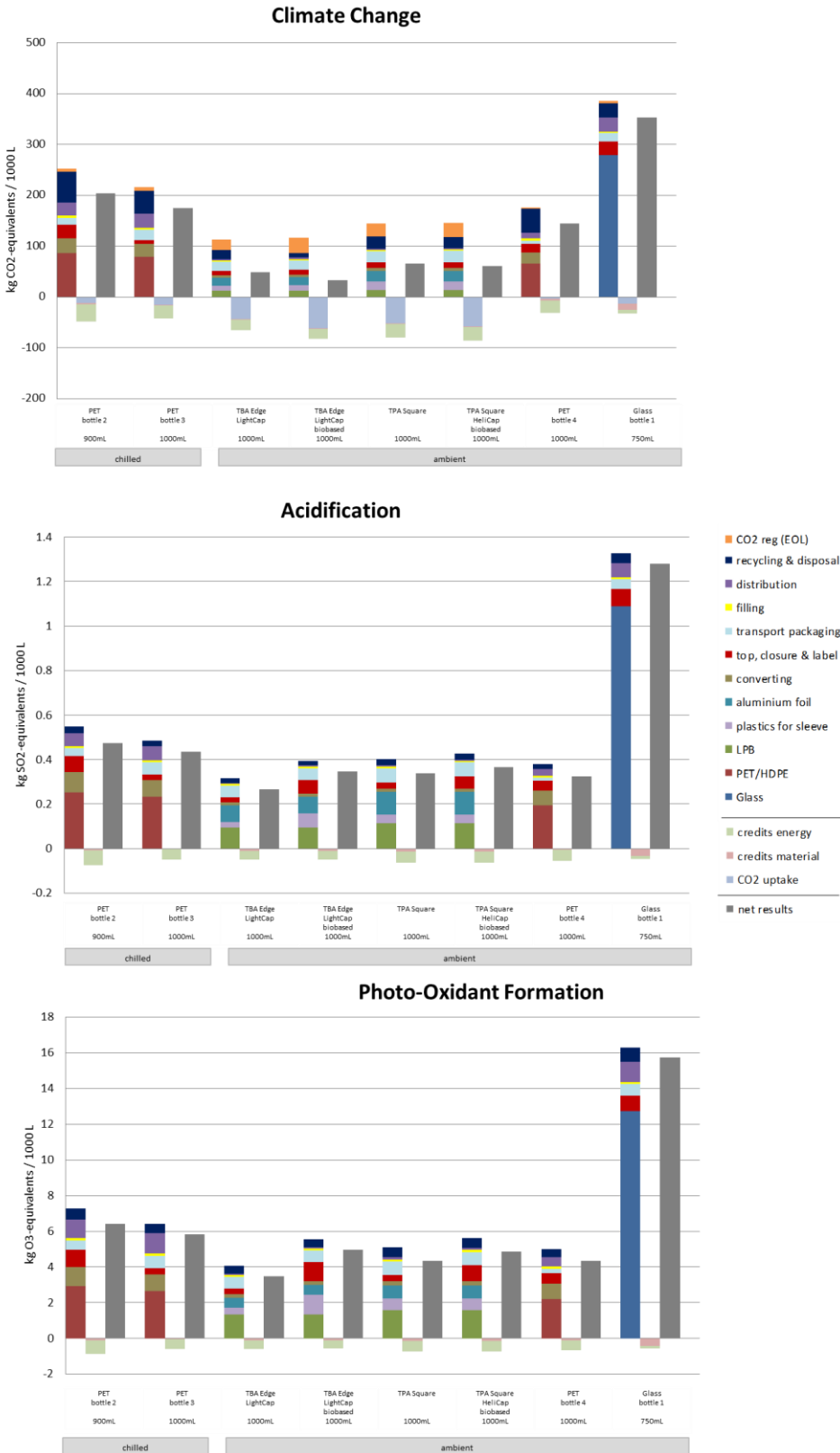


Figure 64: Indicator results for base scenarios of segment JNSD, Finland, allocation factor 50% (Part 1)

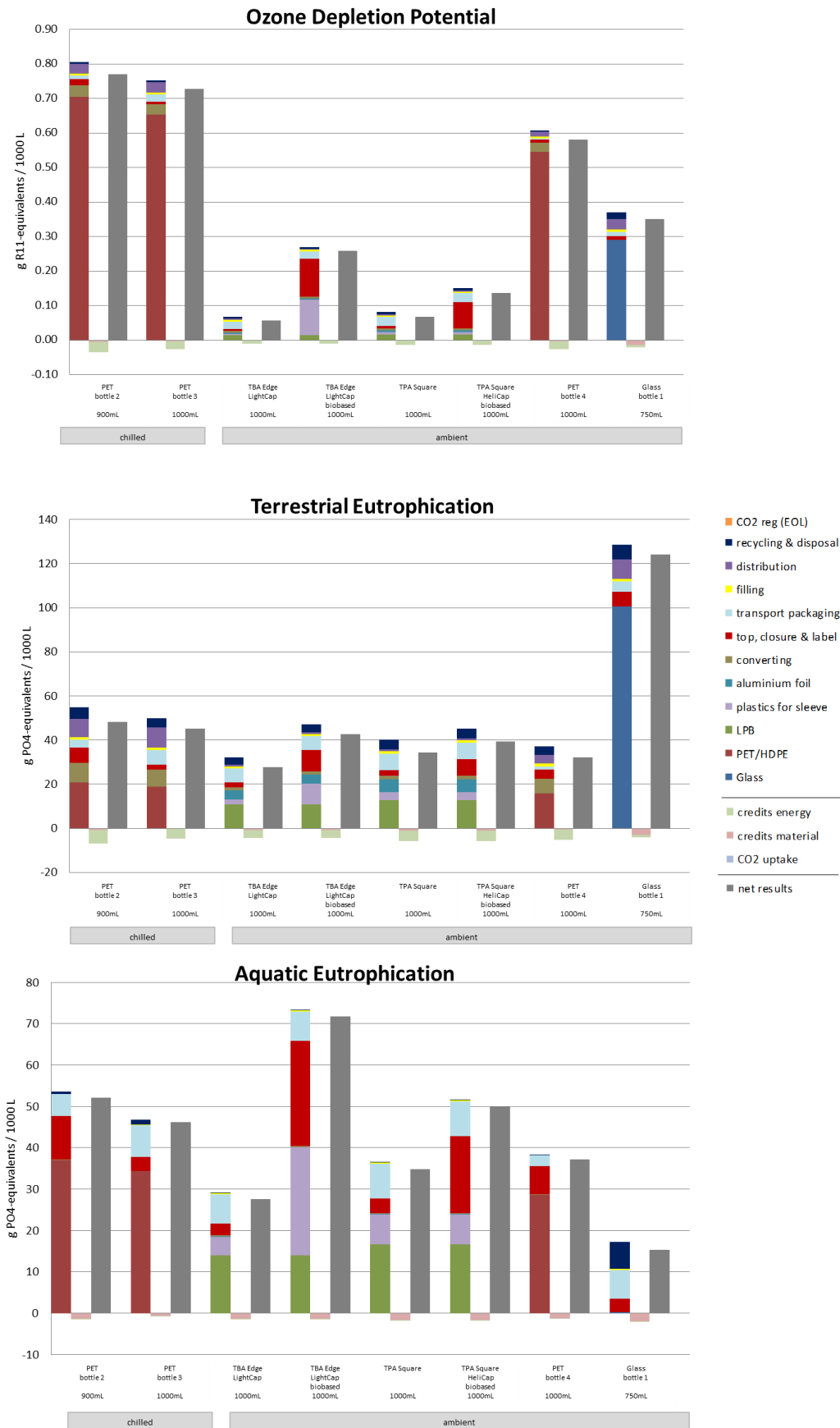


Figure 65: Indicator results for base scenarios of segment JNSD, Finland, allocation factor 50% (Part 2)



Figure 66: Indicator results for base scenarios of segment JNSD, Finland, allocation factor 50% (Part 3)

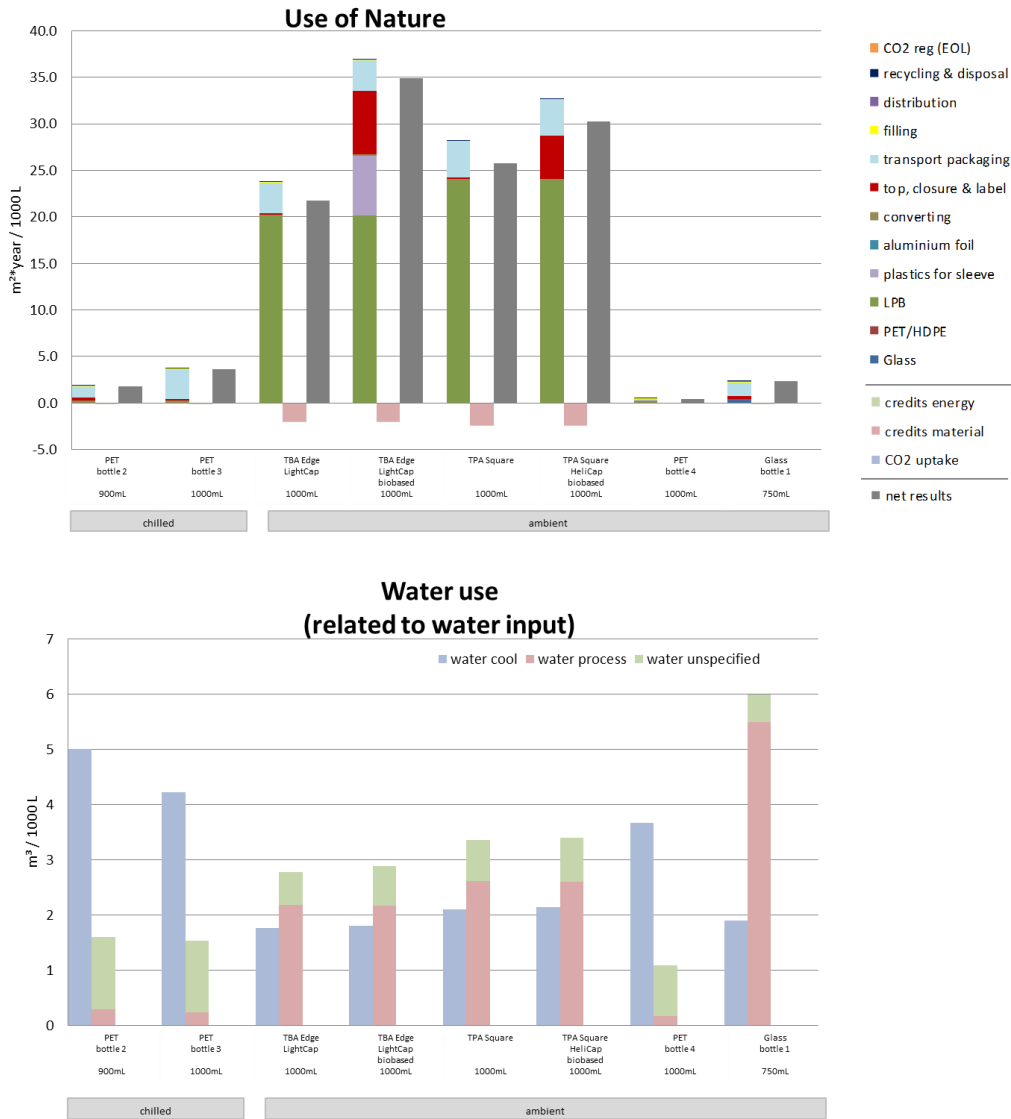


Figure 67: Indicator results for base scenarios of segment JNSD, Finland, allocation factor 50% (Part 4)

Table 72: Category indicator results per impact category for base scenarios of segment **JNSD, Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		PET bottle 2 900mL	PET bottle 3 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change [kg CO2-e/1000 L]	Burdens	246.85	208.61	92.10	86.01	119.59	117.62	173.84	380.31
	CO2 (reg)	5.74	7.75	21.34	30.21	25.33	28.33	1.91	5.76
	Credits	-37.11	-25.97	-21.60	-21.29	-28.01	-28.03	-27.95	-20.25
	CO2 uptake	-11.60	-15.69	-43.32	-61.39	-51.41	-57.56	-3.84	-12.47
	net results	203.87	174.71	48.52	33.53	65.50	60.36	143.96	353.36
Acidification [kg SO2-e/1000 L]	Burdens	0.55	0.49	0.32	0.39	0.40	0.43	0.38	1.33
	Credits	-0.07	-0.05	-0.05	-0.05	-0.06	-0.06	-0.06	-0.05
	Net results	0.47	0.44	0.27	0.35	0.34	0.36	0.32	1.28
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	7.29	6.41	4.06	5.55	5.09	5.61	5.01	16.30
	Credits	-0.87	-0.59	-0.58	-0.57	-0.75	-0.75	-0.66	-0.57
	Net results	6.42	5.82	3.48	4.97	4.35	4.87	4.36	15.72
Ozone Depletion [g R11/1000 L]	Burdens	0.81	0.75	0.07	0.27	0.08	0.15	0.61	0.37
	Credits	-0.04	-0.03	-0.01	-0.01	-0.01	-0.01	-0.03	-0.02
	Net results	0.77	0.73	0.06	0.26	0.07	0.14	0.58	0.35
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	54.91	49.91	32.24	47.02	40.20	45.24	37.21	128.40
	Credits	-6.78	-4.70	-4.50	-4.45	-5.77	-5.77	-5.12	-4.27
	Net results	48.12	45.21	27.74	42.58	34.43	39.47	32.09	124.13
Aquatic Eutrophication [g PO4/1000 L]	Burdens	53.55	46.82	29.11	73.28	36.60	51.65	38.32	17.25
	Credits	-1.46	-0.66	-1.47	-1.47	-1.74	-1.74	-1.20	-1.97
	Net results	52.10	46.16	27.65	71.81	34.86	49.91	37.13	15.28
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	520.64	460.53	296.60	410.77	375.14	413.56	359.41	1314.49
	Credits	-65.49	-45.37	-44.57	-44.04	-57.00	-57.04	-49.46	-48.48
	Net results	455.15	415.17	252.03	366.73	318.14	356.53	309.96	1266.00
Total Primary Energy [GJ]	Burdens	5.53	4.53	2.48	2.47	3.16	3.16	3.99	5.41
	Credits	-0.73	-0.49	-0.49	-0.49	-0.63	-0.63	-0.56	-0.39
	Net results	4.80	4.04	1.99	1.98	2.53	2.54	3.43	5.02
Non-renewable Primary Energy [GJ]	Burdens	5.14	4.17	1.71	1.37	2.23	2.12	3.73	5.13
	Credits	-0.67	-0.45	-0.36	-0.36	-0.47	-0.47	-0.51	-0.37
	Net results	4.47	3.72	1.34	1.01	1.76	1.65	3.22	4.76
Use of Nature [m²*year]	Burdens	1.87	3.70	23.73	36.88	28.20	32.68	0.50	2.40
	Credits	-0.12	-0.10	-2.02	-2.02	-2.41	-2.41	-0.09	-0.05
	Net results	1.75	3.61	21.71	34.86	25.79	30.27	0.41	2.35
Water use [m³/1000 L]	water cool	5.01	4.23	1.77	1.80	2.10	2.14	3.67	1.89
	water process	0.28	0.24	2.18	2.16	2.61	2.61	0.17	5.50
	water unspecified	1.32	1.30	0.60	0.72	0.74	0.78	0.92	0.49

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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. While in Finland 21% of used beverage 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 CO₂ 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 CO₂.

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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

JNSD ambient

Table 73: Comparison of net results: **Tetra Brik Aseptic Edge LightCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Finland**

<i>JNSD (ambient), Finland</i>	The net results of TBA Edge LightCap 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	45%	-26%	-20%	-66%	-86%
Acidification	-23%	-21%	-27%	-17%	-79%
Photo-Oxidant Formation	-30%	-20%	-29%	-20%	-78%
Ozone Depletion Potential	-78%	-17%	-59%	-90%	-84%
Terrestrial Eutrophication	-35%	-19%	-30%	-14%	-78%
Aquatic Eutrophication	-62%	-21%	-45%	-26%	81%
Particulate Matter	-31%	-21%	-29%	-19%	-80%
Total Primary Energy	0%	-22%	-22%	-42%	-60%
Non-renewable Primary Energy	33%	-24%	-18%	-58%	-72%

Table 74: 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**

<i>JNSD (ambient), Finland</i>	The net results of TBA Edge LightCap biobased 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	-31%	-49%	-44%	-77%	-91%
Acidification	29%	2%	-5%	7%	-73%
Photo-Oxidant Formation	43%	14%	2%	14%	-68%
Ozone Depletion Potential	358%	282%	90%	-55%	-26%
Terrestrial Eutrophication	53%	24%	8%	33%	-66%
Aquatic Eutrophication	160%	106%	44%	93%	370%
Particulate Matter	46%	15%	3%	18%	-71%
Total Primary Energy	0%	-22%	-22%	-42%	-60%
Non-renewable Primary Energy	-25%	-43%	-39%	-69%	-79%

Table 75: Comparison of net results **Tetra Prisma Aseptic square 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Finland**

<i>JNSD (ambient), Finland</i>	The net results of TPA Square 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	35%	95%	9%	-54%	-81%
Acidification	27%	-2%	-7%	5%	-74%
Photo-Oxidant Formation	25%	-13%	-11%	0%	-72%
Ozone Depletion Potential	20%	-74%	-50%	-88%	-81%
Terrestrial Eutrophication	24%	-19%	-13%	7%	-72%
Aquatic Eutrophication	26%	-51%	-30%	-6%	128%
Particulate Matter	26%	-13%	-11%	3%	-75%
Total Primary Energy	27%	28%	0%	-26%	-49%
Non-renewable Primary Energy	31%	74%	7%	-45%	-63%

Table 76: 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**

<i>JNSD (ambient), Finland</i>	The net results of TPA Square HeliCap biobased 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	24%	80%	-8%	-58%	-83%
Acidification	36%	5%	8%	13%	-72%
Photo-Oxidant Formation	40%	-2%	12%	12%	-69%
Ozone Depletion Potential	142%	-47%	102%	-76%	-61%
Terrestrial Eutrophication	42%	-7%	15%	23%	-68%
Aquatic Eutrophication	81%	-31%	43%	34%	227%
Particulate Matter	41%	-3%	12%	15%	-72%
Total Primary Energy	27%	28%	0%	-26%	-49%
Non-renewable Primary Energy	23%	63%	-6%	-49%	-65%

7.3 Results Grab & Go Finland

7.3.1 Presentation of results Grab & Go Finland

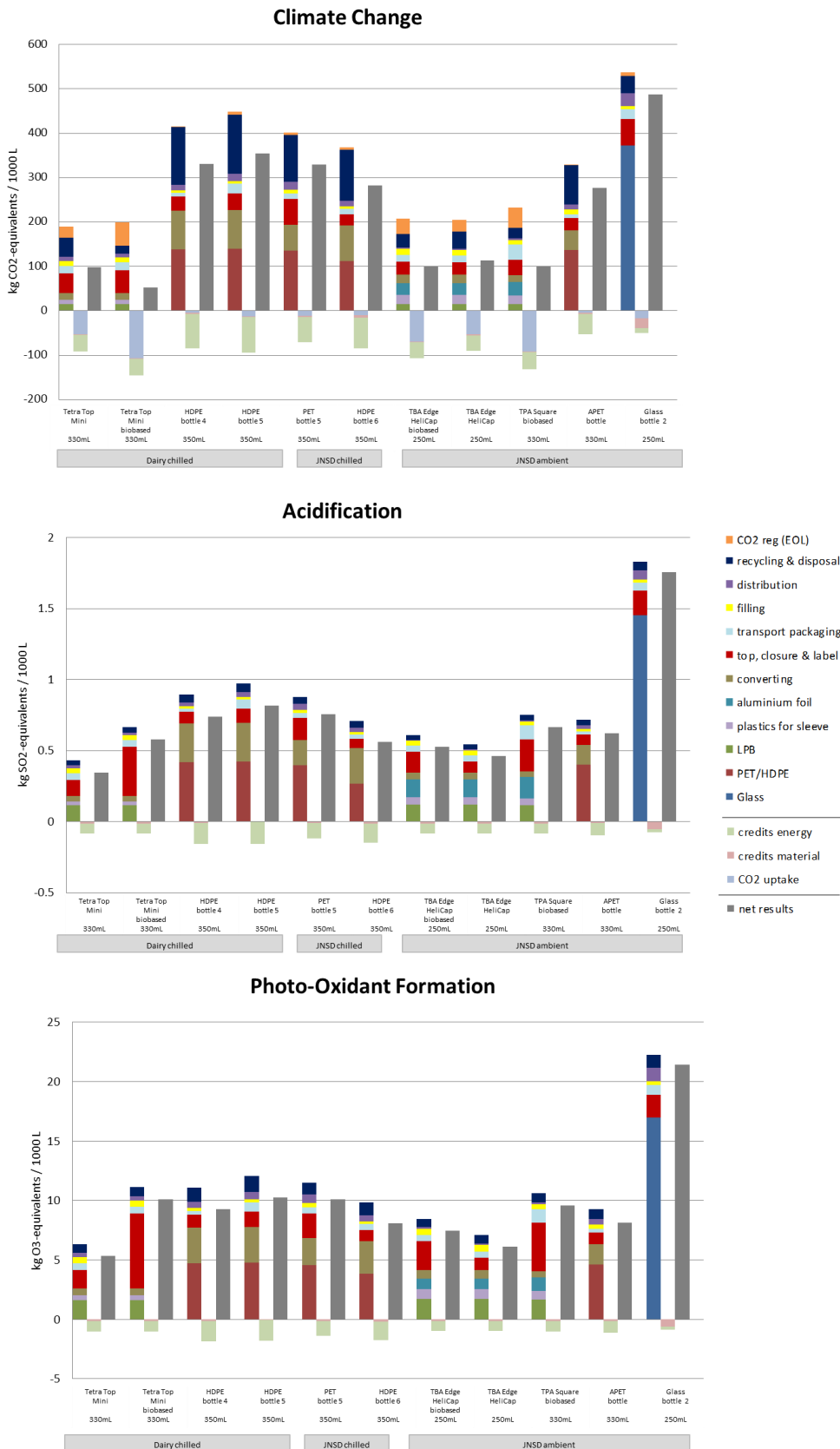


Figure 68: Indicator results for base scenarios of segment Grab & Go, Finland, allocation factor 50% (Part 1)

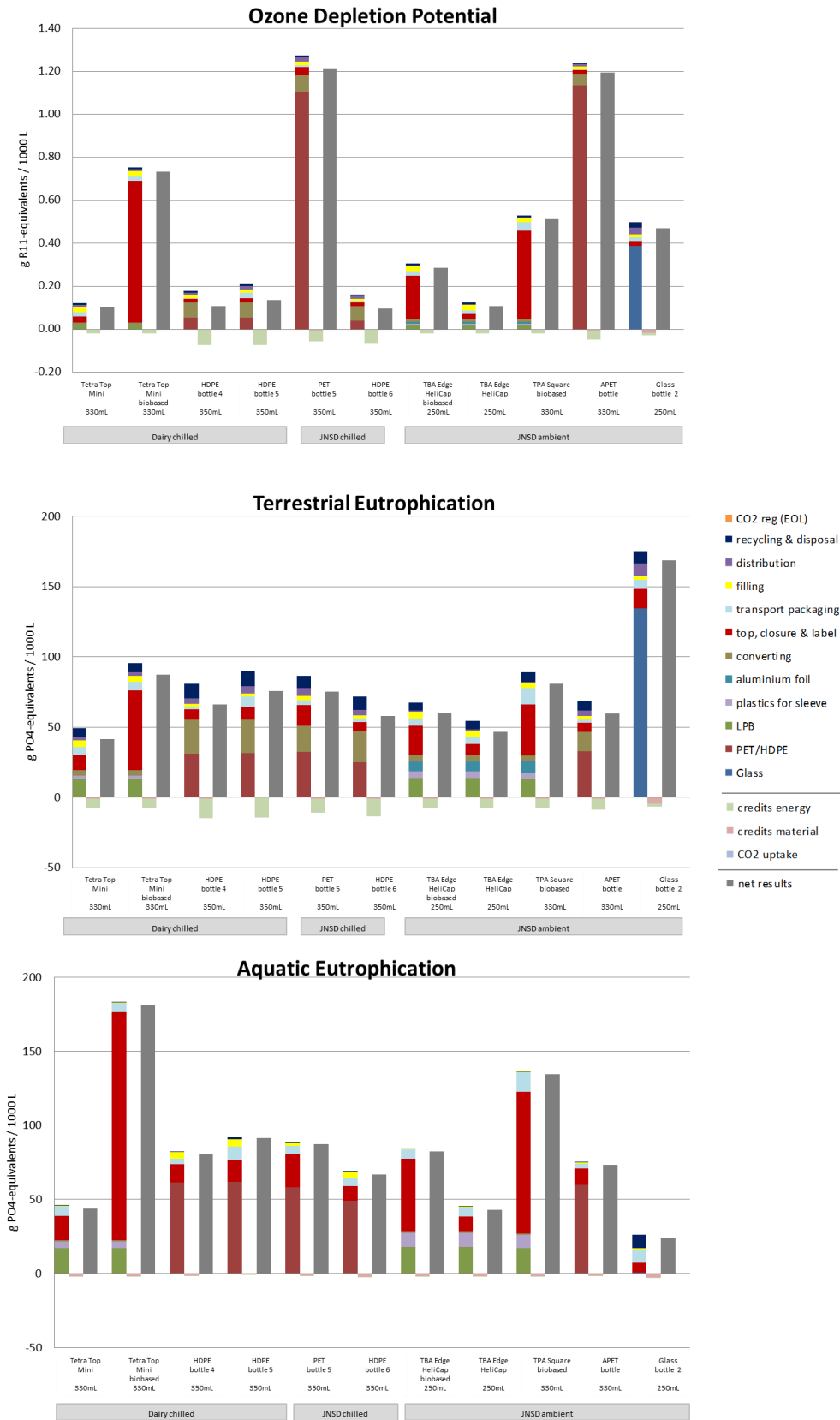


Figure 69: Indicator results for base scenarios of segment Grab & Go, Finland, allocation factor 50% (Part 2)

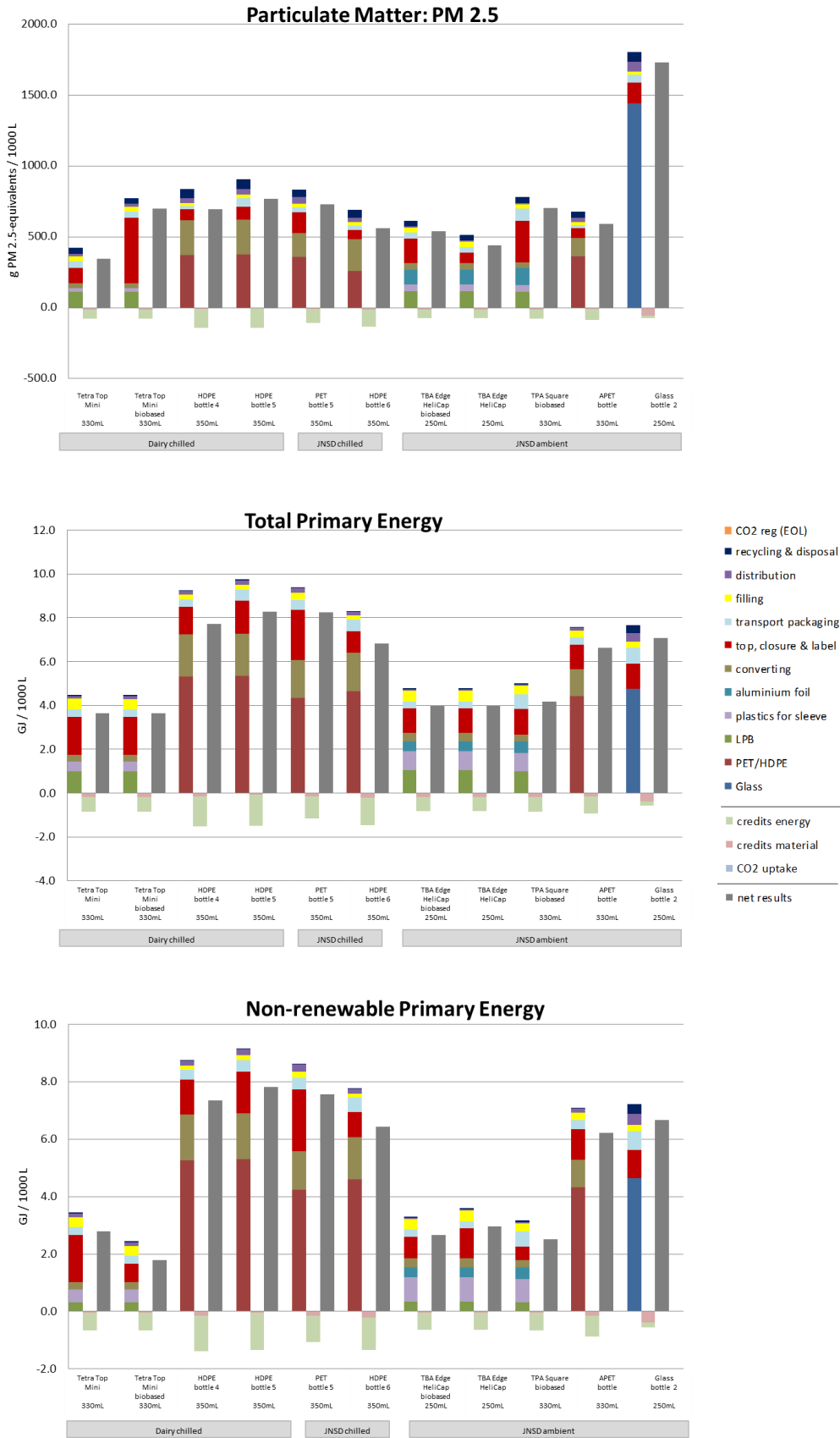


Figure 70: Indicator results for base scenarios of segment Grab & Go, Finland, allocation factor 50% (Part 3)

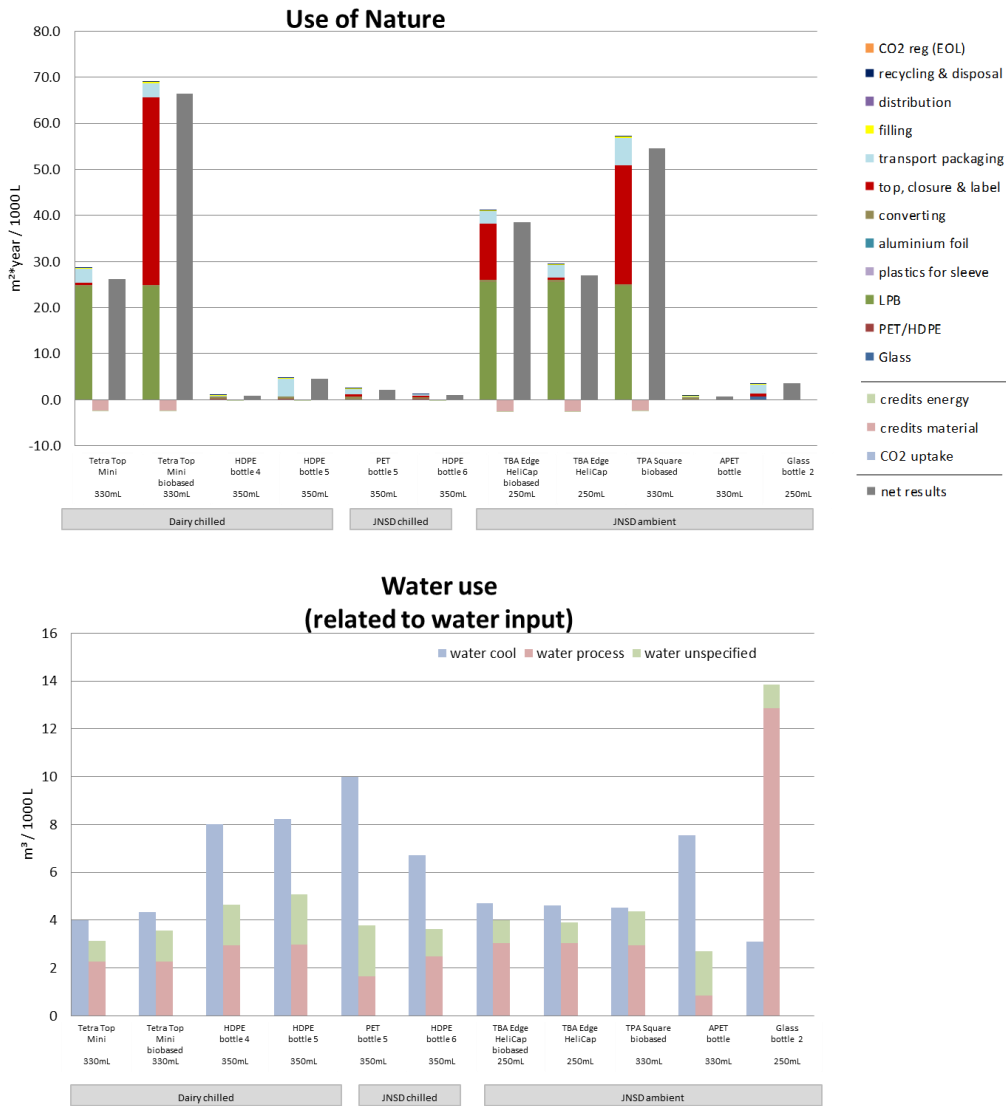


Figure 71: Indicator results for base scenarios of segment segment Grab & Go, Finland, allocation factor 50% (Part 4)

Table 77: Category indicator results per impact category for base scenarios of segment **Grab & Go, Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL	PET bottle 5 350mL	HDPE bottle 6 350mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change [kg CO2-e/1000 L]	Burdens	163.99	146.05	413.42	441.76	395.42	363.00	173.34	178.52	186.92	327.33	529.10
	CO2 (reg)	25.75	52.49	1.90	6.19	5.45	4.94	33.95	26.09	45.29	1.87	7.93
	Credits	-39.78	-39.42	-80.81	-81.30	-60.28	-75.08	-37.87	-37.79	-39.44	-48.65	-32.32
	CO2 uptake	-52.32	-106.74	-3.81	-12.54	-11.02	-9.99	-69.09	-53.07	-91.67	-3.75	-17.21
	net results	97.63	52.38	330.70	354.12	329.57	282.87	100.32	113.75	101.11	276.80	487.50
Acidification [kg SO2-e/1000 L]	Burdens	0.43	0.66	0.90	0.97	0.88	0.71	0.61	0.54	0.75	0.72	1.83
	Credits	-0.09	-0.08	-0.16	-0.16	-0.12	-0.15	-0.08	-0.08	-0.08	-0.10	-0.07
	Net results	0.35	0.58	0.74	0.82	0.76	0.56	0.53	0.46	0.67	0.62	1.76
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	6.35	11.11	11.10	12.05	11.51	9.84	8.47	7.10	10.62	9.25	22.27
	Credits	-1.02	-1.01	-1.84	-1.81	-1.38	-1.74	-0.98	-0.98	-1.01	-1.13	-0.86
	Net results	5.32	10.10	9.26	10.24	10.12	8.10	7.48	6.12	9.61	8.13	21.41
Ozone Depletion [g R11/1000 L]	Burdens	0.12	0.75	0.18	0.21	1.27	0.16	0.30	0.12	0.53	1.24	0.50
	Credits	-0.02	-0.02	-0.07	-0.07	-0.06	-0.07	-0.02	-0.02	-0.02	-0.05	-0.03
	Net results	0.10	0.73	0.11	0.14	1.22	0.10	0.29	0.11	0.51	1.19	0.47
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	49.34	95.37	80.82	90.07	86.34	71.53	67.54	54.40	88.84	68.61	175.31
	Credits	-7.92	-7.85	-14.62	-14.60	-10.95	-13.67	-7.60	-7.58	-7.84	-8.86	-6.48
	Net results	41.42	87.52	66.20	75.46	75.39	57.86	59.95	46.82	81.00	59.75	168.82
Aquatic Eutrophication [g PO4/1000 L]	Burdens	45.78	182.87	82.24	92.07	88.87	68.84	84.18	44.95	136.12	75.01	26.16
	Credits	-1.89	-1.89	-1.64	-0.65	-1.68	-2.35	-1.93	-1.93	-1.86	-1.62	-2.65
	Net results	43.89	180.98	80.59	91.42	87.19	66.49	82.25	43.02	134.26	73.39	23.51
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	423.42	774.27	836.32	907.72	834.00	692.40	613.71	513.56	782.12	676.93	1802.47
	Credits	-77.69	-77.07	-140.57	-140.12	-105.51	-131.63	-74.64	-74.49	-76.97	-85.52	-74.24
	Net results	345.73	697.21	695.75	767.60	728.49	560.77	539.07	439.06	705.15	591.41	1728.23
Total Primary Energy [GJ]	Burdens	4.48	4.47	9.25	9.74	9.40	8.29	4.78	4.78	5.02	7.57	7.65
	Credits	-0.85	-0.84	-1.52	-1.48	-1.15	-1.46	-0.81	-0.81	-0.84	-0.94	-0.58
	Net results	3.63	3.63	7.72	8.26	8.24	6.83	3.97	3.97	4.18	6.62	7.07
Non-renewable Primary Energy [GJ]	Burdens	3.45	2.45	8.75	9.17	8.62	7.77	3.31	3.60	3.18	7.08	7.22
	Credits	-0.67	-0.66	-1.40	-1.35	-1.06	-1.34	-0.64	-0.64	-0.66	-0.87	-0.55
	Net results	2.79	1.78	7.35	7.82	7.56	6.43	2.67	2.96	2.52	6.21	6.66
Use of Nature [m²/year]	Burdens	28.65	68.97	0.99	4.69	1.20	41.13	29.46	57.09	0.84	3.54	
	Credits	-2.50	-2.50	-0.24	-0.24	-0.18	-0.22	-2.56	-2.56	-2.48	-0.15	-0.06
	Net results	26.14	66.47	0.75	4.44	2.19	0.98	38.57	26.90	54.61	0.69	3.48
Water use [m³/1000 L]	water cool	3.99	4.35	8.02	8.23	9.99	6.71	4.72	4.62	4.51	7.54	3.10
	water process	2.28	2.26	2.96	2.97	1.65	2.50	3.03	3.04	2.94	0.85	12.87
	water unspecified	0.85	1.31	1.70	2.11	2.12	1.14	0.98	0.87	1.42	1.85	0.99

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 SO₂, 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 N₂O 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 N₂O 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 NO₂ emissions from incineration plants.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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. While in Finland 21% of used beverage 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 CO₂ 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 CO₂.

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 terephthalic 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

DAIRY chilled**Table 78:** Comparison of net results **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, Dairy chilled, Finland**

<i>Grab & Go DAIRY (chilled), Finland</i>	The net results of Tetra Top Mini are lower (green)/ higher (orange) than those of		
	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	86%	-70%	-72%
Acidification	-40%	-53%	-58%
Photo-Oxidant Formation	-47%	-43%	-48%
Ozone Depletion Potential	-86%	-3%	-24%
Terrestrial Eutrophication	-53%	-37%	-45%
Aquatic Eutrophication	-76%	-46%	-52%
Particulate Matter	-50%	-50%	-55%
Total Primary Energy	0%	-53%	-56%
Non-renewable Primary Energy	56%	-62%	-64%

Table 79: 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**

<i>Grab & Go DAIRY (chilled), Finland</i>	The net results of Tetra Top Mini biobased 330mL are lower (green)/ higher (orange) than those of		
	Tetra Top Mini 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	-46%	-84%	-85%
Acidification	68%	-22%	-29%
Photo-Oxidant Formation	90%	9%	-1%
Ozone Depletion Potential	610%	586%	439%
Terrestrial Eutrophication	111%	32%	16%
Aquatic Eutrophication	312%	125%	98%
Particulate Matter	102%	0%	-9%
Total Primary Energy	0%	-53%	-56%
Non-renewable Primary Energy	-36%	-76%	-77%

JNSD ambient**Table 80:** 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**

<i>Grab & Go JNSD (ambient), Finland</i>	The net results of TBA Edge HeliCap biobased 250mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	-12%	-1%	-72%	-79%
Acidification	14%	-21%	-15%	-70%
Photo-Oxidant Formation	22%	-22%	-8%	-65%
Ozone Depletion Potential	169%	-44%	-76%	-39%
Terrestrial Eutrophication	28%	-26%	0%	-64%
Aquatic Eutrophication	91%	-39%	12%	250%
Particulate Matter	23%	-24%	-9%	-69%
Total Primary Energy	0%	-5%	-40%	-44%
Non-renewable Primary Energy	-10%	6%	-57%	-60%

Table 81: 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**

<i>Grab & Go JNSD (ambient), Finland</i>	The net results of TBA Edge HeliCap 250mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	13%	13%	-59%	-77%
Acidification	-13%	-31%	-26%	-74%
Photo-Oxidant Formation	-18%	-36%	-25%	-71%
Ozone Depletion Potential	-63%	-79%	-91%	-77%
Terrestrial Eutrophication	-22%	-42%	-22%	-72%
Aquatic Eutrophication	-48%	-68%	-41%	83%
Particulate Matter	-19%	-38%	-26%	-75%
Total Primary Energy	0%	-5%	-40%	-44%
Non-renewable Primary Energy	11%	18%	-52%	-56%

Table 82: 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**

<i>Grab & Go JNSD (ambient), Finland</i>	The net results of TPA Square biobased 330mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	1%	-11%	-63%	-79%
Acidification	26%	44%	7%	-62%
Photo-Oxidant Formation	28%	57%	18%	-55%
Ozone Depletion Potential	79%	380%	-57%	9%
Terrestrial Eutrophication	35%	73%	36%	-52%
Aquatic Eutrophication	63%	212%	83%	471%
Particulate Matter	31%	61%	19%	-59%
Total Primary Energy	5%	5%	-37%	-41%
Non-renewable Primary Energy	-6%	-15%	-59%	-62%

7.4 Results base scenarios *water Finland*

7.4.1 Presentation of results water Finland



Figure 72: Indicator results for base scenarios of segment Water, Finland, allocation factor 50% (Part 1)

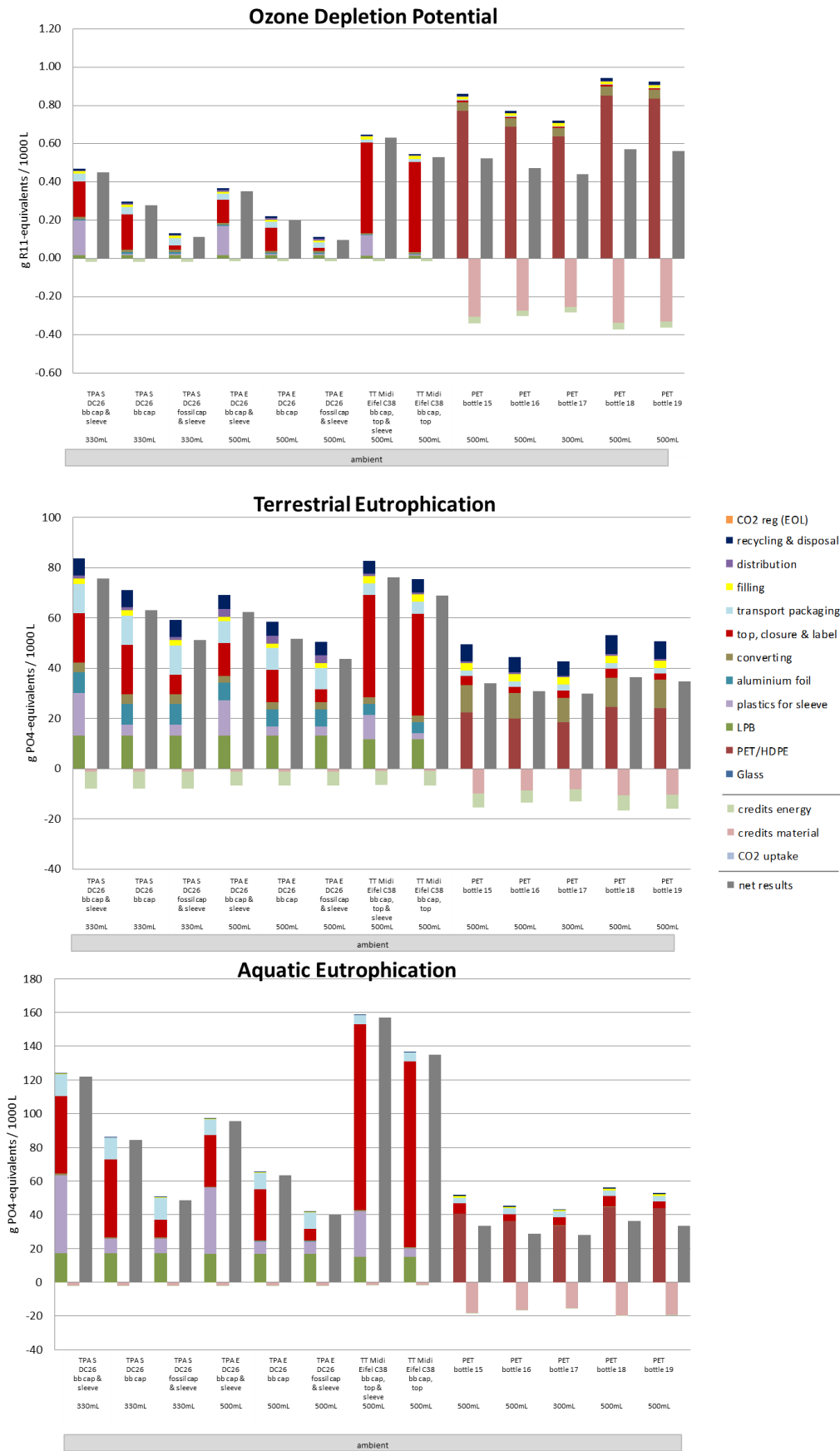


Figure 73: Indicator results for base scenarios of segment Water, Finland, allocation factor 50% (Part 2)



Figure 74: Indicator results for base scenarios of segment Water, Finland, allocation factor 50% Part 3)

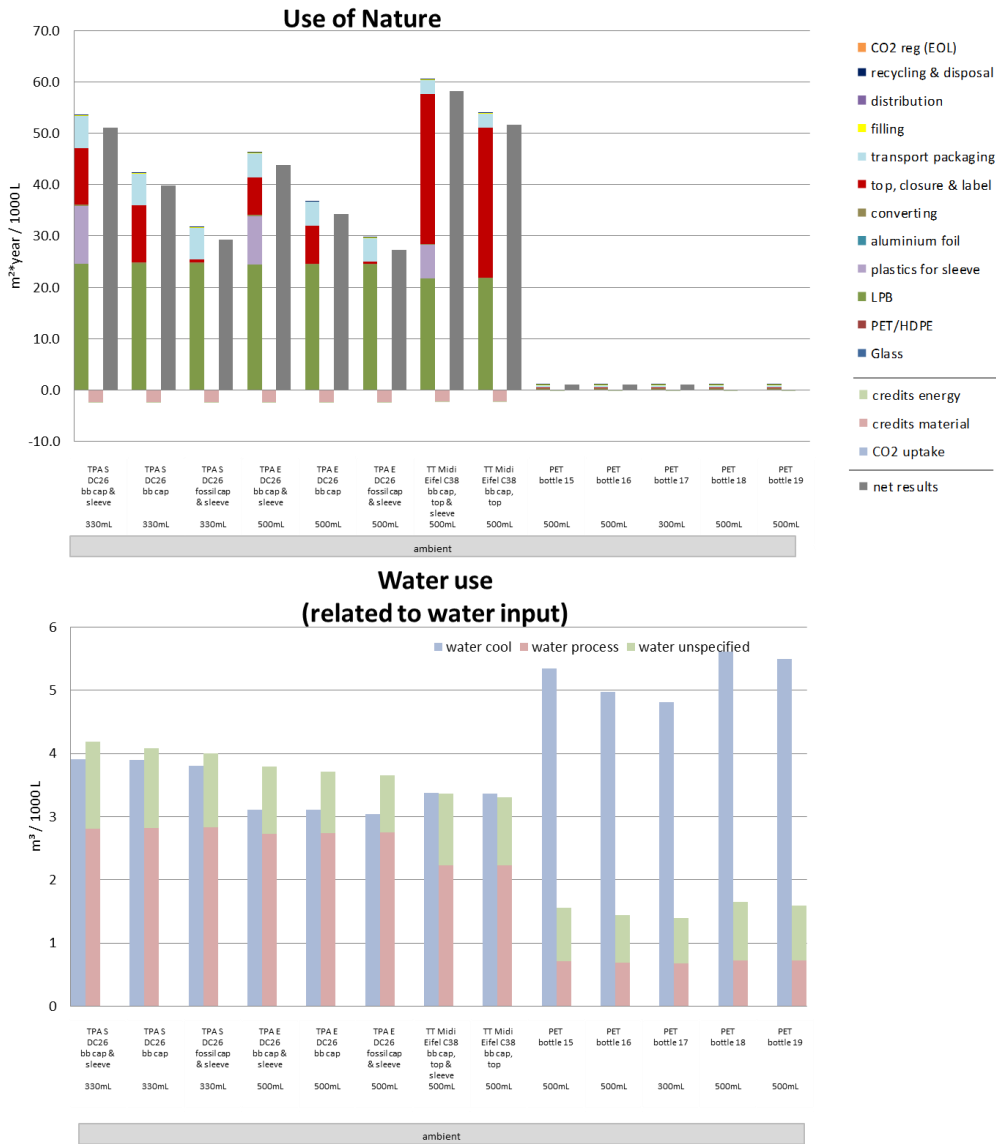


Figure 75 Indicator results for base scenarios of segment Water, Finland, allocation factor 50% (Part 4)

Table 83: Category indicator results per impact category for base scenarios of segment **Water Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	183.25	188.55	193.27	148.21	152.69	155.81	123.18	126.28	230.27	203.66	196.45	247.60	234.03
	CO ₂ (reg)	45.03	37.43	30.27	40.50	34.06	29.34	47.68	43.22	1.55	1.55	1.55	1.55	1.55
	Credits	-40.00	-40.15	-40.08	-33.48	-33.67	-33.63	-32.74	-33.20	-72.55	-63.36	-60.77	-78.11	-73.81
	CO ₂ uptake	-90.88	-75.46	-60.95	-82.01	-68.95	-69.35	-96.97	-87.94	-3.13	-3.13	-3.13	-3.13	-3.13
	net results	97.41	110.36	122.51	73.23	84.14	92.17	41.16	48.37	156.14	138.72	134.11	167.92	158.65
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.72	0.66	0.60	0.60	0.54	0.50	0.62	0.58	0.51	0.45	0.43	0.55	0.52
	Credits	-0.09	-0.09	-0.09	-0.07	-0.07	-0.07	-0.07	-0.07	-0.18	-0.16	-0.15	-0.19	-0.19
	Net results	0.64	0.57	0.51	0.52	0.47	0.43	0.55	0.51	0.33	0.30	0.28	0.35	0.34
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	9.99	8.73	7.50	8.30	7.24	6.42	9.67	8.93	6.62	5.91	5.70	7.09	6.75
	Credits	-1.02	-1.03	-1.03	-0.87	-0.88	-0.88	-0.85	-0.85	-2.10	-1.84	-1.76	-2.26	-2.15
	Net results	8.96	7.70	6.47	7.43	6.36	5.54	8.82	8.07	4.51	4.07	3.94	4.83	4.59
Ozone Depletion [g R11/1000 L]	Burdens	0.47	0.30	0.13	0.37	0.22	0.11	0.65	0.55	0.86	0.77	0.72	0.94	0.92
	Credits	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-0.34	-0.30	-0.28	-0.37	-0.36
	Net results	0.45	0.28	0.11	0.35	0.20	0.10	0.63	0.53	0.52	0.47	0.44	0.57	0.56
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	83.58	70.98	59.09	69.07	58.40	50.53	82.79	75.41	49.57	44.40	42.81	53.05	50.61
	Credits	-7.92	-7.95	-7.94	-6.76	-6.79	-6.78	-6.57	-6.65	-15.47	-13.55	-12.95	-16.68	-15.84
	Net results	75.66	63.03	51.15	62.32	51.61	43.74	76.23	68.76	34.09	30.85	29.87	36.38	34.78
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	123.75	86.08	50.57	97.20	65.29	41.79	158.65	136.59	51.67	45.20	43.36	56.03	52.77
	Credits	-1.83	-1.83	-1.83	-1.81	-1.81	-1.81	-1.84	-1.84	-18.41	-18.31	-15.36	-19.84	-19.27
	Net results	121.92	84.25	48.73	95.39	63.49	39.99	157.01	134.94	33.26	28.89	28.00	36.19	33.50
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	742.56	644.81	554.15	612.77	529.97	469.97	699.67	642.41	483.16	430.95	414.14	519.01	495.12
	Credits	-77.73	-78.02	-77.89	-66.49	-66.82	-66.76	-64.53	-65.33	-161.66	-141.75	-135.18	-174.41	-166.04
	Net results	664.81	566.80	476.26	546.27	463.15	403.21	635.15	577.08	321.49	289.20	278.96	344.60	329.07
Total Primary Energy [GJ]	Burdens	4.84	4.86	4.86	3.99	4.00	4.00	3.74	3.74	5.48	4.88	4.72	5.87	5.55
	Credits	-0.85	-0.85	-0.85	-0.73	-0.73	-0.73	-0.70	-0.71	-1.94	-1.70	-1.63	-2.09	-1.99
	Net results	4.00	4.01	4.01	3.26	3.26	3.26	3.03	3.03	3.54	3.17	3.09	3.78	3.56
Non-renewable Primary Energy [GJ]	Burdens	3.12	3.42	3.68	2.50	2.75	2.92	1.92	2.10	5.04	4.47	4.32	5.41	5.11
	Credits	-0.67	-0.67	-0.67	-0.56	-0.57	-0.56	-0.55	-0.56	-1.87	-1.64	-1.56	-2.00	-1.91
	Net results	2.45	2.74	3.01	1.94	2.19	2.36	1.38	1.54	3.18	2.83	2.76	3.41	3.20
Use of Nature [m ² /year]	Burdens	53.53	42.31	31.74	46.28	36.77	29.78	60.49	53.91	1.14	1.11	1.10	1.16	1.14
	Credits	-2.45	-2.45	-2.45	-2.44	-2.44	-2.44	-2.25	-2.25	-0.10	-0.09	-0.09	-0.11	-0.10
	Net results	51.08	39.86	29.29	43.84	34.33	27.34	58.24	51.67	1.04	1.02	1.02	1.05	1.04
Water use [m ³ /1000 L]	water cool	3.91	3.90	3.81	3.11	3.10	3.04	3.37	3.36	5.35	4.97	4.81	5.61	5.49
	water process	2.81	2.82	2.83	2.73	2.74	2.75	2.23	2.23	0.71	0.68	0.67	0.72	0.72
	water unspecified	1.38	1.27	1.17	1.06	0.97	0.91	1.13	1.07	0.85	0.75	0.72	0.93	0.88

7.4.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the water 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 SO₂, 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 water 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 shows visible impacts in almost all impact categories.

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 N₂O 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 water 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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. While in Finland 21% of used beverage 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 CO₂ 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 CO₂.

Plastic bottles

In the regarded plastic bottle systems in the water 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 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 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 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'.

For the regarded plastic bottles for water more material credits are given than for bottles in other beverage segments as the deposit system for water bottles leads to a high recycling rate.

7.4.3 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

Table 84: Comparison of net results **Tetra Prisma Square bio-based cap & sleeve 330 mL** versus competing carton based and alternative packaging systems in **segment Water, Finland**

WATER (ambient), Finland	The net results of TPA S DC26 bb cap & sleeve 330mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	-12%	-20%	33%	16%	6%	137%	101%	-38%	-30%	-27%	-42%	-39%
Acidification	12%	25%	21%	36%	49%	17%	26%	93%	116%	124%	80%	88%
Photo-Oxidant Formation	16%	38%	21%	41%	62%	2%	11%	99%	120%	128%	86%	95%
Ozone Depletion Potential	63%	295%	29%	121%	371%	-29%	-15%	-14%	-5%	2%	-21%	-20%
Terrestrial Eutrophication	20%	48%	21%	47%	73%	-1%	10%	122%	145%	153%	108%	118%
Aquatic Eutrophication	45%	150%	28%	92%	205%	-22%	-10%	267%	322%	335%	237%	264%
Particulate Matter	17%	40%	22%	44%	65%	5%	15%	107%	130%	138%	93%	102%
Total Primary Energy	0%	0%	23%	22%	22%	32%	32%	13%	26%	29%	6%	12%
Non-renewable Primary Energy	-11%	-18%	26%	12%	4%	78%	59%	-23%	-13%	-11%	-28%	-23%

Table 85: Comparison of net results: **Tetra Prisma Aseptic Square bio-based cap 330 mL** versus competing carton based and alternative packaging systems in **segment Water,, Finland**

WATER (ambient), Finland	The net results of TPA S DC26 bb cap 330mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	13%	-10%	51%	31%	20%	168%	128%	-29%	-20%	-18%	-34%	-30%
Acidification	-11%	12%	9%	22%	33%	4%	13%	73%	100%	100%	61%	68%
Photo-Oxidant Formation	-14%	19%	4%	21%	39%	-13%	-5%	71%	90%	96%	60%	68%
Ozone Depletion Potential	-38%	143%	-21%	36%	190%	-56%	-48%	-47%	-41%	-37%	-52%	-51%
Terrestrial Eutrophication	-17%	23%	1%	22%	44%	-17%	-8%	85%	104%	111%	73%	81%
Aquatic Eutrophication	-31%	73%	-12%	33%	111%	-46%	-38%	153%	192%	201%	133%	151%
Particulate Matter	-15%	19%	4%	22%	41%	-11%	-2%	76%	96%	103%	64%	72%
Total Primary Energy	0%	0%	23%	23%	23%	32%	32%	13%	26%	30%	6%	13%
Non-renewable Primary Energy	12%	-9%	41%	26%	16%	99%	78%	-14%	-3%	-1%	-20%	-14%

Table 86: Comparison of net results: Tetra Prisma Aseptic Square fossil cap & sleeve 330 mL versus competing carton based and alternative packaging systems in segment Water Finland

WATER (ambient), Finland	The net results of TPA S DC26 fossil cap & sleeve 330mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	26%	11%	67%	46%	33%	198%	153%	-22%	-12%	-9%	-27%	-23%
Acidification	-20%	-11%	-3%	9%	19%	-7%	1%	55%	72%	79%	44%	51%
Photo-Oxidant Formation	-28%	-16%	-13%	2%	17%	-27%	-20%	43%	59%	64%	34%	41%
Ozone Depletion Potential	-75%	-59%	-68%	-44%	19%	-82%	-79%	-78%	-76%	-74%	-80%	-80%
Terrestrial Eutrophication	-32%	-19%	-18%	-1%	17%	-33%	-26%	50%	66%	71%	41%	47%
Aquatic Eutrophication	-60%	-42%	-49%	-23%	22%	-69%	-64%	47%	69%	74%	35%	45%
Particulate Matter	-28%	-16%	-13%	3%	18%	-25%	-17%	48%	65%	71%	38%	45%
Total Primary Energy	0%	0%	23%	23%	23%	32%	32%	13%	26%	30%	6%	12%
Non-renewable Primary Energy	23%	10%	55%	38%	27%	119%	95%	-5%	6%	9%	-12%	-6%

Table 87: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap & sleeve 500 mL versus competing carton based and alternative packaging systems in segment Water, Finland

WATER (ambient), Finland	The net results of TPA E DC26 bb cap & sleeve 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	-25%	-34%	-40%	-13%	-21%	78%	51%	-53%	-47%	-45%	-56%	-54%
Acidification	-18%	-8%	3%	12%	23%	-4%	4%	59%	78%	85%	48%	55%
Photo-Oxidant Formation	-17%	-4%	15%	17%	34%	-16%	-8%	64%	83%	89%	54%	62%
Ozone Depletion Potential	-22%	26%	208%	72%	266%	-45%	-34%	-33%	-26%	-20%	-39%	-38%
Terrestrial Eutrophication	-18%	-1%	22%	21%	42%	-18%	-9%	83%	102%	109%	71%	79%
Aquatic Eutrophication	-22%	13%	96%	50%	139%	-39%	-29%	187%	230%	241%	164%	185%
Particulate Matter	-18%	-4%	15%	18%	35%	-14%	-5%	70%	89%	96%	59%	66%
Total Primary Energy	-18%	-19%	-19%	0%	0%	7%	7%	-8%	3%	5%	-14%	-9%
Non-renewable Primary Energy	-21%	-29%	-35%	-11%	-18%	41%	26%	-39%	-31%	-30%	-43%	-39%

Table 88: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap 500 mL versus competing carton based and alternative packaging systems in segment Water, Finland

WATER (ambient), Finland	The net results of TPA E DC26 bb cap 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	-14%	-24%	-31%	15%	-9%	104%	74%	-46%	-39%	-37%	-50%	-47%
Acidification	-27%	-18%	-8%	-11%	9%	-14%	-8%	42%	58%	65%	32%	38%
Photo-Oxidant Formation	-29%	-17%	-2%	-14%	15%	-28%	-21%	41%	56%	61%	32%	38%
Ozone Depletion Potential	-55%	-27%	79%	-42%	113%	-68%	-62%	-61%	-57%	-54%	-64%	-64%
Terrestrial Eutrophication	-32%	-18%	1%	-17%	18%	-32%	-25%	51%	67%	73%	42%	48%
Aquatic Eutrophication	-48%	-25%	30%	-33%	59%	-60%	-53%	91%	120%	127%	75%	90%
Particulate Matter	-30%	-18%	-3%	-15%	15%	-27%	-20%	44%	60%	66%	34%	41%
Total Primary Energy	-18%	-19%	-19%	0%	0%	8%	8%	-8%	3%	6%	-14%	-8%
Non-renewable Primary Energy	-11%	-20%	-27%	13%	-7%	59%	42%	-31%	-23%	-21%	-36%	-32%

Table 89: Comparison of net results: Tetra Prisma Aseptic Edge fossil cap & sleeve 500 mL versus competing carton based and alternative packaging systems in segment Water, Finland

WATER (ambient), Finland	The net results of TPA E DC26 fossil cap & sleeve 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	-5%	-16%	-25%	26%	10%	124%	91%	-41%	-34%	-31%	-45%	-42%
Acidification	-33%	-25%	-16%	-18%	-9%	-22%	-15%	30%	45%	50%	21%	27%
Photo-Oxidant Formation	-38%	-28%	-14%	-25%	-13%	-37%	-31%	23%	36%	41%	15%	21%
Ozone Depletion Potential	-79%	-65%	-16%	-73%	-53%	-85%	-82%	-82%	-80%	-78%	-83%	-83%
Terrestrial Eutrophication	-42%	-31%	-14%	-30%	-15%	-43%	-36%	28%	42%	46%	20%	26%
Aquatic Eutrophication	-67%	-53%	-18%	-58%	-37%	-75%	-70%	20%	38%	43%	10%	19%
Particulate Matter	-39%	-29%	-15%	-26%	-13%	-37%	-30%	25%	39%	45%	17%	23%
Total Primary Energy	-18%	-19%	-19%	0%	0%	8%	8%	-8%	3%	6%	-14%	-8%
Non-renewable Primary Energy	-4%	-14%	-22%	22%	8%	72%	53%	-26%	-17%	-14%	-31%	-26%

Table 90: Comparison of net results: **Tetra Top Midi Eifel C38 bio-based cap, top & sleeve 500 mL** versus competing carton based and alternative packaging systems in **segment Water, Finland**

WATER (ambient), Finland	The net results of TT Midi Eifel C38 bb cap, top & sleeve 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	-58%	-63%	-66%	-44%	-51%	-55%	-15%	-74%	-70%	-69%	-75%	-74%
Acidification	-14%	-4%	7%	4%	17%	28%	8%	66%	85%	92%	54%	61%
Photo-Oxidant Formation	-2%	14%	36%	19%	39%	59%	9%	95%	117%	124%	83%	92%
Ozone Depletion Potential	40%	128%	455%	80%	211%	561%	19%	21%	34%	43%	11%	13%
Terrestrial Eutrophication	1%	21%	49%	22%	48%	74%	11%	124%	147%	155%	110%	119%
Aquatic Eutrophication	29%	86%	222%	65%	147%	293%	16%	372%	443%	461%	334%	369%
Particulate Matter	-4%	12%	33%	16%	37%	58%	10%	98%	120%	128%	84%	93%
Total Primary Energy	-24%	-24%	-24%	-7%	-7%	-7%	0%	-14%	-4%	-2%	-20%	-15%
Non-renewable Primary Energy	-44%	-50%	-54%	-29%	-37%	-42%	-11%	-57%	-51%	-50%	-60%	-57%

Table 91: Comparison of net results: **Tetra Top Midi Eifel C38 bio-based cap & top 500 mL** versus competing carton based and alternative packaging systems in **segment Water, Finland**

WATER (ambient), Finland	The net results of TT Midi Eifel C38 bb cap, top 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change	-50%	-66%	-61%	-34%	-43%	-48%	18%	-69%	-65%	-64%	-71%	-70%
Acidification	-21%	-11%	-1%	-4%	8%	18%	-7%	54%	71%	78%	43%	50%
Photo-Oxidant Formation	-10%	5%	25%	9%	27%	46%	-8%	79%	99%	105%	67%	76%
Ozone Depletion Potential	18%	92%	366%	51%	161%	455%	-16%	1%	12%	20%	-7%	-6%
Terrestrial Eutrophication	-9%	9%	34%	10%	33%	57%	-10%	102%	123%	130%	89%	98%
Aquatic Eutrophication	11%	60%	177%	41%	113%	237%	-14%	306%	367%	382%	273%	303%
Particulate Matter	-13%	2%	21%	6%	25%	43%	-9%	79%	100%	107%	67%	75%
Total Primary Energy	-24%	-24%	-24%	-7%	-7%	-7%	0%	-14%	-4%	-2%	-20%	-15%
Non-renewable Primary Energy	-37%	-44%	-49%	-21%	-30%	-35%	12%	-52%	-46%	-44%	-55%	-52%

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%.

