INSTITUT FÜR ENERGIE-
UND UMWELTFORSCHUNG
HEIDELBERG

Comparative Life Cycle Assessment of Tetra Recart packages and alternative packaging systems for shelf stable soup on the European market

Final Report

commissioned by Tetra Pak

Heidelberg, April 2021

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Abbreviations

ACE	Alliance for Beverage Cartons and the Environment
CED	Cumulative energy demand
CML	Centrum voor Milieukunde (Center of Environmental Science), Leiden University, Netherlands
COD	Chemical oxygen demand
CRD	Cumulative raw material demand
EAA	European Aluminium Association
EEA	European Environment Agency
EU27+2	European Union & Switzerland and Norway
EVOH	Ethylene vinyl alcohol
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (Brussels)
GWP	Global Warming Potential
HBEFA	Handbuch für Emissionsfaktoren (Handbook for Emission Factors)
ifeu	Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
HDPE	High density polyethylene
LPB	Liquid packaging board
MIR	Maximum Incremental Reactivity
MSWI	Municipal solid waste incineration
NMIR	Nitrogen-Maximum Incremental Reactivity
NMVOC	Non-methane volatile organic compounds
NO_X	Nitrogen oxides
ODP	Ozone Depletion Potential
pc	packs
PM2.5	Particulate matter with an aerodynamic diameter of 2.5 µm or smaller

PP	Polypropylene
PA	Polyamide
SBM	Stretch blow moulding
UBA	Umweltbundesamt (German Federal Environmental Agency)
UHT	Ultra-heat treatment
VOC	Volatile organic compounds
WMO	World Meteorological Organization

1 Goal and scope

1.1 Background and objectives

Tetra Recart® is the world's first retortable carton. Tetra Pak offers a complete packaging and retorting system for shelf stable food to food producing customers. With over 15 years on the market the value proposition to the entire value chain has been confirmed. Tetra Recart's environmental profile is one of the key sales arguments vs established competing retortable packaging type like cans, glass jars, aluminium trays and pouches.

Ifeu has supported Tetra Pak in doing Life Cycle Analysis (LCA) studies in Europe, most recently in Germany and Italy 2017, and in the ongoing European LCA. As Tetra Recart® wants to further grow in the soup category for 500 ml products in Europe where pouches are the main competitive packaging types, there is a need to complement the existing fact base with a new study.

The main objectives of the study will be:

- To provide knowledge of the environmental strengths and weaknesses of the Tetra Recart® retortable carton vs other packaging types in the canned soup segment.
- To demonstrate robustness in the results for Tetra Recart® vs competing packaging systems with sensitivity analysis.
- To provide quantitative data for Tetra Recart® Key Sales Arguments to be used in external communication

Reference time period for primary data will be 2020. All other data are intended to be as close as possible to this period.

The functional unit for this study will be the packaging and delivery of 1000 L packed soup to the point of sale.

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

The goal of the study is to conduct an LCA analysing the environmental performance of Tetra Pak's Tetra Recart® carton systems compared to alternative food packaging systems. Competing packaging systems on the regarded market include:

- Pouches

The analysed packaging systems are divided into the following food segments:

- Soups

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

(1) to provide knowledge of the environmental strengths and weaknesses of carton packaging systems in the described segment and market.

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

Further objectives are addressed through scenario variants:

(3) to provide knowledge regarding the environmental performance of carton packaging systems compared to competing packaging systems with increased recycling rates for carton packaging systems and competing packaging systems.

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

1.2 Organisation of the study

This study was commissioned by Tetra Pak in 2020. It is conducted by the Institute for Energy and Environmental Research Heidelberg gGmbH (ifeu).

The members of the project panel are:

- **Tetra Pak:** Göran Alm, Olof Persson, Erika Kloow
- **ifeu:** Samuel Schlecht, Frank Wellenreuther

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

1.3 Use of the study and target audience

The comparative results of this study are intended to be used by the commissioner (Tetra Pak). Further they shall serve for information purposes of Tetra Pak's customers, e.g. fillers and retail customers. The study and/or its results are therefore intended to be disclosed. According to the ISO standards on LCA [ISO 14040 and 14044 (2006)], this requires a critical review process undertaken by a critical review panel.

The members of the critical review panel are

- Dr. Martin Baitz (chair), Sphera Solutions GmbH, Germany
- Beverly Sauer, Franklin Associates (Eastern Research Group, Inc.), USA
- Dr. Jun Nakatani, University of Tokyo, Japan

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

1.4 Functional unit

The function examined in this LCA study is the packaging of shelf stable food for retail. The functional unit for this study is the provision of packaging volume for 1000 L of shelf stable food at the point of sale.

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

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

1.5 System boundaries

The study is designed as a 'cradle-to-grave' LCA without the use phase, in other words it includes the extraction and production of raw materials, converting processes, all transports and the final disposal or recycling of the packaging system.

In general, the study covers the following steps:

- production, converting, collection, sorting, recycling and final disposal of the primary base materials used in the primary packaging elements from the studied systems including closures and in one case spoons as well as related transports.
- production, converting, collection, sorting, recycling and final disposal of primary packaging elements and related transports.
- production, recycling, collection, sorting, and final disposal of transport packaging (stretch foil, pallets, cardboard trays)
- production and disposal of process chemicals, as far as not excluded by the cut-off criteria (see below).
- transports of packaging material from producers to converters and fillers.
- filling and retorting processes, which are fully assigned to the packaging system.
- transport from fillers to potential central warehouses and final distribution to the point of sale.

Not included are:

- the production and disposal of the infrastructure (machines, transport media, roads, etc.) and their maintenance (spare parts, heating of production halls) as no significant impact is expected. To determine if infrastructure can be excluded the authors apply two criteria by Reinout Heijungs [Heijungs et al. 1992] and Rolf Frischknecht [Frischknecht et al. 2007]: Capital goods should be included if the costs of maintenance and depreciation are a substantial part of the product and if environmental hot spots within the supply chain can be identified. Considering relevant information about the supply chain from producers and retailers both criteria are considered to remain unfulfilled. An inclusion of capital goods might also lead to data asymmetries as data on infrastructure is not available for many production data sets.

- production of food and its transport to fillers as no relevant differences between the systems under examination are to be expected
- distribution of food from the filler to the point-of-sale (distribution of packages is included).
- environmental effects from accidents like breakages during transportation.
- losses of food at different points in the supply and consumption chain which might occur for instance in the filling process, during handling and storage, etc. as they are considered to be roughly the same for all examined packaging systems. Significant differences in the amount of food between the regarded packaging systems might be conceivable only if non-intended uses or product treatments are considered as for example in regard to different breakability of packages or potentially different amount of residues left in an emptied package due to the design of the package/closure. Further possible losses are directly related to the handling of the consumer in the use phase, which is not part of this study as handling behaviours are very different and difficult to assess. Some data about food losses in households is available, these losses though cannot be allocated to the different food packaging systems. Further no data is available for losses at the point of sale. Therefore, possible food loss differences are not quantifiable. In consequence, a sensitivity analysis regarding food losses would be highly speculative and is not part of this study. This is indeed not only true for the availability of reliable data, but also uncertainties in inventory modelling methodology of regular and accidental processes and the allocation of potential food waste treatment aspects.
- activities at the points of sale, as no relevant differences between the systems under examination are to be expected.
- 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 Tetra Recart® carton (Figure 1) and pouch (Figure 2).

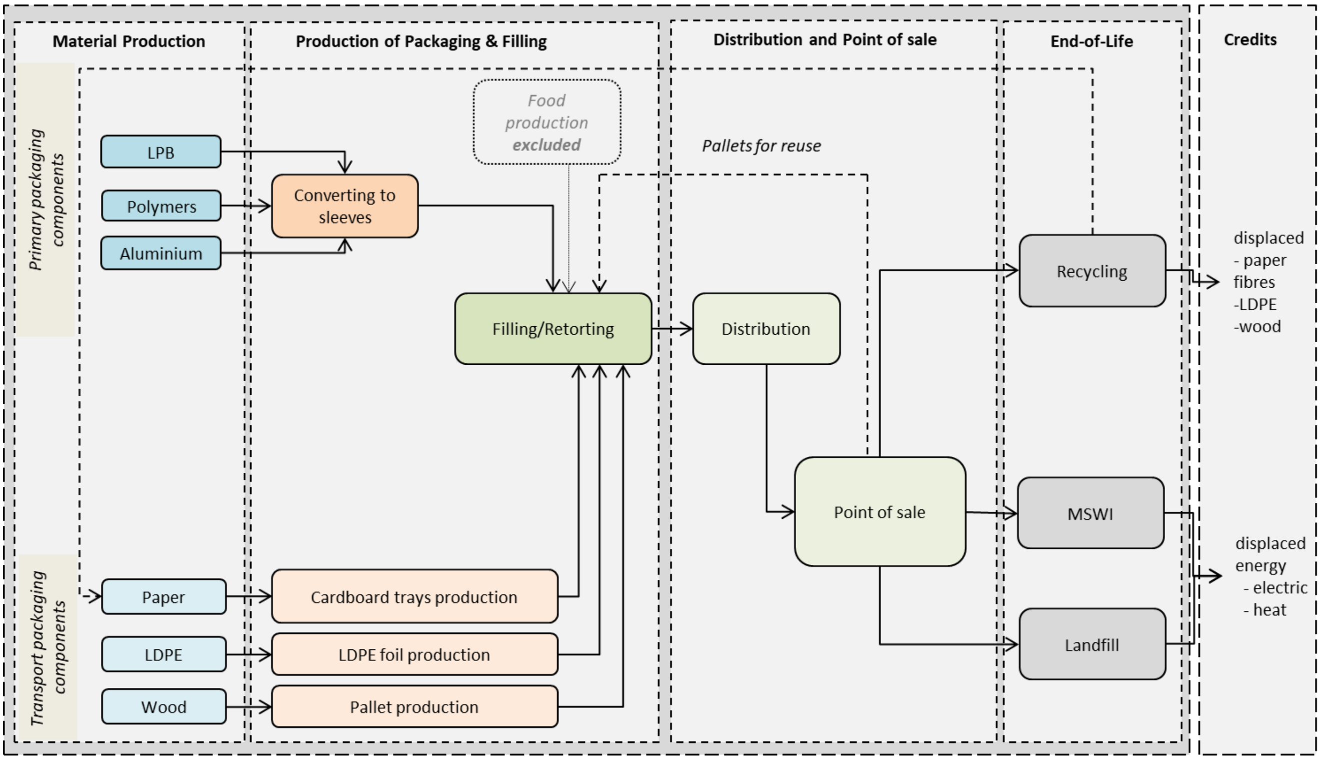

Figure 1: System boundaries of Tetra Recart® carton

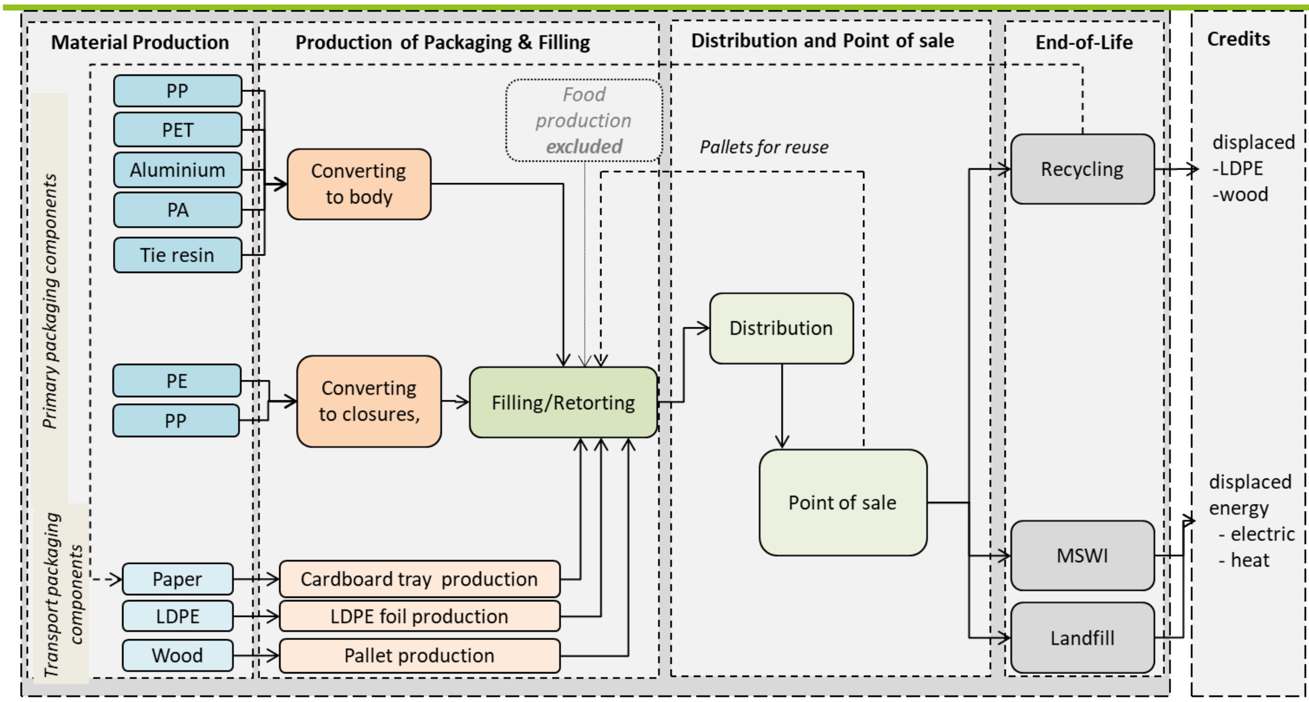

Figure 2: System boundaries of pouch

Cut-off criteria

In order to ensure the symmetry of the packaging systems to be examined and in order to maintain the study within a feasible scope, a limitation on the detail in system modelling is necessary. So-called cut-off criteria are used for that purpose. According to ISO standard [ISO 14044], cut-off criteria shall consider mass, energy or environmental significance. Regarding mass-related cut-off, prechains from preceding systems with an input material share of less than 1% of the total mass input of a considered process were excluded from the present study. However, total cut-off is not to surpass 5% of input materials as referred to the functional unit.

1.6 Data gathering and data quality

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

Geographic scope

In terms of the geographic scope, the LCA study focuses on the production, distribution and disposal of the packaging systems in Europe. In case of Tetra Recart® cartons a certain share of the raw material production and the converting takes place in specific countries. For these, country-specific data is used. In other cases mostly European average data are used, as Tetra Pak sources its materials mainly from Europe. Examples are the liquid packaging board production process and converting process (country-specific) and the production of aluminium foil (available only as European average). In case of alternative packaging systems processes are modelled with the corresponding European data. The following tables show an overview of the locations for the processes for each type of packaging system.

Table 1: Locations for Tetra Recart® cartons

	Europe
materials	
LPB	Sweden
plastics	Europe
aluminium	Europe
converting	Hungary
filling/retorting	Europe
end of life	Europe

Table 2: Locations for pouches

	Europe
materials	
plastics	Europe
aluminium	Europe
converting	Europe
filling/retorting	Europe
end of life	Europe

Time scope

The packaging specifications listed in section 2 as well as the market situation for the choice packaging systems refers to 2020. Therefore, the reference time period for the comparison of packaging systems is 2020. Where no figures are available for these years, the used data shall be as up-to-date as possible. Particularly with regard to data on end-of-life processes of the examined packages, the most current information available is used to correctly represent the recent changes in this area.

Most of the applied data refers to the period between 1997 and 2020 (see Table 15 in section 3). Where only old datasets are available, the data has been checked for its representativeness. The datasets for transportation, energy generation and waste treatment processes (except recycling process for Tetra Recart® cartons) are taken from ifeu's internal database in the most recent version. The data for plastic production originates from the Plastics Europe datasets and refer to different years, depending on material and year of publication.

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

Technical reference

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

Completeness

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

Table 3: The summary of the completeness check according to [ISO 14044]

Life cycle steps	Tetra Recart® cartons	Pouches	Complete?	Representative?
x: inventory data for all processes available				
Base material production	x	x	yes	yes
Production of packaging (converting)	x	x	yes	yes
Filling	x	x	yes	yes
Distribution	x	x	yes	yes
End of life				
Recycling processes	x	x	yes	yes
MSWI	x	x	yes	yes
Landfill	x	x	yes	yes
Credits	x	x	yes	yes
Transportation of materials to the single production steps	x	x	yes	yes
Life Cycle Impact Assessment				
Climate Change	x	x	yes	yes
Acidification	x	x	yes	yes
Photo-Oxidant Formation	x	x	yes	yes
Ozone Depletion Potential	x	x	yes	yes
Terrestrial Eutrophication	x	x	yes	yes
Aquatic Eutrophication	x	x	yes	yes
Particulate Matter	x	x	yes	yes
Use of Nature	x	x	yes	yes

Consistency

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

Sources of data

Process data for base material production and converting were either collected in cooperation with the industry or taken from literature and the ifeu database. Ifeu's internal database includes data either collected in cooperation with industry or is based on literature. The database is continuously updated. Background processes such as energy generation, transportation, MSWI and landfill were taken from the most recent version of it. All data sources are summarized in Table 15 and described in section 3.

Precision and uncertainty

For studies to be used in comparative assertions and intended to be disclosed to the public, ISO 14044 asks for an analysis of results for sensitivity and uncertainty. Uncertainties of datasets and chosen parameters are often difficult to determine by mathematically sound statistical methods. Hence, for the calculation of probability distributions of LCA results, statistical methods are usually not applicable or of limited validity. To define the significance of differences of results, an estimated significance threshold of 10 % is chosen as pragmatic approach. This can be considered a common practice for LCA studies comparing different product systems [Kupfer et al. 2017]. This means differences ≤ 10 % are considered as insignificant. Based on the contribution analyses in the sections 'Description and interpretation' the dominant life cycle steps are discussed with their underlying data in the following tables:

Table 4: Data quality discussion Tetra Recart®

Packaging type	Life cycle steps with considerable impact shares	Impact categories	data	data quality
Tetra Recart®	filling and retorting	all except AE and UN	[Tetra Pak 2020]	primary data up to date high quality
	LPB	all except CC, OD	[ACE 2012]	primary data older dataset high quality
	aluminium foil	AC and PM	[EEA 2013], [EEA 2018]	secondary data up to date high quality
	plastics for Tetra Recart® carton	all except UN, especially OD	PP [PlasticsEurope 2014a]	secondary data up to date high quality
			PA [PlasticsEurope 2005a]	secondary data older dataset high quality
	recycling and disposal (MSWI and landfill)	CC	[ifeu database]	secondary data up to date high quality

AC: Acidification, AE: Aquatic Eutrophication, CC: Climate Change, OD: Ozone Depletion, PM: Particulate Matter, PO: Photo-Oxidant Formation, TE: Terrestrial Eutrophication, UN: Use of Nature

Table 5: Data quality discussion pouches

Packaging type	Life cycle steps with considerable impact shares	Impact categories	data	data quality
pouches	filling and retorting	all except AE and UN	[Tetra Pak 2020]	primary data up to date high quality
	aluminium foil for body	AC and PM	[EEA 2013], [EEA 2018]	secondary data up to date high quality
	plastics for body	all except UN especially OD	[PlasticsEurope 2014a], [PlasticsEurope 2014b], [PlasticsEurope 2017]	secondary data up to date high quality
			PA: PlasticsEurope 2014a]	secondary data older dataset unknown quality
	transport packaging	UN, AE	[FEFCO 2018]	secondary data up to date high quality
	recycling and disposal (MSWI)	CC	[ifeu database]	secondary data up to date high quality

AC: Acidification, AE: Aquatic Eutrophication, CC: Climate Change, OD: Ozone Depletion, PM: Particulate Matter, PO: Photo-Oxidant Formation, TE: Terrestrial Eutrophication, UN: Use of Nature

1.7 Methodological aspects

1.7.1 Allocation

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

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

Both approaches are further explained in the subsequent sections.

Process-related allocation

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

Multi-input processes

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

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 food are excluded. The allocation between package and filling goods is based on mass criterion. This allocation is applied as the functional unit of the study defines a fixed amount of food through all scenarios. Impacts related to transporting the food itself would be the same in all scenarios. Therefore they don't need to be included in this comparative study of food packaging systems.

System-related allocation

System-related allocation is applied in this study regarding open loop recycling and recovery processes. Recycling refers to material recycling, whereas recovery refers to thermal recovery for example in MSWI with energy recovery or cement kilns. System-related allocation is applied to both, recycling and recovery in the end of life of the regarded system and processes regarding the use of recycled materials by the regarded system. System-related allocation is not applied regarding disposal processes like landfills with minor energy recovery possibilities. Figure 3 illustrates the general allocation approach used for uncoupled systems and systems which are coupled through recycling. In Figure 3 (upper graph) in both, 'system A' and 'system B', a virgin material (e.g. polymer) is produced, converted into a product which is used and finally disposed. A virgin material in this case is to be understood as a material without recycled content. A different situation is shown in the lower graph of Figure 3. Here product A is recovered after use and supplied as a raw material to 'system B' avoiding thus the environmental burdens related to the production ('MP-B') of the virgin materials, e.g. polymer and the disposal of product A ('Dis-A'). In order to do the allocation consistently, besides the virgin material production ('MP-A') already mentioned above and the disposal of product B ('Dis-B'), also the recovery process 'Rec' has to be taken into consideration.

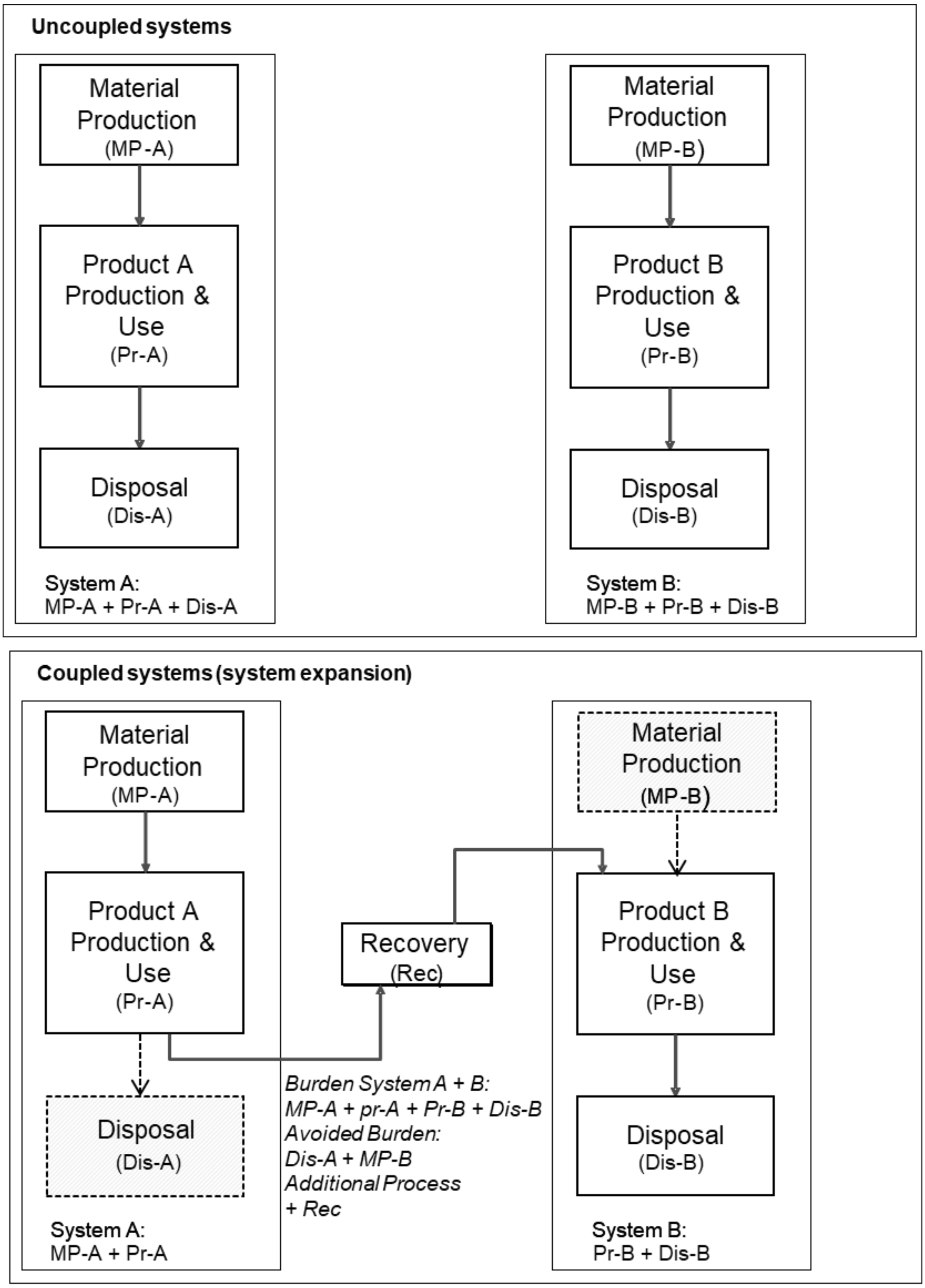

Figure 3: Additional system benefit/burden through recycling (schematic flow chart)[1]

[1] shaded boxes are avoided processes

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

System allocation approaches used in this study

The approach chosen for system-related allocation is illustrated in Figure 4, Figure 5 and Figure 6. All graphs show two example product systems, referred to as product 'system A' and 'product system B'. 'System A' shall represent systems under study in this LCA in the case if material is provided for recycling or recovery. 'System B' shall represent systems under study in this LCA in the case recycled materials are used. The recycled content can be fed by a preceding system (open loop) or by the regarded system (closed loop). System allocation applies only for the open loop share of recycled content provided by preceding systems. In case of all regarded base scenarios which include recycled content (glass jars, aluminium can and tray, steel can) the recycled content is fed by closed loop material.

