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Comparative Life Cycle Assessment of sterilised food packaging systems on the European market

Final report

commissioned by SIG Combibloc

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Executive summary

Background, goal and scope

The “Comparative life cycle assessment of sterilised food packaging systems on the European market” conducted by *IFEU Heidelberg* investigates the environmental performance of the heat resistant food carton *combisafe* and the aseptic food carton *combibloc* and its performance in comparison to alternative systems for the packaging of ambient liquid food products with particulate contents (retortable pouch, glass jar, steel can and plastic pot).

The study covers the European market situation for the EU 27 countries & Switzerland & Norway in 2011/2012. The choice of the analysed packaging systems has been done according to the European market share.

The study was performed in accordance with the relevant ISO standards (ISO 14040 and ISO 14044) and accompanied by a critical review process. The results may be used in internal and external communication, i.e. SIG Combibloc’s customers, retailers, authorities and NGOs.

A wide range of environmental impact categories and inventory level indicators is covered. The considered emission-related impact categories are *Climate Change*, *Summer Smog*, *Acidification* and *terrestrial* as well as *aquatic Eutrophication*, furthermore *Human toxicity: PM10*. The regarded impact indicator related to the consumption of resources is *Abiotic Resource Depletion*. The following inventory categories are included: *Primary energy consumption* – both *total* and *non-renewable* – as well as *Transport intensity: Lorry*. The assessment of the environmental impacts of *Water Consumption* and *Use of Nature* is omitted, as there are no robust methodologies to assess these in LCA that work with the detail of data in inventories available so far for both of them.

For each packaging system a base scenario was defined and calculated. In these base scenarios a 50% allocation approach was used for open-loop-recycling. Regarding the end-of-life phase, an average recycling rate and an average final waste disposal split (landfill/incineration) for Europe (EU27+2) was applied.

Furthermore, sensitivity analyses were performed to verify the influence of the applied allocation method in the base scenarios and to provide indications about the environmental performance of the regarded packaging systems, if varying recycling rates are applied. A further sensitivity analysis was calculated using a different assessment method for eutrophication potential to verify the influence of consideration of the Chemical Oxygen Demand for aquatic eutrophication. To evaluate the relative importance of each regarded indicator, a normalisation step was included in the study.

Results and conclusions

For the examined packaging systems the major impact in most of the analysed environmental indicators originates from the production of the base materials used for primary packaging. This is especially true for the production of plastics and aluminium as well as for the production of tinplate and glass. The production of LPB for food cartons plays a somewhat less important role in many impact categories though it still is a main contributor to the net results in the impact categories *Aquatic Eutrophication* and *Acidification*. Apart from this the sterilizing (retorting & UHT) process also demands high amount of energy and therefore contributes to the energy-related impact indicators. The transport related impacts are determined to be very high for the packaging systems pouch, plastic pot and glass jar due to either disadvantageous pallet configuration.

Regarding the base scenarios, the food cartons *combisafe* and *combibloc* show a more favourable environmental performance in all impact categories regarded when compared with alternative packaging solutions, except when *combisafe* is compared to the steel can. In the indicator *Aquatic Eutrophication* the results of the can match those of the *combisafe*.

The sensitivity analysis with varying recycling rates confirms the pattern, when the food cartons are compared to competing packaging systems.

The robustness and validity of the results regarding the allocation factor used for open-loop recycling are generally confirmed by the sensitivity analyses. It must be taken into account, that the findings are only valid within this LCA study's framework conditions. Accordingly, several limitations must be considered and are documented in detail in the full report.

Recommendations

Based on the findings of this study, summarised in section 8-1 to 8-5, the authors developed the following recommendations:

- From an environmental point of view the food cartons *combisafe* and *combibloc* clearly show a better performance compared to the examined retortable pouch, glass jar, steel can and plastic pot not only in the base scenarios but also in the analysed sensitivity scenarios regarding an allocation factor of 100%, different recycling rates and the different method for the assessment of the eutrophication potential. For the packaging of sterilised liquid food on the European market (EU27+2) the authors therefore recommend to prefer food cartons over the alternative packages examined.
- The results of this study show that of both examined food cartons the *combibloc* has slightly bigger competitive advantages over the regarded alternative packages than the *combisafe*. It is therefore recommended to prefer *combibloc* over *combisafe* in case an UHT treatment combined with an aseptic filling is technically viable for a dedicated product application. If a retortable packaging system is necessary due to requirements of the food to be packed, *combisafe* is the best option of all the examined packaging systems from an environmental point of view.
- Though, as described in the discussion in section 6.1, the assessment of the consumption of wood and the use of forest area is difficult to accomplish in the scope of a LCA study, it is recommended to aim at sourcing wood from forests with state-of-the-art management systems. In this context, the authors recommend the Forest Stewardship Council's (FSC) criteria for orientation and would like to point out that SIG Combibloc has been making special efforts to achieve FSC certification at different levels of the company and of the chain of custody. The authors appreciate the continuous pursuing of these endeavours by SIG Combibloc and recommend to further put an effort into that aspect. A continuous close cooperation between SIG Combibloc and the company's LPB suppliers may be one crucial element of a successful strategy for further achievements.
- The normalisation performed with the results of the base scenarios allows a conclusion on where a reduction of the examined packaging systems' environmental

loads could be most effective in order to improve the quality of the environment at the European level. These are the impact categories *Abiotic Resource Depletion*, *Climate Change*, *Acidification*, *Terrestrial Eutrophication* and *Human Toxicity: PM 10*. In all of these both examined food cartons show considerably better environmental performances than the pouch, glass jar, steel can and plastic pot. This confirms the recommendation to prefer food cartons over the alternative packages for the packaging of sterilised liquid food products.

- Due to the potential generation of methane emissions on landfills, diversion of residual waste streams of all fibre-based products (both food cartons and subsequent products made of recycled fibres) from landfill should still be the goal of SIG Combibloc – as producer of *combisafe* and *combibloc* to further reduce the environmental impact of the food carton packaging systems. SIG Combibloc - as well as its customers, mainly the retorted food producers as well as the retailers should contribute to the development of an infrastructure which avoids that food cartons or products made of recycled fibres end up in landfills.
- 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 emissions relevant for the assessment of impact indicators as Human Toxicity: Carcinogenic Risk) and to allow recently developed methods as for the assessment of water consumption to be successfully applicable.

Abbreviations

ACE	Alliance for Beverage Cartons & the Environment (Brussels, Belgium)
ADP	Abiotic Depletion Potential
APEAL	Association of European Producers of Steel for Packaging (Brussels, Belgium)
BOD	biological oxygen demand
BUWAL	Bundesamt für Umwelt, Wald und Landschaft (Swiss Agency for the Environment, Forests and Landscape)
CED	cumulative energy demand
CML	Centrum voor Milieukunde (Center of Environmental Science), Leiden University, Netherlands
COD	chemical oxygen demand
EAA	European Aluminium Association
EEA	European Environment Agency
EU27+2	European Union & Switzerland and Norway
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (Brussels)
g	gramme(s)
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
JRC	Joint Research Centre (European Commission)
kg	kilogramme(s)
km	kilometre(s)
L	litre(s)
LCA	life cycle assessment
LCI	life cycle inventory
LDPE	low density polyethylene
LPB	liquid packaging board
MP	material production
MSWI	municipal solid waste incineration
NMVOC	non-methane volatile organic compounds
NO_X	nitrogen oxides
ODP	Ozone Depletion Potential
PA	Polyamide
PET	Polyethylenterephthalat
PM10	Particulate matter with a diameter smaller than 10µm
POCP	photochemical ozone creation potential
PP	Polypropylene

ReCiPe	initials of the institutes that were the main contributors to this project and the major collaborators in its design: RIVM and Radboud University, CML, and PRé
t	tonne(s)
TRS	Total reduced sulphur
UBA	Umweltbundesamt (German Federal Environment Agency)
VOC	volatile organic compounds

1 Goal and scope definition

1.1 Background and objectives

SIG Combibloc is one of the world's leading system suppliers of carton packaging and filling machines for beverages and food. In 2012 the company achieved a turnover of 1,620 million Euro with around 4,950 employees in 40 countries. SIG Combibloc is part of the New Zealand based Rank Group.

For more than 20 years SIG Combibloc has been actively working to address major environmental issues.
As environment is an integral part of the corporate strategy it is of high importance for SIG Combibloc to gain credible knowledge about the environmental performance of its product portfolio. This will on the one hand serve as a basis for further improvements of the packaging systems. On the other hand such knowledge is of high importance and interest for various stakeholders, as environmental concerns are increasing and politics, NGOs, customers as well as consumers are increasingly demanding such information. With a constantly changing market in competing industry sectors, it is even more important for stakeholders in the value chain to understand how different packaging solutions impact the environment throughout their life cycle.

Therefore, in 2008 IFEU Heidelberg was already commissioned by SIG to evaluate the environmental impact of their heat-resistant food carton *combisafe* that are sterilised in an autoclave and the aseptic food carton *combibloc* for the packaging of ambient liquid food products with particulate contents on the European market [IFEU 2008]. Furthermore the environmental performance of the SIG food carton packs compared to alternative packaging systems on the European market was analysed.

In terms of the packaging solutions in the sterilised food segment the current study shall consider the recent developments for the food carton packs from SIG and alternative packaging systems on the European market as well as verify the results from the LCA on food packaging systems conducted in 2008.

Hence, the *ifeu - Institut für Energie- und Umweltforschung Heidelberg GmbH* (Institute for Energy and Environmental Research, IFEU) was commissioned by SIG Combibloc to conduct the current study with the following goals:

- to provide knowledge of the environmental strengths and weaknesses of the SIG food carton packs *combibloc* and *combisafe* for the packaging of sterilised liquid food products under European market conditions (EU 27 and Norway & Switzerland)
- to compare the environmental performance of the food carton packs *combibloc* and *combisafe* with those of competing packaging systems with a high market relevance in Europe (e.g. steel can, glass jar, retortable[1] pouch, plastic pot).

This study is performed according to the ISO standard on LCA [ISO 14040 and 14044 (2006)].

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[1] retortable: sterilisable in an autoclave

1.2 Organisation of the study

This study was commissioned by SIG Combibloc in 2013. It is being conducted by *IFEU – Institut für Energie- und Umweltforschung Heidelberg GmbH* (IFEU).

The members of the project panel are:

- Udo Felten (SIG Combibloc)
- Dominik Haug (SIG Combibloc)
- Katja Saragazki (SIG Combibloc)
- Frank Wellenreuther (IFEU)
- Stefanie Markwardt (IFEU)

1.3 Use of the study, target audience and critical review

The results of this study will be used in both internal and external communication, i.e. with retailers, authorities and NGOs as well as SIG Combibloc's customers (e.g. food producers).

According to the ISO standards on LCA [ISO 14040 and 14044 (2006)], this requires a critical review process done by a critical review panel. In SIG*'s* and *IFEU*'s experience, the most cost- and time-efficient way to run the critical review is to have it as an accompanying process. Thus the critical reviewers will be able to comment on the project from the time the goal and scope description is available.

The members of the critical review panel are:

- Prof. Dr. Birgit Grahl (chair), Heidekamp, Germany
- Dipl.-Eng. Philippe Osset (co-reviewer), CEO of Solinnen S.A.S, Paris, France
- Prof. Dr. Richard Murphy, (co-reviewer), Centre for Environmental Strategy, University of Surrey, Guildford, United Kingdom

A short curriculum vita of each member is attached in Appendix C with the critical review report.

1.4 Functional unit

The function examined in this LCA study is the packing of ambient liquid food products with particulate contents (e.g. soups, sauces, pasta sauces) for retail. The functional unit for this study is defined as the packaging, protection and delivery of 1000 L of packed liquid food to the point of sale. The point of sale is defined as the place, where the food product is sold to the consumer, e.g. supermarket.

The reference flow of the product system regarded here refers to the actually filled volume of the containers and includes all packaging elements, i.e. food carton or glass jars and closures as well as the transport packaging (corrugated cardboard trays and shrink foil, pallets), which are necessary for the packaging, filling and delivery of 1000 L liquid food. Table 2-1 and Table 2-2 provide an overview of all packaging elements required as well as of the actually filled volume, the package volume and the mass of food contained in the pack[2]. Furthermore transport processes related to the production of raw materials and the distribution distances are considered.

1.5 System boundaries

The study is designed as a ‘cradle-to-grave’ LCA, in other words it includes the extraction and production of raw materials, converting processes, all transports and the final disposal or recycling of the packaging system.

In general, the study covers the following steps:

- production, converting, recycling and final disposal of the primary base materials used in the primary packaging elements from the studied systems (incl. closures)
- production, converting, recycling and final disposal of primary packaging elements and related transports
- production, recycling and final disposal of transport packaging materials (pallets, cardboard trays)
- production and disposal of process chemicals, as far as not excluded by the cut-off criteria (see below)
- filling processes, which are fully assigned to the packaging system.
- transports of packaging material and final distribution from fillers to point of sale

Not included are:

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

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[2] This is of calculative nature (and does not necessarily correspond to weights found on the market as for all packs the density of a tomato sauce was applied exemplarily).

- distribution of food from the filler to the point-of-sale (distribution of packages is included). No differences resulting from the choice of packaging systems are to be expected.
- environmental effects of cooling (retorted food is not cooled during transport and storage)
- environmental effects related to storage phases as no relevant differences between the systems under examination are to be expected
- environmental effects from accidents
- 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 lost 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 different amount of food residues left in an emptied package due to the design of the package/closure.

  This holds also true for differences in shelf life as the printed best before date is only an indication for the longevity of a product but not a physical measurement of the barrier quality and performance. Data on lost food due to the failure of packaging systems after a longer storage period is not available. In consequence it is currently not possible to approximate differences between packaging systems in the desired depth and quality.

  Further possible food losses are directly related to the handling of the consumer in the use phase, which is not part of this study as handling behaviours are very different and difficult to assess. Therefore these possible food loss differences are not quantifiable as almost no data is available regarding these issues. 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.
- 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 after packaging at the consumers 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. This includes potential washing processes of the packages by the user after emptying. As the washing is not recommended by waste management associations and again no data is available about differences between packagings it is assumed for the modelling of this study that no washing processes by users take place.

For recycling and recovery routes the system boundary is set at the point where a secondary product (energy or recycled material) is obtained. The secondary products can replace primary energy generation processes and virgin materials, respectively. This effect is accounted for in the life cycle assessment by attributing credits for secondary products. These credits are calculated based on the environmental loads of the corresponding primary energy generation process or material (see section 1.8).