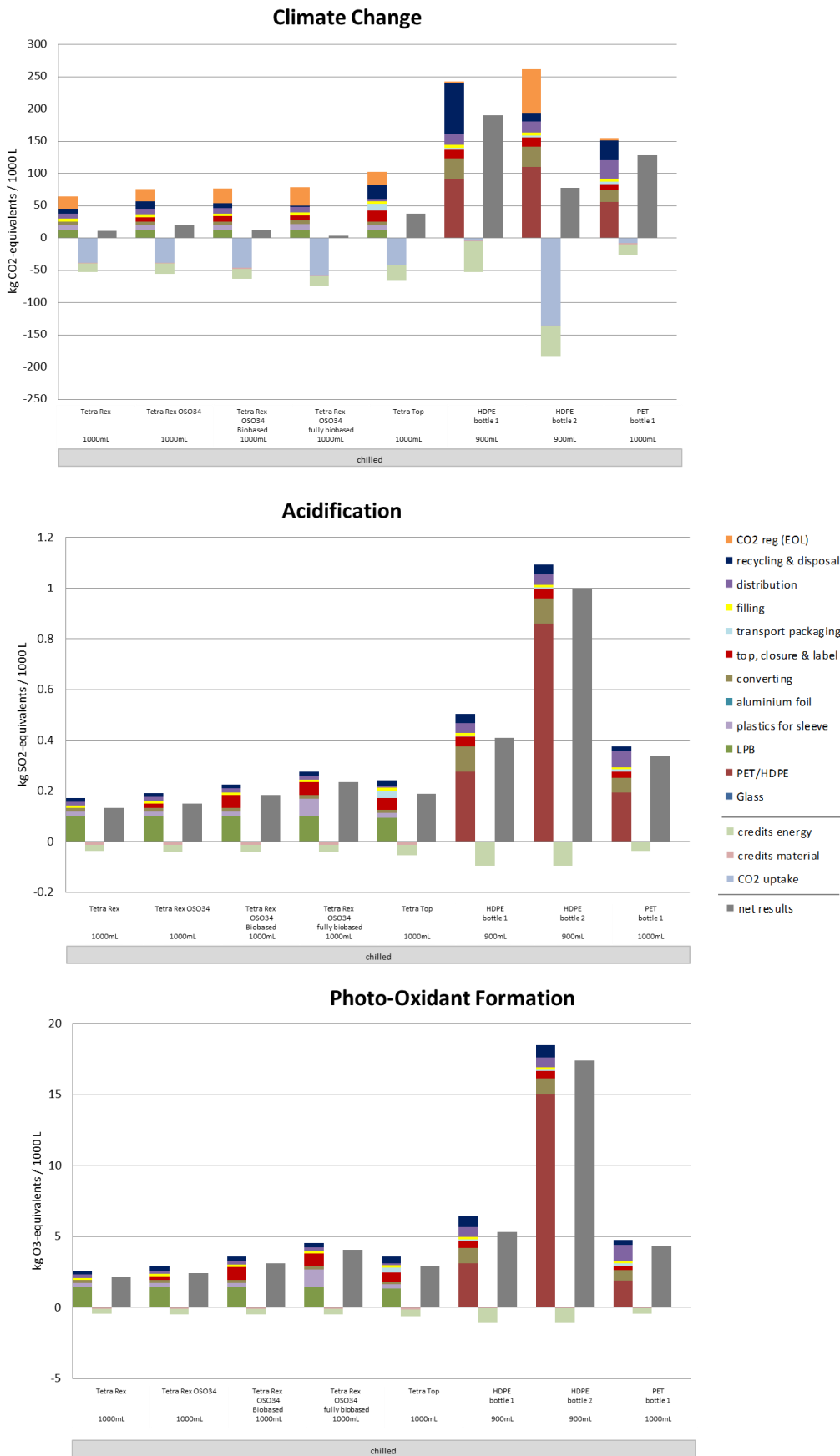


Figure 76: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Finland, allocation factor 100% (Part 1)

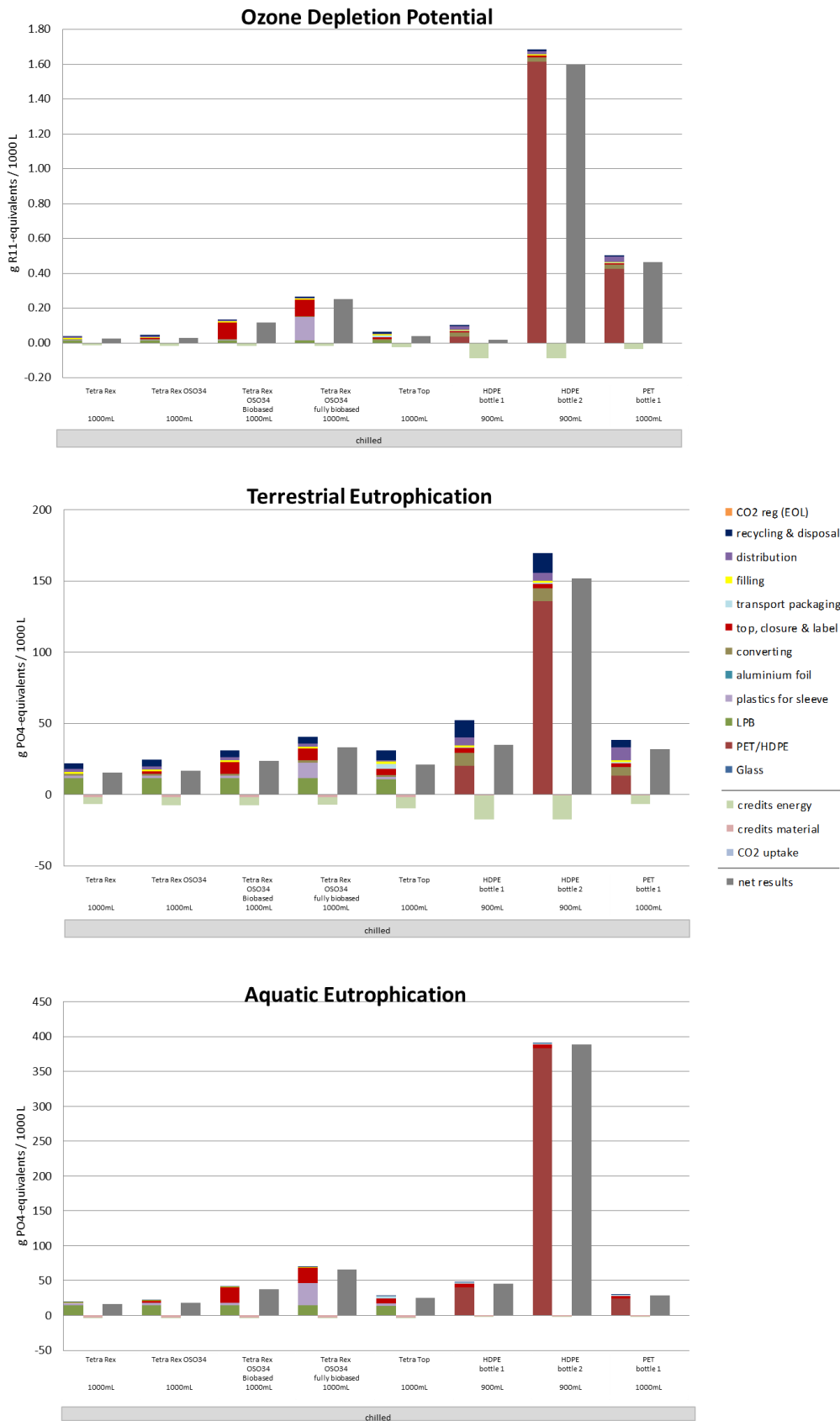


Figure 77: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Finland, allocation factor 100% (Part 2)

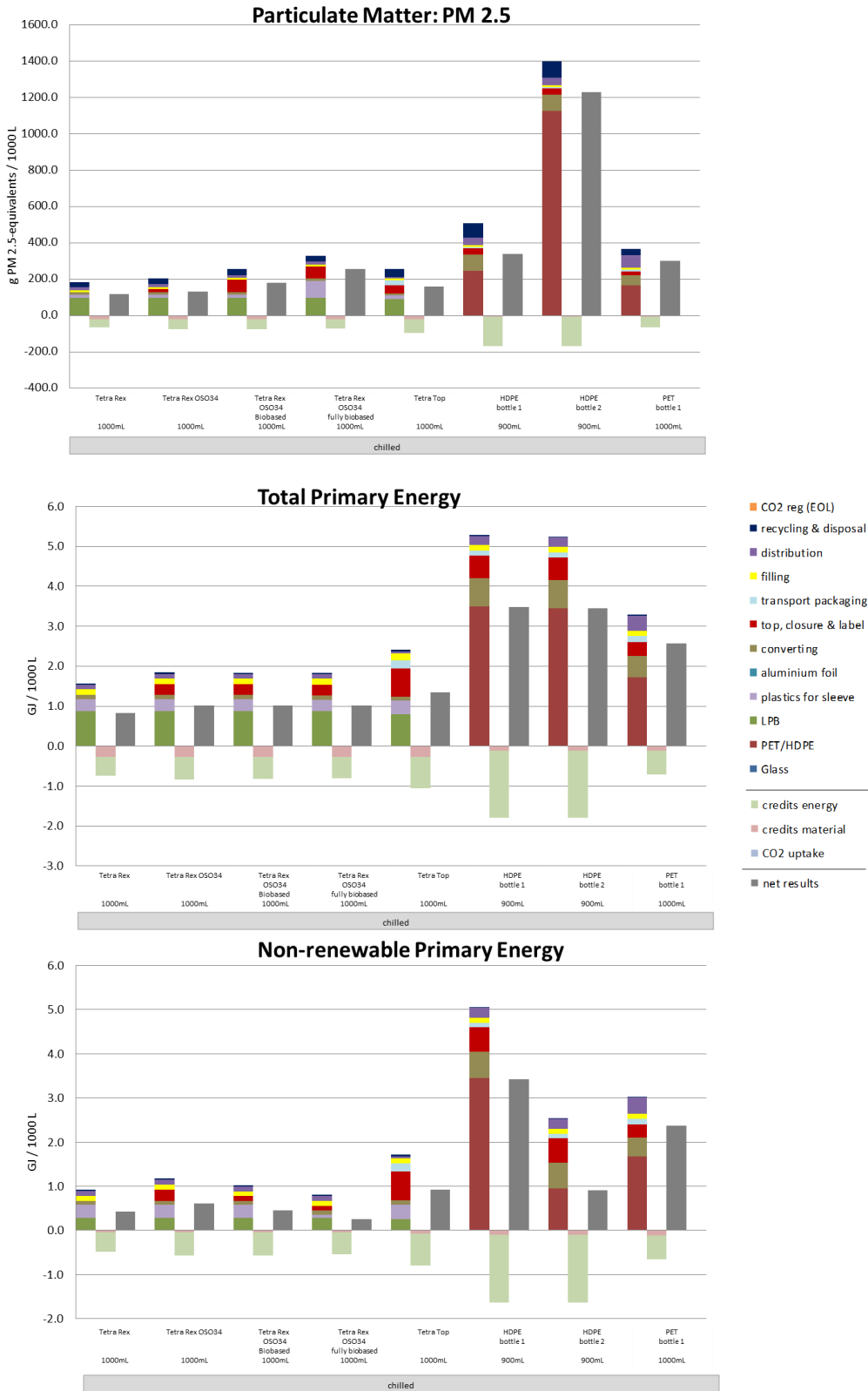


Figure 78: Indicator results for sensitivity analysis on system allocation of segment DAIRY, Finland, allocation factor 100% (Part 3)

Table 92: Category indicator results per impact category for sensitivity analysis on system allocation of **segment Dairy, Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO2-e/1000 L]	Burdens	52.38	67.45	61.01	51.38	102.25	318.83	206.85	180.83
	CO2 (reg)	37.01	37.09	44.75	55.97	40.12	4.25	135.06	8.27
	Credits	-29.23	-34.25	-34.03	-32.86	-47.44	-97.08	-97.11	-36.79
	net results	-38.24	-38.31	-46.26	-57.90	-41.02	-4.27	-135.64	-8.34
Acidification [kg SO2-e/1000 L]	Burdens	0.18	0.20	0.24	0.29	0.26	0.54	1.13	0.39
	Credits	-0.07	-0.08	-0.08	-0.08	-0.11	-0.19	-0.19	-0.07
	Net results	0.11	0.12	0.15	0.21	0.15	0.35	0.94	0.32
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	2.82	3.17	3.84	4.78	3.93	7.11	19.25	5.02
	Credits	-0.85	-0.96	-0.96	-0.93	-1.26	-2.17	-2.18	-0.85
	Net results	1.97	2.21	2.88	3.85	2.67	4.94	17.07	4.17
Ozone Depletion [g R11/1000 L]	Burdens	0.04	0.05	0.14	0.27	0.06	0.10	1.69	0.50
	Credits	-0.01	-0.02	-0.02	-0.02	-0.02	-0.09	-0.09	-0.04
	Net results	0.03	0.03	0.12	0.25	0.04	0.02	1.60	0.47
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	21.89	24.44	30.95	40.44	30.84	52.40	169.35	38.45
	Credits	-6.57	-7.47	-7.43	-7.22	-9.76	-17.48	-17.48	-6.70
	Net results	15.32	16.97	23.51	33.22	21.07	34.93	151.86	31.75
Aquatic Eutrophication [g PO4/1000 L]	Burdens	18.89	21.32	40.77	69.20	28.34	47.13	390.34	29.63
	Credits	-2.89	-2.92	-2.92	-2.92	-2.94	-1.17	-1.19	-1.25
	Net results	16.00	18.40	37.85	66.29	25.40	45.96	389.16	28.38
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	182.13	204.39	254.40	328.12	256.81	506.06	1396.93	365.27
	Credits	-65.96	-74.66	-74.27	-72.25	-96.60	-167.83	-167.88	-64.65
	Net results	116.18	129.74	180.13	255.86	160.21	338.23	1229.05	300.61
Total Primary Energy [GJ]	Burdens	1.56	1.84	1.84	1.83	2.41	5.28	5.24	3.28
	Credits	-0.74	-0.83	-0.83	-0.81	-1.06	-1.79	-1.79	-0.72
	Net results	0.82	1.01	1.01	1.02	1.35	3.49	3.44	2.57
Non-renewable Primary Energy [GJ]	Burdens	0.92	1.17	1.02	0.80	1.72	5.05	2.55	3.03
	Credits	-0.48	-0.57	-0.57	-0.55	-0.80	-1.63	-1.63	-0.66
	Net results	0.43	0.60	0.46	0.26	0.92	3.42	0.91	2.37
Use of Nature [m ² *year]	Burdens	21.60	21.71	27.50	35.97	21.97	0.55	100.07	0.67
	Credits	-4.21	-4.22	-4.22	-4.21	-3.99	-0.31	-0.31	-0.15
	Net results	17.39	17.49	23.28	31.75	17.98	0.24	99.76	0.51
Water use [m ³ /1000 L]	water cool	1.07	1.29	1.33	1.35	1.53	1.90	2.75	2.91
	water process	2.03	2.03	2.03	2.02	1.71	0.14	0.20	0.23
	water unspecified	0.20	0.24	0.30	0.38	0.48	1.00	2.41	0.80

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 2.4.3). Results are shown in the following break even graphs.

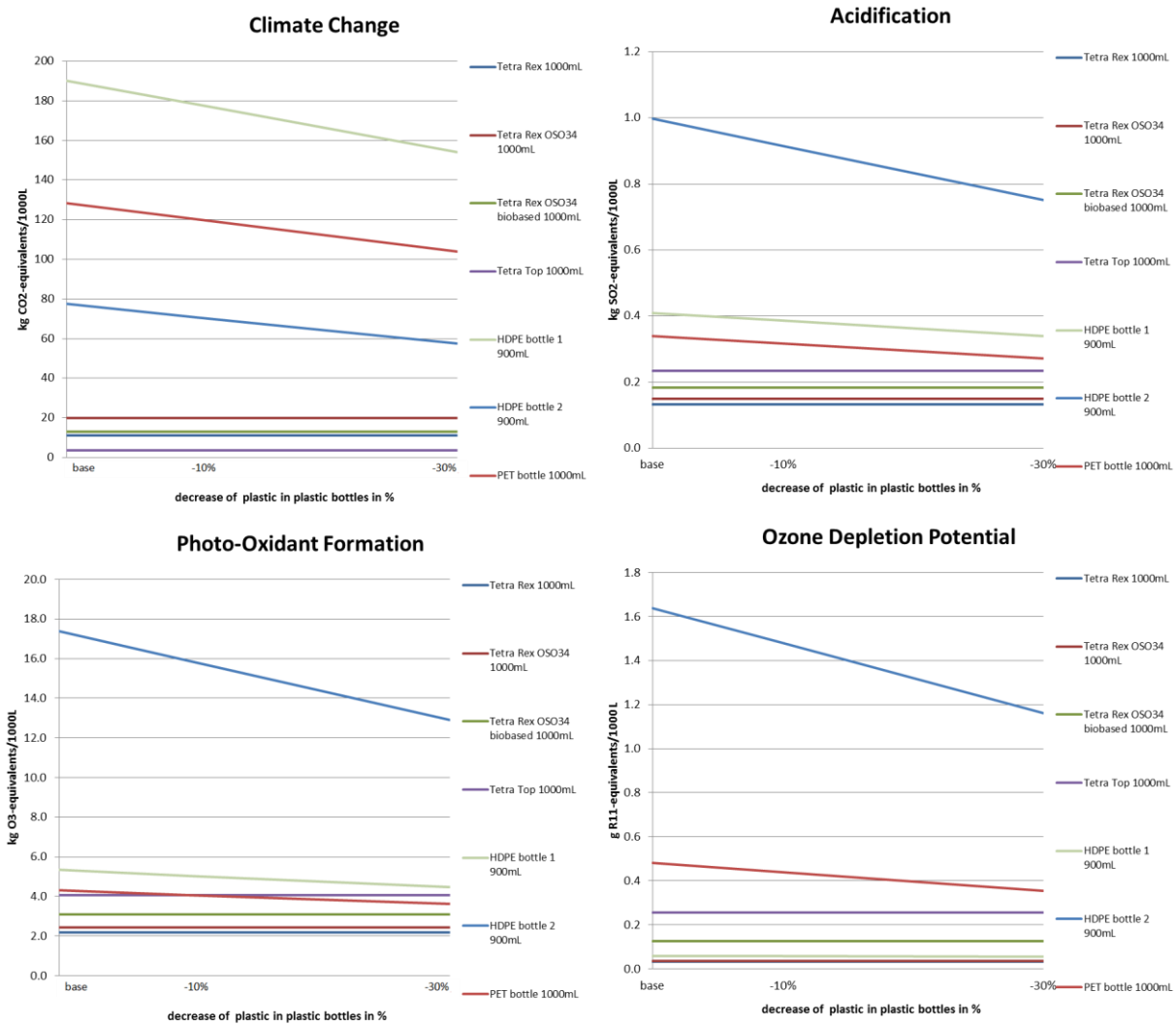


Figure 79: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Finland, allocation factor 50% (Part 1)

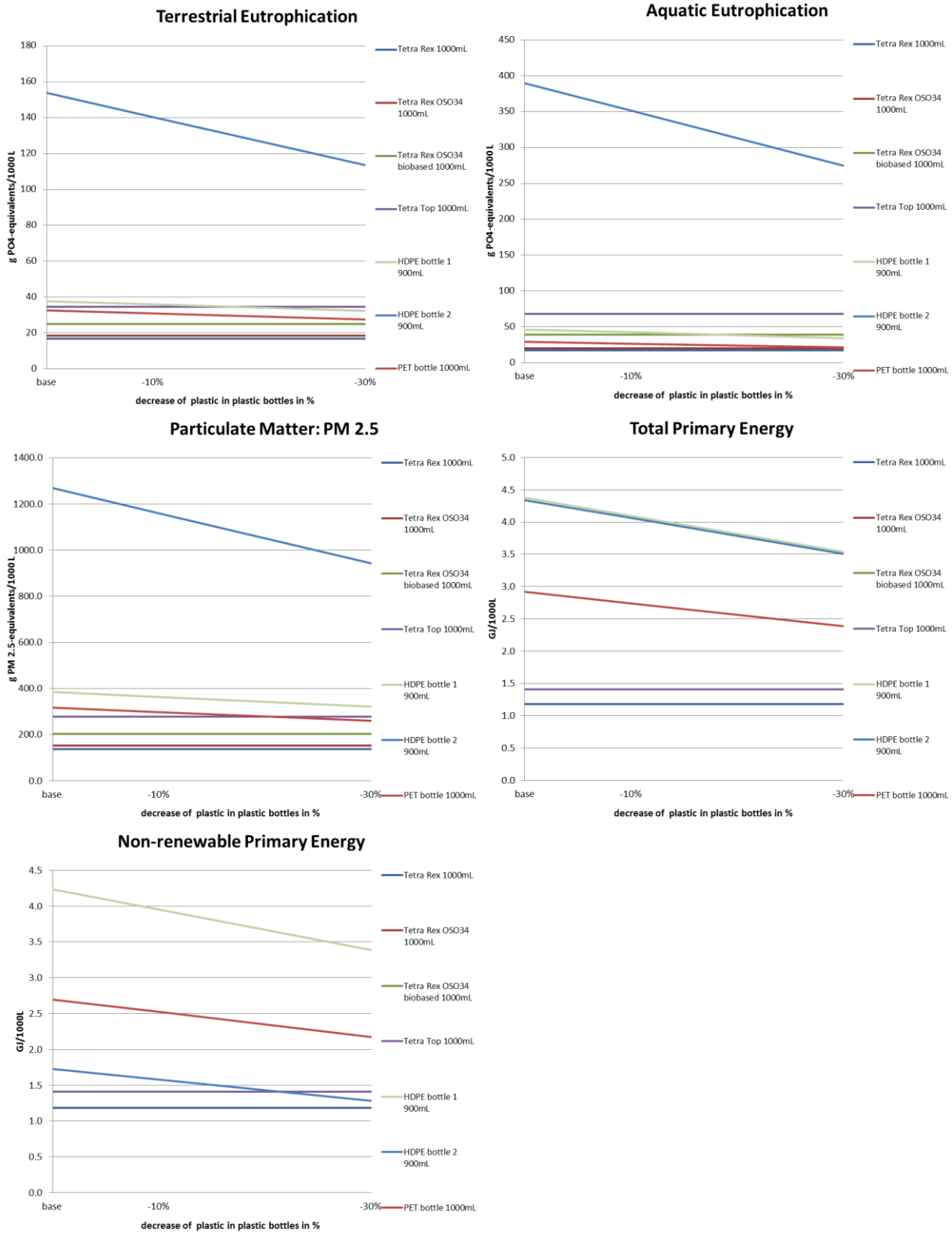


Figure 80: Indicator results for sensitivity analysis on plastic bottle weights of segment DAIRY, Finland, allocation factor 50% (Part 2)

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.

The lightweight bottles C does not break even with any beverage carton that showed lower results in the base scenarios.

The lightweight versions of the 'PET bottle 1' and the 'HDPE bottle 1' reach break-even with 'Tetra Rex fully bio-based' and 'Tetra Top' in some categories.

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.

8.2 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 81: Indicator results for sensitivity analysis on system allocation of segment JNSD, Finland, allocation factor 100% (Part 1)

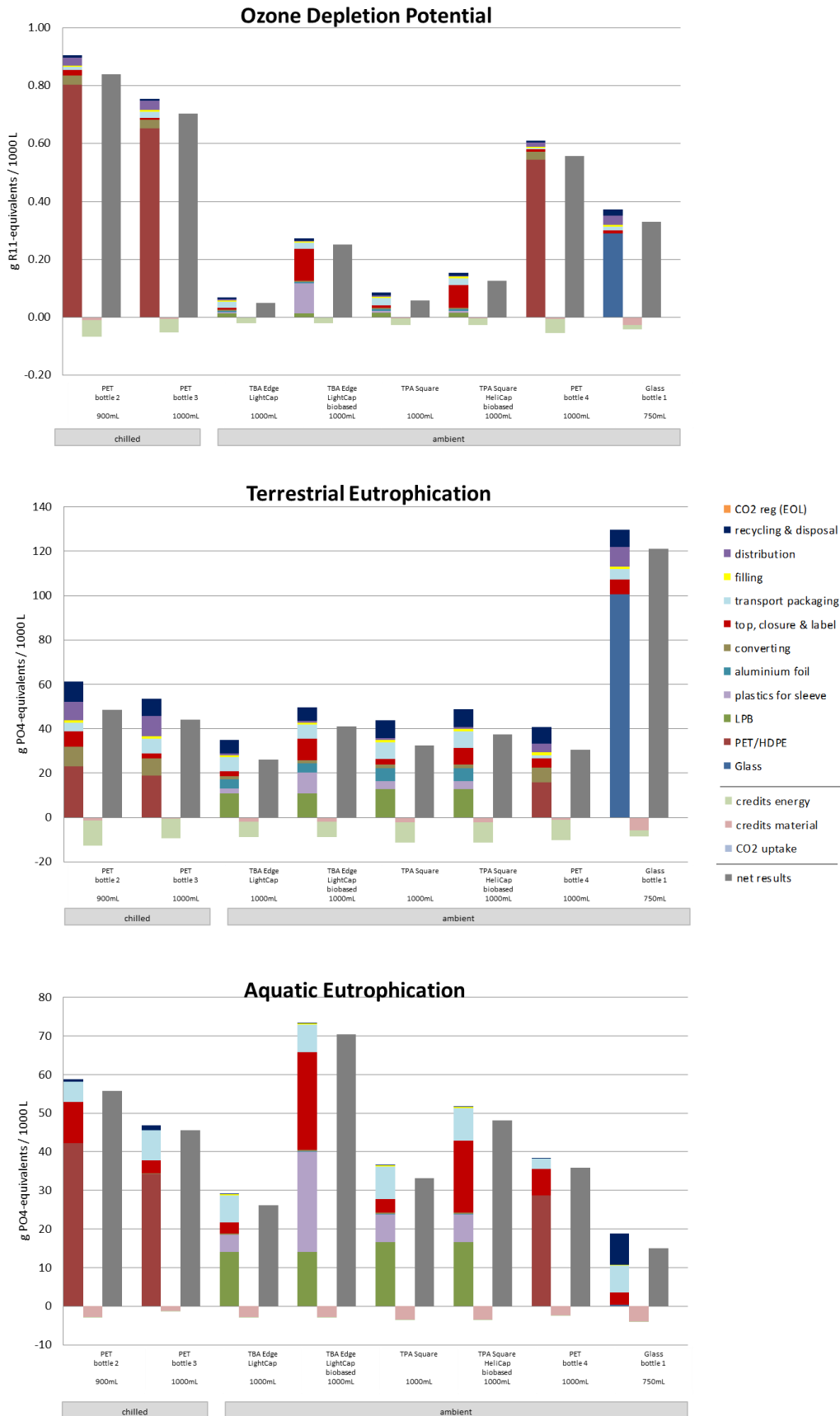


Figure 82: Indicator results for sensitivity analysis on system allocation of segment JNSD, Finland, allocation factor 100% (Part 2)

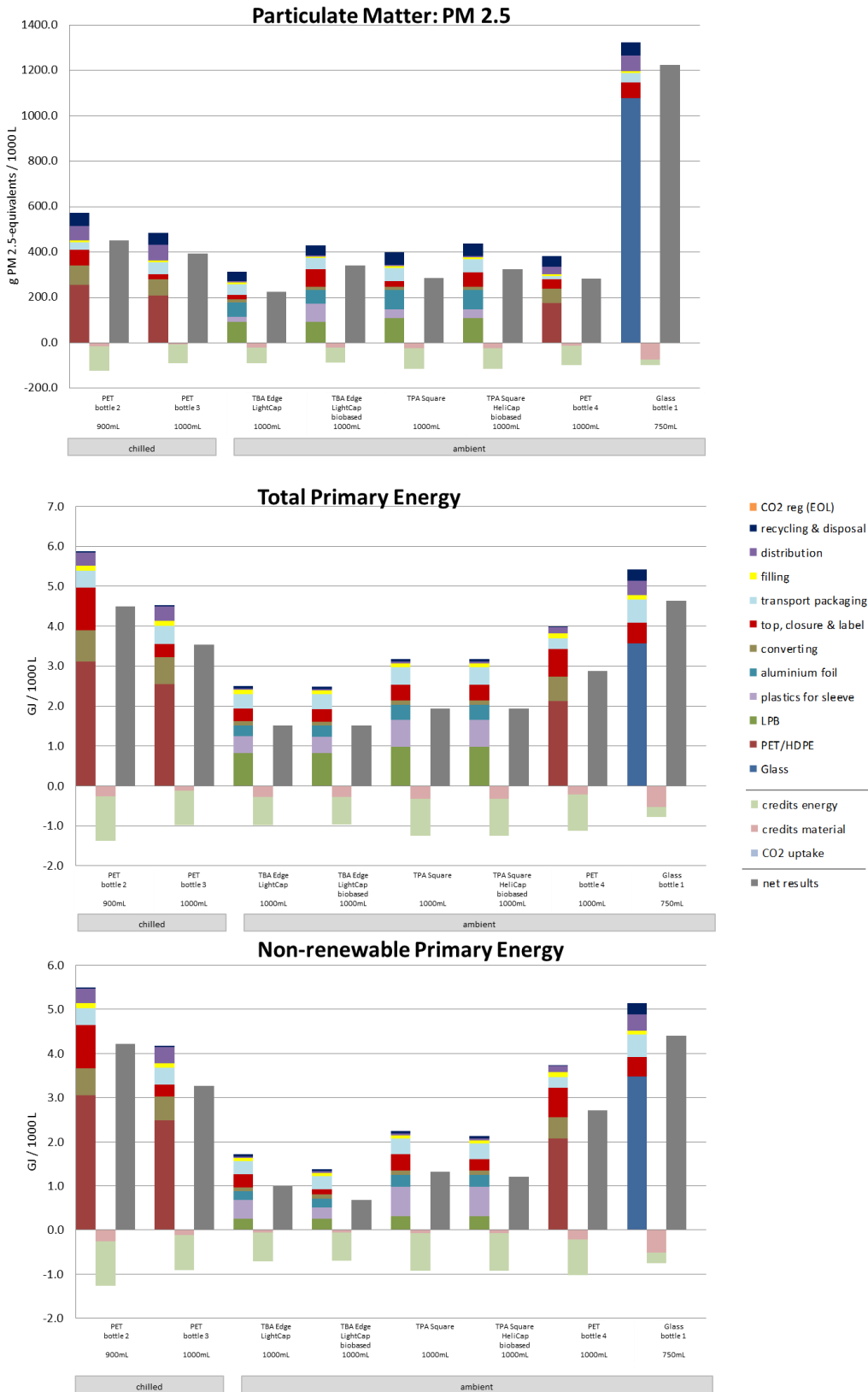


Figure 303: Indicator results for sensitivity analysis on system allocation of segment JNSD, Finland, allocation factor 100% (Part 3)

Table 93: Category indicator results per impact category for sensitivity analysis on system allocation of **segment JNSD, Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		PET bottle 2 900mL	PET bottle 3 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	306.81	251.34	106.85	92.11	140.71	135.86	220.76	389.19
	CO ₂ (reg)	11.48	15.50	42.57	59.94	50.53	56.42	3.83	11.53
	Credits	-69.19	-51.98	-42.73	-41.88	-55.45	-55.42	-55.99	-40.59
	CO ₂ uptake	-11.60	-15.69	-43.32	-61.39	-51.41	-57.56	-3.84	-12.47
	net results	237.50	199.17	63.36	48.77	84.39	79.30	164.76	347.66
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.60	0.51	0.33	0.41	0.42	0.45	0.40	1.34
	Credits	-0.14	-0.10	-0.10	-0.10	-0.13	-0.13	-0.11	-0.09
	Net results	0.46	0.40	0.23	0.31	0.30	0.32	0.29	1.24
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	8.09	6.82	4.39	5.87	5.52	6.04	5.43	16.45
	Credits	-1.63	-1.19	-1.15	-1.13	-1.48	-1.48	-1.32	-1.15
	Net results	6.47	5.64	3.23	4.74	4.04	4.56	4.11	15.29
Ozone Depletion [g R11/1000 L]	Burdens	0.91	0.76	0.07	0.27	0.09	0.15	0.61	0.37
	Credits	-0.07	-0.05	-0.02	-0.02	-0.03	-0.03	-0.05	-0.04
	Net results	0.84	0.70	0.05	0.25	0.06	0.13	0.56	0.33
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	61.18	53.40	34.96	49.73	43.74	48.78	40.72	129.64
	Credits	-12.67	-9.41	-8.93	-8.77	-11.45	-11.44	-10.25	-8.56
	Net results	48.51	43.98	26.04	40.96	32.29	37.34	30.47	121.08
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	58.73	46.82	29.13	73.30	36.62	51.67	38.33	18.86
	Credits	-2.91	-1.33	-2.93	-2.93	-3.48	-3.48	-2.39	-3.94
	Net results	55.82	45.49	26.19	70.36	33.14	48.19	35.94	14.92
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	573.56	483.19	314.56	428.65	398.47	436.89	382.19	1322.75
	Credits	-122.38	-90.80	-88.62	-87.15	-113.38	-113.33	-99.04	-97.11
	Net results	451.18	392.39	225.93	341.50	285.09	323.56	283.14	1225.64
Total Primary Energy [GJ]	Burdens	5.88	4.53	2.49	2.48	3.18	3.18	3.99	5.42
	Credits	-1.38	-0.99	-0.98	-0.96	-1.24	-1.24	-1.12	-0.78
	Net results	4.50	3.54	1.52	1.52	1.93	1.94	2.87	4.63
Non-renewable Primary Energy [GJ]	Burdens	5.49	4.18	1.72	1.38	2.24	2.13	3.74	5.14
	Credits	-1.27	-0.90	-0.72	-0.70	-0.93	-0.93	-1.03	-0.75
	Net results	4.22	3.27	1.00	0.67	1.31	1.20	2.71	4.39
Use of Nature [m ² /year]	Burdens	1.86	3.71	23.74	36.89	28.21	32.69	0.51	2.40
	Credits	-0.23	-0.19	-4.05	-4.05	-4.83	-4.83	-0.19	-0.10
	Net results	1.63	3.51	19.69	32.84	23.38	27.86	0.32	2.31
Water use [m ³ /1000 L]	water cool	4.32	3.46	1.50	1.54	1.76	1.80	2.86	1.61
	water process	0.25	0.20	2.10	2.09	2.52	2.52	0.13	5.47
	water unspecified	1.43	1.28	0.59	0.72	0.74	0.78	0.89	0.46

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 2.4.3). Results are shown in the following break even graphs.

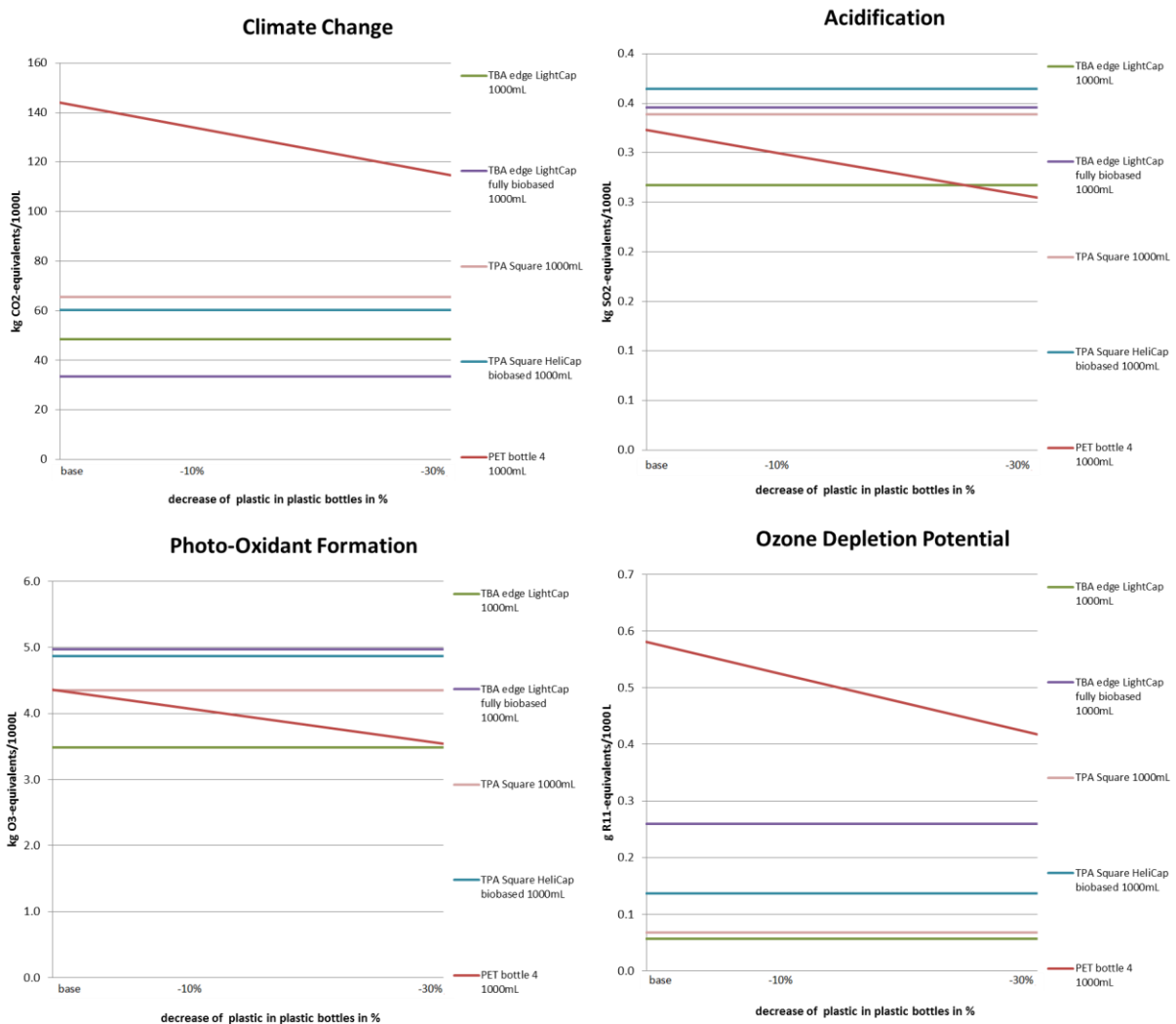


Figure 84: Indicator results for sensitivity analysis on plastic bottle weights of segment JNSD, Finland, allocation factor 50% (Part 1)

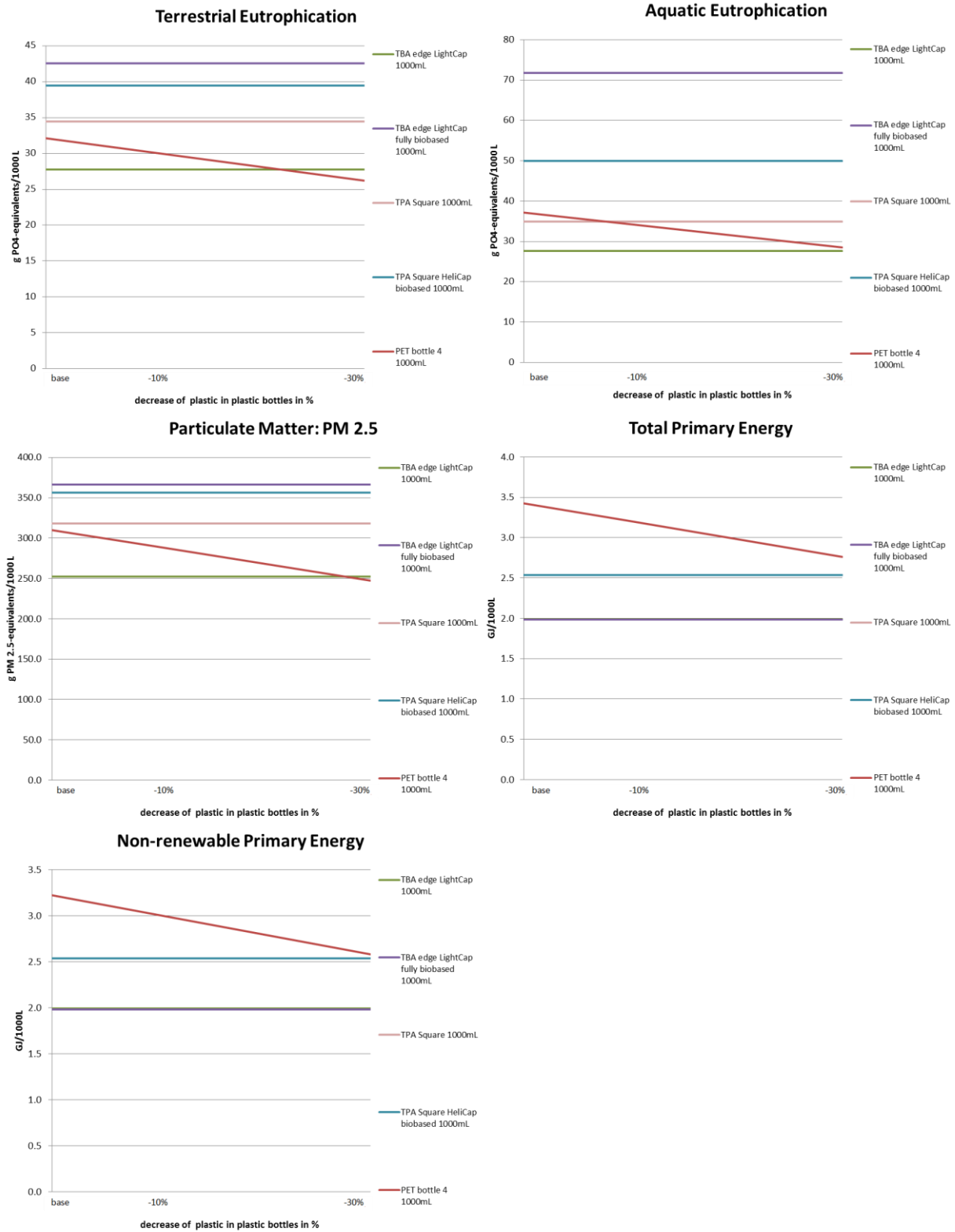


Figure 85: Indicator results for sensitivity analysis on plastic bottle weights segment JNSD, Finland, allocation factor 50% (Part 2)

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 the other impact categories with 'TPA square HeliCap bio-based'.

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)

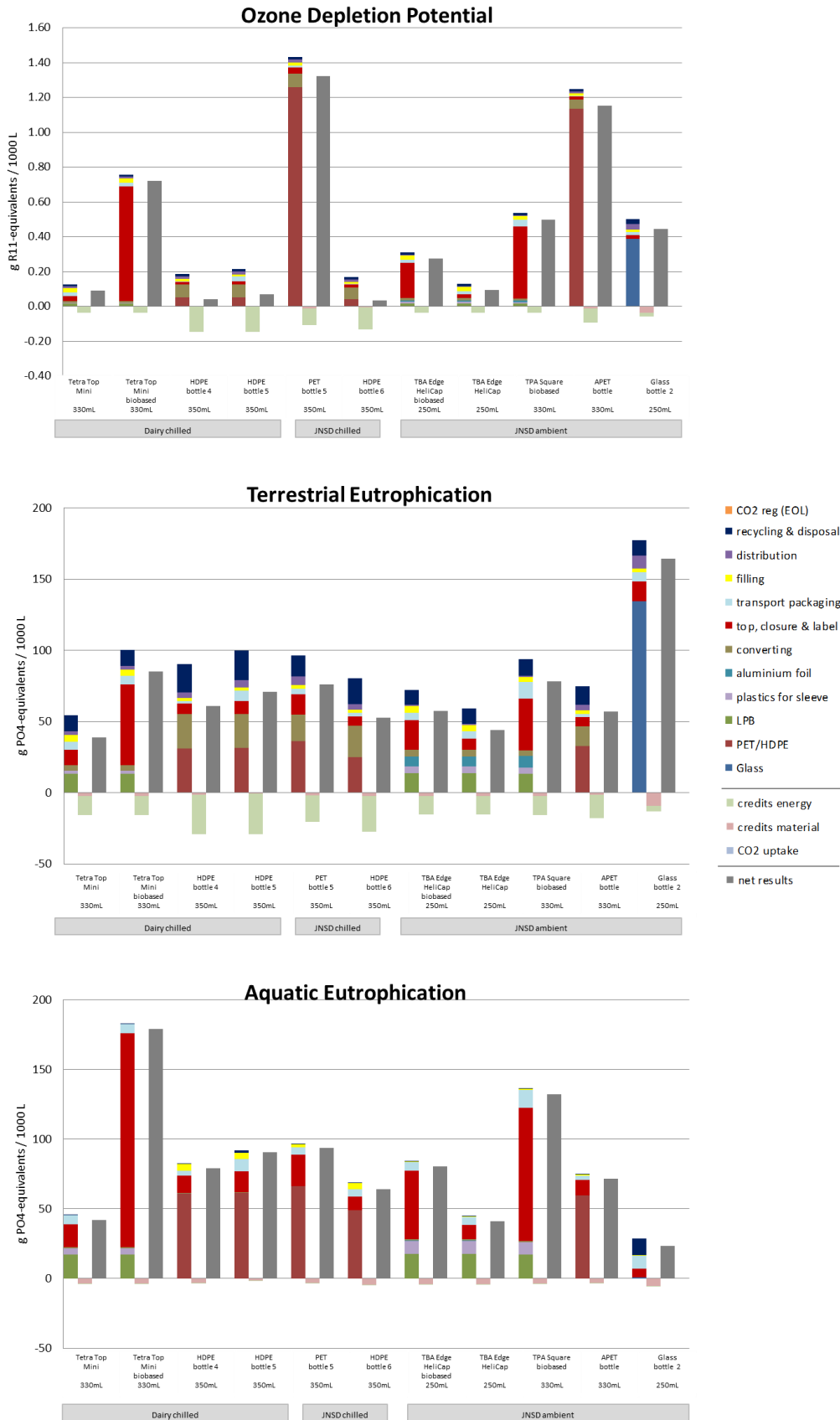


Figure 87: Indicator results for sensitivity analysis on system allocation of segment JNSD, Finland, allocation factor 100% (Part 2)

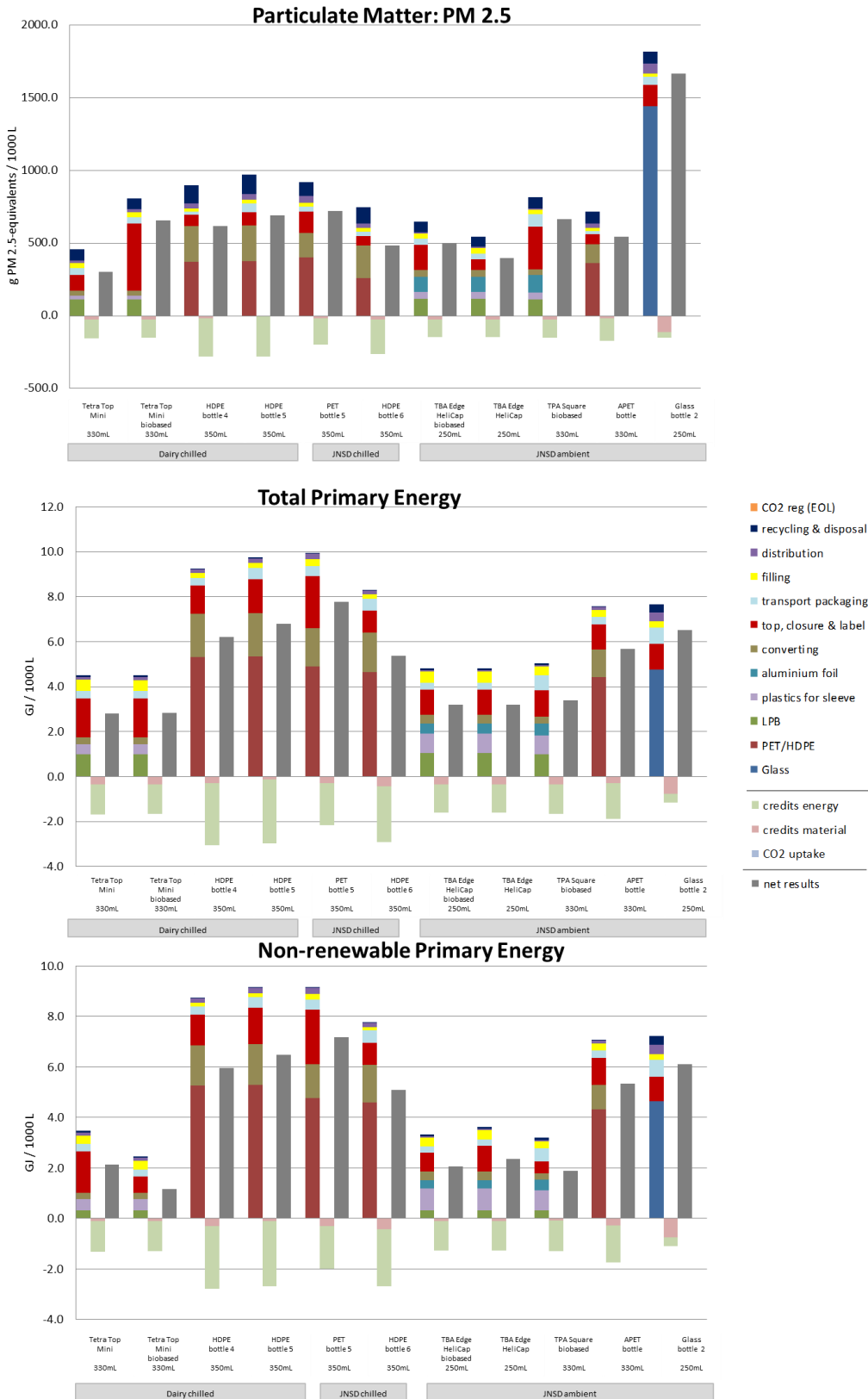


Figure 88: Indicator results for sensitivity analysis on system allocation of segment JNSD, Finland allocation factor 100% (Part 3)

Table 94: Category indicator results per impact category for sensitivity analysis on system allocation of **segment JNSD,Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL	PET bottle 5 350mL	HDPE bottle 6 350mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change [kg CO2-e/1000 L]	Burdens	203.71	159.89	542.49	572.51	498.05	477.47	201.17	213.91	206.67	414.20	542.57
	CO2 (reg)	51.37	103.74	3.80	12.39	10.89	9.88	67.49	52.05	89.81	3.73	15.86
	Credits	-78.99	-77.56	-161.73	-162.63	-112.64	-150.31	-74.96	-74.98	-77.90	-97.40	-64.75
	Net results	123.77	79.33	380.75	409.73	385.29	327.04	124.60	137.91	126.91	316.79	476.47
Acidification [kg SO2-e/1000 L]	Burdens	0.46	0.69	0.95	1.03	0.96	0.76	0.64	0.57	0.78	0.75	1.84
	Credits	-0.17	-0.17	-0.32	-0.32	-0.22	-0.30	-0.16	-0.16	-0.17	-0.19	-0.15
	Net results	0.29	0.53	0.63	0.71	0.74	0.46	0.47	0.41	0.61	0.56	1.69
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	6.96	11.72	12.23	13.21	12.80	10.86	9.04	7.68	11.22	9.99	22.49
	Credits	-2.03	-2.00	-3.67	-3.62	-2.59	-3.48	-1.95	-1.95	-2.01	-2.26	-1.73
	Net results	4.93	9.72	8.55	9.60	10.21	7.38	7.09	5.73	9.21	7.73	20.75
Ozone Depletion [g R11/1000 L]	Burdens	0.13	0.76	0.19	0.22	1.43	0.17	0.31	0.13	0.54	1.25	0.50
	Credits	-0.04	-0.04	-0.14	-0.15	-0.11	-0.13	-0.04	-0.04	-0.04	-0.09	-0.06
	Net results	0.09	0.72	0.04	0.07	1.32	0.03	0.27	0.09	0.50	1.15	0.44
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	54.48	100.48	90.38	99.94	96.46	80.25	72.35	59.21	93.85	74.80	177.10
	Credits	-15.74	-15.48	-29.26	-29.21	-20.48	-27.37	-15.06	-15.06	-15.51	-17.74	-12.99
	Net results	38.74	85.00	61.12	70.73	75.98	52.88	57.29	44.14	78.33	57.06	164.12
Aquatic Eutrophication [g PO4/1000 L]	Burdens	45.80	182.89	82.24	92.07	96.98	68.85	84.20	44.97	136.14	75.01	28.68
	Credits	-3.78	-3.77	-3.29	-1.30	-3.35	-4.71	-3.86	-3.86	-3.73	-3.24	-5.31
	Net results	42.02	179.12	78.96	90.77	93.63	64.14	80.34	41.11	132.41	71.78	23.37
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	457.08	807.81	897.18	970.55	918.47	748.02	645.28	545.12	814.98	716.85	1814.45
	Credits	-154.75	-152.27	-281.32	-280.30	-197.47	-263.52	-148.31	-148.34	-152.62	-171.21	-148.65
	Net results	302.33	655.53	615.86	690.25	721.00	484.50	496.96	396.78	662.37	545.64	1665.79
Total Primary Energy [GJ]	Burdens	4.50	4.49	9.25	9.75	9.94	8.30	4.80	4.80	5.04	7.57	7.66
	Credits	-1.68	-1.66	-3.05	-2.96	-2.17	-2.92	-1.62	-1.62	-1.66	-1.89	-1.16
	Net results	2.81	2.84	6.21	6.78	7.77	5.38	3.19	3.18	3.38	5.68	6.51
Non-renewable Primary Energy [GJ]	Burdens	3.47	2.46	8.75	9.17	9.16	7.78	3.32	3.61	3.19	7.08	7.23
	Credits	-1.33	-1.30	-2.79	-2.70	-1.99	-2.69	-1.26	-1.26	-1.31	-1.74	-1.11
	Net results	2.14	1.16	5.96	6.47	7.17	5.10	2.06	2.35	1.89	5.34	6.12
Use of Nature [m²*year]	Burdens	28.66	68.98	1.00	4.69	2.35	1.20	41.14	29.47	57.10	0.84	3.55
	Credits	-5.01	-5.00	-0.48	-0.49	-0.34	-0.44	-5.13	-5.13	-4.97	-0.30	-0.12
	Net results	23.65	63.97	0.52	4.20	2.01	0.76	36.02	24.34	52.13	0.55	3.43
Water use [m³/1000 L]	water cool	3.50	3.87	5.58	5.73	8.82	4.48	4.26	4.15	4.03	6.10	2.69
	water process	2.19	2.17	2.82	2.83	1.60	2.38	2.93	2.94	2.85	0.77	12.84
	water unspecified	0.84	1.30	1.65	2.08	2.30	1.08	0.97	0.86	1.41	1.81	0.95

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 analysed and illustrated in this sensitivity analysis (for details please see section 2.4.3). Results are shown in the following break even graphs.

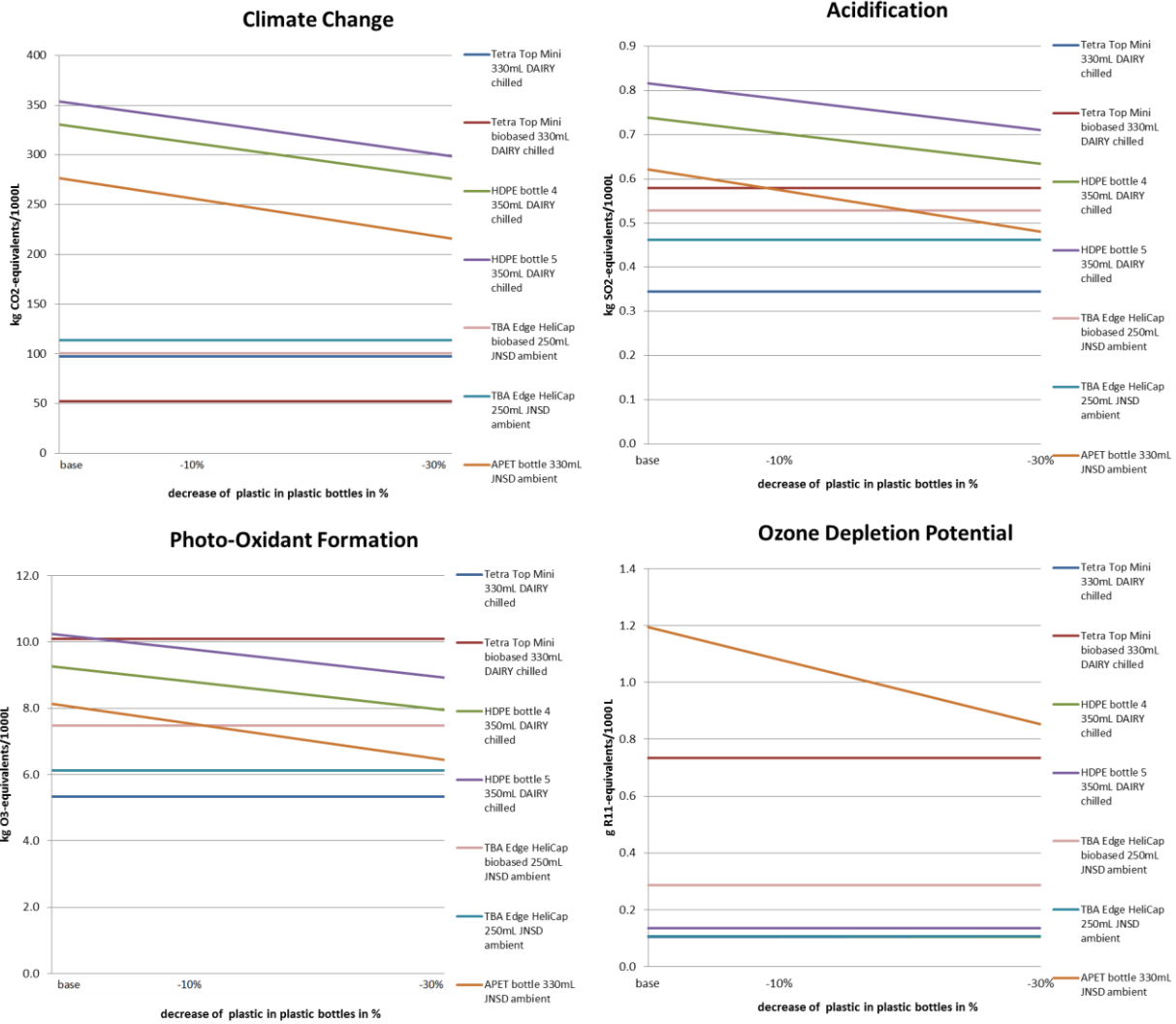


Figure 89: Indicator results for sensitivity analysis on plastic bottle weights of segment Grab & Go, Finland, allocation factor 50% (Part 1)

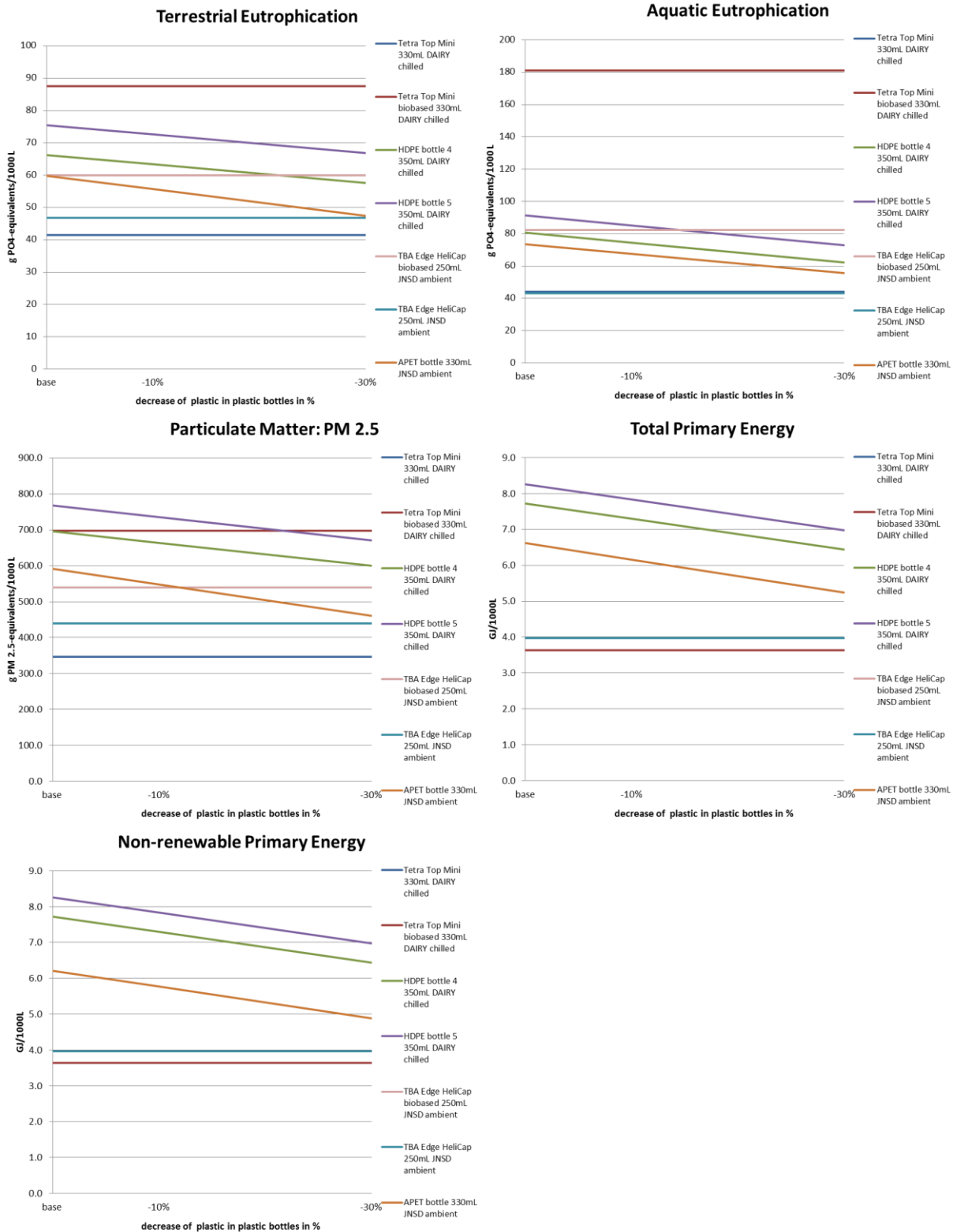


Figure 90: Indicator results for sensitivity analysis on plastic bottle weights segment Grab & Go, Finland, allocation factor 50% (Part 2)

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' and 'Ozone Depletion Potential'.

The 'HDPE bottle 4' and HDPE bottle 5' break even with some of the beverage cartons in the other impact categories.

8.4 Water Finland

8.4.1 Sensitivity analysis on system allocation WATER Finland

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%.