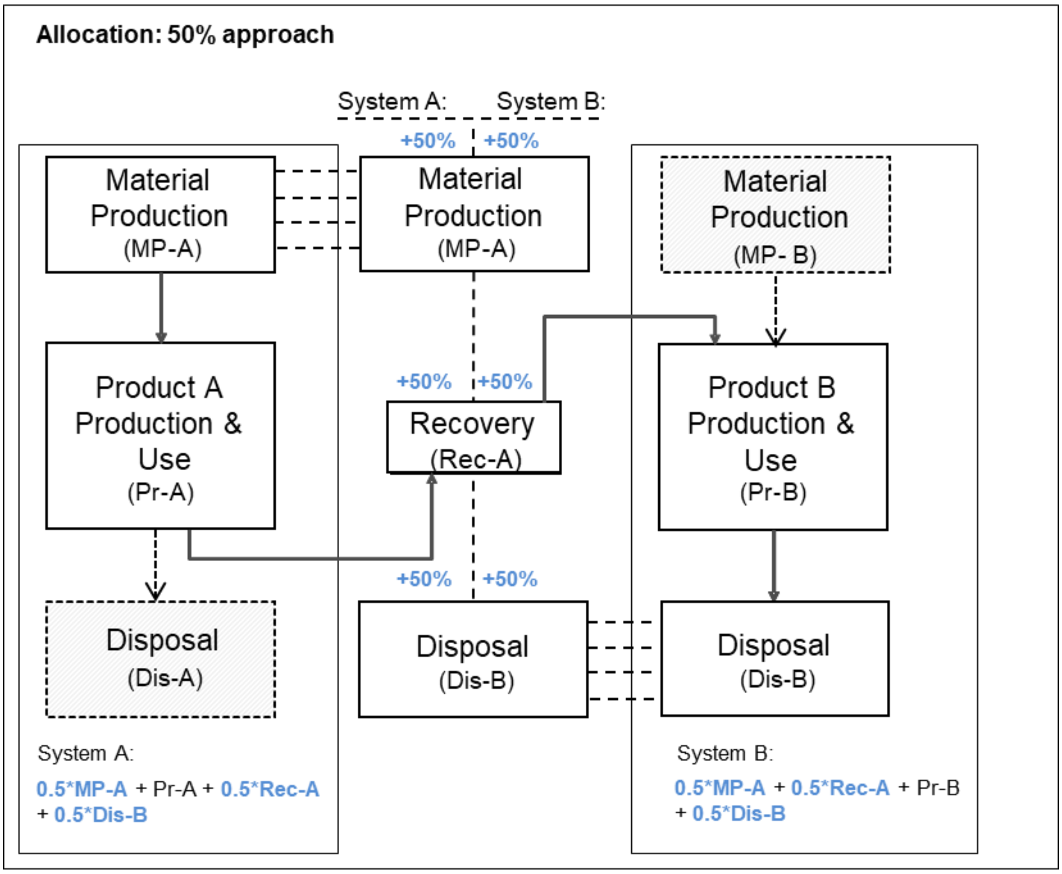

Figure 4: Principles of 50% allocation (schematic flow chart)[1]

[1] shaded boxes are avoided processes

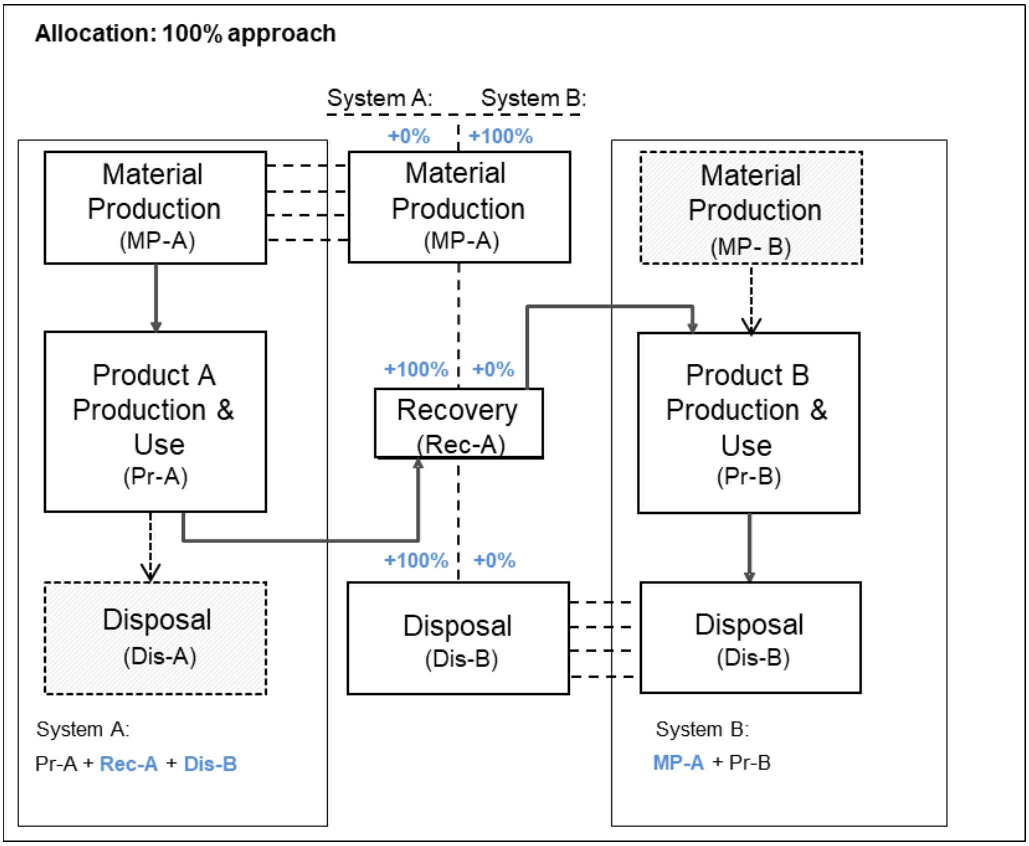

Figure 5: Principles of 100% allocation (schematic flow chart) [1]

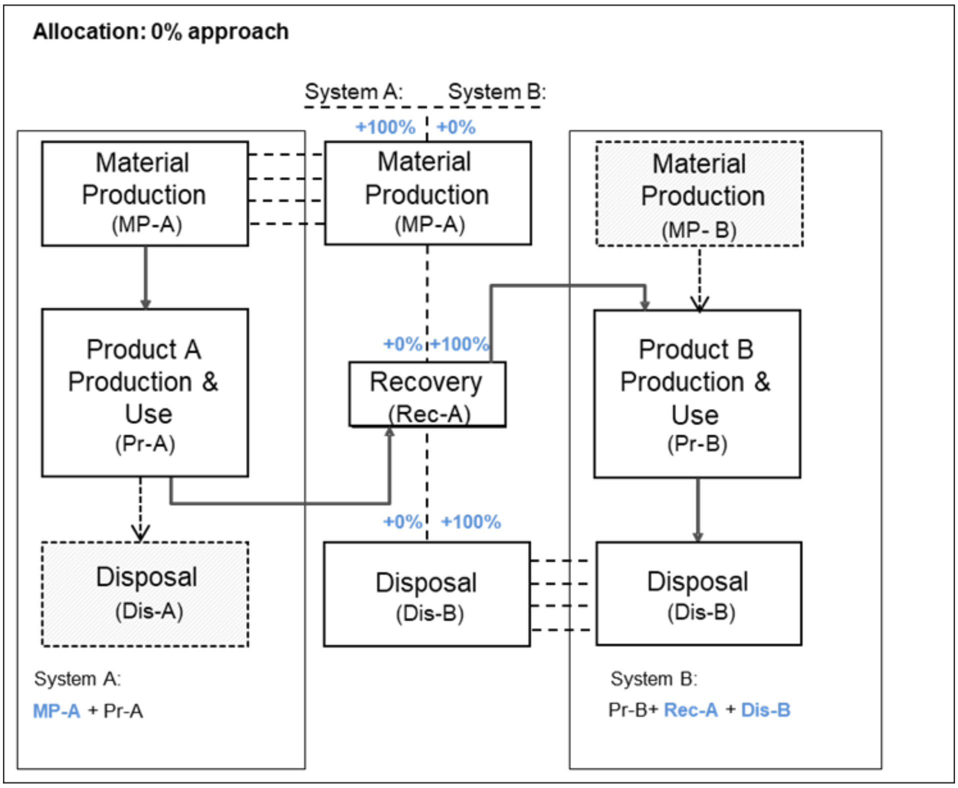

Figure 6: Principles of 0% allocation (schematic flow chart) [1]

[1] shaded boxes are avoided processes
[2] shaded boxes are avoided processes

Allocation with the 50% method (Figure 4)

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

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

The approach of sharing the burdens and benefit from both, providing material for recycling and recovery, as well as using recycled material, follows the goal of encouraging the increase in recyclability as well as the use of recycled material. These goals are aligned with §21 of the German packaging law [VerpackG 2017].

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

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

Allocation with the 100% method (Figure 5)

In this method, the principal rule is applied that 'system A' gets all benefits for displacing the virgin material and the involved production process 'MP-B'. At the same time, all burdens for producing the secondary raw material via 'Rec-A' are assigned to 'system A'. The same is valid for thermal recovery. All benefits and burdens for displacing energy production are allocated to 'system A'. In addition, also the burdens that are generated by waste treatment of 'product B' in 'Dis-B' is charged to 'system A' as after the material is used in System B, System A gave up the control but not responsibility for putting the material in the market. The the waste treatment of 'product A' is avoided and thus charged neither to 'system A' nor to 'system B'.

If open loop recycled material, provided by a preceding system, recycled material is used in the regarded system, the perspective of 'system B' applies. The burdens associated with the production process 'MP-A' are then allocated to 'System B' (otherwise the mass balance rule would be violated). However, 'system B' is not charged with burdens related

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[1] shaded boxes are avoided processes

to 'Rec' as the burdens are already accounted for in 'system A'. At the same time, 'Dis-B' is not charged to 'system B' (again a requirement of the mass balance rule), as it is already assigned to 'system A'. As for all regarded base scenarios which include recycled content (glass jars, aluminium can and tray, steel can) the recycled content is fed by closed loop material, this case does not apply in this study.

The application of the allocation 100% is considered as a conservative approach from the view of the Tetra Recart® carton. It means that a comparatively unfavourable case for the Tetra Recart® cartons is chosen. The pouch benefits 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 pouches.

Allocation with the 0% method (Figure 6)

In this method, the principal rule is applied that 'system A' gets no benefits for displacing the virgin material and the involved production process 'MP-B'. At the same time, also no burdens for producing the secondary raw material via 'Rec-A' are assigned to 'system A'. The same is valid for thermal recovery. All benefits and burdens for displacing energy production are allocated to 'system B'. In addition, also the burdens that are generated by waste treatment of 'product B' in 'Dis-B' is charged to 'system B', whereas the waste treatment of 'product A' is avoided and thus charged neither to 'system A' nor to 'system B'. This method is also known as a cut of approach as all burdens and credits from recycling and recovery processes in the end of life are cut off from the regarded system.

Following the ISO standard's recommendation on subjective choices, the 50% and 100% and 0 % allocation methods are applied equally in this study. Conclusions in terms of comparing results between packaging systems are only drawn if they apply to all three allocation methods.

General notes regarding Figure 3 to Figure 6

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

- to illustrate the difference between the 50% allocation method and the 100% allocation method
- to show which processes are allocated:
  - primary material production
  - recycling and recovery processes
  - waste treatment of final residues

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

The allocation of final waste treatment is consistent with UBA LCA methodology [UBA 2000] and [UBA 2016] and additionally this approach – beyond the UBA methodology – is also in accordance with [ISO 14044].
For simplification some aspects are not explicitly documented in the mentioned graphs, among them the following:

- Material losses occur in both 'systems A and B', but are not shown in the graphs. These losses are of course taken into account in the calculations, their disposal is included within the respective systems.
- Hence, not all material flows from 'system A' are passed on to 'system B', as the simplified material flow graphs may imply. Consequently only the effectively recycled and recovered material's life cycle steps are allocated between 'systems A and B'.
- The graphs do not show the individual process steps relevant for the waste material flow out of 'packaging system A', which is sorted as residual waste, including the respective final waste treatment.
- For simplification, a substitution factor of 1 underlies the graphs. However, in the real calculations smaller values are used where appropriate. For example if a material's properties after recycling are different from those of the primary material it replaces, this translates to a loss in material quality. A substitution factor < 1 accounts for such effects. For further details regarding substitution factors please see subsection 'Application of allocation rules'.

Application of allocation rules

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

The substitution factors used in the current LCA study to calculate the credits for recycled materials provided for consecutive (down-stream) uses are based on expert judgments from German waste sorting operator "Der Grüne Punkt – Duales System Deutschland GmbH" from the year 2003 [DSD 2003].

- Paper fibres

  - from LPB (carton-based primary packaging): 0.9
  - in cardboard trays (secondary packaging): 0.9

1.7.2 Biogenic carbon

Renewable materials like paper fibres or plant-based plastics originate from renewable biomass that absorbs carbon from the air. The growth of biomass reduces the amount of CO_2 in the atmosphere. In this study, the fixation of CO_2 by the plants is referred as CO_2

uptake and the (re-)emission of CO_2 at the material's end of life is referred as CO_2 biogenic.

Application and allocation

At the impact assessment level, it must be decided how to model and calculate the uptake and emissions of biogenic CO_2. In the present study, the non-fossil CO_2 has been included at two points in the model, its uptake during the plant growth phase attributed with negative GWP values and the corresponding re-emissions at end of life with positive ones. In this study biogenic CO_2 is treated in the same way as other resources and emissions and is therefore subject to the same allocation rules as other resources and emissions. According to §21 of the German packaging law [VerpackG 2017] the following practices in packaging production shall be promoted:

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

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

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

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

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

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

The authors of this study acknowledge that with the application of this convention only the producers of products containing primary biogenic materials benefit. This is considered appropriate as these producers are responsible for sourcing renewable materials in the first place. Producers of products which merely contain biogenic materials sourced from recycling processes would not be benefited. As no primary packaging systems, which contain recycled biogenic materials are analysed in this study, this approach of not considering CO_2 uptake in credits is seen suitable within this study. Corrugated cardboard for secondary packaging includes recycled biogenic material. As corrugated cardboard is recycled in a closed loop, the applied convention does not affect the biogenic recycled material in corrugated cardboard. This convention does also comply with ISO 14040/14044 as the mass balance of all inputs and outputs regarding biogenic CO_2 of 'system A' and 'system B' together stays the same.

As described in section 1.7.1 system-related allocation is applied in this study for thermal recovery processes like MSWI with energy recovery and incineration in cement kilns. Therefore system-related allocation applies for the emissions of CO_2 reg. from thermal recovery of biogenic materials. In case of allocation 50%, half of the CO_2 reg. emissions are attributed to the examined system and half of the biogenic CO_2 (CO_2 reg.) emissions are attributed to the following system, for example the MSWI plants with thermal recovery. In case biogenic materials are disposed on landfills system-related allocation does not apply. In contrast to MSWI with energy recovery landfill gas recovery leads to only small amounts of produced energy. Therefore landfilling is not regarded as a recovery process with a following system. All burdens from landfill including CO2 reg. emissions and methane emissions caused by the degradation of biogenic material as well as credits from landfill gas recovery are accounted to the regarded system.

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

In case of applying allocation 100% for recovery processes all of the CO_2 reg. emissions as well as the CO_2 uptake are attributed to the regarded system. Therefore, in this case the extra benefit for 'Climate Change' results, packaging systems with primary biogenic materials receive by only getting allocated 50% or 0% of the CO_2 reg. emissions, is gone.

As these decisions and conventions applied in this study are partly based on political reasons, it is especially important to consider the results of the 100% allocation approach equally alongside those of the 50% and 0% allocation approaches. All conclusions in this study will always be based on the outcomes of all assessments, the 0% allocation, 50% allocation and 100% allocation approach.

1.8 Environmental Impact Assessment

The environmental impact assessment is intended to increase the understanding of the potential environmental impacts for a product system throughout the whole life cycle [ISO 14040 and 14044].

1.8.1 Mandatory elements

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

The selection of the impact categories is based both on the current practice in LCA and the applicability of as less as uncertain characterisation models also with regard to the completeness and availability of the inventory data. The choice is also based on the German Federal Environmental Agency (UBA) approach 2016 [UBA 2016], which is fully consistent with the requirements of ISO 14040 and ISO 14044. However, it is nearly impossible to carry out an assessment in such a high level of detail, that all environmental issues are covered. A broad examination of as many environmental issues as possible is highly dependent on the quality of the available inventory datasets and of the scientific acceptance of the certain assessment methods.

The description of the different inventory categories and their indicators is based on the terminology by [ISO 14044]. It has to be noted that the impact categories, represent the environmental issues of concern, to which life cycle inventory analysis results per functional unit are assigned, but do not reflect actual environmental damages. The results of the impact categories are expressed by category indicators, which represent potential environmental impacts per functional unit. The category indicator results also do not quantify an actual environmental damage. Table 6 gives one example how the terms are applied in this study.

Table 6: 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 7 includes an overview of elementary flows per category.

Table 7: Examples of elementary flows and their classification into impact categories

Impact categories	Elementary Flows								Unit
Climate Change	CO_2*	CH_4**	N_2O	$C_2F_2H_4$	CF_4	CCl_4	C_2F_6	R22	kg CO_2-e
Stratospheric Ozone Depletion	CFC-11	N_2O	HBFC-123	HCFC-22	Halon-1211	Methyl Bromide	Methyl Chloride	Tetrachlor-methane	kg CFC-11-e
Photo-Oxidant Formation	CH_4	NMVOC	Benzene	Formal-dehyde	Ethyl acetate	VOC	TOC	Ethanol	kg O_3-e
Acidification	NOx	NH_3	SO_2	TRS***	HCl	H_2S	HF		kg SO_2-e
Terrestrial Eutrophication	NOx	NH_3							kg PO_4-e
Aquatic Eutrophication	COD	N	NH_4+	NO_3-	NO_2-	P			kg PO_4-e
Particulate Matter	PM2.5	SO_2	NOX	NH_3	NMVOC				kg PM2.5-e

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

Climate change

Climate Change addresses the impact of anthropogenic emissions on the radiative forcing of the atmosphere. Greenhouse gas emissions enhance the radiative forcing, resulting in an increase of the earth's temperature. The characterisation factors applied here are based on the category indicator Global Warming Potential (GWP) for a 100-year time horizon [IPCC 2013]. In reference to the functional unit (fu), the category indicator results, GWP results, are expressed as kg CO_2-e per functional unit.

Note on biogenic carbon: At the impact assessment level, it must be decided how to model and calculate CO_2-based GWP. In the present study the non-fossil CO_2 has been included at two points in the model, its uptake during the plant growth phase attributed with negative GWP values and the corresponding re-emissions at end of life with positive ones. For more details see section 1.7.2.

Note on direct land use change (dLUC): Impacts on Climate Change resulting from dLUC are not included as no change from forest area to non-forest area is taking place. Greenhouse gas emissions or removals from forest to forest do not apply as there is no data available for different management systems.

Stratospheric Ozone Depletion

In this impact category the anthropogenic impact on the earth's atmosphere, which leads to the decomposition of naturally present ozone molecules, thus disturbing the molecular equilibrium in the stratosphere is addressed. The underlying chemical reactions are very slow processes and the actual impact, often referred to in a simplified way as the 'ozone hole', takes place only with considerable delay of several years after emission. The consequence of this disequilibrium is that an increased amount of UV-B radiation reaches the earth's surface, where it can cause damage to certain natural resources or human health. In this study, the ozone depletion potential (ODP) compiled by the World Meteorological Organisation (WMO) in 2011 [WMO 2011] is used as category indicator. In reference to the functional unit, the unit for Ozone Depletion Potential is kg CFC-11-e/fu.

Photo-Oxidant Formation

Photo-oxidant formation, also known as summer smog, is the photochemical creation of reactive substances (mainly ozone), which affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides and volatile organic compounds in the presence of sunlight.

In this study, 'Maximum Incremental Reactivity'(MIR) developed in the US by William P. L. Carter is applied as category indicator for the impact category photo-oxidant formation. MIRs expressed as kg O_3-equivalents are used in several reactivity-based VOC (Volatile Organic Compounds) regulations by the California Air Resources Board (CARB 1993, 2000). The recent approach of William P. L. Carter includes characterisation factors for individual VOC, unspecified VOC and NOx. The 'Nitrogen-Maximum Incremental Reactivity'(NMIR) for NOx is introduced for the first time in 2008 (Carter 2008). The MIRs and NMIRs are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NOx inputs. The recent factors applied in this study were published by [Carter 2010]. According to [Carter 2008], "MIR values may also be appropriate to quantify relative ozone impacts of VOCs for life cycle assessment analyses as well, particularly if the objective is to assess the maximum adverse impacts of the emissions of the compounds involved." The results reflect the potential where VOC or NOx reductions are the most effective for reducing ozone.

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

- Provision of characterisation factors for more than 1100 individual VOC, VOC mixtures, nitrogen oxides and nitrogen dioxides
- Consistent modelling of potential impacts for VOC and NOx
- Considering of the maximum formation potential by inclusion of most supporting background concentrations of the gas mixture and climatic conditions. This is in accordance with the precautionary principle.

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

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

Acidification

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

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

The method by [Heijungs et al. 1992] is, in contrast to methods using European dispersion models, applicable for emissions outside Europe. The authors of the method using accumulated exceedance note that “the current situation does not allow one to use these advanced characterisation methods, such as the AE method, outside of Europe due to a lack of suitable atmospheric dispersion models and/or measures of ecosystem sensitivity” [Posch et al. 2008].

The unit for the acidification potential is kg SO_2-e/functional unit (fu).

Eutrophication and oxygen-depletion

Eutrophication means the excessive supply of nutrients and can apply to both surface waters and soils. As these two different media are affected in very different ways, a distinction is made between water-eutrophication and soil-eutrophication[1]:

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

Compounds containing nitrogen and phosphorus are among the most eutrophicating elements. The eutrophication of surface waters also causes oxygen-depletion. A measure of the possible perturbation of the oxygen levels is given by the Chemical Oxygen Demand (COD). In order to quantify the magnitude of this undesired supply of nutrients and oxygen depletion substances, the eutrophication potential by [Heijungs et al. 1992, CML 2002] category was chosen as impact indicator.

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

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

Terrestrial Eutrophication (including eutrophication of oligotrophic systems)

Category indicator: terrestrial eutrophication potential

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

Emissions to compartment: emissions to air

Aquatic Eutrophication

Category indicator: aquatic eutrophication potential

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

Emissions to compartment: emissions to water

Particulate matter

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

The characterisation models suggested by [ReCiPe 2008] and [JRC 2011] calculate intake fractions based on population densities. This means that emissions transported to rural areas are weighted lower than transported to urban areas. These approaches contradict the idea that all humans independent of their residence should be protected against potential impacts. Therefore, not the intake potential, but the formation potential is applied for the impact category particulate matter. In reference to the functional unit, the unit for Particulate Matter is kg PM 2.5-e/fu.