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, pre-chains from preceding systems with an input material share of less than 1% of the total mass input of a considered process were excluded from the present study. However, total cut-off is not to surpass 5% of input materials as referred to the functional unit. All energy inputs are considered, except the energy related to the material inputs from pre-chains which are cut off according to the mass related rule. Pre-chains with low input material shares, which would be excluded by the mass criterion, are nevertheless included if they are of environmental relevance, e.g. flows that include known toxic substances. The environmental relevance of material input flows was determined based on expert judgement.

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 food packages in the European Union plus Norway and Switzerland (EU27+2). A certain share of the raw material production as well as converting processes for packaging systems take place in specific European countries. For these, country-specific data is used as well as European averages depending on the availability. Examples are the liquid packaging board production process (country-specific) and the production of aluminium foil (European average).

Time scope

The reference time period for the comparison of packaging systems is 2013, as the packaging specification listed in Table 2-1 and Table 2-2 refer to the market situation in 2013. 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. As some of these data are not yet publicly available, expert judgements are applied in some cases, for example based on exchanges with representatives from the logistics sector regarding distribution distances.

Most of the applied data refer to the period between 1999 and 2013. The process-specific data, such as filling data for food cartons refer to 2013. The datasets for transportation, energy generation and waste treatment processes are taken from *IFEU's* internal database in the most recent version (time reference between 2000 and 2009). The data for plastic production originates from the Plastics Europe dataset and refer to 1999 and 2008 for the production of PET respectively.

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.

1.7 Modelling and calculation of inventories

For the implementation of the system models the computer tool Umberto® (version 5.5) is used. Umberto® is a standard software for mass flow modelling and LCA. It has been developed by the institute for environmental informatics (ifu) in Hamburg, Germany in collaboration with *IFEU*, Heidelberg.

All system models and the related module processes were implemented into mass-flow scenarios. Calculations of input/output balances are scaled to the defined reference flow. Input/output balances are composed of elementary and non-elementary flows. Elementary flows are materials or energy entering the system being studied, which have been drawn from the environment without previous human transformation or materials and energy respectively leaving the system, which are discarded into the environment without subsequent human transformation. The materials listed in the input/output balances are compiled into environmental profiles.

1.8 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 latter referring to allocation procedures in the context of open loop recycling.

Both approaches are further explained in the subsequent sections. The approaches explained below (both regarding process-related and system-related allocation) have been developed in the context of German Federal Environmental Agency (UBA) commissioned packaging LCAs and applied amongst others in [UBA 2000].

Process-related allocation

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

Multi-output processes

For data sets prepared by the authors of this study, the allocation of the outputs from coupled processes is generally carried out via the mass. If different allocation criteria are used, they are documented in the description of the data in case they are of special importance for the individual data sets. For literature data, the source is generally referred to.

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 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. The allocation between package and filling good is based on mass criterion.

System-related allocation

The approach chosen for system-related allocation is illustrated in figure 1-1: both graphs show two exemplary product systems, referred to as product system A and product system B. System A shall represent systems under study in this LCA. In figure 1-1 (upper graph) in both, system A and system B, a virgin material (e.g. polymer) is produced, converted into a product which is used and finally disposed of via MSWI. A virgin material in this case is to be understood as a material without recycled content. A different situation is shown in the lower graph of figure 1-1. Here product A is recovered after use and supplied as a raw material to system B avoiding thus the environmental loads related to the production (‘MP-B’) of the virgin materials, e.g. polymer and the disposal of product A (‘MSWI-A’). Note: Avoided processes are indicated by dashed lines in the graphs.

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

General notes regarding figures 1-1 to 1-4

The following graphs (figures 1-1 to 1-4) 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 0% allocation method, the 50%:50% allocation method and the 100% allocation method

- to show which processes are allocated[3]:

– primary material production

– recovery processes (e.g. material recycling, thermal recovery as refuse-derived fuel RDF)

– waste treatment of final residues (here represented by MSWI, could also be landfilling)

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

The allocation of final waste treatment is consistent with UBA LCA methodology 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 being included within the respective systems.
- Hence not all material flows from system A are passed on to system B, as the simplified material flow graphs may imply. Consequently only the effectively recycled material's life cycle steps are allocated between systems A and B.
- The graphs do not show the individual process steps relevant for the waste material flow out of packaging system A, which is sorted as residual waste, including the respective final waste treatment.
- For simplification, a substitution factor of 1 underlies the graphs. However, in the real calculations smaller values are used where appropriate. For example if a material's properties after recycling are different from those of the primary material it replaces, this translates to a loss in material quality. A substitution factor < 1 accounts for such 'down-cycling' effects. For further details regarding substitution factors please see subsection 'Application of allocation rules' (p. 9)
- Furthermore, the material which is replaced by the recycled material may be a completely different one (e.g. plastic substituting for wood). This case, even if not relevant in this study, is not addressed in the graphs either.
- The final waste treatment for the materials from both systems A and B is represented in the graphs only as municipal solid waste incineration (MSWI). However, the LCA

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[3] according to [ISO 14044], § 4.3.4.3.2: However, in these situations, additional elaboration is needed for the following reasons:

  - o reuse and recycling (as well as composting, energy recovery and other processes that can be assimilated to reuse/recycling) may imply that the inputs and outputs associated with unit processes for extraction and processing of base materials and final disposal of products are to be shared by more than one product system;
  - o reuse and recycling may change the inherent properties of materials in subsequent use;
  - o specific care should be taken when defining system boundary with regard to recovery processes.

model implemented by means of Umberto® software applications comprehends a final waste management ‘mix‘ made up of both landfilling and MSWI processes.

Figure 1-1 illustrates the general allocation approach used for uncoupled and coupled systems. The allocation methods used in this study are shown in figures 1-3 to 1-4. In order to do the allocation consistently, besides the virgin material production (‘MP-A’) already mentioned above and the disposal of product B (’MSWI-B’), the recovery process ‘Rec’ has to be taken into consideration. This has been highlighted in figure 1-3 by placing these processes in between system A and B. Regarding the waste treatment process (here represented as ‘MSWI-B’), burdens or benefits are considered in a similar way as the avoided primary raw material production.

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

Allocation with the 0% method (figure 1-2)

In this method, the assessment of material flows ends from system A with the recovery of post-consumer waste. The method implies that recyclates are not dealt with as co-products. Consequently the benefits of avoided ‘MP-B’ are completely assigned to system B, which also has to carry the full loads of ‘Rec’ and ‘MSWI-B’. System A, from its viewpoint, receives a zero credit for avoided primary material production.

It still saves the final waste treatment of the material going to recycling instead of going to incineration in ‘MSWI-A’. The final waste treatment of the material going to recycling now occurs after the use phase in System B. In the 0% method this waste treatment is completely assigned to System B.

The 0%-method could be regarded a simplified approach as it does not require any information, for example, about the quality of recyclates and their potential applications in consecutive product lives.

Allocation with the 50% method (figure 1-3)

In this method, benefits and loads of ‘MP-A’, ‘Rec’ and ‘MSWI-B’ are equally shared between system A and B (50:50 method). Thus, system A, from its viewpoint, receives a 50% credit for avoided primary material production and is assigned with 50% of the burden or benefit from waste treatment (MSWI-B).

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

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

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

Allocation with the 100% method (figure 1-4)

In this method the principal rule is applied that system A gets all benefits for displacing the virgin material and the involved production process ‘MP-B’. At the same time, all loads for producing the secondary raw material via ‘Rec-A’ are assigned to system A. In addition, also the loads that are generated by waste treatment of product B in ‘MSWI-B’ is charged to system A, whereas the waste treatment of product A is avoided and thus charged neither to System A nor to System B.

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

Application of allocation rules

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

As discussed above, system related allocation addresses the issue of how to account for secondary products in the context of open loop recycling. Still, any procedure chosen will involve value judgements. Consequently, it is a typical subject of sensitivity analysis which according to [ISO 14044] has to be applied in order to check the uncertainty of results due to subjective choices. In this study, the implementation of the 100% approach serves this purpose.

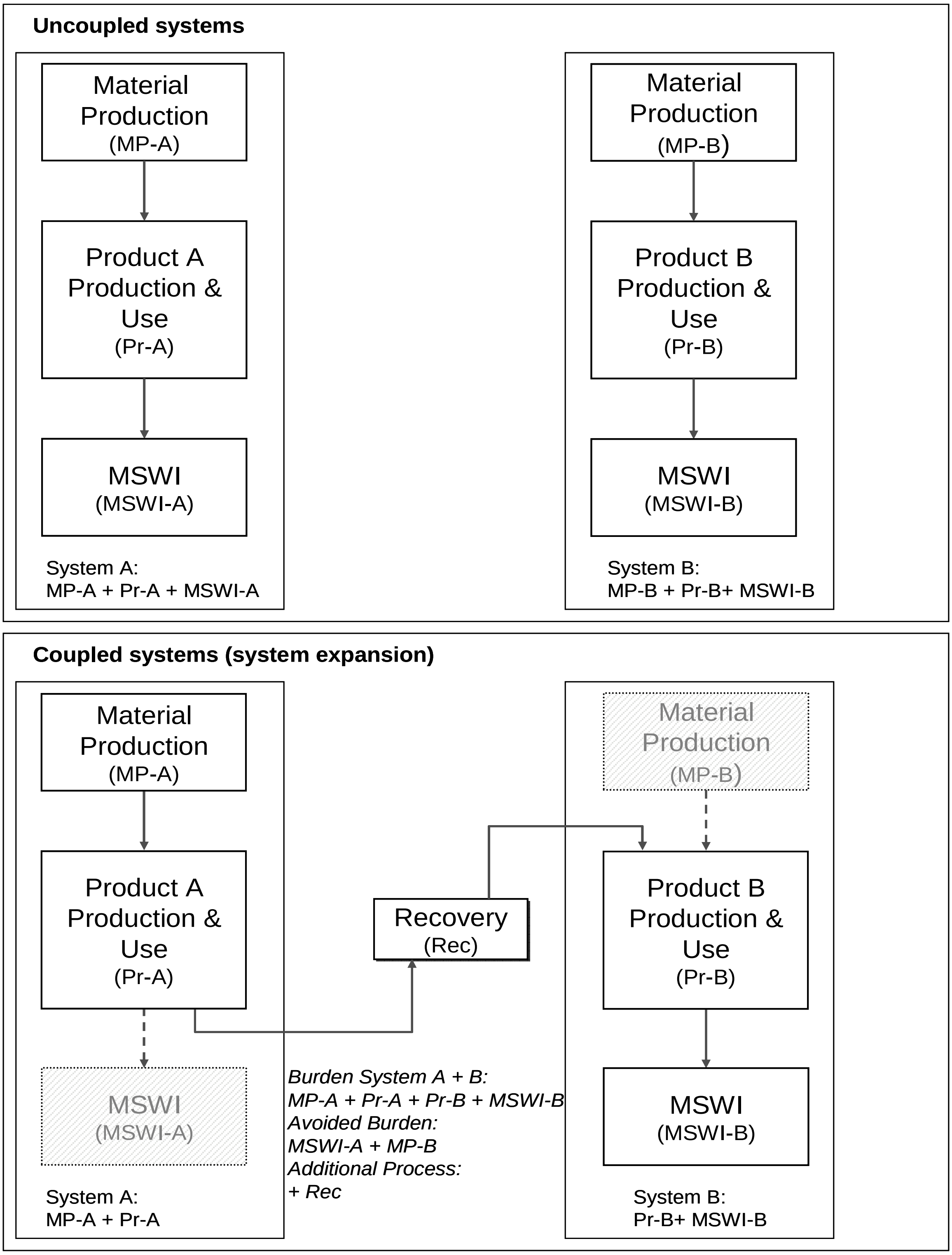

Figure 1-1: Additional system benefit/burden through recycling (schematic flow chart)

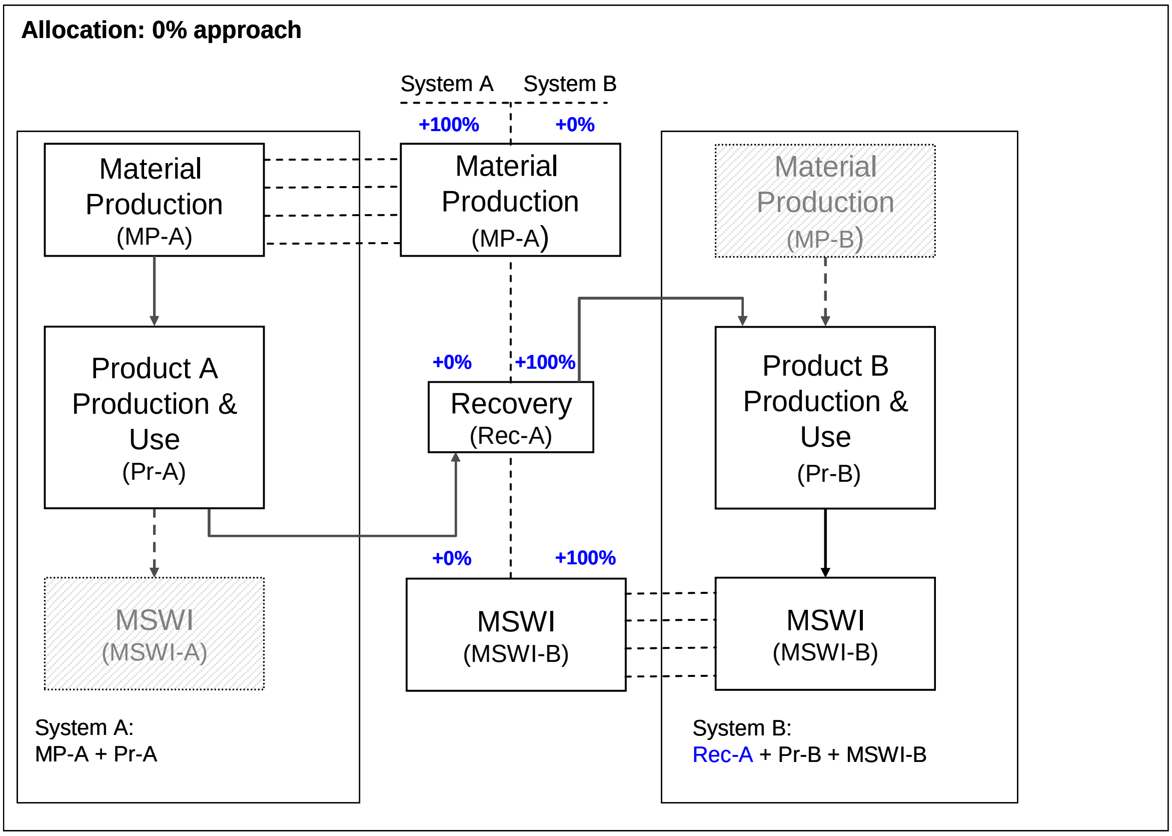

Figure 1-2: Principles of 0% allocation (schematic flow chart)