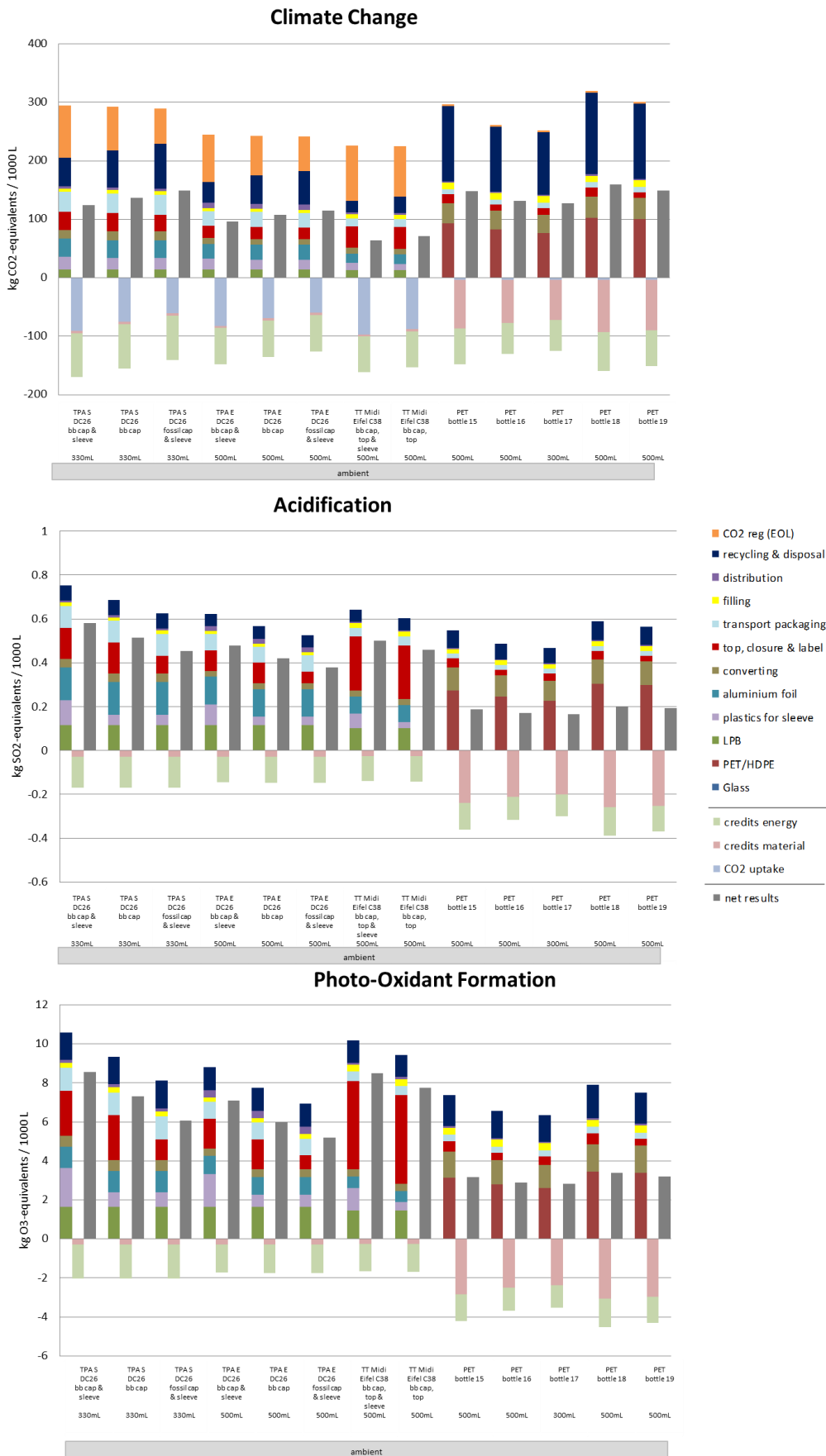


Figure 91: Indicator results for sensitivity analysis on system allocation of segment Water, Finland, allocation factor 100% (Part 1)

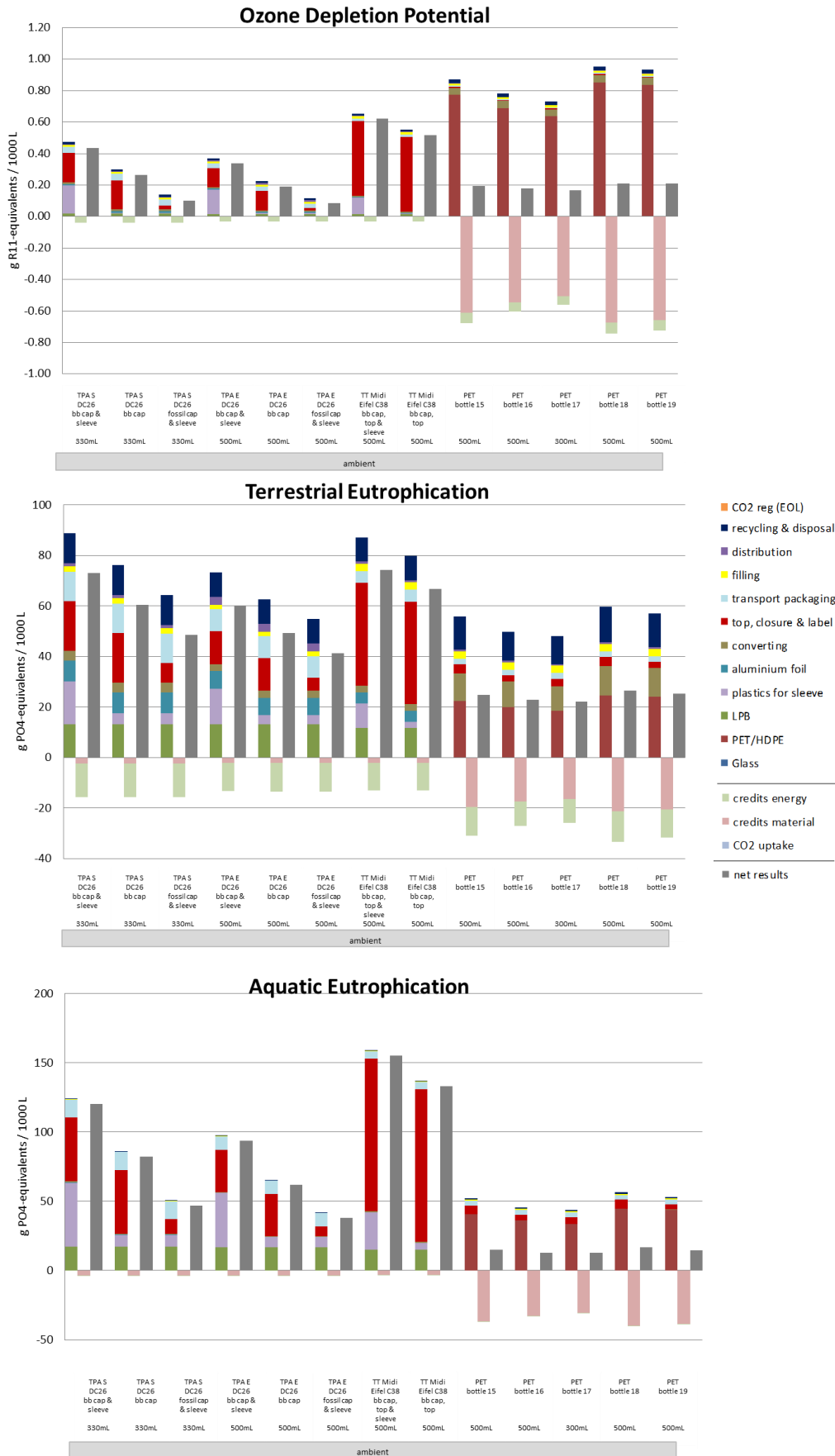


Figure 92: Indicator results for sensitivity analysis on system allocation of segment Water, Finland, allocation factor 100% (Part 2)

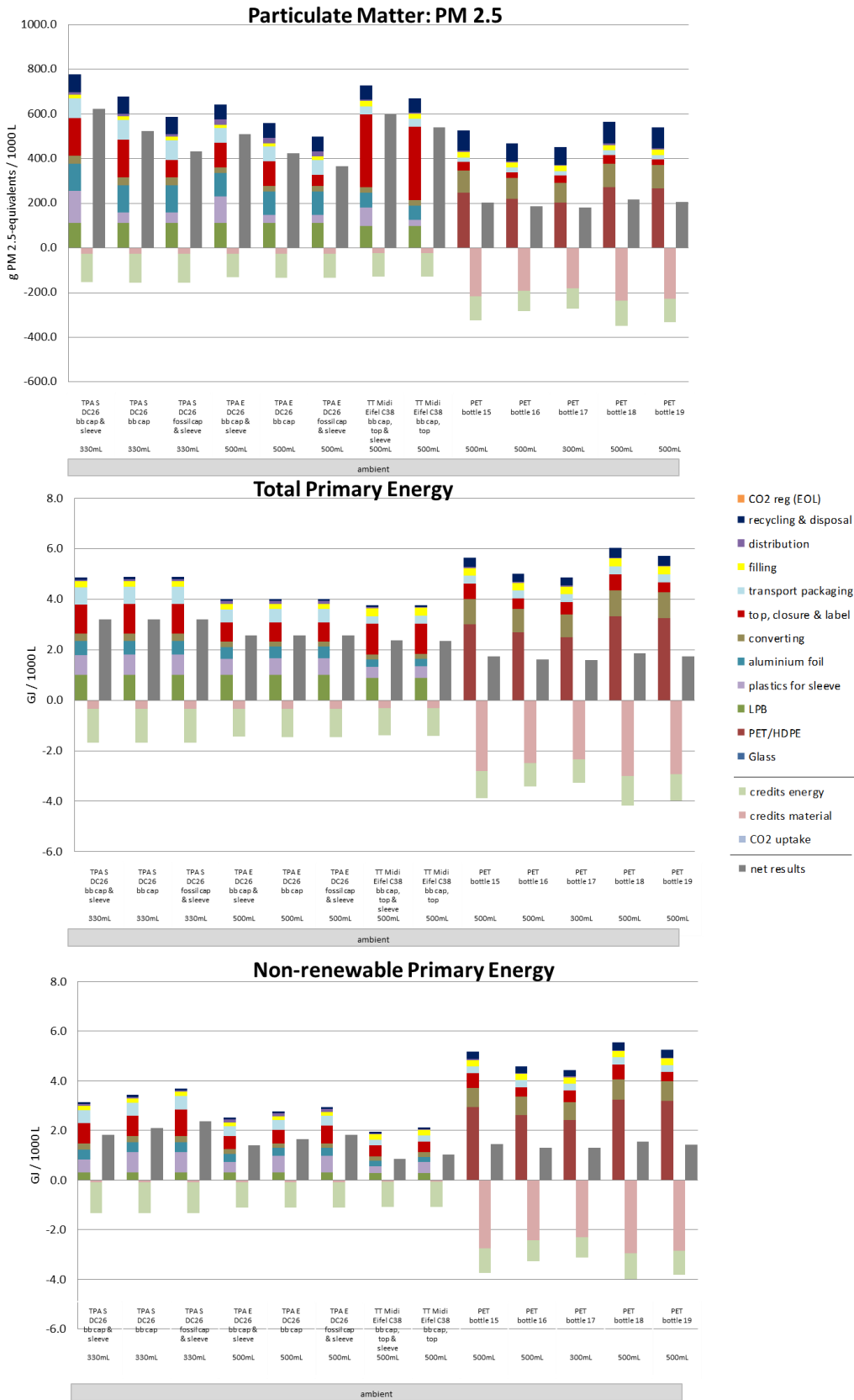


Figure 93: Indicator results for sensitivity analysis on system allocation of segment Water, Finland, allocation factor 100% (Part 3)

Table 95: Category indicator results per impact category for sensitivity analysis on system allocation of **Water, Finland**- burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 15 500mL	PET bottle 16 500mL	PET bottle 17 500mL	PET bottle 18 500mL	PET bottle 19 500mL
Climate Change [kg CO2-e/1000 L]	Burdens	204.97	217.70	229.32	164.24	175.03	182.69	131.60	139.05	293.74	258.28	249.48	316.35	297.42
	CO2 (reg)	89.31	74.44	60.38	80.41	67.82	58.54	94.21	85.50	3.11	3.11	3.11	3.11	3.11
	Credits	-79.04	-79.56	-79.58	-66.09	-66.65	-66.69	-64.29	-65.35	-145.15	-126.78	-121.59	-156.27	-147.68
	CO2 uptake	-90.88	-75.46	-60.95	-82.01	-68.95	-59.35	-96.97	-87.94	-3.13	-3.13	-3.13	-3.13	-3.13
	Net results	124.36	137.12	149.17	96.56	107.25	115.19	64.55	71.27	148.56	131.48	127.86	160.05	149.71
Acidification [kg SO2-e/1000 L]	Burdens	0.75	0.68	0.62	0.62	0.57	0.53	0.64	0.60	0.55	0.49	0.47	0.59	0.56
	Credits	-0.17	-0.17	-0.17	-0.15	-0.15	-0.15	-0.14	-0.14	-0.36	-0.32	-0.30	-0.39	-0.37
	Net results	0.58	0.51	0.45	0.48	0.42	0.38	0.50	0.46	0.19	0.17	0.17	0.20	0.19
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	10.60	9.34	8.11	8.81	7.75	6.93	10.18	9.45	7.37	6.57	6.33	7.90	7.51
	Credits	-2.03	-2.04	-2.04	-1.73	-1.74	-1.74	-1.67	-1.69	-4.20	-3.69	-3.52	-4.52	-4.30
	Net results	8.57	7.31	6.07	7.08	6.01	5.19	8.51	7.75	3.17	2.88	2.81	3.38	3.21
Ozone Depletion [g R11/1000 L]	Burdens	0.47	0.30	0.14	0.37	0.22	0.12	0.65	0.55	0.87	0.78	0.73	0.96	0.94
	Credits	-0.04	-0.04	-0.04	-0.03	-0.03	-0.03	-0.03	-0.03	-0.68	-0.60	-0.56	-0.74	-0.73
	Net results	0.44	0.26	0.10	0.34	0.19	0.08	0.62	0.52	0.20	0.18	0.17	0.21	0.21
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	88.68	76.10	64.20	73.34	62.68	54.81	87.08	79.70	55.78	49.82	48.05	59.77	56.90
	Credits	-15.69	-15.78	-15.78	-13.37	-13.47	-13.47	-12.93	-13.12	-30.96	-27.11	-26.91	-33.36	-31.69
	Net results	73.00	60.32	48.42	59.98	49.21	41.33	74.15	66.58	24.83	22.72	22.14	26.40	25.22
Aquatic Eutrophication [g PO4/1000 L]	Burdens	123.77	86.10	50.59	97.22	65.31	41.81	158.67	136.61	52.00	45.49	43.63	56.38	53.13
	Credits	-3.66	-3.66	-3.66	-3.62	-3.62	-3.62	-3.28	-3.28	-36.82	-32.62	-30.72	-39.67	-38.55
	Net results	120.11	82.44	46.92	93.61	61.70	38.20	155.39	133.32	15.17	12.87	12.92	16.71	14.58
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	776.06	678.40	587.72	640.83	558.11	498.11	727.77	670.56	526.81	469.14	450.86	566.18	539.51
	Credits	-154.21	-155.12	-155.14	-131.85	-132.82	-132.90	-127.34	-129.18	-323.43	-283.61	-270.47	-348.93	-332.19
	Net results	621.85	523.29	432.58	508.98	425.28	365.21	600.42	541.38	203.38	185.53	180.39	217.24	207.31
Total Primary Energy [GJ]	Burdens	4.86	4.88	4.88	4.00	4.02	4.01	3.75	3.76	5.64	5.01	4.85	6.04	5.72
	Credits	-1.67	-1.68	-1.68	-1.44	-1.45	-1.45	-1.39	-1.41	-3.89	-3.41	-3.26	-4.17	-3.97
	Net results	3.19	3.19	3.19	2.56	2.56	2.56	2.37	2.36	1.75	1.61	1.59	1.86	1.74
Non-renewable Primary Energy [GJ]	Burdens	3.14	3.43	3.70	2.52	2.76	2.94	1.94	2.11	5.17	4.58	4.43	5.55	5.24
	Credits	-1.33	-1.33	-1.33	-1.11	-1.12	-1.12	-1.08	-1.09	-3.73	-3.27	-3.13	-4.00	-3.82
	Net results	1.81	2.10	2.36	1.41	1.65	1.82	0.86	1.02	1.44	1.31	1.30	1.55	1.43
Use of Nature [m²*year]	Burdens	53.54	42.32	31.75	46.29	36.78	29.79	60.49	53.92	1.20	1.16	1.15	1.22	1.20
	Credits	-4.90	-4.91	-4.91	-4.89	-4.89	-4.89	-4.49	-4.49	-0.20	-0.17	-0.17	-0.21	-0.19
	Net results	48.63	37.41	26.84	41.40	31.90	24.90	56.00	49.43	1.00	0.98	0.98	1.00	0.00
Water use [m³/1000 L]	water cool	3.43	3.41	3.32	2.70	2.69	2.63	2.98	2.96	3.85	3.67	3.55	3.99	3.98
	water process	2.72	2.73	2.74	2.64	2.65	2.66	2.14	2.15	0.63	0.61	0.61	0.64	0.64
	water unspecified	1.37	1.26	1.16	1.06	0.96	0.90	1.13	1.06	0.39	0.34	0.34	0.43	0.39

8.4.2 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 2.4.3). Results are shown in the following break even graphs.

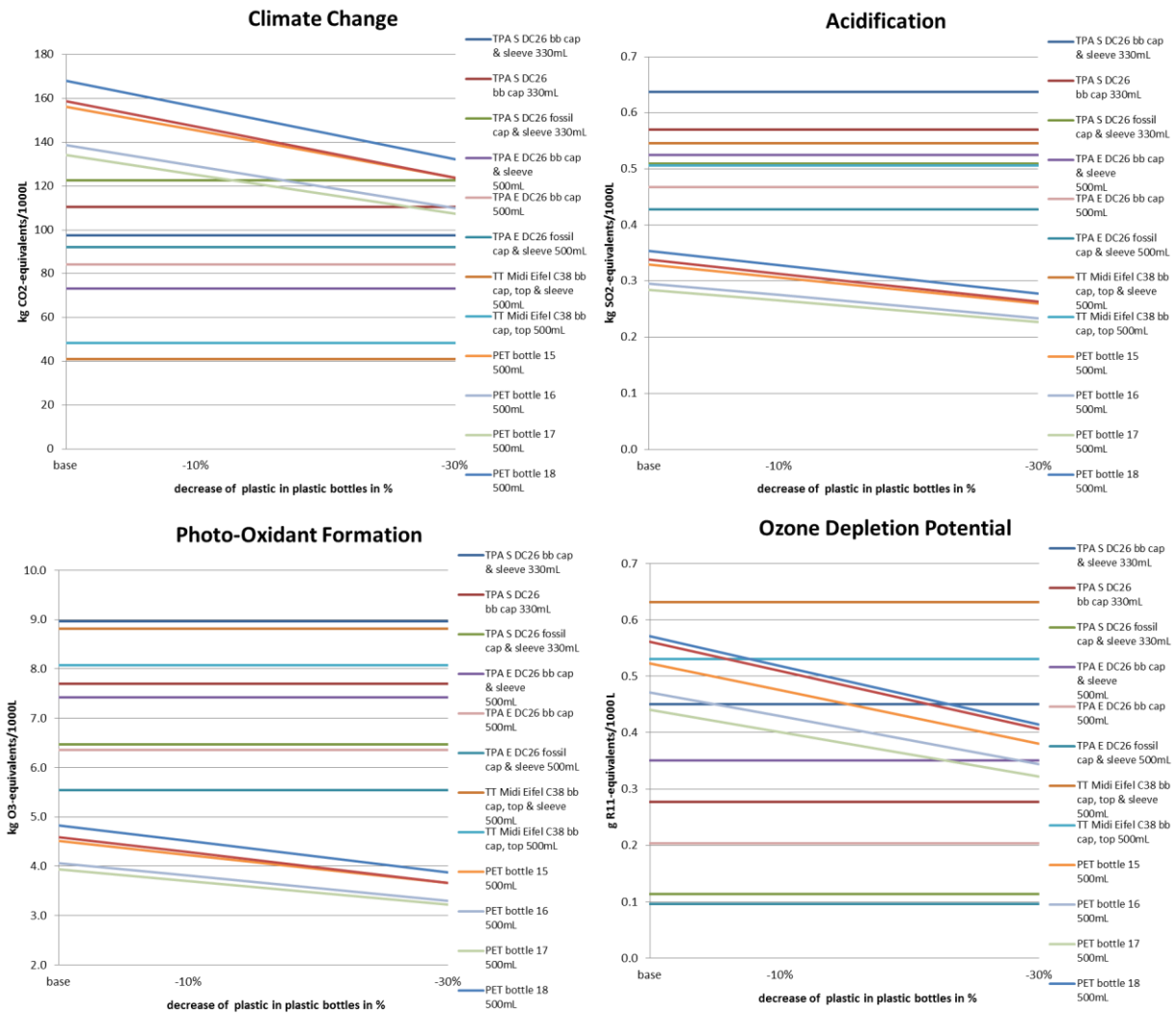


Figure 94: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Finland, allocation factor 50% (Part 1)

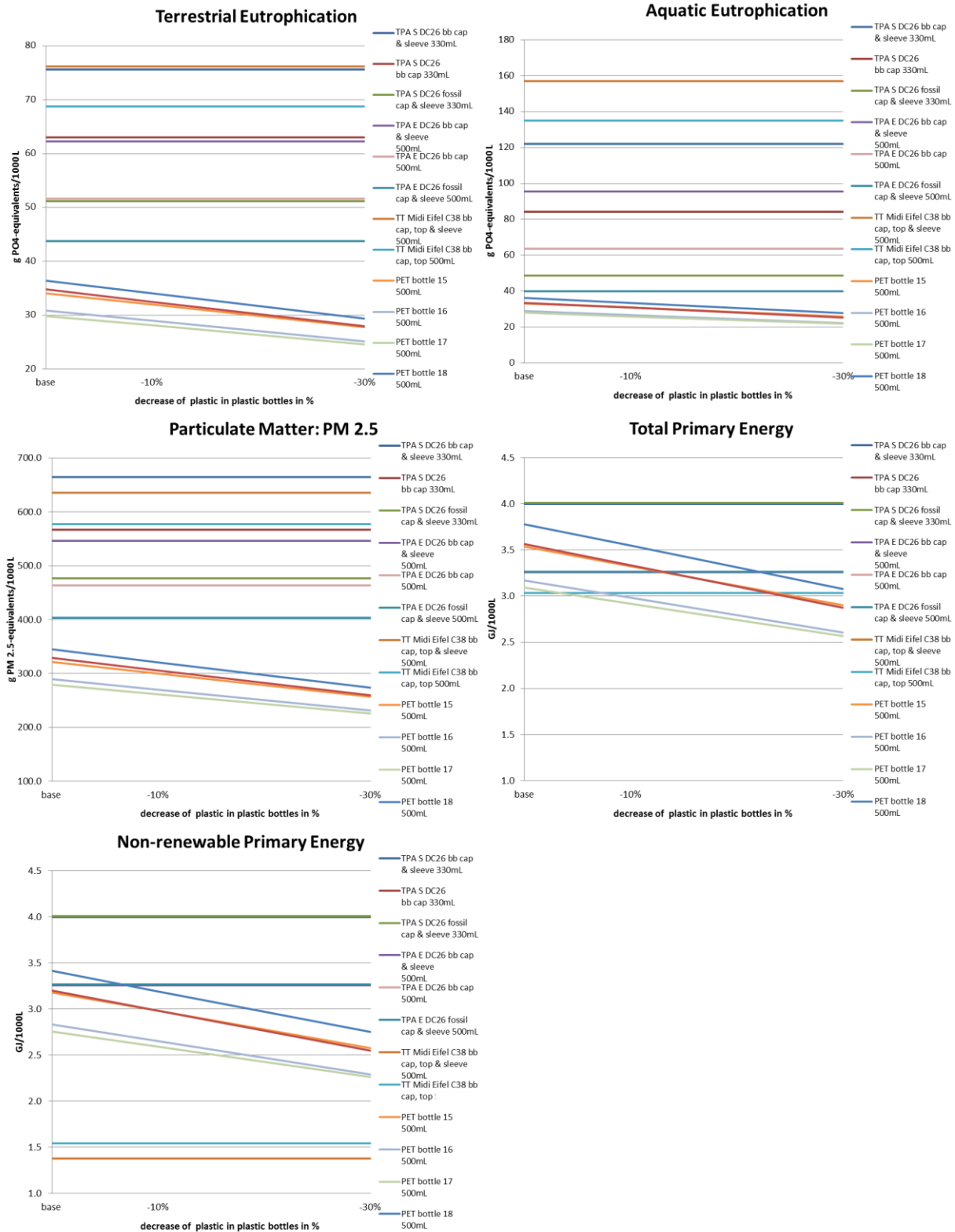


Figure 95: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Finland, allocation factor 50% (Part 2)

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In all categories where the base versions of the bottles showed higher results than the beverage cartons break even points are reached with at least some beverage cartons.

8.4.3 Sensitivity analysis regarding recycled PET in PET bottles

To consider potential future developments in terms of the share of recyclate of the plastic bottles, two additional scenarios for plastic bottles with a recycled content of PET of 50% and 100% 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.

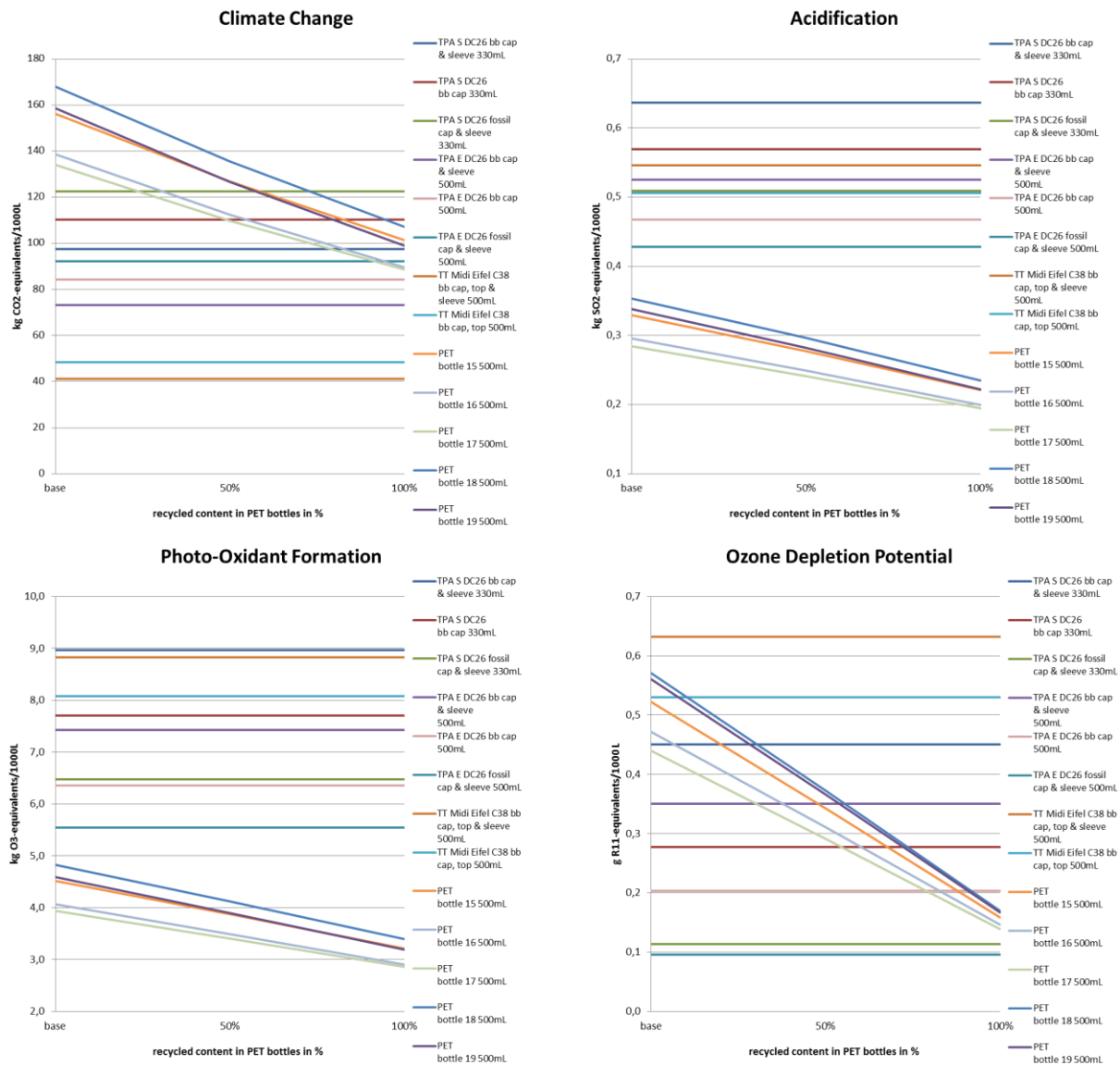


Figure 96: Indicator results for sensitivity analysis regarding recycled PET of segment Water, Finland, allocation factor 50% (Part 1)

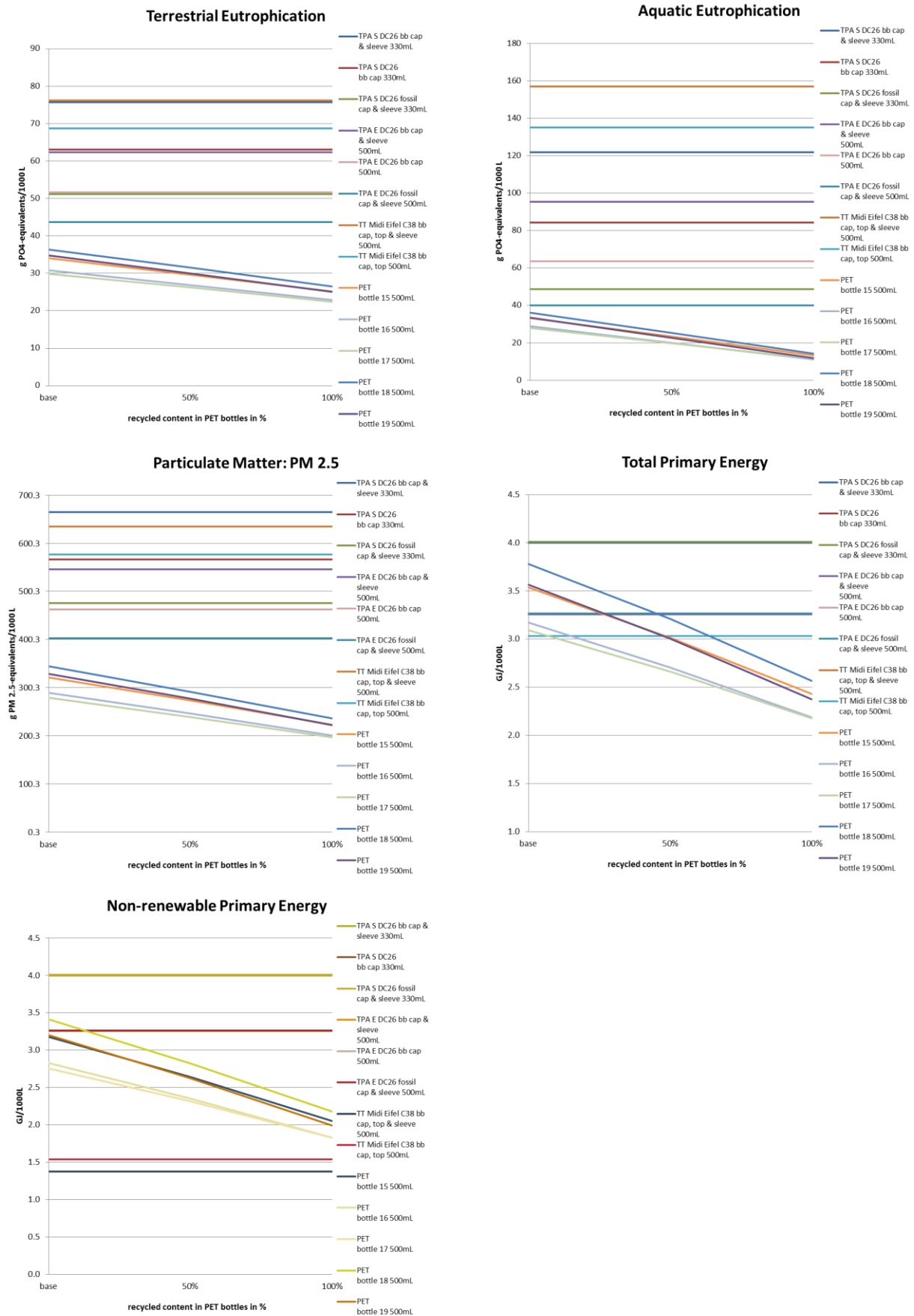


Figure 97: Indicator results for sensitivity analysis regarding recycled PET of segment Water, Finland, allocation factor 50% (Part 2)

In all categories, in which PET bottles without recycled content show higher results than the examined beverage cartons, an increased share of recycled content leads to break even points with at least some beverage cartons.

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 CO₂-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.

9.4 Water Finland

In the segment water no unambiguous result can be observed. While all examined beverage cartons show lower 'Climate Change' results than all the examined PET bottles, in other categories the beverage cartons often show higher impacts. Especially beverage cartons with a high share of biobased polyethylene show higher results than the bottles in

the categories 'Acidification', 'Photo-Oxidant Formation', 'Terrestrial and Aquatic Eutrophication'

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

10 Results 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. TiO₂ (**'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 CO₂ (**'recycling/disposal'**)
- CO₂ 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 atmospheric CO₂ during the plant growth phase ('CO₂-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 subtraction 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.

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

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 $\leq 10\%$ are considered as insignificant.

10.1 Results DAIRY Norway

10.1.1 Presentation of results DAIRY Norway

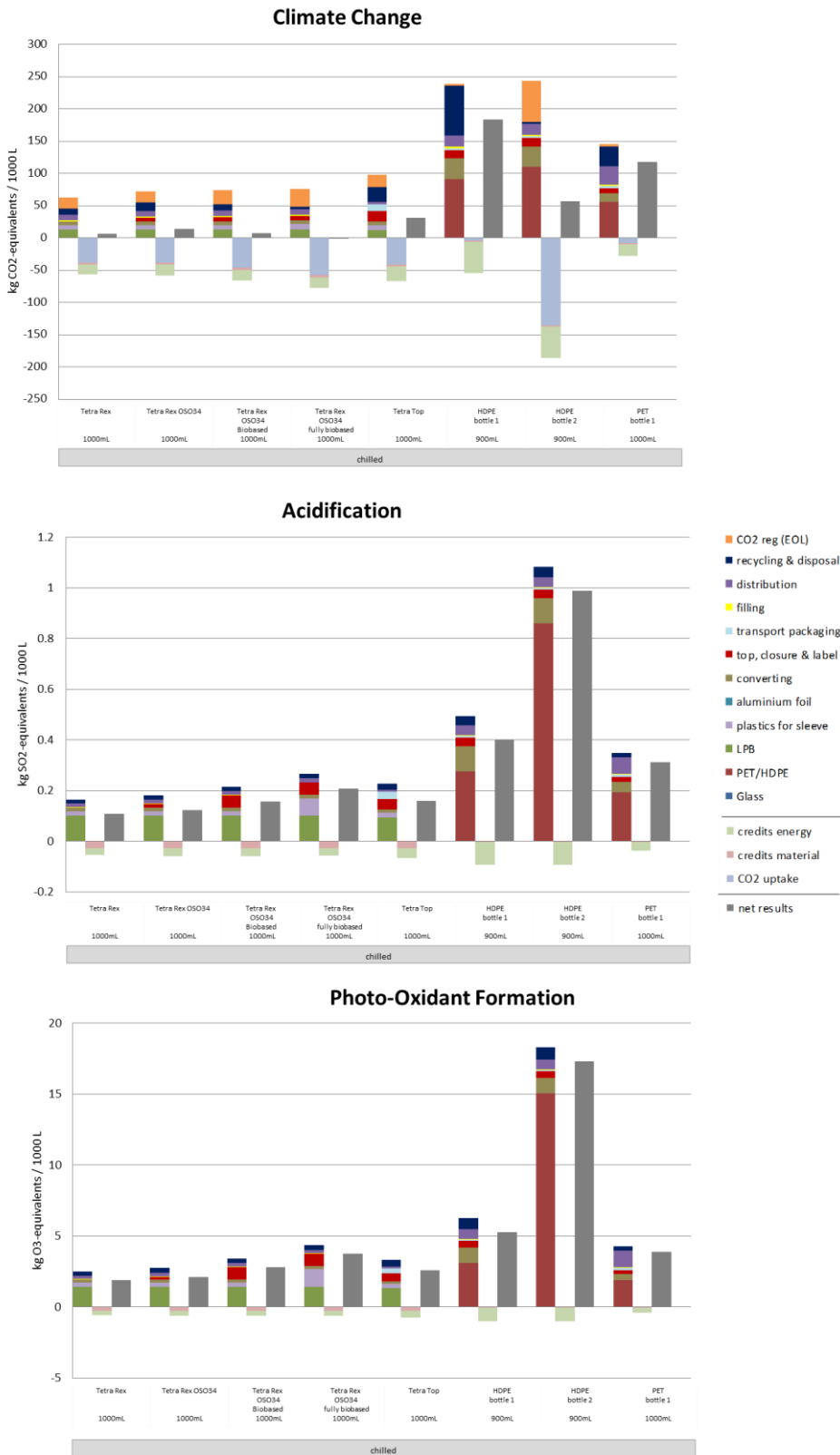


Figure 98: Indicator results for base scenarios of segment Dairy, Norway, allocation factor 50% (Part 1)

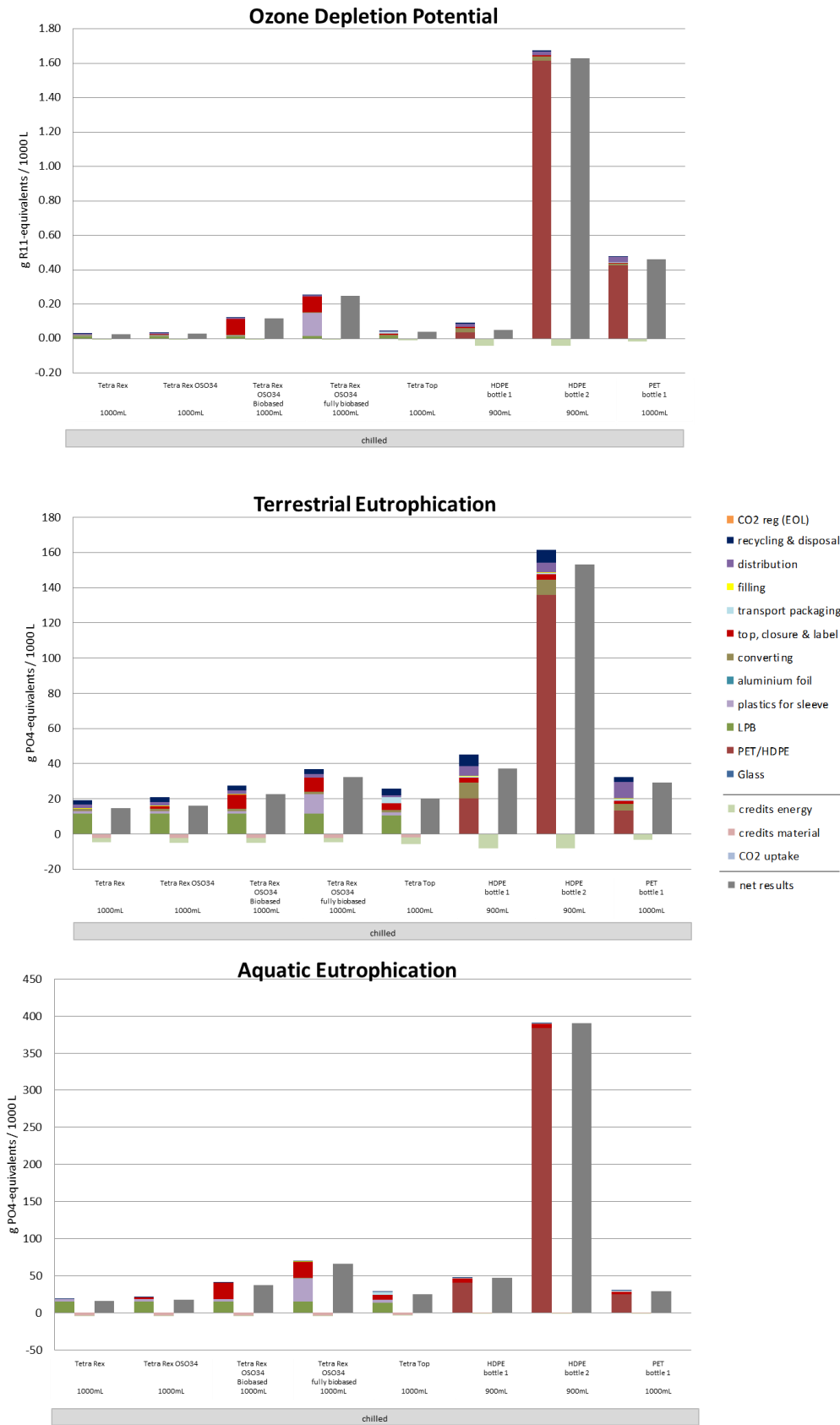


Figure 99 Indicator results for base scenarios of segment Dairy, Norway, allocation factor 50% (Part 2)

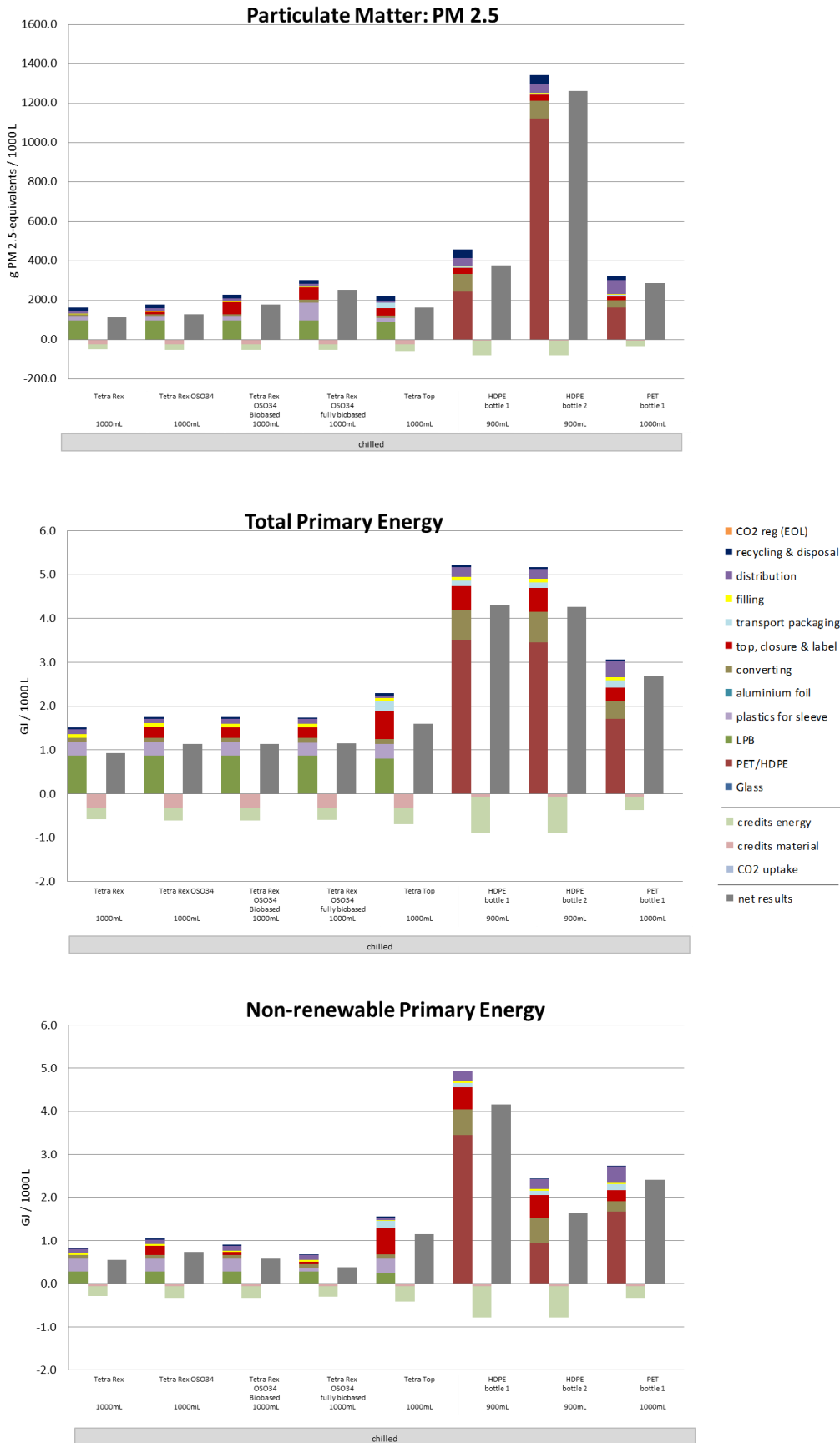


Figure 100: Indicator results for base scenarios of segment Dairy, Norway, allocation factor 50% (Part 3)

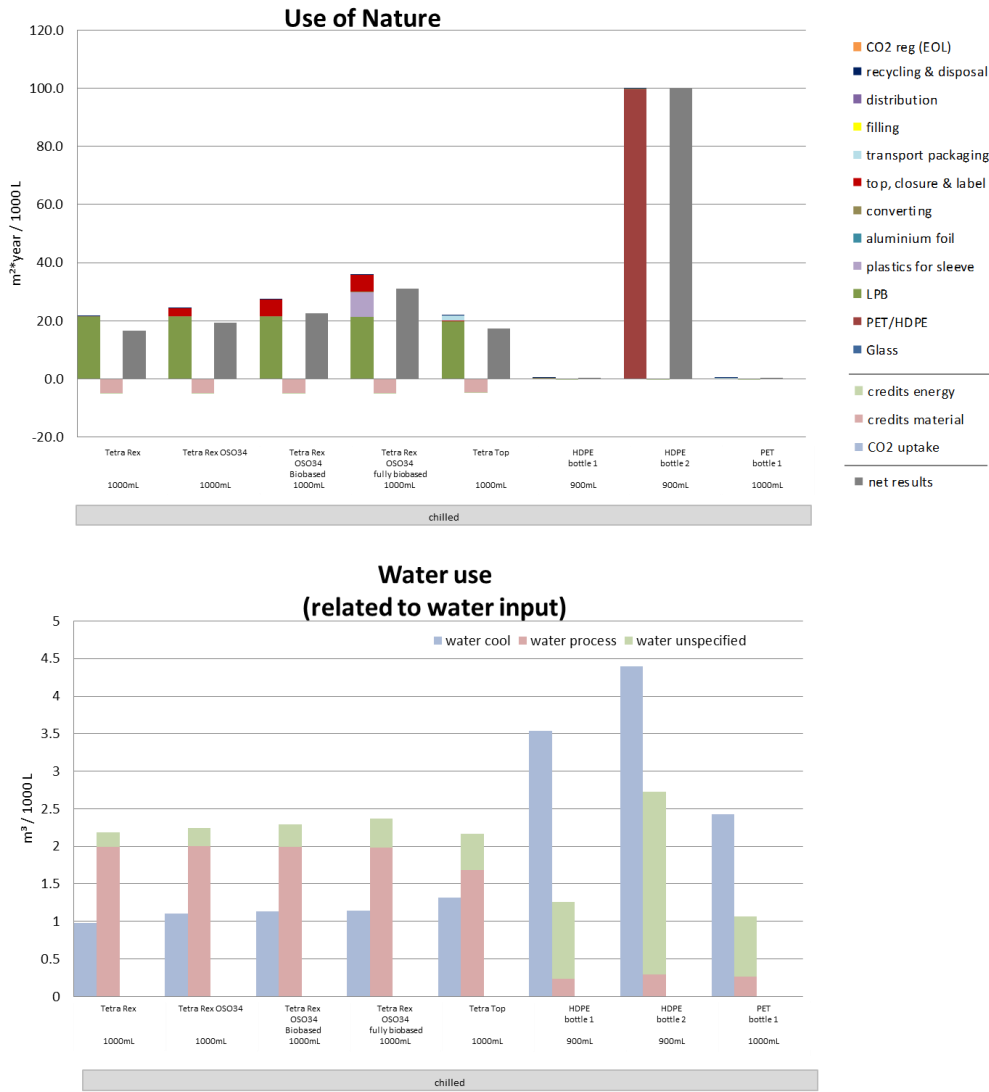


Figure 101: Indicator results for base scenarios of segment dairy, Norway, allocation factor 50% (Part 4)

Table 96: Category indicator results per impact category for base scenarios of **segment DAIRY, Norway**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO2-e/1000 L]	Burdens	45.06	54.83	52.35	48.55	78.78	236.12	179.44	141.47
	CO2 (reg)	17.62	17.67	21.54	27.27	19.26	2.11	63.75	4.06
	Credits	-18.16	-20.31	-20.16	-19.15	-25.76	-50.70	-50.71	-19.50
	CO2 uptake	-38.24	-38.31	-46.26	-57.90	-41.02	-4.27	-135.64	-8.34
	net results	6.28	13.88	7.47	-1.23	31.25	183.26	56.84	117.69
Acidification [kg SO2-e/1000 L]	Burdens	0.16	0.18	0.21	0.26	0.23	0.49	1.08	0.35
	Credits	-0.05	-0.06	-0.06	-0.06	-0.07	-0.09	-0.09	-0.04
Photo-Oxidant Formation [kg O3 e/1000 L]	Net results	0.11	0.12	0.16	0.21	0.16	0.40	0.99	0.31
	Burdens	2.50	2.75	3.41	4.36	3.33	6.28	18.30	4.29
	Credits	-0.59	-0.63	-0.63	-0.61	-0.73	-1.00	-1.00	-0.40
Ozone Depletion [g R11/1000 L]	Net results	1.91	2.12	2.78	3.75	2.60	5.28	17.30	3.89
	Burdens	0.03	0.04	0.13	0.26	0.05	0.09	1.67	0.48
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01	-0.04	-0.04	-0.02
Terrestrial Eutrophication [g PO4/1000 L]	Net results	0.03	0.03	0.12	0.25	0.04	0.05	1.63	0.46
	Burdens	19.15	20.87	27.39	36.91	25.79	45.32	161.34	32.29
	Credits	-4.54	-4.88	-4.85	-4.70	-5.61	-8.04	-8.05	-3.16
Aquatic Eutrophication [g PO4/1000 L]	Net results	14.61	15.99	22.53	32.22	20.18	37.28	153.29	29.13
	Burdens	18.95	21.38	40.82	69.26	28.40	47.30	390.52	29.69
	Credits	-3.40	-3.41	-3.41	-3.41	-3.26	-0.57	-0.57	-0.62
Particulate Matter [g PM 2.5-e/1000 L]	Net results	15.55	17.96	37.41	65.85	25.14	46.74	389.95	29.07
	Burdens	162.95	179.18	229.27	303.16	221.32	459.19	1343.56	320.53
	Credits	-48.00	-51.42	-51.17	-49.59	-58.72	-80.27	-80.29	-31.63
Total Primary Energy [GJ]	Net results	114.95	127.76	178.09	253.57	162.60	378.93	1263.27	288.90
	Burdens	1.51	1.75	1.75	1.74	2.29	5.20	5.16	3.06
	Credits	-0.58	-0.61	-0.61	-0.59	-0.69	-0.90	-0.90	-0.37
Non-renewable Primary Energy [GJ]	Net results	0.93	1.14	1.14	1.15	1.60	4.30	4.26	2.69
	Burdens	0.84	1.05	0.91	0.69	1.56	4.94	2.44	2.73
	Credits	-0.29	-0.32	-0.32	-0.31	-0.41	-0.79	-0.79	-0.32
Use of Nature [m ² *year]	Net results	0.55	0.73	0.59	0.38	1.15	4.16	1.65	2.41
	Burdens	21.53	24.34	27.40	35.87	21.84	0.46	99.98	0.44
	Credits	-4.95	-4.95	-4.95	-4.95	-4.58	-0.19	-0.19	-0.11
Water use [m ³ /1000 L]	Net results	16.59	19.39	22.45	30.93	17.25	0.27	99.79	0.33
	water cool	0.97	1.11	1.13	1.14	1.31	3.54	4.40	2.42
	water process	1.99	2.00	1.99	1.99	1.68	0.24	0.30	0.26
	water unspecified	0.19	0.24	0.30	0.38	0.48	1.02	2.43	0.80

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 CO₂ emissions.

For the beverage cartons the majority of the credits are given for energy recovery. Material credits are very low. Although in Norway 61.7% 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 CO₂ 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 CO₂.

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', 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 terephthalic 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 N₂O 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 CO₂ emissions from the bio-based 'HDPE bottle 2' are of course similarly high, but they are attributed to the sector CO₂ 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹. In cases where positive net results are compared to negative ones, and the other way around, no meaningful percentage numbers could be calculated. In these cases the tables just show by their colour code, if the net results are lower or higher than those of the packaging systems the respective beverage carton is compared to.

Table 97: Comparison of net results **Tetra Rex 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

Dairy (chilled), Norway	The net results of Tetra Rex 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-55%	-16%		-80%	-97%	-89%	-95%
Acidification	-10%	-30%	-48%	-32%	-73%	-89%	-65%
Photo-Oxidant Formation	-10%	-31%	-49%	-27%	-64%	-89%	-51%
Ozone Depletion Potential	-9%	-78%	-90%	-34%	-48%	-98%	-94%
Terrestrial Eutrophication	-9%	-35%	-55%	-28%	-61%	-90%	-50%
Aquatic Eutrophication	-13%	-58%	-76%	-38%	-67%	-96%	-47%
Particulate Matter	-10%	-35%	-55%	-29%	-70%	-91%	-60%
Total Primary Energy	-18%	-18%	-19%	-42%	-78%	-78%	-65%
Non-renewable Primary Energy	-25%	-7%	44%	-52%	-87%	-67%	-77%

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



Table 98: Comparison of net results **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

<i>Dairy (chilled), Norway</i>	The net results of Tetra Rex OSO34 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	121%	86%		-56%	-92%	-76%	-88%
Acidification	12%	-22%	-42%	-24%	-70%	-88%	-61%
Photo-Oxidant Formation	11%	-24%	-44%	-18%	-60%	-88%	-46%
Ozone Depletion Potential	9%	-76%	-89%	-28%	-43%	-98%	-94%
Terrestrial Eutrophication	9%	-29%	-50%	-21%	-57%	-90%	-45%
Aquatic Eutrophication	16%	-52%	-73%	-29%	-62%	-95%	-38%
Particulate Matter	11%	-28%	-50%	-21%	-66%	-90%	-56%
Total Primary Energy	23%	0%	-1%	-29%	-73%	-73%	-58%
Non-renewable Primary Energy	34%	25%	92%	-36%	-82%	-56%	-70%

Table 99: Comparison of net results **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

<i>Dairy (chilled), Norway</i>	The net results of Tetra Rex OSO34 biobased 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	19%	-46%		-76%	-96%	-87%	-94%
Acidification	43%	28%	-25%	-3%	-61%	-84%	-50%
Photo-Oxidant Formation	46%	31%	-26%	7%	-47%	-84%	-28%
Ozone Depletion Potential	353%	314%	-53%	199%	135%	-93%	-74%
Terrestrial Eutrophication	54%	41%	-30%	12%	-40%	-85%	-23%
Aquatic Eutrophication	141%	108%	-43%	49%	-20%	-90%	29%
Particulate Matter	55%	39%	-30%	10%	-53%	-86%	-38%
Total Primary Energy	23%	0%	-1%	-29%	-73%	-73%	-58%
Non-renewable Primary Energy	7%	-20%	54%	-49%	-86%	-65%	-76%

Table 100: Comparison of net results **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

<i>Dairy (chilled), Norway</i>	The net results of Tetra Rex OSO34 fully biobased 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change							
Acidification	91%	71%	34%	30%	-48%	-79%	-33%
Photo-Oxidant Formation	97%	77%	35%	45%	-29%	-78%	-3%
Ozone Depletion Potential	856%	774%	111%	531%	396%	-85%	-46%
Terrestrial Eutrophication	120%	101%	43%	60%	-14%	-79%	11%
Aquatic Eutrophication	324%	267%	76%	162%	41%	-83%	127%
Particulate Matter	121%	98%	42%	56%	-33%	-80%	-12%
Total Primary Energy	23%	1%	1%	-28%	-73%	-73%	-57%
Non-renewable Primary Energy	-30%	-48%	-35%	-67%	-91%	-77%	-84%

Table 101: Comparison of net results **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment Dairy, Norway**

<i>Dairy (chilled), Norway</i>	The net results of Tetra Top 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	398%	125%	319%	2639%	-83%	-45%	-73%
Acidification	47%	31%	3%	-23%	-60%	-84%	-48%
Photo-Oxidant Formation	36%	23%	-7%	-31%	-51%	-85%	-33%
Ozone Depletion Potential	51%	39%	-67%	-84%	-21%	-98%	-91%
Terrestrial Eutrophication	38%	26%	-10%	-37%	-46%	-87%	-31%
Aquatic Eutrophication	62%	40%	-33%	-62%	-46%	-94%	-14%
Particulate Matter	41%	27%	-9%	-36%	-57%	-87%	-44%
Total Primary Energy	71%	40%	40%	39%	-63%	-62%	-41%
Non-renewable Primary Energy	110%	57%	96%	202%	-72%	-31%	-52%

10.2 Results JNSD Norway

10.2.1 Presentation of results JNSD Norway

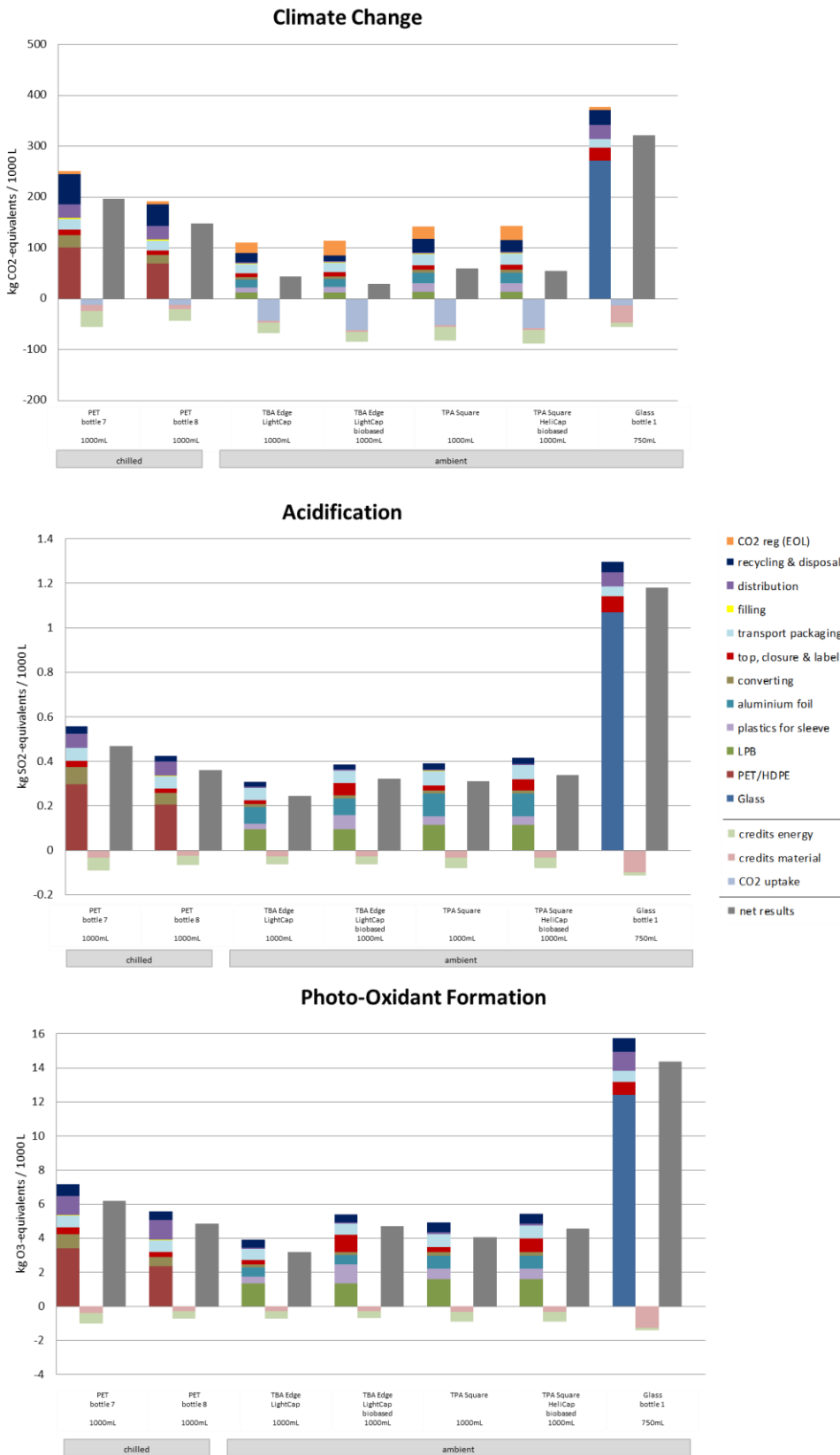


Figure 102 Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 1)

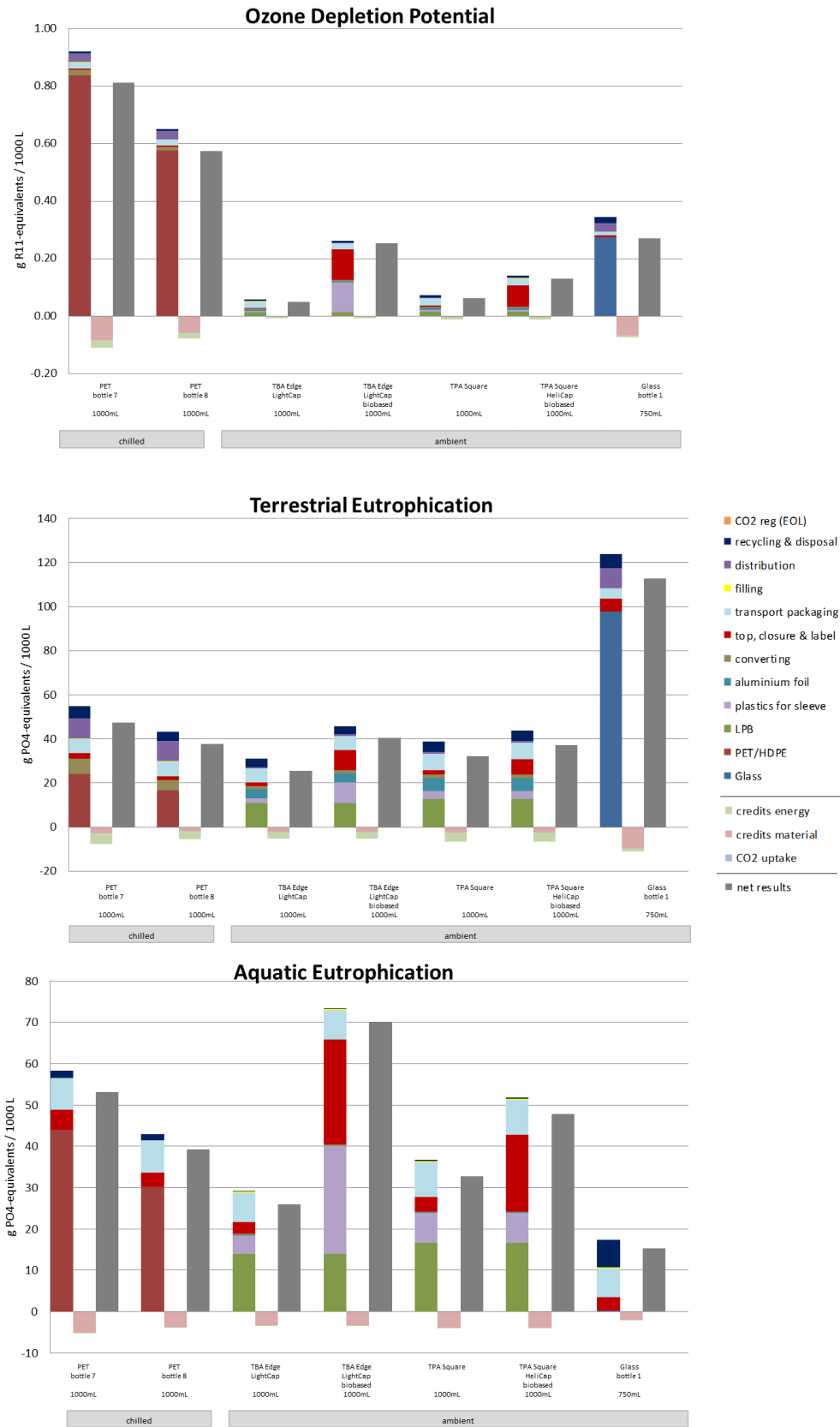


Figure 103: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 2)

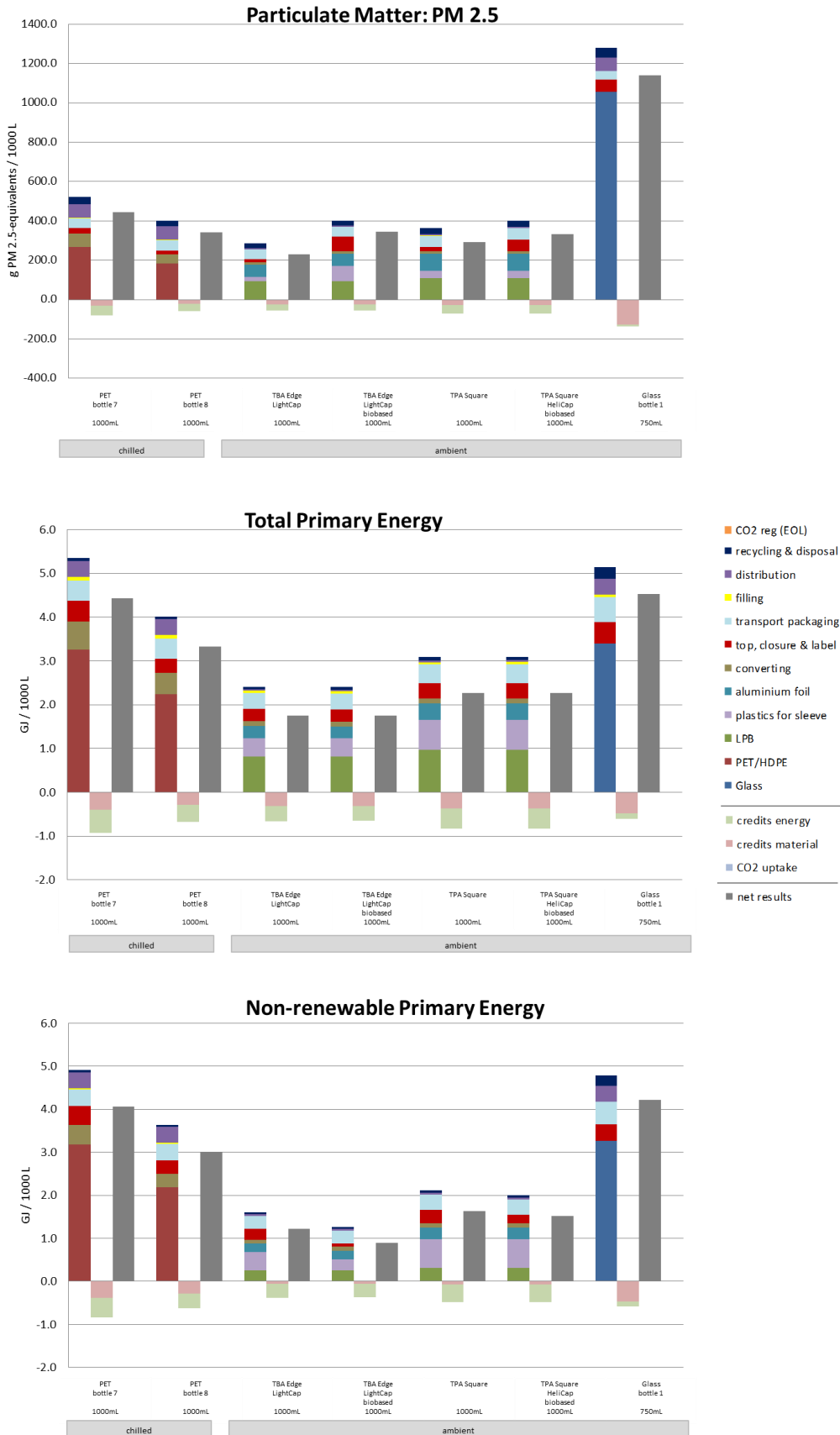


Figure 104: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 3)

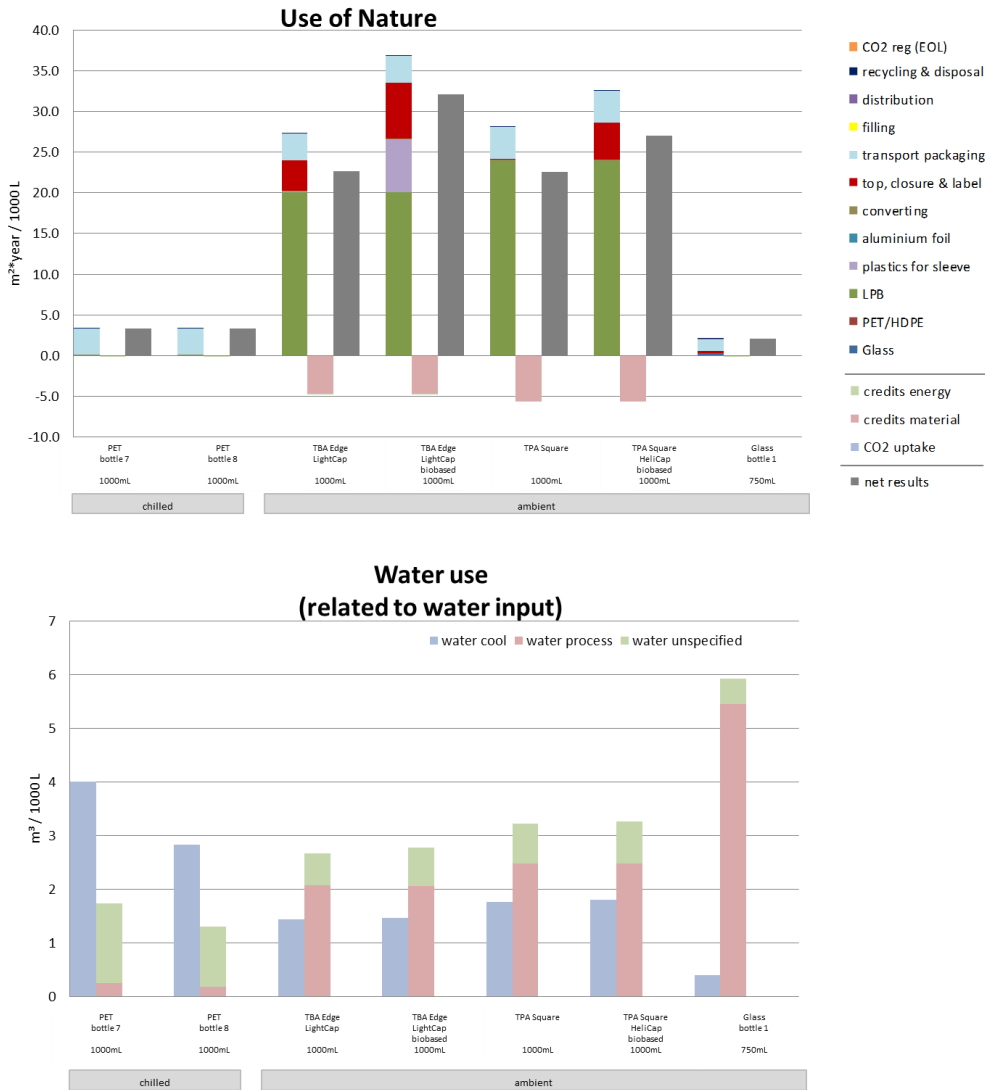


Figure 105: Indicator results for base scenarios of segment JNSD, Norway, allocation factor 50% (Part 4)

Table 102: Category indicator results per impact category for base scenarios of segment **JNSD, Norway**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		PET bottle 7 1000mL	PET bottle 8 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	Glass bottle 1 750mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	245.15	185.97	90.43	84.69	117.79	115.94	370.82
	CO ₂ (reg)	5.89	5.89	20.45	29.28	24.28	27.26	6.16
	Credits	-42.81	-31.46	-23.97	-23.41	-30.72	-30.77	-42.79
	CO ₂ uptake	-12.19	-12.19	-43.32	-61.39	-51.41	-57.56	-12.47
	net results	196.04	148.22	43.59	29.16	59.94	54.87	321.72
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.56	0.43	0.31	0.38	0.39	0.42	1.30
	Credits	-0.09	-0.07	-0.06	-0.06	-0.08	-0.08	-0.11
	Net results	0.47	0.36	0.24	0.32	0.31	0.34	1.18
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	7.18	5.58	3.91	5.40	4.92	5.45	15.75
	Credits	-1.00	-0.73	-0.70	-0.69	-0.88	-0.88	-1.39
	Net results	6.18	4.84	3.21	4.71	4.05	4.57	14.36
Ozone Depletion [g R11/1000 L]	Burdens	0.92	0.65	0.06	0.26	0.07	0.14	0.34
	Credits	-0.11	-0.08	-0.01	-0.01	-0.01	-0.01	-0.07
	Net results	0.81	0.57	0.05	0.25	0.06	0.13	0.27
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	54.89	43.18	30.93	45.73	38.75	43.80	123.84
	Credits	-7.61	-5.58	-5.36	-5.27	-6.72	-6.73	-10.98
	Net results	47.28	37.60	25.57	40.46	32.03	37.07	112.86
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	58.25	42.92	29.20	73.37	36.71	51.76	17.36
	Credits	-5.11	-3.68	-3.29	-3.29	-3.91	-3.91	-1.99
	Net results	53.14	39.23	25.91	70.08	32.80	47.85	15.37
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	522.85	401.08	286.39	400.73	363.92	402.39	1279.18
	Credits	-78.92	-57.70	-56.19	-55.31	-70.31	-70.38	-137.41
	Net results	443.94	343.37	230.20	345.41	293.61	332.01	1141.77
Total Primary Energy [GJ]	Burdens	5.34	4.01	2.41	2.40	3.09	3.09	5.14
	Credits	-0.92	-0.68	-0.66	-0.65	-0.83	-0.83	-0.61
	Net results	4.42	3.33	1.75	1.75	2.26	2.26	4.53
Non-renewable Primary Energy [GJ]	Burdens	4.91	3.63	1.60	1.26	2.12	2.01	4.79
	Credits	-0.84	-0.62	-0.38	-0.37	-0.49	-0.49	-0.58
	Net results	4.07	3.01	1.22	0.89	1.63	1.52	4.21
Use of Nature [m ² /year]	Burdens	3.37	3.33	27.30	36.80	28.10	32.58	2.12
	Credits	-0.05	-0.04	-4.67	-4.67	-5.55	-5.55	-0.03
	Net results	3.33	3.28	22.63	32.13	22.55	27.03	2.08
Water use [m ³ /1000 L]	water cool	4.01	2.82	1.43	1.47	1.77	1.81	0.40
	water process	0.25	0.18	2.07	2.06	2.48	2.48	5.45
	water unspecified	1.48	1.12	0.59	0.72	0.74	0.78	0.47

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 61.7% 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 CO₂ 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 CO₂.