Note on human toxicity: The potential impacts of particulate matter on human health are part of the often addressed impact category "human toxicity". But, a generally accepted approach covering the whole range of toxicological concerns is not available. The inclusion of particulate matter in USEtox is desired but not existent. In general, LCA results on toxicity are often unreliable, mainly due to incomplete inventories, and also due to incomplete impact assessment methods and uncertainties in the characterisation factors. None of the available methods is clearly better than the others, although there is a slight preference for the consensus model USEtox. Based on comparisons among the different methods, the USEtox authors employ following residual errors (RE) related to the square geometric standard deviation (GSD^2):

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

Figure 7: Model uncertainty estimates for USEtox characterisation factors (reference: [Rosenbaum et al. 2008])

To define the borders of the 95% confidence interval, the mean value of each substance would have to be divided and respectively multiplied by the GSD^2. To draw comparative conclusions based on the existing characterisation models for toxicity categories is therefore not possible.

Impact categories related to the use/consumption of resources

Use of nature

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

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

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

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

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

The used inventory data for paper production have been determined by Tiedemann (2000). The classification of forest is shown in Table 8.

To address 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 -e* 1a) based on the hemeroby concept by [Fehrenbach et al. 2015]. The DNP is a midpoint metric, focussing on the occupation impact. In reference to the functional unit (fu), the unit for use of nature is m^2-e*1a/fu.

Table 8: Examples of use of nature and their classification into hemeroby categories

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

Raw materials

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

Even the complex models which refer to statistics on stock reserves do not cover all resources especially biotic ones. Furthermore, potential impacts on the environment are not addressed by the available LCIA models as required by ISO 14044. The abiotic resource depletion (ADP) approach of [CML 2002] based on parameters on ultimate reserves and extraction rates is not applied in this study. This model considers the scarcity of materials as a function of the natural reserve of the resource in connection with the annual extraction rate. The natural reserve of raw materials is based on ultimate reserves, i.e. on concentrations of elements and fossil carbon in the Earth's crust. This approach is not seen appropriate as resources like sulphur are not extracted from the nature but are produced as side products from processes in the technosphere.

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 (016] is still under development. Characterisation factors are not yet available for all materials to be considered.

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

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

Additional categories at the inventory level

Inventory level categories differ from impact categories to the extent that no characterisation step using characterisation factors is used for assessment.

Water scarcity

Due to the growing water demand, increased water scarcity in many areas and degradation of water quality, water as a scarce natural resource has become increasingly central to the global debate on sustainable development. This drives the need for a better understanding of water related impacts as a basis for improved water management at local, regional, national and global levels (ISO 14046). To ensure consistency in assessing the so called water footprint ISO 14046 was published in 2014. It provides guidance in principles and requirements to assess water related impacts based on life cycle assessment (according to ISO 14044).

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

According to ISO 14046, the consideration of spatial water scarcity is mandatory to assess the related environmental impacts of the water consumption. Water consumption occurs due to evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea (ISO 14046). Thus information on the specific geographic location and quantity of water withdrawal and release is requisite.

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

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

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.

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

Table 9: Examples of elementary flows and their classification into inventory level categories

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

1.8.2 Optional elements

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

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

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

2 Packaging systems and scenarios

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

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

2.1 Selection of packaging systems

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

The choice of Tetra Recart® cartons has been made by Tetra Pak based on the 500ml Tetra Recart. This carton is examined for the packaging of soup on the European market. For this segment on the regarded market typical alternative packaging systems have been chosen by Tetra Pak. For the market and the segment included in the study, the selection of competitive packaging systems to be benchmarked with the Tetra Recart® 500 mL was based on consumption data from Euromonitor Passport database and Mintel, where the top brands for each segment, market and package sizes similar to the Tetra Recart® 500 mL and packaging systems used to fill the products were mapped out.

As an addition to the mapping out process, complementary discussions with the Tetra Pak Market Company and/or Cluster function responsible for the market in the study have taken place, with the purpose to agree on which brands and packaging systems to be included in the study.

The following tables show which Tetra Recart® cartons are compared with the selected competing systems. The comparison will be conducted as follows:

- Only packaging systems in the same segment and geographical scope are compared to each other

Table 10: List of Tetra Recart® cartons in segment **soup,** and corresponding competing packaging systems

Carton based packaging systems		chilled (C) / ambient (A)	Geographic scope	Competing packaging systems		chilled (C) / ambient (A)	Geographic scope
Tetra Recart Tray 2x6 500 ml		A	Europe	Pouch 5 570 ml		A	Europe

2.2 Packaging specifications

Specifications of Tetra Recart® carton packaging systems are listed in Table 11 and were provided by Tetra Pak. In Tetra Pak's internal database typical specifications of all primary packages sold are registered. The specifications of individual packages of one single carton system may vary to a small degree over different production batches or production sites. To get the final specifications Tetra Recart® carton type the exact specifications of different batches were averaged taking into consideration the production volumes of each production batch. For confidentially in case of the polymers used in the Tetra Recart® carton systems no differentiations to specific polymers are shown in the tables. The calculations are calculated with the specific shares of each polymer used. In case the study is critically reviewed, these specific shares are disclosed to the critical review panel.

Data on secondary and tertiary packaging for Tetra Recart® cartons was also provided by Tetra Pak from its internal packaging system model. The data is periodically updated and the most recent data of 2020 is used in this LCA.

Specifications of the competing packaging type that has been identified as relevant in the examined segment are listed in Table 12. Specifications of primary packing were obtained by identifying the different materials and their weights per packaging systems. The pouch was analysed in a laboratory by Norner AS. Specifications of secondary packaging were identified by ifeu by analysing one sample for each packaging system. Tertiary packaging specifications and the pallet configurations was calculated based on the dimensions of secondary packaging systems with the online tool onpallet.com[1].

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

[1] https://www.onpallet.com/

2.2.1 Specifications of Tetra Recart® carton systems

Table 11: Packaging specifications for regarded carton systems for the *packaging of soup*

		Soup
	Unit	Tetra Recart Tray 2x6
volume	ml	500
geographic Scope	-	Europe
primary packaging (sum)[1]	g	**20.5**
primary packaging (per FU)	g	**41000**
composite material (sleeve)	g	**20.5**
- liquid packaging board	g	14.6
- polymer	g	5.0
- aluminium	g	0.9
secondary packaging (sum)[2]	g	**70.0**
secondary packaging (per FU)	g	**11667**
tray/box (corr.cardboard)	g	70.0
tertiary packaging (sum)[3]	g	**25596**
tertiary packaging (per FU)	g	**35849**
pallet (wood)	g	25000
type of pallet	-	EURO
number of use cycles	-	25
stretch foil (per pallet) (LDPE)	g	596
pallet configuration		
packs per sec. packaging	pc	12
sec. packaging units per layer	pc	17
layers per pallet	pc	7
packs per pallet	pc	1428

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

2.2.2 Specifications of alternative packaging systems

Table 12: Packaging specifications for regarded alternative systems in the segment *soup*

		Soup
	Unit	Pouch 5
volume	ml	570
geographic scope	-	Europe
primary packaging (sum)[1]	**g**	**12.48**
primary packaging (per FU)	**g**	**21895**
body (sum)	**g**	**12.48**
- aluminium	g	1.93
- PET	g	1.41
- PP	g	6.68
- PA	g	1.49
- tie layer (LLDPE)	g	0.79
- ink	g	0.18
secondary packaging (sum)[2]	**g**	**57.57**
secondary packaging (per FU)	**g**	**20200**
- tray (cardboard)	g	57.57
tertiary packaging (sum)[3]	**g**	**25630**
tertiary packaging (per FU)	**g**	**35686**
pallet (wood)	g	25000
type of pallet	-	EURO
number of use cycles		25
stretch foil (per pallet) (LDPE)	g	630
pallet configuration		
packs per sec. packaging	pc	5
sec. packaging units per layer	pc	36
layers per pallet	pc	7
packs per pallet	pc	1260

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

2.3 End-of-life

For each packaging system regarded in the study, the scenarios are modelled and calculated with average recycling rates for post-consumer packaging on the European market. The applied recycling quotas are based on published quotas relating to the amount of packaging on the market. The recycling quotas represent the actual amount of material undergoing a material recycling process after sorting took place. The remaining part of the post-consumer packaging waste is modelled and calculated according to the average split between landfilling and incineration (MSWI) in Europe. The material treated in MSWI is energetically recovered. The applied end-of-life quotas and the related references are given in Table 13. Regarding secondary and tertiary packaging, a material recycling rate of 46% is applied for plastic foil on all markets based on internal expert judgement. Corrugated cardboard is modelled in a closed loop in order to feed its 88.5% recycled fibres based on the applied corrugated cardboard data set [FEFCO 2018].

Table 13: Applied end of life quotas for Tetra Recart® cartons and competing packaging systems in Europe:

Geographical scope	Packaging system		Material recycling	Fuel substitution	MSWI	Landfill
Europe	Tetra Recart® carton	quota	48%	0%	29%	23%
		source	[ACE 2019]		[Eurostat 2020]	
		reference year	2017		2018	
	pouch	quota	0%	0%	56%	44%
		source	[Niaounakis 2019]		[Eurostat 2020]	
		reference year	2019		2018	

2.4 Scenarios

2.4.1 Base scenarios

For each of the studied packaging systems a scenario on the European market is defined, which is intended to reflect the most realistic situation under the described scope. These scenarios are clustered into groups within the same segment and volume group. Following the ISO standard's recommendation, a variation of the allocation procedure is conducted. Therefore, three scenarios regarding the open-loop allocation are calculated for each packaging system:

- with a system allocation factor of 50 %
- with a system allocation factor of 100 %
- with a system allocation factor of 0 %

2.4.2 Scenario variants regarding recycling rate

Packaging systems in the base scenarios are calculated with the material recycling rates as seen in Table 13. It is expected that recycling rates will increase in the future. In order to consider potential increases in recycling rates all scenarios are calculated with recycling rates up to 90%. In these analyses, the system allocation factor applied for open-loop-recycling is 50%.

In case of pouches no scenario variants regarding recycling rates are calculated. Pouches are flexible multilayer films with different material layers. For packaging systems like this currently no proper material recycling system or technology is available [Niaounakis 2019]. There are large varieties of materials used in the different layers. There is a lack of material recycling systems which can identify and separate the different materials in an economic way [Niaounakis 2019]. Instead of material recycling chemical recycling could be an option for multilayer films, reducing the need of complex separation processes [Niaounakis 2019]. In chemical recycling polymers are depolymerized in order to yield monomers and/or oligomers, from which new polymers can be produced [Niaounakis 2019]. Currently chemical recycling is still in an early stage, making it difficult to obtain process data for LCA.

2.4.3 Scenario variants regarding recycled content

In the base scenarios materials for the competing packaging systems are calculated with recycled content in cases in which the use of recycled material is currently applied. In order to show effects of potential increases in recycled content scenario variants are calculated with increased shares of recycled content their main materials (see Table 14). The results are shown in break-even graphs with a recycled content ranging from the value of the base scenario up to its maximum share of recycled content. In these analyses, the system allocation factor applied for open-loop-recycling is 50%.

Table 14: Scenario variants: recycled content, Europe

Base packaging system	recycled content base		recycled content max		Comparing packaging systems	Segment
Pouch 5, 570ml	aluminium:	0%	aluminium:	0%	Tetra Recart, Tray 2x5, 500 ml	soup, Europe
	PET:	0%	PET:	100%		
	PP:	0%	PP:	100%		
	PA:	0%	PA:	0%		
	tie layer:	0%	tie layer:	0%		

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 15 gives an overview of important datasets applied in the current study. Primary data collected in 2020 for example for filling processes are not extrapolated for the end of the year as the data are based on machine consumption. All data used meet the general requirements and characteristics regarding data gathering and data quality as summarised in section 1.6.

Table 15: Overview on inventory/process datasets used in the current study

Material / Process step	Source	Reference period	primary / secondary data
Intermediate goods			
PP	Plastics Europe, published online April 2014	2011	secondary
LDPE	Plastics Europe, published April 2014	2011	secondary
LLDPE	Plastics Europe, published April 2014	2011	secondary
PET	Plastics Europe, published online June 2017	2015	secondary
PA6	Plastics Europe, last online retrieval in 2005	1999	secondary
Aluminium (primary)	EAA Environmental Profile report 2018 [EAA 2018]	2015	secondary
Aluminium foil	EAA Environmental Profile report 2013 [EAA 2013]	2010	secondary
Corrugated cardboard	[FEFCO 2018]	2017	secondary
Liquid packaging board	ifeu data, obtained from ACE [ACE 2012]	2009	secondary
Printing ink	[IFEU 1997]	1997	primary
Production			
Tetra Recart® carton converting	Tetra Pak converting plant Budaörs	2018	primary
Composite material production	ifeu database	2007	primary
Filling and Retorting			
Filling and Retorting of Tetra Recart® cartons and competing packaging systems	Data provided by Tetra Pak	2020	primary

Material / Process step	Source	Reference period	primary / secondary data
Recovery			
Tetra Recart® carton recycling	ifeu database, based on data from various European recycling plants	2004	primary
Background data			
Electricity production	ifeu database, based on statistics and power plant models	2015	secondary
Municipal waste incineration	ifeu database, based on statistics and incineration plant models	2008	secondary
Landfill	ifeu database, based on statistics and landfill models	2008	secondary
lorry transport	ifeu database, based on statistics and transport models, emission factors based on HBEFA 3.3 [INFRAS 2017].	2016	secondary
rail transport	[EcoTransIT 2016]	2016	secondary
sea ship transport	[EcoTransIT 2016]	2016	secondary

3.1 Plastics

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

- Polypropylene (PP)
- High density polyethylene (HDPE)
- Low density polyethylene (LDPE)
- Polyethylene terephthalate (PET)
- Polyamide 6 (PA6)
- Ethylene vinyl alcohol (EVOH)
- Tie resin

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. The Plastics Europe data set represented 77% of PP production in Europe.

3.1.2 PET (polyethylene terephthalate)

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

3.1.3 PA6 (polyamide)

Polyamide 6 is manufactured from the precursors benzene and hydroxylamine. The present LCA study uses the ecoprofile published on the website of Plastics Europe (data last calculated March 2005) and referring to the year 1999 [Plastics Europe 2005a]. A more recent dataset is available provided by PlasticsEurope. However in this dataset ammonium sulphate is seen as a by-product of the PA6 production process of the PA6 pre-product caprolactam. The dataset uses a substitution approach to account for ammonium sulphate. As basically all ammonium sulphate on the market is derived from the PA6 production, in the view of the authors it is not valid to substitute a separate ammonium sulphate production process. Even within the PlasticsEurope methodology this approach is only allowed, "…if there is a dominant, identifiable production path for the displaced product" [Plastics Europe 2019]. Unfortunately, no dataset applying another approach apart from the substitution approach is available.

3.1.4 Low Density Polyethylene (LDPE)

Low density polyethylene (LDPE) is manufactured in a high pressure process and contains a high number of long side chains. The present LCA study uses the eco-profile published on the website of Plastics Europe [Plastics Europe 2014b].
The data set covers the production of LDPE granulates from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the 2011 time period. Data were acquired from a total of 22 participating polymerisation units. The data set represent 72% of LDPE production in Europe (EU27+2).

3.1.5 Tie resin

Typical materials for tie layers in multilayer films are ethylene vinyl acetate (EVA) and LLDPE. Due to similar production processes in this study the eco-profile of LLDPE published on the website of Plastics Europe [Plastics Europe 2014b] is used.

The dataset covers the production of LLDPE-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 86% of LLDPE production in Europe (EU27+2).

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 2015. The data are covering primary aluminium used in Europe consisting of 51% European aluminium data and 49% IAI data developed by the International Aluminium Institute (IAI) for imported aluminium [EEA 2018].

The data set for aluminium foil (5-200 µm) for the use in Tetra Recart® cartons, pouches, closures of rigid plastic and aluminium trays is based on data acquired by the EAA together with EAFA covering the year 2010 for the manufacture of semi-finished products made of aluminium. For aluminium foils, this represents 51% of the total production in Europe (EU27 + EFTA countries). Aluminium foil for the packages examined in this study on the European market is assumed to be sourced in Europe.

3.3 Production of liquid packaging board (LPB)

The production of liquid packaging board (LPB) was modelled using data gathered from all board producers in Sweden and Finland. It covers data from four different production sites where more than 95% of European LPB is produced. The reference year of these data is 2009. It is the most recent available and also published in the ELCD database.

The four datasets based on similar productions volumes were combined to one average. They cover all process steps including pulping, bleaching and board manufacture. They were combined with data sets for the process chemicals used from ifeu´s database and Ecoinvent 2.2 (same datasets as in Ecoinvent 3.1), including a forestry model to calculate inventories for this sub-system. Energy required is supplied by electricity as well as by on-site energy production by incineration of wood and bark. The specific energy sources were taken into account.

3.4 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2018 [FEFCO 2018] 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 2017. All corrugated board and cardboard trays are assumed to be sourced from European production. The data represents about 54% of the European cardboard production.

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated card-board trays. According to [FEFCO 2018] this fraction on average is 11.5% in Europe. Due to a lack of more specific information this split was also used for the present study.

3.5 Converting

3.5.1 Converting of Tetra Recart® cartons

The manufacture of composite board sleeves is modelled using converting data from Tetra Pak's converting plant in Budaörs in Hungary referring to the year 2018. The converting process covers the lamination of LPB with polymers and aluminium including, cutting and packing of the composite material. The packaging materials used for shipping of carton sleeves to fillers are included in the model as well as the transportation of the package material.

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

3.5.2 Production of composite material for pouches

Data for the production of composite material are taken from the internal ifeu data base.

3.6 Filling and retorting

Filling and retorting processes are different for Tetra Recart® cartons and alternative packaging systems regarding material and energy flows. The respective data for filling and retorting processes for Tetra Recart® cartons and competing packaging systems were provided by Tetra Pak in 2020 distinguishing between the consumption of electric and thermal energy as well as of water and air demand. The data were sourced from Tetra Pak' technical product data, input from Tetra Pak's customers, consultancy reports and internal calculations at Tetra Pak. Additionally the data were cross-checked by ifeu with data collected for earlier studies.

3.7 Transport settings

Table 16 provides an overview of the transport settings (distances and modes) applied for packaging materials. Data were obtained from Tetra Pak, ACE and several producers of raw materials. Where no such data were available, expert judgements were made, e.g. exchanges with representatives from the logistic sector and suppliers.

Table 16: Transport distances and means: Transport defined by distance and mode [km/mode], Europe

Packaging element	Material producer to converter Distance [km]	Converter to filler Distance [km]
aluminium ingot for aluminium foil production	primary: 100 /rail, 300 ship* secondary: 500 / road*	
Plastic granulate for carton sleeve	800 / road*	
Aluminium foil for carton sleeve	300 / road*	
Paper board for carton sleeve	1076 / road* 1034 / sea*	
Plastic and aluminium foil for pouches	500 / road*	
carton sleeves		1000 / road*
pouches		400 / road*
Cardboard for trays	1733 / sea, 326 / rail, 456 / road**	
Wood for pallets	100 / road*	
LDPE stretch foil	500/road*	

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

3.8 Distribution of filled packs from filler to point of sale

Table 17 shows the applied distribution distances in this study. Distribution centres are the places where the products are temporarily stored and then distributed to the different point of sales (i.e. supermarkets). For the distances generic assumptions are applied. Therefore, no filling and Distribution centre locations are specified specifically for the different segments and packaging systems. Instead an average distance based on internal intelligence from Tetra Pak is applied.

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 food 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. Based on BAG [2014] if the delivery distance is longer than 150km, 10.2% the delivery distances is calculated as an empty return trip. This is only valid for the distribution steps to the distribution centres. Usually no utilisation of lorries on their return trips from the point of sale to the warehouse is possible and the full return trip to the warehouse is attributed as an empty return trip to the examined system.

Table 17: Distribution distances in km for the examined packaging systems

geographic scope	Distribution distance [km] as applied in this study			
	Distribution Step 1		Distribution step 2	
	filler > distribution centre (delivery)	**distribution centre > filler** (return trip)	**distribution centre > POS** (delivery)	**POS > distribution centre** (return trip)
Europe	850	87	30	30

3.9 Recovery and recycling

Tetra Recart® cartons

Tetra Recart® cartons which are collected and sorted are subsequently sent to a paper recycling facility for fibre recovery. Sorting residues are disposed on landfills or treated in MSWI plants based on the local split between landfill and MSWI. A confidential efficiency of paper fibre recycling is applied. The secondary fibre material is used e.g. as a raw material for cardboard. A substitution factor 0.9 is applied. Rejects, in term of plastics and aluminium compounds are disposed on landfills or treated in MSWI plants based on the local split between landfill and MSWI. Related process data used are taken from ifeu's internal database, referring to the year 2004 and are based on data from various European recycling plants collected by ifeu.

Pouches

As multilayer films are currently not recycled [Niaounakis 2019] no recycling process for pouches is included the study.

3.10 Background data

3.10.1 Transport processes

Lorry transport

The dataset used is based on standard emission data that were collated, validated, extrapolated and evaluated for the Austrian, German, French, Norwegian, Swedish and Swiss Environment Agencies in the 'Handbook of emission factors' [INFRAS 2017]. The 'Handbook' is a database application referring to the year 2017 and giving as a result the transport distance related fuel consumption and the emissions differentiated into lorry size classes and road categories. Data are based on average fleet compositions within several lorry size classes. Data in this study refer to lorries with a loading capacity of 23 tonnes. The emission factors used in this study refer to the year 2016.

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

Ship transport

The data used for the present study represent freight transport with an overseas container ship (10.5 t/TEU[1]) and an utilisation capacity of 70% [EcoTransIT World 2016]. Energy use is based on an average fleet composition of this ship category with data taken from [EcoTransIT World 2016]. The Ecological Transport Information Tool (EcoTransIT) calculates environmental impacts of any freight transport. Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on [EcoTransIT World 2016]. For the consideration of well-to-tank emissions data were taken from IFEU's internal database.

Rail transport

The data used for rail transport for the present study also is based on data from [EcoTransIT World 2016]. Emission factors and fuel consumption have been applied for direct emissions based on [EcoTransIT World 2016]. The needed electricity is modelled with the electricity mix of the country the train is operating (see also section 3.10.2).

3.10.2 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 2016]. This model includes losses during power transformation and distribution along the distance between power plant and consumer. It is based on national electricity mix data by the International Energy Agency (IEA)[2]. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2015 for the production of LPB, the Hungarian of the year 2015 for Tetra Recart® converting processes. For all other processes the European mix of energy suppliers in the year 2015 is applied. The applied shares of energy sources to the related market are given in Table 18.

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

Table 18: Share of energy source to specific energy mix, reference year 2015.

geographic scope / Energy source	EU 28	Hungary	Sweden	Finland
Hard coal	14.11%	0.00%	0.23%	7.34%
Brown coal	10.32%	18.98%	0.00%	0.00%
Fuel oil	1.65%	0.19%	0.15%	0.30%
Natural gas	16.51%	17.19%	0.67%	12.65%
Nuclear energy	26.70%	52.46%	33.85%	33.66%
Hydropower/Wind/Solar/Geothermal	24.50%	3.64%	57.99%	29.14%
Hydropower	45.74%	22.42%	82.15%	87.77%
Wind power	40.42%	66.39%	17.75%	12.18%
Solar energy	13.01%	11.19%	0.10%	0.04%
Geothermal energy	0.83%	0.00%	0.00%	0.00%
Biomass energy	4.84%	6.40%	5.36%	15.69%
Waste	1.35%	1.14%	1.75%	1.23%

3.10.3 Municipal waste incineration

The electrical and thermal efficiencies of the municipal solid waste incineration plants (MSWI) are shown in Table 19.

Table 19: Electrical and thermal efficiencies of the incineration plants for Europe

Geographic Scope	Electrical efficiency	Thermal efficiency	Reference period	Source
Europe	12%	29%	2010	[CEWEP 2012]

The efficiencies are used as parameters for the incineration model, which assumes a technical standard (especially regarding flue gas cleaning) that complies with the requirements given by the EU incineration directive, ([EC 2000] Council Directive 2000/76/EC).

The electric energy generated in MSWI plants is assumed to substitute market specific grid electricity. Thermal energy recovered in MSWI plants is assumed to serve as process heat. The latter mix of energy sources represents a European average assumed to consist to 50% of oil and gas used for all regarded markets. According to the knowledge of the authors of this study, official data regarding this aspect are not available.

3.10.4 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 Tetra Recart® 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. The share of methane recovered via landfill gas capture systems is based on data from National Inventory Reports (NIR) under consideration of different catchment efficiencies at different stages of landfill operation. The applied shares of recovered methane are for Europe 36%. 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. Uncoated cardboard is modelled with a 50% decomposition rate.