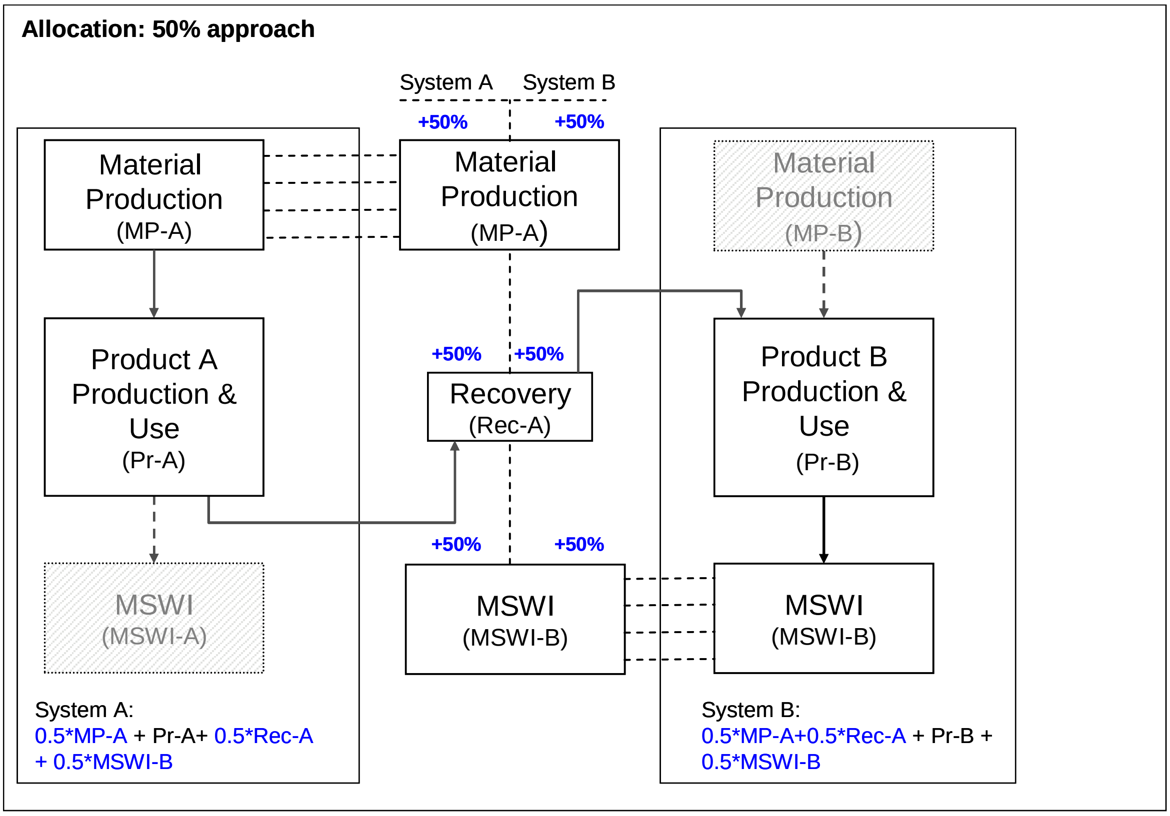

Figure 1-3: Principles of 50% allocation (schematic flow chart)

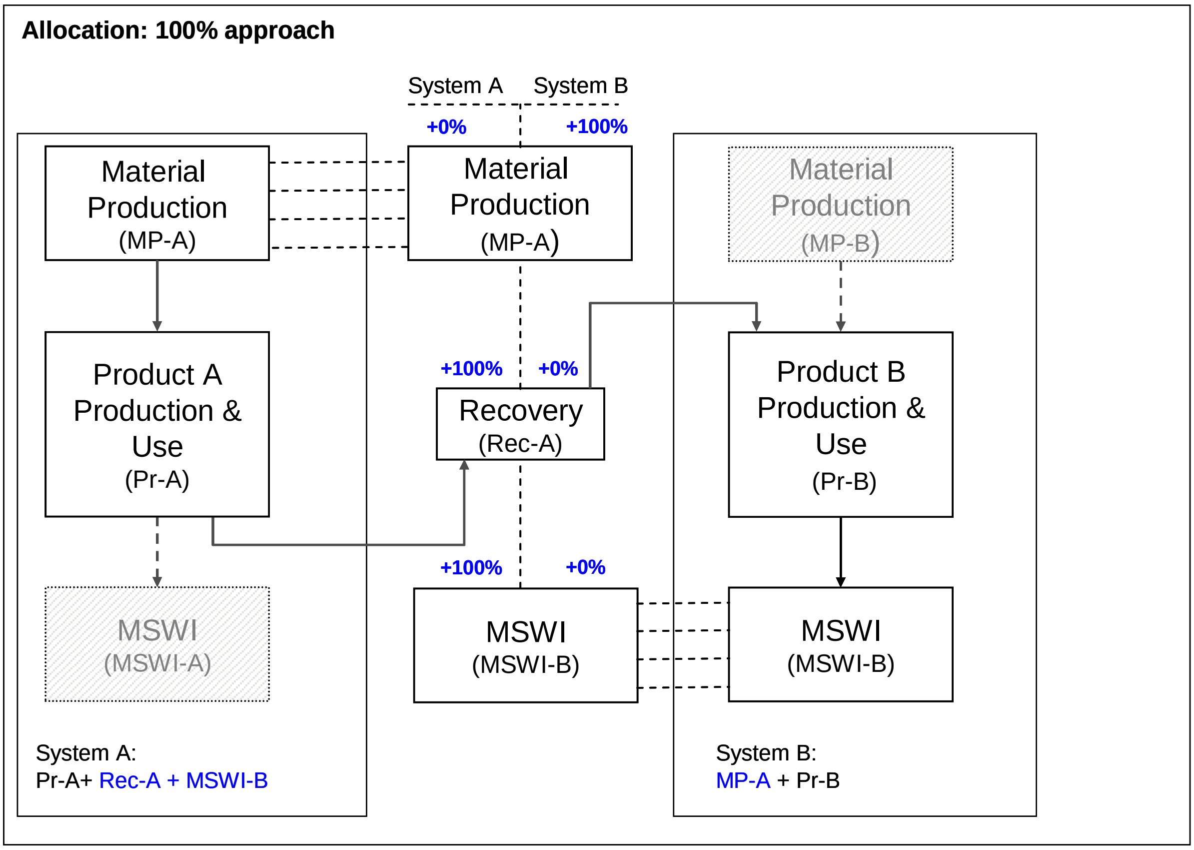

Figure 1-4: Principles of 100% allocation (schematic flow chart)

System allocation approaches used in this study

For the base scenario a system allocation factor of 50% is chosen. This corresponds to the system allocation approaches recommended by the German Federal Environment Agency, the latest version of the French Standard NF BP X30-323 [AFNOR 2011] and the recently published Product Environmental Footprint document by the European Commission's JRC [JRC 2013]. To verify how different approaches regarding system related allocation would influence LCA results, a sensitivity analysis using a 100% allocation factor is applied.

1.9 Environmental impact assessment and interpretation

To assess the environmental performance of the examined packaging systems, a set of environmental impact categories according to the current practice in LCA is used. This selection is based on the German Federal Environmental Agency (UBA) approach 2000/2002. Exceptions to this approach are the consideration of the impact category *'Human Toxicity: PM10'* and the assessment of resource depletion following the CML methodology.

With regard to the inventory data sets, the applied impact mechanisms of the regarded categories (see below) are scientifically justified and are feasible for implementation. This is confirmed by the common use of the applied indicators in many national and international LCAs and therefore can be seen as standard in LCA's practice. However, it is nearly impossible to carry out an assessment in such a high level of detail, that all environmental aspects are covered. A broad examination of as many environmental issues as possible is highly dependent on the quality of the available inventory data sets and of the scientific acceptance of the certain assessment methods.

Data asymmetries in the available inventory data sets have been identified regarding the assessment of the impact indicator *'Human Toxicity: Carcinogenic Risk'.* While the relevant emissions are listed in the inventory dataset for aluminium production the same emissions are not included in the inventory datasets of paperboard and polyethylene. Using data showing such asymmetric inventories for the assessment of an impact indicator will cause a misinterpretation of the results, therefore the impact category *'Human Toxicity: Carcinogenic Risk'* will not be assessed in this study.

The newly developed assessment method USEtox requires great amounts and high quality of inventory data. The inventories currently used for different materials are clearly asymmetric and not yet harmonised regarding the emissions to water and air. Therefore, the authors do not apply the USEtox method for the evaluation of the carcinogenic risk, as incomplete inventory data may lead to misinterpretation of the results in the study.

The selected impact indicators to be assessed in this study are listed and briefly addressed below. In the present study midpoint indicators are applied. Midpoint indicators represent environmental issues, for example acidification, whereas the fate of the substances causing the environmental problems is not taken into account.

A more detailed description of the examined impact indicators is given in Appendix A of the final report of this LCA.

Impact indicators related to emissions

- **Acidification**
  Acidification affects aquatic and terrestrial eco-systems by changing the acid-basic-equilibrium through the input of acidifying substances. The acidification potential is applied here as characterisation factor.
- **Climate change ('Global Warming')**
  Climate change is the impact of emissions from human activities 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 Global Warming Potential for a 100-year time horizon [IPCC 2007].

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. The non-fossil 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.

In the present study, the latter approach has been applied for the impact assessment. The CO_2 uptake has been documented at the inventory level. 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).

- **Summer Smog ('Photo-Oxidant Formation')**
  Photo-oxidant formation 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. Another name for this problem is 'summer smog'. The characterisation factor applied here is the 'Photochemical Ozone Creation Potential' (POCP).

- **Stratospheric Ozone Depletion**
  This term is used to describe the anthropogenic impact on the earth's atmosphere, which leads to the decomposition of naturally present ozone molecules, thus disturbing the molecular equilibrium in the stratosphere. The underlying chemical reactions are very slow processes and the actual impact, often referred to in a simplified way as the 'ozone hole', takes place only with considerable delay of several years after emission. The consequence of this disequilibrium is that an increased amount of UV-B radiation reaches the earth's surface, where it can cause damage to certain natural resources or human health. In this study, the ozone depletion potential (ODP) of air emissions is the characterisation factor used for this impact category, taking into account their residence time in the atmosphere.

- **Eutrophication**
  Eutrophication includes all impacts due to excessive levels of macro-nutrients in ecosystems. Compounds containing nitrogen and phosphorus are among the most eutrophicating elements. Within the CML method the eutrophication is differentiated by its target media:

– ***Terrestrial Eutrophication*** (i.e., eutrophication of soils by atmospheric emissions)

– ***Aquatic Eutrophication*** (i.e., eutrophication of water bodies by effluent releases)

The Eutrophication potential of emissions to air and to water is applied here as characterisation factor. A gross calculation of the emissions in waste water is made for *Aquatic Eutrophication*. Pollutants already in the input water are not considered.

On the European level the calculation of the eutrophication potential is conducted with different approaches. In the final version of their recently published ILCD[4] Handbook [JRC-IES 2011], the Joint Research Centre (JRC) of the European Commission recommends the application of the ReCiPe methodology [Struijs et al. 2009] for the calculation of the aquatic eutrophication. This approach differs greatly from the CML method described above.

For the midpoint characterization the ReCiPe methodology follows the concept of limiting nutrients. In temperate and subtropical regions of Europe, freshwaters are typical limited by phosphorus, whereas nitrogen usually limits the production of algal biomass in marine waters. Therefore, two different impact subcategories under eutrophication are applied in this method:

– ***Freshwater eutrophication*** (i.e., eutrophication of inland water by P-emissions in water and soil)

– ***Marine eutrophication*** (i.e., eutrophication of coastal waters by N-emissions in water and soil/air)

IFEU recently conducted an internal cradle-to-gate study to exemplarily examine different LCA methods recommended by the JRC and their impacts on the results of selected beverage cartons and plastic bottles. This study showed, that the ranking between the analysed packaging systems does not change when compared to the results of the methods used in this study except in the eutrophication potential. Therefore, the authors decided to verify the results of freshwater and marine eutrophication with the settings of the base scenario described in the sections 2-1, 2-2 and 2-3 in a sensitivity analysis (see further details in section 2-5). The freshwater eutrophication corresponds more or less to the aquatic eutrophication potential of the CML method, however it does not consider N-emissions into water (due to the concept of limited nutrients) and the Chemical Oxygen Demand (COD). The marine eutrophication has to be considered in the sensitivity analysis as well as otherwise N-emissions from wastewater sewage are not taken into account as they are in the aquatic eutrophication potential according to the CML method.

- **Human toxicity: PM10**
  This category covers effects of fine primary and secondary particles, where a correlation has been shown with respiratory diseases by epidemiological studies.

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[4] International Reference Life Cycle Data System

Following an approach proposed by EEA[5], secondary fine particulates are quantified and aggregated with primary fine particulates as PM10 equivalents[6].

Impact indicators related to the use/consumption of resources

- **Abiotic resource depletion (abiotic depletion potential: ADP)**
  This category covers the extraction of minerals and fossil fuels. The characterisation model is based on reserves and the rate of de-accumulation., the indicator being the depletion of the ultimate reserve in relation to annual use. Results are presented in kg antimony equivalents.
  Further result graphs regarding resource depletion are presented in this study:
    - As usually the ADP is dominated by the depletion of fossil fuels used for energy production the ADP results are presented in an additional graphic for which the fossil fuels and uranium depletion is not considered to focus on mineral resources. The recently proposed method by CML [CML 2013] to separate ADP into two single impact categories, the one for fossil resource depletion is not applied as the authors feel that this leads to two separate impact indicators to assess an environmental impact with the same area of protection which should be avoided.
    - In the previous LCA study on food cartons and alternative packagings [IFEU 2008] only the consumption of fossil resources has been assessed by applying a method based on static ranges that serve as indicators for the scarcity of fossil resources. The scarcity values are converted to Crude Oil Equivalents. To allow an easier comparison of the results of the previous and the present study Crude Oil Equivalents of fossil resources used are presented in Appendix B of this study report.