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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

Table 103: Comparison of net results **Tetra Brik Aseptic Edge LightCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Norway**

<i>JNSD (ambient), Norway</i>	The net results of TBA Edge LightCap 1000mL are lower (green)/ higher (orange) than those of			
	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	Glass bottle 1 750mL
Climate Change	40%	-32%	-26%	-87%
Acidification	-20%	-17%	-23%	-78%
Photo-Oxidant Formation	-25%	-13%	-23%	-75%
Ozone Depletion Potential	-64%	49%	-30%	-66%
Terrestrial Eutrophication	-29%	-11%	-23%	-75%
Aquatic Eutrophication	-50%	7%	-27%	128%
Particulate Matter	-27%	-14%	-24%	-78%
Total Primary Energy	0%	-23%	-23%	-61%
Non-renewable Primary Energy	30%	-29%	-24%	-73%

Table 104: 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**

<i>JNSD (ambient), Norway</i>	The net results of TBA Edge LightCap biobased 1000mL are lower (green)/ higher (orange) than those of			
	TBA Edge LightCap 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	Glass bottle 1 750mL
Climate Change	-28%	-51%	-47%	-91%
Acidification	24%	3%	-4%	-73%
Photo-Oxidant Formation	34%	16%	3%	-67%
Ozone Depletion Potential	176%	310%	94%	-7%
Terrestrial Eutrophication	41%	26%	9%	-64%
Aquatic Eutrophication	100%	114%	46%	356%
Particulate Matter	36%	18%	4%	-70%
Total Primary Energy	0%	-23%	-23%	-61%
Non-renewable Primary Energy	-23%	-45%	-41%	-79%

Table 105: Comparison of net results **Tetra Prisma Aseptic square HeliCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD ambient, Norway**

<i>JNSD (ambient), Norway</i>	The net results of TPA Square 1000mL are lower (green)/ higher (orange) than those of			
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square HeliCap biobased 1000mL	Glass bottle 1 750mL
Climate Change	47%	106%	9%	-81%
Acidification	20%	-3%	-8%	-74%
Photo-Oxidant Formation	15%	-14%	-11%	-72%
Ozone Depletion Potential	-33%	-76%	-53%	-77%
Terrestrial Eutrophication	12%	-21%	-14%	-72%
Aquatic Eutrophication	-6%	-53%	-31%	113%
Particulate Matter	16%	-15%	-12%	-74%
Total Primary Energy	29%	29%	0%	-50%
Non-renewable Primary Energy	41%	83%	7%	-61%

Table 106: 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**

<i>JNSD (ambient), Norway</i>	The net results of TPA Square HeliCap biobased 1000mL are lower (green)/ higher (orange) than those of			
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	Glass bottle 1 750mL
Climate Change	35%	88%	-8%	-83%
Acidification	30%	5%	8%	-71%
Photo-Oxidant Formation	30%	-3%	13%	-68%
Ozone Depletion Potential	42%	-48%	112%	-52%
Terrestrial Eutrophication	30%	-8%	16%	-67%
Aquatic Eutrophication	37%	-32%	46%	211%
Particulate Matter	31%	-4%	13%	-71%
Total Primary Energy	29%	29%	0%	-50%
Non-renewable Primary Energy	31%	70%	-7%	-64%

10.3 Results Grab & Go Norway

10.3.1 Presentation of results Grab & Go Norway

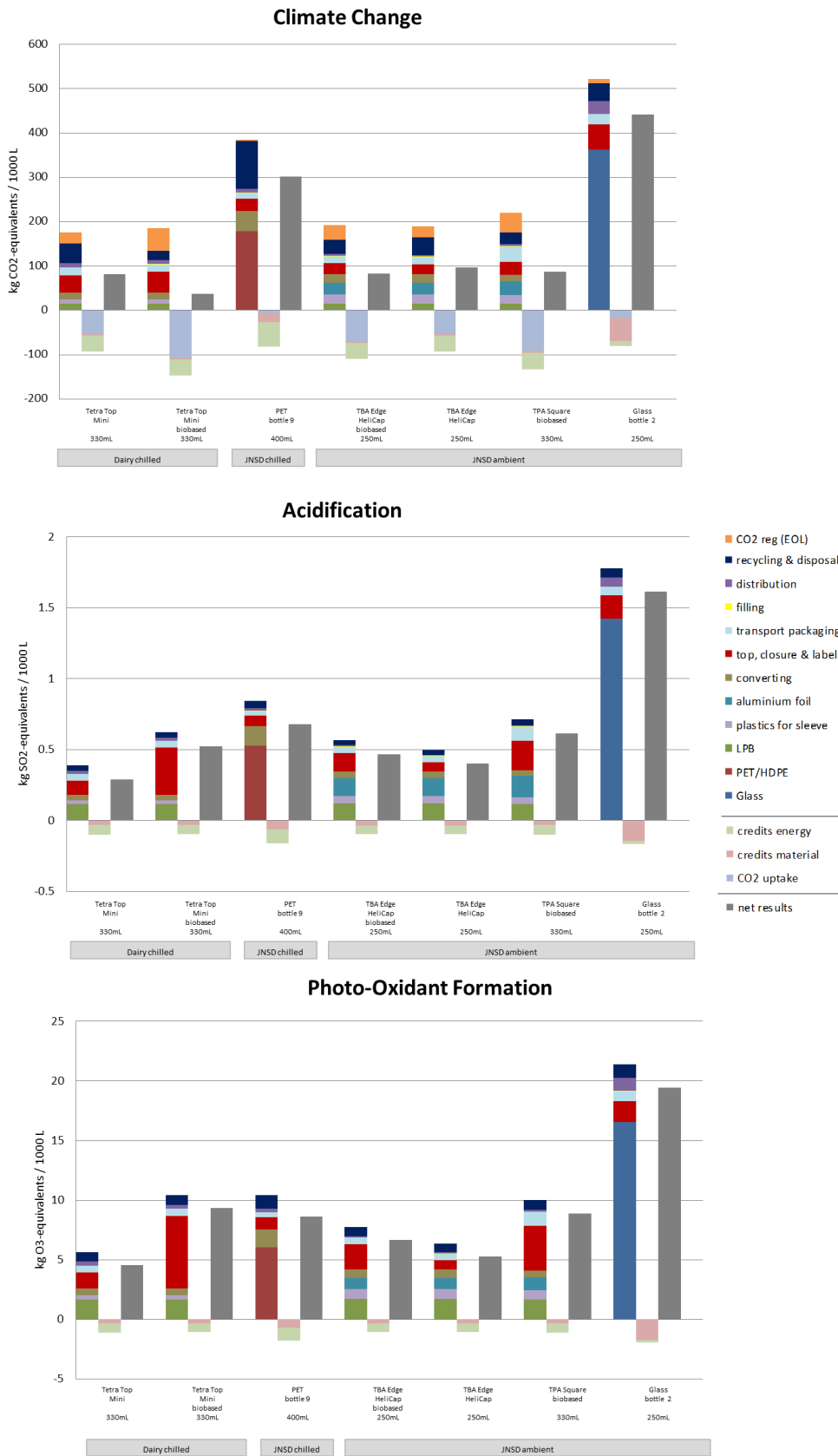


Figure 106: Indicator results for base scenarios of segment Grab & Go, Norway, allocation factor 50% (Part 1)

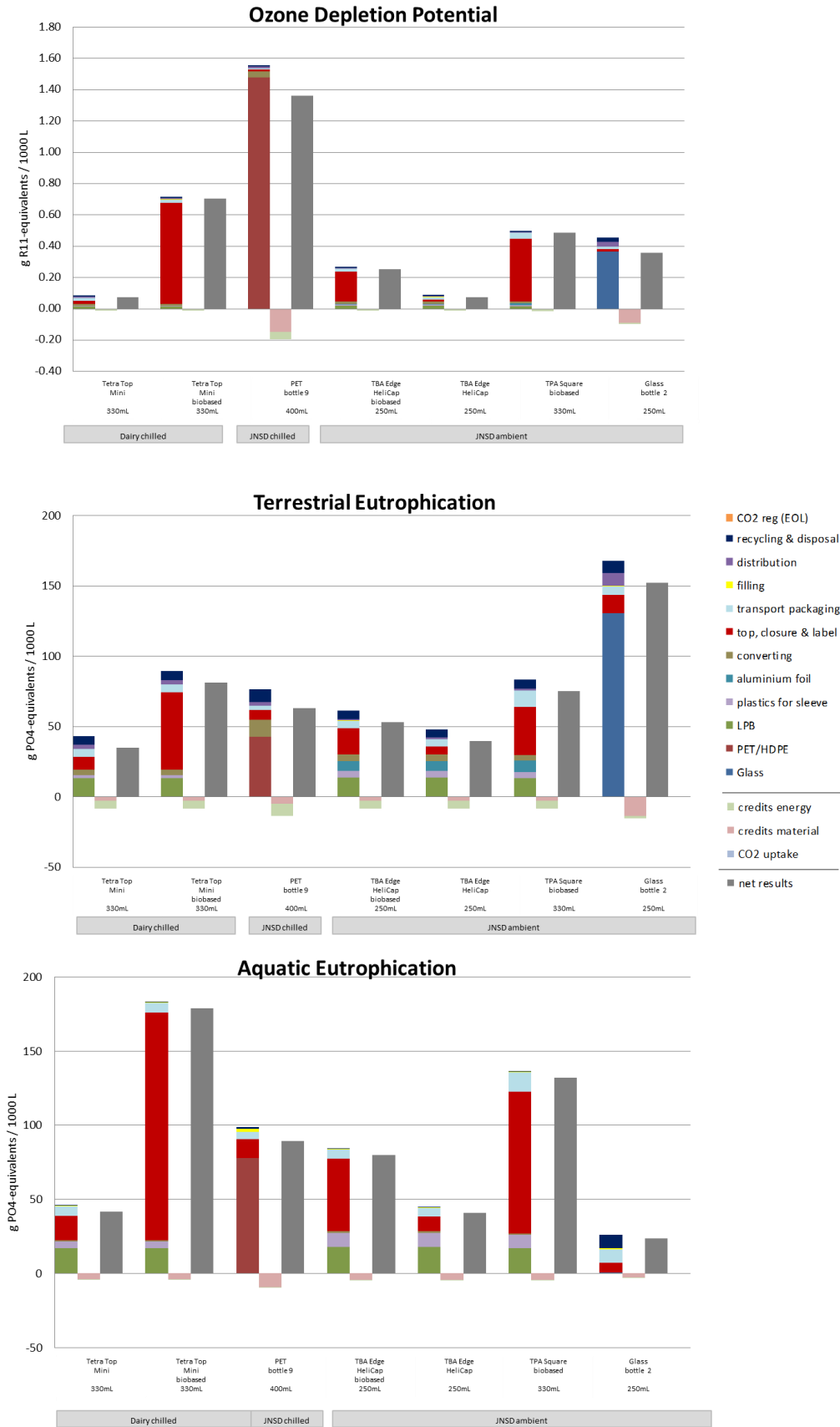


Figure 107: Indicator results for base scenarios of segment Grab & Go, Norway, allocation factor 50% (Part 2)

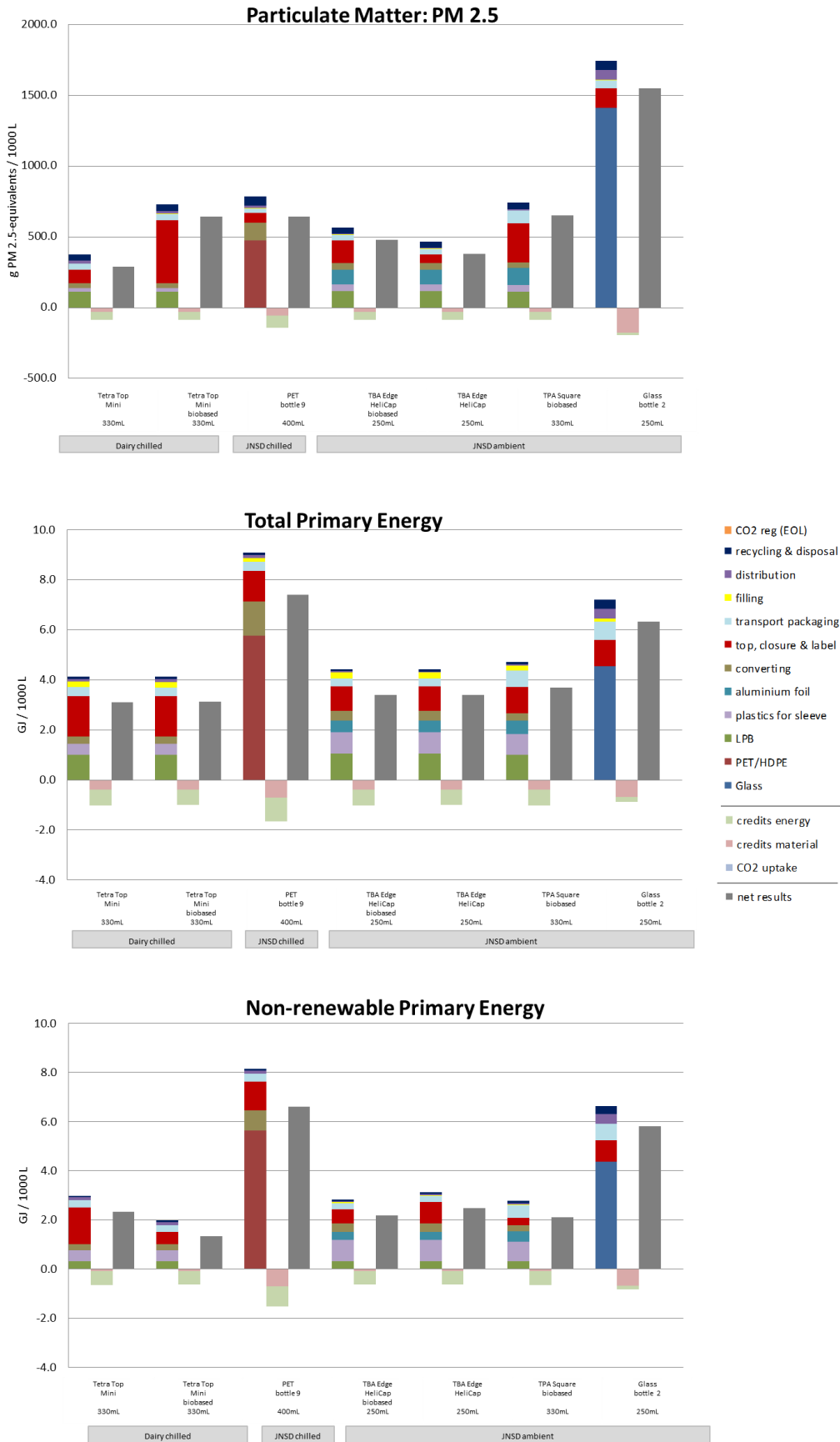


Figure 108: Indicator results for base scenarios of segment Grab & Go, Norway, allocation factor 50% (Part 3)



Figure 109: Indicator results for base scenarios of segment Grab & Go, Norway, allocation factor 50% (Part 4)

Table 107: Category indicator results per impact category for base scenarios of **segment Grab & Go, Norway**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Mini biobased 330mL	PET bottle 9 400mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	Glass bottle2 250mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	150.27	133.43	381.76	159.71	164.57	176.23	512.71
	CO ₂ (reg)	24.71	51.32	2.68	32.80	25.00	44.08	8.51
	Credits	-40.95	-40.23	-76.99	-40.27	-40.08	-41.33	-62.97
	CO ₂ uptake	-52.32	-106.74	-5.52	-69.09	-53.07	-91.67	-17.21
	net results	81.70	37.77	301.93	83.14	96.43	87.31	441.04
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.39	0.62	0.84	0.57	0.50	0.71	1.78
	Credits	-0.10	-0.10	-0.16	-0.10	-0.10	-0.10	-0.17
	Net results	0.29	0.52	0.68	0.47	0.40	0.61	1.61
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	5.63	10.40	10.42	7.73	6.36	9.99	21.37
	Credits	-1.10	-1.08	-1.80	-1.09	-1.09	-1.11	-1.96
	Net results	4.53	9.32	8.62	6.63	5.27	8.89	19.41
Ozone Depletion [g R11/1000 L]	Burdens	0.09	0.72	1.56	0.27	0.09	0.50	0.46
	Credits	-0.01	-0.01	-0.19	-0.01	-0.01	-0.01	-0.10
	Net results	0.07	0.70	1.36	0.25	0.07	0.49	0.36
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	43.21	89.32	76.65	61.26	48.10	83.52	167.74
	Credits	-8.38	-8.27	-13.71	-8.35	-8.32	-8.44	-15.47
	Net results	34.83	81.05	62.95	52.91	39.78	75.08	152.26
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	45.85	182.94	98.66	84.25	45.02	136.22	26.22
	Credits	-4.11	-4.11	-9.31	-4.26	-4.26	-4.11	-2.71
	Net results	41.74	178.83	89.35	79.99	40.76	132.11	23.51
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	376.01	727.38	783.70	565.06	464.78	740.88	1743.88
	Credits	-87.16	-86.04	-142.00	-86.94	-86.64	-87.81	-193.62
	Net results	288.85	641.34	641.70	478.12	378.14	653.06	1550.26
Total Primary Energy [GJ]	Burdens	4.12	4.12	9.07	4.42	4.42	4.71	7.20
	Credits	-1.01	-1.00	-1.66	-1.01	-1.01	-1.02	-0.87
	Net results	3.11	3.12	7.41	3.40	3.41	3.69	6.33
Non-renewable Primary Energy [GJ]	Burdens	2.99	1.98	8.14	2.82	3.12	2.77	6.64
	Credits	-0.65	-0.64	-1.53	-0.64	-0.63	-0.65	-0.83
	Net results	2.34	1.34	6.61	2.19	2.48	2.12	5.81
Use of Nature [m ² *year]	Burdens	28.28	68.60	1.40	40.75	29.08	56.76	3.08
	Credits	-5.70	-5.70	-0.05	-5.91	-5.91	-5.72	-0.04
	Net results	22.57	62.90	1.35	34.84	23.16	51.05	3.04
Water use [m ³ /1000 L]	water cool	2.29	2.64	7.01	2.93	2.83	3.04	0.64
	water process	2.14	2.13	1.65	2.88	2.90	2.81	12.81
	water unspecified	0.84	1.29	2.24	0.96	0.86	1.41	0.96

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 61.7% 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 CO₂ 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 CO₂.

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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

DAIRY chilled

Table 108: Comparison of net results **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in segment **Grab & Go, DAIRY, chilled, Norway**

<i>Grab & Go DAIRY (chilled), Norway</i>	The net results of Tetra Top Mini 330mL are lower (green)/ higher (orange) than those of Tetra Top Mini biobased 330mL
Climate Change	116%
Acidification	-45%
Photo-Oxidant Formation	-51%
Ozone Depletion Potential	-90%
Terrestrial Eutrophication	-57%
Aquatic Eutrophication	-77%
Particulate Matter	-55%
Total Primary Energy	0%
Non-renewable Primary Energy	74%

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



JNSD ambient**Table 109:** 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**

<i>Grab & Go JNSD (ambient), Norway</i>	The net results of TBA Edge HeliCap 250mL are lower (green)/ higher (orange) than those of		
	TBA Edge HeliCap biobased 250mL	TPA Square biobased 330mL	Glass bottle2 250mL
Climate Change	16%	10%	16%
Acidification	-14%	-35%	-75%
Photo-Oxidant Formation	-20%	-41%	-73%
Ozone Depletion Potential	-71%	-85%	-79%
Terrestrial Eutrophication	-25%	-47%	-74%
Aquatic Eutrophication	-49%	-69%	73%
Particulate Matter	-21%	-42%	-76%
Total Primary Energy	0%	-8%	-46%
Non-renewable Primary Energy	13%	17%	-57%

Table 110: 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**

<i>Grab & Go JNSD (ambient), Norway</i>	The net results of TBA Edge HeliCap biobased 250mL are lower (green)/ higher (orange) than those of		
	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	Glass bottle2 250mL
Climate Change	-14%	-5%	0%
Acidification	17%	-24%	-71%
Photo-Oxidant Formation	26%	-25%	-66%
Ozone Depletion Potential	242%	-48%	-29%
Terrestrial Eutrophication	33%	-30%	-65%
Aquatic Eutrophication	96%	-39%	240%
Particulate Matter	26%	-27%	-69%
Total Primary Energy	0%	-8%	-46%
Non-renewable Primary Energy	-12%	3%	-62%

Table 111: 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**

<i>Grab & Go JNSD (ambient), Norway</i>	The net results of TPA Square biobased 330mL are lower (green)/ higher (orange) than those of		
	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	Glass bottle2 250mL
Climate Change	5%	-9%	-80%
Acidification	31%	53%	-62%
Photo-Oxidant Formation	34%	69%	-54%
Ozone Depletion Potential	91%	553%	36%
Terrestrial Eutrophication	42%	89%	-51%
Aquatic Eutrophication	65%	224%	462%
Particulate Matter	37%	73%	-58%
Total Primary Energy	8%	8%	-42%
Non-renewable Primary Energy	-3%	-15%	-64%

10.4 Results base scenarios *water NORWAY*

10.4.1 Presentation of results water Norway

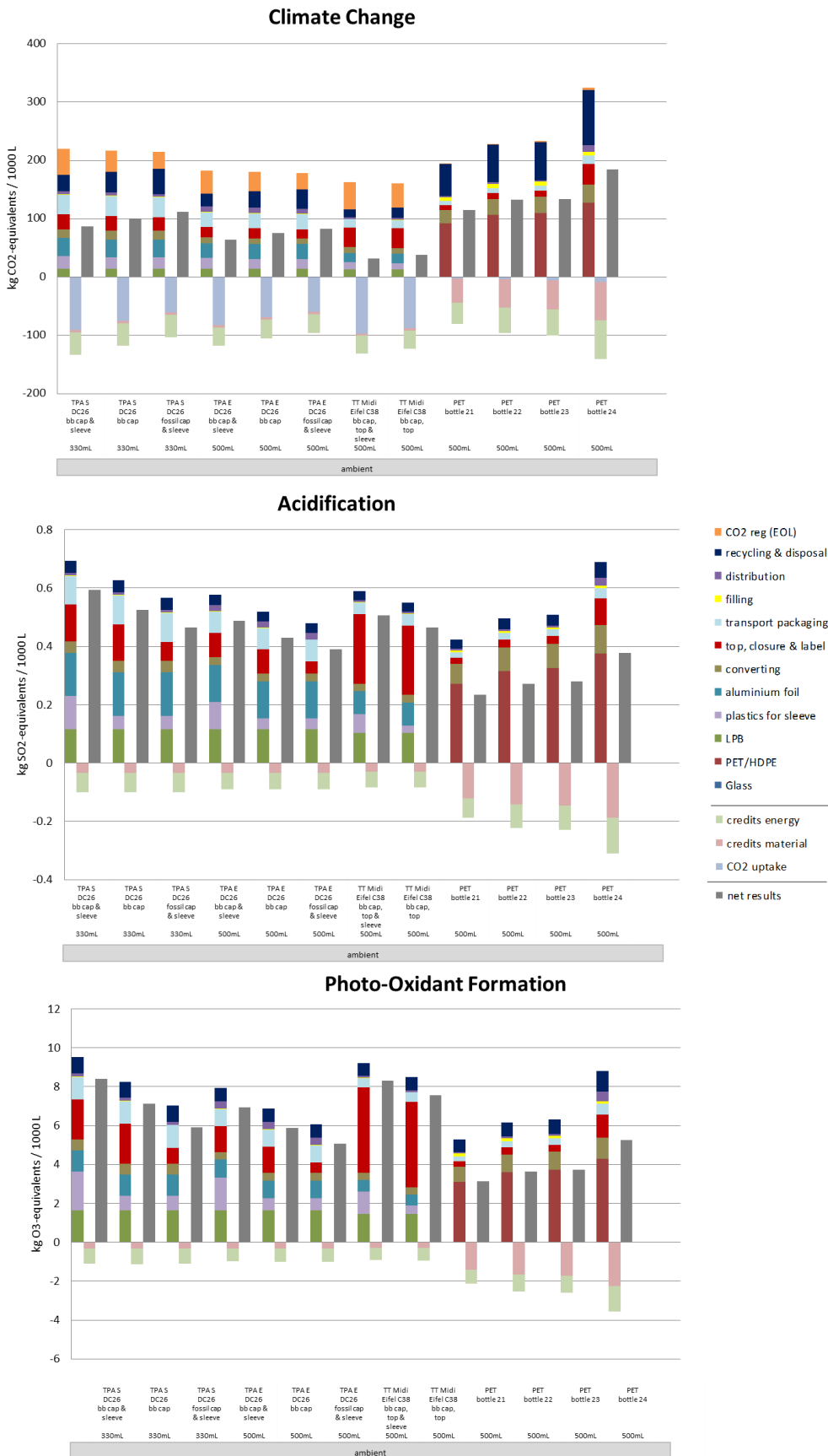


Figure 110: Indicator results for base scenarios of segment Water, Norway, allocation factor 50% (Part 1)

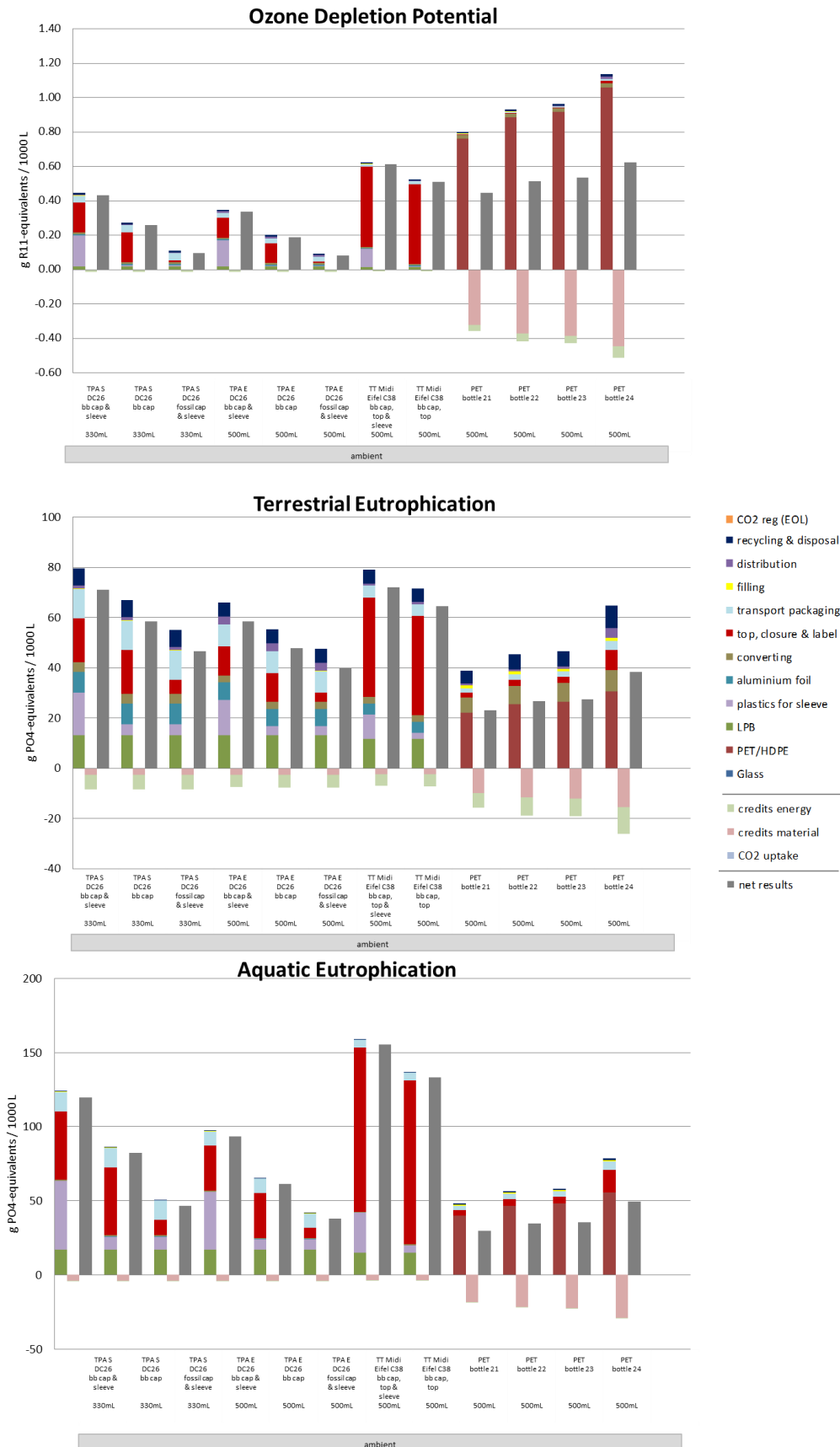


Figure 111: Indicator results for base scenarios of segment Water, Norway, allocation factor 50% (Part 2)

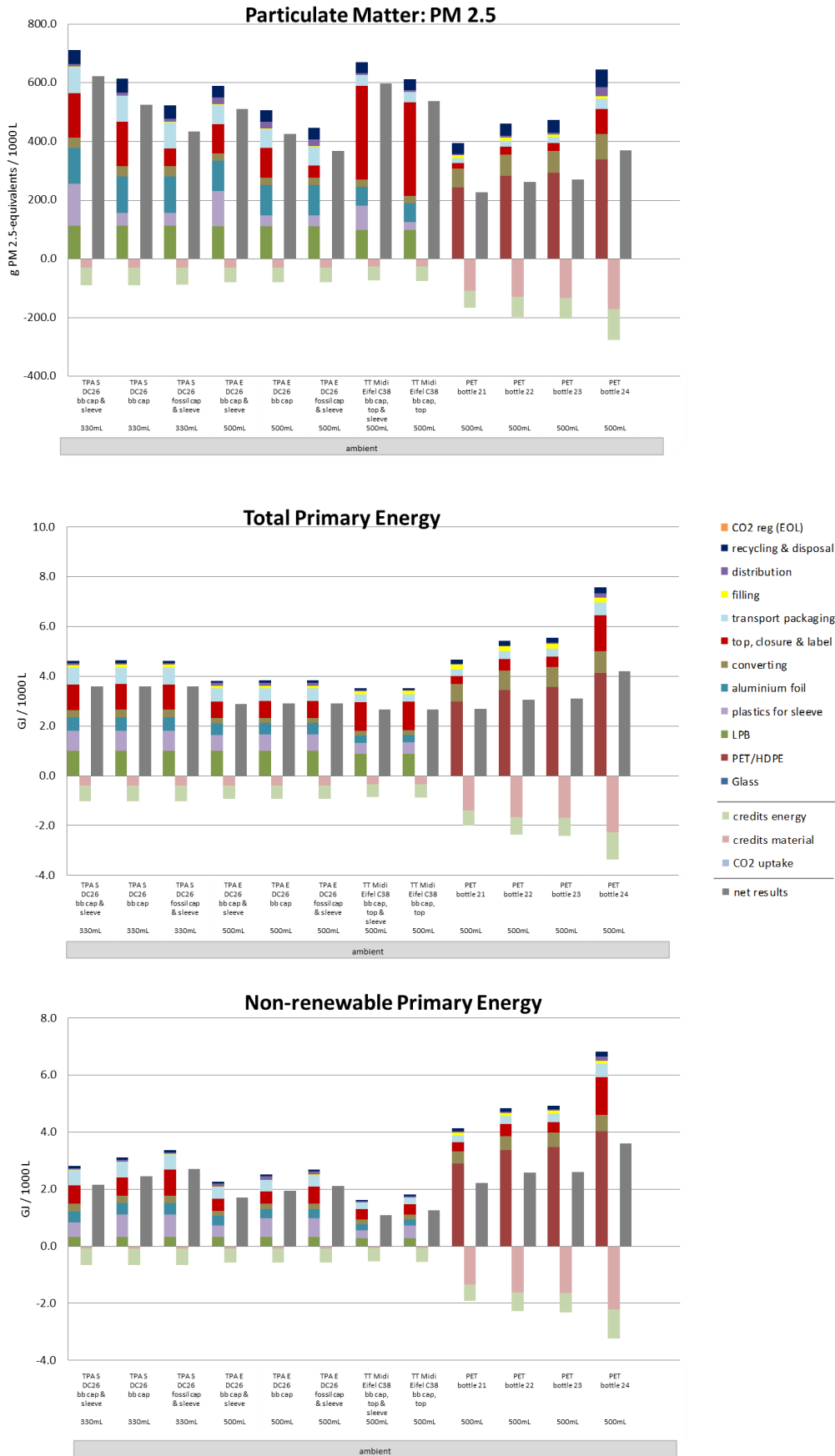


Figure 112: Indicator results for base scenarios of segment Water, Norway, allocation factor 50% (Part 3)

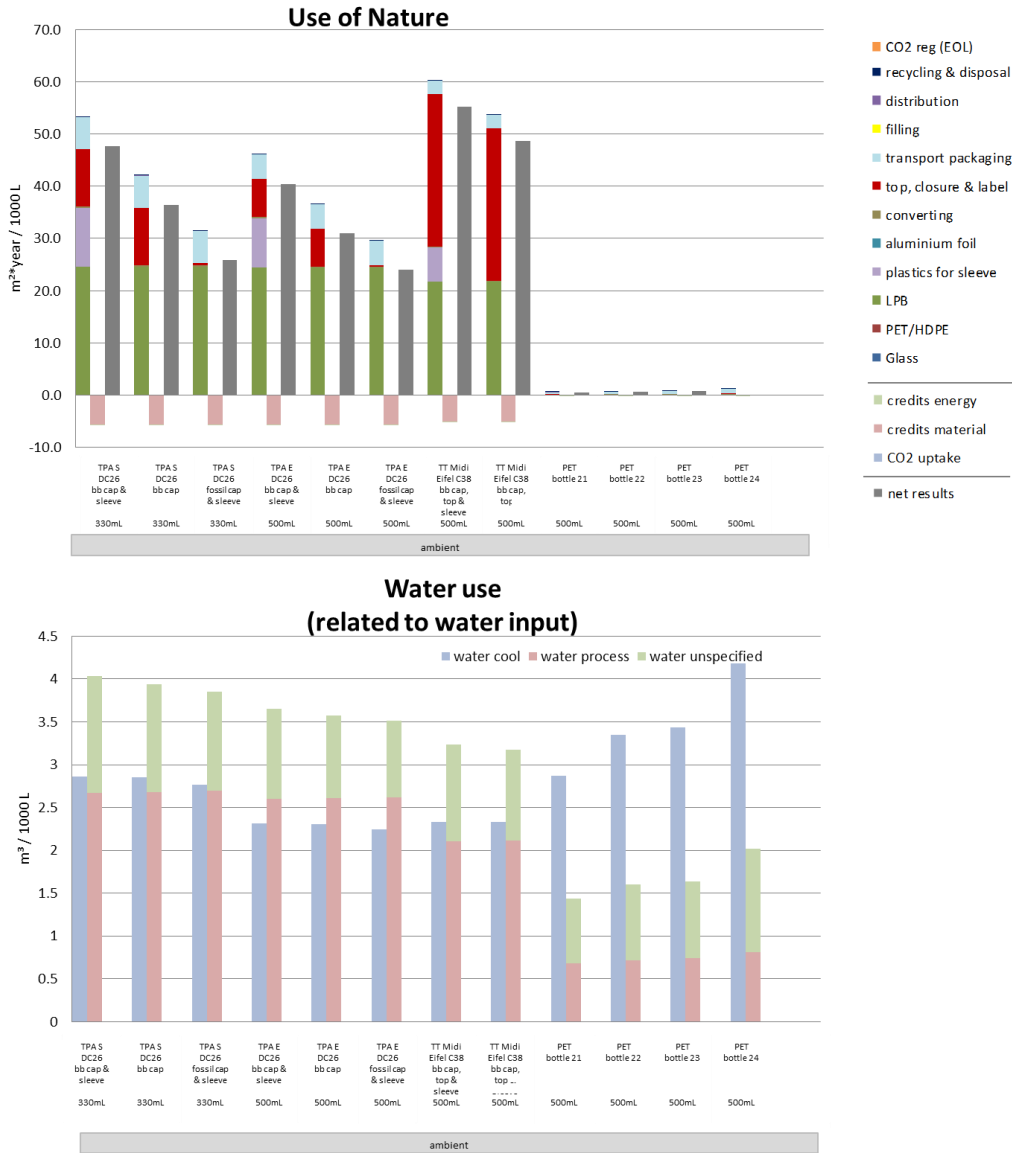


Figure 113: Indicator results for base scenarios of segment Water, Norway, allocation factor 50% (Part 4)

Table 112: Category indicator results per impact category for base scenarios of **Water, Norway-** burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change [kg CO2-e/1000 L]	Burdens	175.67	180.65	185.10	142.96	147.19	150.11	115.91	118.83	193.64	226.75	231.04	320.41
	CO2 (reg)	43.88	36.28	29.18	39.37	32.94	28.25	46.67	42.22	1.27	1.53	2.61	3.97
	Credits	-41.89	-42.01	-41.84	-35.88	-36.10	-36.04	-33.78	-34.72	-77.71	-92.58	-94.50	-131.80
	CO2 uptake	-90.88	-75.46	-60.95	-82.01	-68.95	-59.35	-96.97	-87.94	-2.61	-3.13	-5.42	-8.21
	net results	86.77	99.47	111.49	64.45	75.08	82.99	31.83	38.39	114.60	132.57	133.74	184.37
Acidification [kg SO2-e/1000 L]	Burdens	0.69	0.63	0.57	0.58	0.52	0.48	0.59	0.55	0.42	0.50	0.51	0.69
	Credits	-0.10	-0.10	-0.10	-0.09	-0.09	-0.09	-0.08	-0.08	-0.19	-0.22	-0.23	-0.31
	Net results	0.59	0.53	0.47	0.49	0.43	0.39	0.51	0.47	0.23	0.27	0.28	0.38
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	9.52	8.26	7.02	7.94	6.88	6.06	9.22	8.49	5.27	6.18	6.33	8.82
	Credits	-1.12	-1.12	-1.11	-0.99	-0.99	-0.99	-0.92	-0.94	-2.13	-2.53	-2.59	-3.55
	Net results	8.40	7.14	5.91	6.95	5.88	5.07	8.30	7.55	3.15	3.64	3.74	5.27
Ozone Depletion [g R11/1000 L]	Burdens	0.44	0.27	0.11	0.35	0.20	0.09	0.62	0.52	0.80	0.93	0.96	1.14
	Credits	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.36	-0.42	-0.43	-0.51
	Net results	0.43	0.26	0.10	0.34	0.19	0.08	0.61	0.51	0.45	0.52	0.53	0.62
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	79.55	66.93	55.01	66.04	55.34	47.46	79.00	71.60	38.79	45.35	46.59	64.64
	Credits	-8.52	-8.53	-8.51	-7.57	-7.60	-7.59	-7.03	-7.17	-15.75	-18.73	-19.15	-26.22
	Net results	71.03	58.39	46.50	58.47	47.74	39.87	71.97	64.43	23.05	26.62	27.43	38.42
Aquatic Eutrophication [g PO4/1000 L]	Burdens	123.86	86.20	50.68	97.31	65.40	41.90	158.73	136.67	48.05	56.40	57.91	78.51
	Credits	-4.08	-4.08	-4.08	-4.04	-4.04	-4.04	-3.59	-3.59	-18.33	-21.76	-22.33	-29.14
	Net results	119.79	82.12	46.60	93.27	61.37	37.87	155.14	133.07	29.73	34.64	35.58	49.37
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	711.33	613.42	522.63	589.22	506.29	446.22	670.20	612.85	394.20	461.22	473.21	645.49
	Credits	-88.52	-88.70	-88.43	-78.91	-79.25	-79.14	-73.18	-74.66	-166.48	-197.81	-202.34	-274.95
	Net results	622.81	524.72	434.20	510.32	427.04	367.07	597.02	538.18	227.72	263.41	270.87	370.54
Total Primary Energy [GJ]	Burdens	4.61	4.63	4.63	3.82	3.83	3.83	3.52	3.52	4.67	5.43	5.54	7.57
	Credits	-1.03	-1.03	-1.03	-0.93	-0.93	-0.93	-0.85	-0.87	-1.99	-2.38	-2.43	-3.37
	Net results	3.59	3.60	3.60	2.89	2.90	2.90	2.66	2.66	2.68	3.05	3.11	4.20
Non-renewable Primary Energy [GJ]	Burdens	2.81	3.10	3.37	2.27	2.52	2.69	1.63	1.80	4.13	4.85	4.93	6.82
	Credits	-0.66	-0.66	-0.66	-0.57	-0.57	-0.57	-0.53	-0.55	-1.91	-2.28	-2.33	-3.23
	Net results	2.15	2.44	2.71	1.70	1.94	2.12	1.10	1.25	2.23	2.57	2.60	3.59
Use of Nature [m²*year]	Burdens	53.28	42.06	31.49	46.09	36.58	29.59	60.25	53.67	0.58	0.70	0.80	1.25
	Credits	-5.68	-5.68	-5.68	-5.66	-5.66	-5.66	-5.05	-5.05	-0.04	-0.05	-0.05	-0.09
	Net results	47.59	36.37	25.81	40.43	30.92	23.93	55.19	48.62	0.54	0.64	0.74	1.16
Water use [m³/1000 L]	water cool	2.86	2.86	2.76	2.31	2.31	2.25	2.33	2.33	2.87	3.35	3.44	4.18
	water process	2.67	2.68	2.69	2.60	2.61	2.61	2.11	2.11	0.68	0.72	0.74	0.81
	water unspecified	1.37	1.26	1.16	1.06	0.96	0.90	1.12	1.06	0.75	0.88	0.89	1.21

10.4.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the water 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 SO₂, 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 water 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 shows visible impacts in almost all impact categories.

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 N₂O 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 water 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 Norway 61.7% 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 CO₂ 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 CO₂.

Plastic bottles

In the regarded plastic bottle systems in the water 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 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 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 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'.

For the regarded plastic bottles for water more material credits are given than for bottles in other beverage segments as the deposit system for water bottles leads to a high recycling rate.

10.4.3 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

Table 113: Comparison of net results: Tetra Prisma Aseptic Square bio-based cap & sleeve 330 mL versus competing carton based and alternative packaging systems in segment Water Norway

WATER (ambient), Norway	The net results of TPA S DC26 bb cap & sleeve 330mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	-13%	-22%	35%	16%	5%	173%	126%	-24%	-35%	-35%	-53%
Acidification	13%	27%	22%	38%	52%	17%	27%	153%	118%	112%	57%
Photo-Oxidant Formation	18%	42%	21%	43%	66%	1%	11%	167%	131%	124%	59%
Ozone Depletion Potential	67%	354%	28%	128%	431%	-30%	-16%	-3%	-16%	-19%	-31%
Terrestrial Eutrophication	22%	53%	21%	49%	78%	-1%	10%	208%	167%	159%	85%
Aquatic Eutrophication	46%	157%	28%	95%	216%	-23%	-10%	303%	246%	237%	143%
Particulate Matter	19%	43%	22%	46%	70%	4%	16%	173%	136%	130%	68%
Total Primary Energy	0%	0%	24%	24%	24%	35%	35%	34%	18%	15%	-15%
Non-renewable Primary Energy	-12%	-21%	27%	11%	2%	96%	72%	-3%	-16%	-17%	-40%

Table 114: Comparison of net results: Tetra Prisma Aseptic Square bio-based cap 330 mL versus competing carton based and alternative packaging systems in segment Water Norway

WATER (ambient), Norway	The net results of TPA S DC26 bb cap 330mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	15%	-11%	54%	32%	20%	212%	159%	-13%	-25%	-26%	-46%
Acidification	-11%	13%	8%	22%	35%	4%	13%	124%	93%	88%	39%
Photo-Oxidant Formation	-15%	21%	3%	21%	41%	-14%	-5%	127%	96%	91%	35%
Ozone Depletion Potential	-40%	172%	-23%	36%	218%	-58%	-50%	-42%	-50%	-52%	-59%
Terrestrial Eutrophication	-18%	26%	0%	22%	46%	-19%	-9%	153%	119%	113%	52%
Aquatic Eutrophication	-31%	76%	-12%	34%	117%	-47%	-38%	176%	137%	131%	66%
Particulate Matter	-16%	21%	3%	23%	43%	-12%	-3%	130%	99%	94%	42%
Total Primary Energy	0%	0%	24%	24%	24%	35%	35%	34%	18%	16%	-14%
Non-renewable Primary Energy	14%	-10%	44%	26%	15%	123%	95%	10%	-5%	-6%	-32%

Table 115: Comparison of net results: Tetra Prisma Aseptic Square fossil cap & sleeve 330 mL versus competing carton based and alternative packaging systems in segment Water, Norway

WATER (ambient), Norway	The net results of TPA S DC26 fossil cap & sleeve 330mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	28%	12%	73%	48%	34%	250%	190%	-3%	-16%	-17%	-40%
Acidification	-22%	-11%	-4%	8%	20%	-8%	0%	98%	71%	66%	23%
Photo-Oxidant Formation	-30%	-17%	-15%	0%	17%	-29%	-22%	88%	62%	58%	12%
Ozone Depletion Potential	-78%	-63%	-72%	-50%	17%	-85%	-81%	-79%	-82%	-82%	-85%
Terrestrial Eutrophication	-35%	-20%	-20%	-3%	17%	-35%	-28%	102%	75%	70%	21%
Aquatic Eutrophication	-61%	-43%	-50%	-24%	23%	-70%	-65%	57%	35%	31%	-6%
Particulate Matter	-30%	-17%	-15%	2%	18%	-27%	-19%	91%	65%	60%	17%
Total Primary Energy	0%	0%	24%	24%	24%	35%	35%	34%	18%	16%	-14%
Non-renewable Primary Energy	26%	11%	59%	39%	28%	147%	116%	22%	6%	4%	-25%

Table 116: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap & sleeve 500 mL versus competing carton based and alternative packaging systems in **segment Water, Norway**

WATER (ambient), Norway	The net results of TPA E DC26 bb cap & sleeve 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	-26%	-35%	-42%	-14%	-22%	102%	68%	-44%	-51%	-52%	-65%
Acidification	-18%	-7%	5%	13%	25%	-4%	5%	107%	79%	74%	29%
Photo-Oxidant Formation	-17%	-3%	18%	18%	37%	-16%	-8%	121%	91%	86%	32%
Ozone Depletion Potential	-22%	30%	253%	78%	313%	-45%	-34%	-25%	-35%	-37%	-46%
Terrestrial Eutrophication	-18%	0%	26%	22%	47%	-19%	-9%	154%	120%	113%	52%
Aquatic Eutrophication	-22%	14%	100%	52%	146%	-40%	-30%	214%	169%	162%	89%
Particulate Matter	-18%	-3%	18%	20%	39%	-15%	-5%	124%	94%	88%	38%
Total Primary Energy	-19%	-20%	-20%	0%	0%	9%	9%	8%	-5%	-7%	-31%
Non-renewable Primary Energy	-21%	-30%	-37%	-13%	-20%	55%	35%	-24%	-34%	-35%	-53%

Table 117: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap 500 mL versus competing carton based and alternative packaging systems in **segment Water, Norway**

WATER (ambient), Norway	The net results of TPA E DC26 bb cap 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	-13%	-25%	-33%	16%	-10%	136%	96%	-34%	-43%	-44%	-59%
Acidification	-28%	-18%	-8%	-12%	10%	-15%	-8%	83%	58%	53%	13%
Photo-Oxidant Formation	-30%	-18%	0%	-15%	16%	-29%	-22%	87%	61%	57%	12%
Ozone Depletion Potential	-56%	-27%	99%	-44%	133%	-69%	-63%	-58%	-63%	-65%	-70%
Terrestrial Eutrophication	-33%	-18%	3%	-18%	20%	-34%	-26%	107%	79%	74%	24%
Aquatic Eutrophication	-49%	-25%	32%	-34%	62%	-60%	-54%	106%	77%	72%	24%
Particulate Matter	-31%	-19%	-2%	-16%	16%	-28%	-21%	88%	62%	58%	15%
Total Primary Energy	-19%	-19%	-19%	0%	0%	9%	9%	8%	-5%	-7%	-31%
Non-renewable Primary Energy	-10%	-20%	-28%	14%	-8%	77%	55%	-13%	-24%	-25%	-46%

Table 118: Comparison of net results: Tetra Prisma Aseptic Edge fossil cap & sleeve 500 mL versus competing carton based and alternative packaging systems in **segment Water, Norway**

WATER (ambient), Norway	The net results of TPA E DC26 fossil cap & sleeve 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	-4%	-17%	-26%	29%	11%	161%	116%	-28%	-37%	-38%	-55%
Acidification	-34%	-26%	-16%	-20%	-9%	-23%	-16%	66%	43%	39%	3%
Photo-Oxidant Formation	-40%	-29%	-14%	-27%	-14%	-39%	-33%	61%	39%	35%	-4%
Ozone Depletion Potential	-81%	-69%	-15%	-76%	-57%	-87%	-84%	-82%	-84%	-85%	-87%
Terrestrial Eutrophication	-44%	-32%	-14%	-32%	-16%	-45%	-38%	73%	50%	45%	4%
Aquatic Eutrophication	-68%	-54%	-19%	-59%	-38%	-76%	-72%	27%	9%	6%	-23%
Particulate Matter	-41%	-30%	-15%	-28%	-14%	-39%	-32%	61%	39%	36%	-1%
Total Primary Energy	-19%	-19%	-19%	0%	0%	9%	9%	8%	-5%	-7%	-31%
Non-renewable Primary Energy	-2%	-13%	-22%	25%	9%	93%	69%	-5%	-17%	-19%	-41%

Table 119: Comparison of net results: **Tetra Top Midi Eifel C38 bio-based cap, top & sleeve 500 mL** versus competing carton based and alternative packaging systems in **segment Water, Norway**

WATER (ambient), Norway	The net results of TT Midi Eifel C38 bb cap, top & sleeve 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	-63%	-68%	-71%	-51%	-58%	-62%	-17%	-72%	-76%	-76%	-83%
Acidification	-15%	-4%	9%	4%	18%	30%	9%	116%	96%	81%	34%
Photo-Oxidant Formation	-1%	16%	41%	19%	41%	64%	10%	164%	128%	122%	58%
Ozone Depletion Potential	42%	138%	545%	83%	224%	655%	20%	38%	19%	15%	-1%
Terrestrial Eutrophication	1%	23%	55%	23%	51%	81%	12%	212%	170%	162%	87%
Aquatic Eutrophication	30%	89%	233%	66%	153%	310%	17%	422%	348%	336%	214%
Particulate Matter	-4%	14%	37%	17%	40%	63%	11%	162%	127%	120%	61%
Total Primary Energy	-26%	-26%	-26%	-8%	-8%	-8%	0%	-1%	-13%	-14%	-37%
Non-renewable Primary Energy	-49%	-55%	-60%	-35%	-44%	-48%	-13%	-51%	-57%	-58%	-69%

Table 120: Comparison of net results: **Tetra Top Midi Eifel C38 bio-based cap & top 500 mL** versus competing carton based and alternative packaging systems in **segment Water, Norway**

WATER (ambient), Norway	The net results of TT Midi Eifel C38 bb cap, top 500mL are lower (green)/ higher (orange) than those of										
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change	-56%	-61%	-66%	-40%	-49%	-54%	21%	-66%	-71%	-71%	-79%
Acidification	-22%	-11%	0%	-4%	8%	20%	-8%	98%	71%	66%	23%
Photo-Oxidant Formation	-10%	6%	28%	9%	28%	49%	-9%	140%	107%	102%	43%
Ozone Depletion Potential	19%	98%	438%	52%	171%	530%	-17%	15%	-1%	-4%	-18%
Terrestrial Eutrophication	-9%	10%	39%	10%	35%	62%	-10%	180%	142%	135%	68%
Aquatic Eutrophication	11%	62%	186%	43%	117%	251%	-14%	348%	284%	274%	170%
Particulate Matter	-14%	3%	24%	5%	26%	47%	-10%	136%	104%	99%	45%
Total Primary Energy	-26%	-26%	-26%	-8%	-8%	-8%	0%	-1%	-13%	-15%	-37%
Non-renewable Primary Energy	-42%	-49%	-54%	-26%	-35%	-41%	14%	-44%	-51%	-52%	-65%

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%.

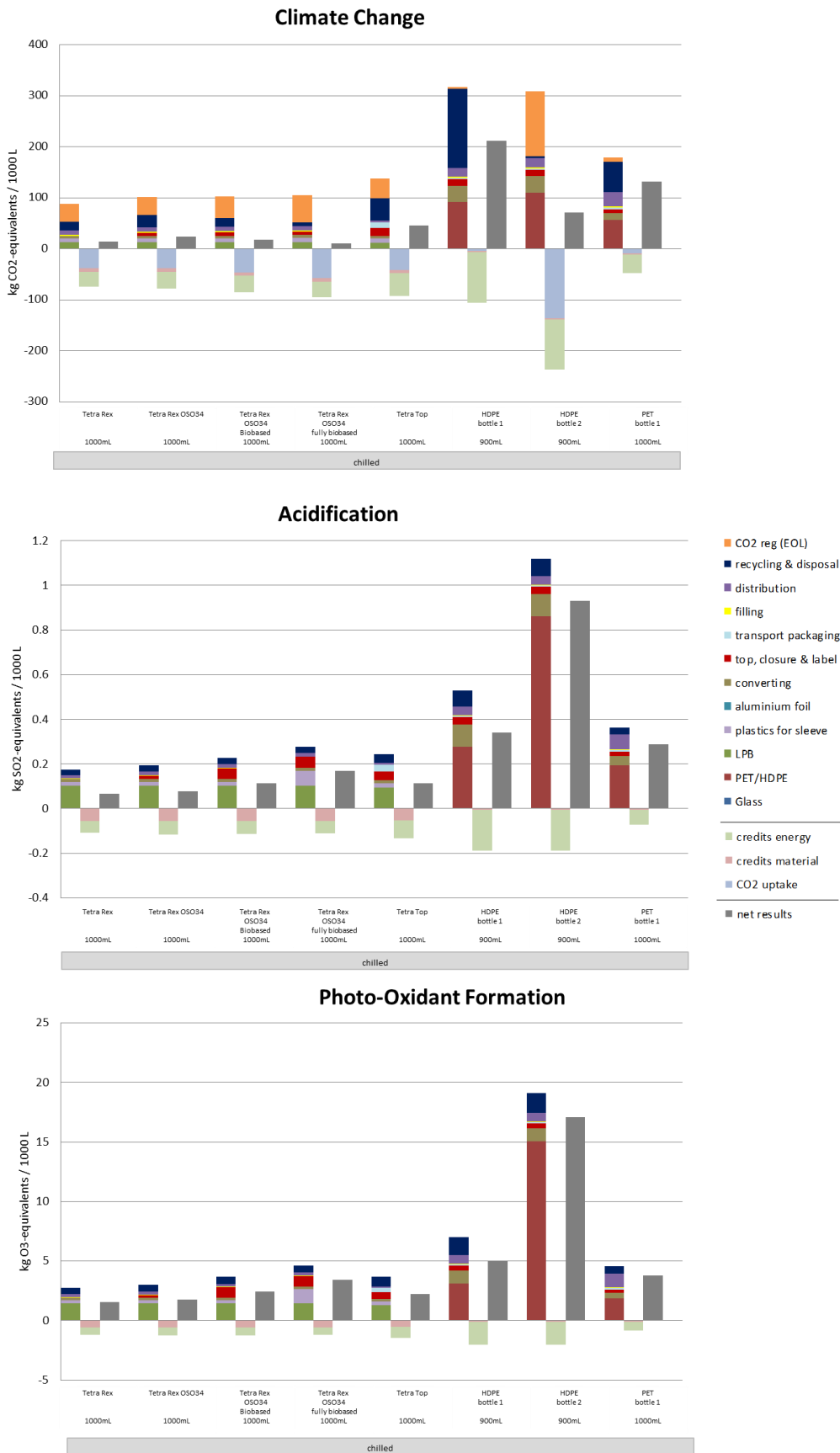


Figure 114: Indicator results for sensitivity analysis on system allocation of segment Water, Norway, allocation factor 100% (Part 1)

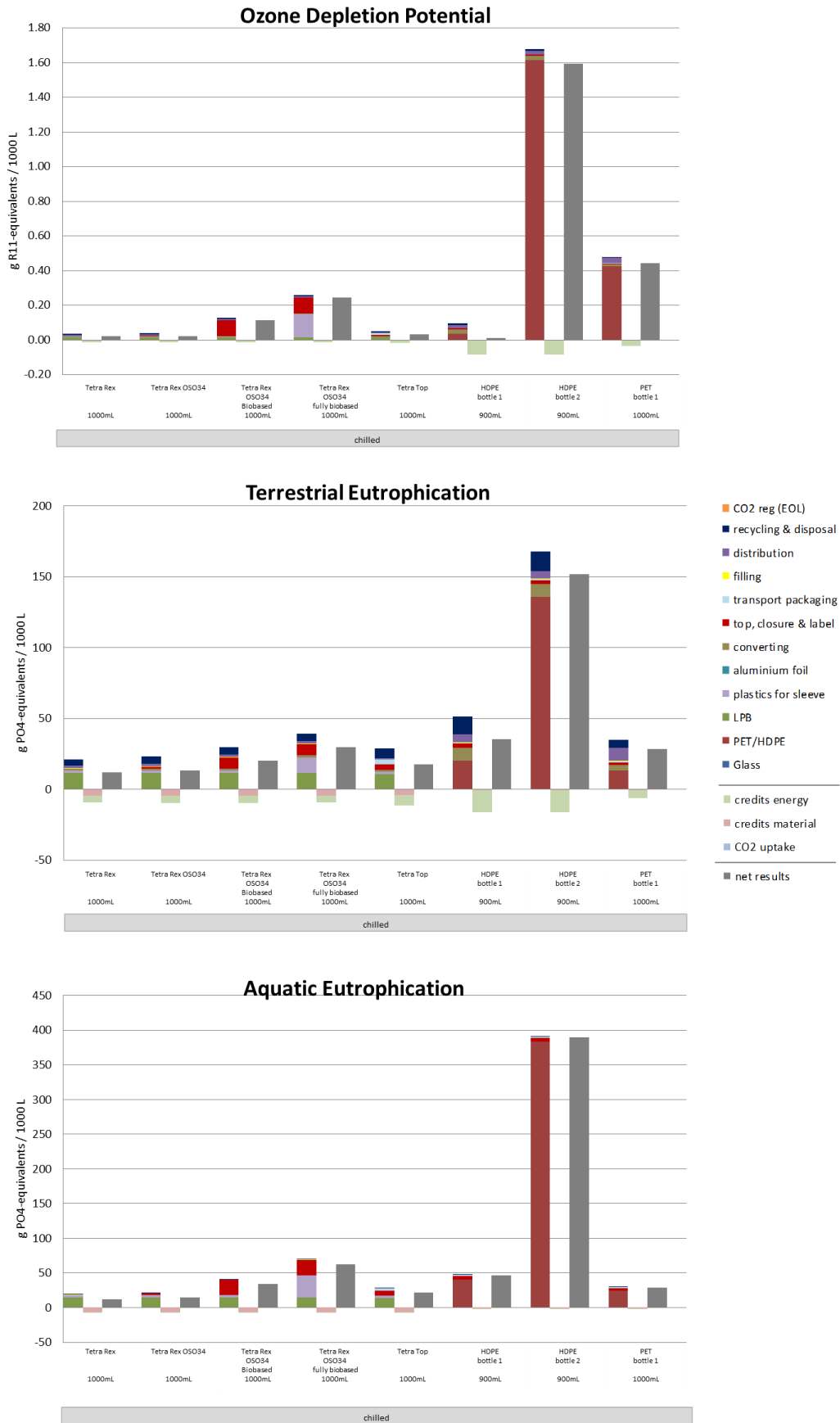


Figure 115: Indicator results for sensitivity analysis on system allocation of segment Water Norway, allocation factor 100% (Part 2)

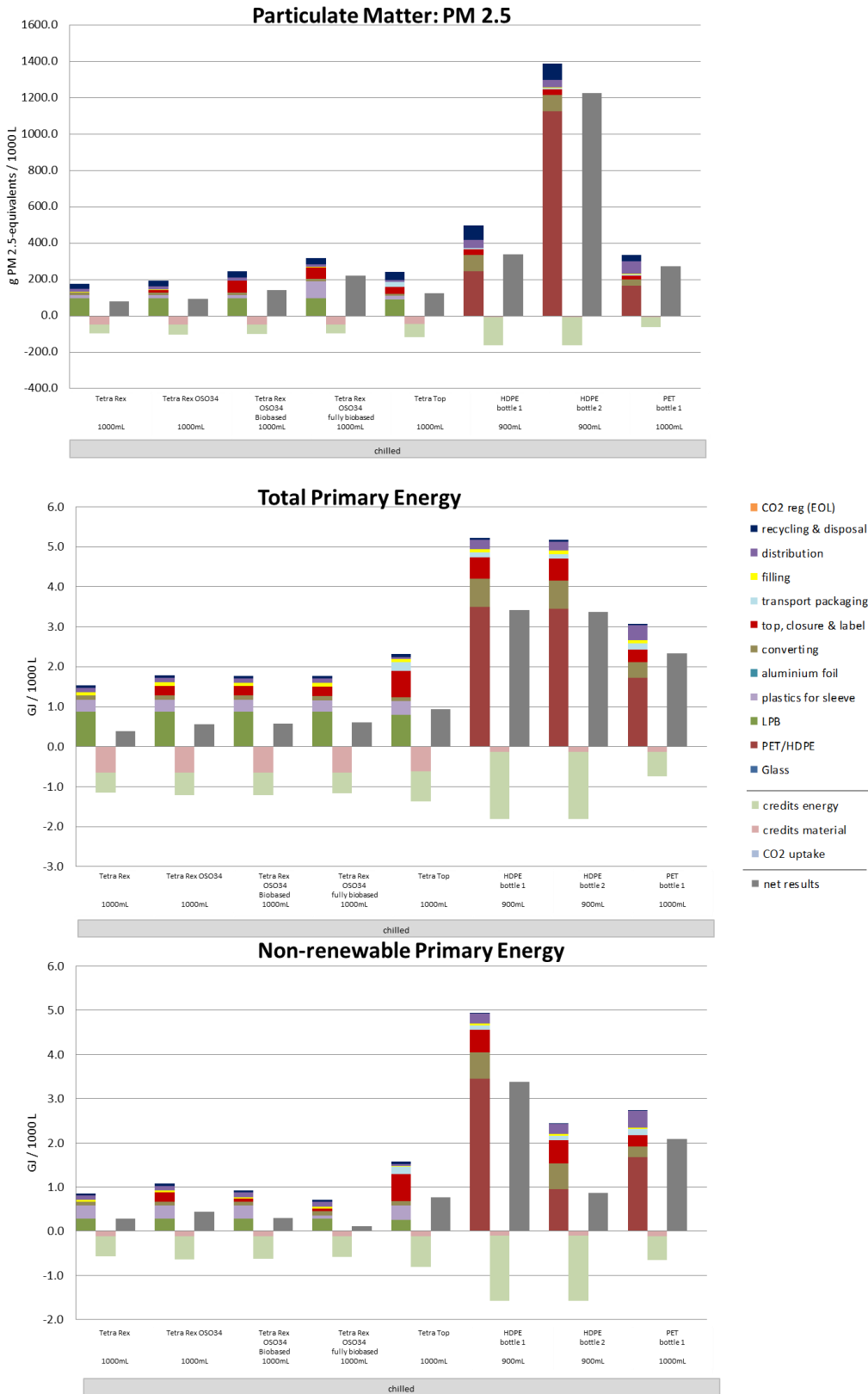


Figure 116: Indicator results for sensitivity analysis on system allocation of segment Water, Norway, allocation factor 100% (Part 3)

Table 121: Category indicator results per impact category for for sensitivity analysis on system allocation of **segment DAIRY, Norway**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	53.01	66.66	60.54	51.32	99.55	313.19	181.05	171.07
	CO ₂ (reg)	35.11	35.20	42.55	53.31	38.34	4.21	127.50	8.12
	Credits	-35.81	-40.11	-39.42	-36.73	-51.05	-101.52	-101.55	-39.05
	CO ₂ uptake	-38.24	-38.31	-46.26	-57.90	-41.02	-4.27	-135.64	-8.34
	Net results	14.07	23.44	17.40	10.00	45.81	211.61	71.36	131.80
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.17	0.19	0.23	0.28	0.24	0.53	1.12	0.36
	Credits	-0.11	-0.12	-0.12	-0.11	-0.13	-0.19	-0.19	-0.07
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Net results	0.07	0.08	0.11	0.17	0.11	0.34	0.93	0.29
	Burdens	2.73	3.02	3.68	4.63	3.70	7.00	19.09	4.58
	Credits	-1.17	-1.26	-1.24	-1.19	-1.46	-2.01	-2.01	-0.81
	Net results	1.56	1.76	2.44	3.44	2.24	4.99	17.08	3.77
Ozone Depletion [g R11/1000 L]	Burdens	0.03	0.04	0.13	0.26	0.05	0.10	1.68	0.48
	Credits	-0.01	-0.01	-0.01	-0.01	-0.02	-0.09	-0.09	-0.04
	Net results	0.02	0.02	0.11	0.24	0.03	0.01	1.59	0.44
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	21.05	23.10	29.61	39.10	28.88	51.37	167.98	34.74
	Credits	-9.00	-9.67	-9.56	-9.14	-11.15	-16.10	-16.11	-6.34
	Net results	12.05	13.43	20.04	29.96	17.73	35.27	151.87	28.40
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	19.02	21.45	40.90	69.34	28.48	47.32	390.53	29.70
	Credits	-6.80	-6.83	-6.83	-6.83	-6.52	-1.13	-1.14	-1.23
	Net results	12.22	14.62	34.07	62.51	21.96	46.19	389.39	28.47
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	175.65	194.05	244.05	317.74	241.78	498.02	1386.52	336.53
	Credits	-95.44	-102.27	-101.18	-96.94	-116.93	-160.72	-160.77	-63.34
	Net results	80.20	91.77	142.87	220.80	124.85	337.31	1225.75	273.19
Total Primary Energy [GJ]	Burdens	1.53	1.78	1.78	1.77	2.32	5.22	5.18	3.07
	Credits	-1.14	-1.22	-1.21	-1.16	-1.38	-1.81	-1.81	-0.74
	Net results	0.39	0.56	0.57	0.61	0.94	3.41	3.37	2.33
Non-renewable Primary Energy [GJ]	Burdens	0.85	1.07	0.92	0.70	1.58	4.95	2.44	2.74
	Credits	-0.57	-0.64	-0.63	-0.59	-0.81	-1.57	-1.57	-0.65
	Net results	0.28	0.44	0.30	0.12	0.77	3.37	0.87	2.09
Use of Nature [m ² /year]	Burdens	21.54	24.35	27.41	35.88	21.84	0.46	99.98	0.44
	Credits	-9.90	-9.90	-9.90	-9.90	-9.17	-0.38	-0.38	-0.23
	Net results	11.64	14.45	17.51	25.98	12.67	0.08	99.60	0.21
Water use [m ³ /1000 L]	water cool	0.84	0.98	1.00	1.01	1.19	2.69	3.54	2.09
	water process	1.80	1.81	1.80	1.79	1.50	0.17	0.23	0.24
	water unspecified	0.19	0.24	0.30	0.38	0.48	1.01	2.41	0.79

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 2.4.3). Results are shown in the following break even graphs.