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

4 Results EUROPE

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

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

- production and transport of glass including converting to jars (**'Glass'**)
- production and transport of plastics for the bodies of pouches, rigid plastic packaging systems, aluminium for bodies of trays and cans, and steel for bodies of cans (**'plastics for rigid plastic and pouch bodies/alu for tray and can bodies/steel for can body'**)
- production and transport of liquid packaging board for Tetra Recart® carton **('LPB')**
- production and transport of plastics for Tetra Recart® carton **('plastics for Tetra Recart® carton')**
- production and transport of aluminium & converting to foil for Tetra Recart® cartons and pouches **('aluminium foil for Tetra Recart® carton and pouch')**
- converting processes of cartons, as well as bodies of pouches, rigid plastic, trays and cans **('converting of body')**
- production, converting and transport of closures and labels and their base materials **('closure & label')**
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink wrap and corrugated cardboard **('transport packaging')**
- filling and retorting process including packaging handling **('filling and retorting')**
- distribution of the packages from filler to the point-of-sale **('distribution')**
- sorting, recycling and disposal processes **('recycling & disposal')**
- CO_2 emissions from incineration of plant-based materials **('CO_2 biogenic (EOL)')**; in the following also the term biogenic CO_2 emissions is used
- Uptake of atmospheric CO_2 during the plant growth phase ('**CO_2-uptake**')

Secondary products (recycled materials and recovered energy) are obtained through recovery processes of used packaging materials, e.g. recycled fibres from cartons may replace primary fibres. It is assumed, that those secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental burdens of the substituted material. Following the ISO standard's recommendation on subjective choices, both, the 50% and 100% allocation approach are used for the recycling and recovery as well as crediting procedure to verify the influence of the allocation method on the final results. (see section 1.7). For each segment the results are shown for the allocation factor 50% and allocation factor 100%.

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

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

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

- sectoral results of the packaging system itself (first stacked bar with positive values)
- credits given for secondary products leaving the system and CO_2 uptake (second stacked bar with negative values)
- net results as a results of the subtraction of credits from overall environmental burdens (grey bar)

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

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

4.1 Results soup EUROPE; allocation factor 50%

4.1.1 Presentation of results

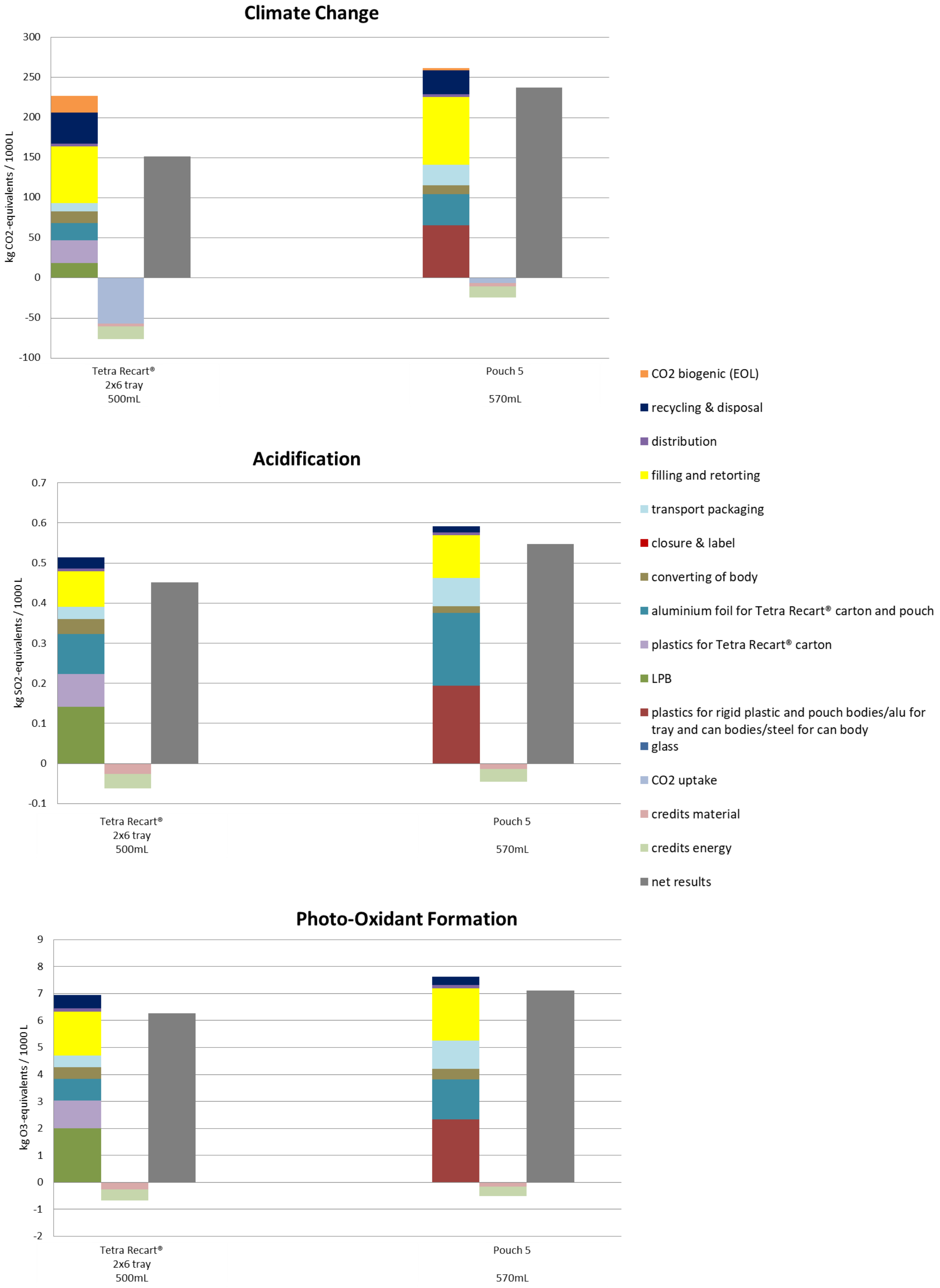


Figure 8: Indicator results of segment soup Europe, allocation factor 50% (Part 1)

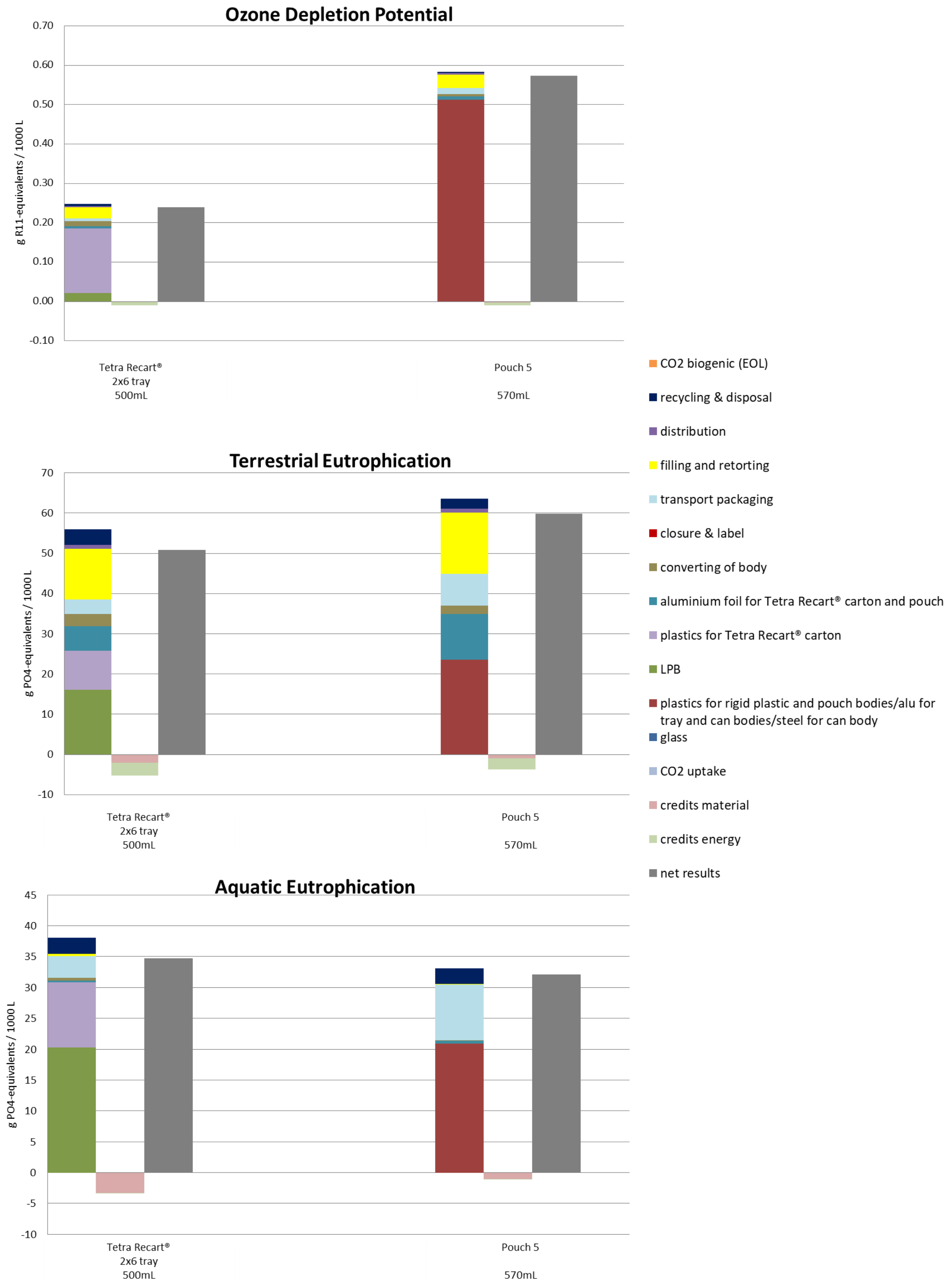


Figure 9 Indicator results of segment soup Europe, allocation factor 50% (Part 2)

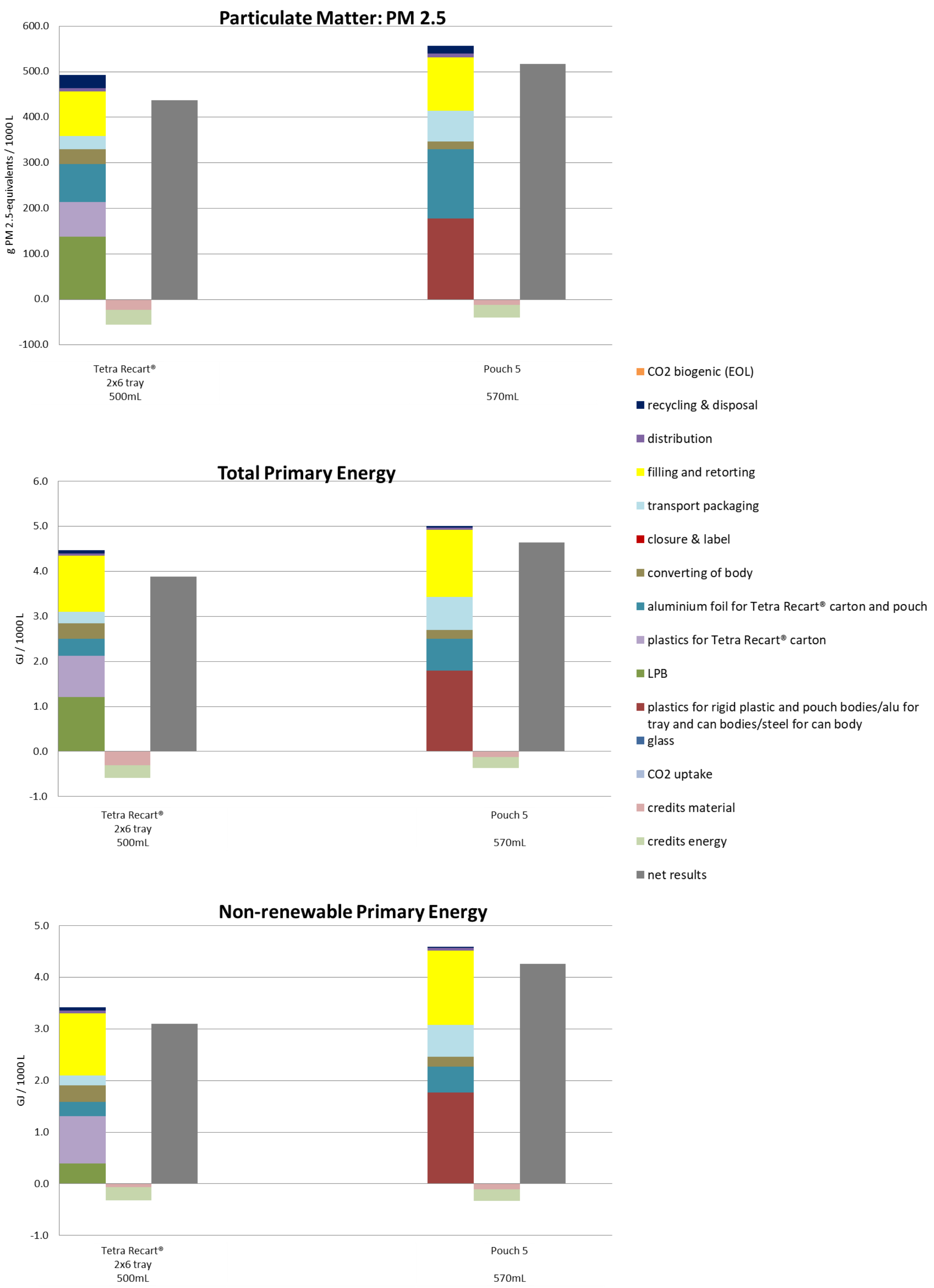
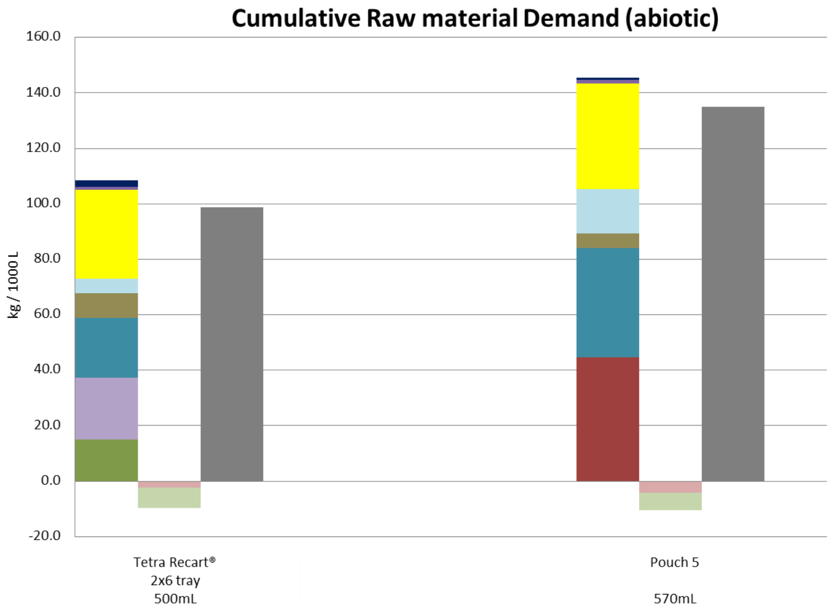
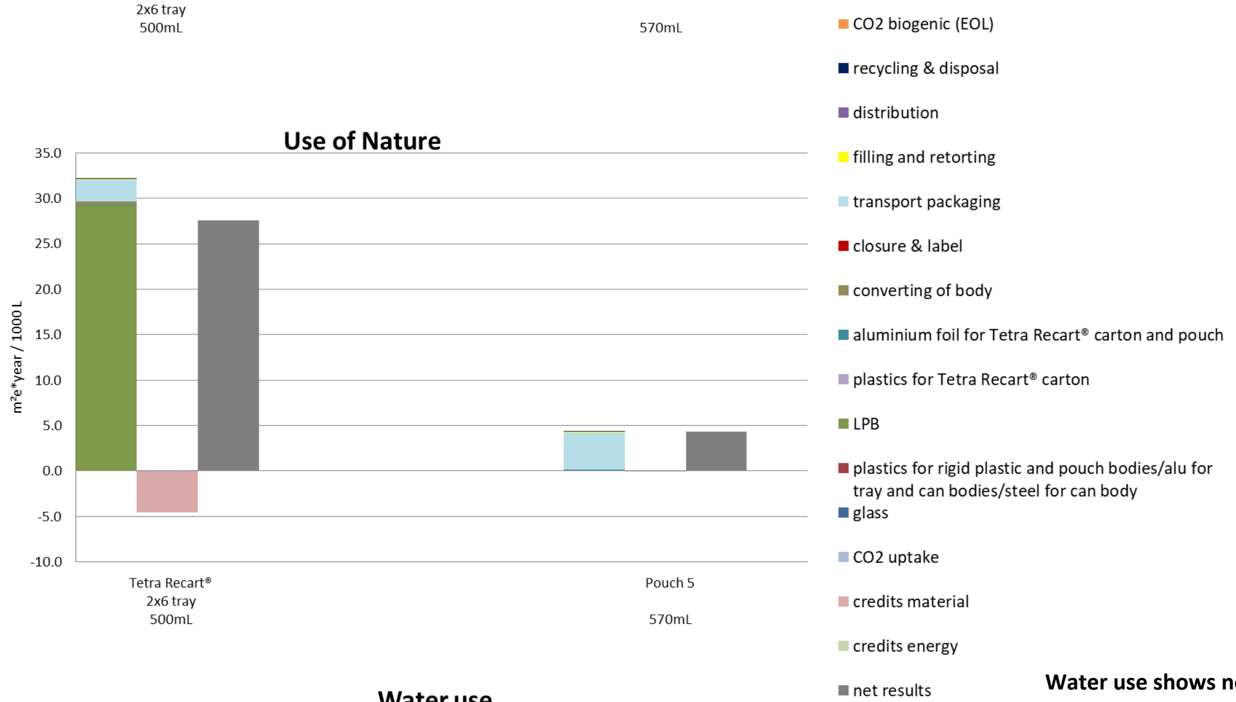
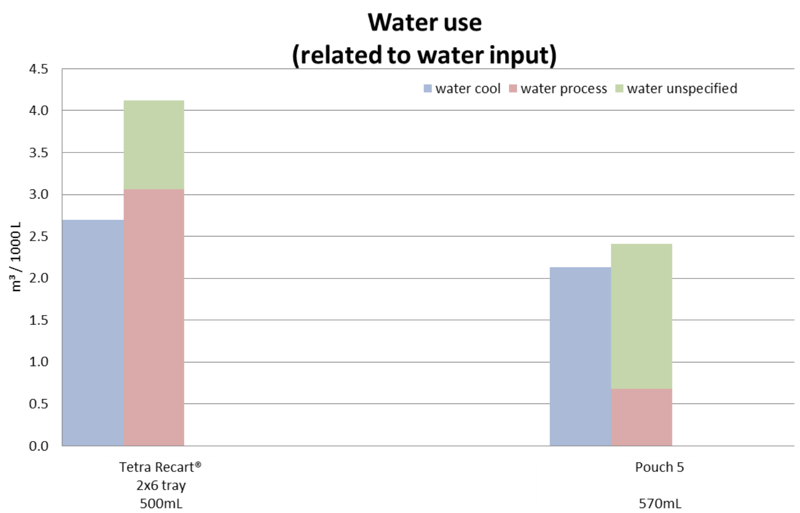


Figure 10: Indicator results of **segment soup Europe**, allocation factor 50% (Part 3)







Water use shows no outstanding values for the assessed packaging systems. In case of Tetra Recart® the shown values result mainly from the paper board production. Please note that the category 'Water Use' will not feature in the comparison and scenario variants sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

Figure 11: Indicator results of **segment soup Europe**, allocation factor 50% (Part 4)

Table 20: Category indicator results per impact category of segment soup Europe - burdens, credits and net results per functional unit of 1000 L, allocation factor 50% (All figures are rounded to two decimal places.)

Allocation 50		Tetra Recart® 2x6 tray 500mL		Pouch 5 570mL
Climate Change [kg CO_2-e/1000 L]	Burdens	206.21		259.16
	CO2 (reg)	21.10		2.19
	Credits	-18.96		-17.63
	CO2 uptake	-57.11		-6.48
	net results	151.23		237.24
Acidification [kg SO_2-e/1000 L]	Burdens	0.51		0.59
	Credits	-0.06		-0.05
	Net results	0.45		0.55
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	6.94		7.62
	Credits	-0.67		-0.50
	Net results	6.27		7.12
Ozone Depletion [g R11 e/1000 L]	Burdens	0.25		0.58
	Credits	-0.01		-0.01
	Net results	0.24		0.57
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	56.00		63.52
	Credits	-5.21		-3.74
	Net results	50.78		59.77
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	38.03		33.09
	Credits	-3.28		-1.01
	Net results	34.75		32.08
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	492.94		556.79
	Credits	-54.93		-40.17
	Net results	438.00		516.62
Total Primary Energy [GJ/1000 L]	Burdens	4.47		5.00
	Credits	-0.59		-0.36
	Net results	3.88		4.64
Non-renewable Primary Energy [GJ/1000 L]	Burdens	3.42		4.59
	Credits	-0.32		-0.33
	Net results	3.10		4.26
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	108.33		145.41
	Credits	-9.58		-10.34
	Net results	98.75		135.07
Use of Nature [m^2e*year/1000 L]	Burdens	32.13		4.34
	Credits	-4.56		-0.05
	Net results	27.57		4.29
Water use [m^3/1000 L]	water cool	2.70		2.13
	water process	3.06		0.68
	water unspecified	1.06		1.73

4.1.2 Description and interpretation

Tetra Recart® (specifications see section 2.2.1)

For the Tetra Recart® carton system considered in the soup Europe segment, in all categories except ‘Aquatic Eutrophication’ and ‘Use of Nature’ a considerable to major share (11%-35%) of the environmental burdens is caused by the life cycle step ‘filling and retorting’. These result mainly from the heat energy needed for the retorting process.

The production of LPB is responsible for a substantial share of the burdens of the impact categories ‘Aquatic Eutrophication’ (53%) and ‘Use of Nature’ (91%). It shows also major shares of burdens regarding 'Photo-Oxidant Formation' (29%) 'Acidification' (28%), 'Terrestrial Eutrophication' (29%), 'Particulate Matter' (28%) and also the consumption of 'Total Primary Energy' (27%). Regarding 'Climate Change' the production of LPB is responsible for only 8% of the burdens.

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

The production of paperboard generates emissions that cause contributions to both 'Aquatic Eutrophication' and 'Terrestrial Eutrophication', the latter to a lesser extent. Approximately half of the 'Aquatic Eutrophication Potential' is caused by the Chemical Oxygen Demand (COD). As the production of paper causes contributions of organic compounds into the surface water an overabundance of oxygen-consuming reactions takes place which therefore may lead to oxygen shortage in the water. In the 'Terrestrial Eutrophication Potential', nitrogen oxides are determined as main contributor.

For the separation of the cellulose needed for paper production from the ligneous wood fibres, the so called 'Kraft process' is applied, in which sodium hydroxide and sodium sulphide are used. This leads to additional emissions of SO_2, thus contributing considerably to the acidifying potential.

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

The production of 'plastics for Tetra Recart® carton' shows considerable burdens in most impact categories (up to 28%). The exception is 'Ozone Depletion Potential' in which major shares of burdens (66%) are shown by this life cycle step mainly resulting from the production of PA.

The production of 'aluminium foil for Tetra Recart® carton and pouch' shows minor burdens in most impact categories. More considerable shares of burdens can be seen for the impact categories 'Acidification' (19%) and 'Particulate Matter' (17%). These result from SO_2 and NOx emissions from the aluminium production. Also the inventory category 'Cumulative Raw material Demand (abiotic)' shows considerable shares of burdens (20%).

The life cycle step 'closure & label' shows no burdens for the Tetra Recart® carton as it only consists of the sleeve.

The 'converting' process plays a small to minor role (1%-10%). Main source of the emissions from this process is the electricity demand of the converting process.

The production and provision of 'transport packaging' for the Tetra Recart® carton system shows small impact shares in all categories (3%-9%).

The life cycle step 'distribution' shows only minor burdens in all impact categories for the Tetra Recart® carton system (max. 2%).

The life cycle step 'recycling & disposal' of the regarded Tetra Recart® carton is most relevant in the impact category 'Climate Change' (17%). Greenhouse gases are generated by the energy production required in the respective recycling processes as well as by incineration of packaging materials in MSWI. A large contributor in this step is also methane emitted by landfills, resulting from the degradation of paper board.

'CO_2 reg. (recycling & disposal)' describes separately all regenerative CO_2 emissions from recycling and disposal processes. These derive from the incineration of paper. They account (9%) of the burdens in the impact category 'Climate Change'. Together with the fossil-based CO_2 emissions of the life cycle step 'recycling & disposal' they represent the total CO_2 emissions from the packaging's end-of-life. Due to the energy recovery at incineration plants system-related allocation is applied. In this case system-related allocation is applied with the allocation factor 50%.