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[5] EEA: European Environment Agency

[6] PM_{10}: particulate matter with a diameter smaller than 10µm

Table 1-1: Examples of elementary flows and their classification into impact categories

Impact indicators ***emissions***	**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 eq.
Acidification	NOx	NH_3	SO_2	TRS	HCl	H_2S	HF		kg SO_2 eq.
Summer Smog (POCP)	CH_4	NMVOC	Benzene	Formaldehyde	Ethyl acetate	VOC	TOC	Ethanol	kg Ethene eq.
Stratospheric Ozone Depletion	CFC-11	N_2O	HBFC-123	HCFC-22	Halon-1211	Methyl Bromide	Methyl Chloride	Tetrachlormethane	kg CFC-11 eq]
Terrestrial Eutrophication	NOx	NH_3	N_2O						kg PO_4 eq.
Aquatic Eutrophication	COD	N	NH_4^+	NO_3^-	NO_2^-	P			kg PO_4 eq.
Human toxicity: PM10	PM10	SO_2	NO_X	NH_3	NMVOC				kg PM10 eq.
Impact indicators ***use / consumption of resources***									
Abiotic resource depletion	Crude oil	Natural gas	Hard coal	Soft coal	Al	Sb	Ir	Fe	[kg antimony eq.]

* CO_2 fossil ** CH_4 fossil and CH_4 regenerative included

Additional categories at the inventory level

Additional categories for information purposes were selected for this study:

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. The same applies for the inventory category *Transport intensity (Lorry)*, which is used to assess the transport intensity of the individual packaging systems, and therefore serve as an indicator for noise generation.

The selected categories at inventory level to be assessed in this study are listed in Table 1-2 and briefly addressed below.

- **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 indicator is described in [VDI 1997]. It is a measure for the overall energy efficiency of a system, regardless the type of energy resource which is used.

- **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.

- **Transport intensity (Lorry)**
  Transport intensity is a parameter to measure the overall transport demand of a system. It focuses on road transports and it is calculated by summing up all kilometres driven by trucks. This indicator can be seen as a measure for environmental issues related to road transport operations, such as noise, which is seen as an important environmental issue in several surveys. However, the indicator remains at the inventory level, as an impact model based on physical measurements (as used e.g. for climate change impacts) is currently not available.

Table 1-2: Examples of elementary flows and their classification into categories at inventory level

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
Transport intensity	lorry distance							Km

Two more potential environmental impacts that are not selected for assessment are ‘*Water Consumption*’ and ‘*Use of Nature*’. These are omitted as there are no robust methodologies to assess these in LCA that work with the detail of data in inventories available so far for both of them. The current state of assessment methodologies and why these are not applicable for this study are discussed in section 6.

Both water and land are included in the life cycle inventory of this study and figures of the respective categories will be presented on the inventory level in section 6.

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

In the present study, only normalisation will be applied with data for Europe (EU 27+2) and valid for the year ~2000 (see Table 6-1 in section 6). In the regarded project scope the normalisation will be conducted exemplarily for the results of the base scenario.

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 food product to the point-of-sale.

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). Flow charts of the respective systems (Figure 2.3 & 2.4) illustrate their life cycles as analysed and finally, an overview of all regarded scenarios, including those chosen for sensitivity analyses, is provided in section 2.5.

2.1 Choice of packaging systems

The focus of this study lies on the food cartons *combisafe* and *combibloc* developed by SIG Combibloc, for which this study aims to provide knowledge of its strengths and weaknesses regarding environmental aspects.

The selection of the competing packaging systems for the packaging of liquid food is based on an external market research[7] commissioned by SIG Combibloc and has been done according to market shares on the European market as well as due to store checks.

This research firstly identified the most relevant food segments within the geographic scope of this study according to production size and development: soups and broths (4345 kT; +1.1%) vegetables (6565 kT; +1.6%), ready meals as soups and stews (2.203 kT; +4.2%), sauces (827 kT; +2.8%), tomatoes (7905 kT; +4.0%) and pasta sauces (1274 kT; +6.1%).

Secondly, the most relevant packaging types within the selected food segments were determined, namely the plastic pot, metal can, food carton, glass jar and the stand-up pouch. While metal can (70%), glass jar (11%) and carton (13%) dominated the market[7] in 2011, a rising share for plastic and pouch packaging as well as for carton packaging is observed.

In terms of volume per packaging, the most produced range for the defined food segments in Europe is the volume 200-500g (57%)[7]. Major container volumes per food category were determined by several store checks in 2012/2013:
Soups and broths 375-500 mL and 1000 mL; tomatoes 375-425 g and 500 g; sauces 200-450 g and 500 g, vegetables 375-450 g and 750-850 g; ready meals, soups and stews 375-425 g and 700-850 g.

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[7] Source: Euromonitor, April 2012

Finally, the food product with the highest market share in Europe according to each packaging type was identified, which are illustrated and listed in section 2.2.

Another criterion for the choice of competing packages is the full compliance to the functional unit defined in section 1.4 including the protection of the product.

2.2 Packaging specifications

The present study compares the following packaging systems intended for the delivery of sterilised liquid food to the consumer:

1. SIG *combisafe* food carton
2. SIG *combibloc* food carton
3. Retortable pouch
4. Steel can (3 piece ring pull cap)
5. Glass jar (tin plate twist off cap)
6. Plastic pot

The packaging systems examined in the LCA study are specified in Table 2-1 and Table 2-2 and are based on information provided by SIG Combibloc. All packaging specifications gathered refer to the year 2013. Those for the primary packaging were determined by a microscopic analysis conducted by SIG. The data on transport packaging and pallet configuration were gathered and verified by Packforce in 2013. Figure 2-1 illustrates the respective primary packaging components for the food cartons and the pouch, Figure 2-2 shows those for the regarded steel can, glass jar and plastic pot. In these tables printing ink is only listed for the retortable pouch as the amount of ink used for the other packagings is so low that it is cut off for the purposes of this study (see cut-off rules in section 1.5)

Figure 2-1: Regarded food cartons *combisafe* 400 mL and *combibloc* 400 mL (left) and pouch 460 mL(right) (please note: pictures are not to scale)

Table 2-1: Packaging specifications for regarded food cartons and pouch: packaging components and masses - as applied in the model

Components	**SIG *combisafe***	**SIG *combibloc***	**Pouch**
Food Content			
Package Volume	400 mL	400 mL	460 mL
Volume of contained food	364 mL	383 mL	442 mL
Mass of contained food	358 g	376 g	434 g
Primary packaging	**16.41 g**	**13.90 g**	**10.34 g**
sleeve	**16.41 g**	**13.90 g**	**10.34 g**
- *LPB*	*10.10 g*	*9.30 g*	
- *Aluminium*	*1.20 g*	*1.10 g*	*1.46 g*
- *LDPE*	*1.21 g*	*3.50 g*	
- *PP*	*3.90 g*		*5.75 g*
- *PET*			*1.90*
- *PU*			*1.08 g*
- *Ink*			*0.15 g*
Secondary packaging	**47.3 g**	**47.3 g**	**116.9 g**
tray (corrugated cardboard)	47.3 g	47.3 g	116.9 g
Tertiary packaging	**23283 g**	**23283 g**	**23283 g**
pallet weight	23000 g	23000 g	23000 g
type of pallet (trip rate)	25	25	25
stretch foil (per pallet) (LDPE)	283 g	283 g	283 g
Pallet configuration for retail			
Packages per tray	16	16	6
trays per layer	10	10	20
layers per pallet	9	9	5
packages per pallet	1440	1440	600
Packages per lorry	47520	47520	19800

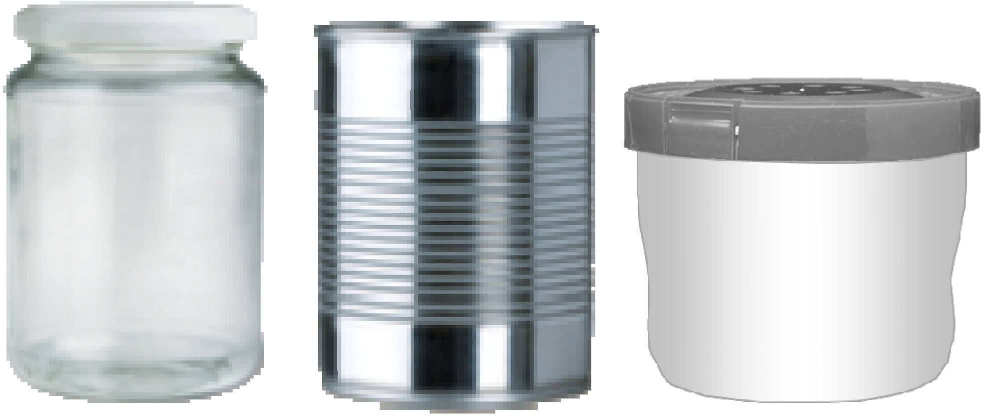

Figure 2-2: Regarded glass jar 425 mL (left), steel can 425 mL (middle) and plastic pot 400 mL (right) (please note: pictures are not to scale)

Table 2-2: Packaging specifications for regarded glass jar, steel can and plastic pot: packaging components and masses – as applied in the model

Components	Glass Jar	Steel Can	Plastic Pot
Food Content			
Package Volume	425 mL	425 mL	400 mL
Volume of contained food	393 mL	393 mL	374 mL
Mass of contained food	386 g	386 g	368 g
Primary packaging	**220.51 g**	**53.36 g**	**28.10**
body	**211.12 g**	**44.19 g**	**20.26 g**
- *Glass (external cullet: 59%)*	*211.12 g*		
- *tinplate*[8]		*44.19 g*	
- *PP*			*7.86 g*
- *EVOH*			*0.65 g*
- *PP with filler material*			*11.75 g*
closure	**8.00 g**	**5.88 g**	**5.27 g**
- *tinplate*	*6.8 g*	*5.88 g*	
- *PP*			*5.27 g*
- *LDPE*	*1.2 g*		
Lid		**1.09 g**	**1.18 g**
- *tinplate*		*1.09 g*	
- *PP*			*0.73 g*
- *PA*			*0.23 g*
- *PET*			*0.22 g*
Label	**1.39 g**	**2.20 g**	**1.39 g**
- *Paper*	*1.39 g*	*2.20 g*	
- *PP*			*1.39 g*
Secondary packaging	**30.5 g**	**52.37 g**	**103 g**
tray (corrugated cardboard)	22.7 g	52.37 g	92.3 g
Shrink foil per tray	7.8 g		10.7 g
Tertiary packaging	**23340 g**	**23283 g**	**23315 g**
pallet weight	23000 g	23000 g	23000 g
type of pallet (trip rate)	25	25	25
stretch foil (per pallet) (LDPE)	340 g	283 g	315 g
Pallet configuration for retail			
Packages per tray	6	12	6
trays per layer	25	15	20
layers per pallet	7	8	5
packages per pallet	1050	1440	600
Packages per lorry	34650	47520	19800

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[8] Includes 5.8% post-consumer scraps (see section 2.3)

2.3 End-of-life settings

For each packaging system regarded in the study, a base scenario is modelled and calculated assuming an average recycling rate for post-consumer packaging and an average rate for landfilling and incineration respectively for Europe.

The applied recycling quotas are based on the latest available publications of European industry associations, as ACE or FEVE.

The average recycling rate of beverage and food cartons for EU27+2 are obtained from the *Alliance for Beverage Cartons & the Environment (ACE)* and amount to 37% with reference year 2011 [ACE 2012].
The recycling rate of 69% for one-way glass jars are provided by the *European Container Glass Federation (FEVE)* and refer to 2011 [FEVE 2013].

The average recycling rate of food steel cans for EU27+2 are provided by the *Association of European Producers of Steel for Packaging (APEAL)* and amount to 71% for the reference year 2010 [APEAL 2013]. Recycled steel cans are used to replace pig iron in the basic oxygen furnace (BAF) route of the steel production process. According to information from the steel industry steel converters in Europe usually use a ratio of input materials 94% pig iron and up to 6% post-consumer scraps (closed-loop recycling] within this process. This ratio is also implemented in the steel converting model applied in this study. The remaining steel cans are assumed to replace pig iron in the steel production outside of the can packaging system examined (open-loop recycling).
IFEU is aware, that more recent data regarding the converting of steel cans are available from APEAL. As those data are not publicly available, the authors sent a request to APEAL. If IFEU will receive the approval during the course of this study, the data will be implemented in the respective model.

To the authors knowledge the plastic pot mainly consisting of PP can be detected within the sorting process by near infrared spectroscopy (NIR) and therefore separated into the PP-fraction. However, for the collection and recycling of the plastic pot no reliable data of recent years for the regarded geographic scope are available. Therefore, the average collection rate for EU27+2 were taken from [Pilz et al. 2010] with reference to the year 2007. Packaging systems made of PP can be either assigned to the group “small packaging” or “other rigid packaging”. For the present study the authors assign the plastic pot to the group “other rigid packaging” with a collection rate of 22.2%.

For the collection and recovery of the pouch packaging system no legal obligation for source-separated quotas are set on a European level. Although recycling technologies for a material-specific separation of the laminates for pouches are in the implementation phase (i.e. via microwave-induced pyrolysis), supported by several food producers within Europe, it still cannot be seen as a standard recycling technology with a high share throughout Europe. Hence, it is assumed that pouch packages do not undergo a material recycling on the regarded market and end up in the mixed plastic fraction, which is disposed according to the general disposal mix (landfill : incineration) for Europe published by [EUROSTAT 2013].
However, to at least consider the latest development of pouch recycling collected pouch packages are assumed to undergo pyrolysis treatment for aluminium recovery in the recycling variant scenarios.

The remaining part of the post-consumer packaging waste is modelled and calculated according to the average rates for landfilling and incineration in Europe (EU27+2). The waste treatment mix (60% landfill; 40% MSWI) has been derived from Eurostat data [Eurostat 2013] and refers to the year 2011.
Figure 2-3, Figure 2-4 and Table 2-3 provide an overview of the applied average end-of-life quotas for the base scenarios of the packaging systems regarded.