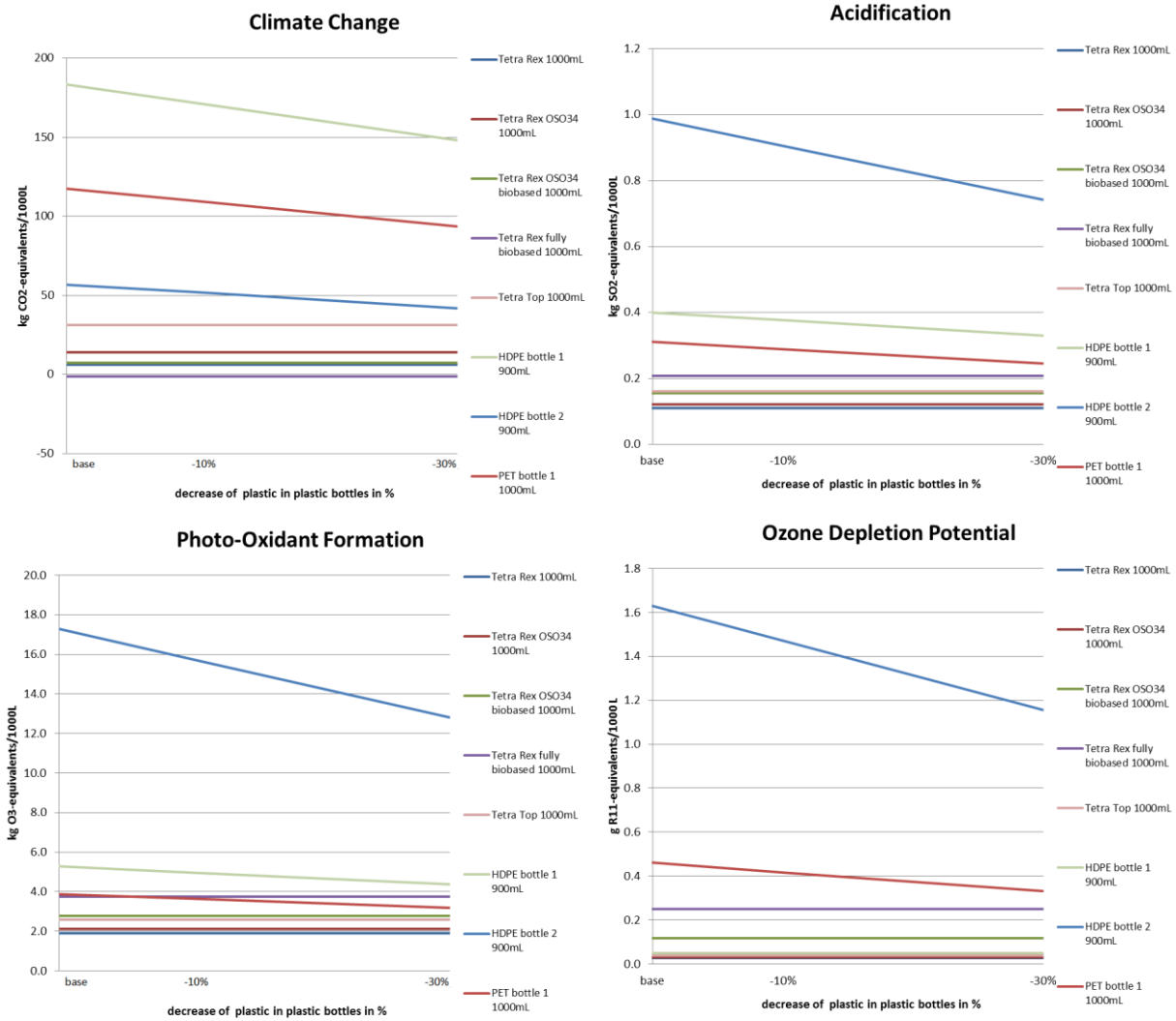


Figure 117: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Norway, allocation factor 50% (Part 1)

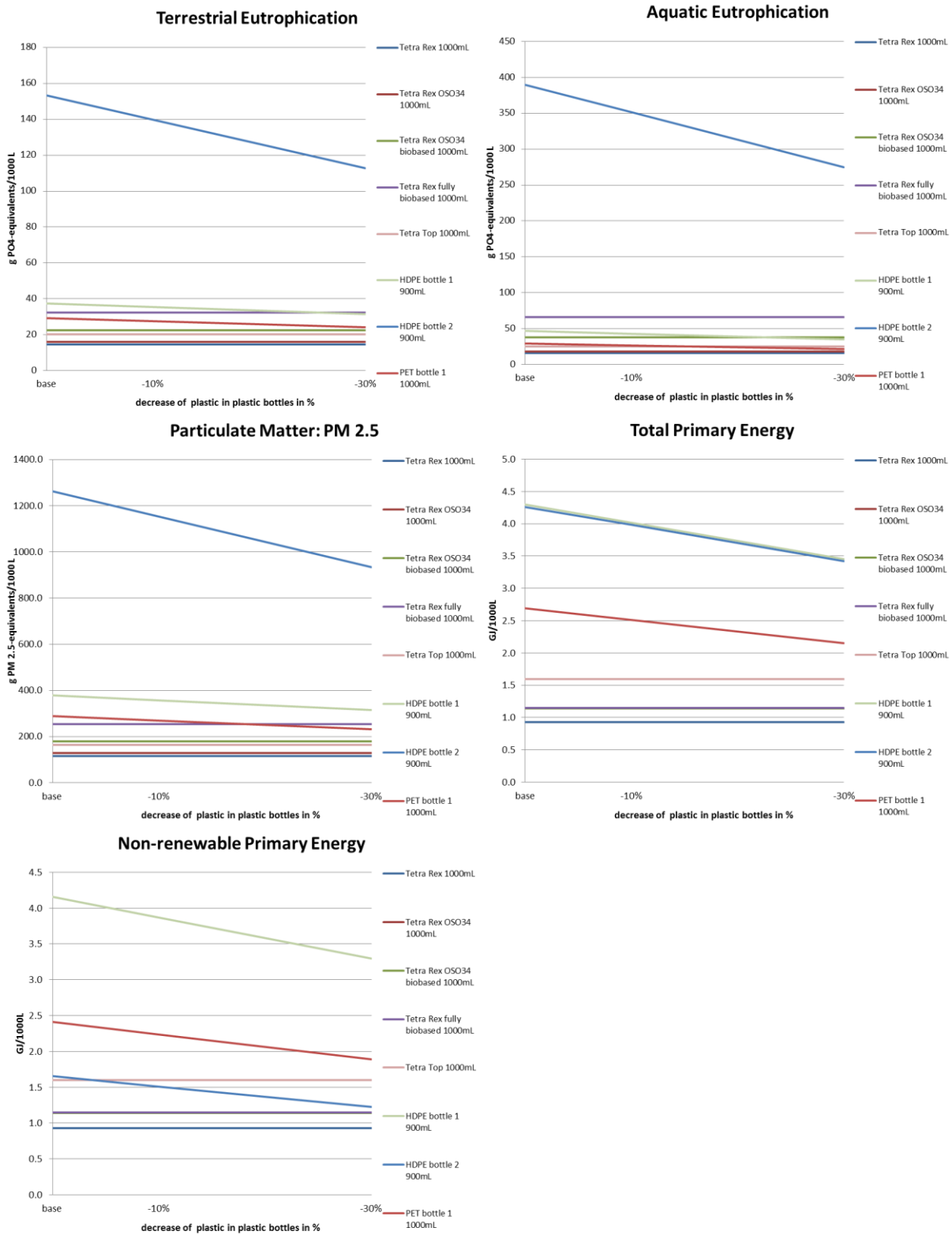


Figure 118: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Norway, allocation factor 50% (Part 2)

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.

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.

Lightweight 'HDPE bottle 1' and 'PET bottle 1' break even with some beverage cartons in some of the other categories.

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%.

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%.

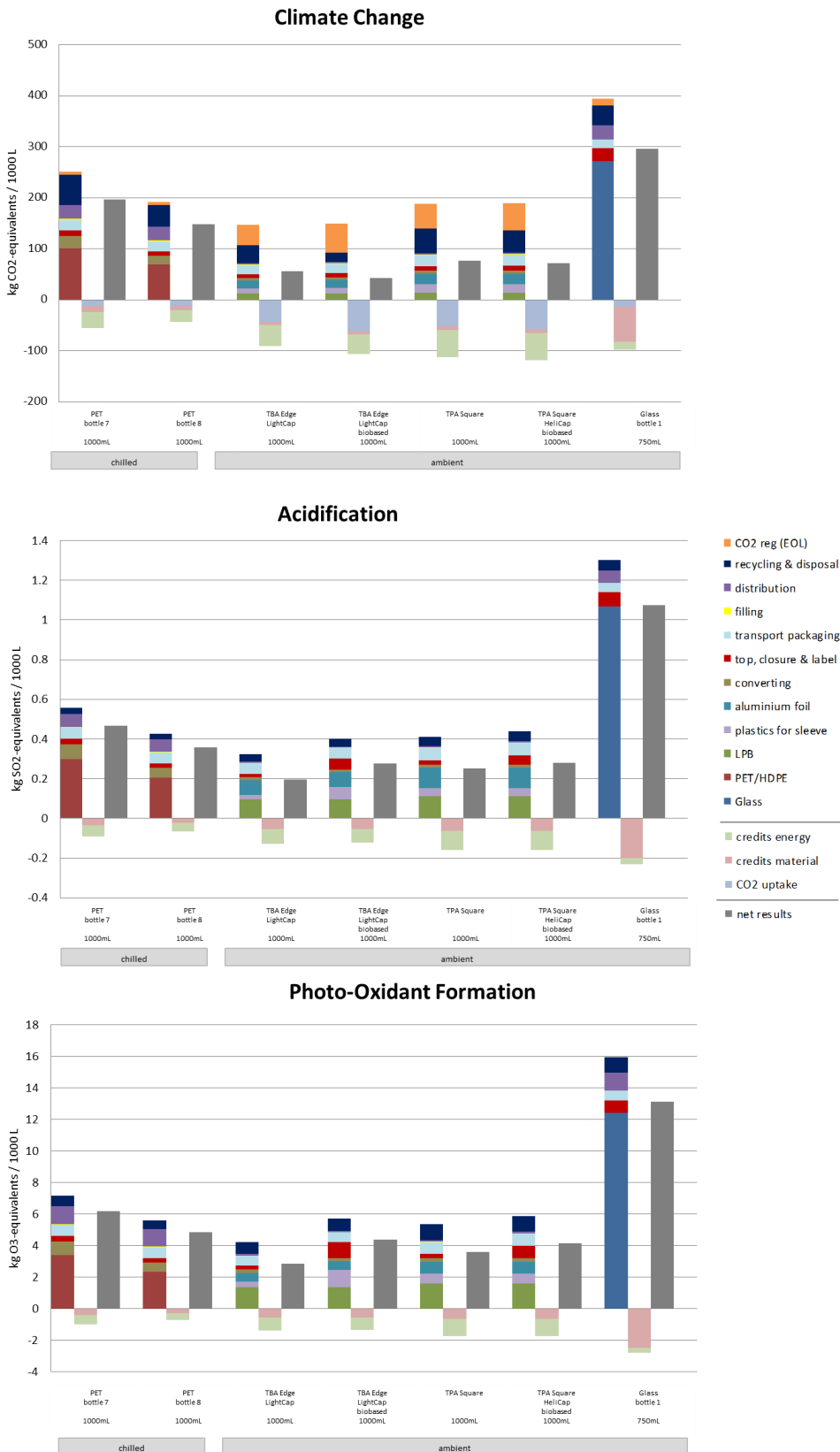


Figure 119: Indicator results for sensitivity analysis on system allocation of segment JNSD, Norway, allocation factor 100% (Part 1)

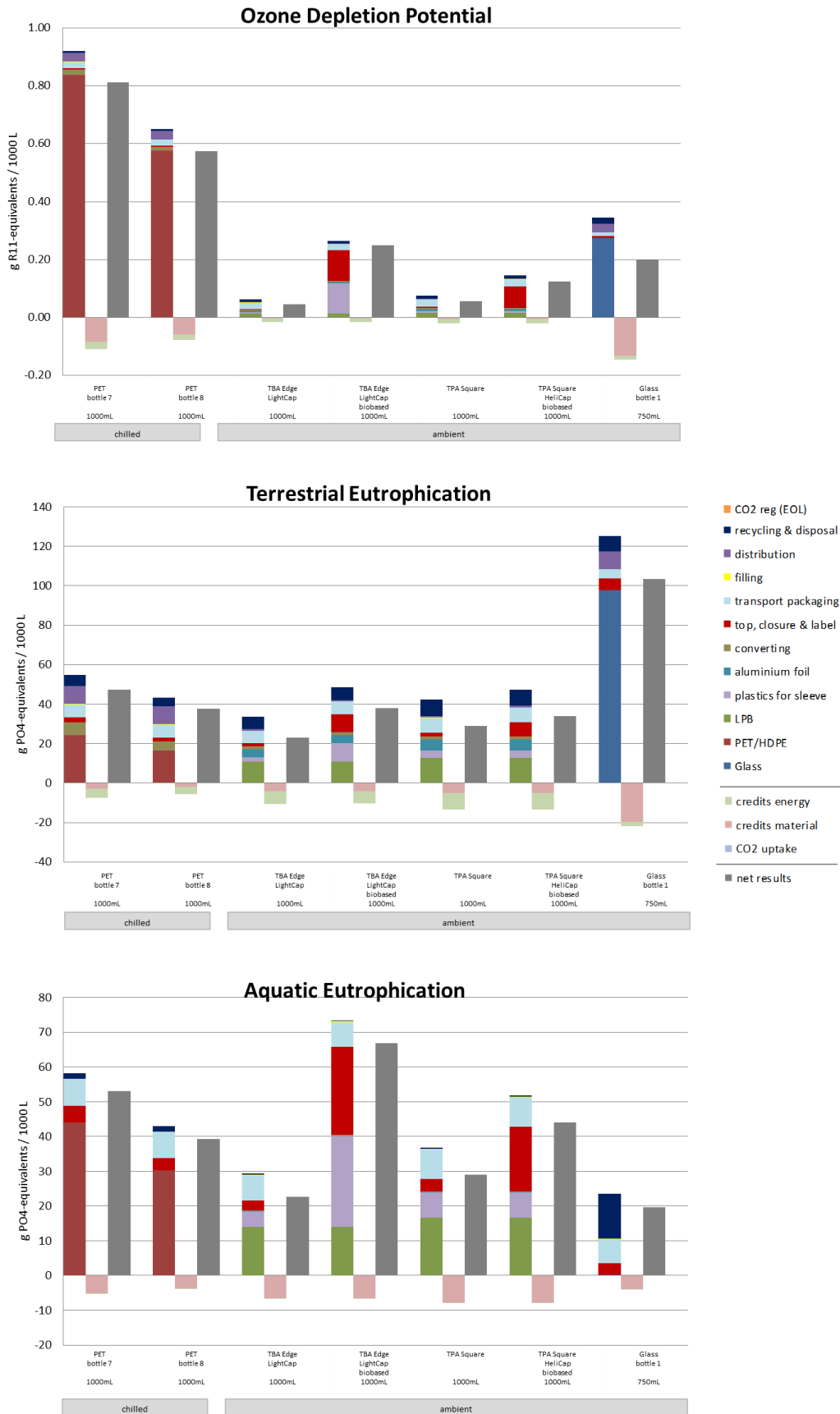


Figure 120: Indicator results for sensitivity analysis on system allocation of segment JNSD, Norway, allocation factor 100% (Part 2)

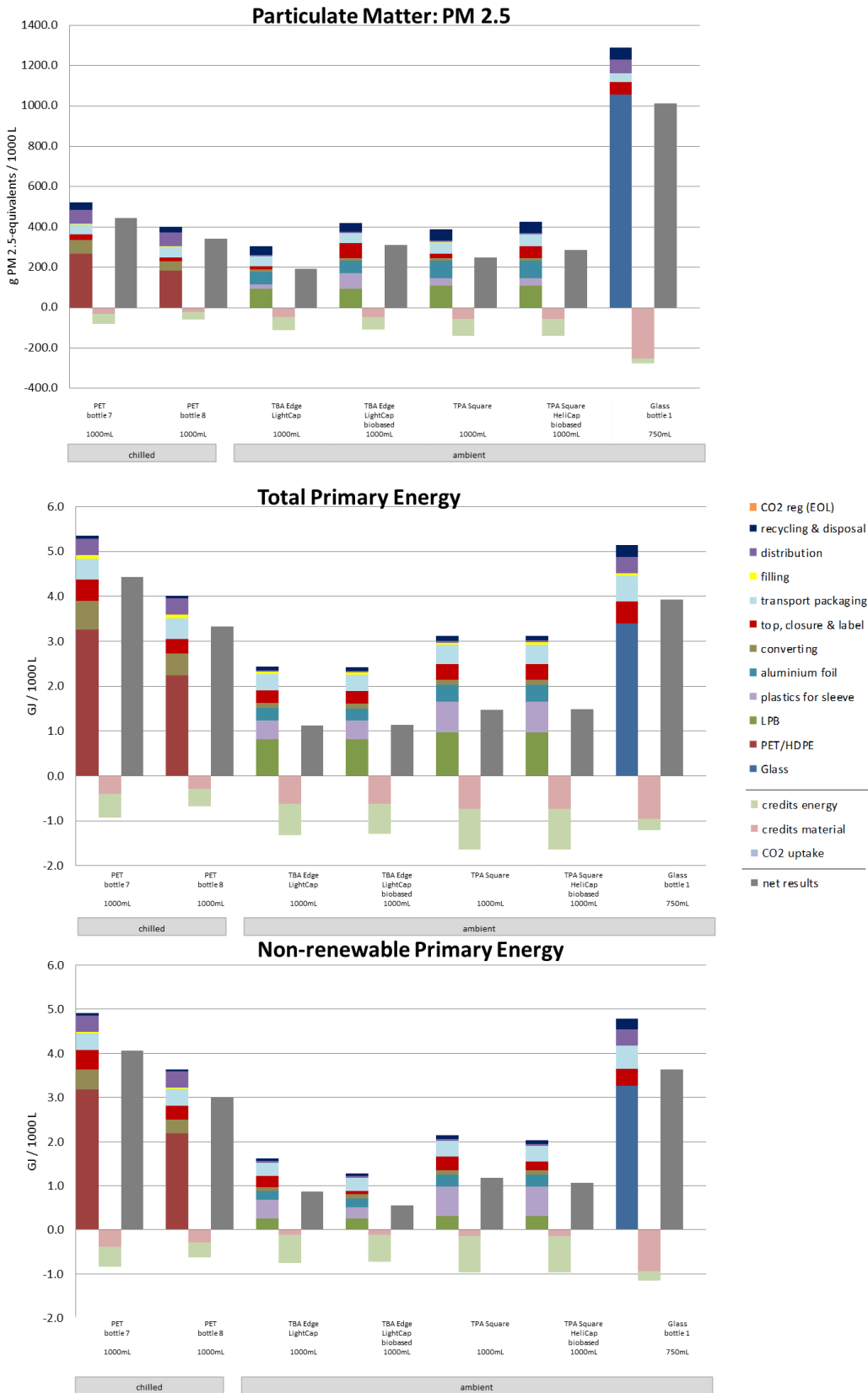


Figure 121: Indicator results for sensitivity analysis on system allocation of segment JNSD, Norway, allocation factor 100% (Part 3)

Table 122: Category indicator results per impact category for sensitivity analysis on system allocation of **segment JNSD, Norway**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		PET bottle 7 1000mL	PET bottle 8 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	Glass bottle 1 750mL
Climate Change [kg CO2-e/1000 L]	Burdens	245.15	185.97	106.30	92.27	140.17	135.55	381.24
	CO2 (reg)	5.89	5.89	40.69	57.35	48.32	53.96	12.32
	Credits	-42.81	-31.46	-47.47	-45.39	-60.88	-60.67	-85.69
	CO2 uptake	-12.19	-12.19	-43.32	-61.39	-51.41	-57.56	-12.47
	net results	196.04	148.22	56.20	42.84	76.19	71.28	295.40
Acidification [kg SO2-e/1000 L]	Burdens	0.56	0.43	0.32	0.40	0.41	0.44	1.30
	Credits	-0.09	-0.07	-0.13	-0.12	-0.16	-0.16	-0.23
	Net results	0.47	0.36	0.20	0.28	0.25	0.28	1.07
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	7.18	5.58	4.24	5.73	5.36	5.88	15.92
	Credits	-1.00	-0.73	-1.39	-1.35	-1.74	-1.74	-2.79
	Net results	6.18	4.84	2.85	4.38	3.61	4.14	13.14
Ozone Depletion [g R11/1000 L]	Burdens	0.92	0.65	0.06	0.26	0.08	0.15	0.35
	Credits	-0.11	-0.08	-0.02	-0.02	-0.02	-0.02	-0.15
	Net results	0.81	0.57	0.05	0.25	0.06	0.12	0.20
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	54.89	43.18	33.68	48.45	42.33	47.37	125.25
	Credits	-7.61	-5.58	-10.65	-10.32	-13.35	-13.32	-21.98
	Net results	47.28	37.60	23.03	38.12	28.98	34.05	103.27
Aquatic Eutrophication [g PO4/1000 L]	Burdens	58.25	42.92	29.28	73.45	36.81	51.86	23.58
	Credits	-5.11	-3.68	-6.59	-6.59	-7.82	-7.82	-3.98
	Net results	53.14	39.23	22.69	66.86	28.98	44.03	19.60
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	522.85	401.08	304.67	418.76	387.63	426.05	1288.61
	Credits	-78.92	-57.70	-111.87	-108.59	-140.01	-139.68	-274.99
	Net results	443.94	343.37	192.80	310.17	247.63	286.38	1013.63
Total Primary Energy [GJ]	Burdens	5.34	4.01	2.44	2.43	3.12	3.12	5.15
	Credits	-0.92	-0.68	-1.32	-1.29	-1.65	-1.64	-1.21
	Net results	4.42	3.33	1.12	1.14	1.48	1.48	3.93
Non-renewable Primary Energy [GJ]	Burdens	4.91	3.63	1.62	1.28	2.14	2.03	4.79
	Credits	-0.84	-0.62	-0.75	-0.72	-0.96	-0.96	-1.15
	Net results	4.07	3.01	0.87	0.56	1.18	1.07	3.64
Use of Nature [m²/year]	Burdens	3.37	3.33	27.31	36.80	28.11	32.59	2.12
	Credits	-0.05	-0.04	-9.34	-9.34	-11.10	-11.10	-0.07
	Net results	3.33	3.28	17.97	27.47	17.01	21.49	2.05
Water use [m³/1000 L]	water cool	4.01	2.82	1.31	1.34	1.62	1.66	0.17
	water process	0.25	0.18	1.89	1.87	2.27	2.26	5.39
	water unspecified	1.48	1.12	0.59	0.72	0.74	0.78	0.43

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 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%.

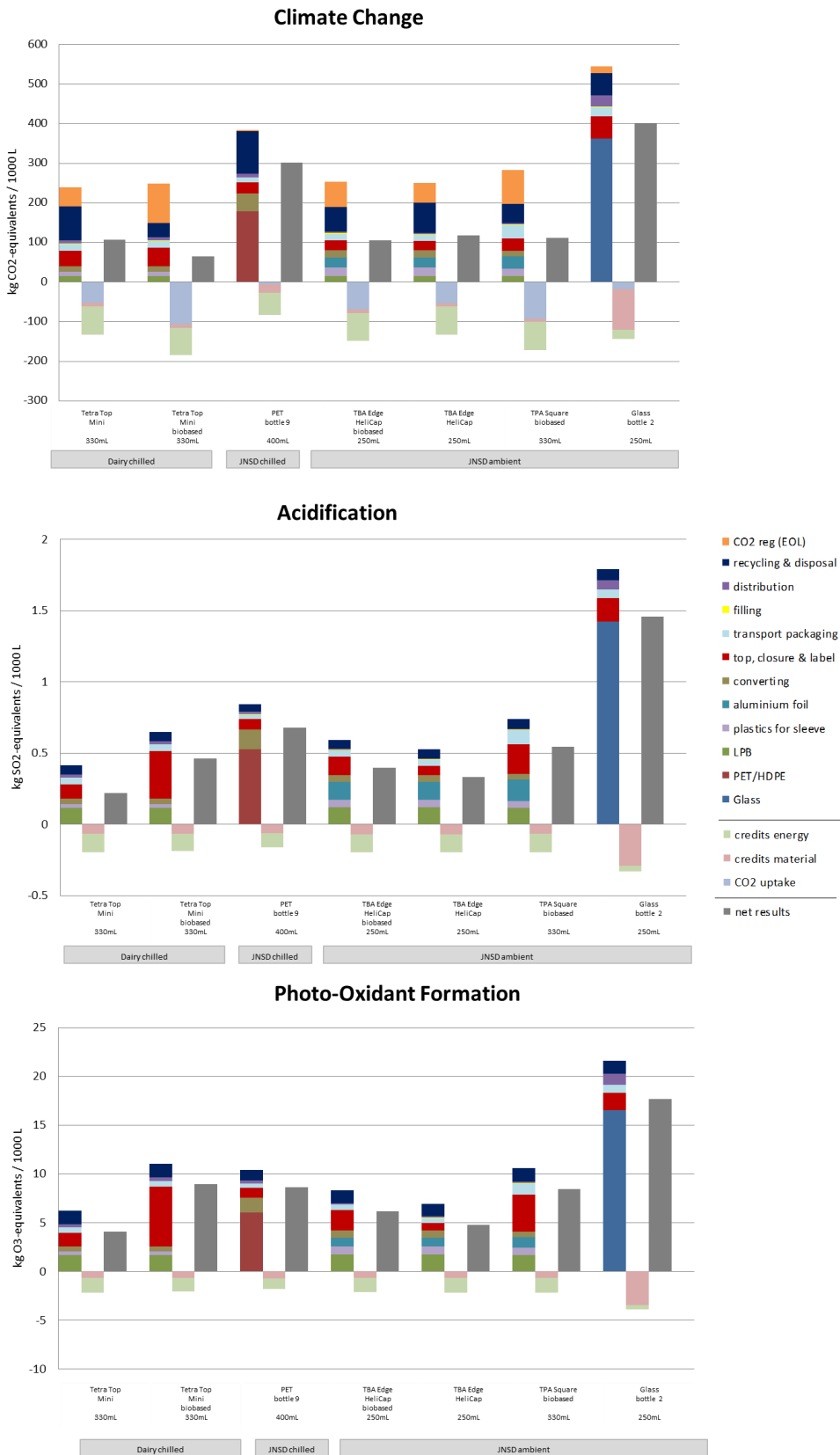


Figure 122: Indicator results for sensitivity analysis on system allocation of segment Grab & Go, Norway, allocation factor 100% (Part 1)

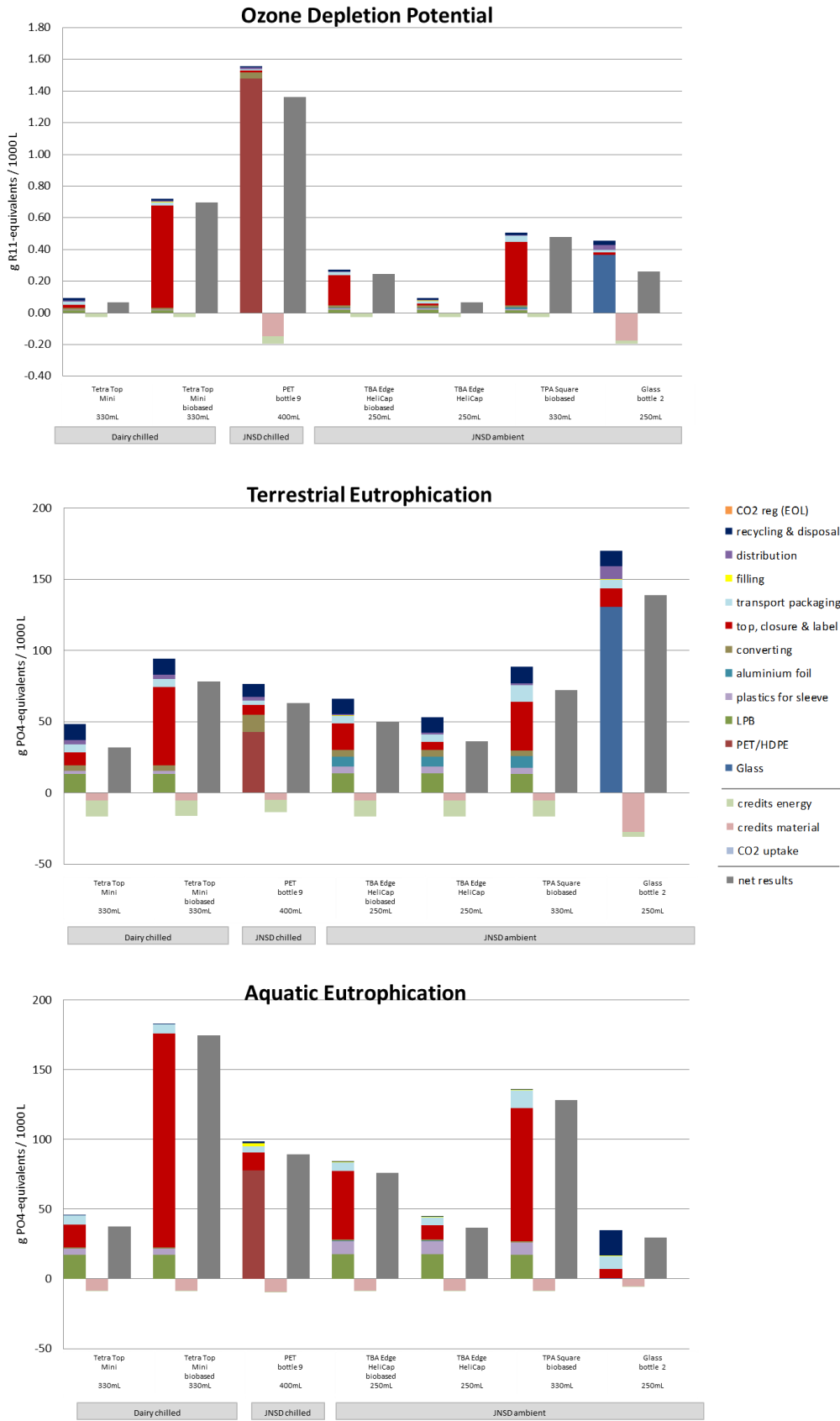


Figure 123: Indicator results for sensitivity analysis on system allocation of segment Grab & Go, Norway, allocation factor 100% (Part 2)

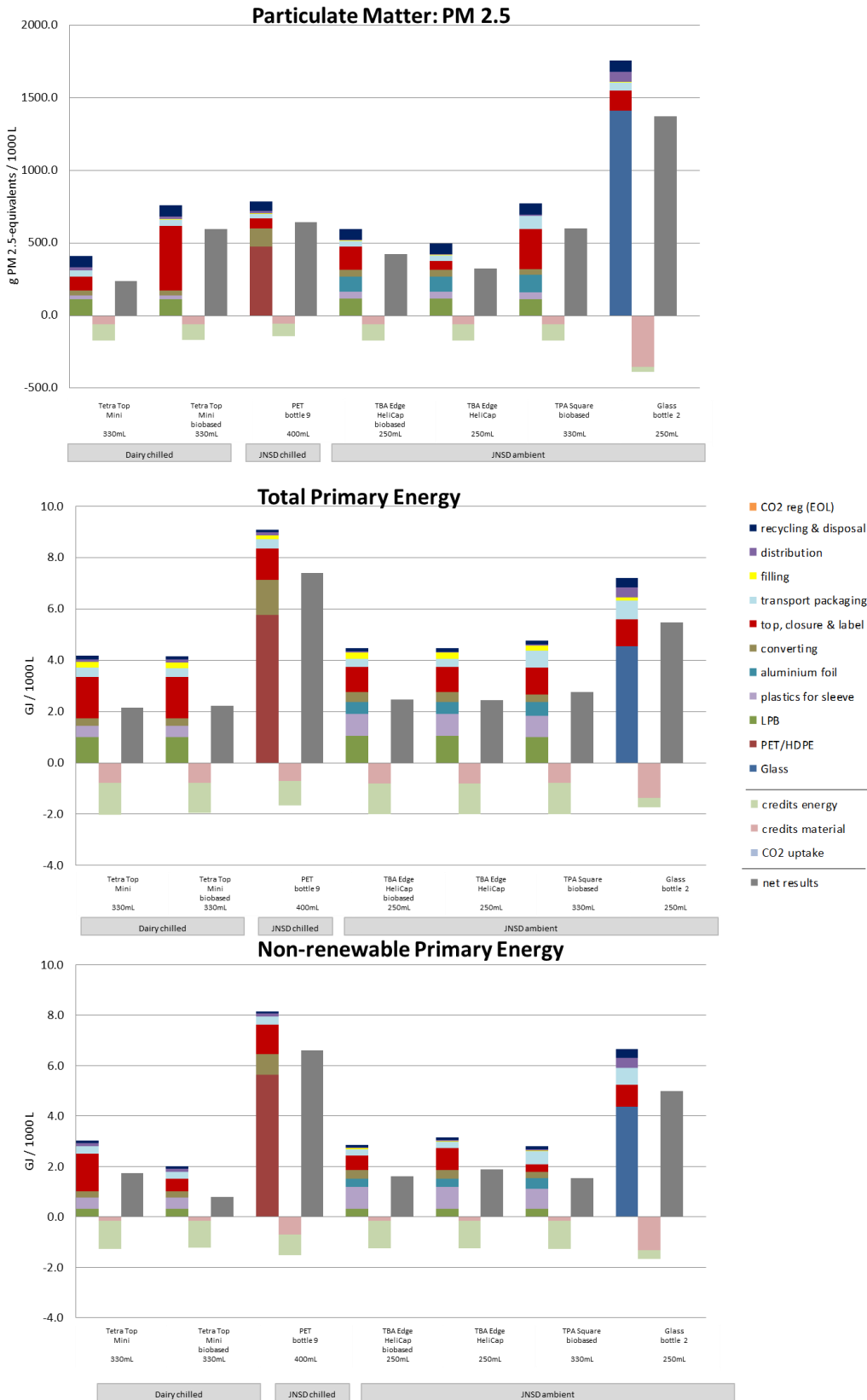


Figure 124: Indicator results for sensitivity analysis on system allocation of segment Grab & Go, Norway, allocation factor 100% (Part 3)

Table 123: Category indicator results per impact category for sensitivity analysis on system allocation of **segment Grab & Go, Norway**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Mini biobased 330mL	PET bottle 9 400mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	Glass bottle2 250mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	190.74	149.10	381.76	188.85	200.96	197.60	528.46
	CO ₂ (reg)	49.18	99.33	2.68	64.57	49.77	86.11	17.01
	Credits	-81.32	-76.93	-76.99	-79.18	-79.57	-80.40	-126.07
	CO ₂ uptake	-52.32	-106.74	-5.52	-69.09	-53.07	-91.67	-17.21
	net results	106.27	64.77	301.93	105.15	118.10	111.64	402.19
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.42	0.65	0.84	0.59	0.53	0.74	1.79
	Credits	-0.20	-0.19	-0.16	-0.19	-0.20	-0.20	-0.33
	Net results	0.22	0.46	0.68	0.40	0.33	0.54	1.46
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	6.24	11.01	10.42	8.31	6.95	10.59	21.62
	Credits	-2.18	-2.09	-1.80	-2.16	-2.17	-2.16	-3.93
	Net results	4.06	8.91	8.62	6.15	4.78	8.43	17.69
Ozone Depletion [g R11/1000 L]	Burdens	0.09	0.72	1.56	0.27	0.09	0.50	0.46
	Credits	-0.03	-0.03	-0.19	-0.03	-0.03	-0.03	-0.20
	Net results	0.07	0.70	1.36	0.25	0.07	0.48	0.26
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	48.36	94.37	76.65	66.07	52.93	88.50	169.78
	Credits	-16.67	-15.98	-13.71	-16.48	-16.54	-16.53	-30.97
	Net results	31.70	78.38	62.95	49.59	36.39	71.97	138.81
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	45.95	183.04	98.66	84.35	45.12	136.32	34.92
	Credits	-8.22	-8.22	-9.31	-8.51	-8.51	-8.22	-5.42
	Net results	37.73	174.82	89.35	75.84	36.61	128.10	29.50
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	409.95	760.67	783.70	596.86	496.71	773.77	1757.55
	Credits	-173.70	-166.78	-142.00	-172.01	-172.63	-172.35	-387.45
	Net results	236.25	593.88	641.70	424.85	324.08	601.42	1370.10
Total Primary Energy [GJ]	Burdens	4.16	4.16	9.07	4.46	4.46	4.76	7.21
	Credits	-2.02	-1.94	-1.66	-2.01	-2.01	-2.00	-1.74
	Net results	2.14	2.22	7.41	2.46	2.45	2.75	5.47
Non-renewable Primary Energy [GJ]	Burdens	3.02	2.01	8.14	2.86	3.15	2.80	6.64
	Credits	-1.28	-1.22	-1.53	-1.25	-1.26	-1.27	-1.66
	Net results	1.74	0.79	6.61	1.60	1.89	1.53	4.98
Use of Nature [m ² /year]	Burdens	28.28	68.61	1.40	40.76	29.09	56.77	3.08
	Credits	-11.40	-11.40	-0.05	-11.83	-11.83	-11.43	-0.07
	Net results	16.88	57.20	1.35	28.93	17.26	45.34	3.01
Water use [m ³ /1000 L]	water cool	2.14	2.49	7.01	2.77	2.67	2.89	0.31
	water process	1.92	1.91	1.65	2.65	2.67	2.58	12.72
	water unspecified	0.83	1.29	2.24	0.96	0.85	1.40	0.91

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.

11.4 Water Norway

11.4.1 Sensitivity analysis on system allocation WATER Norway

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 125: Indicator results for sensitivity analysis on system allocation of segment Water Norway, allocation factor 100% (Part 1)

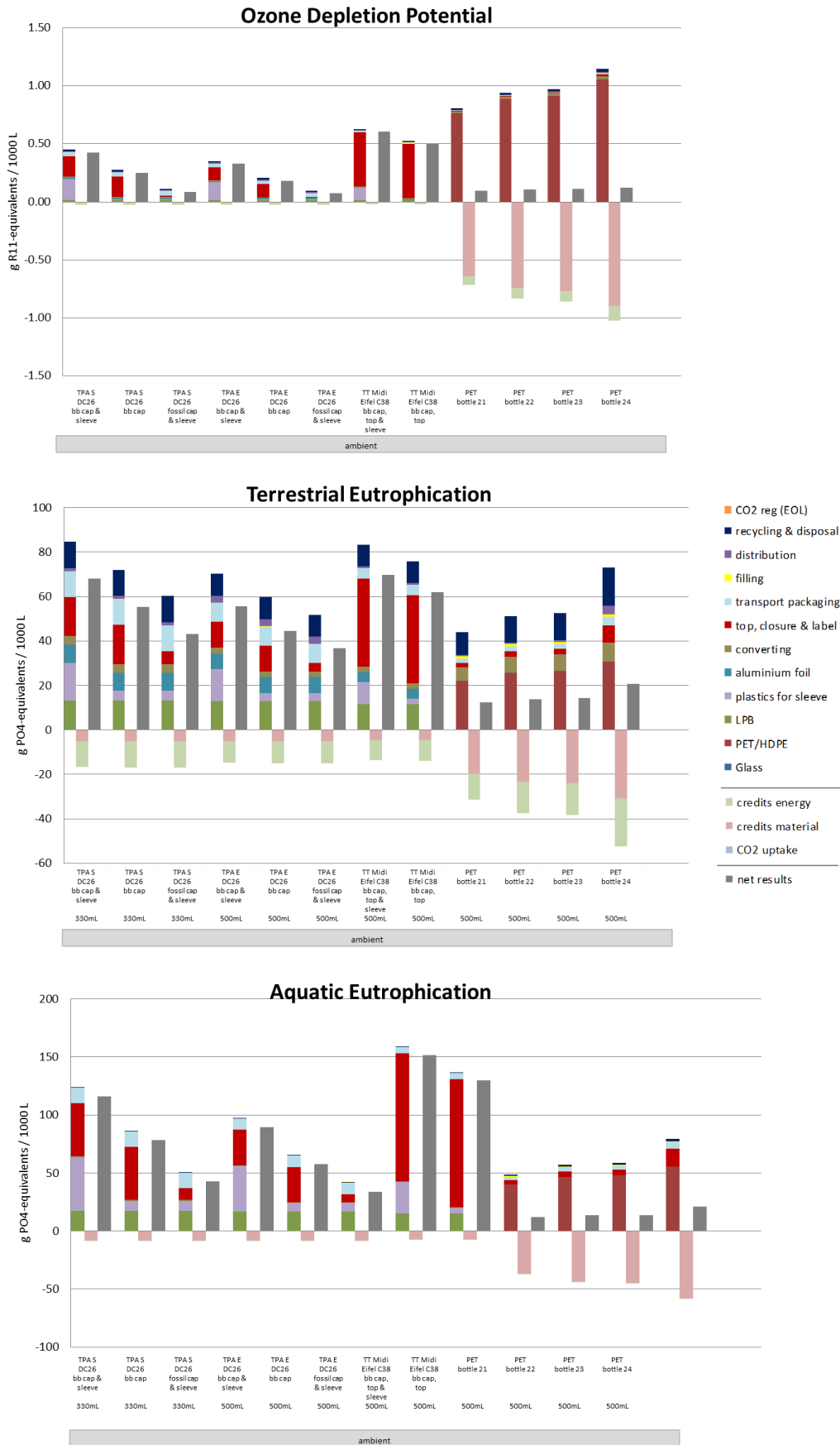


Figure 126: Indicator results for sensitivity analysis on system allocation of segment Water, Norway, allocation factor 100% (Part 2)

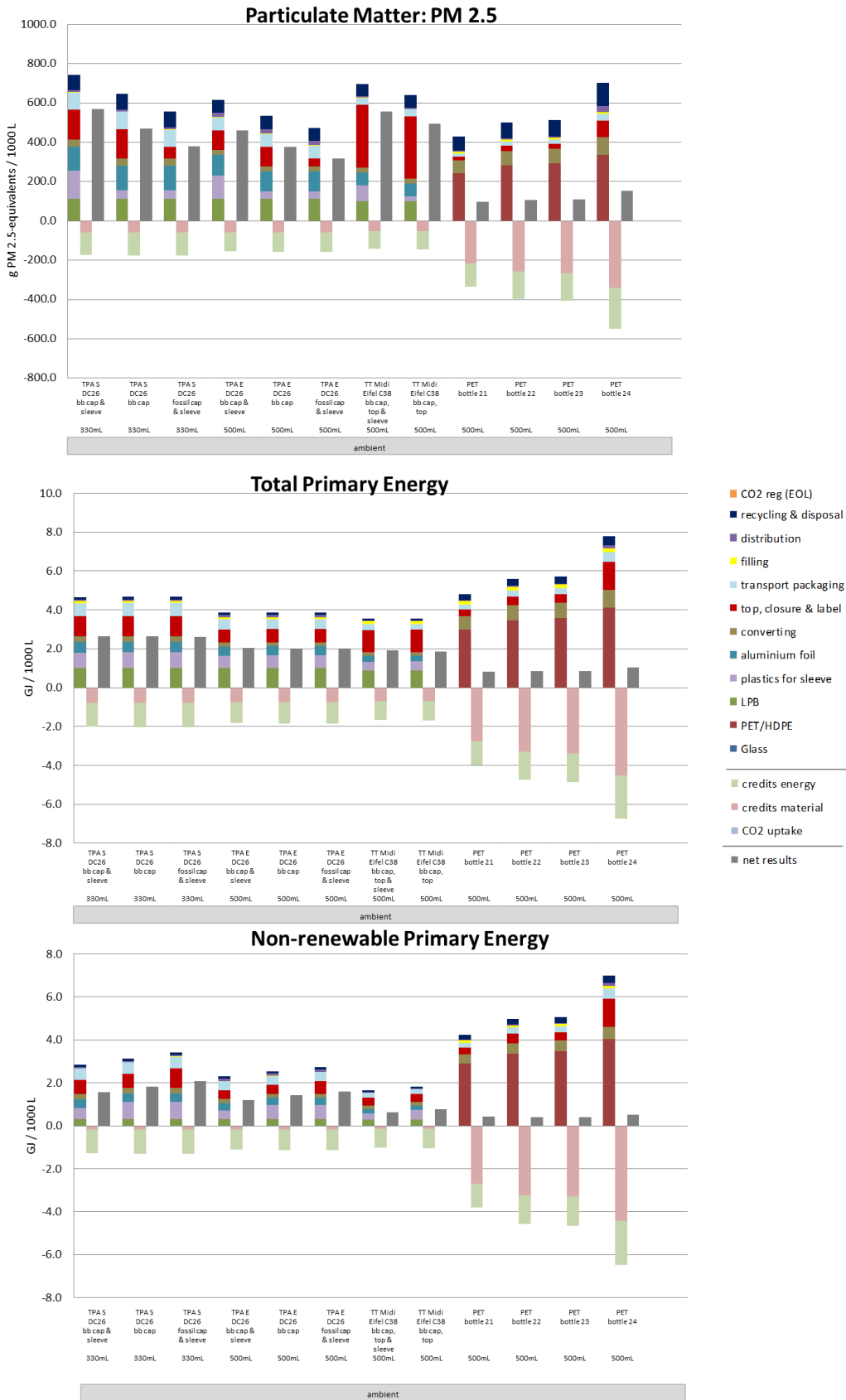


Figure 127: Indicator results for sensitivity analysis on system allocation of segment Water, Norway, allocation factor 100% (Part 3)

Table 124: Category indicator results per impact category for sensitivity analysis on system allocation of **segment Water, Norway**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 25 600mL	PET bottle 26 500mL	PET bottle 27 500mL	PET bottle 28 300mL
Climate Change [kg CO2-e/1000 L]	Burdens	198.95	211.06	222.11	160.63	170.90	178.18	126.11	133.20	247.69	290.65	295.23	413.38
	CO2 (reg)	85.77	71.52	58.04	77.20	65.13	56.23	90.33	81.98	2.55	3.06	5.23	7.94
	Credits	-81.61	-82.73	-83.10	-69.97	-71.17	-71.50	-64.33	-66.75	-155.46	-185.21	-189.05	-263.66
	CO2 uptake	-90.88	-75.46	-60.95	-82.01	-68.95	-59.35	-96.97	-87.94	-2.61	-3.13	-5.42	-8.21
	net results	112.23	124.39	136.10	85.86	95.91	103.57	55.13	60.50	92.17	105.36	105.99	149.44
Acidification [kg SO2-e/1000 L]	Burdens	0.72	0.66	0.60	0.60	0.54	0.50	0.61	0.57	0.45	0.53	0.55	0.74
	Credits	-0.20	-0.20	-0.20	-0.18	-0.18	-0.18	-0.16	-0.16	-0.38	-0.45	-0.46	-0.62
	Net results	0.53	0.46	0.40	0.42	0.37	0.33	0.45	0.41	0.08	0.08	0.09	0.12
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	10.13	8.87	7.64	8.46	7.40	6.58	9.73	9.00	5.89	6.90	7.06	9.85
	Credits	-2.19	-2.21	-2.22	-1.94	-1.97	-1.97	-1.77	-1.82	-4.25	-5.06	-5.18	-7.10
	Net results	7.94	6.66	5.42	6.51	5.43	4.61	7.96	7.18	1.63	1.83	1.89	2.75
Ozone Depletion [g R11/1000 L]	Burdens	0.45	0.28	0.11	0.35	0.21	0.10	0.63	0.53	0.81	0.94	0.97	1.15
	Credits	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.71	-0.83	-0.86	-1.03
	Net results	0.42	0.25	0.09	0.33	0.18	0.07	0.61	0.51	0.10	0.11	0.11	0.12
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	84.63	72.05	60.15	70.30	59.64	51.77	83.22	75.85	43.80	51.25	52.59	73.14
	Credits	-16.69	-16.86	-16.92	-14.85	-15.04	-15.09	-13.55	-13.92	-31.50	-37.47	-38.31	-52.46
	Net results	67.94	55.18	43.23	55.45	44.60	36.68	69.68	61.93	12.30	13.78	14.28	20.68
Aquatic Eutrophication [g PO4/1000 L]	Burdens	123.97	86.30	50.78	97.41	65.50	42.00	158.82	136.76	48.49	56.92	58.45	79.16
	Credits	-8.15	-8.15	-8.15	-8.08	-8.08	-8.08	-7.18	-7.18	-36.65	-43.51	-44.66	-58.29
	Net results	115.81	78.15	42.63	89.34	57.43	33.93	151.64	129.57	11.84	13.40	13.78	20.87
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	744.88	647.22	556.55	617.44	534.71	474.72	698.12	640.91	429.04	502.21	515.00	703.82
	Credits	-173.89	-175.66	-176.23	-155.25	-157.15	-157.67	-141.54	-145.34	-333.04	-395.71	-404.77	-549.98
	Net results	570.99	471.56	380.32	462.19	377.57	317.05	556.59	495.57	95.99	106.51	110.23	153.84
Total Primary Energy [GJ]	Burdens	4.66	4.67	4.67	3.85	3.86	3.86	3.55	3.56	4.81	5.59	5.71	7.77
	Credits	-2.02	-2.04	-2.05	-1.82	-1.84	-1.85	-1.65	-1.70	-3.98	-4.75	-4.85	-6.75
	Net results	2.63	2.63	2.62	2.03	2.02	2.02	1.90	1.87	0.83	0.84	0.85	1.03
Non-renewable Primary Energy [GJ]	Burdens	2.84	3.14	3.40	2.29	2.54	2.72	1.66	1.83	4.24	4.97	5.06	6.98
	Credits	-1.29	-1.30	-1.31	-1.11	-1.13	-1.13	-1.02	-1.05	-3.81	-4.56	-4.66	-6.46
	Net results	1.56	1.83	2.09	1.19	1.42	1.58	0.64	0.78	0.43	0.41	0.40	0.52
Use of Nature [m²*year]	Burdens	53.29	42.07	31.50	46.10	36.59	29.60	60.26	53.68	0.61	0.73	0.83	1.28
	Credits	-11.37	-11.37	-11.37	-11.32	-11.32	-11.32	-10.11	-10.11	-0.09	-0.11	-0.11	-0.18
	Net results	41.92	30.70	20.13	34.78	25.27	18.28	50.15	43.57	0.52	0.62	0.72	0.00
Water use [m³/1000 L]	water cool	2.71	2.71	2.61	2.16	2.15	2.09	2.21	2.20	1.48	1.71	1.76	1.90
	water process	2.45	2.46	2.47	2.38	2.39	2.40	1.91	1.92	0.60	0.63	0.65	0.69
	water unspecified	1.36	1.25	1.15	1.05	0.96	0.89	1.12	1.06	0.28	0.33	0.33	0.49

11.4.2 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 2.4.3). Results are shown in the following break even graphs.

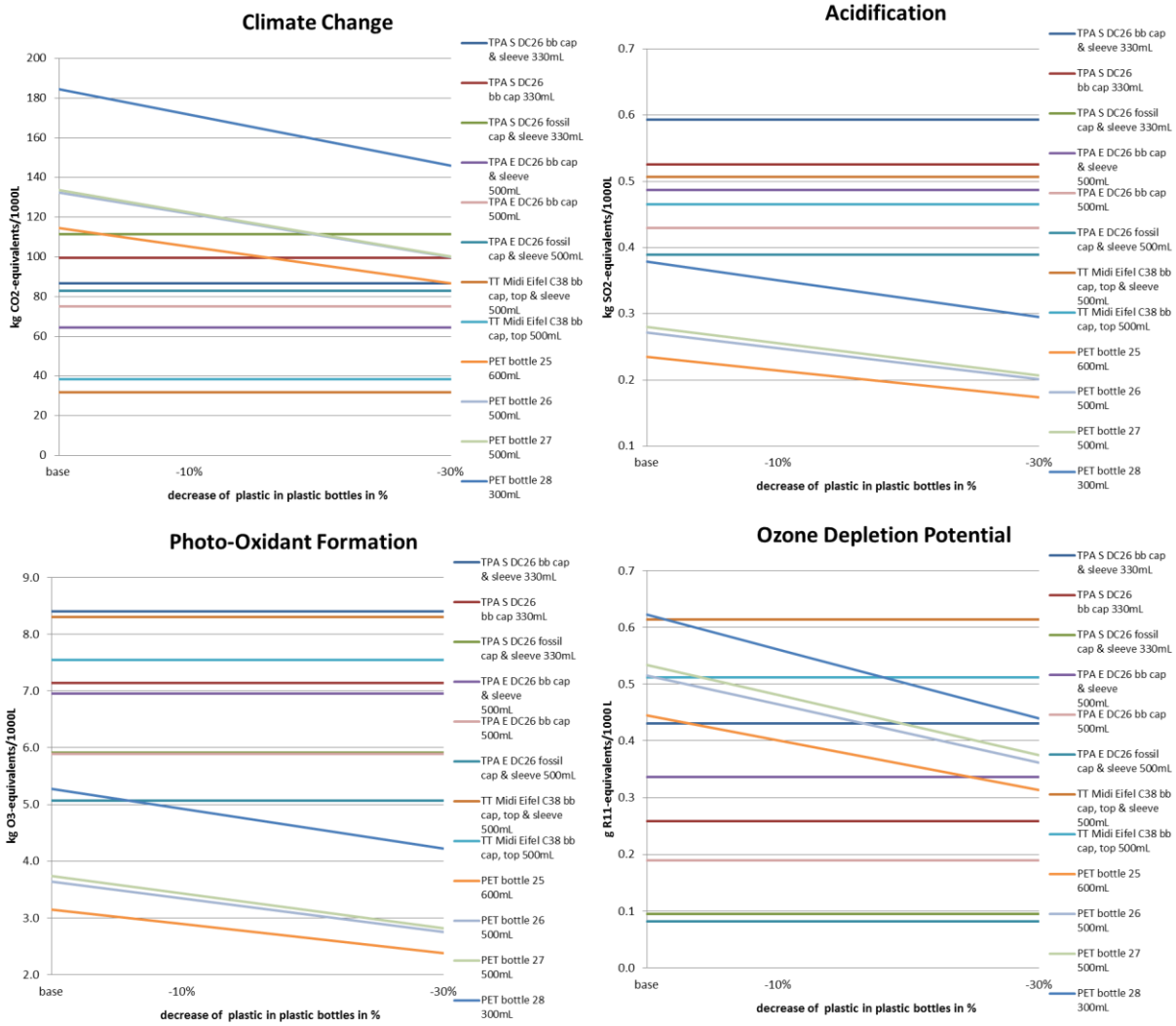


Figure 128: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Norway, allocation factor 50% (Part 1)

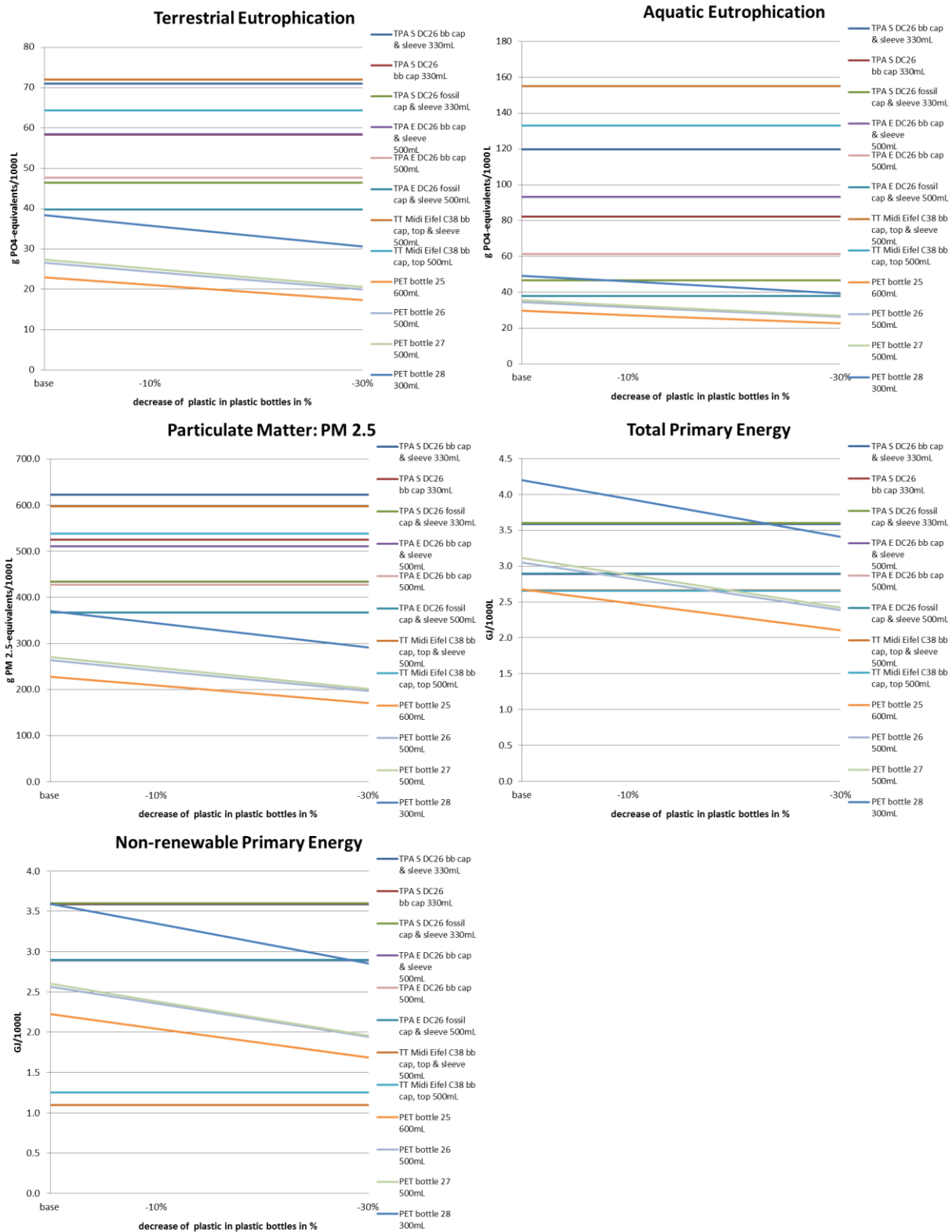


Figure 129: Indicator results for sensitivity analysis on plastic bottle weights of segment Water, Norway, allocation factor 50% (Part 2)

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In all categories where the base versions of the bottles showed higher results than the beverage cartons break even points are reached with at least some beverage cartons.

11.4.3 Sensitivity analysis regarding recycled PET in PET bottles

To consider potential future developments in terms of the share of recyclate of the plastic bottles, two additional scenarios for plastic bottles with a recycled content of PET of 50% and 100% 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.

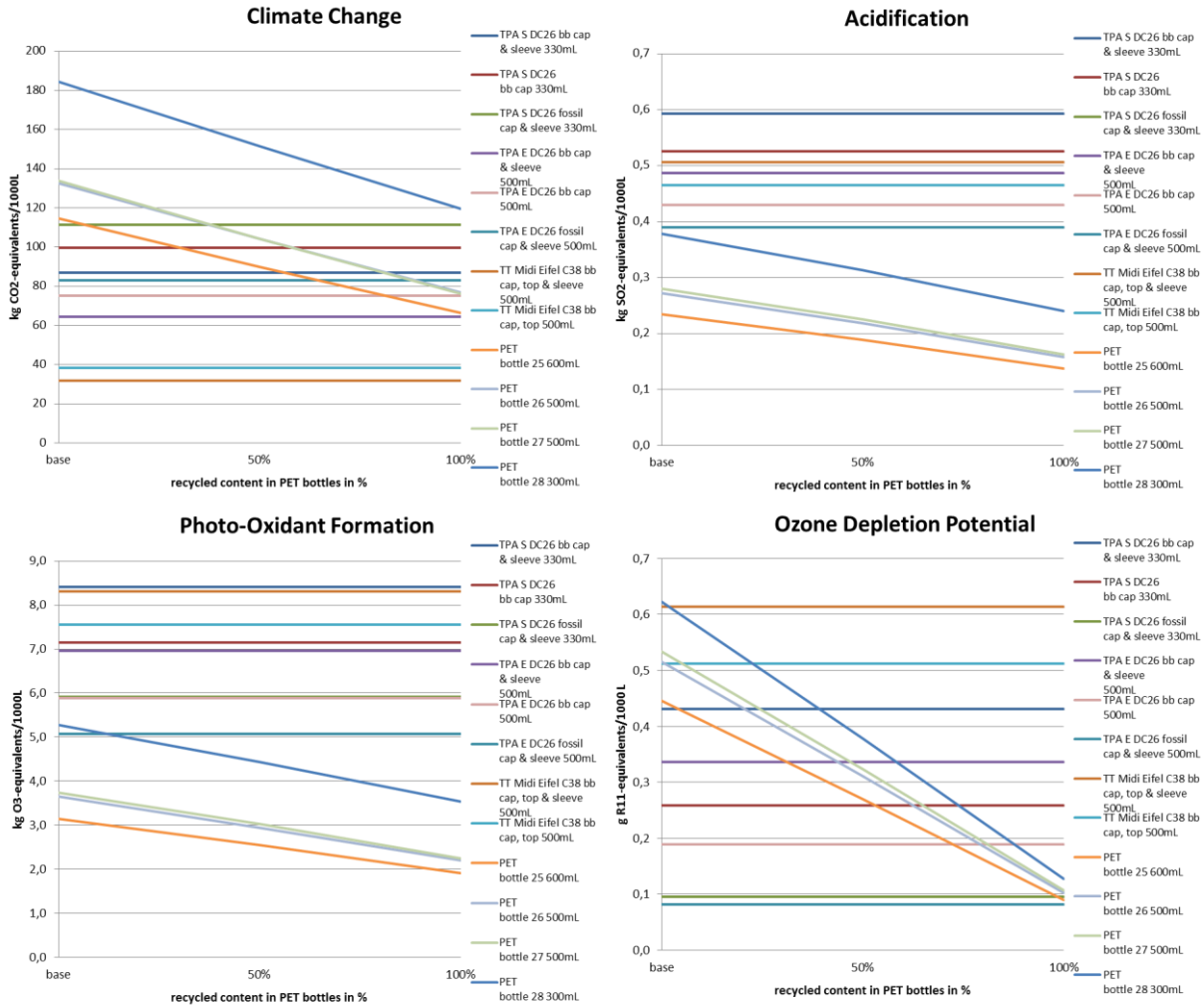


Figure 130: Indicator results for sensitivity analysis regarding recycled PET of segment Water, Norway, allocation factor 50% (Part 1)

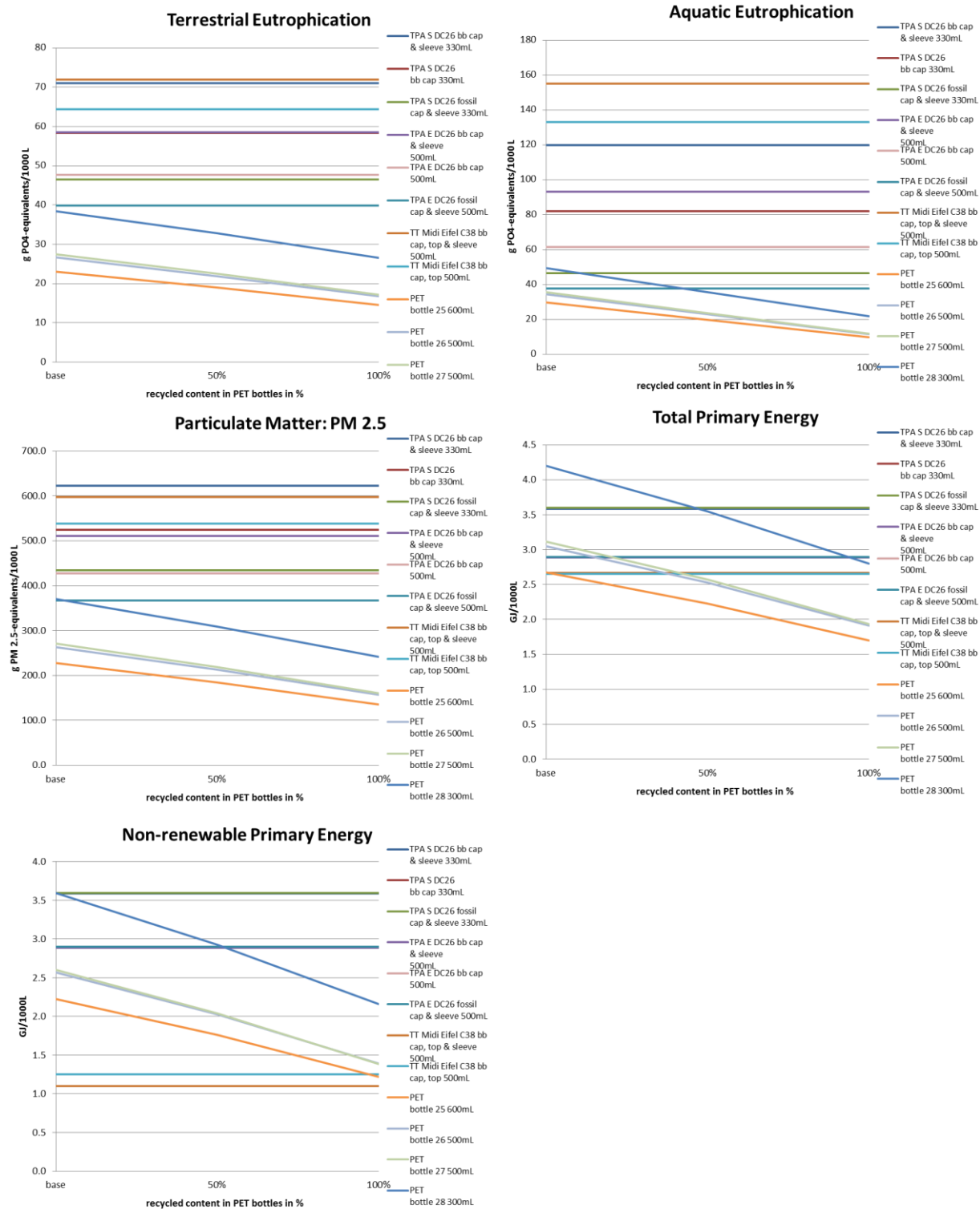


Figure 131: Indicator results for sensitivity analysis regarding recycled PET of segment Water, Norway, allocation factor 50% (Part 2)

In all categories, in which PET bottles without recycled content show higher results than the examined beverage cartons, an increased share of recycled content leads to break even points with at least some beverage cartons.

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 CO₂-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.