Energy credits result from the recovery of energy in incineration plants. They sum up to 0%-8% of the total burdens. Material credits from material recycling sum up to 1%-14%. Material credits are low for 'Climate Change' (1%) because the production of substituted primary paper fibres has low greenhouse gas emissions. System-related allocation (in this case with allocation factor 50%) is applied for energy and material credits.

The uptake of CO_2 by trees harvested for the production of paperboard plays an important role in the impact category 'Climate Change'. The carbon uptake refers to the conversion process of carbon dioxide to organic compounds by trees. The assimilated carbon is then used to produce energy and to build body structures. However, the carbon uptake in this context describes only the amount of carbon which is stored in the product under study. This amount of carbon can be re-emitted in the end-of-life either by landfilling or incineration. Due to the convention in this study which implies that no CO_2 uptake is considered in credits, only for the regarded system, the producer of biogenic material, the CO_2 uptake is applied and seen in the results. In case of allocation factor 50% this leads to a benefit in 'Climate Change' for of the regarded system. (see section1.7.2)

Pouch (specifications see section 2.2.2)

For the pouch system considered in the soup Europe segment, in all categories except 'Aquatic Eutrophication' and 'Use of Nature' a considerable to major share (18%-32%) of the environmental burdens is caused by the life cycle step 'filling and retorting'. These result mainly from the heat energy needed for the retorting process.

The production of plastics for the pouch body contributes to a considerable to major share of burdens (25%-88%) in all categories except 'Use of Nature' (1%). Especially high shares of burdens are shown by this life cycle step for 'Ozone Depletion Potential' (88%) mainly resulting from the production of PA and PET.

The production of aluminium foil for the body shows small to considerable burdens (2%-19%) in most impact categories. More major shares of burdens can be seen for the impact categories 'Acidification' (31%) and 'Particulate Matter' (27%). These result from SO_2 and

NOx emissions from the aluminium production. Also the inventory category 'Cumulative Raw material Demand (abiotic)' shows more considerable shares of burdens (27%).

The 'converting of body' process shows a small share of burdens (1%-5%) in most categories apart from 'Aquatic Eutrophication' and 'Use of Nature', for which the share of burdens are less than 1%. Emissions from the 'converting of body' process almost exclusively derive from electricity production.

The life cycle step 'closure & label' shows no shares of burdens as the regarded pouch consists only of a body.

The production and provision of 'transport packaging' for the pouch system shows small to minor impact shares (3%-15%) in most categories. The exceptions in this life cycle step are 'Use of Nature' which accounts 94% and 'Aquatic Eutrophication' which accounts 27% of the total burdens, resulting from the production of cardboard.

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

The 'recycling & disposal' life cycle step contributes regarding 'Climate Change' with 12% of the total burdens caused mainly from the incineration of plastics in MSWI plants. In all other categories this life cycle step contributes with only small shares of burdens (up to 8%)

Energy credits (up to 5% of the total burdens) and material credits (up to 3% of the total burdens) have a small influence on the net results in all categories. As pouches are not being recycled, material credits result only from production waste in the aluminium foil production.

Water use shows no outstanding values for the assessed packaging systems. In case of Tetra Recart® the shown values result mainly from the paper board production. Please note that the category 'Water Use' will not feature in the comparison and sensitivity sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

4.2 Results soup EUROPE; allocation factor 100%

4.2.1 Presentation of results

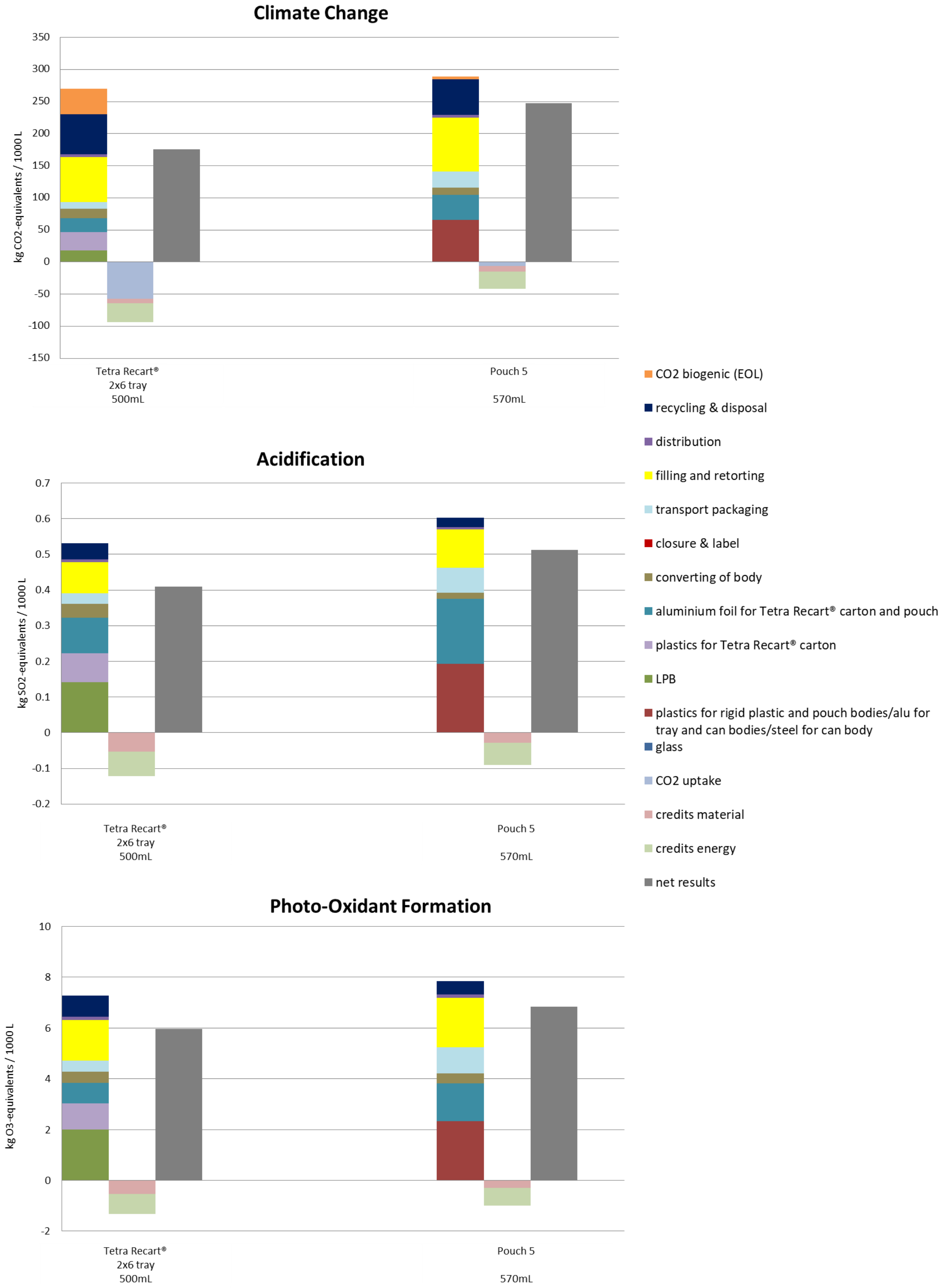


Figure 12: Indicator results of segment soup Europe, allocation factor 100% (Part 1)

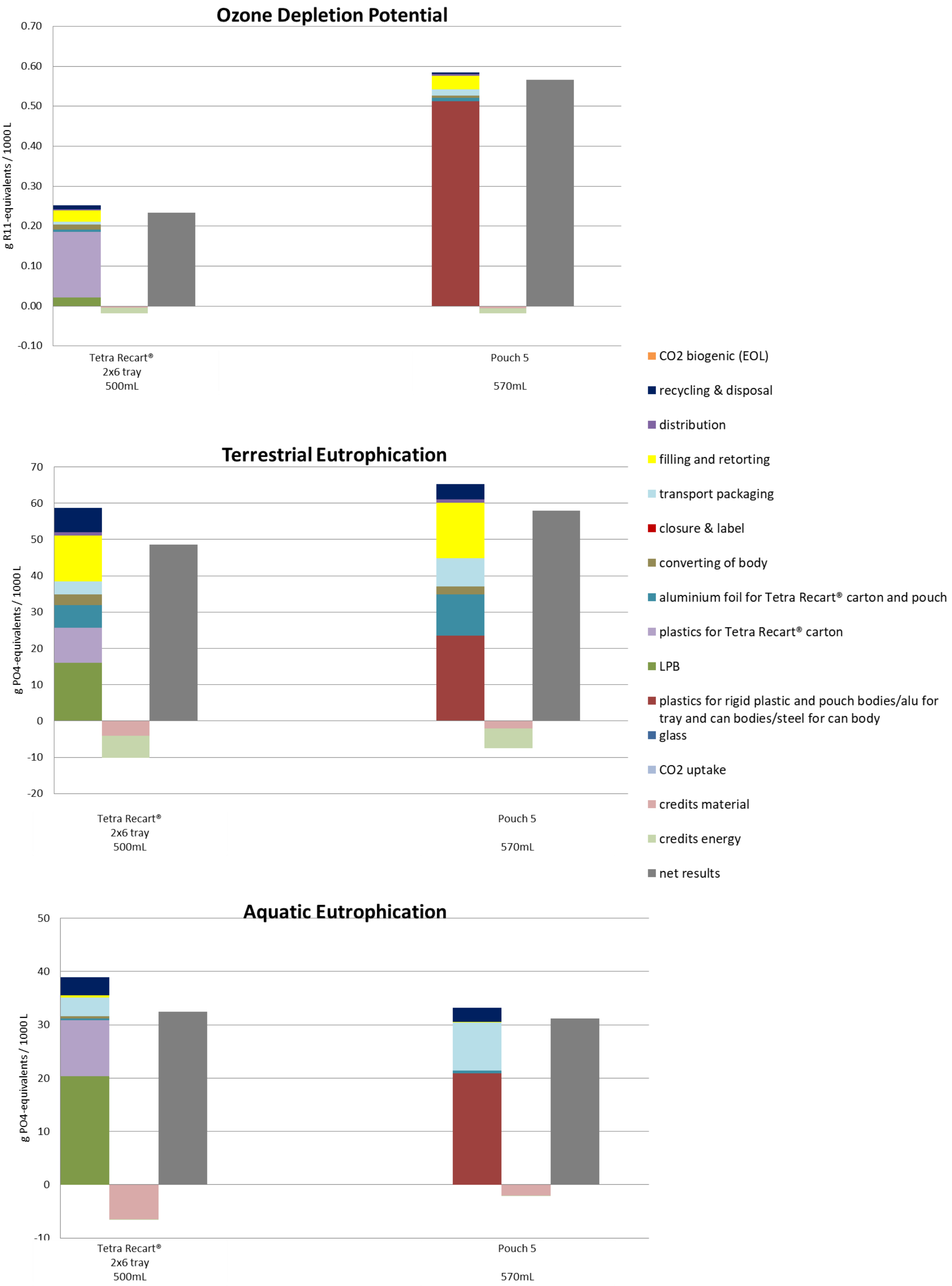


Figure 13 Indicator results of segment soup Europe, allocation factor 100% (Part 2)

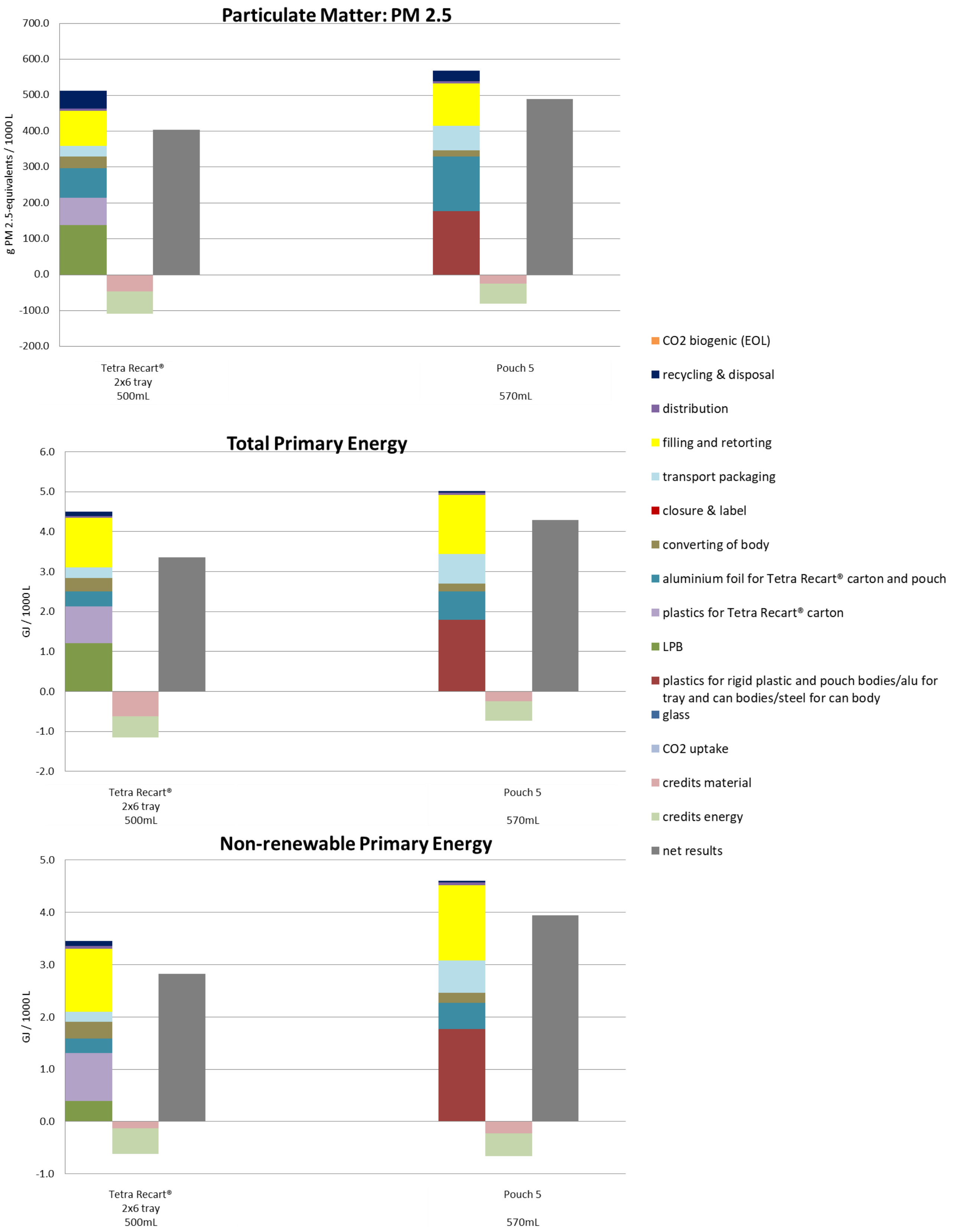
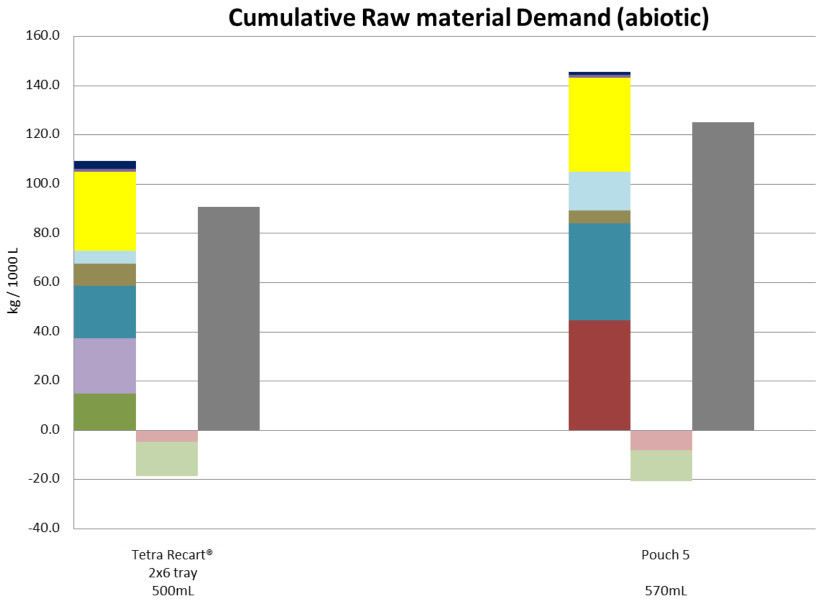
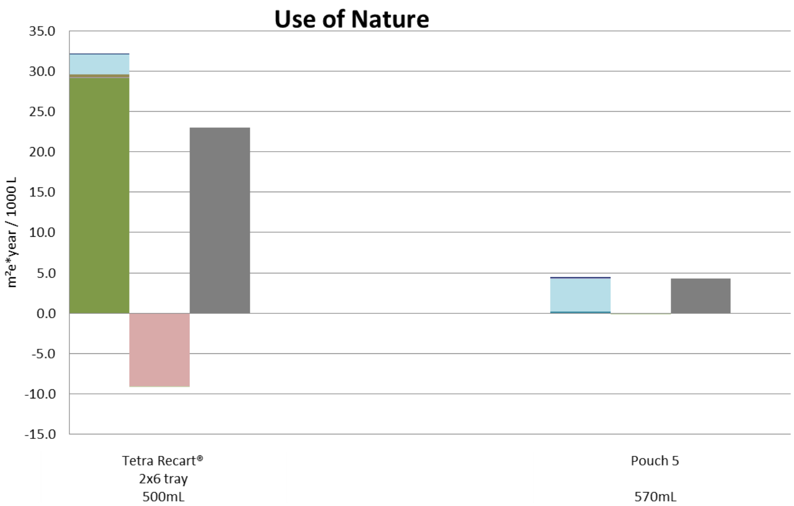
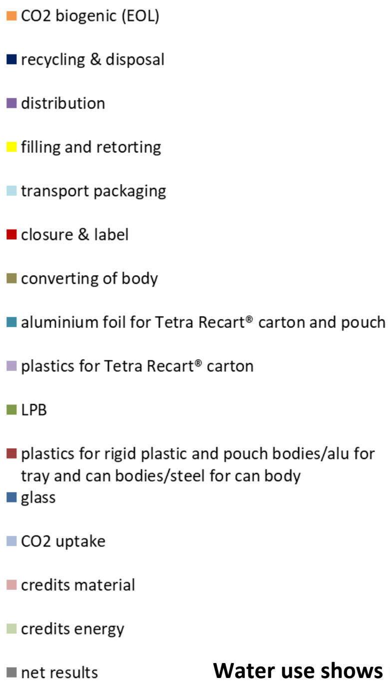
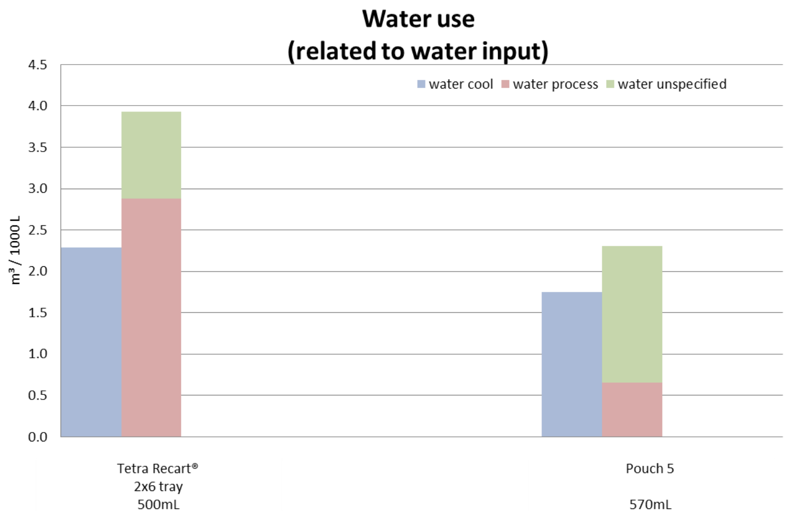


Figure 14: Indicator results of **segment soup Europe**, allocation factor 100% (Part 3)









Water use shows no outstanding values for the assessed packaging systems. In case of Tetra Recart® the shown values result mainly from the paper board production. Please note that the category 'Water Use' will not feature in the comparison and scenario variants sections, nor will it be considered for the final conclusions (please see details in section 1.8). The graphs of the allocation 50 and allocation 100 results are included anyhow to give an indication about the importance of this category.

Figure 15: Indicator results of **segment soup Europe**, allocation factor 100% (Part 4)

Table 21: Category indicator results per impact category of **segment soup Europe** - burdens, credits and net results per functional unit of 1000 L, allocation factor 100% (All figures are rounded to two decimal places.)

Allocation 100		Tetra Recart® 2x6 tray 500mL		Pouch 5 570mL
Climate Change [kg CO_2-e/1000 L]	Burdens	230.47		284.83
	CO2 (reg)	39.53		4.39
	Credits	-36.82		-35.19
	CO2 uptake	-57.11		-6.48
	net results	176.07		247.54
Acidification [kg SO_2-e/1000 L]	Burdens	0.53		0.60
	Credits	-0.12		-0.09
	Net results	0.41		0.51
Photo-Oxidant Formation [kg O_3 e/1000 L]	Burdens	7.28		7.84
	Credits	-1.32		-1.00
	Net results	5.97		6.84
Ozone Depletion [g R11 e/1000 L]	Burdens	0.25		0.58
	Credits	-0.02		-0.02
	Net results	0.23		0.57
Terrestrial Eutrophication [g PO_4 e/1000 L]	Burdens	58.73		65.33
	Credits	-10.20		-7.47
	Net results	48.52		57.86
Aquatic Eutrophication [g PO_4 e/1000 L]	Burdens	38.97		33.18
	Credits	-6.56		-2.01
	Net results	32.41		31.17
Particulate Matter [g PM 2.5-e/1000 L]	Burdens	512.32		568.81
	Credits	-108.03		-80.15
	Net results	404.29		488.66
Total Primary Energy [GJ/1000 L]	Burdens	4.50		5.01
	Credits	-1.15		-0.73
	Net results	3.35		4.28
Non-renewable Primary Energy [GJ/1000 L]	Burdens	3.45		4.60
	Credits	-0.62		-0.66
	Net results	2.83		3.94
Cumulative Raw material Demand (abiotic) [kg/1000 L]	Burdens	109.43		145.72
	Credits	-18.64		-20.65
	Net results	90.79		125.07
Use of Nature [m²e*year/1000 L]	Burdens	32.13		4.34
	Credits	-9.12		-0.10
	Net results	23.02		4.25
Water use [m³/1000 L]	water cool	2.29		1.75
	water process	2.88		0.65
	water unspecified	1.05		1.66

4.2.2 Description and interpretation

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

When applying an allocation factor of 100%, all burdens and all credits are allocated to the regarded system.

In the cases of Tetra Recart carton systems in the segment soup Europe applying the allocation factor 100% instead of 50% leads to lower net results in almost all impact categories. This is because the absolute value of the credits is higher than that of the burdens from recycling and disposal regardless of the allocation factor. In case of 'Climate Change', applying the allocation factor 100% instead of 50% leads to higher net results. This is because in this case the absolute value of the credits is lower than that of the burdens from recycling and disposal regardless of the allocation factor. Also the extra benefit for the regarded systems containing primary biogenic mater is gone when applying the allocation factor 100% as all burdens from 'CO_2 reg. (recycling & disposal)' are allocated to the regarded system (see section 1.7.2).

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

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

4.3 Results soup EUROPE; allocation factors 0%, 50% 100%

In the previews sections the results with allocation factor 50% and 100% are shown on a detailed level in order to show amongst others the effects of the allocation on the applied approach to consider biogenic carbon (see section 1.7.2). In order to consider the full range of system allocation, this section shows additionally the net results of all three included allocation factors 50% and 100% and 0%.