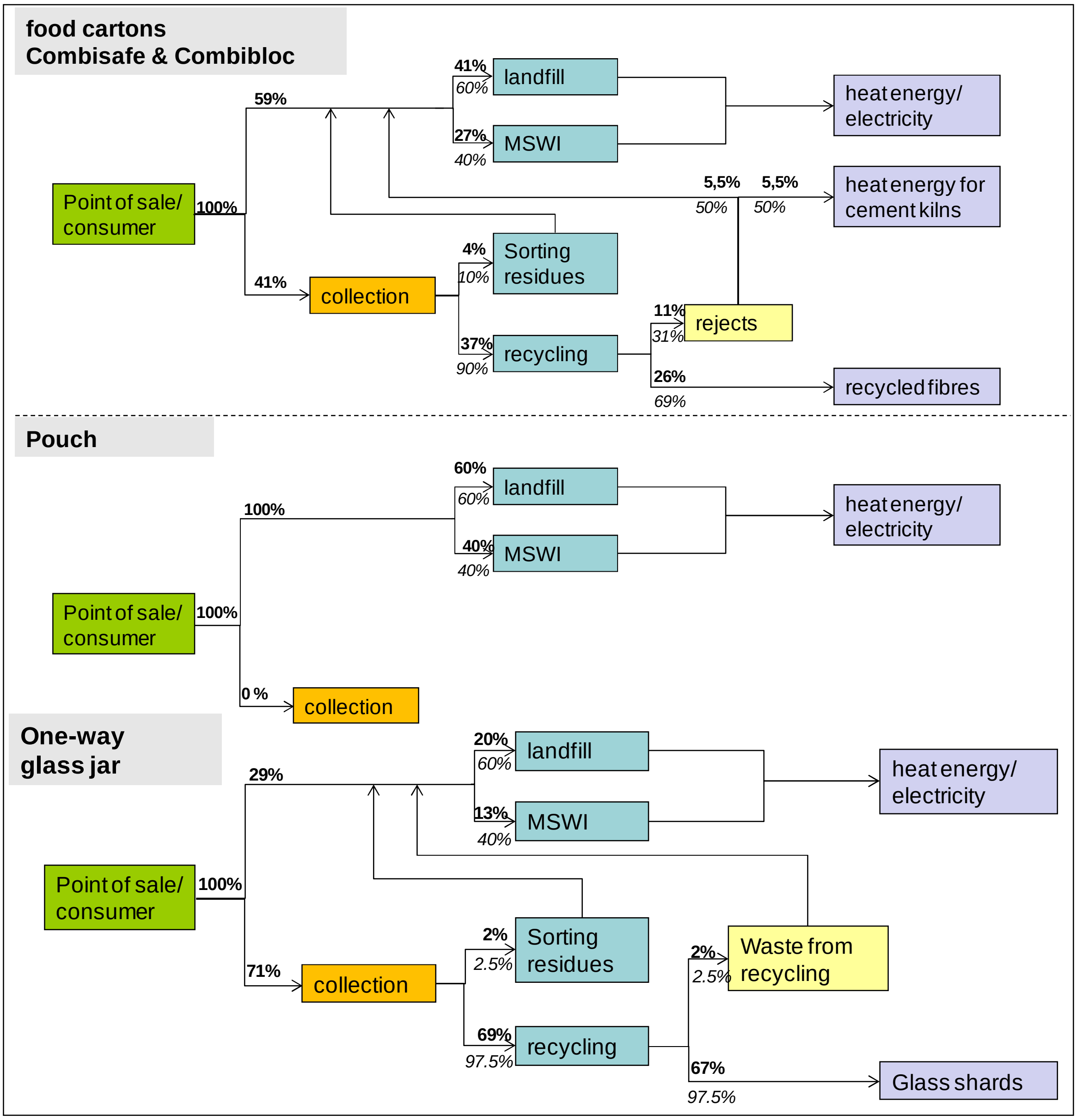

Figure 2-3: Average end-of-life quotas for the regarded **food cartons *combisafe* and *combibloc*, pouch and glass jar** (based on [ACE 2012], [FEVE 2013] and [Eurostat 2013]). Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

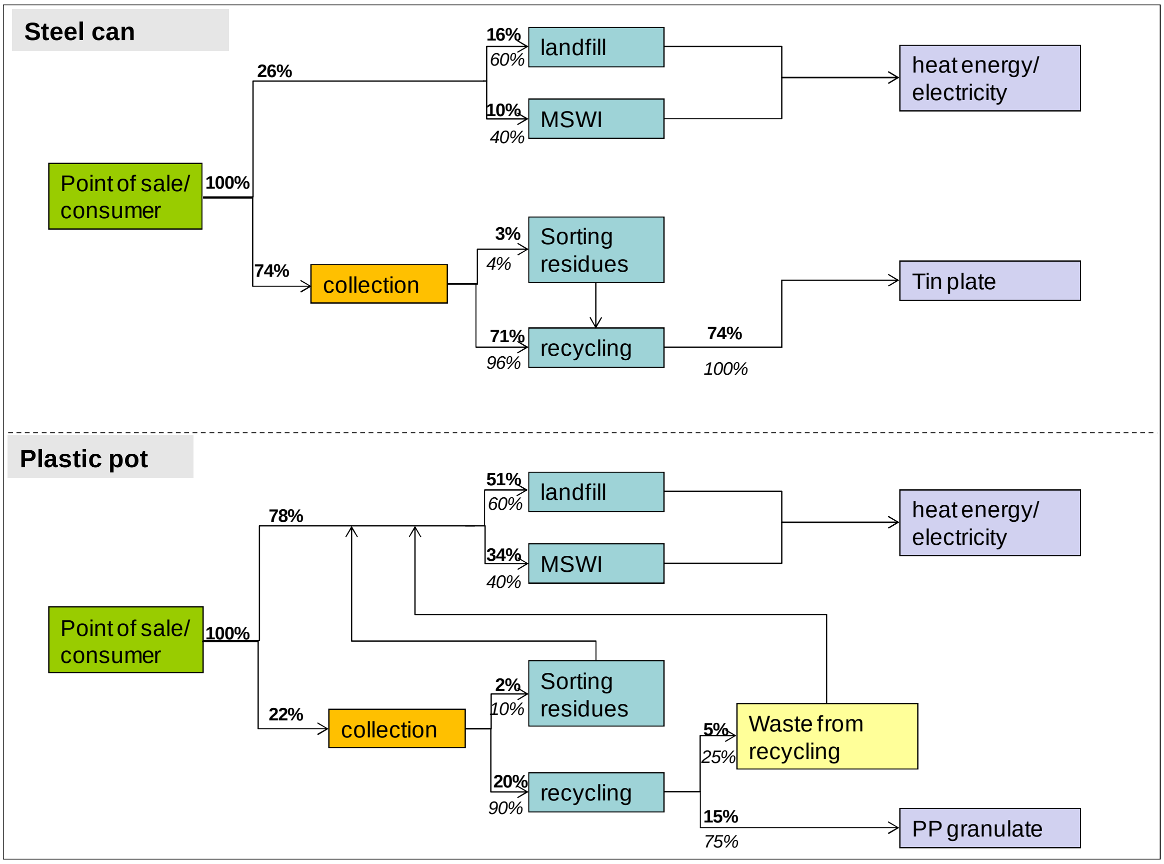

Figure 2-4: Average end-of-life quotas for the regarded **steel can and plastic pot** (based on [APEAL 2013], [Pilz et al.2010] and [Eurostat 2013]). Numbers in bold print represent the share on total mass flow, those in italics illustrate the share on the specific process.

Table 2-3: Collection and recycling rates as well as disposal split of packaging systems regarded in this study – EU27+2 averages applied in bas scenarios

End-of-life rates (EU27+2)	
Food cartons *combibloc & combisafe*	
Collection rate	41%
*Recovery at sorting process (share of collection rate)**	*90%*
*Residues at sorting process (share of collection rate)**	*10%*
Recycling rate after collection (reference year 2011) [ACE 2012]	37%
Pouch	
Collection rate & recycling rate*	0%
Glass jar	
Collection rate (reference year 2011) [FEVE 2013]	71%
*Recovery at sorting process (share of collection rate)**	*97.5%*
*Residues at sorting process (share of collection rate)**	*2.5%*
Recycling rate after collection	69%
Steel Can	
Collection rate	74%
*Recovery at sorting process (share of collection rate)**	*96%*
*Residues at sorting process (share of collection rate)**	*4%*
Recycling rate after collection (reference year 2010) [APEAL 2013]	71%
Plastic Pot	
Collection rate	22%
*Recovery at sorting process (share of collection rate)**	*90%*
*Residues at sorting process (share of collection rate)**	*10%*
Recycling rate after collection (reference year 2007) [Pilz et al.2010]	20%
Final waste disposal (reference year 2011) [EUROSTAT 2013]	
Landfill rate (share of total final waste)	60%
Incineration rate (MSWI with energy recovery; share of total final waste)	40%
**** IFEU assumption***	

2.4 System models and material flows

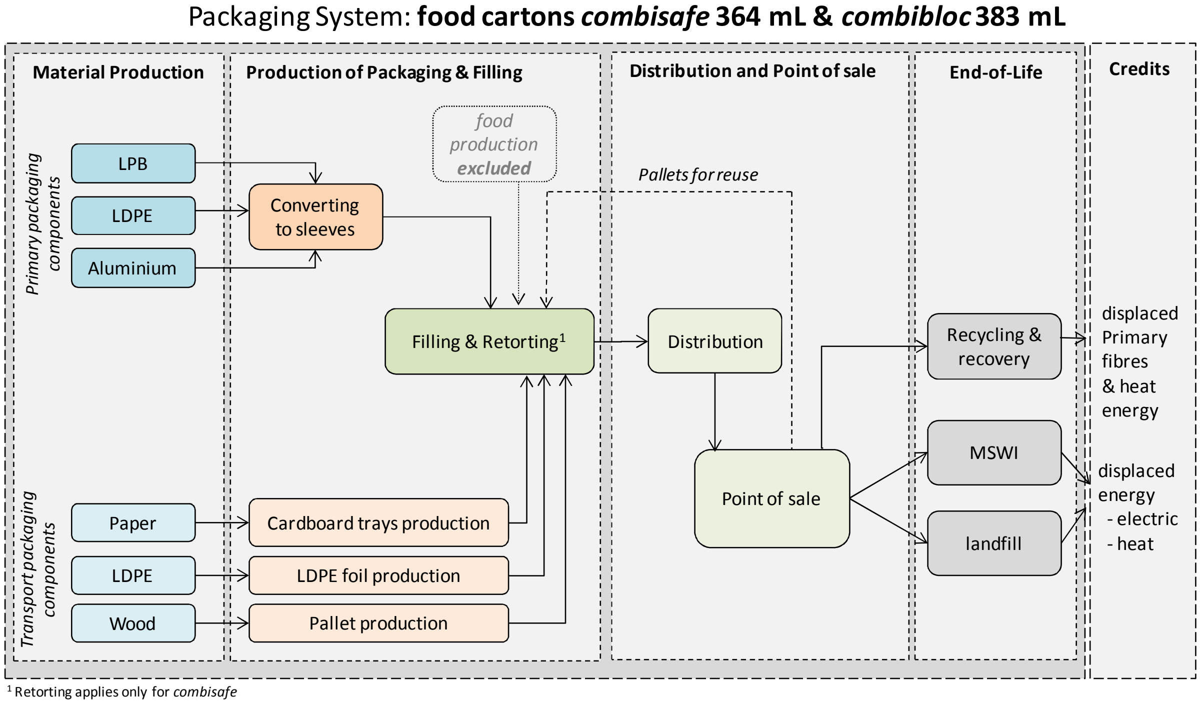

Figure 2-5: System flow chart for the **food cartons *combisafe & combibloc*** including material flows for the base scenario

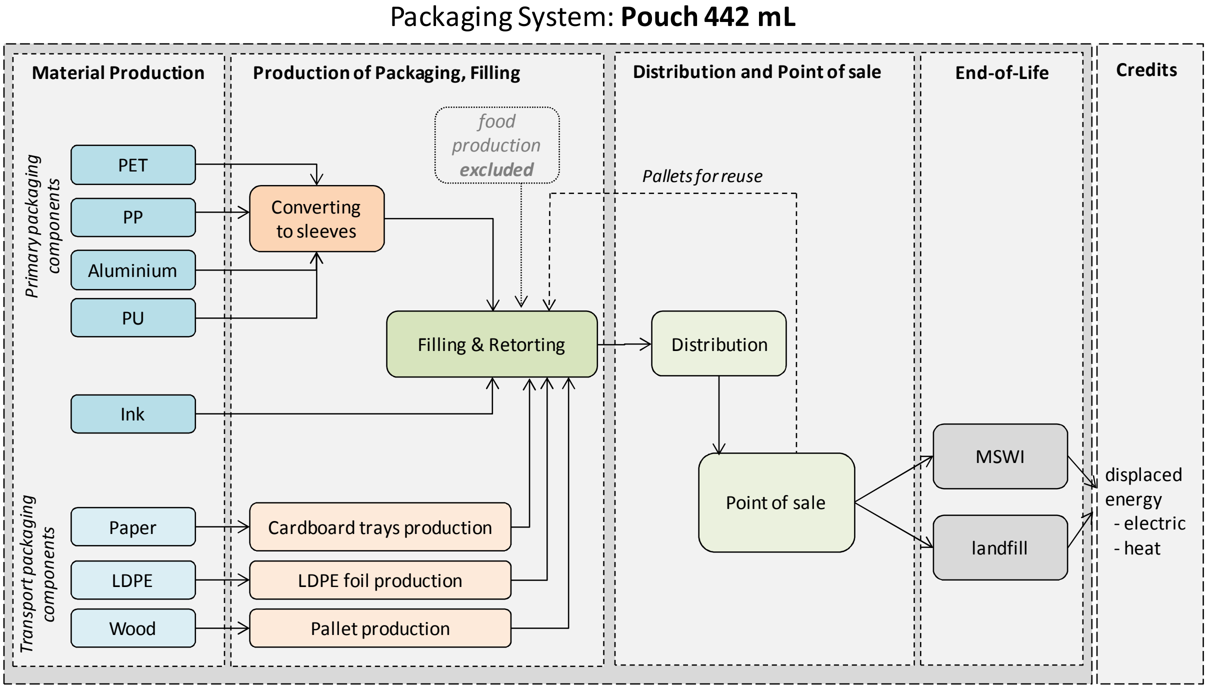

Figure 2-6: System flow chart for the regarded **pouch** including material flows for the base scenario