12.4 Water Norway

In the segment water no unambiguous result can be observed. While all examined beverage cartons show lower 'Climate Change' results than all the examined PET bottles, in other categories the beverage cartons often show higher impacts. Especially beverage cartons with a high share of biobased polyethylene show higher results than the bottles in the categories 'Acidification', 'Photo-Oxidant Formation', 'Terrestrial and Aquatic Eutrophication'

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

13 Results 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. TiO₂ (**'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 CO₂ (**'recycling/disposal'**)
- CO₂ 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 atmospheric CO₂ during the plant growth phase ('CO₂-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 subtraction 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.

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

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 $\leq 10\%$ are considered as insignificant.

13.1 Results Dairy Denmark

13.1.1 Presentation of results DAIRY Denmark

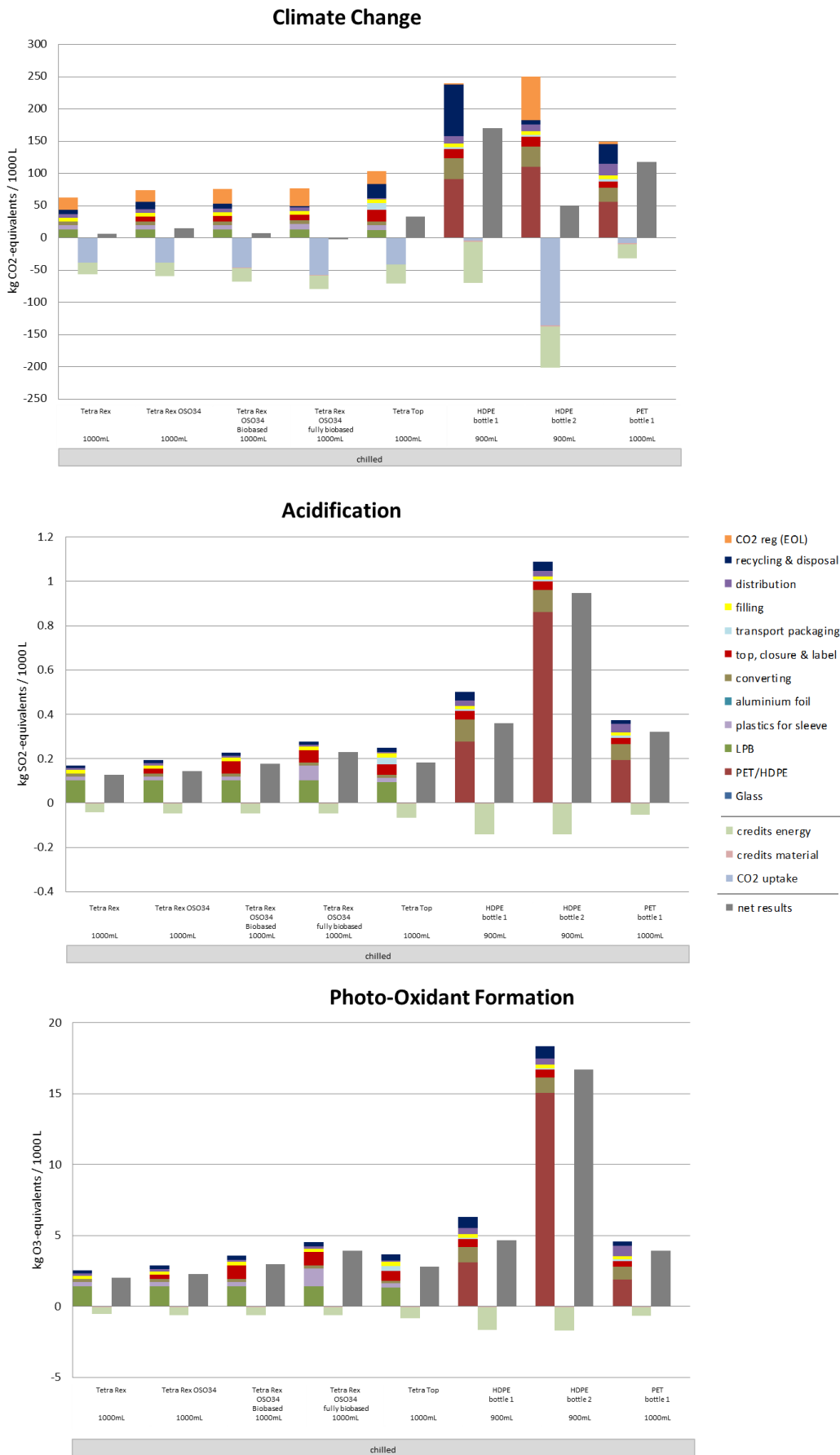


Figure 132: Indicator results for base scenarios of segment Dairy, Denmark, allocation factor 50% (Part 1)

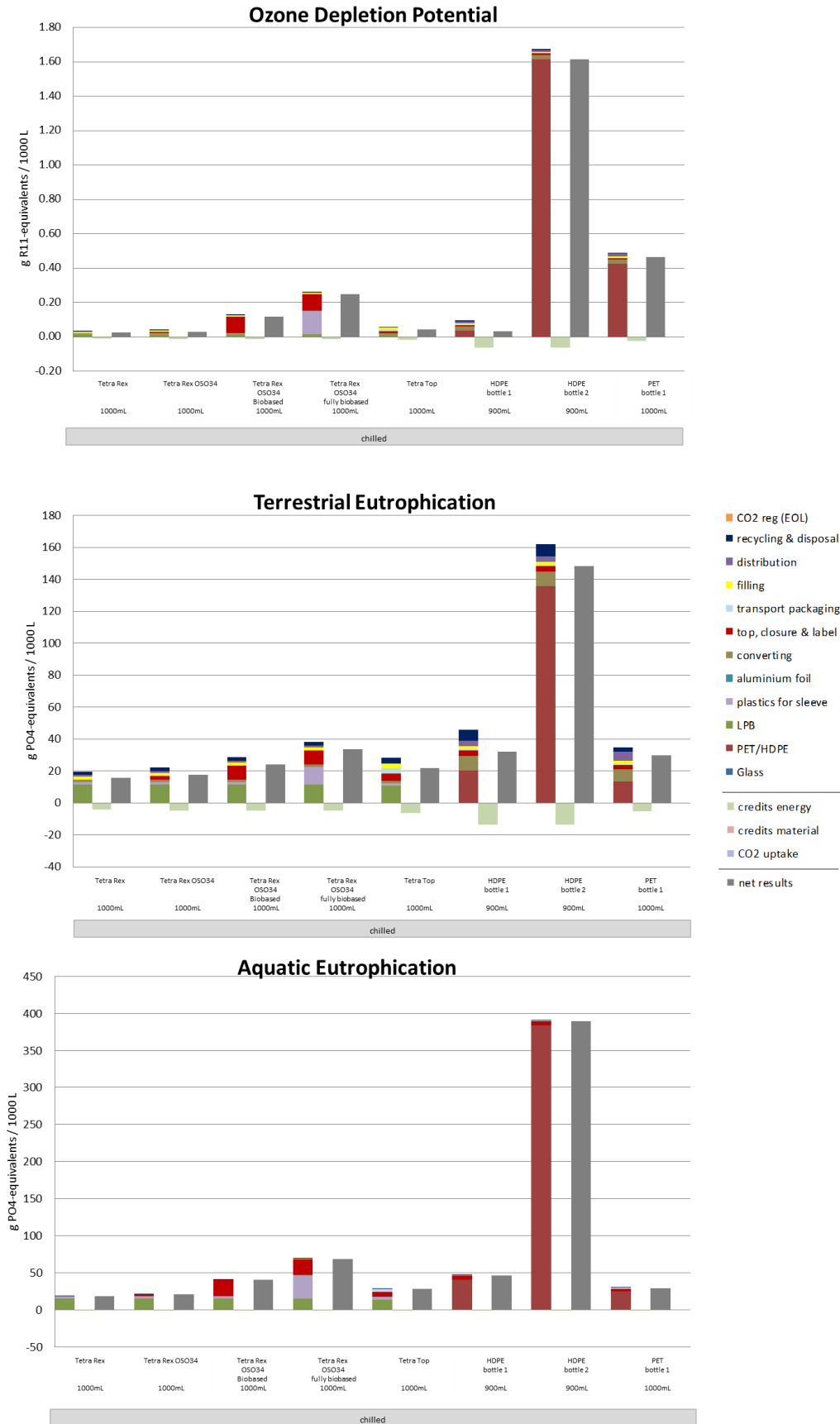


Figure 133 Indicator results for base scenarios of segment Dairy, Denmark, allocation factor 50% (Part 2)

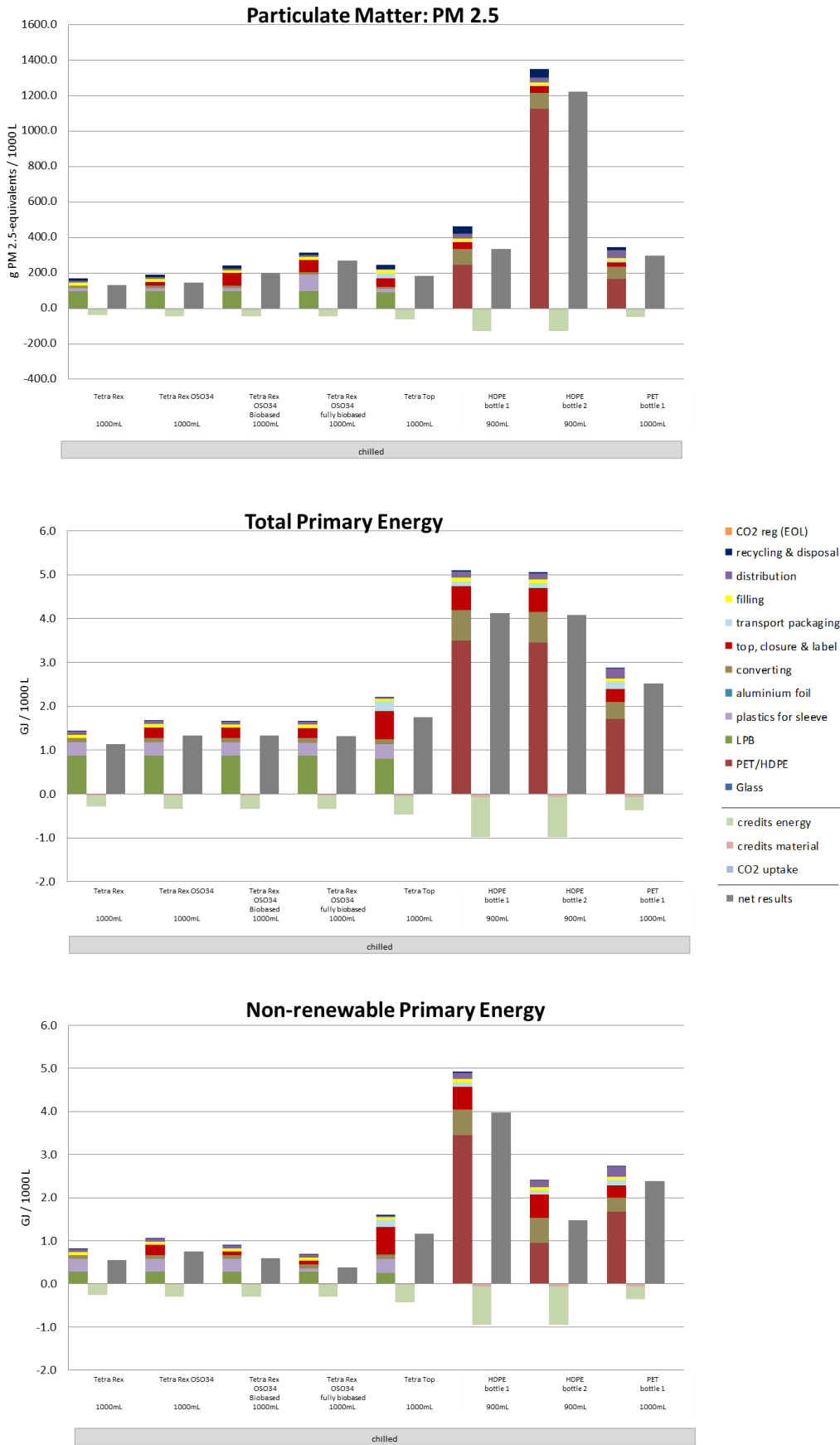


Figure 134: Indicator results for base scenarios of segment Dairy, Denmark, allocation factor 50% (Part 3)

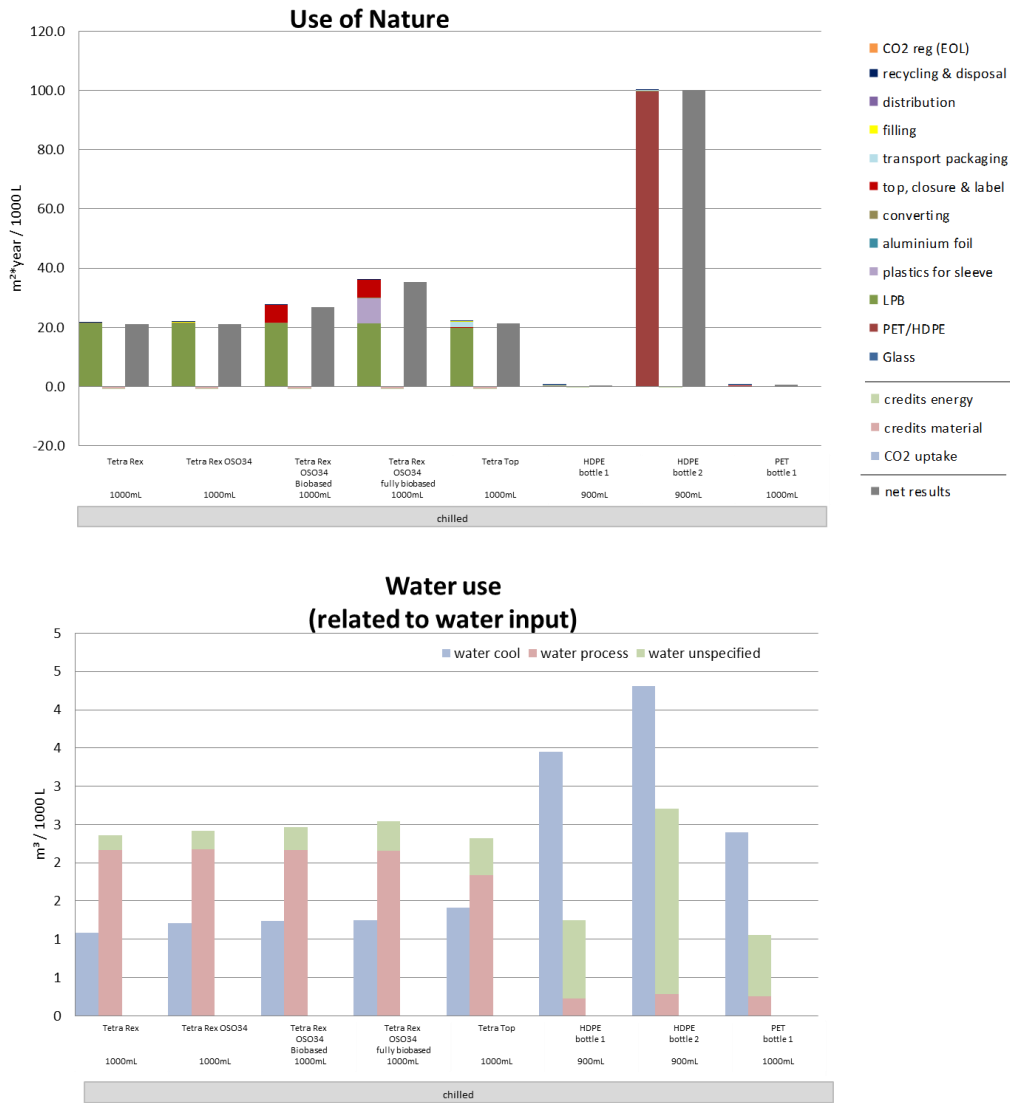


Figure 135: Indicator results for base scenarios of segment Dairy, Denmark, allocation factor 50% (Part 4)

Table 125 Category indicator results per impact category for base scenarios of **segment DAIRY, Denmark**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	43.80	55.44	52.78	48.74	83.38	237.48	182.42	145.31
	CO ₂ (reg)	18.74	18.78	22.62	28.28	20.26	2.13	67.60	4.14
	Credits	-18.12	-21.42	-21.46	-21.32	-29.78	-65.37	-65.38	-23.53
	CO ₂ uptake	-38.24	-38.31	-46.26	-57.90	-41.02	-4.27	-135.64	-8.34
	net results	6.18	14.48	7.68	-2.20	32.85	169.97	49.00	117.58
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.17	0.19	0.23	0.28	0.25	0.50	1.09	0.37
	Credits	-0.04	-0.05	-0.05	-0.05	-0.07	-0.14	-0.14	-0.05
	Net results	0.13	0.14	0.18	0.23	0.18	0.36	0.95	0.32
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	2.56	2.91	3.57	4.51	3.65	6.32	18.35	4.59
	Credits	-0.51	-0.60	-0.60	-0.60	-0.83	-1.68	-1.68	-0.64
	Net results	2.04	2.30	2.96	3.91	2.81	4.64	16.67	3.95
Ozone Depletion [g R11/1000 L]	Burdens	0.04	0.04	0.13	0.26	0.06	0.10	1.68	0.49
	Credits	-0.01	-0.01	-0.01	-0.01	-0.02	-0.06	-0.06	-0.02
	Net results	0.03	0.03	0.12	0.25	0.04	0.03	1.61	0.47
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	19.69	22.19	28.70	38.20	28.44	45.72	161.82	34.85
	Credits	-4.02	-4.73	-4.74	-4.71	-6.52	-13.53	-13.53	-5.09
	Net results	15.67	17.46	23.96	33.49	21.92	32.19	148.29	29.76
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	18.90	21.32	40.77	69.21	28.35	47.07	390.29	29.57
	Credits	-0.41	-0.42	-0.42	-0.42	-0.51	-0.57	-0.58	-0.62
	Net results	18.49	20.90	40.35	68.79	27.83	46.51	389.71	28.95
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	168.25	191.09	241.08	314.80	244.23	464.30	1349.23	345.41
	Credits	-38.09	-44.76	-44.84	-44.55	-61.63	-127.68	-127.70	-47.97
	Net results	130.17	146.33	196.24	270.25	182.59	336.62	1221.53	297.44
Total Primary Energy [GJ]	Burdens	1.43	1.67	1.67	1.66	2.22	5.10	5.06	2.88
	Credits	-0.29	-0.34	-0.34	-0.34	-0.46	-0.98	-0.98	-0.36
	Net results	1.14	1.33	1.33	1.32	1.76	4.12	4.08	2.51
Non-renewable Primary Energy [GJ]	Burdens	0.82	1.05	0.90	0.68	1.60	4.92	2.42	2.74
	Credits	-0.26	-0.31	-0.31	-0.30	-0.43	-0.95	-0.95	-0.36
	Net results	0.56	0.75	0.60	0.38	1.17	3.98	1.47	2.38
Use of Nature [m ² /year]	Burdens	21.58	21.68	27.47	35.94	21.94	0.54	100.06	0.63
	Credits	-0.62	-0.63	-0.63	-0.63	-0.65	-0.29	-0.29	-0.10
	Net results	20.96	21.06	26.85	35.32	21.29	0.25	99.77	0.53
Water use [m ³ /1000 L]	water cool	1.09	1.21	1.24	1.25	1.41	3.45	4.31	2.40
	water process	2.16	2.17	2.17	2.16	1.84	0.22	0.28	0.26
	water unspecified	0.20	0.24	0.30	0.38	0.49	1.02	2.43	0.80

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants as well.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 CO₂ 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 CO₂ 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 CO₂.

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', 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 terephthalic 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 N₂O 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 CO₂ emissions from the bio-based 'HDPE bottle 2' are of course similarly high, but they are attributed to the sector CO₂ 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹. In cases where positive net results are compared to negative ones, and the other way around, no meaningful percentage numbers could be calculated. In these cases the tables just show by their colour code, if the net results are lower or higher than those of the packaging systems the respective beverage carton is compared to.

Table 126: Comparison of net results Tetra Rex 1000 mL versus competing carton based and alternative packaging systems in segment DAIRY, Denmark

DAIRY (chilled), Denmark	The net results of Tetra Rex 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	-57%	-19%		-81%	-96%	-87%	-95%
Acidification	-11%	-28%	-44%	-30%	-64%	-86%	-60%
Photo-Oxidant Formation	-11%	-31%	-48%	-27%	-56%	-88%	-48%
Ozone Depletion Potential	-14%	-79%	-90%	-40%	-24%	-98%	-95%
Terrestrial Eutrophication	-10%	-35%	-53%	-28%	-51%	-89%	-47%
Aquatic Eutrophication	-12%	-54%	-73%	-34%	-60%	-95%	-36%
Particulate Matter	-11%	-34%	-52%	-29%	-61%	-89%	-56%
Total Primary Energy	-14%	-14%	-14%	-35%	-72%	-72%	-55%
Non-renewable Primary Energy	-25%	-7%	47%	-52%	-86%	-62%	-77%

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

Table 127: Comparison of net results **Tetra Rex OSO 34 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

DAIRY (chilled), Denmark	The net results of Tetra Rex OSO34 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	134%	89%		-56%	-91%	-70%	-88%
Acidification	12%	-19%	-37%	-21%	-60%	-85%	-55%
Photo-Oxidant Formation	13%	-22%	-41%	-18%	-50%	-86%	-42%
Ozone Depletion Potential	16%	-75%	-88%	-30%	-11%	-98%	-94%
Terrestrial Eutrophication	11%	-27%	-48%	-20%	-46%	-88%	-41%
Aquatic Eutrophication	13%	-48%	-70%	-25%	-55%	-95%	-28%
Particulate Matter	12%	-25%	-46%	-20%	-57%	-88%	-51%
Total Primary Energy	17%	0%	1%	-24%	-68%	-67%	-47%
Non-renewable Primary Energy	34%	25%	97%	-36%	-81%	-49%	-69%

Table 128: Comparison of net results **Tetra Rex OSO 34 biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

DAIRY (chilled), Denmark	The net results of Tetra Rex OSO34 biobased 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	24%	-47%		-77%	-95%	-84%	-93%
Acidification	39%	23%	-22%	-3%	-50%	-81%	-45%
Photo-Oxidant Formation	45%	29%	-24%	5%	-36%	-82%	-25%
Ozone Depletion Potential	370%	304%	-52%	184%	258%	-93%	-75%
Terrestrial Eutrophication	53%	37%	-28%	9%	-26%	-84%	-19%
Aquatic Eutrophication	118%	93%	-41%	45%	-13%	-90%	39%
Particulate Matter	51%	34%	-27%	7%	-42%	-84%	-34%
Total Primary Energy	17%	0%	1%	-24%	-68%	-67%	-47%
Non-renewable Primary Energy	7%	-20%	58%	-49%	-85%	-59%	-75%

Table 129: Comparison of net results **Tetra Rex OSO 34 fully biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

DAIRY (chilled), Denmark	The net results of Tetra Rex OSO34 fully biobased 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change							
Acidification	78%	59%	29%	25%	-36%	-76%	-29%
Photo-Oxidant Formation	92%	70%	32%	39%	-16%	-77%	-1%
Ozone Depletion Potential	888%	749%	110%	496%	652%	-85%	-47%
Terrestrial Eutrophication	114%	92%	40%	53%	4%	-77%	13%
Aquatic Eutrophication	272%	229%	70%	147%	48%	-82%	138%
Particulate Matter	108%	85%	38%	48%	-20%	-78%	-9%
Total Primary Energy	16%	-1%	-1%	-25%	-68%	-68%	-47%
Non-renewable Primary Energy	-32%	-49%	-37%	-67%	-90%	-74%	-84%

Table 130: Comparison of net results **Tetra Top 1000 mL** versus competing carton based and alternative packaging systems in **segment DAIRY, Denmark**

DAIRY (chilled), Denmark	The net results of Tetra Top 1000mL are lower (green)/ higher (orange) than those of						
	Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change	431%	127%	328%		-81%	-33%	-72%
Acidification	43%	27%	3%	-20%	-49%	-81%	-43%
Photo-Oxidant Formation	38%	22%	-5%	-28%	-39%	-83%	-29%
Ozone Depletion Potential	66%	43%	-65%	-83%	26%	-97%	-91%
Terrestrial Eutrophication	40%	26%	-9%	-35%	-32%	-85%	-26%
Aquatic Eutrophication	51%	33%	-31%	-60%	-40%	-93%	-4%
Particulate Matter	40%	25%	-7%	-32%	-46%	-85%	-39%
Total Primary Energy	54%	32%	32%	33%	-57%	-57%	-30%
Non-renewable Primary Energy	109%	57%	95%	208%	-71%	-21%	-51%

13.2 Results JNSD Denmark

13.2.1 Presentation of results JNSD Denmark



Figure 136: Indicator results for base scenarios of segment JNSD, Denmark, allocation factor 50% (Part 1)

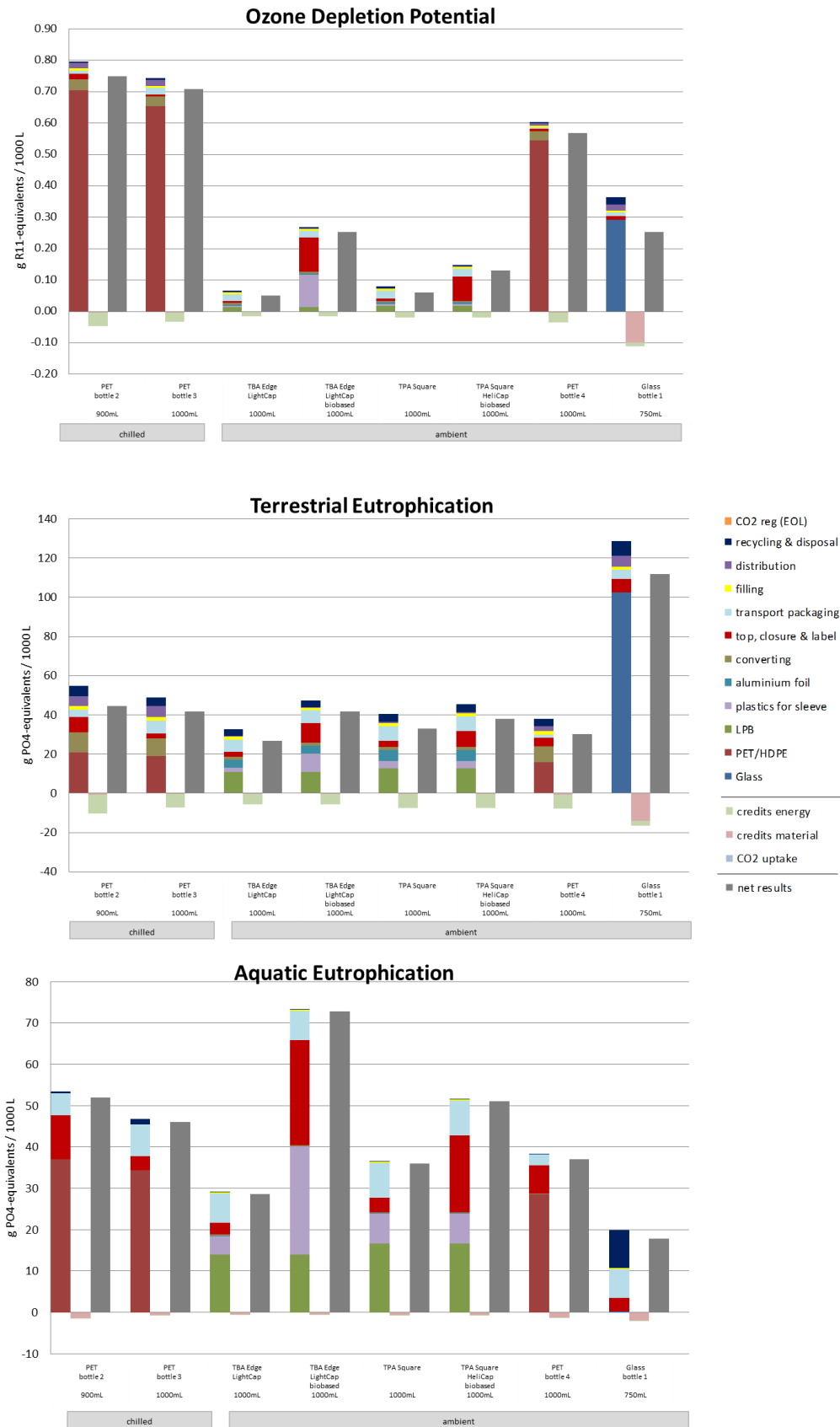


Figure 137 Indicator results for base scenarios of segment JNSD, Denmark, allocation factor 50% (Part 2)



Figure 138: Indicator results for base scenarios of segment JNSD, Denmark, allocation factor 50% (Part 3)



Figure 139: Indicator results for base scenarios of segment JNSD, Denmark, allocation factor 50% (Part 4)

Table 131: Category indicator results per impact category for base scenarios of **segment JNSD, Denmark**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		PET bottle 2 900mL	PET bottle 3 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	244.01	203.47	92.70	86.56	120.12	118.13	174.57	380.35
	CO ₂ (reg)	5.75	7.77	21.50	30.24	25.52	28.48	1.91	6.21
	Credits	-47.39	-33.41	-26.24	-26.19	-34.12	-34.17	-35.63	-60.42
	CO ₂ uptake	-11.60	-15.69	-43.32	-61.39	-51.41	-57.56	-3.84	-12.47
	net results	190.76	162.14	44.64	29.23	60.10	54.87	137.02	313.66
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.56	0.49	0.32	0.40	0.41	0.43	0.39	1.34
	Credits	-0.11	-0.07	-0.06	-0.06	-0.08	-0.08	-0.08	-0.17
	Net results	0.45	0.41	0.26	0.34	0.33	0.36	0.31	1.17
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	7.29	6.28	4.11	5.60	5.14	5.66	5.12	16.32
	Credits	-1.30	-0.90	-0.74	-0.74	-0.96	-0.96	-0.98	-2.08
	Net results	5.99	5.38	3.37	4.86	4.18	4.70	4.14	14.24
Ozone Depletion [g R11/1000 L]	Burdens	0.80	0.74	0.07	0.27	0.08	0.15	0.60	0.36
	Credits	-0.05	-0.03	-0.01	-0.01	-0.02	-0.02	-0.03	-0.11
	Net results	0.75	0.71	0.05	0.25	0.06	0.13	0.57	0.25
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	54.84	48.83	32.62	47.38	40.55	45.59	38.03	128.58
	Credits	-10.26	-7.22	-5.76	-5.75	-7.48	-7.49	-7.72	-16.63
	Net results	44.58	41.61	26.86	41.63	33.08	38.10	30.32	111.96
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	53.46	46.75	29.14	73.31	36.64	51.69	38.26	19.84
	Credits	-1.44	-0.65	-0.50	-0.50	-0.58	-0.58	-1.19	-2.01
	Net results	52.02	46.10	28.65	72.81	36.06	51.10	37.07	17.83
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	526.38	457.30	301.17	415.24	379.74	418.13	370.57	1322.54
	Credits	-96.79	-67.99	-54.50	-54.39	-70.69	-70.80	-72.82	-204.93
	Net results	429.59	389.31	246.66	360.85	309.05	347.33	297.75	1117.61
Total Primary Energy [GJ]	Burdens	5.07	4.13	2.35	2.34	3.01	3.01	3.66	4.98
	Credits	-0.74	-0.50	-0.41	-0.41	-0.53	-0.53	-0.57	-0.76
	Net results	4.32	3.63	1.94	1.93	2.49	2.49	3.10	4.22
Non-renewable Primary Energy [GJ]	Burdens	4.83	3.90	1.63	1.29	2.14	2.03	3.53	4.86
	Credits	-0.73	-0.49	-0.38	-0.38	-0.49	-0.49	-0.55	-0.75
	Net results	4.11	3.40	1.25	0.91	1.65	1.53	2.98	4.11
Use of Nature [m ² ·year]	Burdens	1.83	3.67	23.71	36.86	28.18	32.66	0.47	2.34
	Credits	-0.17	-0.13	-0.64	-0.64	-0.77	-0.77	-0.13	-0.07
	Net results	1.66	3.54	23.07	36.22	27.41	31.88	0.34	2.26
Water use [m ³ /1000 L]	water cool	3.80	3.26	1.53	1.56	1.88	1.92	2.72	0.38
	water process	0.27	0.23	2.23	2.22	2.68	2.67	0.17	5.42
	water unspecified	1.31	1.29	0.59	0.72	0.74	0.78	0.91	0.47

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants as well.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 CO₂ 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 CO₂.

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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((|\text{net result heading} - \text{net result column}|) / \text{net result column}) * 100$

Table 132: Comparison of net results **Tetra Brik Aseptic Edge LightCap 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

<i>JNSD (ambient), Denmark</i>	The net results of TBA Edge LightCap 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	42%	-31%	-24%	-70%	-87%
Acidification	-18%	-16%	-22%	-11%	-76%
Photo-Oxidant Formation	-24%	-12%	-22%	-11%	-74%
Ozone Depletion Potential	-64%	53%	-29%	-84%	-64%
Terrestrial Eutrophication	-28%	-10%	-22%	-1%	-73%
Aquatic Eutrophication	-48%	5%	-26%	2%	112%
Particulate Matter	-25%	-13%	-22%	-9%	-76%
Total Primary Energy	1%	-22%	-22%	-37%	-54%
Non-renewable Primary Energy	30%	-28%	-23%	-60%	-71%

Table 133: 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**

<i>JNSD (ambient), Denmark</i>	The net results of TBA Edge LightCap biobased 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	-30%	-51%	-47%	-79%	-91%
Acidification	22%	3%	-4%	9%	-71%
Photo-Oxidant Formation	32%	16%	3%	17%	-66%
Ozone Depletion Potential	175%	320%	96%	-55%	0%
Terrestrial Eutrophication	39%	26%	9%	37%	-63%
Aquatic Eutrophication	93%	102%	42%	96%	308%
Particulate Matter	34%	17%	4%	21%	-68%
Total Primary Energy	-1%	-22%	-22%	-38%	-54%
Non-renewable Primary Energy	-23%	-45%	-41%	-69%	-78%

Table 134: Comparison of net results **TPA square 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

<i>JNSD (ambient), Denmark</i>	The net results of TPA Square 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	44%	106%	10%	-56%	-81%
Acidification	19%	-3%	-7%	6%	-72%
Photo-Oxidant Formation	13%	-14%	-11%	1%	-71%
Ozone Depletion Potential	-35%	-76%	-53%	-89%	-76%
Terrestrial Eutrophication	11%	-21%	-13%	9%	-70%
Aquatic Eutrophication	-4%	-50%	-29%	-3%	102%
Particulate Matter	14%	-14%	-11%	4%	-72%
Total Primary Energy	28%	29%	0%	-20%	-41%
Non-renewable Primary Energy	39%	81%	7%	-45%	-60%

Table 135: Comparison of net results **Tetra Prisma Aseptic square HeliCap biobased 1000 mL** versus competing carton based and alternative packaging systems in **segment JNSD, Denmark**

<i>JNSD (ambient), Denmark</i>	The net results of TPA Square HeliCap biobased 1000mL are lower (green)/ higher (orange) than those of				
	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change	32%	88%	-9%	-60%	-83%
Acidification	28%	5%	8%	14%	-70%
Photo-Oxidant Formation	27%	-3%	12%	14%	-67%
Ozone Depletion Potential	40%	-49%	114%	-77%	-49%
Terrestrial Eutrophication	27%	-8%	15%	26%	-66%
Aquatic Eutrophication	36%	-30%	42%	38%	187%
Particulate Matter	29%	-4%	12%	17%	-69%
Total Primary Energy	28%	29%	0%	-20%	-41%
Non-renewable Primary Energy	30%	69%	-7%	-49%	-63%

13.3 Results Grab & Go Denmark

13.3.1 Presentation of results Grab & Go Denmark



Figure 140: Indicator results for base scenarios of segment Grab & Go, Denmark, allocation factor 50% (Part 1)

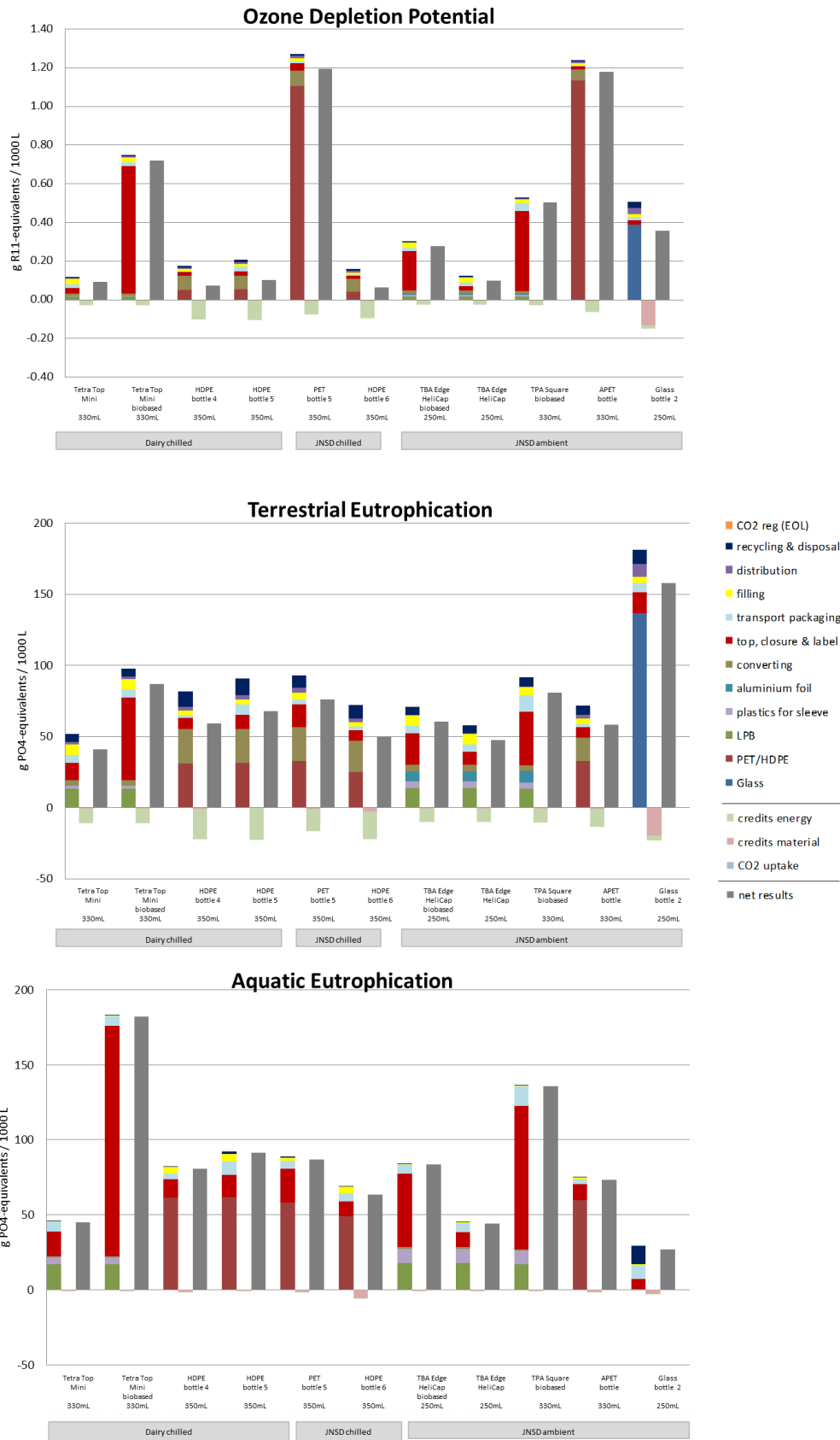


Figure 141 Indicator results for base scenarios of segment Grab & Go, Denmark, allocation factor 50% (Part 2)

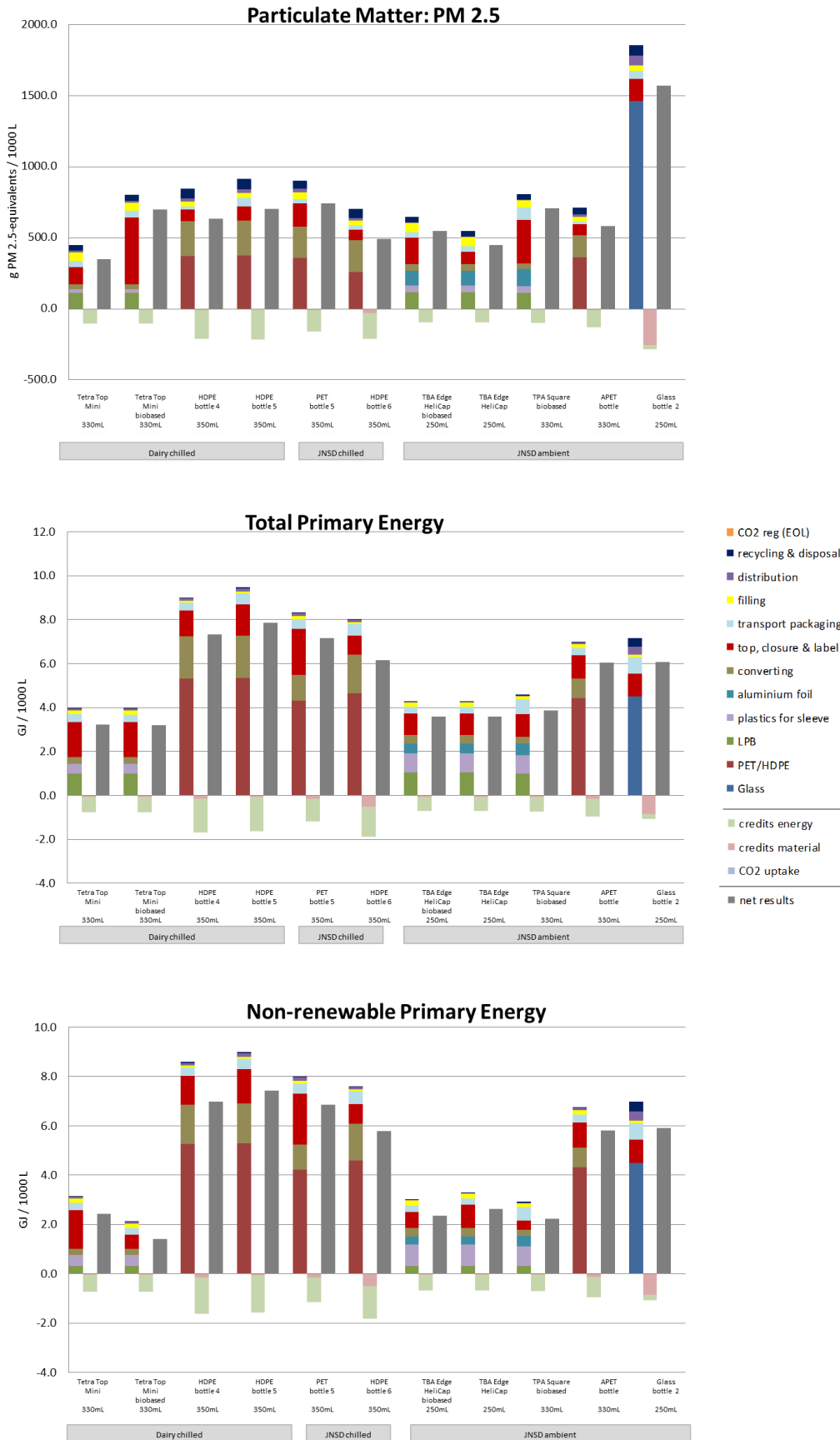


Figure 142: Indicator results for base scenarios of segment Grab & Go, Denmark, allocation factor 50% (Part 3)

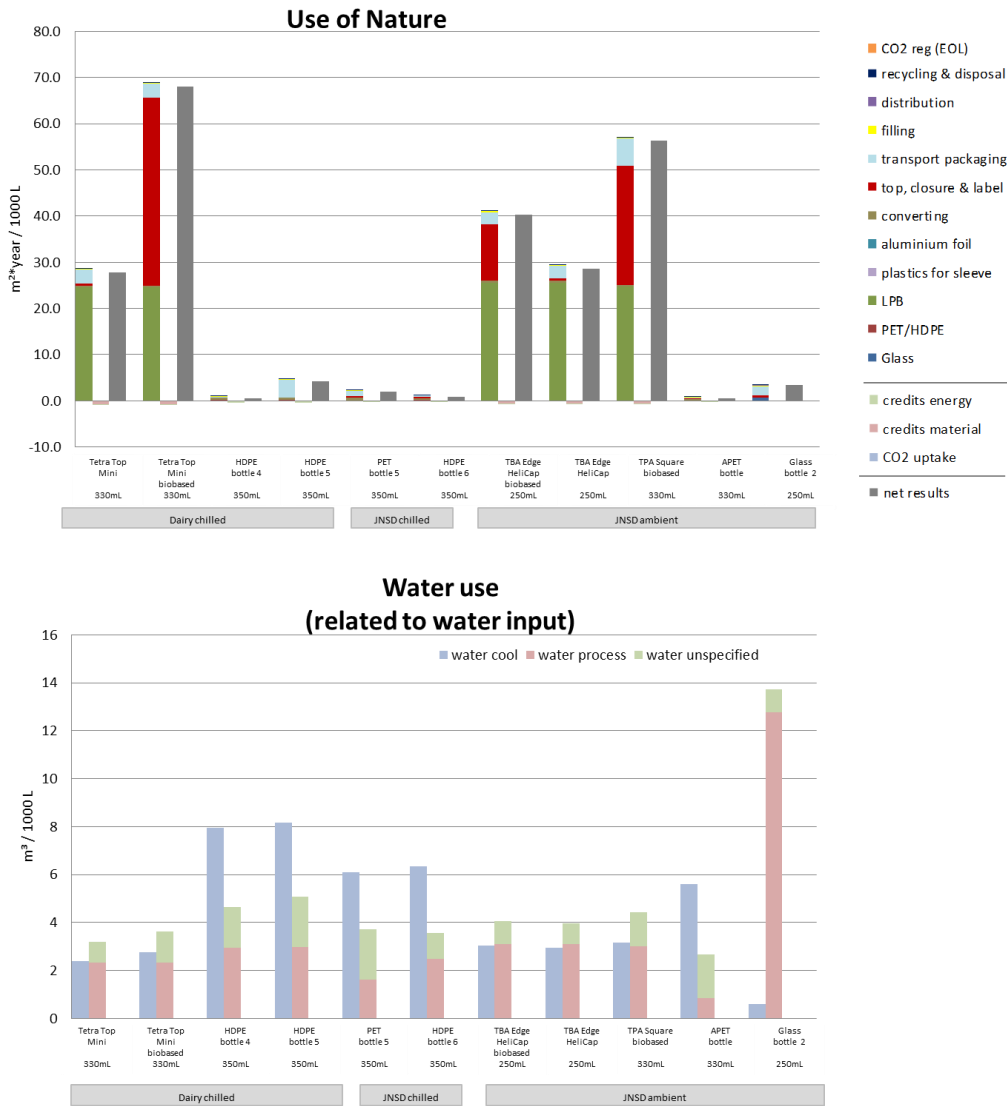


Figure 143: Indicator results for base scenarios of segment Grab & Go, Denmark, allocation factor 50% (Part 4)

Table 136: Category indicator results per impact category for base scenarios of **segment Grab & Go Denmark**- burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL	PET bottle 5 350mL	HDPE bottle 6 350mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change [kg CO2-e/1000 L]	Burdens	168.00	149.91	414.28	441.70	406.36	363.23	179.53	184.74	191.86	332.98	544.05
	CO2 (reg)	25.92	52.28	1.90	6.21	5.46	4.95	34.03	26.28	45.23	1.87	8.57
	Credits	-49.82	-50.06	-108.56	-109.53	-77.48	-106.81	-46.79	-46.65	-48.48	-62.34	-87.36
	CO2 uptake	-52.32	-106.74	-3.81	-12.54	-11.02	-9.99	-69.09	-53.07	-91.67	-3.75	-17.21
	net results	91.78	45.40	303.80	325.84	323.32	251.38	97.68	111.30	96.94	268.76	448.04
Acidification [kg SO2-e/1000 L]	Burdens	0.46	0.69	0.91	0.99	0.95	0.72	0.65	0.58	0.78	0.76	1.89
	Credits	-0.11	-0.11	-0.24	-0.24	-0.17	-0.23	-0.10	-0.10	-0.11	-0.14	-0.24
	Net results	0.35	0.58	0.67	0.75	0.78	0.49	0.54	0.48	0.67	0.62	1.65
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	6.67	11.43	11.22	12.14	12.35	9.95	8.89	7.53	10.96	9.67	22.99
	Credits	-1.39	-1.39	-2.79	-2.81	-2.10	-2.82	-1.30	-1.30	-1.35	-1.70	-2.91
	Net results	5.28	10.04	8.43	9.33	10.24	7.12	7.58	6.23	9.61	7.97	20.08
Ozone Depletion [g R11/1000 L]	Burdens	0.12	0.75	0.18	0.21	1.27	0.16	0.30	0.12	0.53	1.24	0.51
	Credits	-0.03	-0.03	-0.10	-0.10	-0.08	-0.10	-0.03	-0.03	-0.03	-0.06	-0.15
	Net results	0.09	0.72	0.07	0.10	1.19	0.06	0.28	0.10	0.50	1.18	0.36
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	51.84	97.83	81.76	90.75	92.87	72.36	70.81	57.68	91.47	71.89	181.07
	Credits	-10.85	-10.90	-22.40	-22.74	-16.77	-22.08	-10.19	-10.16	-10.55	-13.50	-23.24
	Net results	41.00	86.93	59.36	68.01	76.10	50.29	60.61	47.51	80.93	58.39	157.83
Aquatic Eutrophication [g PO4/1000 L]	Burdens	45.78	182.87	82.15	91.97	88.65	68.76	84.17	44.94	136.13	74.88	29.53
	Credits	-0.70	-0.70	-1.61	-0.62	-1.65	-5.45	-0.69	-0.69	-0.66	-1.60	-2.75
	Net results	45.08	182.17	80.53	91.35	87.00	63.31	83.49	44.26	135.47	73.28	26.78
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	450.01	800.58	846.98	916.64	900.74	702.54	646.30	546.22	808.77	711.14	1856.44
	Credits	-102.45	-102.94	-211.77	-214.37	-157.91	-210.74	-96.29	-96.01	-99.60	-127.22	-285.87
	Net results	347.56	697.65	635.22	702.26	742.83	491.80	550.01	450.22	709.17	583.92	1570.57
Total Primary Energy [GJ]	Burdens	3.97	3.96	9.00	9.47	8.33	8.03	4.29	4.29	4.59	6.99	7.15
	Credits	-0.76	-0.76	-1.68	-1.62	-1.17	-1.88	-0.71	-0.71	-0.74	-0.96	-1.09
	Net results	3.21	3.20	7.33	7.85	7.15	6.15	3.58	3.58	3.86	6.03	6.07
Non-renewable Primary Energy [GJ]	Burdens	3.15	2.14	8.59	8.99	8.00	7.61	3.02	3.31	2.93	6.74	6.97
	Credits	-0.72	-0.72	-1.61	-1.56	-1.15	-1.83	-0.67	-0.67	-0.70	-0.94	-1.07
	Net results	2.44	1.42	6.98	7.43	6.85	5.78	2.35	2.64	2.23	5.80	5.90
Use of Nature [m²*year]	Burdens	28.58	68.90	0.98	4.67	2.25	1.18	41.07	29.39	57.03	0.77	3.49
	Credits	-0.84	-0.84	-0.45	-0.47	-0.27	-0.29	-0.82	-0.82	-0.80	-0.22	-0.10
	Net results	27.74	68.07	0.52	4.20	1.98	0.88	40.25	28.58	56.23	0.56	3.39
Water use [m³/1000 L]	water cool	2.40	2.75	7.94	8.16	6.09	6.35	3.04	2.94	3.15	5.61	0.61
	water process	2.34	2.33	2.95	2.97	1.63	2.49	3.09	3.11	3.01	0.83	12.77
	water unspecified	0.84	1.29	1.70	2.11	2.09	1.08	0.96	0.86	1.41	1.84	0.95

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 SO₂, 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 N₂O 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 NO₂ emissions from incineration plants as well.

Emissions of regenerative CO₂ (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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 CO₂ 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 CO₂.

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 terephthalic 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

Table 137: Comparison of net results **Tetra Top Mini 330 mL** versus competing carton based and alternative packaging systems in segment **Grab & Go, DAIRY chilled, Denmark**

<i>Grab & Go DAIRY (chilled), Denmark</i>	The net results of Tetra Top Mini 330mL are lower (green)/ higher (orange) than those of		
	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	102%	-70%	-72%
Acidification	-40%	-48%	-53%
Photo-Oxidant Formation	-47%	-37%	-43%
Ozone Depletion Potential	-87%	23%	-10%
Terrestrial Eutrophication	-53%	-31%	-40%
Aquatic Eutrophication	-75%	-44%	-51%
Particulate Matter	-50%	-45%	-51%
Total Primary Energy	0%	-56%	-59%
Non-renewable Primary Energy	71%	-65%	-67%

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

Table 138: 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**

<i>Grab & Go DAIRY (chilled), Denmark</i>	The net results of Tetra Top Mini biobased 330mL are lower (green)/ higher (orange) than those of		
	Tetra Top Mini 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL
Climate Change	-51%	-85%	-86%
Acidification	66%	-13%	-22%
Photo-Oxidant Formation	90%	19%	8%
Ozone Depletion Potential	688%	872%	612%
Terrestrial Eutrophication	112%	46%	28%
Aquatic Eutrophication	304%	126%	99%
Particulate Matter	101%	10%	-1%
Total Primary Energy	0%	-56%	-59%
Non-renewable Primary Energy	-42%	-80%	-81%

JNSD chilled

In this segment no beverage cartons were examined for the Danish market.

JNSD ambient

Table 139: 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**

<i>Grab & Go JNSD (ambient), Denmark</i>	The net results of TBA Edge HeliCap biobased 250mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	-12%	1%	-70%	-78%
Acidification	14%	-19%	-12%	-67%
Photo-Oxidant Formation	22%	-21%	-5%	-62%
Ozone Depletion Potential	184%	-45%	-76%	-22%
Terrestrial Eutrophication	28%	-25%	4%	-62%
Aquatic Eutrophication	89%	-38%	14%	212%
Particulate Matter	22%	-22%	-6%	-65%
Total Primary Energy	0%	-7%	-41%	-41%
Non-renewable Primary Energy	-11%	5%	-59%	-60%

Table 140: Comparison of net results **TBA edge HeliCap 250 mL** versus competing carton based and alternative packaging systems in **segment Grab & Go, JNSD ambient, Denmark**

Grab & Go JNSD (ambient), Denmark	The net results of TBA Edge HeliCap 250mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	14%	15%	-59%	-75%
Acidification	-12%	-29%	-23%	-71%
Photo-Oxidant Formation	-18%	-35%	-22%	-69%
Ozone Depletion Potential	-65%	-81%	-92%	-73%
Terrestrial Eutrophication	-22%	-41%	-19%	-70%
Aquatic Eutrophication	-47%	-67%	-40%	65%
Particulate Matter	-18%	-37%	-23%	-71%
Total Primary Energy	0%	-7%	-41%	-41%
Non-renewable Primary Energy	12%	18%	-54%	-55%

Table 141: 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**

Grab & Go JNSD (ambient), Denmark	The net results of TPA Square biobased 330mL are lower (green)/ higher (orange) than those of			
	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change	-1%	-13%	-64%	-78%
Acidification	24%	41%	9%	-59%
Photo-Oxidant Formation	27%	54%	21%	-52%
Ozone Depletion Potential	81%	413%	-57%	41%
Terrestrial Eutrophication	34%	70%	39%	-49%
Aquatic Eutrophication	62%	206%	85%	406%
Particulate Matter	29%	58%	21%	-55%
Total Primary Energy	8%	8%	-36%	-36%
Non-renewable Primary Energy	-5%	-15%	-62%	-62%

13.4 Results base scenarios water DENMARK

13.4.1 Presentation of results water Denmark



Figure 144: Indicator results for base scenarios of segment Water, Denmark, allocation factor 50% (Part 1)

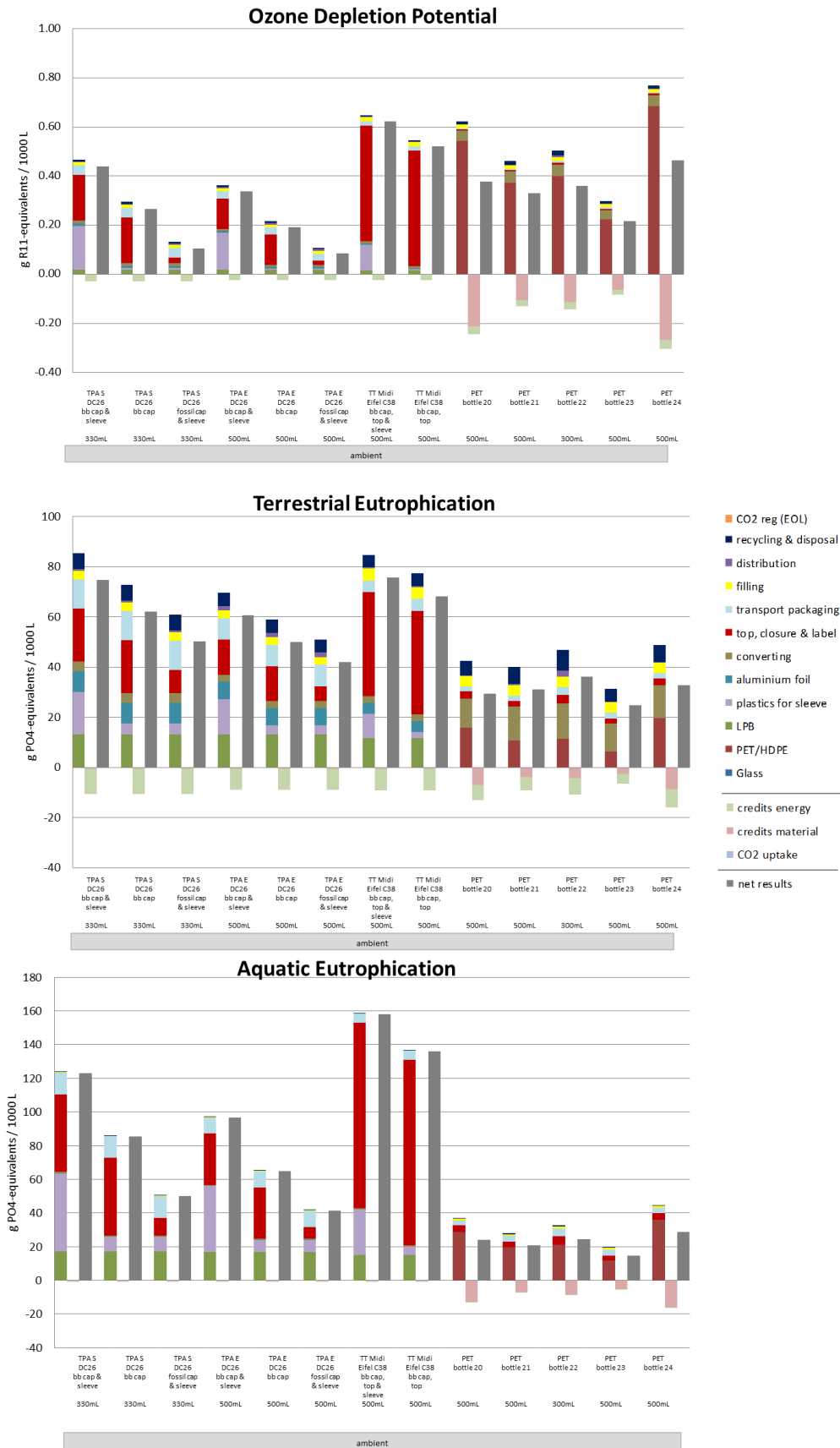


Figure 145: Indicator results for base scenarios of segment Water, Denmark, allocation factor 50% (Part 2)

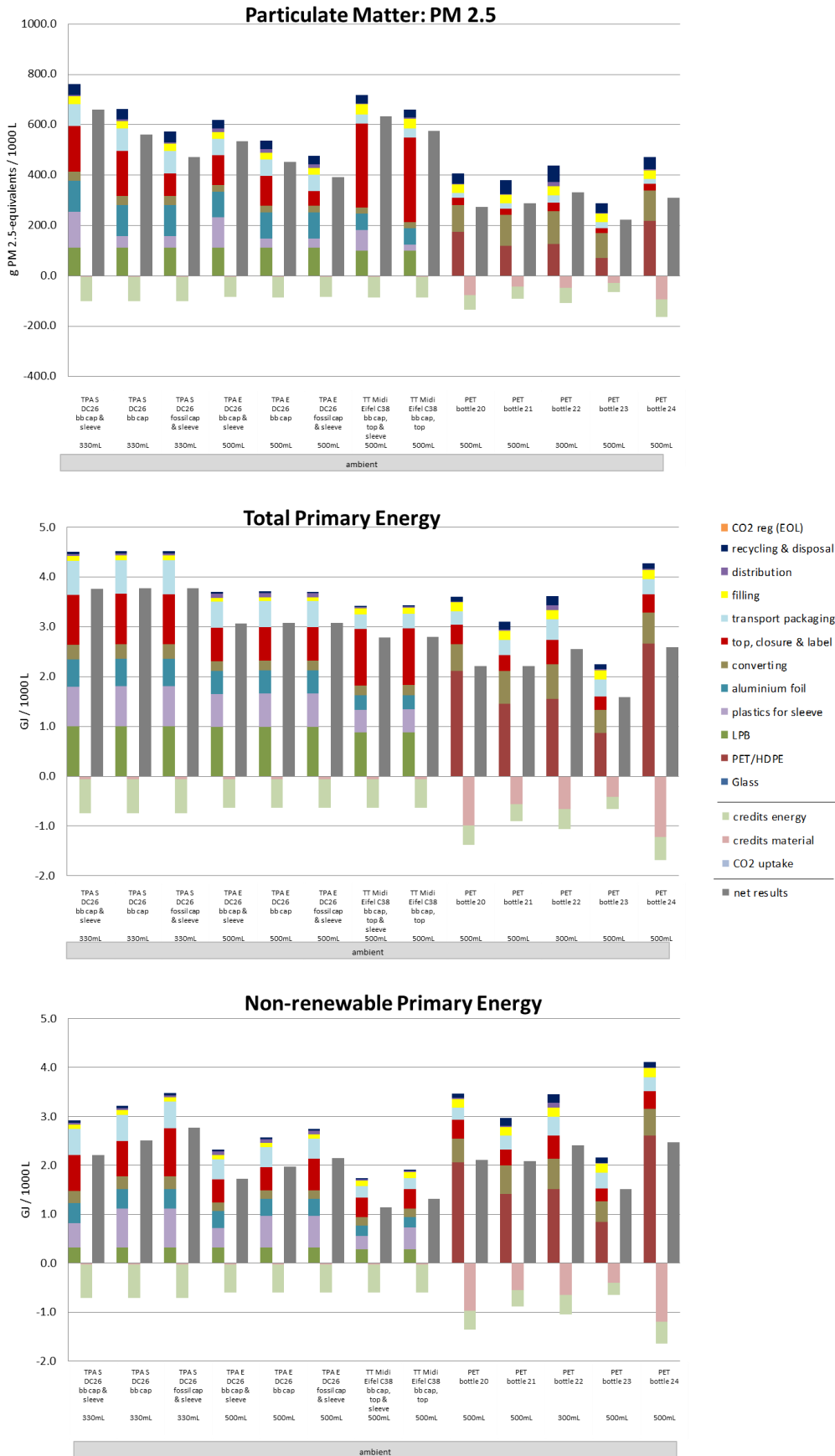


Figure 146: Indicator results for base scenarios of segment Water, Denmark, allocation factor 50% (Part 3)

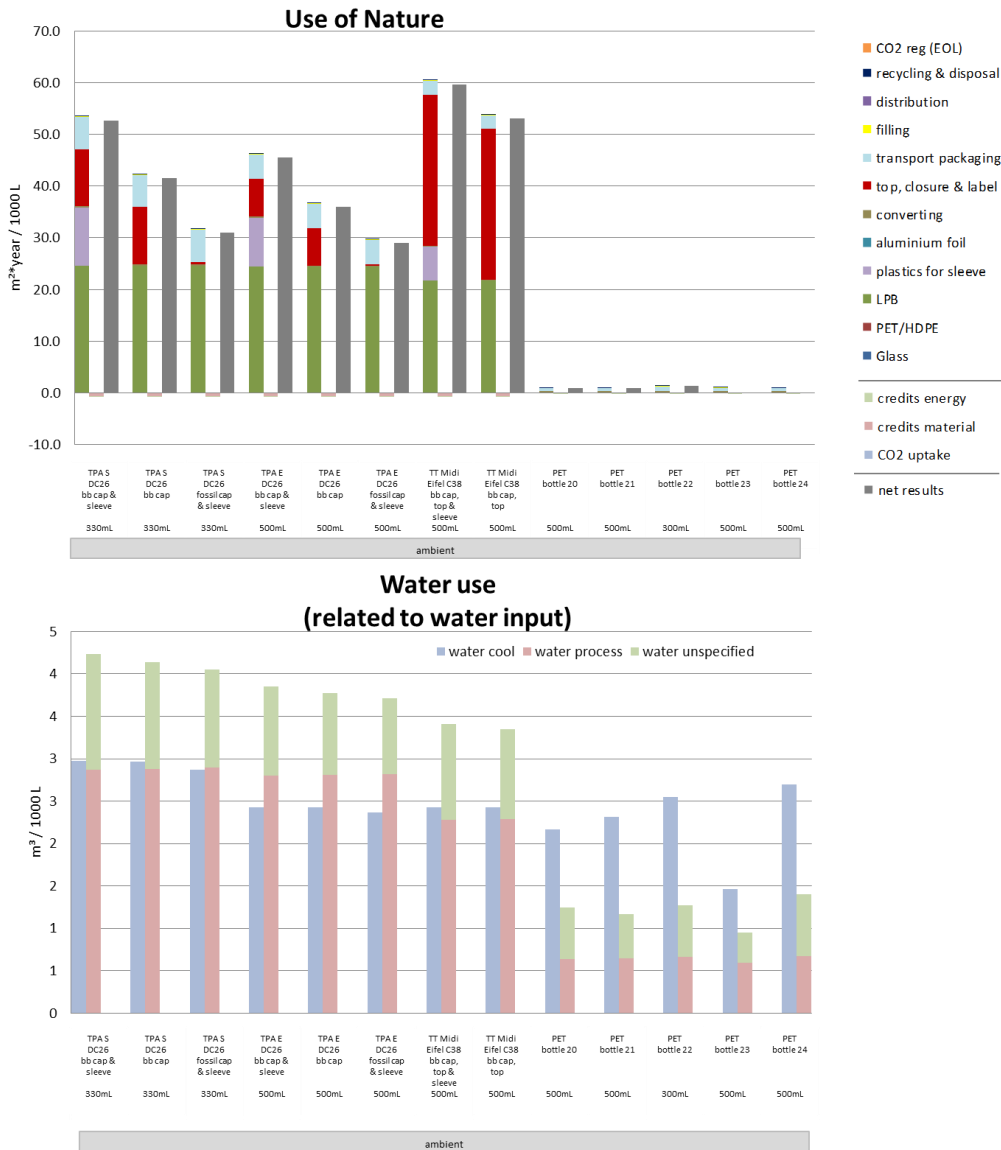


Figure 147: Indicator results for base scenarios of segment Water, Denmark, allocation factor 50% (Part 4)

Table 142: Category indicator results per impact category for base scenarios of **segment Water, Denmark-** burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change [kg CO2-e/1000 L]	Burdens	186.34	191.68	196.45	148.49	153.02	156.16	126.54	129.67	179.68	162.62	189.49	121.63	210.36
	CO2 (req)	44.99	37.50	30.44	40.53	34.18	29.52	47.49	43.10	1.55	1.55	2.58	1.85	1.55
	Credits	-49.21	-49.30	-49.18	-41.17	-41.26	-41.18	-41.62	-41.73	-57.88	-40.36	-48.18	-29.56	-69.79
	CO2 uptake	-90.88	-75.46	-60.95	-82.01	-68.95	-59.35	-96.97	-87.94	-3.13	-3.13	-5.22	-3.74	-3.13
	net results	91.24	104.43	116.76	65.84	76.99	85.15	35.45	43.10	120.22	120.67	138.67	90.17	138.99
Acidification [kg SO2-e/1000 L]	Burdens	0.74	0.68	0.62	0.61	0.55	0.51	0.64	0.60	0.43	0.40	0.46	0.30	0.50
	Credits	-0.11	-0.11	-0.11	-0.09	-0.09	-0.09	-0.09	-0.09	-0.15	-0.10	-0.12	-0.07	-0.18
	Net results	0.63	0.57	0.51	0.52	0.46	0.42	0.55	0.51	0.28	0.30	0.34	0.23	0.32
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	10.21	8.96	7.73	8.36	7.30	6.49	9.90	9.17	5.60	5.24	6.12	4.06	6.46
	Credits	-1.37	-1.37	-1.37	-1.15	-1.15	-1.15	-1.16	-1.16	-1.76	-1.20	-1.43	-0.88	-2.13
	Net results	8.85	7.59	6.36	7.22	6.15	5.34	8.74	8.01	3.84	4.04	4.69	3.18	4.33
Ozone Depletion [g R11/1000 L]	Burdens	0.47	0.29	0.13	0.36	0.22	0.11	0.65	0.62	0.46	0.50	0.30	0.77	
	Credits	-0.03	-0.03	-0.03	-0.02	-0.02	-0.02	-0.02	-0.02	-0.24	-0.13	-0.14	-0.08	-0.30
	Net results	0.44	0.27	0.10	0.34	0.19	0.08	0.62	0.52	0.38	0.33	0.36	0.22	0.46
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	85.31	72.73	60.94	69.53	58.87	51.01	84.62	77.25	42.42	40.14	46.86	31.29	48.71
	Credits	-10.69	-10.71	-10.88	-8.97	-8.99	-8.97	-9.08	-9.10	-13.14	-9.04	-10.76	-6.59	-15.88
	Net results	74.62	62.02	50.16	60.56	49.88	42.04	75.55	68.15	29.27	31.10	36.09	24.70	32.83
Aquatic Eutrophication [g PO4/1000 L]	Burdens	123.78	86.11	50.59	97.23	65.32	41.82	158.67	136.60	37.10	28.05	32.67	19.80	44.71
	Credits	-0.63	-0.63	-0.63	-0.62	-0.62	-0.62	-0.60	-0.60	-12.93	-7.20	-8.31	-5.07	-15.99
	Net results	123.15	85.48	49.96	96.61	64.70	41.20	158.07	136.00	24.16	20.85	24.35	14.73	28.72
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	760.83	663.17	572.57	620.37	537.65	477.70	718.44	661.23	407.58	379.03	437.76	289.28	472.41
	Credits	-100.89	-101.07	-100.81	-84.73	-84.92	-84.75	-86.79	-86.02	-133.94	-90.38	-107.14	-65.43	-162.25
	Net results	659.94	562.10	471.75	535.65	452.73	392.95	632.66	575.21	273.64	288.65	330.62	223.86	310.16
Total Primary Energy [GJ]	Burdens	4.50	4.51	4.51	3.69	3.71	3.70	3.42	3.43	3.60	3.10	3.61	2.25	4.27
	Credits	-0.74	-0.75	-0.74	-0.63	-0.63	-0.63	-0.64	-0.64	-1.38	-0.90	-1.07	-0.66	-1.68
	Net results	3.76	3.77	3.77	3.06	3.07	3.07	2.78	2.79	2.21	2.21	2.55	1.59	2.59
Non-renewable Primary Energy [GJ]	Burdens	2.92	3.21	3.48	2.32	2.57	2.74	1.74	1.91	3.47	2.97	3.46	2.16	4.11
	Credits	-0.71	-0.71	-0.71	-0.59	-0.59	-0.59	-0.60	-0.60	-1.35	-0.88	-1.05	-0.65	-1.64
	Net results	2.21	2.50	2.77	1.73	1.97	2.15	1.14	1.31	2.11	2.09	2.41	1.51	2.47
Use of Nature [m²/year]	Burdens	53.48	42.26	31.69	46.23	36.72	29.73	60.44	53.87	1.00	1.06	1.46	1.08	1.03
	Credits	-0.77	-0.77	-0.77	-0.76	-0.76	-0.76	-0.78	-0.78	-0.11	-0.09	-0.12	-0.08	-0.12
	Net results	52.71	41.49	30.92	45.47	35.96	28.97	59.66	53.08	0.89	0.97	1.34	0.90	0.90
Water use [m³/1000 L]	water cool	2.97	2.97	2.87	2.43	2.42	2.36	2.43	2.42	2.17	2.32	2.55	1.47	2.70
	water process	2.87	2.88	2.89	2.80	2.81	2.81	2.28	2.29	0.64	0.65	0.66	0.59	0.67
	water unspecified	1.37	1.26	1.16	1.06	0.96	0.90	1.13	1.06	0.60	0.52	0.61	0.36	0.73

13.4.2 Description and interpretation

Beverage carton systems

For the beverage carton systems regarded in the water 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 SO₂, 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 water 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 shows visible impacts in almost all impact categories.