4.3.1 Presentation of results

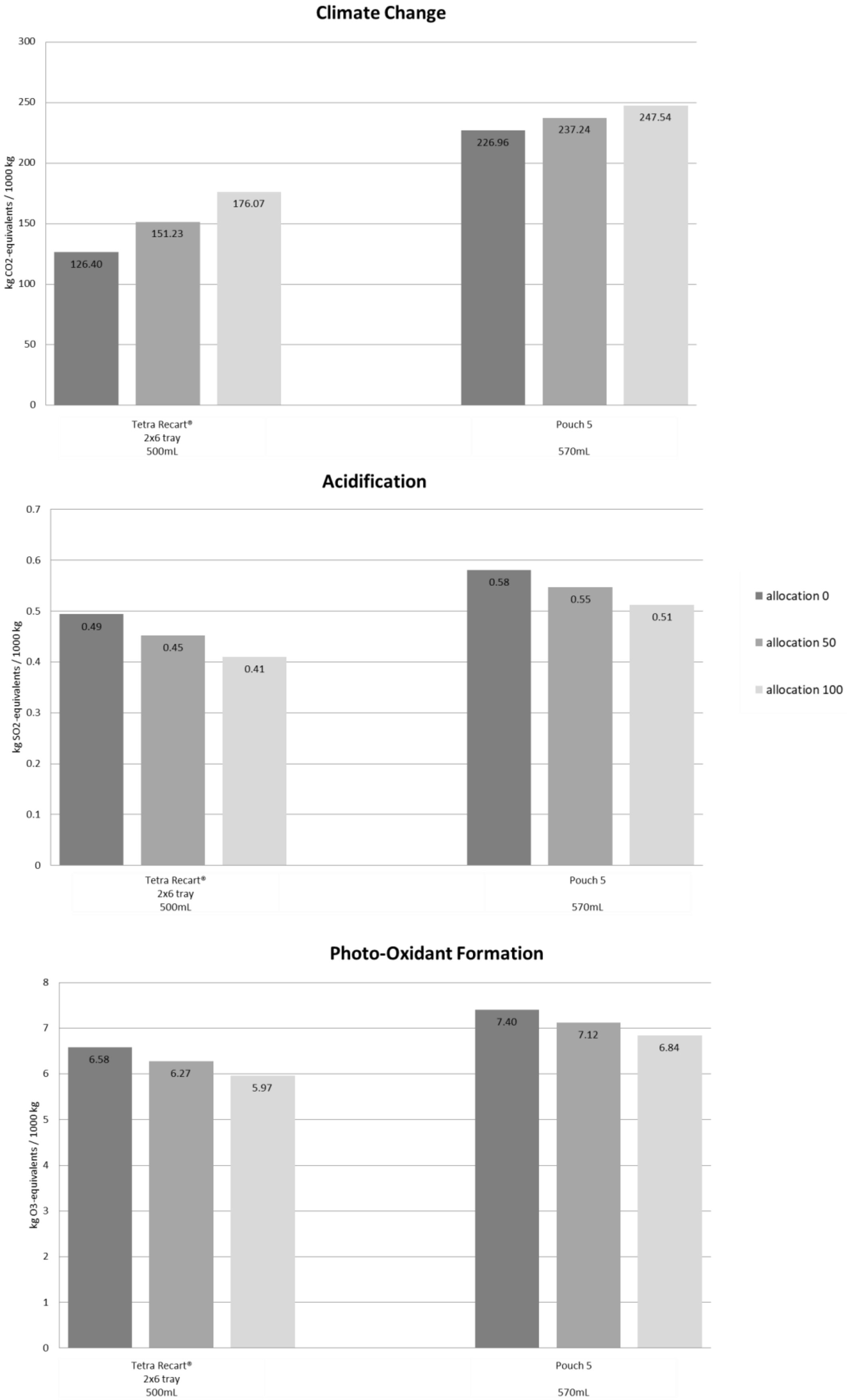


Figure 16: Indicator net results of segment soup Europe, allocation factors 0%, 50%, 100% (Part 1)

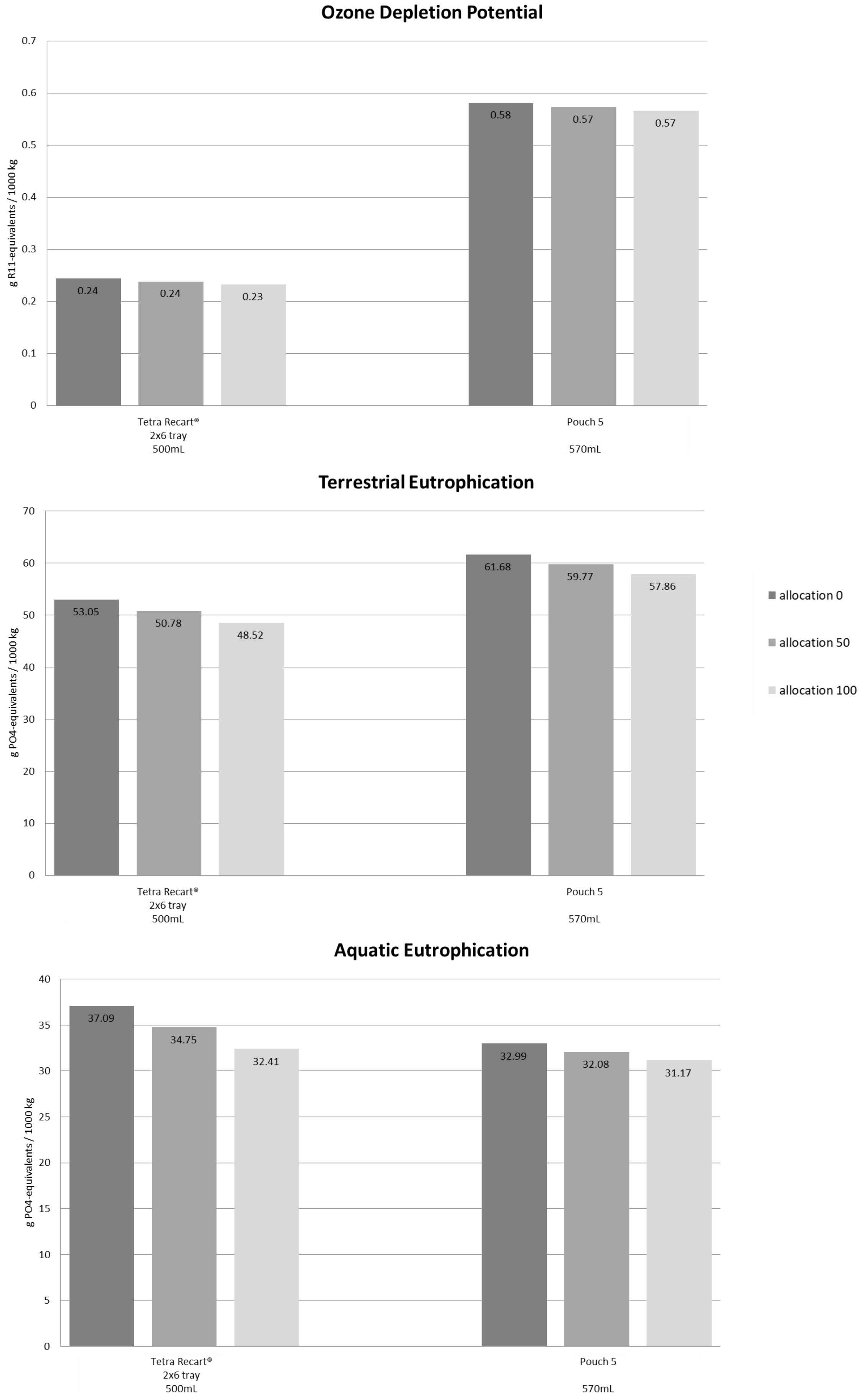


Figure 17 Indicator net results of segment soup Europe, allocation factors 0%, 50%, 100% (Part 2)

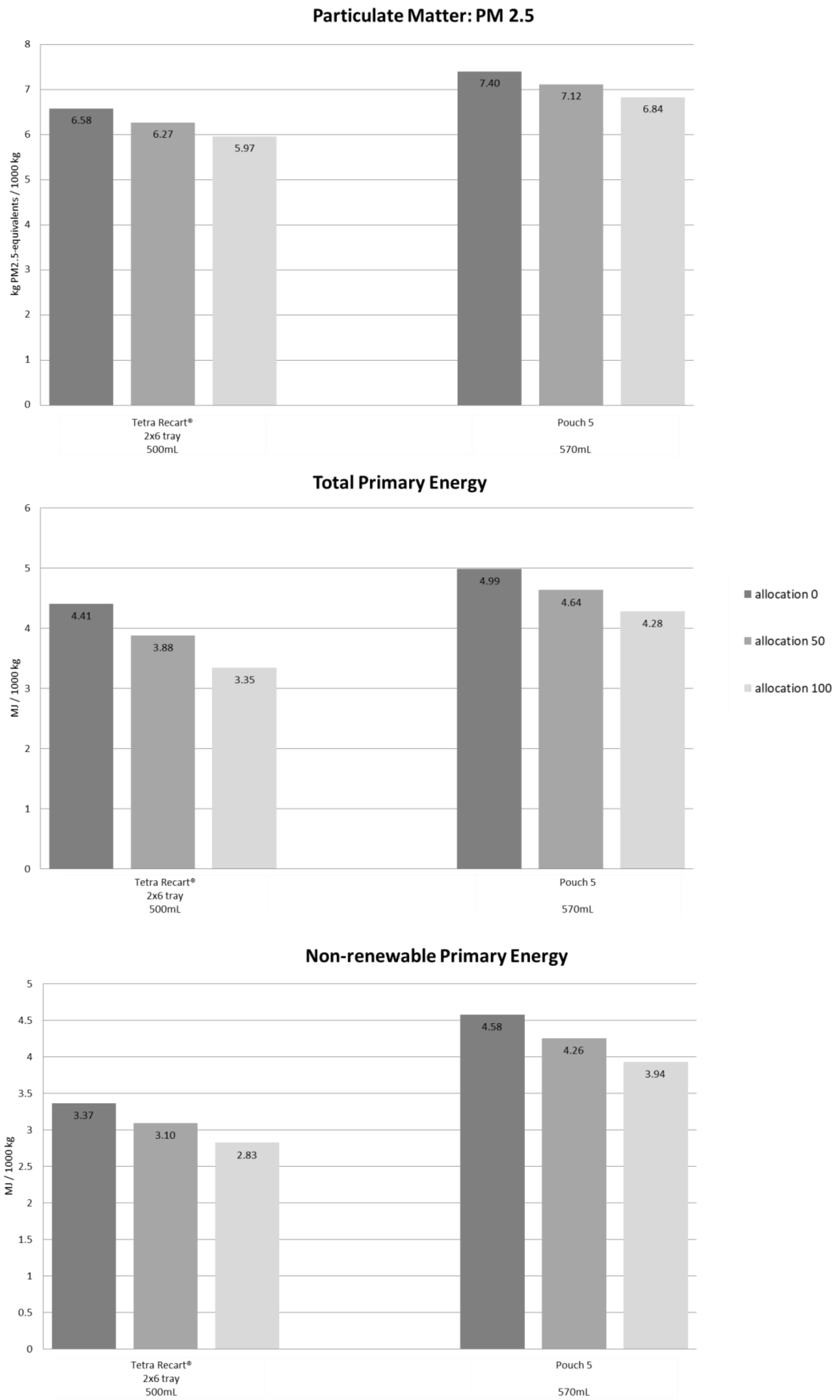


Figure 18: Indicator net results of segment soup Europe, allocation factors 0%, 50%, 100% (Part 3)

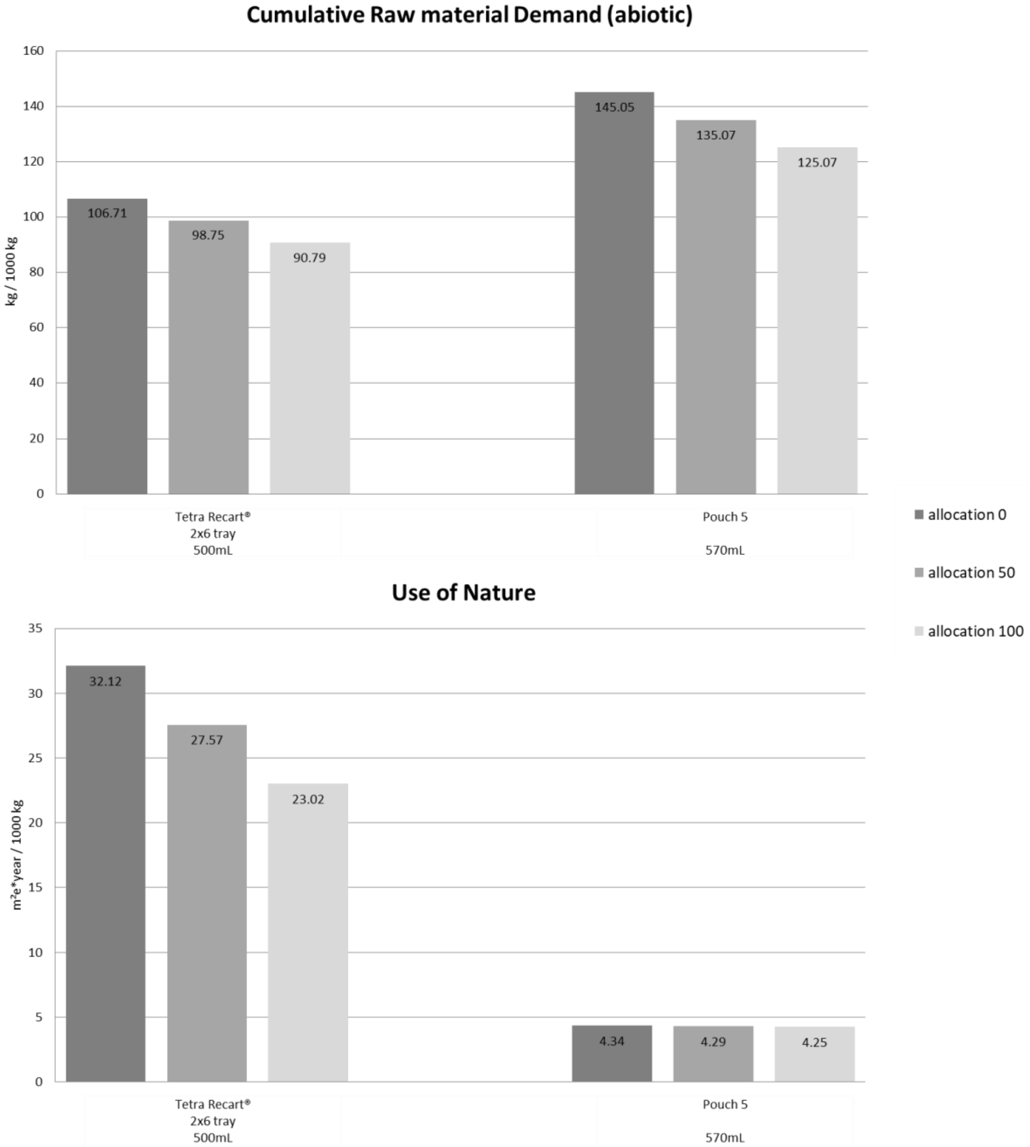


Figure 19: Indicator net results of **segment soup Europe**, allocation factors 0%, 50%, 100% (Part 4)

4.3.2 Description and interpretation

When applying the allocation factor of 50%, 50% of burdens and 50% of credits from recycling and recovery processes are allocated to the regarded system.

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

A lower allocation factor implies the allocation of fewer burdens from the end-of-life processes (for example emissions from incineration, emissions from the production of electricity for recycling processes). It also implies the allocation of fewer credits for the substitution of other processes (for example energy credits for avoided electricity generation due to energy recovery at MSWIs or material credits for avoided production of new materials). When applying the allocation factor of 0%, no burdens and no credits from recycling and recovery processes are allocated to the regarded system.

The effect of the allocation factors on the net results of the compared packaging systems is similar in most categories. The exception is Climate Change in which a higher allocation factors lead to less favourable net results for beverage cartons compared to the alternative packaging systems (see sections 4.2.2 and 1.7.2).

4.4 Comparison between packaging systems soup EUROPE (Allocation 0%, 50%, 100%)

The following tables show the net results per functional unit of the studied Tetra Recart® carton systems for all impact categories compared to those of the other regarded packaging systems in the same segment with the allocation factor 0%, 50% and 100%. Differences lower than 10% are considered to be insignificant (please see section 1.6 on precision and uncertainty).

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

Table 22: Comparison of net results: **Tetra Recart® 2x6 tray 500 mL** versus competing packaging systems in **segment soup Europe**, allocation factor 0%

Soup, Europe, Allocation 0	The net results of **Tetra Recart® 2x6 tray 500mL** are lower (green)/ higher (orange) than those of
	Pouch 5 570mL
Climate Change	-44%
Acidification	-15%
Photo-Oxidant Formation	-11%
Ozone Depletion Potential	-58%
Terrestrial Eutrophication	-14%
Aquatic Eutrophication	+12%
Particulate Matter	-13%
Use of Nature	+640%

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

Table 23: Comparison of net results: **Tetra Recart® 2x6 tray 500 mL** versus competing packaging systems in **segment soup Europe**, allocation factor 50%

Soup, Europe, Allocation 50	The net results of **Tetra Recart® 2x6 tray 500mL** are lower (green)/ higher (orange) than those of
	Pouch 5 570mL
Climate Change	-36%
Acidification	-17%
Photo-Oxidant Formation	-12%
Ozone Depletion Potential	-58%
Terrestrial Eutrophication	-15%
Aquatic Eutrophication	+8%
Particulate Matter	-15%
Use of Nature	+542%

Table 24: Comparison of net results: **Tetra Recart® 2x6 tray 500 mL** versus competing packaging systems in **segment soup Europe**, allocation factor 100%

Soup, Europe, Allocation 100	The net results of **Tetra Recart® 2x6 tray 500mL** are lower (green)/ higher (orange) than those of
	Pouch 5 570mL
Climate Change	-29%
Acidification	-20%
Photo-Oxidant Formation	-13%
Ozone Depletion Potential	-59%
Terrestrial Eutrophication	-16%
Aquatic Eutrophication	+4%
Particulate Matter	-17%
Use of Nature	+442%

5 Scenario Variants EUROPE

5.1 Scenario variants regarding recycling rate

Packaging systems in the base scenarios are calculated with the material recycling rates as seen in Table 13. It is expected that recycling rates will increase in the future. In order to consider potential increases in recycling rates all scenarios are calculated with recycling rates up to 90%. In these analyses, the system allocation factor applied for open-loop-recycling is 50%. In these analyses, the allocation factor applied for open-loop-recycling is 50%. Results are shown in the following graphs.

In case of pouches no scenario variants regarding recycling rates are calculated. Pouches are flexible multilayer films with different material layers. For packaging systems like this currently no proper material recycling system or technology is available [Niaounakis 2019]. There are large varieties of materials used in the different layers. There is a lack of material recycling systems which can identify and separate the different materials in an economic way [Niaounakis 2019]. Instead of material recycling chemical recycling could be an option for multilayer films, reducing the need of complex separation processes [Niaounakis 2019]. In chemical recycling polymers are depolymerized in order to yield monomers and/or oligomers, from which new polymers can be produced [Niaounakis 2019]. Currently chemical recycling is still in an early stage, making it difficult to obtain process data for LCA.

5.1.1 Scenario variants regarding recycling rate, soup, Europe

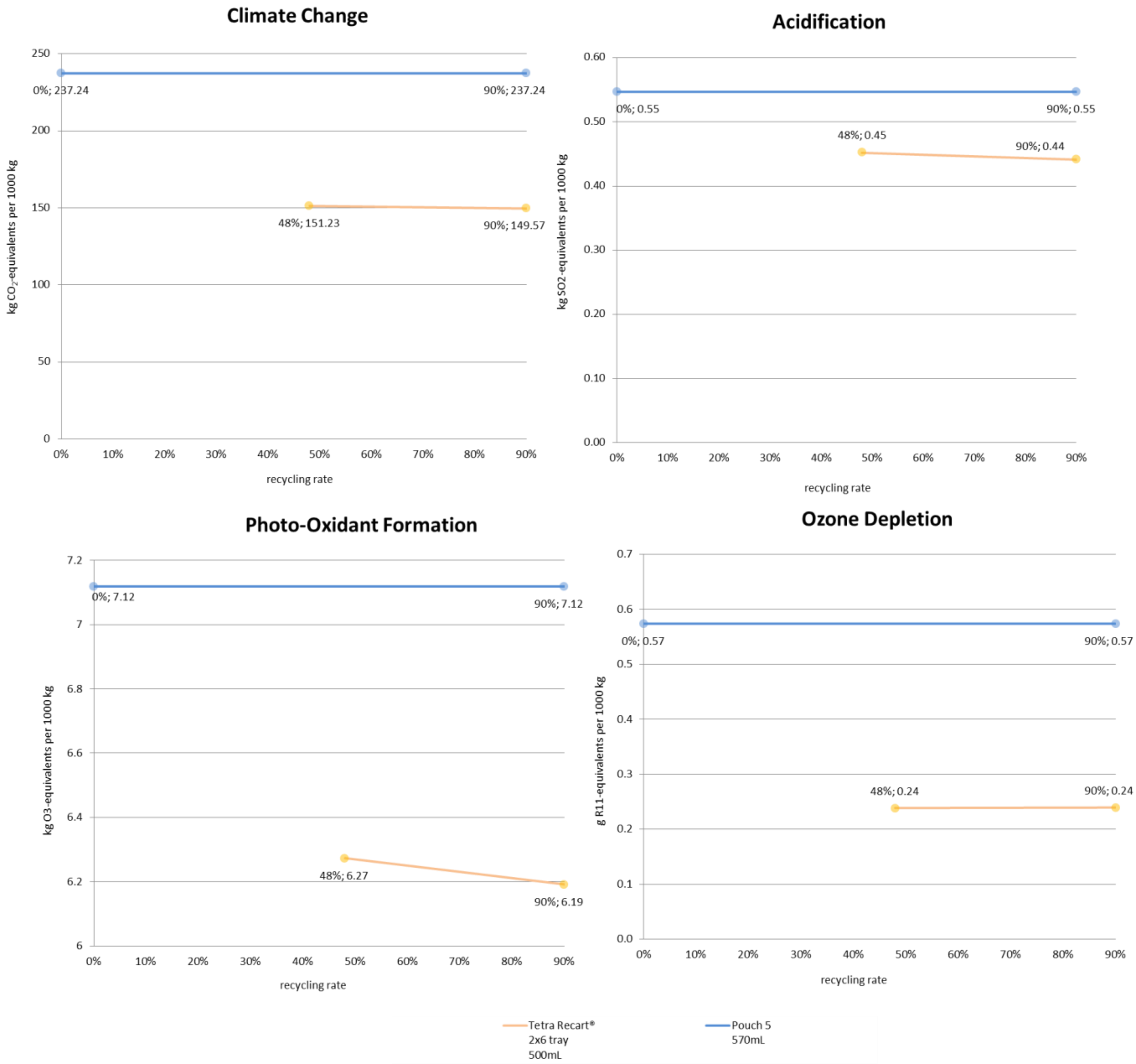


Figure 20: Indicator results for scenario variants recycling rate of **segment soup Europe**, allocation factor 50% (Part 1)