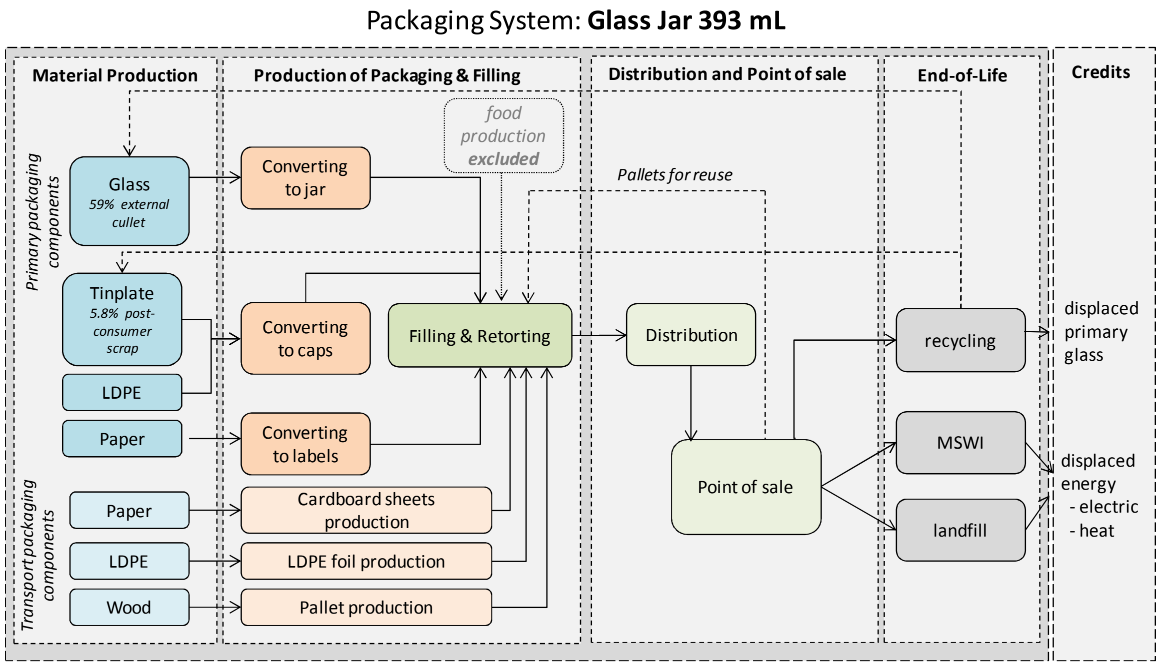

Figure 2-7: System flow chart for the regarded **glass jar** including material flows for the base scenario

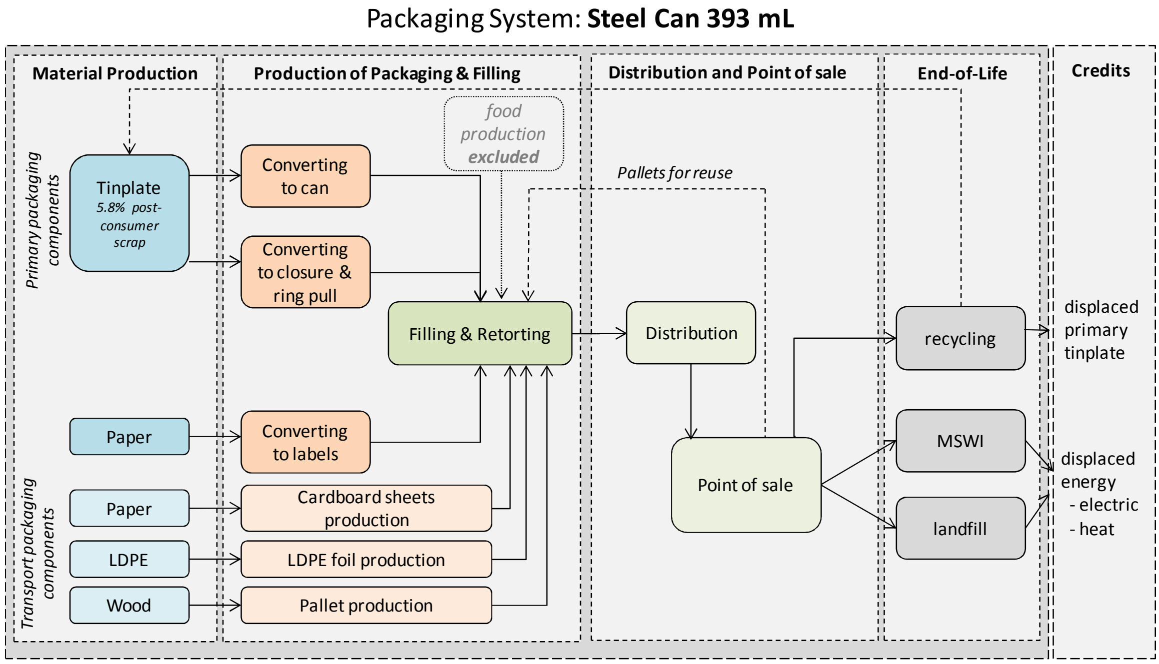

Figure 2-8: System flow chart for the regarded **steel can** including material flows for the base scenario

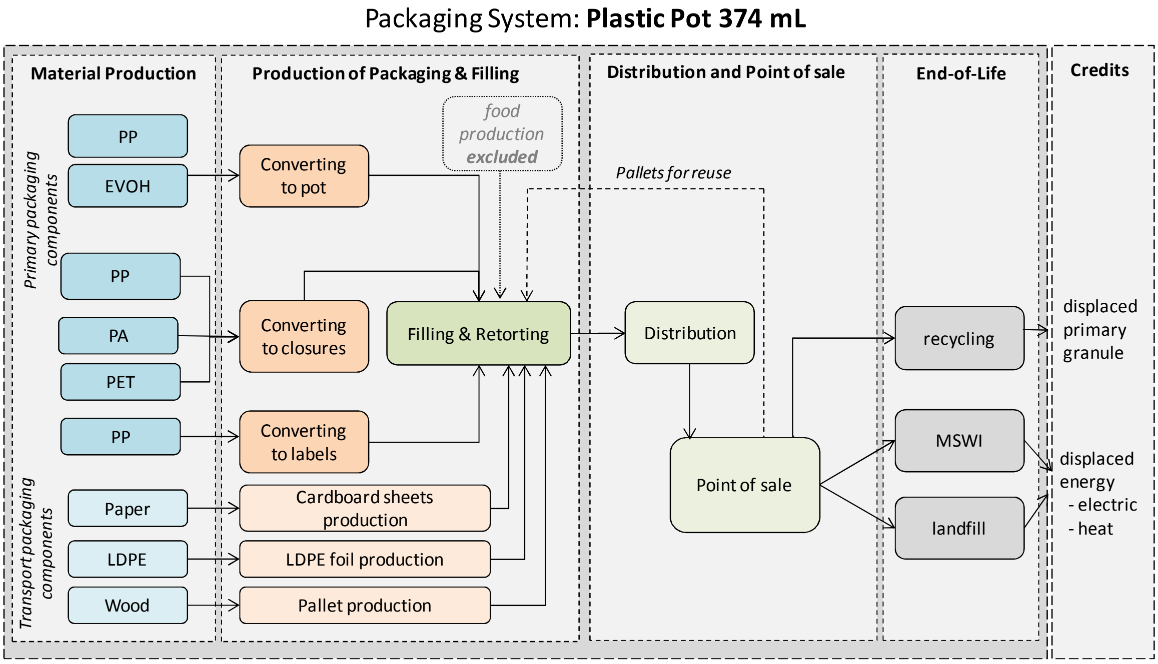

Figure 2-9: System flow chart for the regarded **plastic pot** including material flows for the base scenario

2.5 Scenarios

2.5.1 Base scenarios

For each of the studied packaging systems a base scenario for the European market is defined, which is intended to reflect the most realistic situation under the described scope. Table 2-4 provides an overview of the modelled base scenarios and lists their short names. In these base scenarios the allocation factor applied for open-loop-recycling is 50%.

Table 2-4: Base scenarios evaluated in this LCA: primary packaging element and short name (as used in the result graphs)

Base scenario allocation factor 50%	Short name
Food carton *combisafe* filled with 364 mL	*combisafe* (base)
Food carton *combibloc* filled with 383 mL	*combibloc* (base)
Pouch filled with 442 mL	Pouch (base)
One-way glass jar filled with 393 mL	Glass (base)
Steel can filled with 393 mL	Can (base)
Plastic pot filled with 374 mL	Pot (base)

2.5.2 Sensitivity analysis with focus on the allocation factor

In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50% (see section 1.8). Following the ISO norm’s recommendation on subjective choices, sensitivity analyses are conducted in this study to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied in a ‘sensitivity analysis 100’. The following Table 2-5 gives an overview of the respective scenario model and the corresponding short names used in the report and result graphs.

Table 2-5: **'**Sensitivity analysis 100' regarding allocation factor 100% for open-loop recycling: primary packaging element and short name (as used e.g. in the result graphs)

Sensitivity analysis AF100 allocation factor 100%	Short name
Food carton *combisafe* filled with 364 mL	*combisafe* (AF100)
Food carton *combibloc* filled with 383 mL	*combibloc* (AF100)
Pouch filled with 442 mL	Pouch (AF100)
One-way glass jar filled with 393 mL	Glass (AF100)
Steel can filled with 393 mL	Can (AF100)
Plastic pot filled with 374 mL	Pot (AF100)

2.5.3 Sensitivity analyses with focus on recycling rates

In the base scenarios the average recycling rate for Europe (EU27+2) is applied, based on officially published quotas that are derived from mass flow analyses, which are specific for each packaging system. However, throughout Europe the recycling rates vary.

Although the specific end-of-life situations and types of waste management systems are not within the scope of this study the following sensitivity analyses shall provide indications about the environmental performance of the different packaging systems, if the recycling quota varies within a certain value range. The remaining part of the post-consumer packaging waste is modelled and calculated according to the average rates for landfilling and incineration in Europe (60% landfill; 40% MSWI) (see also section 2.3). The sensitivity analyses include the calculation of scenarios with a

- recycling rate 0%
- middle range recycling rates (close to 35%)
- high range recycling rates (close to 70%)

The upper and lower boundaries of those ranges are oriented at the magnitude of quotas found from an average European perspective throughout different packaging systems. With 71% the highest recycling rate throughout Europe is determined for the steel can. In terms of the pouch system a recycling quota of 0% has been assumed for the base scenarios (see section 2.2). However, to consider the latest development of pouch recycling in Europe, sorted pouch packages are assumed to undergo a pyrolysis treatment for aluminium recovery in case of a recycling quota >0% .

For this analysis an allocation factor of 50% is applied. The results will be interpolated in linear graphs. Table 2-6 gives an overview of the respective sensitivity analyses.

Table 2-6: Sensitivity analyses for different recycling rates: primary packaging element and short name used in the result graphs

Sensitivity analysis: recycling rate close to 0% allocation factor 50%	Applied recycling quota	Short name
Food carton *combisafe* filled with 364 mL	0%	*combisafe*
Food carton *combibloc* filled with 383 mL		*combibloc*
Pouch filled with 442 mL		Pouch
One-way glass jar filled with 393 mL		Glass
Steel can filled with 393 mL	0%	Can
Plastic pot filled with 374 mL	0%	Pot
Sensitivity analysis: recycling rate close to 35%; allocation factor 50%	Applied recycling quota	Short name
Food carton *combisafe* filled with 364 mL	37% (as applied in base scenario)	*combisafe*
Food carton *combibloc* filled with 383 mL		*combibloc*
Pouch filled with 442 mL	35%	Pouch
One-way glass jar filled with 393 mL	35%	Glass
Steel can filled with 393 mL	35%	Can
Plastic pot filled with 374 mL	35%	Pot
Sensitivity analysis: recycling rate close to 70% allocation factor 50%	Applied recycling quota	Short name
Food carton *combisafe* filled with 364 mL	70%	*combisafe*
Food carton *combibloc* filled with 383 mL	70%	*combibloc*
Pouch filled with 442 mL	70%	Pouch
One-way glass jar filled with 393 mL	69% (as applied in base scenario)	Glass
Steel can filled with 393 mL	71% (as applied in base scenario)	Can
Plastic pot filled with 374 mL	70%	Pot

2.5.4 Sensitivity analysis eutrophication potential according to ReCiPe

As explained in section 1.9 the Chemical Oxygen Demand (COD) is not considered in the freshwater eutrophication potential of the ReCiPe method, while within the CML method it is in the aquatic eutrophication potential. Apart from this difference fate factors for the determination of characterisation factors are calculated as well as characterisation factors for emissions from manure and fertilizer are provided in freshwater eutrophication. However, the applied characterisation factors in both methods are weighted and converted stoichiometrically according to phosphorus equally to the CML method. Furthermore manure and fertilizer are not relevant for the present study as they are not included in the regarded datasets. Therefore, with the exception of COD and N-emissions considered, freshwater eutrophication more or less corresponds to the aquatic eutrophication potential. To therefore verify the influence of the COD on the results of the eutrophication potential a sensitivity analysis is conducted.

To capture all considered emissions considered in the aquatic eutrophication potential and to make results comparable to the base scenarios, the marine eutrophication according to the ReCiPe method has to be calculated as well, otherwise N- emissions from wastewater sewage will not be considered as they are in the respective method for the aquatic eutrophication applied for the base scenarios. For this analysis an allocation factor of 50% is applied.

The characterization factors applied at the midpoint level for freshwater and marine eutrophication are given in Table 2-7 and were taken from [ReCiPe107].

Table 2-7: Eutrophication potential at midpoint level of substances considered in this study

emission type	**compartment**	**Eutrophication potential seawater [kg N equivalents]**	**Source**
emission NH_3	Air	0.092	[ReCiPe107] (July 2012)
emission NO_x as NO_2	Air	0.039	
Emission NO_2^-	Water	0.3	
NO_3^{2-}	Water	0.226	
Emission NH_4^+	Water	0.824	
N from sewage treatment plants	Water	1	
emission type	**compartment**	**Eutrophication potential freshwater**	**Source**
emission P	Water	1	[ReCiPe107] (July 2012)

Table 2-8 gives an overview of the respective scenario model and the corresponding short names used in the report and result graphs.

Table 2-8: Sensitivity analyses eutrophication potential according to ReCiPe: primary packaging element and short name used in the result graphs

Sensitivity analysis eutrophication potential according to ReCiPe allocation factor 50%	Short name
Food carton *combisafe* filled with 364 mL	*combisafe* (ReCiPe)
Food carton *combibloc* filled with 383 mL	*combibloc* (ReCiPe)
Pouch filled with 442 mL	Pouch (ReCiPe)
One-way glass jar filled with 393 mL	Glass (ReCiPe)
Steel can filled with 393 mL	Can (ReCiPe)
Plastic pot filled with 374 mL	Pot (ReCiPe)

3 Life cycle inventory

Process data on packaging material production and converting were either collected at the industry or taken from literature and *IFEU*’s internal database respectively. Data on background processes such as energy generation, transportation, waste treatment and recycling are continuously updated internally by *IFEU*; for the current study the most recent format was drawn upon. On the next page, Table 3.1 gives an overview on datasets used regarding packaging raw materials, production process and background, followed by short descriptions of the datasets relevant for the present study.