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 N₂O 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 water 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 NO₂ emissions from incineration plants.

CO₂ 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 CO₂ emissions of the sector recycling & disposal they represent the total CO₂ 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 Norway 61.7% 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 CO₂ 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 CO₂.

Plastic bottles

In the regarded plastic bottle systems in the water 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 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 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 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'.

For the regarded plastic bottles for water more material credits are given than for bottles in other beverage segments as the deposit system for water bottles leads to a high recycling rate.

13.4.3 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).

The percentages in the following tables show the difference of net results between the packaging system named in the heading and net results of the compared packaging systems listed in the separate columns. The percentage is based on the net result of e¹.

¹ $((| \text{net result heading} - \text{net result column} |) / \text{net result column}) * 100$

Table 143: Comparison of net results: Tetra Prisma Aseptic Square bio-based cap & sleeve 330 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TPA S DC26 bb cap & sleeve 330mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	-13%	-22%	39%	19%	7%	157%	112%	-24%	-24%	-34%	1%	-34%
Acidification	12%	25%	23%	38%	51%	16%	25%	126%	114%	88%	180%	99%
Photo-Oxidant Formation	17%	39%	23%	44%	66%	1%	10%	130%	119%	89%	178%	104%
Ozone Depletion Potential	65%	325%	30%	129%	421%	-29%	-16%	16%	33%	22%	103%	-5%
Terrestrial Eutrophication	20%	49%	23%	50%	78%	-1%	10%	155%	140%	107%	202%	127%
Aquatic Eutrophication	44%	146%	27%	90%	199%	-22%	-9%	410%	491%	406%	736%	329%
Particulate Matter	17%	40%	23%	46%	68%	4%	15%	141%	129%	100%	195%	113%
Total Primary Energy	0%	0%	23%	22%	22%	35%	35%	70%	70%	47%	136%	45%
Non-renewable Primary Energy	-12%	-20%	28%	12%	3%	94%	69%	5%	6%	-8%	46%	-10%

Table 144: Comparison of net results: Tetra Prisma Aseptic Square bio-based cap 330 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TPA S DC26 bb cap 330mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	14%	-11%	59%	36%	23%	195%	142%	-13%	-13%	-25%	16%	-25%
Acidification	-11%	12%	10%	23%	35%	4%	12%	102%	92%	68%	150%	78%
Photo-Oxidant Formation	-14%	19%	5%	23%	42%	-13%	-5%	98%	88%	62%	139%	75%
Ozone Depletion Potential	-39%	157%	-21%	39%	216%	-57%	-49%	-30%	-19%	-26%	23%	-43%
Terrestrial Eutrophication	-17%	24%	2%	24%	48%	-18%	-9%	112%	99%	72%	151%	89%
Aquatic Eutrophication	-31%	71%	-12%	32%	107%	-46%	-37%	254%	310%	251%	480%	198%
Particulate Matter	-15%	19%	5%	24%	43%	-11%	-2%	105%	95%	70%	151%	81%
Total Primary Energy	0%	0%	23%	23%	23%	35%	35%	70%	71%	48%	137%	46%
Non-renewable Primary Energy	13%	-10%	45%	27%	17%	119%	91%	18%	20%	4%	66%	2%

Table 145: Comparison of net results: Tetra Prisma Aseptic Square fossil cap & sleeve 330 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TPA S DC26 fossil cap & sleeve 330mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	28%	12%	77%	52%	37%	229%	171%	-3%	-3%	-16%	29%	-16%
Acidification	-20%	-11%	-2%	10%	21%	-7%	0%	81%	71%	50%	124%	59%
Photo-Oxidant Formation	-28%	-16%	-12%	3%	19%	-27%	-21%	66%	58%	36%	100%	47%
Ozone Depletion Potential	-76%	-61%	-69%	-46%	23%	-83%	-80%	-73%	-69%	-71%	-52%	-78%
Terrestrial Eutrophication	-33%	-19%	-17%	1%	19%	-34%	-26%	71%	61%	39%	103%	53%
Aquatic Eutrophication	-59%	-42%	-48%	-23%	21%	-68%	-63%	107%	140%	105%	239%	74%
Particulate Matter	-29%	-16%	-12%	4%	20%	-25%	-18%	72%	63%	43%	111%	52%
Total Primary Energy	0%	0%	23%	23%	23%	35%	35%	70%	71%	48%	137%	46%
Non-renewable Primary Energy	25%	11%	60%	40%	29%	142%	111%	31%	33%	15%	83%	12%

Table 146: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap & sleeve 500 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TPA E DC26 bb cap & sleeve 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	-28%	-37%	-44%	-14%	-23%	86%	53%	-45%	-45%	-53%	-27%	-53%
Acidification	-19%	-9%	2%	12%	23%	-5%	2%	84%	75%	53%	128%	62%
Photo-Oxidant Formation	-18%	-5%	13%	17%	35%	-17%	-10%	88%	79%	54%	127%	67%
Ozone Depletion Potential	-23%	27%	227%	76%	301%	-46%	-35%	-10%	2%	-6%	57%	-27%
Terrestrial Eutrophication	-19%	-2%	21%	21%	44%	-20%	-11%	107%	95%	68%	145%	84%
Aquatic Eutrophication	-22%	13%	93%	49%	134%	-39%	-29%	300%	363%	297%	556%	236%
Particulate Matter	-19%	-5%	14%	18%	36%	-15%	-7%	96%	86%	62%	139%	73%
Total Primary Energy	-18%	-19%	-19%	0%	0%	10%	10%	38%	39%	20%	92%	18%
Non-renewable Primary Energy	-22%	-31%	-38%	-13%	-20%	51%	31%	-18%	-17%	-28%	14%	-30%

Table 147: Comparison of net results: Tetra Prisma Aseptic Edge bio-based cap 500 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TPA E DC26 bb cap 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	-16%	-26%	-34%	17%	-10%	117%	79%	-36%	-36%	-44%	-15%	-45%
Acidification	-28%	-19%	-9%	-11%	9%	-16%	-9%	64%	55%	36%	103%	44%
Photo-Oxidant Formation	-30%	-19%	-3%	-15%	15%	-30%	-23%	60%	52%	31%	93%	42%
Ozone Depletion Potential	-56%	-28%	86%	-43%	128%	-69%	-63%	-49%	-42%	-47%	-11%	-59%
Terrestrial Eutrophication	-33%	-20%	-1%	-18%	19%	-34%	-27%	70%	60%	38%	102%	52%
Aquatic Eutrophication	-47%	-24%	30%	-33%	57%	-59%	-52%	168%	210%	166%	339%	125%
Particulate Matter	-31%	-19%	-4%	-15%	15%	-28%	-21%	65%	57%	37%	102%	46%
Total Primary Energy	-18%	-18%	-18%	0%	0%	10%	10%	39%	39%	21%	93%	19%
Non-renewable Primary Energy	-11%	-21%	-29%	14%	-8%	73%	50%	-7%	-6%	-18%	30%	-20%

Table 148: Comparison of net results: Tetra Prisma Aseptic Edge fossil cap & sleeve 500 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TPA E DC26 fossil cap & sleeve 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	-7%	-18%	-27%	29%	11%	140%	98%	-29%	-29%	-39%	-6%	-39%
Acidification	-34%	-26%	-17%	-19%	-9%	-23%	-17%	50%	42%	25%	85%	32%
Photo-Oxidant Formation	-40%	-30%	-16%	-26%	-13%	-39%	-33%	39%	32%	14%	68%	23%
Ozone Depletion Potential	-81%	-68%	-18%	-75%	-56%	-86%	-84%	-78%	-74%	-77%	-61%	-82%
Terrestrial Eutrophication	-44%	-32%	-16%	-31%	-16%	-44%	-38%	44%	35%	16%	70%	28%
Aquatic Eutrophication	-67%	-52%	-18%	-57%	-36%	-74%	-70%	71%	98%	69%	180%	43%
Particulate Matter	-40%	-30%	-17%	-27%	-13%	-38%	-32%	44%	36%	19%	76%	27%
Total Primary Energy	-18%	-18%	-18%	0%	0%	10%	10%	39%	39%	21%	93%	19%
Non-renewable Primary Energy	-3%	-14%	-22%	24%	9%	88%	64%	2%	3%	-11%	42%	-13%

Table 149: Comparison of net results: Tetra Top Midi Eifel C38 bio-based cap, top & sleeve 500 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TT Midi Eifel C38 bb cap, top & sleeve 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	-61%	-66%	-70%	-46%	-54%	-58%	-18%	-71%	-71%	-74%	-61%	-74%
Acidification	-14%	-4%	8%	6%	19%	30%	8%	95%	84%	62%	141%	71%
Photo-Oxidant Formation	-1%	15%	37%	21%	42%	64%	9%	128%	117%	87%	175%	102%
Ozone Depletion Potential	42%	134%	502%	84%	224%	638%	19%	65%	88%	73%	188%	34%
Terrestrial Eutrophication	1%	22%	51%	25%	51%	80%	11%	158%	143%	109%	206%	130%
Aquatic Eutrophication	28%	85%	216%	64%	144%	284%	16%	554%	658%	549%	973%	450%
Particulate Matter	-4%	13%	34%	18%	40%	61%	10%	131%	119%	91%	183%	104%
Total Primary Energy	-26%	-26%	-26%	-9%	-9%	-9%	0%	26%	26%	9%	75%	8%
Non-renewable Primary Energy	-48%	-54%	-59%	-34%	-42%	-47%	-13%	-46%	-45%	-53%	-24%	-54%

Table 150: Comparison of net results: Tetra Top Midi Eifel C38 bio-based cap & top 500 mL versus competing carton based and alternative packaging systems in segment Water, Denmark

WATER (ambient), Denmark	The net results of TT Midi Eifel C38 bb cap, top 500mL are lower (green)/ higher (orange) than those of											
	TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change	-53%	-59%	-63%	-35%	-44%	-49%	22%	-64%	-64%	-69%	-52%	-69%
Acidification	-20%	-11%	0%	-2%	10%	20%	-7%	81%	71%	50%	123%	59%
Photo-Oxidant Formation	-9%	5%	26%	11%	30%	50%	-8%	108%	98%	71%	152%	85%
Ozone Depletion Potential	19%	96%	404%	54%	171%	518%	-16%	38%	58%	45%	141%	12%
Terrestrial Eutrophication	-9%	10%	36%	13%	37%	62%	-10%	133%	119%	89%	176%	108%
Aquatic Eutrophication	10%	59%	172%	41%	110%	230%	-14%	463%	552%	458%	823%	374%
Particulate Matter	-13%	2%	22%	7%	27%	46%	-9%	110%	99%	74%	157%	85%
Total Primary Energy	-26%	-26%	-26%	-9%	-9%	-9%	0%	26%	27%	10%	75%	8%
Non-renewable Primary Energy	-41%	-48%	-53%	-24%	-33%	-39%	15%	-38%	-37%	-46%	-13%	-47%

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%.

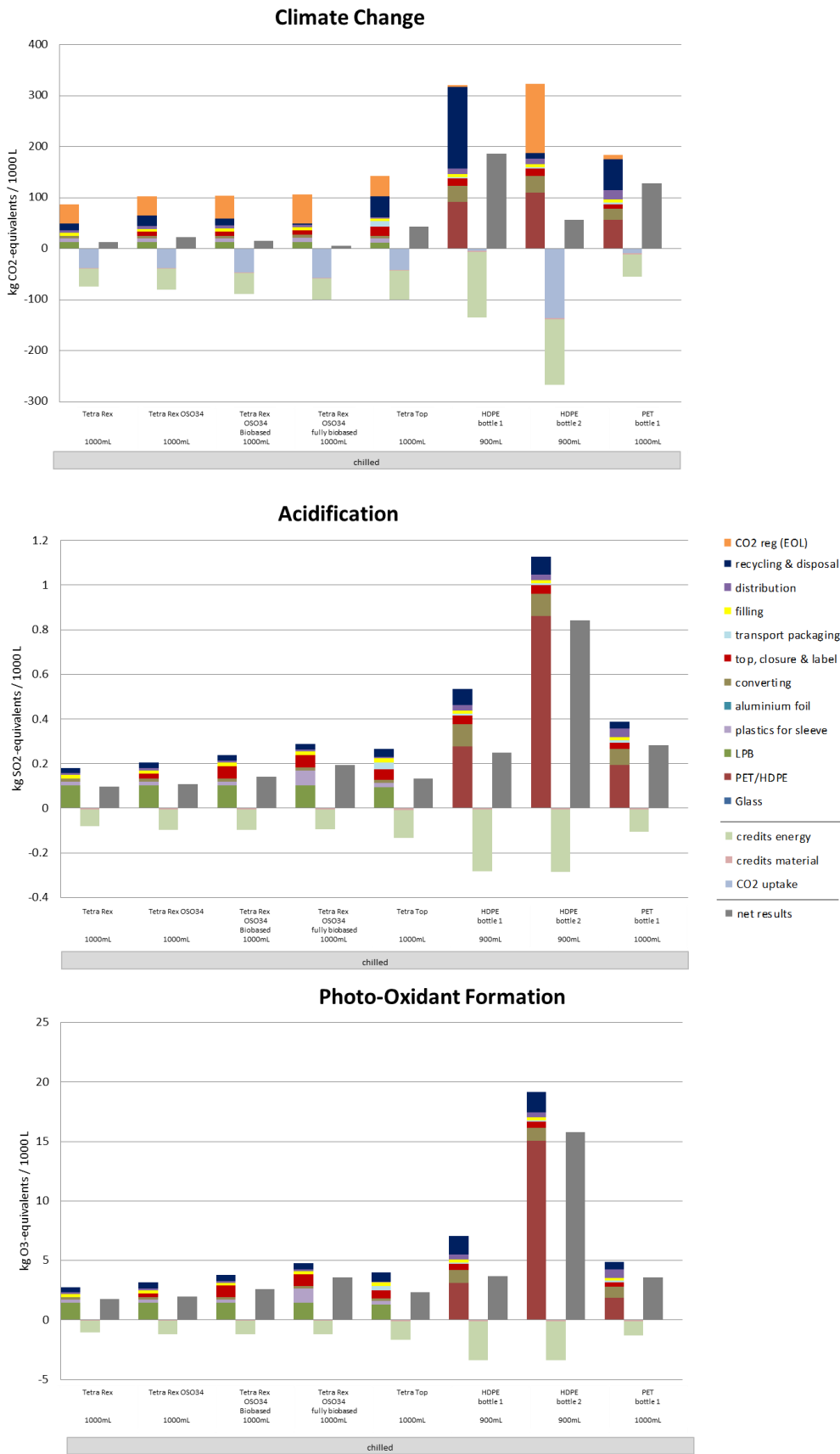


Figure 148: Indicator results for sensitivity analysis on system allocation; segment DAIRY, Denmark, Allocation factor 100% (Part 1)

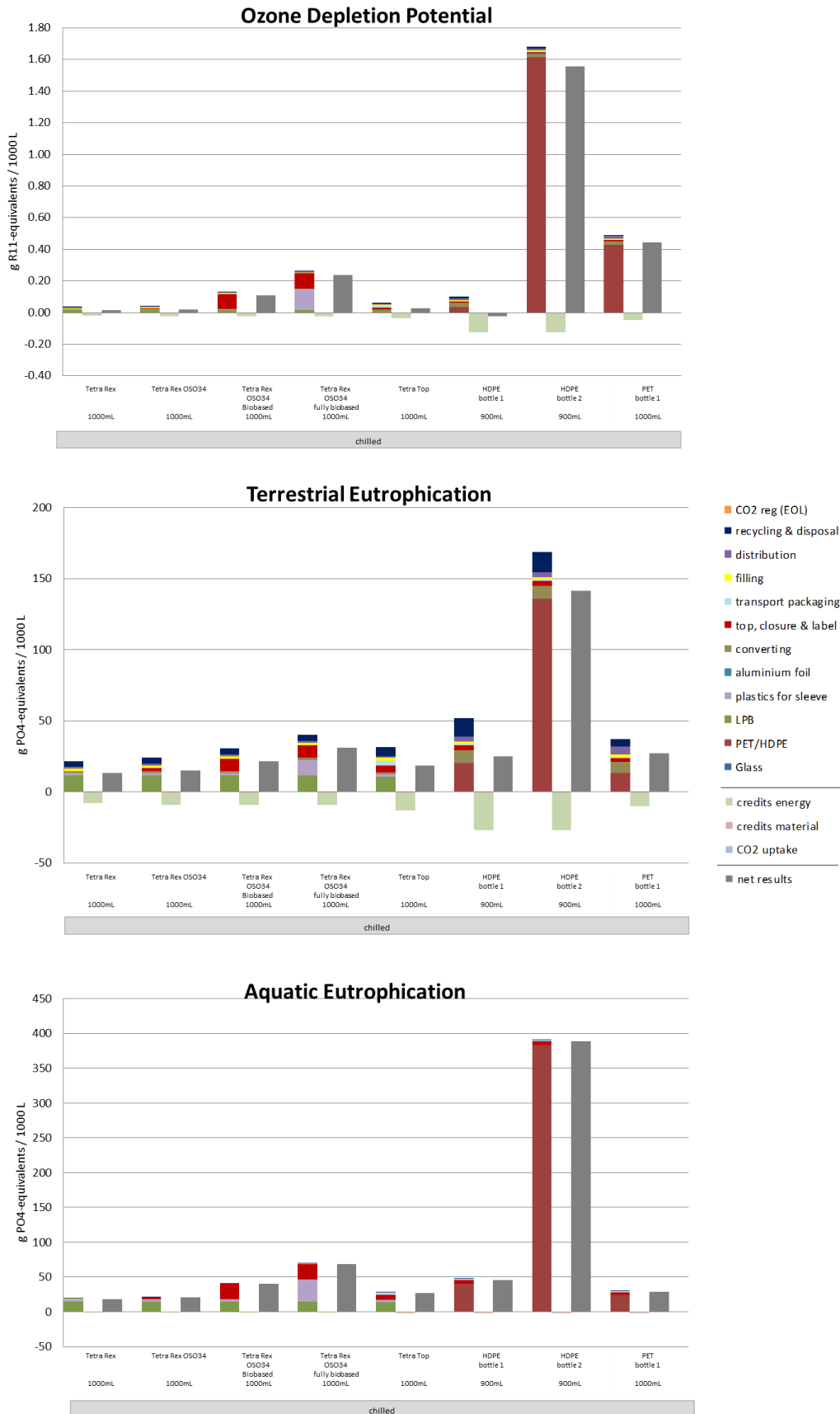


Figure 31: Indicator results for sensitivity analysis on system allocation; segment DAIRY, Denmark, Allocation factor 100% (Part 2)

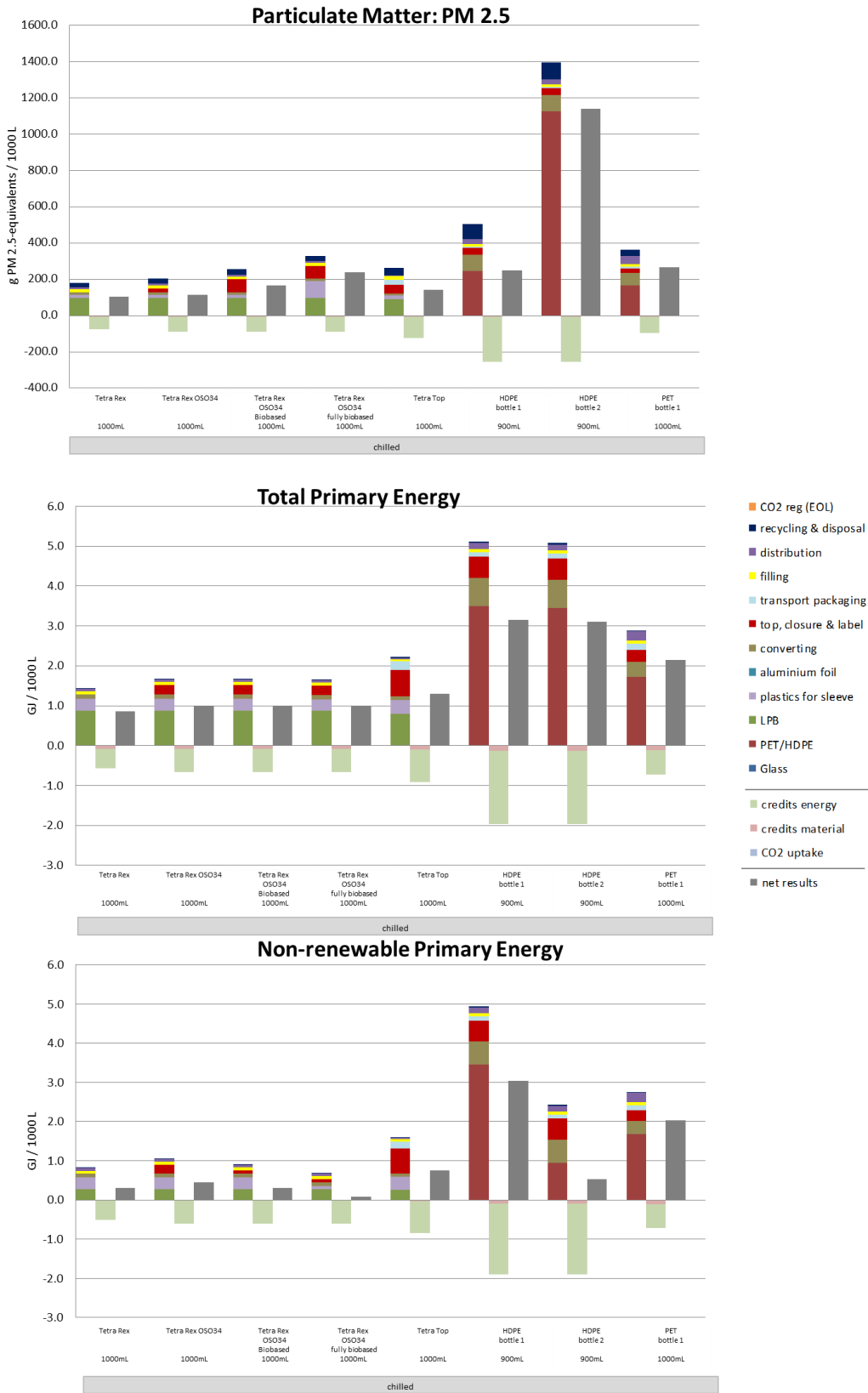


Figure 32: Indicator results for sensitivity analysis on system allocation; segment DAIRY, Denmark, Allocation factor 100% (Part 3)

Table 151: Category indicator results per impact category for sensitivity analysis on system allocation of **segment DAIRY, Denmark**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Rex 1000mL	Tetra Rex OSO34 1000mL	Tetra Rex OSO34 biobased 1000mL	Tetra Rex OSO34 fully biobased 1000mL	Tetra Top 1000mL	HDPE bottle 1 900mL	HDPE bottle 2 900mL	PET bottle 1 1000mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	49.86	65.45	58.99	49.29	102.69	316.59	187.73	175.38
	CO ₂ (reg)	37.32	37.39	45.08	56.38	40.35	4.26	135.16	8.28
	Credits	-35.72	-42.34	-42.41	-42.12	-59.09	-130.86	-130.89	-47.10
	CO ₂ uptake	-38.24	-38.31	-46.26	-57.90	-41.02	-4.27	-135.64	-8.34
	net results	13.22	22.20	15.40	5.67	42.93	185.72	56.37	128.22
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.18	0.20	0.24	0.29	0.27	0.53	1.13	0.39
	Credits	-0.08	-0.10	-0.10	-0.10	-0.13	-0.28	-0.28	-0.11
	Net results	0.10	0.11	0.14	0.19	0.13	0.25	0.84	0.28
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	2.76	3.15	3.81	4.76	4.00	7.05	19.17	4.88
	Credits	-1.02	-1.20	-1.20	-1.19	-1.66	-3.36	-3.36	-1.28
	Net results	1.75	1.96	2.62	3.57	2.34	3.69	15.81	3.60
Ozone Depletion [g R11/1000 L]	Burdens	0.04	0.04	0.13	0.26	0.06	0.10	1.68	0.49
	Credits	-0.02	-0.02	-0.02	-0.02	-0.03	-0.12	-0.12	-0.05
	Net results	0.02	0.02	0.11	0.24	0.03	-0.02	1.56	0.44
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	21.42	24.25	30.76	40.26	31.37	51.87	168.64	37.31
	Credits	-7.96	-9.38	-9.39	-9.33	-12.96	-27.09	-27.09	-10.19
	Net results	13.47	14.88	21.37	30.93	18.41	24.79	141.55	27.12
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	18.90	21.33	40.78	69.21	28.35	47.08	390.29	29.57
	Credits	-0.82	-0.84	-0.84	-0.84	-1.03	-1.14	-1.15	-1.23
	Net results	18.08	20.48	39.93	68.37	27.32	45.94	389.14	28.34
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	179.63	204.60	254.61	328.34	263.37	503.75	1393.39	361.51
	Credits	-75.60	-88.96	-89.10	-88.51	-122.76	-255.62	-255.67	-96.03
	Net results	104.04	115.65	165.51	239.83	140.61	248.13	1137.72	265.47
Total Primary Energy [GJ]	Burdens	1.43	1.67	1.67	1.66	2.22	5.12	5.08	2.88
	Credits	-0.57	-0.66	-0.67	-0.66	-0.91	-1.97	-1.97	-0.73
	Net results	0.86	1.01	1.00	1.00	1.31	3.15	3.11	2.15
Non-renewable Primary Energy [GJ]	Burdens	0.82	1.05	0.91	0.69	1.60	4.93	2.43	2.74
	Credits	-0.51	-0.60	-0.60	-0.60	-0.85	-1.89	-1.89	-0.71
	Net results	0.31	0.45	0.30	0.09	0.75	3.04	0.54	2.03
Use of Nature [m ² /year]	Burdens	21.58	21.68	27.47	35.94	21.94	0.54	100.07	0.63
	Credits	-1.23	-1.25	-1.25	-1.25	-1.29	-0.58	-0.58	-0.20
	Net results	20.35	20.43	26.22	34.69	20.65	-0.04	99.49	0.43
Water use [m ³ /1000 L]	water cool	1.07	1.19	1.22	1.23	1.38	2.52	3.37	2.04
	water process	2.14	2.15	2.15	2.14	1.82	0.14	0.19	0.22
	water unspecified	0.20	0.24	0.30	0.38	0.48	1.01	2.41	0.79

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 analysed and illustrated in this sensitivity analysis (for details please see section 2.4.3). Results are shown in the following break even graphs.

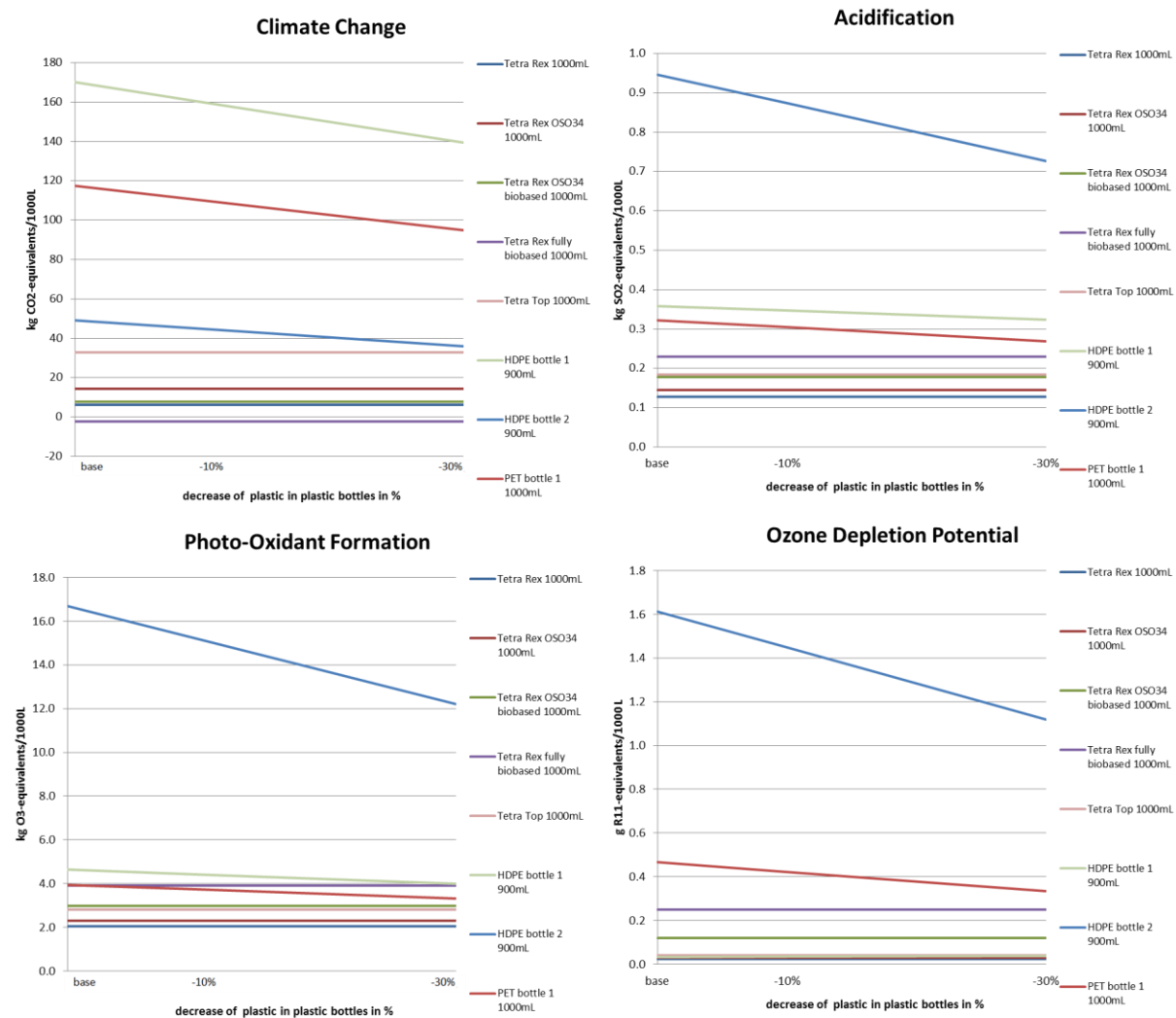


Figure 151: Indicator results for sensitivity analysis on plastic bottle weights; segment DAIRY, Denmark, Allocation factor 50% (Part 1)

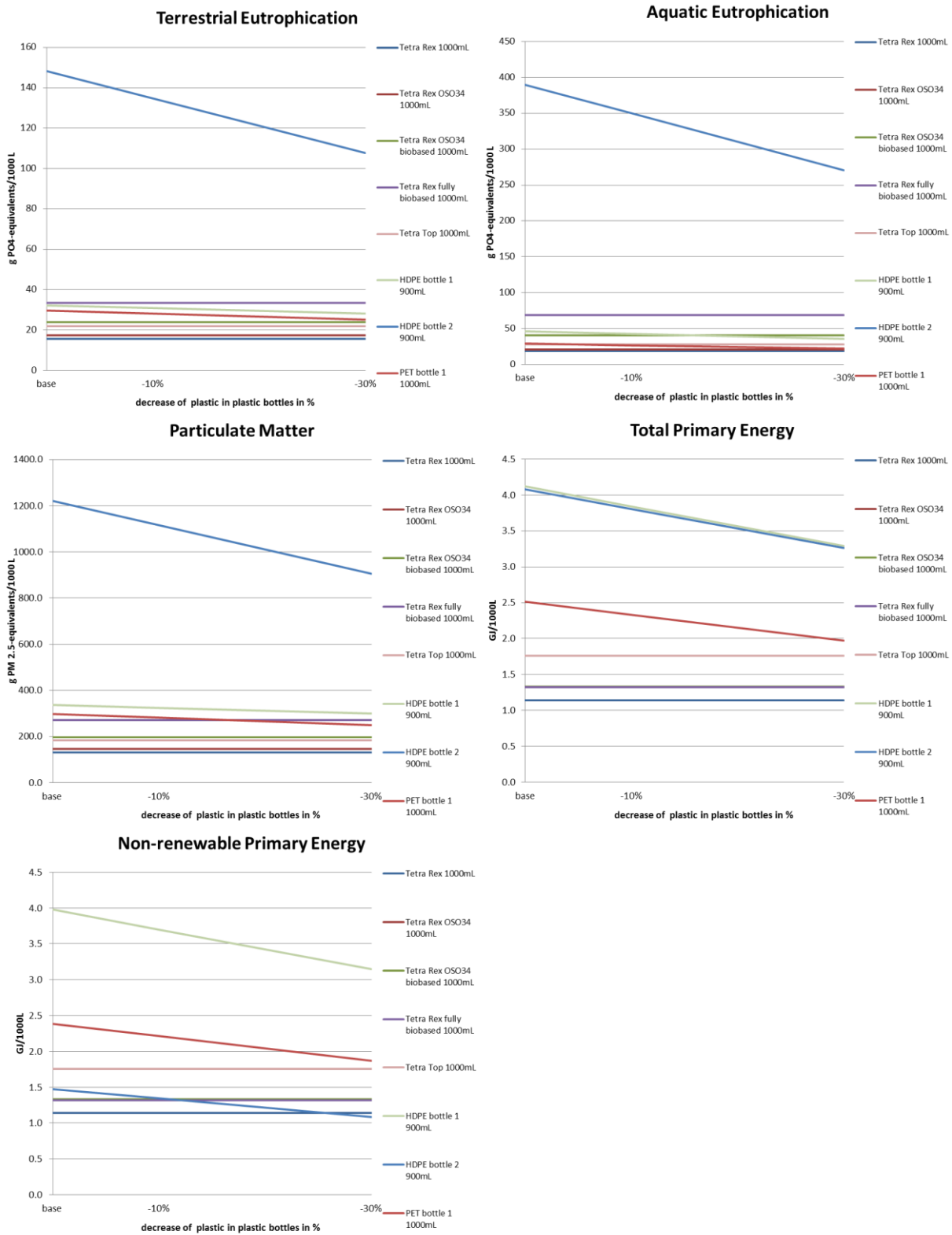


Figure 152: Indicator results for sensitivity analysis on plastic bottle weights; segment DAIRY, Denmark, Allocation factor 50% (Part 2)

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.

The lightweight bottles 'HDPE bottle 1' and 'PET bottle 1' reaches breakeven with the 'Tetra Rex fully bio-based' in some categories at different percentages of weight reduction.

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

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.

14.2 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 153: Indicator results for sensitivity analysis on system allocation; segment JNSD, Denmark, Allocation factor 100% (Part 1)

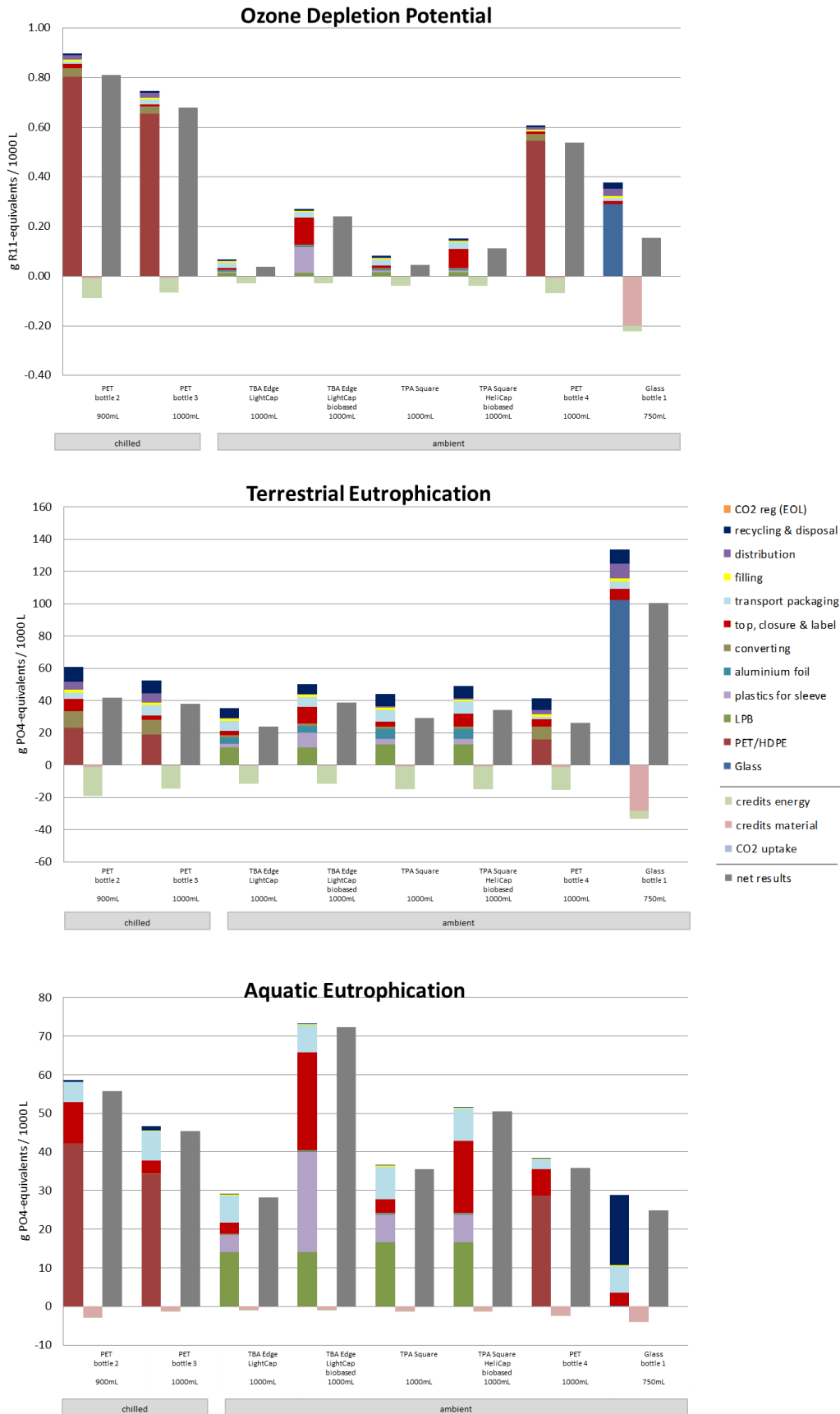


Figure 154: Indicator results for sensitivity analysis on system allocation; segment JNSD, Denmark, Allocation factor 100% (Part 2)

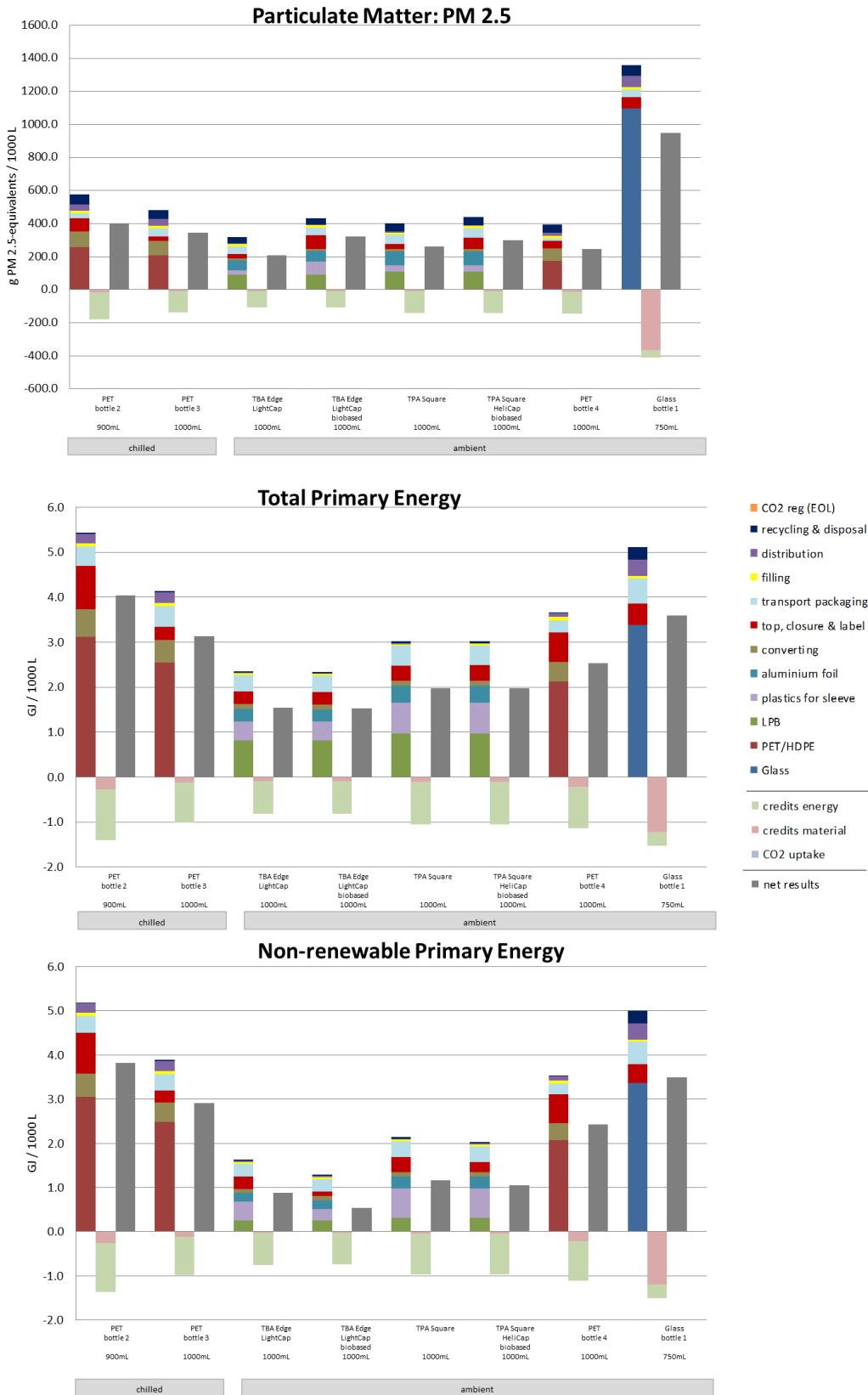


Figure 155: Indicator results for sensitivity analysis on system allocation; segment JNSD, Denmark, Allocation factor 100% (Part 3)

Table 152: Category indicator results per impact category for sensitivity analysis on system allocation of **segment JNSD, Denmark**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		PET bottle 2 900mL	PET bottle 3 1000mL	TBA Edge LightCap 1000mL	TBA Edge LightCap biobased 1000mL	TPA Square 1000mL	TPA Square HeliCap biobased 1000mL	PET bottle 4 1000mL	Glass bottle 1 750mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	303.85	246.35	106.90	92.07	140.57	135.68	221.69	401.16
	CO ₂ (reg)	11.50	15.53	42.81	60.27	50.80	56.72	3.83	12.41
	Credits	-88.23	-66.86	-52.01	-51.88	-67.68	-67.78	-71.36	-121.00
	Net results	215.52	179.33	54.38	39.06	72.28	67.06	150.32	280.10
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.61	0.51	0.34	0.41	0.43	0.45	0.41	1.37
	Credits	-0.20	-0.15	-0.12	-0.12	-0.15	-0.15	-0.16	-0.34
	Net results	0.41	0.36	0.22	0.30	0.27	0.30	0.25	1.04
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	8.08	6.70	4.42	5.91	5.54	6.06	5.55	16.94
	Credits	-2.42	-1.81	-1.46	-1.46	-1.90	-1.90	-1.96	-4.17
	Net results	5.65	4.89	2.96	4.45	3.64	4.16	3.58	12.77
Ozone Depletion [g R11/1000 L]	Burdens	0.90	0.75	0.07	0.27	0.08	0.15	0.61	0.38
	Credits	-0.09	-0.07	-0.03	-0.03	-0.04	-0.04	-0.07	-0.22
	Net results	0.81	0.68	0.04	0.24	0.04	0.11	0.54	0.15
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	60.99	52.34	35.21	49.97	43.93	48.97	41.58	133.60
	Credits	-19.10	-14.45	-11.44	-11.42	-14.86	-14.88	-15.45	-33.29
	Net results	41.88	37.89	23.76	38.56	29.07	34.09	26.13	100.31
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	58.65	46.75	29.15	73.32	36.65	51.70	38.26	28.90
	Credits	-2.88	-1.31	-0.99	-0.99	-1.17	-1.17	-2.37	-4.02
	Net results	55.77	45.45	28.16	72.32	35.48	50.53	35.89	24.88
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	578.05	480.15	318.14	432.23	401.83	440.25	393.67	1359.17
	Credits	-180.31	-136.08	-108.48	-108.23	-140.76	-140.97	-145.84	-410.19
	Net results	397.74	344.07	209.66	324.00	261.07	299.28	247.83	948.98
Total Primary Energy [GJ]	Burdens	5.43	4.13	2.35	2.34	3.02	3.02	3.67	5.12
	Credits	-1.40	-1.01	-0.81	-0.81	-1.05	-1.05	-1.13	-1.53
	Net results	4.03	3.13	1.54	1.53	1.97	1.97	2.53	3.59
Non-renewable Primary Energy [GJ]	Burdens	5.19	3.90	1.63	1.29	2.14	2.03	3.54	5.00
	Credits	-1.37	-0.98	-0.75	-0.75	-0.97	-0.97	-1.11	-1.51
	Net results	3.82	2.91	0.88	0.54	1.17	1.06	2.43	3.49
Use of Nature [m ² /year]	Burdens	1.82	3.67	23.71	36.87	28.18	32.66	0.47	2.38
	Credits	-0.33	-0.27	-1.29	-1.29	-1.55	-1.55	-0.26	-0.15
	Net results	1.49	3.41	22.42	35.58	26.63	31.11	0.21	2.23
Water use [m ³ /1000 L]	water cool	3.50	2.75	1.50	1.54	1.85	1.89	2.17	0.13
	water process	0.24	0.19	2.21	2.20	2.65	2.65	0.12	5.33
	water unspecified	1.42	1.28	0.59	0.72	0.74	0.78	0.89	0.43

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 analysed and illustrated in this sensitivity analysis (for details please see section 2.4.3). Results are shown in the following break even graphs.

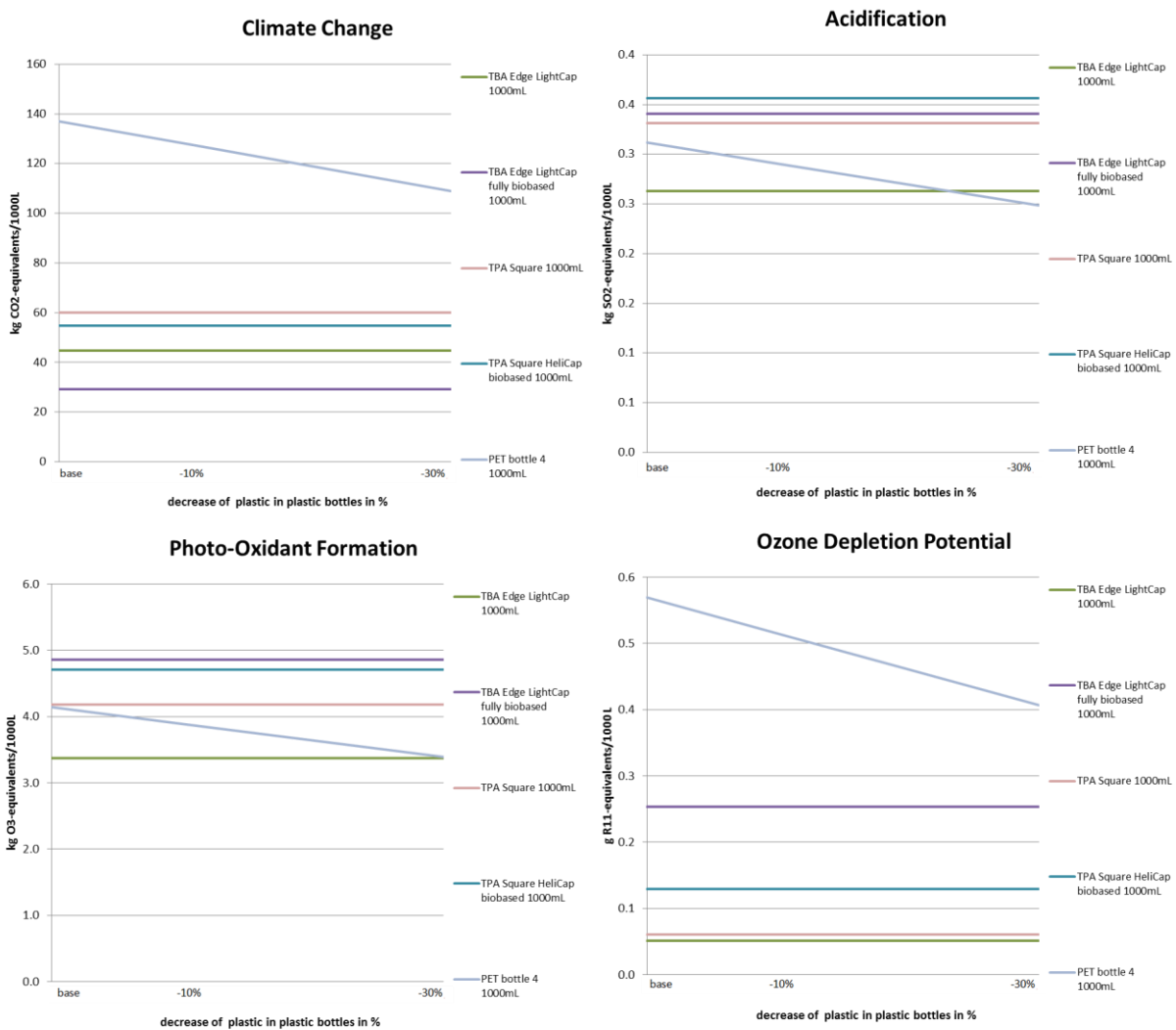


Figure 156: Indicator results for sensitivity analysis on bottle weights, segment JNSD, Denmark, Allocation factor 50% (Part 1)

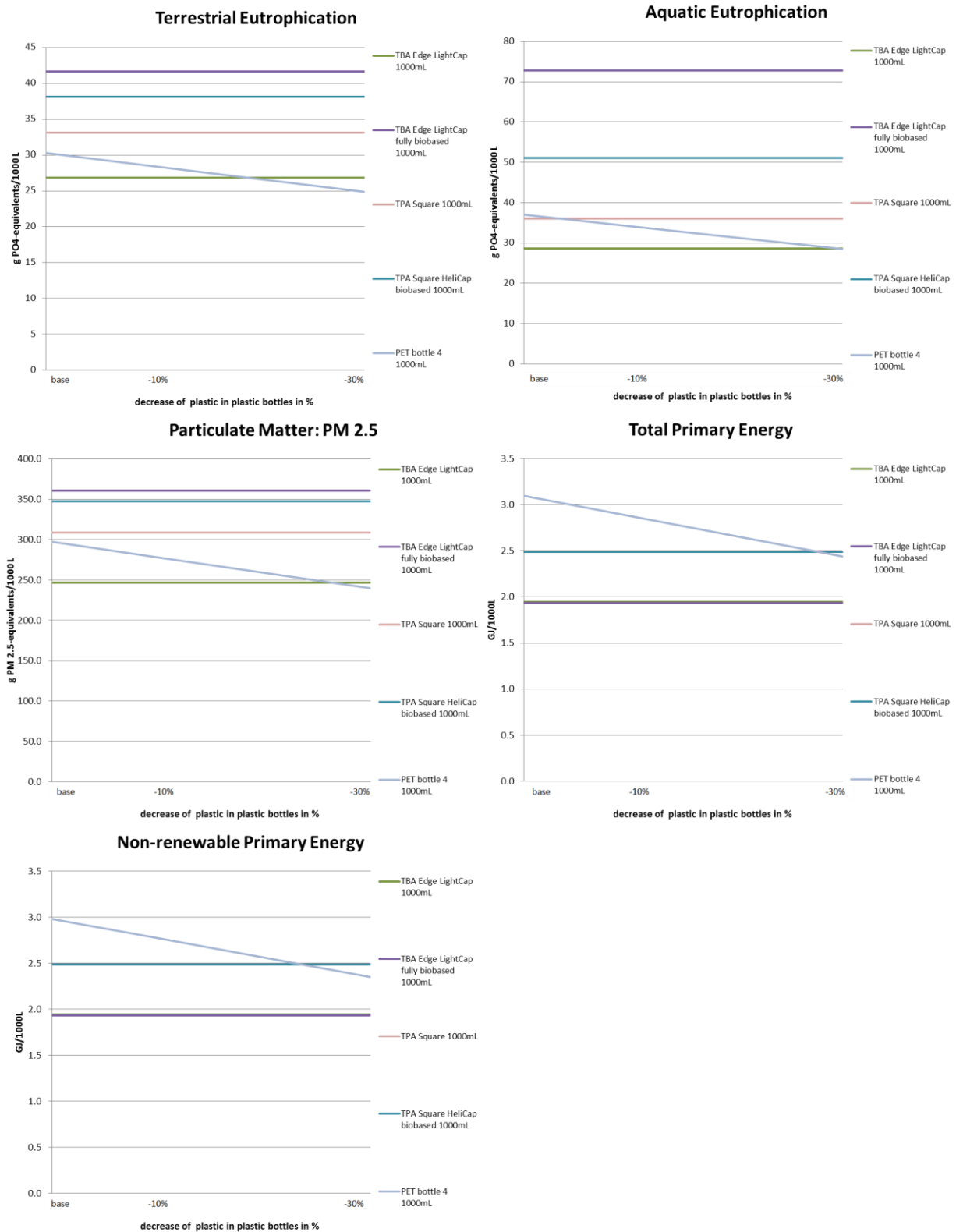


Figure 157: Indicator results for sensitivity analysis on bottle weights, segment JNSD, Denmark, Allocation factor 50% (Part 2)

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 'TBA edge LightCap' in some of the other impact categories..

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 158: Indicator results for sensitivity analysis on system allocation; segment Grab & Go, Denmark, Allocation factor 100% (Part 1)

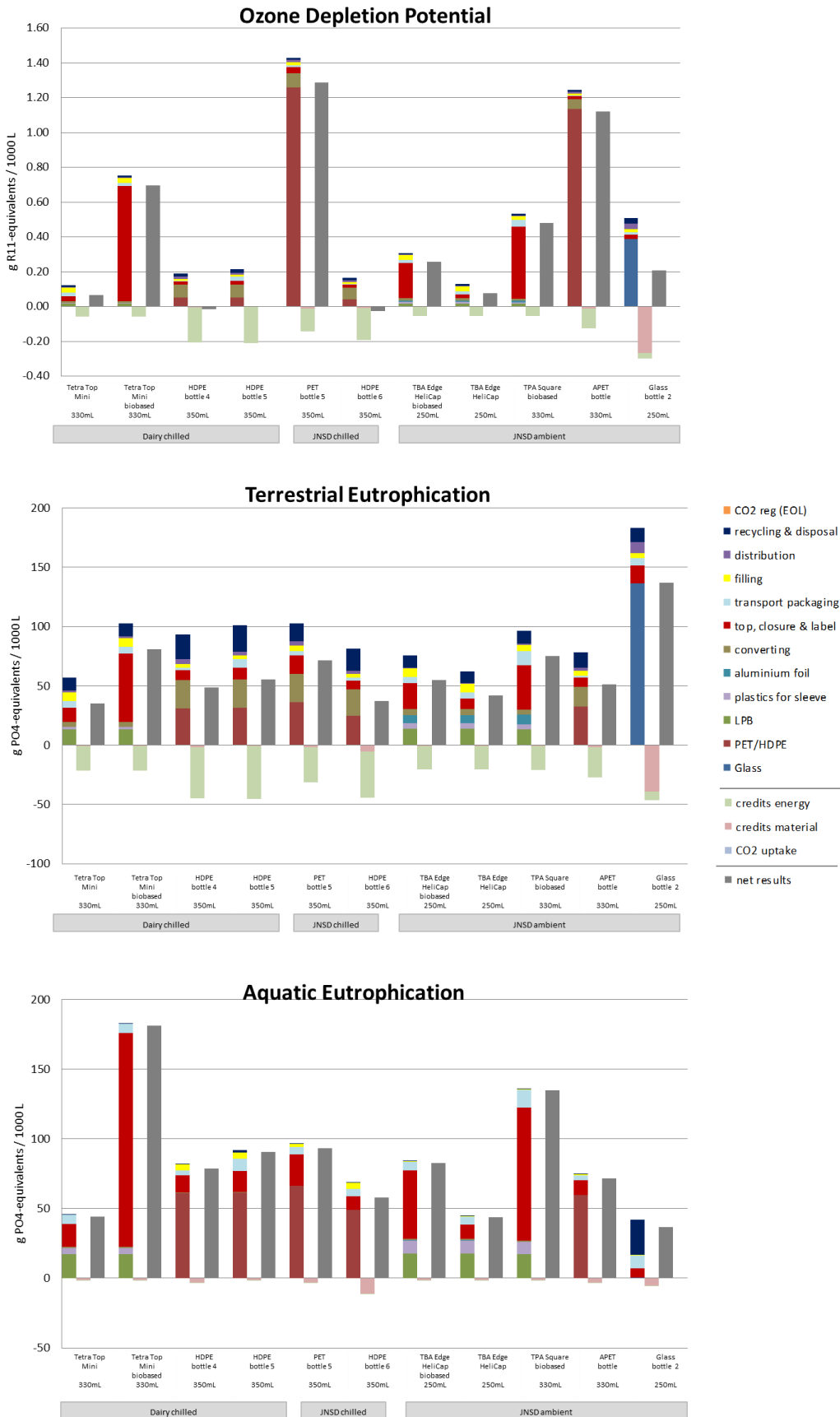


Figure 159: Indicator results for sensitivity analysis on system allocation; segment Grab & Go, Denmark, Allocation factor 100% (Part 2)

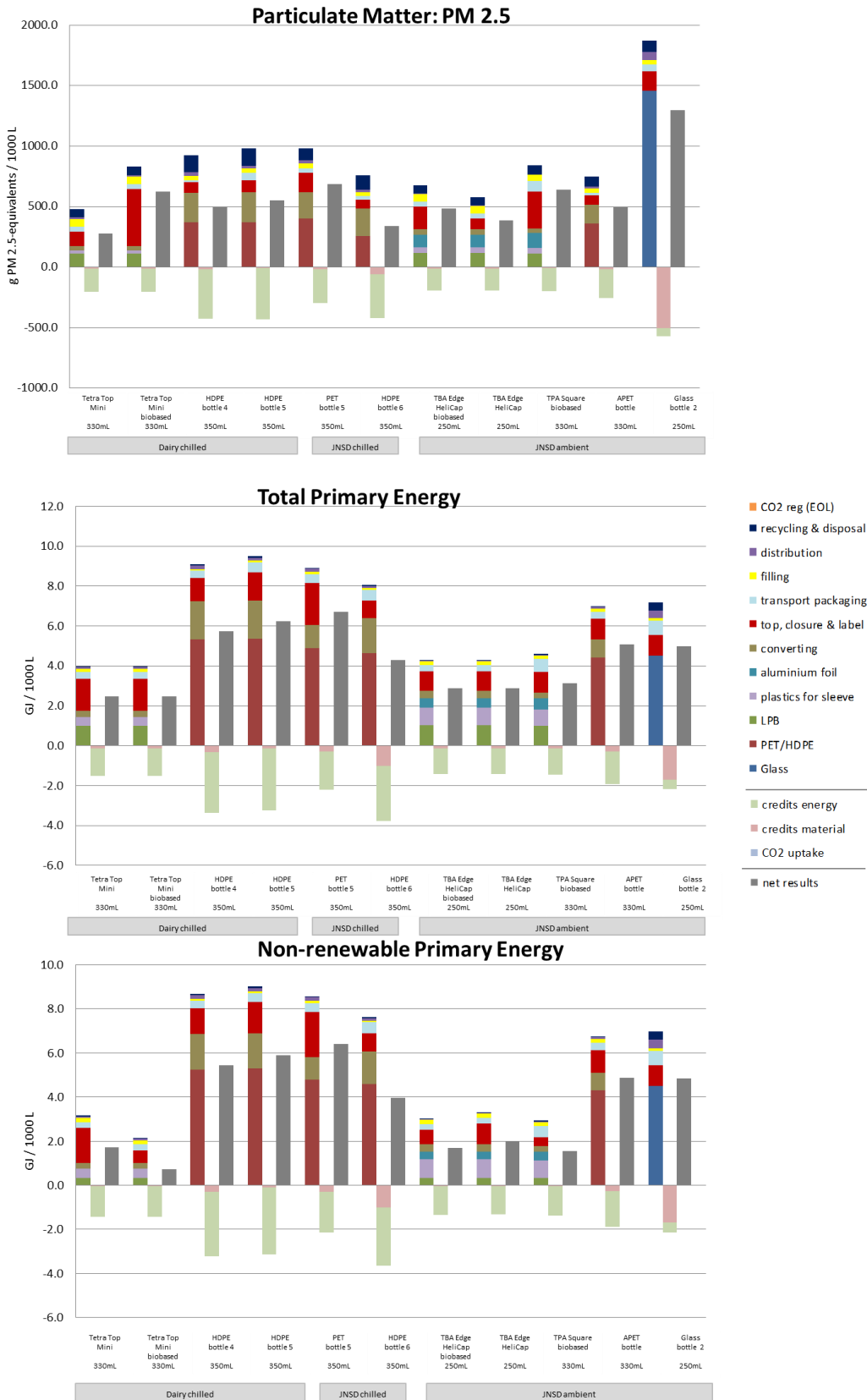


Figure 160: Indicator results for sensitivity analysis on system allocation; segment Grab & Go, Denmark, Allocation factor 100% (Part 3)

Table 153: Category indicator results per impact category for sensitivity analysis on system allocation of **segment Grab & Go, Denmark**-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		Tetra Top Mini 330mL	Tetra Top Mini biobased 330mL	HDPE bottle 4 350mL	HDPE bottle 5 350mL	PET bottle 5 350mL	HDPE bottle 6 350mL	TBA Edge HeliCap biobased 250mL	TBA Edge HeliCap 250mL	TPA Square biobased 330mL	APET bottle 330mL	Glass bottle2 250mL
Climate Change [kg CO ₂ -e/1000 L]	Burdens	206.97	162.84	549.68	574.09	508.79	478.42	206.52	219.33	210.74	420.19	560.52
	CO ₂ (reg)	51.62	104.29	3.80	12.42	10.92	9.90	67.83	52.32	90.19	3.74	17.13
	Credits	-99.06	-99.51	-217.39	-219.23	-144.62	-213.83	-92.98	-92.71	-96.39	-124.81	-174.92
	Net results	107.20	60.88	332.27	354.74	364.07	264.50	112.28	125.87	112.88	295.36	385.52
Acidification [kg SO ₂ -e/1000 L]	Burdens	0.49	0.72	0.97	1.04	1.03	0.77	0.67	0.61	0.81	0.79	1.90
	Credits	-0.22	-0.22	-0.47	-0.48	-0.32	-0.47	-0.21	-0.21	-0.21	-0.28	-0.48
Photo-Oxidant Formation [kg O ₃ e/1000 L]	Burdens	7.26	12.02	12.60	13.36	13.61	11.00	9.44	8.08	11.54	10.42	23.27
	Credits	-2.76	-2.77	-5.59	-5.62	-3.93	-5.65	-2.60	-2.59	-2.68	-3.40	-5.82
Ozone Depletion [g R11/1000 L]	Burdens	4.50	9.25	7.01	7.74	9.68	5.35	6.84	5.49	8.85	7.01	17.45
	Credits	0.12	0.75	0.19	0.21	1.43	0.17	0.31	0.13	0.53	1.24	0.51
Terrestrial Eutrophication [g PO ₄ /1000 L]	Burdens	-0.06	-0.06	-0.21	-0.21	-0.14	-0.19	-0.05	-0.05	-0.05	-0.12	-0.30
	Credits	0.07	0.70	-0.02	0.00	1.29	-0.03	0.26	0.08	0.48	1.12	0.21
Aquatic Eutrophication [g PO ₄ /1000 L]	Burdens	56.78	102.79	93.31	101.05	102.78	81.34	75.42	62.28	96.30	78.13	183.35
	Credits	-21.60	-21.70	-44.85	-45.52	-31.31	-44.20	-20.29	-20.23	-21.00	-27.02	-46.52
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	35.18	81.09	48.46	55.54	71.47	37.14	55.13	42.05	75.30	51.11	136.84
	Credits	45.78	182.88	82.16	91.98	96.77	68.78	84.18	44.95	136.14	74.88	42.06
Total Primary Energy [GJ]	Burdens	-1.39	-1.39	-3.23	-1.24	-3.30	-10.91	-1.38	-1.38	-1.32	-3.20	-5.50
	Credits	44.39	181.48	78.93	90.74	93.46	57.87	82.81	43.58	134.81	71.69	36.57
Non-renewable Primary Energy [GJ]	Burdens	482.14	832.87	922.75	982.54	983.13	760.14	676.40	576.24	840.26	751.53	1872.11
	Credits	-204.27	-205.18	-424.07	-429.09	-294.91	-421.91	-191.92	-191.37	-198.56	-254.71	-572.14
Use of Nature [m ² /year]	Burdens	277.87	627.69	498.68	553.45	688.22	338.23	484.48	384.87	641.70	496.82	1299.97
	Credits	3.97	3.97	9.09	9.50	8.90	8.05	4.29	4.29	4.59	6.99	7.16
Water use [m ³ /1000 L]	Burdens	-1.50	-1.51	-3.36	-3.25	-2.20	-3.77	-1.42	-1.41	-1.46	-1.92	-2.18
	Credits	2.47	2.46	5.73	6.25	6.70	4.28	2.88	2.88	3.13	5.07	4.99
water cool	Burdens	3.15	2.15	8.67	9.01	8.55	7.62	3.03	3.32	2.93	6.74	6.98
	Credits	-1.42	-1.43	-3.23	-3.13	-2.16	-3.66	-1.34	-1.33	-1.38	-1.88	-2.15
water process	Burdens	1.73	0.72	5.44	5.88	6.40	3.96	1.69	1.98	1.55	4.86	4.83
	Credits	28.58	68.91	0.98	4.68	2.23	1.18	41.07	29.40	57.03	0.77	3.50
water unspecified	Burdens	-1.68	-1.68	-0.91	-0.95	-0.50	-0.59	-1.63	-1.63	-1.60	-0.43	-0.20
	Credits	26.91	67.23	0.08	3.73	1.73	0.60	39.44	27.77	55.44	0.34	3.30
water unspecified	Burdens	2.36	2.71	6.37	6.59	5.58	4.74	3.00	2.90	3.11	4.65	0.25
	Credits	2.32	2.30	2.82	2.83	1.57	2.36	3.07	3.08	2.98	0.75	12.65
water unspecified	Burdens	0.83	1.29	1.66	2.09	2.27	0.98	0.96	0.85	1.40	1.80	0.90
	Credits											

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 analysed and illustrated in this sensitivity analysis (for details please see section 2.4.3). Results are shown in the following break even graphs.