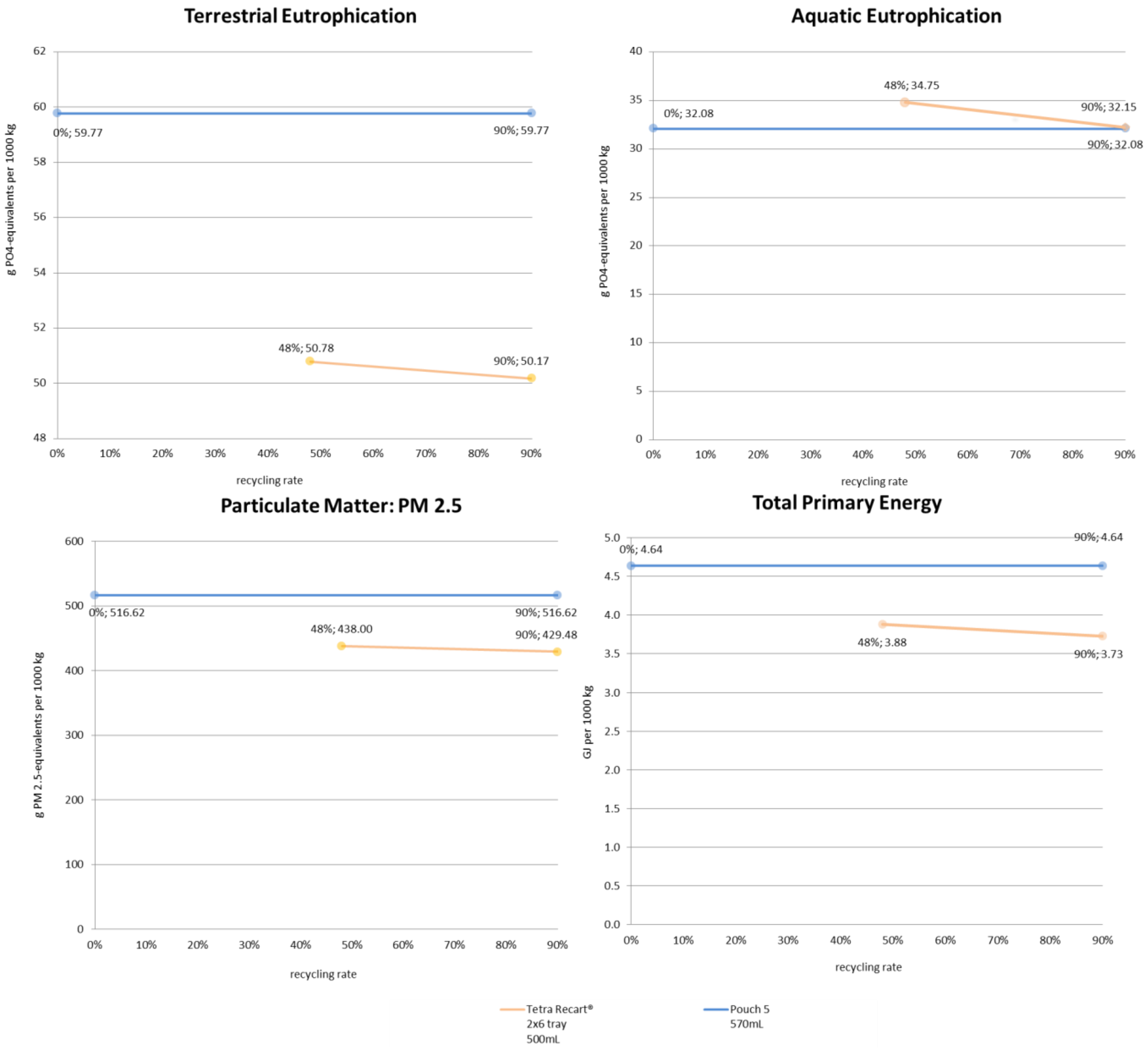


Figure 21: Indicator results for scenario variants recycling rate of segment soup Europe, allocation factor 50% (Part 2)

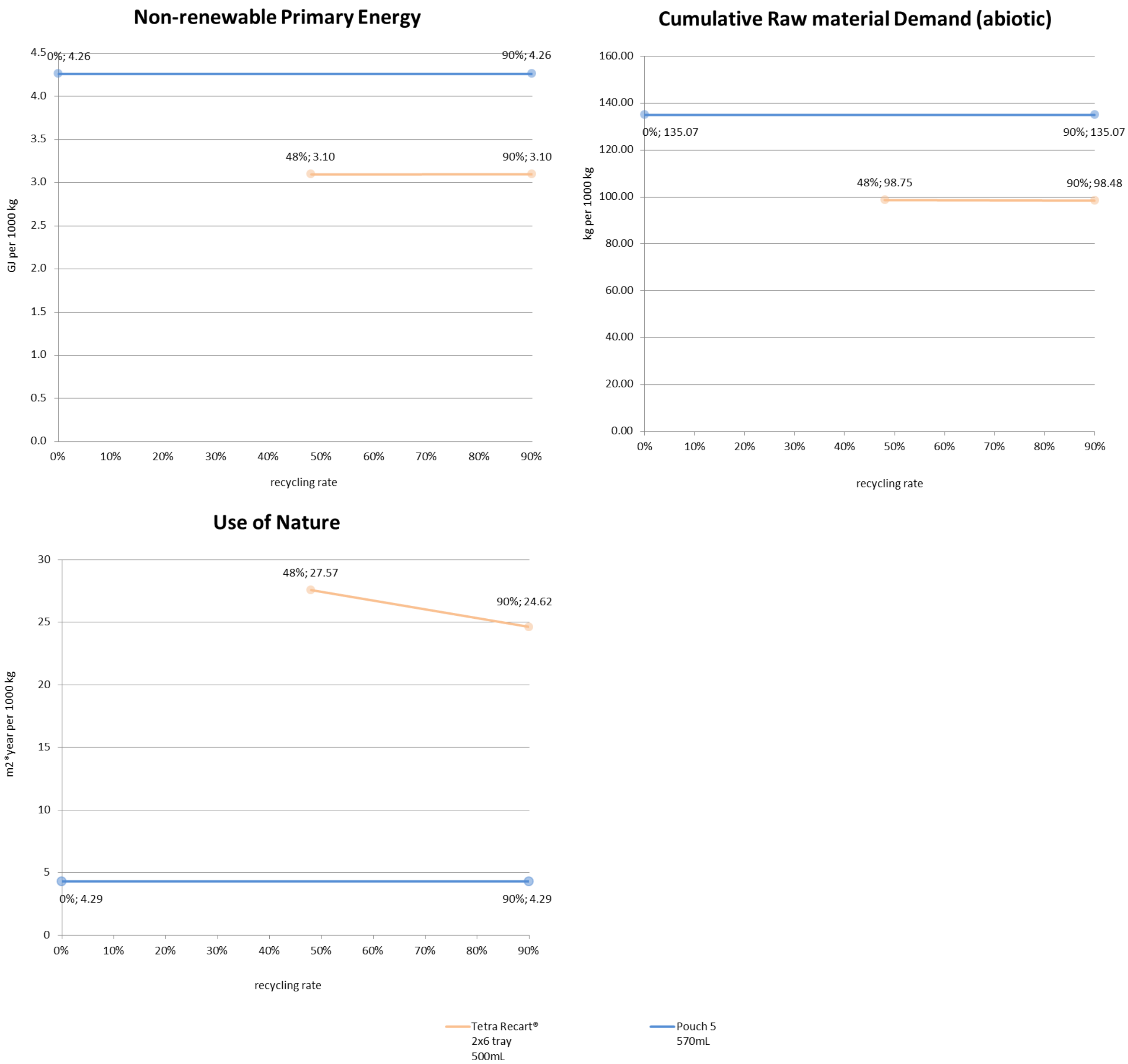


Figure 22: Indicator results for scenario variants recycling rate of **segment soup Europe**, allocation factor 50% (Part 3)

Description and Interpretation

The increase of the recycling rate of the Tetra Recart® and the pouch leads to decreasing net results.

In all comparisons in this segment the increase of recycled content does not change the ranking between Tetra Recart® and the compared packaging system.

5.2 Scenario variants regarding recycled content

In the base scenarios materials for the competing packaging systems are calculated with recycled content in cases in which the use of recycled material is currently applied. In order to show effects of potential increases in recycled content scenario variants are calculated with increased shares of recycled content (see Table 14). The results are shown in break-even graphs with a recycled content ranging from the value of the base scenario up to its maximum share of recycled content. In these analyses, the system allocation factor applied for open-loop-recycling is 50%.

5.2.1 Scenario variants regarding recycled content, soup, Europe

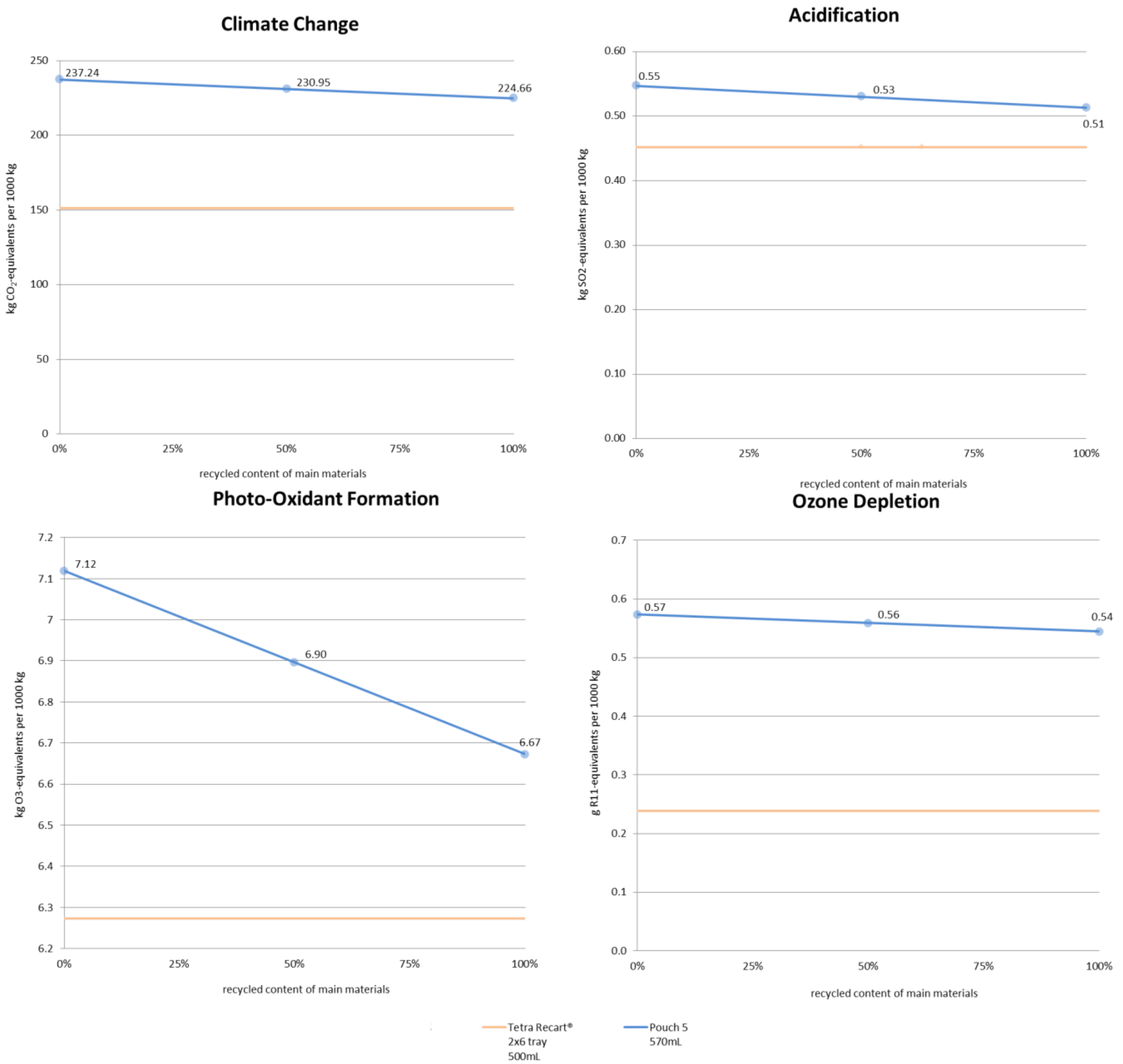


Figure 23: Indicator results for scenario variants recycled content of **segment soup Europe**, allocation factor 50% (Part 1)

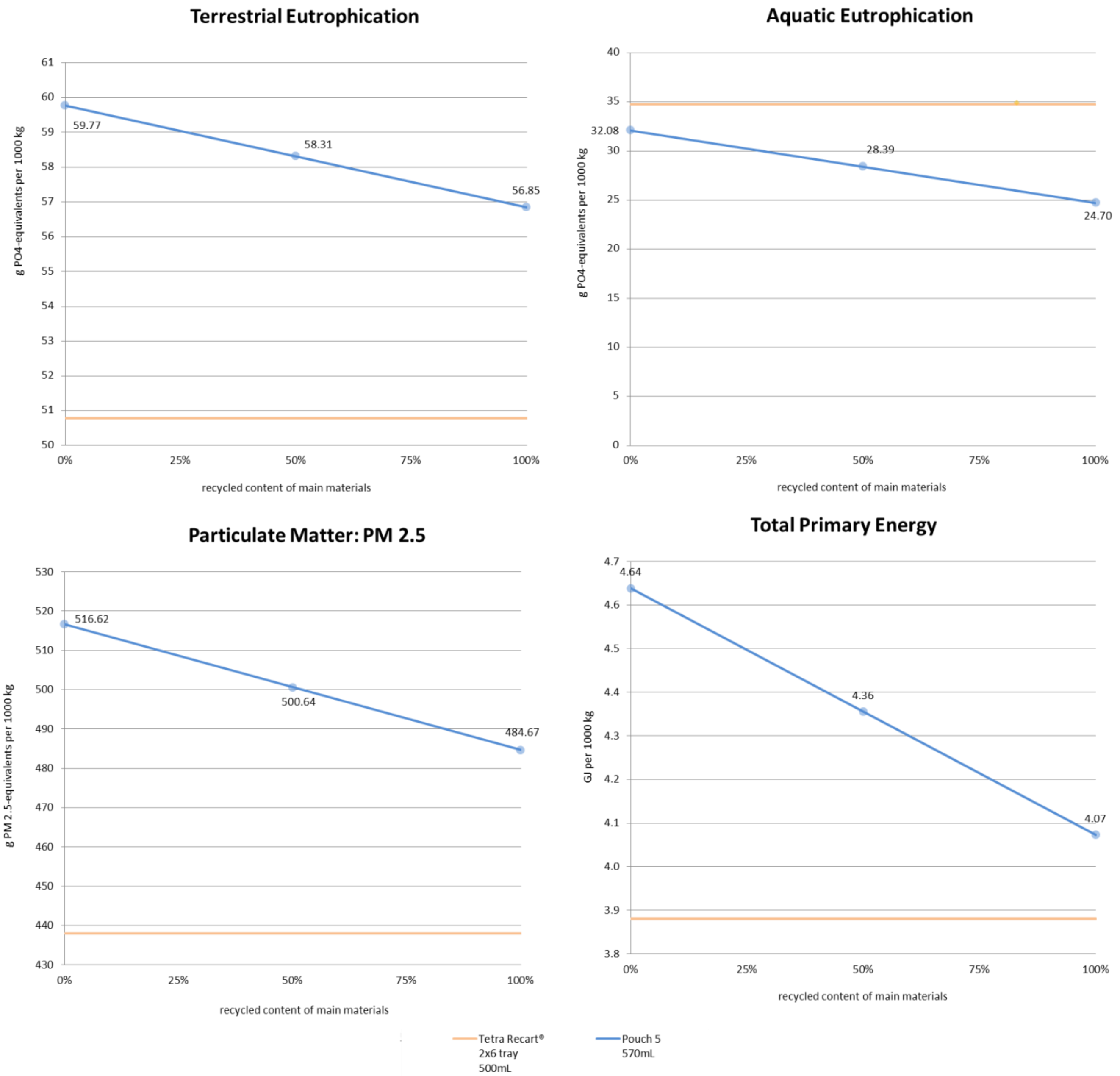


Figure 24: Indicator results for scenario variants recycled content of **segment soup Europe**, allocation factor 50% (Part 2)

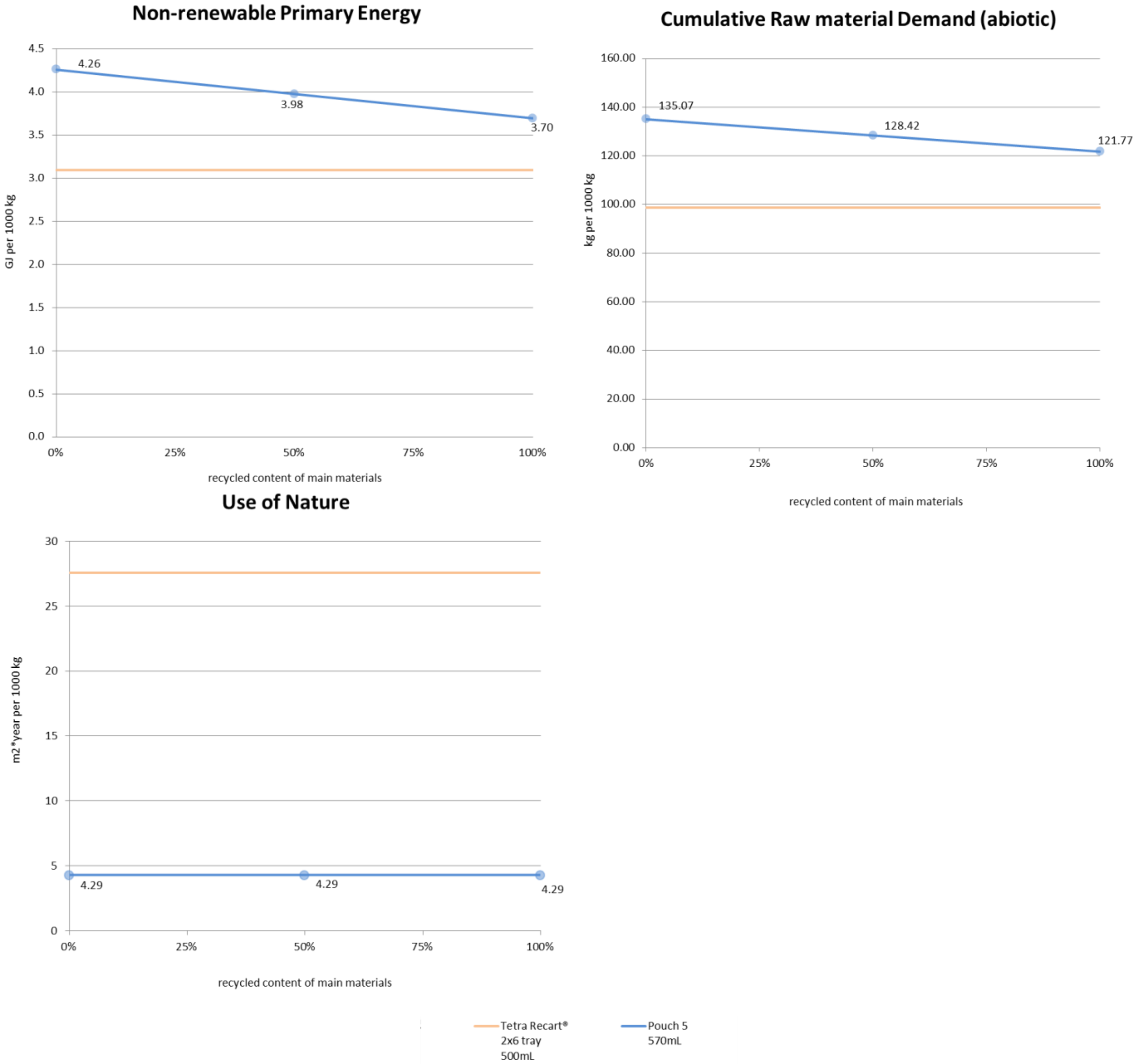


Figure 25: Indicator results for scenario variants recycled content of **segment soup Europe**, allocation factor 50% (Part 3)

Description and Interpretation

The increase of recycled content in the main materials of the pouch leads to decreasing net results.

In case of 'Aquatic Eutrophication' the increase of recycled content in the main materials of the pouch leads to higher net results for the Tetra Recart®.

In the other comparisons the increase of recycled content does not change the ranking between Tetra Recart® and the compared packaging system.

6 Conclusions

In the following sections results are summarised and conclusions are drawn regarding the environmental impact assessment of the packaging systems in the soup segment on the European market. The results of the 0% allocation, 50% allocation and the 100% allocation are taken into account to the same degree. The following sections include also the conclusions regarding the assessed scenario variants.

6.1 Europe

6.1.1 Soup, Europe

In case of 'Climate Change' the Tetra Recart® packaging system in this segment shows lower impacts than the compared competing packaging system regardless of the allocation factor.

In case of 'Use of Nature' the Tetra Recart® packaging system shows higher impacts than the competing packaging system regardless the allocation factor.

In case of the other impact categories the comparison of the examined Tetra Recart® packaging systems with the pouch shows lower or similar impacts for the Tetra Recart® packaging systems depending on the regarded category.

The choice of allocation factor has an influence on the comparative assessment of the environmental impacts in this segment. As all three allocation methods should be included in the conclusion the following clear conclusion can be drawn:

- The impacts of Tetra Recart® compared to the pouch are
  - lower in all impact categories regarded except 'Aquatic Eutrophication' and 'Use of Nature'.
  - higher regarding 'Use of Nature'.

The scenario variants regarding recycling rate and recycled content do not change the comparative conclusions in this segment in most cases with the following exception:

- In case of 'Aquatic Eutrophication' the increase of recycled content in the main materials of the pouch leads to higher net results for the Tetra Recart®.

7 Limitations

The results of the base scenarios and analysed packaging systems and the respective comparisons between packaging systems are valid within the framework conditions described in sections 1 and 2. The following limitations must be taken into account however.

Limitations arising from the selection of **market segments**:
The results are valid only for the filling product soup. Even though Tetra Recart® carton packaging systems and regarded competing packaging systems are common in other market segments, other filling products create different requirements towards their packaging and thus certain characteristics may differ strongly, e.g. barrier functions.

Limitations concerning **selection of packaging systems:**
The results are valid only for the exact packaging systems, which have been chosen by Tetra Pak. Even though this selection is based on market data it does not represent the whole European market.

Limitations concerning **packaging system specifications:**
The results are valid only for the examined packaging systems as defined by the specific system parameters, since any alternation of the latter may potentially change the overall environmental profile.

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

Each packaging system is defined by multiple system parameters, which may potentially alter the overall environmental profile. All packaging specifications of the carton packaging systems were provided by Tetra Pak® and are to represent the typical packaging systems used in the analysed market segment. These data have been cross-checked by ifeu.

To some extent, there may be a certain variation of design (i.e. specifications) within a specific packaging system. Packaging specifications different from the ones used in this study cannot be compared directly with the results of this study.

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

Limitations concerning the analysed impact **categories**:
The results are valid only for the environmental impact categories, which were examined. They are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks. This means that the potential damage caused by the substances is not taken into account.

Limitation concerning the assessment of **raw materials**:
Raw materials are not assessed on impact category level. The abiotic Cumulated Resource Demand (CRD) is included as inventory category. Biotic raw materials are not included in this category. Additionally the Cumulative Energy Demand (CED) is included in the inventory categories as indication for the loss potential of energy resources. The consequence of this methodological decision is that there is an imbalance regarding the information on raw materials. While materials with energy content are inventoried in the CED, raw materials without energy content are not considered.

Limitation concerning the assessment of **water use**:
Due to the lack of mandatory information to assess the potential environmental impact, water scarcity cannot be assessed on LCIA level within this study. However, the use of water will be included as an inventory category. However, it includes neither any reference to the origin of this water, nor to its quality at the time of output/release. The respective results in this category are therefore of mere indicative nature and are not suited for conclusive quantitative statements related to either of the analysed packaging systems.

Limitations concerning **geographic boundaries**:
The results are valid only for the indicated geographic scopes and cannot be assumed to be valid in geographic regions other than Europe, even for the same packaging systems.

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

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

Limitations concerning **allocation**:
The results are only valid for the applied allocation approaches in this study. Allocation approaches other than those used in this study can lead to different results.

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

For all packaging systems, the same methodological choices were applied concerning allocation rules, system boundaries and calculation of environmental categories.

8 Recommendations

The following overall recommendations summarise the findings of the analysed packaging comparisons.

The Tetra Recart® carton analysed in this study shows different environmental performances depending on different segments as well as their packaging specifications.

The alternative pouch packaging system examined in this study shows high burdens from the production of its base materials, like plastics and aluminium. For the Tetra Recart® cartons on the other hand the production of liquid packaging board (LPB) does not contribute as much to most of the environmental impact, as its production utilises mainly renewable energy.

The results of the comparisons of the Tetra Recart® carton with the competing pouch packaging system show lower impacts for the Tetra Recart® carton in all impact categories except 'Aquatic Eutrophication' and 'Use of Nature'. In case of 'Use of Nature' the Tetra Recart® carton shows substantial higher impacts than the compared alternative pouch packaging system.

In general the recommendations are limited concerning the categories related of resources. The only assessed impact category is 'Use of Nature'. The categories 'Water use', 'Cumulative Raw material Demand (abiotic)', 'Total Primary Energy' and 'Non-renewable Energy' are inventory categories only and therefore not fully considered for the conclusions.

From the findings of this study the authors develop the following recommendations:

- From an environmental viewpoint it is recommended to prefer the assessed Tetra Recart® carton over the compared pouch.
- It is recommended to the industries and related associations in general to provide more comprehensive process inventory data, especially for production processes to reduce the level of data asymmetries that could lead to misinterpreted results (f.e. regarding water use: regionalised data and water output flows). This is required to allow recently developed methods such as assessment methods for water consumption and UseTox to be successfully applicable. Further data improvement is also recommended for the application of the impact category Use of Nature.

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Appendix A: Impact categories

The impact categories used in this study are introduced below and the corresponding characterisation factors are quantified. In each case, references are given for the origin of the methods that were used. The procedure for calculating the indicator result is given at the end of each sub-section.