The validation of industry data used in this study was carried out by cross-checks with literature data: manufacturer’s/ machine manufacturer’s data and other data from *IFEU*’s internal database.

Table 3-1: Overview of inventory data sets used in this study

Material / Process step	Source	Reference period
Intermediate goods		
PP	Plastics Europe, published online March 2005	1999
LDPE	Plastics Europe, published online March 2005	1999
PET	Plastics Europe, published online April 2010	2008
PA6	Plastics Europe, published online March 2005	~1996
EVOH	PlasticsEurope, published online March 2005	1999
PU	PlasticsEurope, published online March 2005	1996
Aluminium	EAA Environmental Profile report 2008	2005
Tinplate sheet	IFEU database	2005/2006
Corrugated cardboard incl. manufacture	[FEFCO 2013]	2012
LPB for *combibloc*	IFEU data, obtained from ACE	2009
LPB for *combisafe*	Stora Enso	2007
Production		
Food carton converting	SIG Combibloc	2009
Pouch laminate manufacture	IFEU database	1999/2010
Tinplate can manufacture	Buwal / IFEU database	1995/2008
glass jar converting incl. glass production	UBA 2000 (bottle glass); energy prechains 2009	2000/2009
Plastic pot converting	[Packforce 2013]	2013
Closure production (made of plastic)	IFEU database	2010
Closure production (made of tinplate)	IFEU data, obtained Informationszentrum Weißblech e.V.	2002/2003
Pallet production	[IFEU 1994]	1991
Filling incl. sterilisation		
Filling of BC	Packforce 2013	2013
Filling of pouch	Packforce 2013	2013
Filling of glass-jar	Packforce 2013	2013
Filling of food can	Packforce 2013	2013
Filling of plastic pot	Packforce 2013	2013
Recovery		
Food carton	IFEU database, based on data from various European recycling plants	2004
Steel can	IFEU database	2008
Glass-jar	IFEU database, DSD, FEVE 2010	2004/2005
Plastic pot	IFEU database, based on data from various European recycling plants	2004
Pouch	IFEU database, Aluminium Rheinfelden GmbH	~2004

Material / Process step	Source	Reference period
Background data		
electricity production, Finland & Sweden	IFEU database, based on statistics and power plant models	2009
electricity production, EU27+CH&NO	IFEU database, based on statistics and power plant models	2009
MSWI	IFEU database, based on statistics and incineration plant models	2008
Landfills	IFEU database, based on statistics and landfill models	2008
Distribution	IFEU database, based on data from fillers and packforce	2010
lorry transport	IFEU database, based on statistics and transport models, emission factors based on HBEFA 3.1 [INFRAS 2010].	2009
rail transport	[Borken et al. 1999]	1999
sea ship transport	[EcoTransIT 2010]	2010

3.1 Manufacture of plastics

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

- Polypropylene (PP)
- Low density polyethylene (LDPE)
- Polyethylene terephthalate (PET)
- Polyamide (PA6)
- Ethylene vinyl alcohol (EVOH)
- Polyurethane (PU)

3.1.1 Polypropylene

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 2005a]. The dataset covers the production of PP from cradle to the polymer factory gate. The polymerisation data refer to the 1999 time period and were acquired from a total of 28 polymerisation plants producing 5,690,000 tonnes of PP annually. The total PP production in Western Europe in 1999 was 7,395,000 tonnes. The Plastics Europe data set hence represented 76.9% of PP production in Western Europe.

3.1.2 Low Density Polyethylene

Low density polyethylene (LDPE) is manufactured in a high pressure process and contains a high number of long side chains. The present LCA study uses the ecoprofile published on the website of Plastics Europe (data last calculated March 2005) [Plastics Europe 2005b].

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 1999 time period and were acquired from a total of 27 polymerisation plants producing 4,480,000 tonnes of LDPE annually. The total production in Europe in 1999 was ca. 4,790,000 tonnes. The data set hence represented 93.5% of LDPE production in Western Europe.

3.1.3 PET (polyethylene terephthalate)

Polyethylene terephthalate (PET) is produced by direct esterification and melt polycondensation of purified terephthalic acid (PTA) and ethylene glycol. The model underlying this LCA study uses the ecoprofile published on the website of Plastics Europe with a reference year of 2008 [PLASTICSEUROPE 2010], that represents the production in European PET plants. Primary data from foreground processes of PTA and PET producers were collected in 2009 for the year 2008. Five PTA plants in Belgium, Italy, the Netherlands, Spain and the United Kingdom supplied data with an overall PTA volume of 2.1 million tonnes – this represents 77% of the European production volume (2.7 million tonnes). For PET production data from 14 production lines at 12 sites in Germany, Greece, Italy, Lithuania, the Netherlands, Spain and the United Kingdom could be obtained. With 1.7 million tonnes they cover 72% of the European bottle grade PET production (2.4 million tonnes).

3.1.4 Polyamide (PA6)

Polyamide 6 is manufactured from the precursors benzene and hydroxylamine. The present LCA study uses the ecoprofile published on the website of PlasticsEurope (data last calculated March 2005) [PlasticsEurope 2005c]. PlasticsEurope published this data set alongside the dataset for polyamide 66. Both data sets cover the production of polyamide granulates right from the extraction of the raw materials from the natural environment, including processes associated with this. The data for polyamide 66 refer to the 1996 time period. No information regarding the reference period for the polyamide 6 data set is specified by PlasticsEurope. No information regarding the number of plants that were part of the data gathering or regarding the representativity of the data set is available either.

3.1.5 Ethylene vinyl alcohol (EVOH)

Ethylene Vinyl Alcohol, is a formal copolymer of ethylene and vinyl alcohol. Because the latter monomer mainly exists as its tautomer acetaldehyde, the copolymer is prepared by polymerization of ethylene and vinyl acetate to give the ethylene vinyl acetate (EVA) copolymer followed by hydrolysis. Data for its production is taken from the PlasticsEurope website (data last calculated March 2005) [PlasticsEurope 2005d].

3.1.6 Polyurethane (PU)

Polyurethane is a polymer composed of a chain of organic units joined by carbamate (urethane) links. Its precursors are polyol, diphenylmethane diisocyanate (MDI) and toluene diisocyanate (TDI) The present LCA study uses the ecoprofile published on the website of Plastics Europe (data last calculated March 2005) [Plastics Europe 2005e]. This ecoprofile is an inventory data set of polyurethane flexible foam. Although the PU used in the pouch examined in this study ist not foam but PU foil, the dataset still represents the best available data about the production of PU and is therefore used as a proxy instead of PU foil.

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 2005. Respectively, this represented 90% to 92% of the single production steps alumina production, past and anode production, as well as electrolysis and casthouse of the primary aluminium production in Europe [EAA 2008].

The data set for aluminium foil (5-200 µm) is based on data acquired by the EAA together with EAFA covering the year 2005 for the manufacture of semi-finished products made of aluminium. For aluminium foils, this represents 51% of the total production in Europe (EU27 + EFTA countries). According to EAA [EAA 2008], the foil production is modelled with 20% of the production done through strip casting technology and 80% through classical production route. The LCI dataset is according to EAA applicable for foils with a thickness range of 5-200 µm.

For the present LCA study, aggregated LCI datasets for primary aluminium and aluminium foil are used as published in the EAA report [EAA 2008].

3.3 Manufacture of tinplate

Data for the production of tinplate are taken from the IFEU database and is collected from European steel producers. The reference time of the inventory data is 2005/2006 and includes all relevant prechains.

3.4 Glass and glass jars

The data used for the manufacture of hollow glass were the same as the data acquired and documented for [UBA 2000]. The data set prepared by the glass industry for use in the UBA study gave a representative cross-section of the technologies and energy resources that are used[9]. The energy consumption and the emissions for the glass manufacturing process are determined by the composition of the raw mineral material and in particular by the scrubbing and the fossil energy resource used for the direct heating. The electricity pre-chains were updated to represent the situation in 2009.

As closures of glass jars are made from tinplate and LDPE the same datasets as described in sections 3.1.2 and 3.3 are used for their modelling.

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[9] see [UBA 2000], page 57

3.5 Production of liquid packaging board (LPB)

The production of liquid packaging board (LPB) used for the *combibloc* packaging was modelled using data gathered from 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.

For the manufacture of *combisafe*, a special grade of liquid packaging board is used. It is produced by Stora Enso and has an area weight of 210 g/m^2. Stora Enso provided a site-specific dataset for the manufacture of this LPB grade for the reference year 2007.

Both data cover all process steps including pulping, bleaching and board manufacture. They were combined with data sets for the process chemicals used from IFEU´s database and EcoInvent, including a forestry model to calculate inventories for this sub-system. Energy required is supplied by electricity as well as by on-site energy production by incineration of wood and bark. The specific energy sources were taken into account.

3.6 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2013 [FEFCO 2013] 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 (see also Table 3-2). They refer to the year 2012.

Table 3-2: FEFCO data sets used for corrugated cardboard

Cardboard material	Publication date	Reference year	Representative-ness	Production countries covered
Kraftliner	2013	2012	>80%	AT, FI, FR, P, PL, SE
Testliner	2013	2012	66%	AT, CZ, FR, DE, IT, NL, PL, ES, GB
Wellenstoff	2013	2012		
Corrugated cardboard and trays	2013	2012	38% (221 plants)	AT, BE, CZ, DK, ES, FI, FR, DE; HU, IT, LT, NL, NO, PL, RO, SK, SE, CH, GB

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated cardboard trays. According to [FEFCO 2013] this fraction on average is 15% in Europe. Due to a lack of more specific information (e.g. EU27+2), this split was also used for the present study.

3.7 Converting

3.7.1 Converting of food cartons

The manufacture of composite board was modelled using converting data from SIG Combibloc that refer to the year 2009. Process data has been collected from the site in Linnich. Due to very similar machinery setups in different sites these data can be considered representative for all of SIG Combibloc's European converting sites. The converting process covers the lamination of LPB, LDPE and aluminium, printing, cutting and packing of the composite material. The packaging materials used for shipping of food carton sleeves to fillers are included in the model as well as the transportation of the package material.

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

3.7.2 Converting of pouch

Data for the manufacturing of the pouch food packaging are not publicly available. A literature review on converting data for pouches did not source representative information for this process.

In this study it was necessary to use internal data from IFEU´s database for the production of composite materials which consist of plastics and aluminium. The data are not specific for food packaging. The dataset covers energy inputs and selected air emission outputs and refers to the second half of the 1990s. Process data are combined with required prechains, such as the European grid electricity mix (reference year 2009).

3.7.3 Converting of tinplate can

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

3.7.4 Converting of plastic pot

Data for the manufacturing of the plastic pot were gathered and provided by [Packforce 2013]. Ahead to the implementation of the data in the LCA models IFEU carried out plausibility and validity checks. The converting data cover the electricity demand and consider line capacity and line efficiency as well as provide information regarding the treatment of production waste. The process data were combined with required prechains, such as grid electricity for the European geographic scope (reference year 2009).

3.8 Closure production

The closures of the plastic pot made of PP are produced by thermoforming. The data for the production were taken from IFEU's internal database and are based on values measured in Germany and data taken from literature. The process data were coupled with required prechains such as the production of PP and grid electricity.

Process data for the tinplate closure production used in this study were taken from IFEU's database based on information received from Informationszentrum Weißblech e.V. Reference year is 2002/2003 and represents the production in Germany, which is considered as sufficient for this study due to the lack of alternative data. The process data are coupled with all relevant prechains.

3.9 Pallet production

The manufacture of pallets was modelled using data from [IFEU 1994] and refers to the year 1991, based on the German geographic scope. The process data cover the required amount of wood within a saw mill for the production of timber and are combined with the respective energy prechains such as electricity grid mix and fuel oil.

3.10 Filling

Filling processes are similar for food cartons and alternative packaging systems regarding material and energy flows. The respective data for food cartons and alternative packagings were provided by [Packforce 2013] and cross-checked by IFEU with data collected for earlier studies. Data for the filling of all packaging systems refer to the year 2013. Data provided by packforce on filling includes data on sterilisation which is a retort sterilisation for all packagings apart from the *combibloc* food carton which is filled using ans aseptic processing method (UHT sterilisation).

3.11 Transport settings

The following Table 3-3 provides an overview of the transport settings (distances and modes) applied for packaging materials. Data were obtained from SIG Combibloc and several producers of raw materials. Where no such data were available expert judgements were made, e.g. exchanges with representatives from the logistic sector and supplier.

Table 3-3: Transport distances and means (transport means and distances for transports marked by an asterisk are based on assumptions)

		Transport defined by distance and mode [km / mode]	
Packaging element		**Material producer to converter**	**Converter to filler**
Plastic granulate for all packagings		500 / road	
Aluminium		350 / road 300/river 100/rail	
Paper board for composite board		300 / road 1200 / sea 400/ rail	
Cardboard for trays		primary fibres: 500/sea, 400/rail, 250/road secondary fibres: 300/road	
Wood for pallets*		100 / road	
LDPE stretch foil*		500/road (material production site = converter)	
Raw material for glass production		100-600/rail/road	
Paper for labels*		300/road	
Tinplate		500/road	
Trays*			500 / road
Pallets*			100 / road
Converted carton sleeves			700 / road
Steel cans			400/road
Glass jars			500/road
pouches*			500/road
Plastic pots[10]			1550/road 3050/sea

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[10] The defined plastic pot is mainly produced by two companies serving producers and co-packers within the European Union. One of them is situated in Union (Missouri/USA), the other is based in Bremervörde (Germany). The transport distances from converter to filler represent the average distances of the transport by lorry and ship.

3.12 Distribution of filled packs from filler to point of sale

Large fillers often serve not only regional markets. Transportation distance from filler to retailer is considered to be more closely related to the market structure than to the type of packaging used. For the European market no detailed data are available. Therefore, according to expert judgements by retailers and fillers, a transport distance of 500 km has been selected in context for the present study for all types of packages examined.

The 500km transport distance is implemented in the model as a two-stage delivery to retailers, where the first step indicates the transport to a central warehouse, and the second represents the delivery from a central warehouse to the supermarket (point-of-sale).

The overall structure of the distribution model is shown in Figure 3-1 and distances and assumed lorry types are summarised in Table 3-3. It is aimed to include typical lorry specifications in this study.

Figure 3-1: Simplified distribution model for delivery to the point-of-sale

In the life cycle model, environmental loads related to distribution have been allocated between food and packaging based on respective masses and on the degree of utilisation of the lorry. The lorry model for the 40-tonne articulated lorries is based on a 23-tonne maximum load and a maximum number of 34 pallets per lorry.