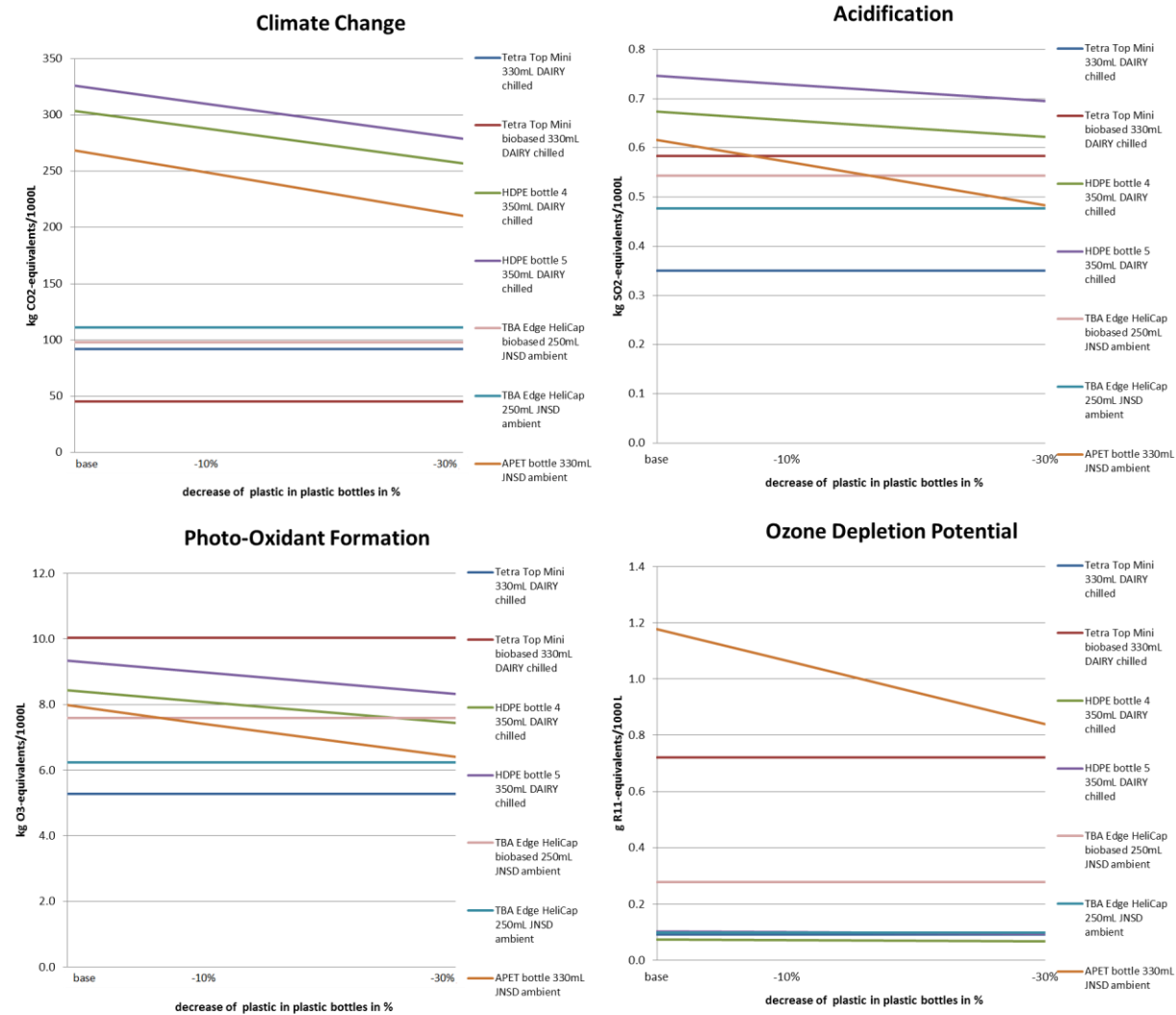


Figure 161: Indicator results for sensitivity analysis on plastic bottle weights; segment **Grab & Go, Denmark**, Allocation factor 50% (Part 1)

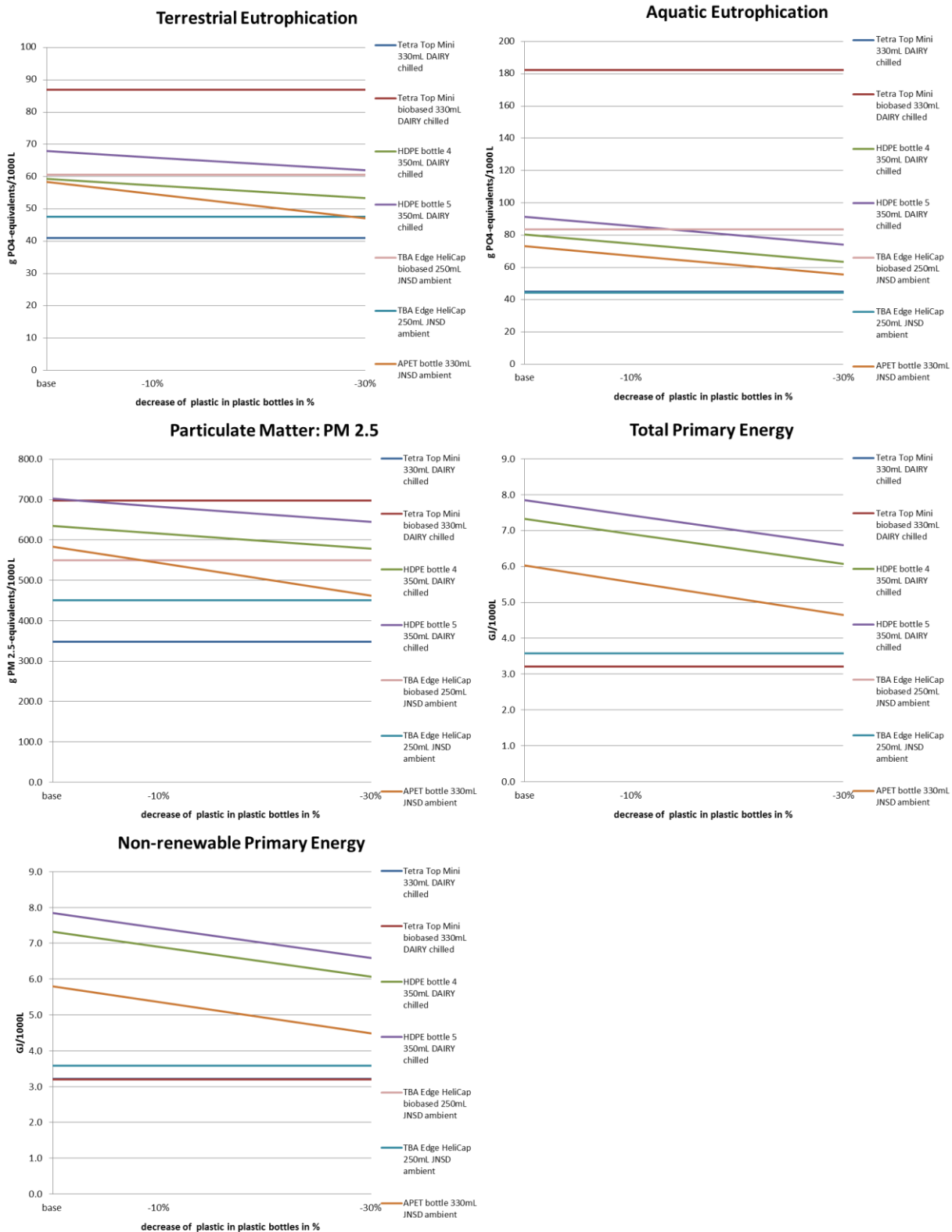


Figure 162: Indicator results for sensitivity analysis on plastic bottle weights; segment Grab & Go, Denmark, Allocation factor 50% (Part 2)

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 categories 'Photo-Oxidant Formation' and 'Terrestrial Eutrophication' break-even is achieved by some bottles.

14.4 Water Denmark

14.4.1 Sensitivity analysis on system allocation WATER Denmark

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 163: Indicator results for sensitivity analysis on system allocation; segment Water, Denmark, Allocation factor 100% (Part 1)

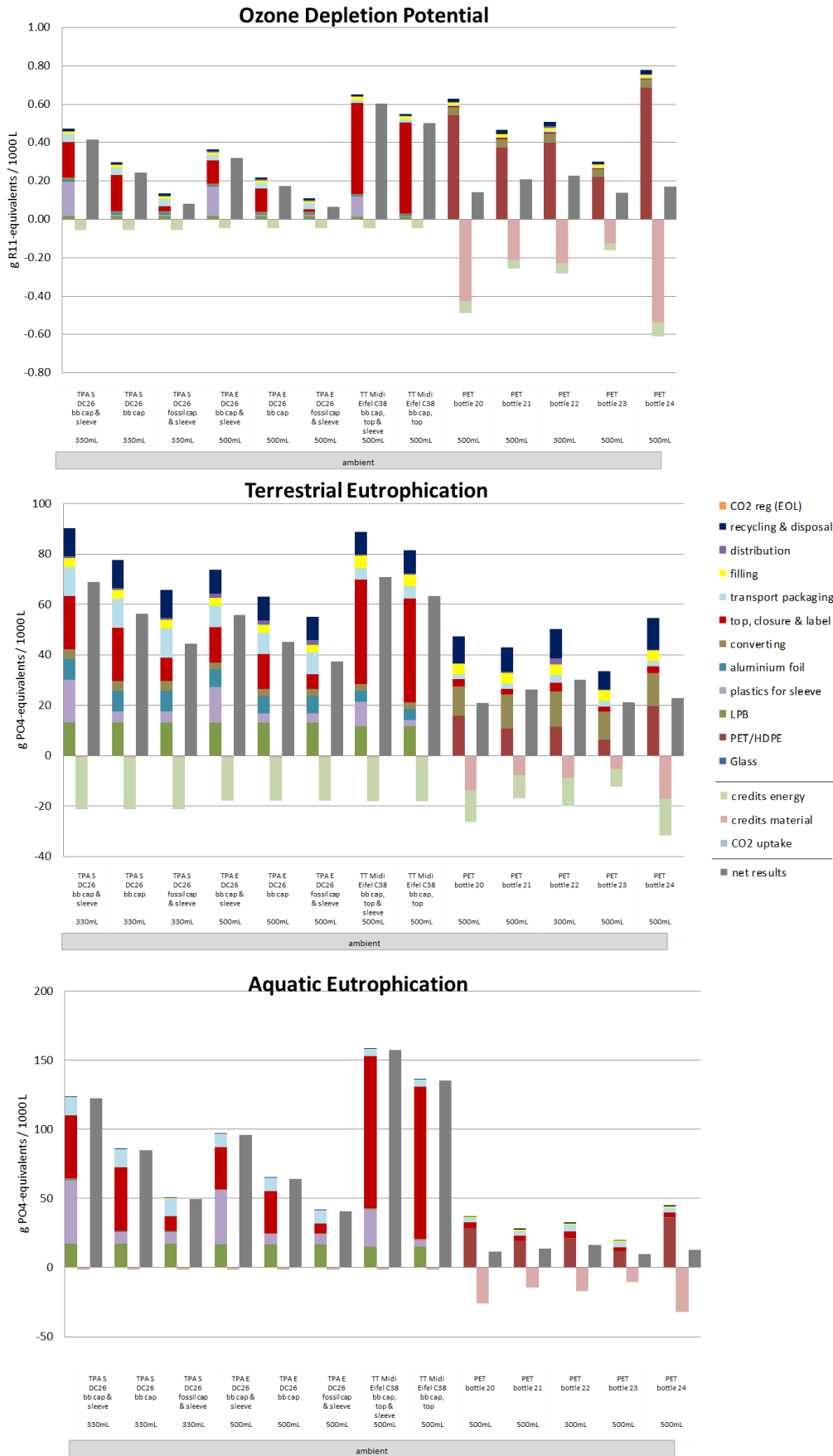


Figure 164: Indicator results for sensitivity analysis on system allocation; segment Water, Denmark, Allocation factor 100% (Part 2)

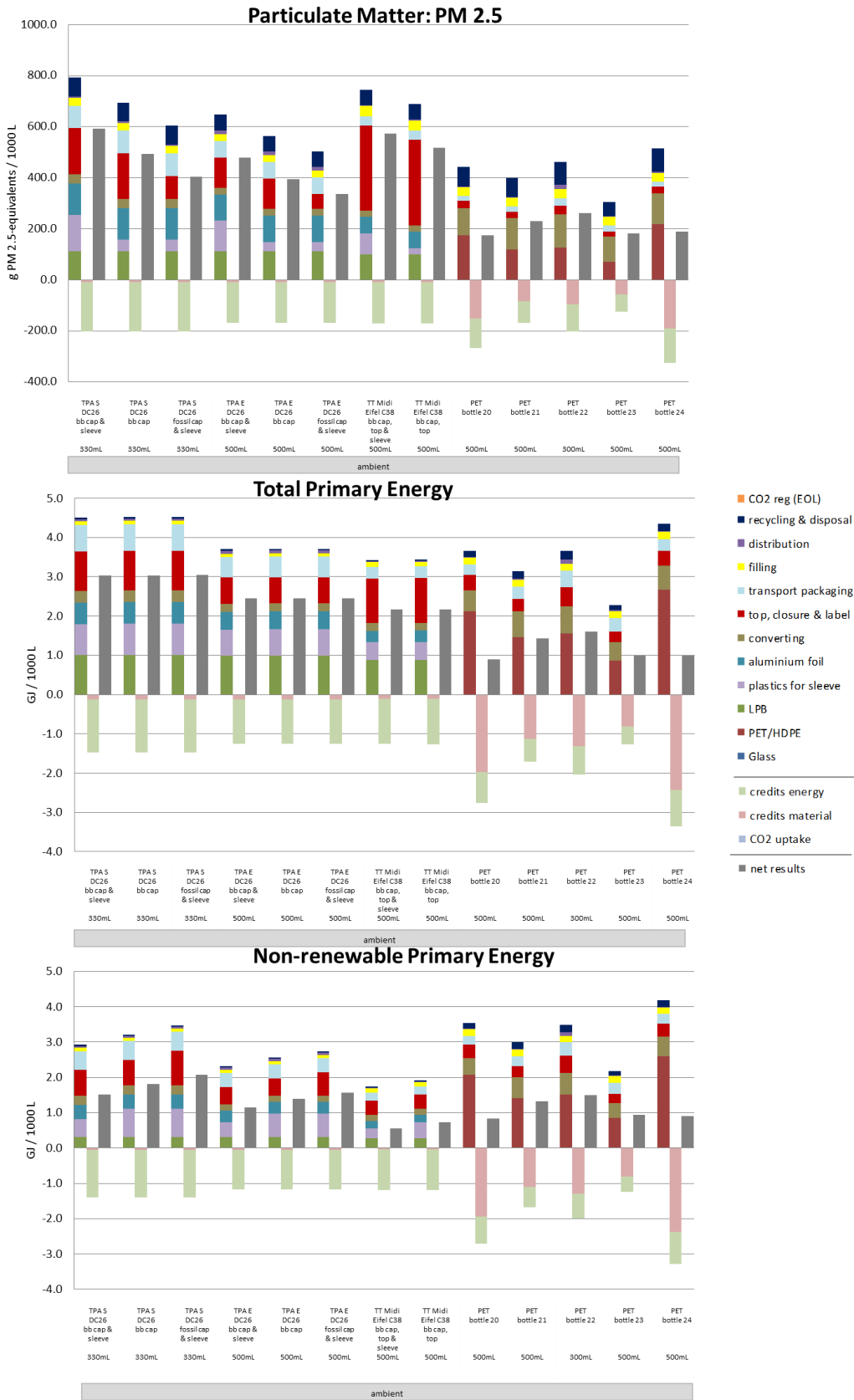


Figure 165: Indicator results for sensitivity analysis on system allocation; segment Water, Denmark, Allocation factor 100% (Part 3)

Table 154: Category indicator results per impact category for *sensitivity analysis on system allocation of segment Water, Denmark*-burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

		TPA S DC26 bb cap & sleeve 330mL	TPA S DC26 bb cap 330mL	TPA S DC26 fossil cap & sleeve 330mL	TPA E DC26 bb cap & sleeve 500mL	TPA E DC26 bb cap 500mL	TPA E DC26 fossil cap & sleeve 500mL	TT Midi Eifel C38 bb cap, top & sleeve 500mL	TT Midi Eifel C38 bb cap, top 500mL	PET bottle 20 500mL	PET bottle 21 500mL	PET bottle 22 300mL	PET bottle 23 500mL	PET bottle 24 500mL
Climate Change [kg CO2-e/1000 L]	Burdens	207.18	220.02	231.69	163.73	174.61	182.31	134.15	141.66	225.16	189.57	221.91	141.38	264.89
	CO2 (reg)	89.70	74.73	60.61	80.80	68.11	58.79	94.71	85.95	3.10	3.10	5.16	3.70	3.10
	Credits	-97.84	-98.02	-97.78	-81.76	-81.95	-81.79	-82.67	-82.92	-115.83	-75.02	-89.86	-55.50	-139.66
	CO2 uptake net results	-90.88 108.16	-75.46 121.26	-60.95 133.57	-82.01 80.77	-68.95 91.82	-59.35 99.97	-96.97 49.23	-87.94 56.76	-3.13 109.30	-3.13 114.51	-5.22 131.99	-3.74 85.84	-3.13 125.20
Acidification [kg SO2-e/1000 L]	Burdens	0.77	0.70	0.64	0.63	0.57	0.53	0.66	0.62	0.46	0.41	0.48	0.31	0.54
	Credits	-0.22	-0.22	-0.22	-0.18	-0.18	-0.18	-0.18	-0.19	-0.30	-0.19	-0.22	-0.14	-0.36
	Net results	0.55	0.49	0.43	0.45	0.39	0.35	0.48	0.44	0.16	0.23	0.26	0.18	0.18
Photo-Oxidant Formation [kg O3 e/1000 L]	Burdens	10.80	9.55	8.31	8.85	7.79	6.98	10.40	9.67	6.19	5.59	6.53	4.32	7.16
	Credits	-2.72	-2.73	-2.72	-2.28	-2.29	-2.28	-2.31	-2.32	-3.52	-2.25	-2.69	-1.67	-4.26
	Net results	8.08	6.82	5.60	6.57	5.50	4.69	8.09	7.35	2.67	3.33	3.84	2.66	2.91
Ozone Depletion [g R11/1000 L]	Burdens	0.47	0.30	0.14	0.37	0.22	0.11	0.65	0.55	0.63	0.47	0.51	0.30	0.78
	Credits	-0.06	-0.06	-0.06	-0.05	-0.05	-0.05	-0.05	-0.05	-0.49	-0.26	-0.28	-0.16	-0.61
	Net results	0.42	0.24	0.08	0.32	0.17	0.06	0.60	0.50	0.14	0.21	0.23	0.14	0.17
Terrestrial Eutrophication [g PO4/1000 L]	Burdens	90.24	77.65	65.75	73.64	62.98	55.11	88.77	81.40	47.25	43.00	50.25	33.43	54.51
	Credits	-21.28	-21.32	-21.27	-17.84	-17.89	-17.85	-18.06	-18.12	-26.30	-16.85	-20.13	-12.40	-31.77
	Net results	68.96	56.33	44.49	55.80	45.09	37.25	70.71	63.28	20.95	26.15	30.13	21.04	22.74
Aquatic Eutrophication [g PO4/1000 L]	Burdens	123.78	86.12	50.60	97.24	65.33	41.83	158.68	136.61	37.33	28.15	32.78	19.87	45.01
	Credits	-1.26	-1.26	-1.26	-1.24	-1.24	-1.24	-1.20	-1.20	-25.86	-14.40	-16.63	-10.15	-31.98
	Net results	122.53	84.86	49.34	96.00	64.09	40.59	157.48	135.41	11.47	13.76	16.16	9.73	13.02
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	792.93	695.27	604.59	647.18	564.46	504.46	745.47	688.26	442.46	399.47	461.79	304.41	514.48
	Credits	-201.13	-201.50	-201.00	-168.81	-169.21	-168.88	-170.91	-171.41	-268.02	-169.20	-201.15	-123.49	-324.66
	Net results	591.80	493.77	403.60	478.37	395.25	335.58	574.56	516.85	174.44	230.27	260.64	180.92	189.81
Total Primary Energy [GJ]	Burdens	4.50	4.52	4.51	3.70	3.71	3.71	3.42	3.43	3.66	3.14	3.65	2.27	4.35
	Credits	-1.48	-1.48	-1.48	-1.25	-1.25	-1.25	-1.26	-1.26	-2.77	-1.71	-2.04	-1.27	-3.36
	Net results	3.02	3.04	3.04	2.45	2.45	2.45	2.16	2.17	0.90	1.42	1.61	1.00	0.99
Non-renewable Primary Energy [GJ]	Burdens	2.92	3.22	3.48	2.32	2.57	2.74	1.74	1.91	3.53	3.00	3.49	2.18	4.19
	Credits	-1.40	-1.41	-1.40	-1.18	-1.18	-1.18	-1.18	-1.19	-2.71	-1.68	-2.00	-1.24	-3.29
	Net results	1.52	1.81	2.07	1.14	1.39	1.57	0.56	0.73	0.83	1.32	1.49	0.94	0.90
Use of Nature [m²*year]	Burdens	53.48	42.26	31.69	46.23	36.73	29.73	60.44	53.87	1.03	1.08	1.48	1.09	1.07
	Credits	-1.53	-1.53	-1.53	-1.53	-1.53	-1.53	-1.57	-1.57	-0.21	-0.17	-0.22	-0.14	-0.25
	Net results	51.94	40.72	30.16	44.70	35.20	28.21	58.88	52.30	0.82	0.91	1.26	0.95	0.82
Water use [m³/1000 L]	water cool	2.93	2.93	2.83	2.39	2.39	2.33	2.39	2.39	1.17	1.74	1.87	1.05	1.48
	water process	2.85	2.86	2.87	2.78	2.79	2.79	2.26	2.27	0.58	0.62	0.62	0.57	0.60
	water unspecified	1.36	1.25	1.16	1.05	0.96	0.90	1.12	1.06	0.28	0.35	0.42	0.24	0.33

14.4.2 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 2.4.3). Results are shown in the following break even graphs.

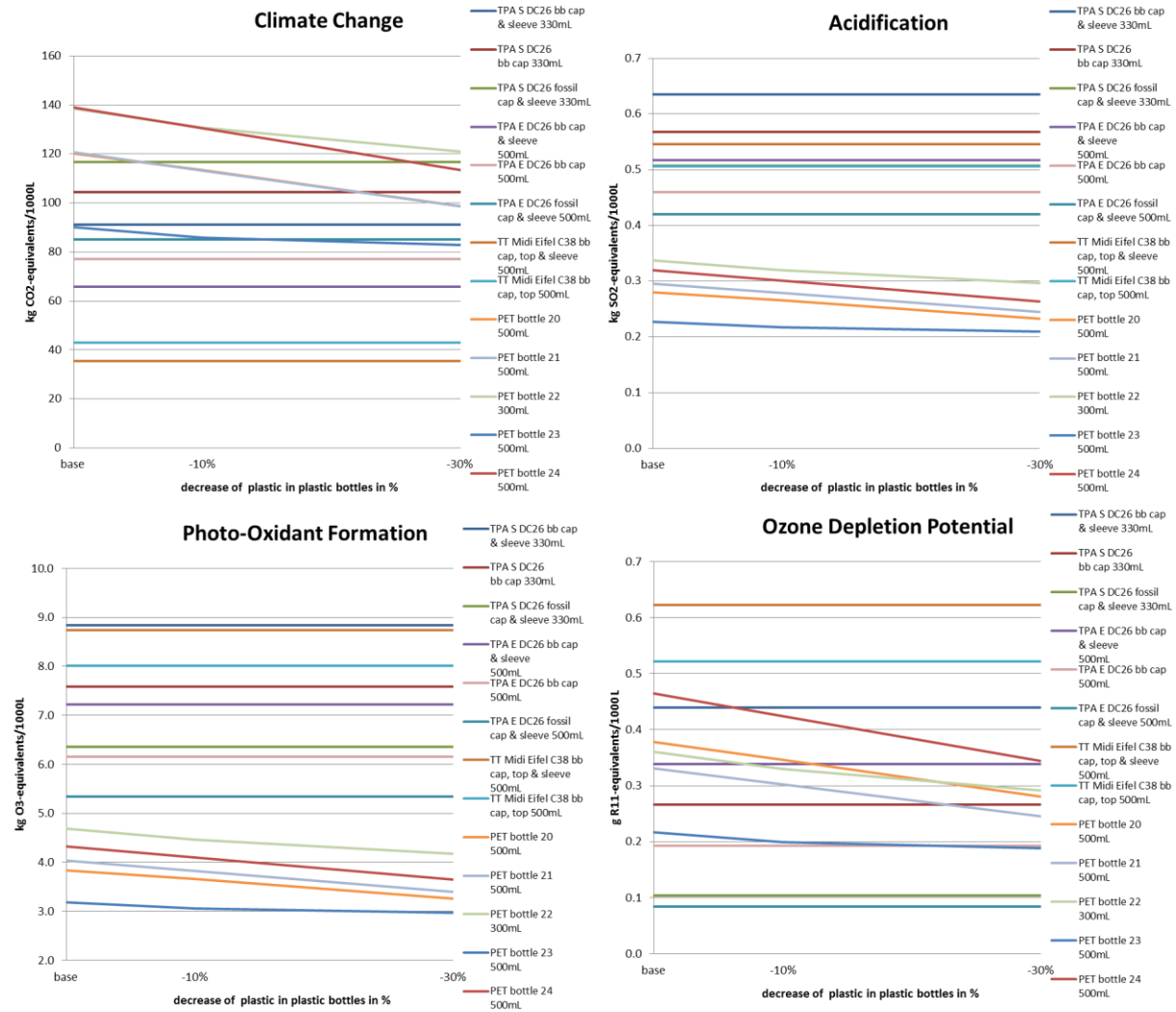


Figure 166: Indicator results for sensitivity analysis on plastic bottle weights; segment Water, Denmark, Allocation factor 50% (Part 1)

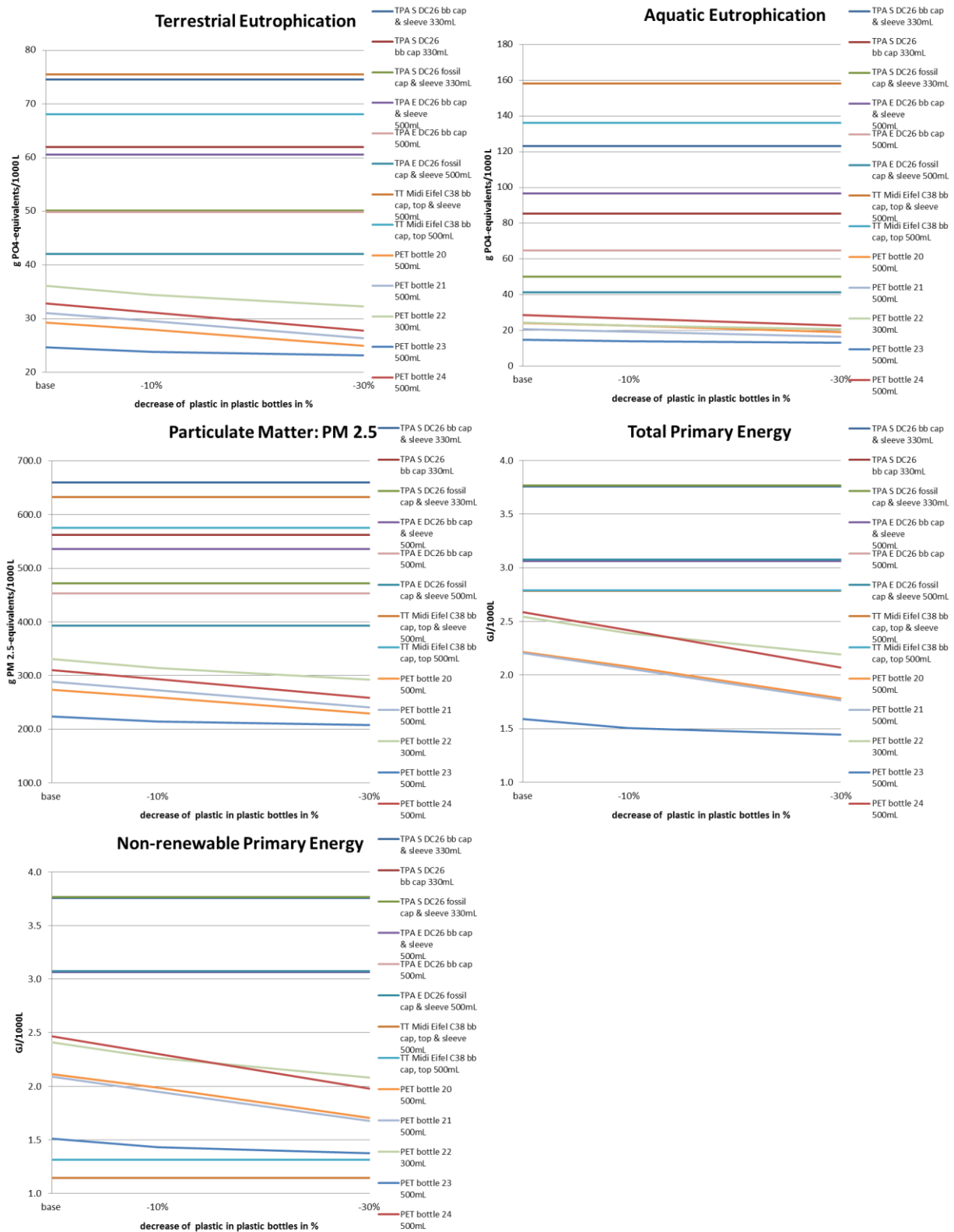


Figure 167: Indicator results for sensitivity analysis on plastic bottle weights; segment Water, Denmark, Allocation factor 50% (Part 2)

The recalculation of bottles with reduced weights shows that the impacts in all categories are lower if less material is used. In all categories where the base versions of the bottles showed higher results than the beverage cartons break even points are reached with at least some beverage cartons.



The bend in the graphs of the PET bottles 22 and 23 can be explained as the minimum weight limit for bottles has been fixed at 10g (see section 2.4.3). As these bottles are very light in the base scenario already their weight is not decreased by exactly 30%.

14.4.3 Sensitivity analysis regarding recycled PET in PET bottles

To consider potential future developments in terms of the share of recyclate of the plastic bottles, two additional scenarios for plastic bottles with a recycled content of PET of 50% and 100% 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.

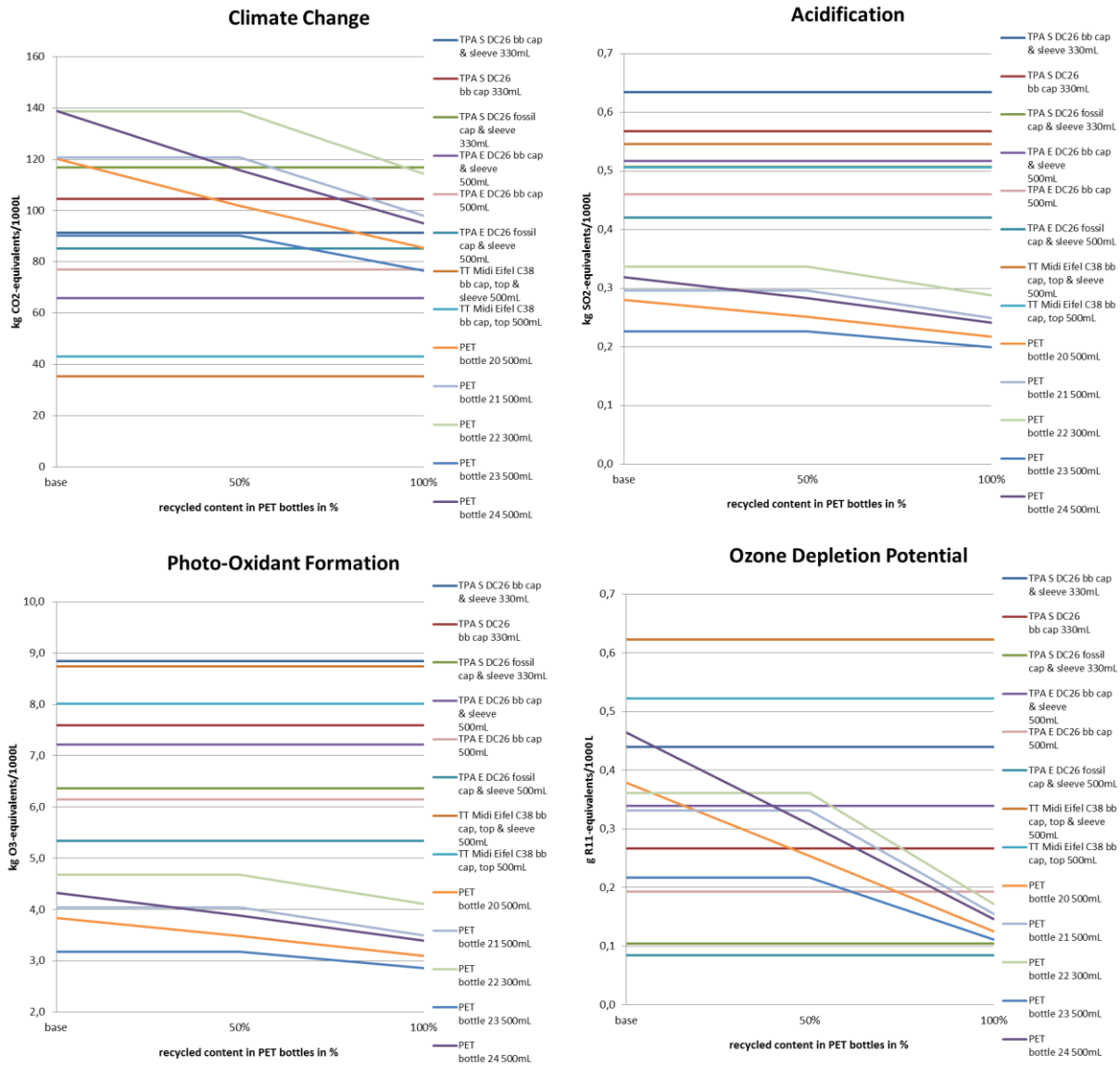


Figure 168: Indicator results for sensitivity analysis regarding recycled PET; segment Water, Denmark, Allocation factor 50% (Part 1)

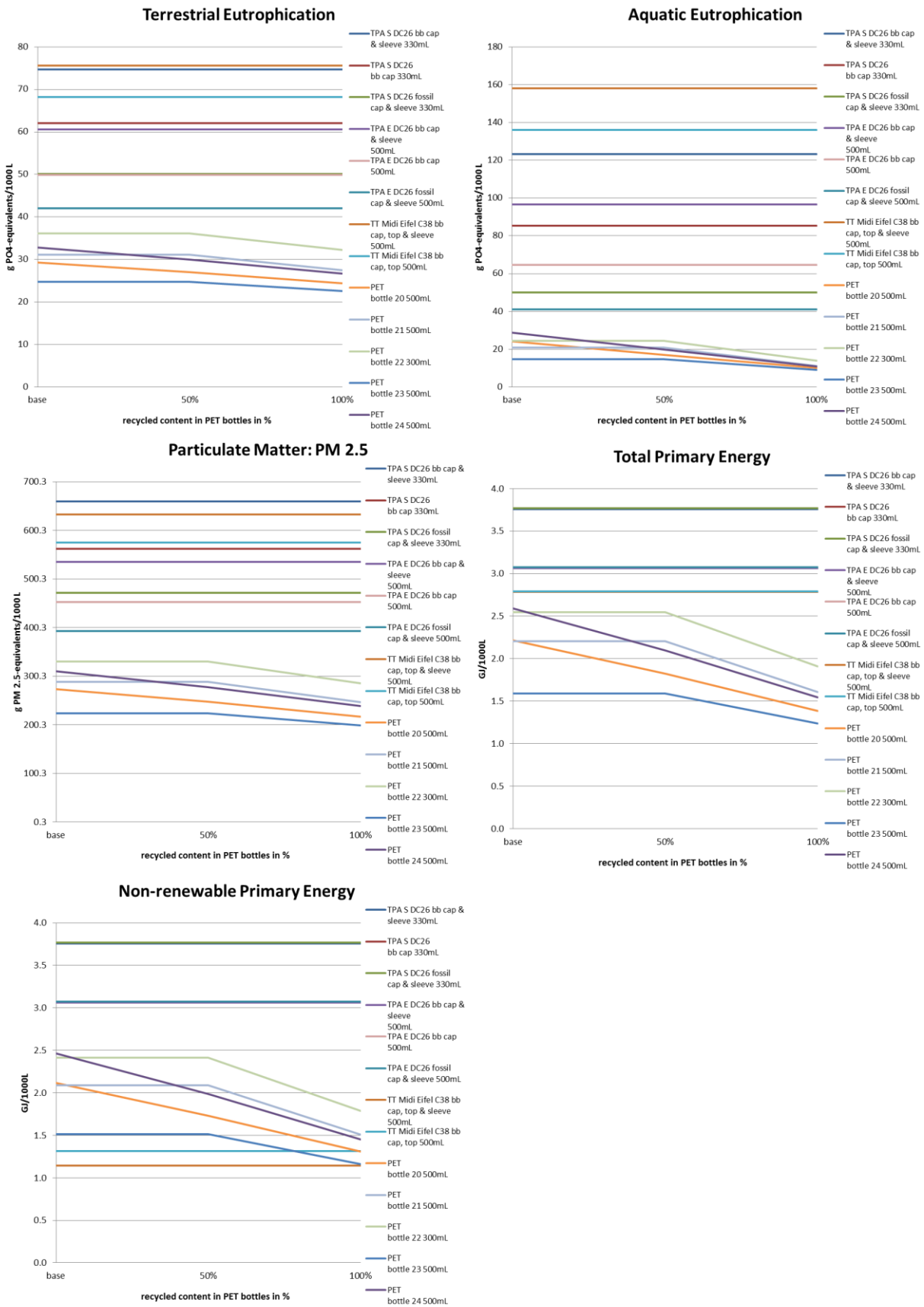


Figure 169: Indicator results for sensitivity analysis regarding recycled PET; segment Water, Denmark, Allocation factor 50% (Part 2)

In all categories, in which PET bottles without recycled content show higher results than the examined beverage cartons, an increased share of recycled content leads to break even points with at least some beverage cartons.

The bend in some of the examined PET bottles' graphs is due to the fact that these bottles already contain recycled content in the base scenario.

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 CO₂-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.

15.4 Water Denmark

In the segment water no unambiguous result can be observed. While the examined beverage cartons show lower 'Climate Change' results than most of the examined PET bottles, in other categories the beverage cartons often show higher impacts. Especially beverage cartons with a high share of biobased polyethylene show higher results than the

bottles in the categories 'Acidification', 'Photo-Oxidant Formation', 'Terrestrial and Aquatic Eutrophication'

The very light weight PET bottle 23 with a recycled content of 50% shows lower results than the Tetra Prisma Aseptic Square cartons even in the environmental impact category 'Climate Change'.

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), JNSD (chilled and unchilled) and water. 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 the segments Dairy, JNSD and Grab & Go in all 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 CO₂ 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.

Regarding the segment water, no unambiguous conclusion can be drawn. PET bottles used for water tend to be lighter than those used for milk or JNSD. Besides their low weight, their high recycling rate, due to the deposit system applied, leads to relatively low results in many categories. The comparison of the different beverage cartons with the water bottles shows an inconclusive result.

Also the use of bio-based polyethylene does not deliver 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:
19.79 kg CO₂-eq/FU

Climate change of Tetra Rex fully bio-based:
3.76 kg CO₂-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 **16.03 kg CO₂-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 CO₂ 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 CO₂ equivalent.

When calculating CO₂ 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 CO₂-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 ₂ O)	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; CO₂ 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 CO₂-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 CO₂ at the material's end of life, for example CO₂ 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. CO₂ may be included at two points in the model, its uptake during the plant growth phase attributed with negative GWP values and the corresponding re-emissions at end of life with positive ones.

¹ The values reported by [IPCC 2013] in Appendix 8.A were rounded off to whole numbers.

² According to [IPCC 2013], the indirect effect from oxidation of CH₄ to CO₂ 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 CO₂ oxidation effect from fossil methane and is thus appropriate methane emissions from biogenic sources and fossil sources for which the carbon has been accounted for in the LCI.

Alternatively, neither the uptake of non-fossil CO₂ by the plant during its growth nor the corresponding CO₂ emissions are taken into account in the GWP calculation.

In the present study, the first approach has been applied for the impact assessment.

Methane emissions originating from any life cycle step of biogenic materials (e.g. their landfilling at end of life) are always accounted for both at the inventory level and in the impact assessment (in form of GWP).

A.2 Photo-oxidant formation

Due to the complex reactions during the formation of near-ground ozone (photo smog or summer smog), the modelling of the relationships between the emissions of unsaturated hydrocarbons and nitrogen oxides is extremely difficult.

The method to be applied for the impact category Photo-oxidant formation, should be the „Maximum Incremental Reactivity“ of VOC und Nitrogen-MIR (Nitrogen-MIR) based on the publication of [Carter 2010]. The MIR concept is the most appropriate characterisation model for LCIA based on generic spatial independent global inventory data and combines a consistent modelling of potential impacts for VOC and NO_x and the precautionary principle. The MIR and NMIR are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NO_x inputs. The unit for the category indicator MIR is kg O₃-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
CH ₃ CCl ₃	0.16
HCFC-22	0.04
HCFC-123	0.01
HCFC-141b	0.12
HCFC-142b	0.06
CH ₃ Br	0.66
N ₂ O	0.017

• Source: [WMO 2011]

Table A-3: 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 estimate¹.

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 (PO_4^{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-4: 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 SO₂ equivalents. The table below shows the harmful substances considered in this study, along with their respective acidification potential (AP) expressed as SO₂ 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 ₂ S)	• 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 ₃ PO ₄)	• 0.98
Sulphur trioxide (SO ₃)	• 0.8
Sulphuric acid (H ₂ SO ₄)	• 0.65

• Source: [Hauschild und Wenzel 1998] taken from [CML 2010]

Table A-5: 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 , NO_x , 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-6: PM2.5 equivalents of substances considered in this study

The contribution to the Aerosol Formation Potential (AFP) is calculated by summing the products of the amounts of the individual harmful substances and the respective AFP equivalent values using the following equation:

$$PFP = \sum_i (m_i \times AFP_i)$$

A.6 Use of Nature

Traditionally, LCAs carried out by the German Federal Environment Agency (UBA) include the impact category land use based on the metric 'Degree of naturalness of areas'. Despite the recent developments on land use in LCAs, the fundamental idea to characterise 'naturalness' as an overarching conservation goal (desired state) forming the basic concept to address selected conservation assets is still appropriate. The idea central to the concept follows the logic that intact ecosystems are not prone to higher levels of disturbance and negative impacts.

Recently the so called hemeroby concept in order to provide an applicable and meaningful impact category indicator for the integration of land use and biodiversity into the Life Cycle (Impact) Assessment has been developed 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 explicit information on naturalness and providing implicit information, at least partly, on biodiversity (number of species, number of rare or threatened species, diversity of structures), and soil quality (low impact.)

The system of hemeroby is subdivided into seven classes (see Tables A-7). 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 ($x \text{ m}^2$ of area classified as class y) as well as the aggregation to the category indicator 'Distance-to-Nature-Potential' (DNP) ($\text{m}^2\text{-e} * 1a$) 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-7.1: 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-7.2: The characterisation factors of hemeroby classes

The ‘Distance-to-Nature-Potential’ (DNP) is calculated by summing the products of the square meters of area classified as land use class 2 to 7 and the respective characterization factor using the following equation:

$$DNP = \sum_i ((m^2 * a)_i \times DNP_i)$$

¹ The global share of area classified as class VII amounts to approximately 3 % of total land area. In consequence, the ratio between class VII land and the sum of other areas is 1:33. (see [Fehrenbach et al. 2015])

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Appendix B-1: Critical Review Statement



Date
Gothenburg 12 April 2017

Your date

Our reference.
Håkan Stripple

Your reference
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Erik Lindroth

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Critical Review of the report and study “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market”

LCA study for review

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

Author(s)

The study has been carried out by Stefanie Markwardt (stefanie.markwardt@ifeu.de), Frank Wellenreuther (frank.wellenreuther@ifeu.de), Andrea Drescher (Andrea.Drescher@ifeu.de), Jonas Harth (Jonas.Harth@ifeu.de), and Mirjam Busch (mirjam.busch@ifeu.de) at ifeu, Germany.

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Study commissioned by:

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Contact persons: Erika Kloow (Erika.Kloow@tetrapak.com) and Erik Lindroth (Erik.Lindroth@tetrapak.com)

Date of the study:

Heidelberg, April 2017.

Critical Reviewers

Due to the requirements specified for Life Cycle Assessment (LCA) in the ISO standard, ISO 14044:2006, a Critical Review panel has been used for the critical review of the present LCA study. The review panel consisted of the following three independent members:

- Håkan Stripple, IVL Swedish Environmental Research Institute Ltd., Sweden, (Chairman), (hakan.strippl@ivl.se)
- Prof. Dr. Birgit Grahl, INTEGRAHL Germany, (integrahl@t-online.de)
- Alessandra Zamagni, Ecoinnovazione, Italy, (a.zamagni@ecoinnovazione.it)

Scope

The task of the review panel was to review the LCA models, the LCA report, underlying data, and methods and strategies for the calculations in the study “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market”. The study covers the market situation of the Swedish, Norwegian, Finish and Danish market as observed in 2016. The beverage segments; dairy, juice, nectar & still drinks (JNSD), and grab & go have been studied on the four Nordic markets. The product areas included in the review are the packagings; Tetra Brik Edge (250 and 1000 ml, normal and biobased), Tetra Rex (1000 and 1500 ml, normal and biobased), Tetra Top (1000 ml), Tetra Prisma Square (330 and 1000 ml, normal and biobased), Tetra Top Midi (250 and 330 ml), and Tetra Top Mini (330 ml, normal and biobased). Aseptic packaging solutions were also included. In the study, Tetra Pak’s packaging solutions are compared with corresponding packaging solutions in plastic bottles (PET 330 ml, 400 ml, 900 ml, 1000 ml, and HDPE 350ml, 380 ml, 900 ml, and 1000 ml) and glass bottles (350 ml and 900 ml). Different plastic concepts such as recycled PET and bio-based plastics are also analysed in the study. The review was conducted as a strategic inspection with sample checks.

The review is performed in order to check the calculations and validity of the system boundaries chosen and model defined, as well as compliance with ISO 14040:2006 and ISO 14044:2006. Formally, this Critical Review is a review by “interested parties” (panel method) according to ISO 14040 section 7.3.3 and ISO 14044 section 4.2.3.7 and 6.3 because the study includes comparative assertions of different liquid packaging systems and is intended to be disclosed to the public. However, despite this title, the inclusion of further representatives of “interested parties” is optional and was not explicitly intended in this study. The review panel is neutral with regard to and independent from particular commercial interests. The panel had to be aware of issues relevant to other interested parties,

as it was outside the scope of the present project to invite governmental or non-governmental organisations or other interested parties, e.g. competitors or consumers.

Note: The present Critical Review statement is delivered to Tetra Pak, Sweden. The Critical Review panel cannot be held responsible for the use of its work by any third party. The conclusions of the Critical Review panel cover the full report from the study for Tetra Pak, Sweden “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market” – Final Report – April 2017 and no other report, extract or publication, which may eventually be undertaken. The Critical Review panel conclusions are given with regard to the current state of the art and the information which has been received. The conclusions expressed by the Critical Review panel are specific to the context and content of the present study only and shall not be generalised any further.

Review process

Ifeu (Institut für Energie- und Umweltforschung) in Germany has developed the present study for review, in-line with their standardised procedures and normal LCA practice, and in accordance to ISO 14040 and 14044. The LCA study “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market” was reviewed by the above mentioned review panel. The documentation (e.g. LCA report) for the study was sent to the review panel by e-mail. The LCA report was then read and commented individually by each panel member. An internal virtual review panel meeting was held where the different comments and remarks were discussed. All comments and remarks, in tabular form and included in the LCA report, were sent to ifeu for comments and actions.

Virtual review meeting with ifeu, Tetra Pak and the review panel were held to discuss and review the LCA study report and other aspects of the study. A special virtual review meeting was held between ifeu and the review panel in order to review inventory data and the LCA model. Due to the extent of the study, not all details can be reviewed. The review was performed as a scientific review where the overall strategies are reviewed and strategic samples of the data and model are reviewed in detail. Specific and foreground data have been in focus in the review while general and background data usually also are reviewed in other studies prior to the inclusion in official databases. These aspects were also considered in the review. For specific and foreground data, a plausibility assessment were made. For the ifeu database data used in the study, no specific check was performed due to confidentiality aspects. Nevertheless, the discussions with ifeu concerning plausibility of data were satisfactory. In this study, different products are compared so it was also an important task for the

review to verify that the different data and models for the different products are relevant, equivalent and comparable.

The present study has been reviewed against the LCA standards ISO 14040 and ISO 14044 as well as against the background of current LCA practice and science. The comments and corrections are documented either in tabular form or direct in the documents. The information in the review process is thus traceable throughout the entire review process.

Review results

In the LCA study, Tetra Pak's packaging products for dairy products, juice, nectar & still drinks (JNSD), and grab & go are compared to competing products made of HDPE, PET and glass. The effects of recycled PET and bio-based production of PE are also investigated. The LCA report is well written and describes the study in a consistent and transparent way. The various products are well described in the report. The different LCA datasets for the materials were reviewed and found relevant and satisfactory with a transparent description/reference. The dataset for the production of the bio-based PE was modified by ifeu to better reflect the real production. The modifications described in the LCA report were reviewed but the original dataset for bio-based PE was not fully transparent and therefore not possible to review from primary data. The modifications were found acceptable with its description in the report and the sensitivity analysis performed. However, both data sets for bio-based PE have to be considered with great care. This is well discussed in the study. The LCA data for the production of the different materials are general database LCA datasets, which usually are reviewed in other projects and contain specific process data. The choice of products is relevant for the application. The process data for the competing products are relevant but have to be considered as more uncertain than the specific data for Tetra Pak's own products. This has to be taken into account when comparing the results from the different products.

The LCA model system and its boundaries was reviewed and found relevant and well described in the report. The allocations made in the study are relevant. A sensitivity analysis of the system allocation performed also exemplifies the effect of the different allocation strategies. In the impact assessment part of the study, the following impact categories were considered: Climate change, Stratospheric Ozone Depletion Potential, Photochemical Ozone Creation Potentials (POCP), Acidification Potential, Eutrophication Potential and oxygen-depletion, Particulate matter, and Use of Nature. Inventory indicators such as Water use and Cumulative Energy Demand (CED, total and non-renewable) have also been used in the result presentation to cover the use of primary raw materials with energy content. However, this is not a full coverage of the primary raw material demand from the system. With this choice of methodology, the primary resource

use of materials without energy content is excluded. The Cumulative Raw material Demand (CRD, non-metallic minerals and metals, and fossil) which show the use of raw materials, also without energy content, has not been included in this study due to a lack of reliable impact assessment methods. Neither have the Abiotic depletion potential (in kg antimony eq./functional unit) been applied. The consequence of this choice is that the primary material use of materials with no energy content is not covered in the study. This means that the raw materials from the liquid board and the plastics are covered by the Cumulative Energy Demand but the raw materials in glass are excluded in the study. This is a major issue to be noticed in the result evaluation. These factors are described in the report of this study. The choice of impact assessment methods and inventory indicators were thoroughly discussed in the review.

All calculated impacts are potential impacts, which represent the standard method for LCA impact assessment calculations. The methods are adequately described in the report. However, the review-panel has the following remarks: The eutrophication calculations are divided into Terrestrial Eutrophication (based on emissions to air) and Aquatic Eutrophication (based on emissions to water). This division is a simplification but the total impact represents an acceptable measure. The calculation of Photo-Oxidant Formation (POCP) is always complex and different methods and assumption can give different results. The selected method is well described and can be justified.

After discussions and request in the review process including report structure, naming of impact assessment methods, choice of impact assessment methods including material resource use without energy content, definition of the competing packaging systems, waste handling, and editorial changes, satisfactory changes were made. However, it should be noted that glass' primary resources are not included in the analysis but this will probably not affect the study's conclusions as the glass primary material components are not considered to be a rare commodity. The review panel has covered the entire product chain including upstream data, core processes, and downstream data. The review panel has covered the product specifications and the change of the material composition, the LCA product systems, the data gaps and cut offs, the methodology applied, the data used and assumptions made for the products/processes in the study, electricity production, and end-of-life treatment. The procedure for the calculations and selection of studied products has also been covered. The Critical Review panel concludes that the interpretations reflect the limitations identified and the goal of the study.

The review process also includes minor editorial changes.

All remarks were accounted for in a satisfactory manner in the revised versions of the LCA report and LCA models.

The Critical Review panel can therefore inform that the LCA results presented in the study are based on consistent data and models, and there are no further issues or comments.

Review Statement

The undersigned reviewers confirm that the reviewed study “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market” has been conducted according to and in compliance with the ISO standards 14040 and 14044 and has relevant data sources. The results from the study are in compliance with the steering documents identified under the abovementioned scope of this review.



Håkan Stripple

IVL Swedish
Environmental Research
Institute



Birgit Grahl

INTEGRAHL



Alessandra Zamagni

Ecoinnovazione

Appendix B-2:

Critical Review Statement – original version of outdated study



Date
Gothenburg 17 July 2019

Your date

Our reference.
Håkan Stripple

Your reference
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Erik Lindroth

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Critical review of the update to the report and study “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market”

LCA study for review

Update to the report “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market”.

Author(s)

The study has been carried out by Samuel Schlecht (Samuel.Schlecht@ifeu.de), Frank Wellenreuther (frank.wellenreuther@ifeu.de), Andrea Drescher (Andrea.Drescher@ifeu.de), Jonas Harth (Jonas.Harth@ifeu.de), Mirjam Busch (mirjam.busch@ifeu.de), and Stefanie Markwardt (stefanie.markwardt@ifeu.de) at ifeu, Germany.

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Study commissioned by:

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Date of the study:

Heidelberg, May 2019.

Critical reviewers

Due to the requirements specified for Life Cycle Assessment (LCA) in the ISO standard, ISO 14044:2006, a Critical Review panel has been used for the critical review of the present LCA study. The review panel is the same as conducted the main review of the previous study. The review panel consisted of the following three independent members:

- Håkan Stripple, IVL Swedish Environmental Research Institute Ltd., Sweden, (Chairman), (hakan.strippl@ivl.se)
- Prof. Dr. Birgit Grahl, INTEGRAHL Germany, (integrahl@t-online.de)
- Dr. Alessandra Zamagni, Ecoinnovazione, Italy, (a.zamagni@ecoinnovazione.it)

Scope

In year 2017, the above-mentioned review panel was reviewing an LCA study and report conducted by ifeu for Tetra Pak AB named “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market”. In year 2019, ifeu has, on behalf of Tetra Pak International SA, conducted an update of this report including packaging systems for water and several update changes and adjustments in the calculations, in this review referred to as the Update 2019. The present review covers only this Update 2019. The present study report for 2019 including also the updates are thus reviewed by both the review for the previous report (review report 2017) and by the present review for the updates 2019 (this review report).

Thus, the task of the review panel was to review the LCA models, the LCA report, underlying data, and methods and strategies for the calculations in the Update 2019 to the study “Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market”. The study covers the market situation of the Swedish, Norwegian, Finish, and Danish market as observed in 2016. The beverage segment Water has been studied on the four Nordic markets. The product areas included in the review are the packagings; Tetra Prisma Aseptic S DC26 (330 ml, normal and biobased), Tetra Prisma Aseptic E DC26 (500 ml, normal and bio-based), and Tetra Top Midi Eifel C38 (500 ml, normal and bio-based). In the study, Tetra Pak’s packaging solutions are compared with corresponding packaging solutions in PET bottles (PET normal, 300, 500, 600 ml). No bio-based PET is included. The review was conducted as a strategic inspection with sample checks.

The review is performed in order to check the calculations and validity of the system boundaries chosen and model defined, as well as consistency with ISO 14040:2006 and ISO 14044:2006. Formally, this Critical Review is a review by “interested parties” (panel method) according to ISO 14040 section 7.3.3 and ISO 14044 section 4.2.3.7 and 6.3 because the study includes comparative assertions of different liquid packaging systems and is intended to be disclosed to the public.

However, despite this title, the inclusion of further representatives of "interested parties" is optional and was not explicitly intended in this study. The review panel is neutral with regard to and independent from particular commercial interests. The panel had to be aware of issues relevant to other interested parties, as it was outside the scope of the present project to invite governmental or non-governmental organisations or other interested parties, e.g. competitors or consumers.

Note: The present Critical Review statement is delivered to Tetra Pak International SA. The Critical Review panel cannot be held responsible for the use of its work by any third party. The conclusions of the Critical Review panel cover the Update 2019 to the full report from the study for Tetra Pak International SA, "Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market" – Final Report – May 2019 and no other report, extract or publication, which may eventually be undertaken. The Critical Review panel conclusions are given with regard to the current state of the art and the information which has been received. The conclusions expressed by the Critical Review panel are specific to the context and content of the present study only and shall not be generalised any further.

Review process

Ifeu (Institut für Energie- und Umweltforschung) in Germany has conducted the present update for review, in line with their standardised procedures and normal LCA practice, and in accordance to ISO 14040 and 14044. The Update 2019 to the LCA study "Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market" was reviewed by the above-mentioned review panel. The documentation (e.g. in the LCA report) for the update was sent to the review panel by e-mail. The Update 2019 to the LCA report was then read and commented individually by each panel member. An internal virtual review panel meeting was held (22 February 2019) where the different comments and remarks were discussed. All comments and remarks, in tabular form and included in the LCA report, were sent to ifeu for comments and actions.

A virtual review meeting with ifeu, Tetra Pak and the review panel was held (9 May 2019) to discuss and review the update to the LCA study report and other aspects of the study. Due to the extent of the study, not all details can be reviewed. The review was performed as a scientific review where the overall strategies are reviewed and strategic samples of the data and model are reviewed in detail. Specific and foreground data have been in focus in the review while general and background data usually also are reviewed in other studies prior to the inclusion in official databases. These aspects were also considered in the review. Nevertheless, it was examined whether the background data sets used are relevant and applicable in the context of the study. For specific and

foreground data, a plausibility assessment were made. For the ifeu database data used in the study, no specific check was performed due to confidentiality aspects. Nevertheless, the discussions with ifeu concerning plausibility of data were satisfactory. In this study, different products are compared so it was also an important task for the review to verify that the different data and models for the different products are relevant, equivalent and comparable.

The present update has been reviewed against the LCA standards ISO 14040 and ISO 14044 as well as against the background of current LCA practice and science. The comments and adjustments are documented either in tabular form or direct in the documents. The information in the review process is thus traceable throughout the entire review process.

Review results

In the update to the LCA study, Tetra Pak's packaging products for water products are compared to competing products made of PET plastics. The effects of recycled PET are also investigated. The update to the LCA report is well written and describes, together with the previous material in the report, the study in a consistent and transparent way. The various products are well described in the report. The various LCA data sets for the materials were checked to see whether their use is meaningful and resilient in the context of the study. The changes in the updated study were considered relevant and satisfactory with a transparent description/reference. The LCA data for the production of the different materials are general database LCA datasets, which usually are reviewed in other projects and contain specific process data. The choice of products is relevant for the application. The process data for the competing products are relevant but have to be considered as more uncertain than the specific data for Tetra Pak's own products. This has to be taken into account when comparing the results from the different products.

The LCA model system and its boundaries was reviewed and found relevant and well described in the report. The allocations made in the study are relevant. A sensitivity analysis of the system allocation performed also exemplifies the effect of the different allocation strategies. In the impact assessment part of the study, the following impact categories were considered: Climate change, Stratospheric Ozone Depletion Potential, Photochemical Ozone Creation Potentials (POCP), Acidification Potential, Eutrophication Potential and oxygen-depletion, Particulate matter, and Use of Nature. Inventory indicators such as Water use and Cumulative Energy Demand (CED, total and non-renewable) have also been used in the result presentation to cover the use of primary raw materials with energy content. The volume of water used in the system is however not sufficient to be able to be used for evaluation of the water impact due to lack of water scarcity data and water quality data. This is well described in the report.

However, this is not a full coverage of the primary raw material demand from the system. With this choice of methodology, the primary resource use of materials without energy content is excluded. The Cumulative Raw material Demand (CRD, non-metallic minerals and metals, and fossil) which show the use of raw materials, also without energy content, has not been included in this study due to a lack of reliable impact assessment methods. Neither have the Abiotic depletion potential (in kg antimony eq./functional unit) been applied. The consequence of this choice is that the primary material use of materials with no energy content is not covered in the study. This means that the raw materials from the liquid board and the plastics are covered by the Cumulative Energy Demand but the raw materials in glass are excluded in the study. This is a major issue to be noticed in the result evaluation. These factors are described in the report of this study. The choice of impact assessment methods and inventory indicators were thoroughly discussed in the review.

All calculated impacts are potential impacts, which represent the standard method for LCA impact assessment calculations. The methods are adequately described in the report. However, the review-panel has the following remarks: The eutrophication calculations are divided into Terrestrial Eutrophication (based on emissions to air) and Aquatic Eutrophication (based on emissions to water). This division is a simplification but the total impact represents an acceptable measure. The calculation of Photo-Oxidant Formation (POCP) is always complex and different characterization models can give different results. Some of the POCP results have been considered as high, which was particularly noticeable for PET. The POCP results have been calculated based on the emissions of VOC and NO_x by the POCP calculation method used in the study. The selected method is well described and can be justified.

After discussions and request in the review process including report structure, choice of datasets, naming of impact assessment methods, choice of impact assessment methods including material resource use without energy content, definition of the competing packaging systems, waste handling, effects of new calculations, calculation errors, corrections of graphs, new dataset and especially for bio-based PE, methods and calculation results for POCP, contents in the appendix, and editorial changes, satisfactory changes were made. However, it should be noted that glass' primary resources are not included in the analysis, but this will probably not affect the study's conclusions as the glass primary material components are not considered to be a rare commodity. In this case, glass bottles are not used for water distribution either.

The review panel has covered the entire product chain including upstream data, core processes, and downstream data. The review panel has covered the product specifications and the change of the material composition, the LCA product systems, the data gaps and cut offs, the methodology applied, the data used and assumptions made for the products/processes in the study, electricity production, and end-of-life treatment. The procedure for the calculations and selection of

studied products has also been covered. The Critical Review panel concludes that the interpretations reflect the limitations identified and the goal of the study.

The review process also includes minor editorial changes.

All remarks were accounted for in a satisfactory manner in the revised versions of the Update 2019 to the LCA report and LCA models.

The Critical Review panel can therefore inform that the LCA results presented in the study are based on consistent data and models, and there are no further issues or comments.

Due to the changes made in the entire LCA report by the Update 2019, the new updated report must now be considered as the current report and the previous report must therefore be replaced. However, the review report for the previous study is still valid for the parts that were not included in the Update 2019.

Review Statement

The undersigned reviewers confirm that the reviewed Update 2019 to the study "Comparative Life Cycle Assessment of Tetra Pak carton packages and alternative packaging systems for liquid food on the Nordic market" has been conducted according to and in consistency with the ISO standards 14040 and 14044 and has relevant data sources. The results from the study are in consistency with the steering documents identified under the abovementioned scope of this review.



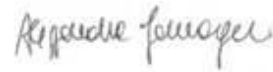
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