A.1 Climate change

Climate Change is the impact of anthropogenic emissions on the radiative forcing of the atmosphere causing a temperature rise at the earth's surface. This could lead to adverse environmental effects on ecosystems and human health. This mechanism is described in detail in the relative references [IPCC 1995]. The category most used in life cycle assessments up to now is the radiative forcing [CML 2002, Klöpffer 1995] and is given as CO_2 equivalents. The characterisation method is a generally recognised method.

The Intergovernmental Panel on Climate Change (IPCC) is an international body of experts that computes and extrapolates methods and relevant parameters for all substances that influence climate change. The latest IPCC reports available at the time of LCA calculations commonly represent the scientific basis for quantifying climate change.

All carbon dioxide emissions, whether they are of regenerative or fossil origin, are accounted for with a characterisation factor of 1 CO_2 equivalent.

When calculating CO_2 equivalents, the gases' residence times in the troposphere is taken into account and the question arises as to what period of time should be used for the climate model calculations for the purposes of the product life cycle. Calculation models for 20, 50 and 100 years have been developed over the years, leading to different global warming potentials (GWPs). The models for 20 years are based on the most reliable prognosis; for longer time spans (500-year GWPs have been used at times), the uncertainties increase [CML 2002]. The Centre of Environmental Science – Leiden University (CML) as well as the German Environmental Agency both recommend modelling on a 100-year basis because it allows to better reflect the long-term impact of Climate Change. According to this recommendation, the 'characterisation factor' applied in the current study for assessing the impact on climate change is the *Global Warming Potential* for a 100-year time period based on IPCC 2013.

An excerpt of the most important substances taken into account when calculating the Climate Change are listed below along with the respective CO_2-equivalent factors – expressed as Global Warming Potential (GWP).

Greenhouse gas	CO_2 equivalents (GWP_i)[1]
Carbon dioxide (CO_2). fossil	1
Methane (CH_4)[2] fossil	30
Methane (CH_4) regenerative	28
Nitrous oxide (N_2O)	265
Tetrafluoromethane	6630
Hexafluoroethane	11100
Halon 1301	6290
R22	1810
Tetrachlormethane	1760
Trichlorethane	160
• Source: [IPCC 2013]	

Table A-1: Global warming potential for the most important substances taken into account in this study; CO_2 equivalent values for the 100-year perspective

Numerous other gases likely have an impact on GWP by IPCC. Those greenhouse gases are not represented in Table A-1 as they are not part of the inventory of this LCA study.

The contribution to the Climate Change is obtained by summing the products of the amount of each emitted harmful material (m_i) of relevance for Climate Change and the respective GWP (GWP_i) using the following equation:

$$GWP = \sum_i (m_i \times GWP_i)$$

Note on biogenic carbon:

At the impact assessment level, it must be decided how to model and calculate CO_2-based GWP. In this context, biogenic carbon (the carbon content of renewable biomass resources) plays a special role: as they grow, plants absorb carbon from the air, thus reducing the amounts of carbon dioxide in the atmosphere. The question is how this uptake should be valued in relation to the (re-)emission of CO_2 at the material's end of life, for example CO_2 fixation in biogenic materials such as growing trees versus the greenhouse gas's release from thermal treatment of cardboard waste.

In the life cycle community two approaches are common. CO_2 may be included at two points in the model, its uptake during the plant growth phase attributed with negative GWP values and the corresponding re-emissions at end of life with positive ones. Alternatively, neither the uptake of non-fossil CO_2 by the plant during its growth nor the corresponding CO_2 emissions are taken into account in the GWP calculation.

[1] The values reported by [IPCC 2013] in Appendix 8.A were rounded off to whole numbers.
[2] According to [IPCC 2013], the indirect effect from oxidation of CH_4 to CO_2 is considered in the GWP value for fossil methane (based on Boucher et al., 2009). The calculation for the additional effect on GWP is based on the assumption, that 50% of the carbon is lost due to deposition as formaldehyde to the surface (IPCC 2013). The GWP reported for unspecified methane does not include the CO_2 oxidation effect from fossil methane and is thus appropriate methane emissions from biogenic sources and fossil sources for which the carbon has been accounted for in the LCI.

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

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

A.2 Photo-oxidant formation

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

The method to be applied for the impact category Photo-oxidant formation, should be the „Maximum Incremental Reactivity“ of VOC und Nitrogen-MIR (Nitrogen-MIR) based on the publication of [Carter 2010]. The MIR concept is the most appropriate characterisation model for LCIA based on generic spatial independent global inventory data and combines a consistent modelling of potential impacts for VOC and NOx and the precautionary principle. The MIR and NMIR are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NOx inputs. The unit for the category indicator MIR is kg O_3-e.
The related characterisation factors applied in this study are based on [Carter 2010]. Examples of the factors for more than 1100 substances are listed in Table A-2.

Harmful gas (examples)	**Characterisation factors (MIR/NMIRs$_i$)** [Carter 2010] [g O_3-e/g-emission]
1-Butene	9.73
1-Propanol	2.50
2-Propanol	0.61
Acetaldehyde	6.54
Acetic acid	0.68
Acetone	0.36
Benzene	0.72
Carbon monoxide, fossil	0.056
Ethane	0.28
Ethanol	1.53
Ethene	9.00
Formaldehyde	9.46
Methane, fossil	0.014
Methanol	0.67
NMVOC, unspecified	3.60
Styrene	1.73
Nitrogen dioxide	16.85
Nitrogen monoxide	24.79
Toluene	4,00
Source: [Carter 2010]	

Table A-2: Maximum Incremental Reactivity (MIR) of substances considered in this project (excerpt)

The contribution to the Maximum Incremental Reactivity is calculated by summing the products of the amounts of the individual harmful substances and the respective MIR values using the following equation:

$$MIR = \sum_i (m_i \times MIR_i)$$

A.3 Stratospheric ozone depletion

Stratospheric ozone depletion refers to the thinning of the stratospheric ozone layer as a result of anthropogenic emissions. This causes a greater fraction of solar UV-B radiation to reach the earth's surface, with potentially harmful impacts on human health, animal health, terrestrial and aquatic ecosystems, biochemical cycles and materials [UNEP 1998]. The ozone depletion potential category indicator that was selected and described in [CML 1992, CML 2002] uses a list of 'best estimates' for ODPs that has been compiled by the World Meteorological Organisation (WMO). These ODPs are steady-state ODPs based on a model. They describe the integrated impact of an emission or of a substance on the ozone layer compared with CFC-11 [CML 2002]. The following table shows the list of harmful substances considered in this study, along with their respective ozone depletion potential (ODP) expressed as CFC-11 equivalents based on the latest publication of the WMO [WMO 2011].

Harmful substance	CFC-11 equivalent (ODP_i)
CFC-11	1
CFC-12	0.82
CFC-113	0.85
CFC-114	0.58
CFC-115	0.57
Halon-1301	15.9
Halon-1211	7.9
Halon-2402	13
CCl_4	0.82
CH3CCl3	0.16
HCFC-22	0.04
HCFC-123	0.01
HCFC-141b	0.12
HCFC-142b	0.06
CH_3Br	0.66
N_20	0.017

- Source: [WMO 2011]

Table A-4: Ozone depletion potential of substances considered in this study

The contribution to the ozone depletion potential is calculated by summing the products of the amounts of the individual harmful substances and the respective ODP values using the following equation:

$$ODP = \sum_i (m_i \times ODP_i)$$

A.4 Eutrophication and oxygen-depletion

Eutrophication means the excessive supply of nutrients and can apply to both surface waters and soils. With respect to the different environmental mechanisms and the different safeguard subjects, the impact category eutrophication is split up into the terrestrial eutrophication and aquatic eutrophication.

The safeguard subject for freshwater aquatic ecosystems is defined as preservation of aerobic conditions and the conservation of site-specific biodiversity, whereas the safeguard subject for terrestrial ecosystems addresses the preservation of the natural balance of the specific ecosystem, the preservation of nutrient-poor ecosystems as high moors and the conservation of site-specific biodiversity.

It is assumed here for simplification that all nutrients emitted via the air cause enrichment of the terrestrial ecosystems and that all nutrients emitted via water cause enrichment of the aquatic ecosystems. Oligotrophy freshwater systems in pristine areas of alpine or boreal regions are often not affected by effluent releases, but due to their nitrogen limitation sensitive regarding atmospheric nitrogen deposition. Therefore, the potential impacts of atmospheric nitrogen deposition on oligotrophic waters are included in the impact category terrestrial eutrophication.

The eutrophication of surface waters also causes oxygen-depletion as secondary effect. If there is an over-abundance of oxygen-consuming reactions taking place, this can lead to oxygen shortage in the water. The possible perturbation of the oxygen levels could be measured by the Bio-chemical Oxygen Demand (BOD) or the Chemical Oxygen Demand (COD). As the BOD is often not available in the inventory data and the COD essentially represents all the available potential for oxygen-depletion, the COD is used as a conservative estimate[1].

In order to quantify the magnitude of this undesired supply of nutrients and oxygen depletion substances, the eutrophication potential category was chosen. This category is expressed as phosphate equivalents [Heijungs et al. 1992]. The table below shows the harmful substances and nutrients that were considered in this study, along with their respective characterisation factors:

[1] The COD is (depending on the degree of degradation) higher than the BOD, which is why the equivalence factor is deemed relatively unreliable and too high.

Harmful substance	PO_4^{3-} equivalents (EP_i) in kg PO_4^{3-} equiv./kg
Eutrophication potential (terrestrial)	
Nitrogen oxides (NO_X as NO_2)	• 0.13
Ammonia (NH_3)	• 0.35
Dinitrogen oxide (N_2O)	• 0.27
Eutrophication potential (aquatic) (+ oxygen depletion)	
Phosphate ($PO4^{3-}$)	• 1
Total phosphorus	• 3.06
Chemical Oxygen Demand (COD)	• 0.022
Ammonium (NH_4^+)	• 0.33
Nitrate (NO_3^{2-})	• 0.1
N-compounds. unspec.	• 0.42
P as P_2O_5	• 1.34
P-compounds unspec.	• 3.06
• Source: [Heijungs et al 1992]	

Table A-3: Eutrophication potential of substances considered in this study

The eutrophication potential (EP) is calculated separately for terrestrial and aquatic systems. In a rough simplification the oligotrophic aquatic systems are covered by the terrestrial eutrophication potential. In each case, that contribution is obtained by summing the products of the amounts of harmful substances that are emitted and the respective EP values.

The following equations are used for terrestrial or aquatic eutrophication:

$$EP(aquatic) = \sum_i (m_i \times EP(aquatic)_i)$$

$$EP(terrestrial) = \sum_i (m_i \times EP(terrestrial)_i)$$

A.4 Acidification

Acidification can occur in both terrestrial and aquatic systems. The emission of acid-forming substances is responsible for this.

The acidification potential impact category that was selected and described in [CML 1992, CML 2002, Klöpffer 1995] is deemed adequate for this purpose. No specific characteristics of the affected soil or water systems are hence necessary. The acidification potential is usually expressed as SO_2 equivalents. The table below shows the harmful substances considered in this study, along with their respective acidification potential (AP) expressed as SO_2 equivalents.

Harmful substance	**SO_2 equivalents (AP_i)**
Sulphur dioxide (SO_2)	• 1
Nitrogen oxides (NO_X)	• 0.7
Hydrochloric acid (HCl)	• 0.88
Hydrogen sulphide (H_2S)	• 1.88
Hydrogen fluoride (HF)	• 1.6
Hydrogen cyanide (HCN)	• 1.6
Ammonia (NH_3)	• 1.88
Nitric acid (HNO_3)	• 0.51
Nitrogen oxide (NO)	• 1.07
Phosphoric acid (H_3PO_4)	• 0.98
Sulphur trioxide (SO_3)	• 0.8
Sulphuric acid (H_2SO_4)	• 0.65
• Source: [Hauschild und Wenzel 1998] taken from [CML 2010]	

Table A-4: Acidification potential of substances considered in this study

The contribution to the acidification potential is calculated by summing the products of the amounts of the individual harmful substances and the respective AP values using the following equation:

$$AP = \sum_i (m_i \times AP_i)$$

A.5 Particulate matter

The category chosen for this assessment examines the potential threat to human health and natural environment due to the emission of fine particulates (primary particulates as well as precursors). Epidemiological studies have shown a correlation between the exposure to particulate matter and the mortality from respiratory diseases as well as a weakening of the immune system. Relevant are small particles with a diameter of less than 10 and especially less than 2.5 µm (in short referred to as PM10 and PM2.5).These particles cannot be absorbed by protection mechanisms and thus deeply penetrate into the lung and cause damage.

Particulate matter is subsuming primary particulates and precursors of secondary particulates. Fine particulate matter can be formed from emissions by different mechanisms: On the one hand particulate matter is emitted directly during the combustion process (primary particles), on the other hand particles are formed by chemical processes from nitrogen oxide and sulphur-dioxide (secondary particles).

They are characterised according to an approach by [De Leeuw 2002].

In accordance with the guidelines of [WHO 2005], PM2.5 is mostly relevant for the toxic effect on human health. Thus, the category indicator aerosol formation potential (AFP) referring to PM2.5-equivalents is applied. The substances assigned to this category are primary particles and secondary particles formed by SO_2, NOx, NH_3 and NMVOCs ([WHO 2005]). The non-organic substances are characterised according to an approach by [De Leeuw 2002]. This characterisation factors were used for reporting by the European Environmental Agency until 2011 and are based on dispersion model results by [Van Jaarsveld 1995]. [ReCiPe 2008] and [JRC 2011] are also using the same base dispersion model results for the calculation of particulate formation. The model by [De Leeuw 2002] covers European emissions and conditions, but is the best available approach for quantifying population density independent factors and is therefore applied for all emissions.

Regarding NMVOC emissions, only the knowledge of exact organic compounds would allow quantification as secondary particles. Therefore, an average value for unspecified NMVOCs calculated by [Heldstab et al. 2003] is applied.

Harmful substance	PM2.5 equivalents (PFP_i) (Air) [kg PM2.5 equivalents/kg]
PM2.5	1
PM10	0.5
NH_3	0.64
SO_2	0.54
SO_x	0.54
NO	0.88
NO_x	0.88
NO_2	0.88
NMVOC[1)]	0.012
Source: [De Leeuw 2002]; [1)] [Heldstab et al. 2003]	

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

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

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

A.6 Use of Nature

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

Recently the so called hemeroby concept in order to provide an applicable and meaningful impact category indicator for the integration of land use and biodiversity into the Life Cycle (Impact) Assessment has been developped by [Fehrenbach et al. 2015]. This approach is operationalized by a multi-criteria assessment linking the use of land to different subjects of protection: Structure and functionality of ecosystems, biological diversity and different ecosystem services contributing to human wellbeing. In this sense hemeroby is understood as a mid-point indicator giving explicite information on naturalness and providing implicite information, at least partly, on biodiversity (number of species, number of rare or threathened species, diversity of structures), and soil quality (low impact.)

The system of hemeroby is subdivided in to seven classes (see Table 1). This system is appropriate to be applied on any type of land-use type accountable in LCA. Particularly production systems for biomass (wood from forests, all kinds of biomass from agriculture) are assessed in a differentiated way:

> To describe forest systems three criteria are defined: (1) natural character of the soil, (2) natural character of the forest vegetation, (3) natural character of the development conditions. The degree of performance is figured out by applying by 7 metrics for each criterion.
>
> Agricultural systems are assessed by four criteria: (1) diversity of weeds, (2) Diversity of structures, (3) Soil conservation, (4) Material input. Three metrics are used for each criterion to calculate the grade of hemeroby.

The approach includes the derivation of inventory results (x m^2 of area classified as class y) as well as the aggregation to the category indicator ‘Distance-to-Nature-Potential’ (DNP) (m^2-e * 1a) by characterization factors.

Class	Class name	Land-use type
I	• Natural	undisturbed ecosystem, pristine forest

II	• close-to-nature	close-to-nature forest management
III	• partially close to nature	intermedium forest management, Highly diversified structured agroforestry systems
IV	• semi-natural	half-natural forest management, Extensive grassland, mixed orchards
V	• partially distant to nature	mono-cultural forest, Intensified grassland (pastures); Agriculture with medium large cuts
VI	• distant-to-nature	Highly intensified agricultural land, large areas cleared landscape
VII	• non-natural, artificial	long-term sealed, degraded or devastated area
Source: Fehrenbach et al. 2015		

Table A-6.1: The classification system of hemeroby classes

Class VII as the category most distant from nature is characterized by factor 1. Each class ascending towards naturalness will be characterized by a factor half from the precedent. Therefore the maximum span from class VII to class II is 1 : 32, an span which corresponds with share of class VII area of entire area.[1] Table A-6.2 lists the characterisation factors for each class.

Class	Characterisation factor (DNP_i)
I	0
II	0.0313
III	0.0625
IV	0.125
V	0.25
VI	0.5
VII	1

Table A-6.2: The characterisation factors of hemeroby classes

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

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

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

A.8 References (for Appendix A)

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Appendix B:

Critical Review Report

Critical Review Report

Critical Review of the reports:

"Comparative Life Cycle Assessment of Tetra Recart® packages and alternative packaging systems for shelf stable pet and baby food on the European, US and Japanese markets"

and

"Comparative Life Cycle Assessment of Tetra Recart® packages and alternative packaging systems for shelf stable soup on the European market"

Commissioner:	Tetra Pak Packaging Solutions AB
Authors:	Samuel Schlecht, Frank Wellenreuther ifeu – Institut für Energie- und Umweltforschung Heidelberg gGmbH**,** Germany
Reviewer:	Panel Leader: Dr. Martin Baitz, Senior Life Cycle Sustainability Expert at Sphera Solutions GmbH, Leinfelden-Echterdingen, Germany Panel Experts: Ms. Beverly Sauer, Senior Life Cycle Analyst at Franklin Associates, a Division of ERG, USA Dr. Jun Nakatani, Assistant Professor at Department of Urban Engineering, The University of Tokyo, Japan
Reference:	ISO 14040 (2006): Environmental Management - Life Cycle Assessment - Principles and Framework ISO 14044 (2006): Environmental Management - Life Cycle Assessment – Requirements and Guidelines ISO/TS 14071(2014): Environment Management-Life Cycle Assessment- Critical review processes and reviewer competencies: Additional requirements and guidelines to ISO 14044:2006

Scope of the Critical Review

The objective of the project was to conduct an ISO Panel Critical review as per ISO/TS 14071:2014, ISO 14040 (2006) and ISO 14044 (2006) for a related "twin" study to assess the environmental performance (based on life cycle assessment) of Tetra Recart packaging solutions compared to alternative packaging solutions on the European, US and Japanese markets.

The commissioner of the study chose and contacted suitable experts that are potentially covering - in a representative and neutral way - the different markets assessed, the needed methodological knowhow and the various materials covered. The commissioner appointed initially Mr. Manfred Russ at Sphera Solutions as Panel Leader to define a suitable review panel of 3 experts. Mr. Martin Baitz (also at Sphera Solutions) took over the Panel Lead after the panel was finally formed, but already in the beginning of the technical review process, due to Mr. Russ leaving the company.

The twin study under review compares Tetra Recart packaging solutions (based on a composite of paper, cardboard, aluminum and polymer layers) with alternative packaging solutions (mainly based on steel, aluminum, glass and polymers).

The study reports are intended for use internally in Tetra Pak towards decision making, in product development to shape future strategies towards product design and technology development, in B2B (Business-to-Business) communications as well as in potential public communication.

The review was performed according to paragraph 6.3 of ISO 14044, because the study is intended to be used for comparative assertions intended to be disclosed to the public.

The review panel had the task to assess whether:

1. The methods used to carry out the LCA are consistent and in accordance with international standards (ISO 14040 and ISO 14044).
2. The methods used to carry out the LCA are scientifically and technically valid.
3. The information and data used are appropriate and reasonable in relation to the goal of the study.
4. The interpretations reflect the limitations identified and the goal of the study.
5. The report of the study is transparent and consistent.

Notices

I. This review is valid for the reports issued in April 2021.

II. A specific verification of individual (Tetra Pak) data and datasets representing the Tetra Pak specific products and technologies as well as the "correctness" of used background datasets are principally outside of the scope of such reviews, however all data(sets) used were checked and no inadequacy leading to different results in this scope was detected.

III. Relevant background data was double checked and partly adapted to reflect the given situation even more appropriately.

The review process

The technical review process was coordinated between the authors of IFEU and the review panel. The review process started with the provision of the first draft of the final report in October 2020, which was reviewed by the panel and questions and comments of the reviewers were compiled. The second draft of the final report followed in December 2020 producing follow-up questions and comments by the reviewers. The final report with all aspects technically addressed and adequately solved was delivered in April 2021 and accepted by the reviewers.

During this iterative review process two extensive online meetings in the plenum to discuss and clarify all aspects concerning the study and reports were undertaken; in late 2020 and early 2021. These online meetings were framed by several email discussion rounds to further discuss, propose, and clarify aspects.

IFEU was anytime supportive to provide additional clarifying information requested by the reviewers. The critical review panel evaluated the first draft producing about 80 questions, comments and suggestions of general, technical and editorial nature; the second draft report produced about 20 follow-up questions, comments and suggestions. The online meetings and email conversations facilitated all stakeholders to reach a common understanding on remaining aspects in these comprehensive and complex reports. A comprehensive internal review documentation of about 40 pages was produced to facilitate the discussions and clarifications during the review process.

With the final report provided in April 2021 all comments and suggestions were technically adequately addressed and the related technical and editorial modifications in the report completed.

The reviewers acknowledge the willingness and competence of the authors to further improve the report iteratively during the review. The authors granted unrestricted access to requested information and supported an open and constructive dialogue during the critical review process.

General evaluation

The study is the result of a comprehensive effort by Tetra Pak and IFEU to analyze various packaging systems from cradle to grave with an LCA model. The LCA models are set-up based on primary data (provided by Tetra Pak or related sources), technical literature, various LCA reports of associations and organizations representing the different materials and mostly consistent secondary data. The aim was to compile the best available and most representative data for each of the packaging variants and connect the data sets with appropriate methodological and technical approaches into a representative LCA model of the given Goal and Scope.

The report is well written and comprehensive. It contains comparative results, many scenario and sensitivity calculations to support proper interpretation of the results. The defined scope for this LCA study was found to be appropriate to achieve the stated goals. Various assumptions were addressed and backed by sensitivity analyses of critical data and related methodological choices. The system under study was carefully defined and modeled.

The study and reports generated comprehensive, transparent, and consistent results. Due to the complex nature assumptions had to be done which is based on “precautionary principle” approach: In any doubt of representativeness or choice concerning a relevant technical parameter or data, a conservative choice or assumption was taken. The assumptions are transparently described and are found to be suitable and acceptable concerning the conclusions.

The reviewers like to underline that all aspects are technically well addressed and solved, and no “critical” aspects were left. However, we like to add 3 concrete notes to support an even better understanding of the complex reports.

Concerning aluminum data used: “Aluminum data of different age was used due to availability reasons at the authors; no indication was identified that the fact is influencing the conclusions”.

Concerning glass data: “Latest glass data was intentionally not used by the authors, due to a different “surplus energy substitution approach”; the rejection was explained to the reviewers and acknowledged; no indication was identified that the fact is influencing the conclusions.”

Concerning water results: “A well-received disclaimer in the report notifies about the water results. As water is still a new topic in LCI data collection in industry and in background databases, the degree of detail and quality of reported or omitted LCI water data is still varying and may not done in the same way for all data used. So direct comparisons between different materials on water should be avoided or be only done carefully. The authors were in favor to keep the water results displayed in the report, to avoid potential criticism for omitting a relevant impact. The authors decision was acknowledged by the reviewers.”

LCA standard software and data, literature Information and suitable own engineering assumptions were used to model upstream process chains and closed data gaps adequately. The study has been performed in a professional manner using engineering expertise, state-of-the-art LCA methods, adequate LCA Software and models.

The background data was in certain cases cross checked - due to its age - and found still suitable for this goal and scope, due to the conservative approach chosen and the relatively small contribution to the results.

The significant material data was taken from related LCA information of material producers or associations and found to be suitable for this goal and scope.

The data quality for the primary information (provided data on Tetra Recart) was found to be high.

All in all, these are very good – hence complex – LCA study reports.

Concluding review statement

The study has been carried out in compliance with ISO 14040 and ISO 14044. The reviewer found the overall quality of the methodology and its execution to be adequate for the purposes of the study. The study is very comprehensive including a transparent documentation of its scope. The used secondary data sources, the used software and background data, the documentation, the adequate scenarios and sensitivity checks, as well as the discreet and careful interpretation make this report and its results very consistent, applicable and valuable. The study report is transparent and consistent, and the interpretation of the results fully supports the intended goal and the identified limitations of the study.

The critical review panel found the overall quality of its methods scientifically and technically valid and the used data appropriate and reasonable.

Japan, USA, Germany 20.04.2021

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