Table 3-4 also shows numbers for an ‘empty transport distance’, which is to be understood as the part of the lorry’s return trip, during which the vehicle is not carrying a load. For example in distribution step 1, the lorry travels a distance of 100 km without carrying any goods, after that it is assumed to be loaded with other products. In other words, only environmental loads for the ‘empty’ part return trip (100 km in this case) of the lorry are assigned to the analysed packaging systems. The remaining part of the return trip, during which the lorry is transporting other goods, would be assigned to these products. The 100 km empty trip is based on an assumed rule that for 25% to 30% of the distribution distance the lorries are empty before they can load up other goods. This rule is only applied to distribution step 1 as recent internal studies showed that for the return trip between the point-of-sale and the central warehouse the lorries usually do not load other goods from other product systems.

Table 3-4: Overview on assumed transport distances and lorry types for distribution to point of sale for the European market (EU27+2).

	Transport distance		**Vehicle type** (percentage = share of distance)			
	fully loaded	**empty (=no load)**	**articulated lorry, 40 t**	**lorry + trailer, 40 t**	**lorry, 23 t**	**lorry, 16.5 t**
Distribution – Step 1	**400 km**	**100 km**	50 %	50 %	0 %	0 %
Distribution – Step 2	**100 km**	**100 km**	34 %	0 %	33 %	33 %
Total distance	**500 km**	**200 km**				

3.13 Recovery and recycling

Food cartons

Food cartons are typically positively sorted into a beverage and food carton fraction, which subsequently is sent to a paper recycling facility for fibre recovery. The secondary fibre material is used e.g. as a raw material for cardboard. A substitution factor 0.9 is applied. The rejects (plastics and aluminium compounds) are assumed to undergo either a thermal treatment in cement kilns or are finally disposed (e.g. MSWI plant or landfill). 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*.

Pouch packages

In the base case, no recovery of post-consumer pouch packaging waste is assumed. However in case of the variant scenarios regarding post-consumer recycling quotas, a recovery of pouch packages via the pyrolysis route is assumed.

In the latter case, the pouch packs are assumed to be recycled together with other aluminium containing materials in pyrolysis plants for the recovery of the aluminium. The data set applied to the pyrolysis process is based on data from the former German Rheinfelden facility and is classified as confidential.

The energy content of the non-metallic components of the composite material is sufficient for an energetic self-sustaining pyrolysis process. Natural gas is used to fuel auxiliary process steps. In a first stage the pyrolysis furnace is heated to 350-550°C allowing the discharge of volatile components which are burnt in a high temperature stage at 800-1200°C. The released energy is used to heat the furnace. The residual aluminium is mixed with slag which has to be removed. The molten aluminium can be used for high-quality castings.

Plastic pot

The plastic pot mainly consists of PP and can be detected within the sorting process by near infrared spectroscopy (NIR) and is therefore separated into the PP-fraction. This plastic fraction is shredded to flakes, other plastic components are separated and the flakes are washed before further use. Primary granulate is credited in the model of this study with an applied substitution factor of 0.8.The data used in the current study is based on IFEU's internal database and information provided by Duales System Deutschland GmbH (DSD). The reference period is 2004/2005.

Steel cans

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

Glass jars

Glass jars are assumed to be recycled with a post-consumer waste glass fraction. As far as possible, remelting of waste glass within the glass jar system is assumed (closed-loop recycling). It therefore directly replaces glass made of primary mineral material (Substitution factor 1.0). Data is taken from the internal IFEU database based on collected data from Duales System Deutschland and European glass recyclers.

3.14 Background data

3.14.1 Transport processes

Lorry transport

The dataset used is based on standard emission data that were collated, validated, extrapolated and evaluated for the German, Austrian and Swiss Environment Agencies (UBA Berlin, UBA Vienna and BUWAL Bern) in the 'Handbook of emission factors' [INFRAS 2010]. The 'Handbook' is a database application referring to the year 2009 and giving as a result the transport distance related fuel consumption and the emissions differentiated into lorry size classes and road categories**.** Data are based on average fleet compositions within several lorry size classes. The emission factors used in this study refer to the year 2008.

Based on the above-mentioned parameters – lorry size class and road category – the fuel consumption and emissions as a function of the transport load and distance were determined.

Rail transport

The rail transport model from [Borken et al. 1999] has been used for this study. This aggregated model represents the situation of freight transport by rail in the late 1990s. Direct emissions as well as consumption of secondary energy (diesel fuel, electricity) are considered.

Ship transport

The data used for the present study represent freight transport with an overseas container ship (10,5 t/TEU[11]) and a utilisation of capacity by 55%. Energy use is based on an average fleet composition of this ship category with data taken from [EcoTransIT 2010]. 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 2010]. For the consideration of well-to-tank emissions data were taken from IFEU's internal database.

3.14.2 Electricity generation

Modelling of electricity generation is particularly relevant for the production of base materials as well as for converting and filling processes. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2009 for the production of paperboard and the European mix of energy suppliers (EU27+2) in the year 2009 for all other processes (see Table 3-5).

Table 3-5: Share of energy source to specific energy mix [Eurostat 2011a], reference year 2009.

country / Energy source	EU 27+2	Sweden	Finland
Hard coal	13.46%	0.36%	15.02%
Brown coal	9.76%	0.50%	5.95%
Fuel oil	2.36%	0.49%	0.69%
Natural gas	22.69%	1.42%	14.56%
Nuclear energy	26.65%	37.33%	32.69%
Hydropower	15.74%	49.50%	18.45%
Windpower	4.97%	1.88%	0.41%
Solar energy	0.51%	0%	0.01
Geothermal energy	0.91%	0%	0%
Biomass energy	3.08%	8.0	11.92%
Waste	0.59%	0.52%	0.30%

The mix of energy suppliers to the respective electricity networks was determined by using data based on the Statistical Office of the European Communities [EUROSTAT 2011] and on the UMBERTO based electricity grid model created by IFEU [IFEU 2011].

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[11] Twenty-foot Equivalent Unit

3.14.3 Landfills

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 Europe is currently not 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 food carton material on a landfill. Empirical data regarding degradation rates of laminated food 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:

- it is assumed that 50% of methane generated is actually recovered via landfill gas capture systems. This assumption is based on data from National Inventory Reports (NIR) under consideration of different catchment efficiencies at different stages of landfill operation.
- regarding the degradation of the food carton board under landfill conditions, it is assumed that it behaves like coated paper-based material in general. According to [Micales and Skog 1996], 30% of paper is decomposed anaerobically on landfills.
- it is assumed that the degraded carbon is converted into landfill gas with with 50% methane content by volume.

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

3.14.4 Municipal waste incineration

It is assumed that from the energy content in the incinerated waste, 11% is recovered as electricity and 30% as thermal energy for the European market. The numbers are supported by a report of the European Waste Incineration Plant Operators [CEWEP 2006]. In the incineration model a technical standard (especially regarding flue gas cleaning) is assumed which complies with the requirements given by the EU incineration directive, ([EC 2000] Council Directive 2000/76/EC). The model calculation considers a grid-firing with boiler system with steam turbine and flue gas cleaning.

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, replacing process heat generated by light fuel oil (50%) and natural gas (50%). The latter mix of energy sources is an assumption made by *IFEU*, as official data regarding this aspect are not available according to the knowledge of the authors of this study.

4 Results of the life cycle inventory and impact assessment

In this section the results of the examined packaging systems are presented separately for the different indicators in graphic form. The methodology of the life cycle impact assessment is documented in Appendix A.

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

- Production and transport of glass including converting to jar(**‘glass’**)
- Production and transport of tinplate (**‘tinplate’**)
- production and transport of liquid packaging board (**‘LPB’**)
- production and transport of plastics and fillers (**‘plastics’**)
- production and transport of aluminium & converting to foil (**‘aluminium foil’**)
- converting processes of food cartons, steel can, pouch and plastic pot (**‘converting’**)
- production and transport of base materials for closures and labels and related converting (**‘closure & label’**)
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays (**‘secondary & tertiary packaging’**)
- filling process including packaging handling (**‘filling’**)
- retort sterilization or UHT **(‘retorting/UHT’**)
- retail of the packages from filler to the point-of-sale (**‘distribution’**)
- sorting, recycling and disposal processes (**‘recycling & disposal’**)

Secondary products (recycled materials and recovered energy) are obtained through recovery processes of used packaging materials, e.g. recycled fibres from food cartons may replace primary fibres. It is assumed, that those secondary materials are used by a subsequent system. In order to consider this effect in the LCA, the environmental impacts of the packaging system under investigation are reduced by means of credits based on the environmental loads of the substituted material. The so-called 50% allocation method has been used for the crediting procedure (see section 1.8) in the base scenarios.

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

- credits for 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 (stacked bar **‘environmental burdens’**)
- credits given for secondary products leaving the system (negative stacked bar **‘credits’**)
- net results as a results of the substraction of credits from overall environmental loads (grey bar **‘net results’**)

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

4.1 Presentation of results

Figure 4-1 below illustrates how to read the result graphs included in the current report. Figure 4-2 till Figure 4-5 on the following pages illustrate the quantitative results for the base scenarios regarded in the current LCA study by impact/inventory level category. The stacked bar graphs allow the identification of the relative contribution of certain parts of the packaging system (life cycle elements) as well as credits to the respective final result.

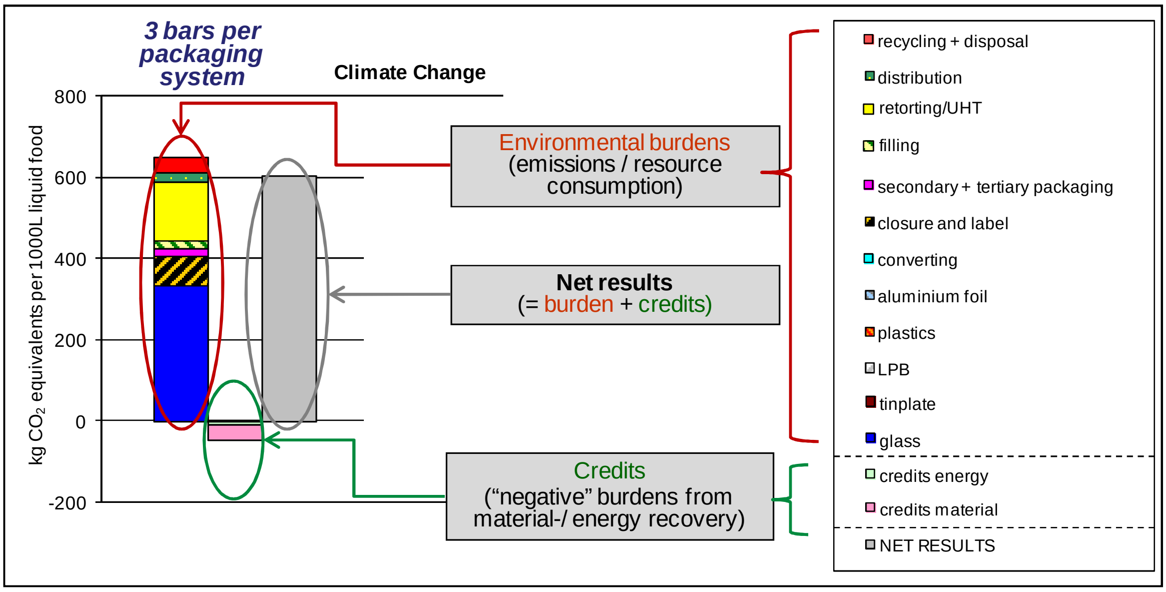

Figure 4-1: How to read the result graphs

The result graphs for the base scenarios (Figure 4-2 to 4-5) with the respective numerical values (Table 4-1 and 4-2) are presented on the following pages.

Table 4-1: Results for base scenarios - burdens, credits and net results[12]:

Base scenarios allocation factor 50%		***combisafe***	***combibloc***	**pouch**	**glass**	**can**	**pot**
Impact indicators: *emissions*							
Climate change [kg CO_2 equivalents]	Burdens	304,54	244,87	398,58	656,37	688,18	613,18
	Credits	-26,82	-21,09	-20,68	-46,84	-108,53	-73,06
	Net results (∑)	277,72	223,78	377,90	609,53	579,65	540,12
Acidification [kg SO_2 equivalents]	Burdens	0,78	0,68	1,16	1,88	1,55	1,75
	Credits	-0,07	-0,06	-0,06	-0,12	-0,24	-0,19
	Net results (∑)	0,72	0,62	1,10	1,75	1,31	1,56
Summer Smog [g ethene equivalents]	Burdens	146,64	111,07	235,94	269,63	259,56	442,96
	Credits	-4,77	-4,08	-6,01	-37,46	-50,89	-48,82
	Net results (∑)	141,87	106,99	229,93	232,17	208,67	394,15
Ozone Depletion Potential [g R11 equivalents]	Burdens	0,10	0,10	0,16	0,58	0,17	0,26
	Credits	-0,01	-0,01	-0,01	-0,08	-0,01	-0,04
	Net results (∑)	0,09	0,09	0,15	0,49	0,16	0,22
Terrestial eutrophication [g PO_4 equivalents]	Burdens	75,71	64,53	118,95	230,59	134,64	182,59
	Credits	-5,29	-4,40	-4,20	-11,59	-16,40	-14,72
	Net results (∑)	70,42	60,12	114,74	219,00	118,24	167,88
Aquatic eutrophication [g PO_4 equivalents]	Burdens	26,66	22,42	31,89	34,61	28,18	46,87
	Credits	-2,90	-2,52	-0,15	-0,65	-3,81	-2,36
	Net results (∑)	23,75	19,89	31,74	33,95	24,38	44,52
Human toxicity – PM10 [kg PM10 equivalents]	Burdens	0,75	0,66	1,16	2,17	1,51	1,75
	Credits	-0,06	-0,05	-0,05	-0,19	-0,23	-0,17
	Net results (∑)	0,69	0,61	1,11	1,98	1,28	1,58
Impact indicators: *use / consumption of resources*							
Abiotic Resource Depletion (total) [kg Sb equivalents]	Burdens	2,40	1,84	3,00	4,81	4,43	5,36
	Credits	-0,17	-0,14	-0,16	-0,29	-0,66	-0,69
	Net results (∑)	2,23	1,70	2,85	4,52	3,77	4,67
Categories at inventory level							
Total primary energy (PE) [GJ]	Burdens	6,35	5,01	7,16	10,30	9,90	11,80
	Credits	-0,64	-0,53	-0,41	-0,66	-1,27	-1,61
	Net results (∑)	5,72	4,49	6,75	9,64	8,63	10,19
Non-renewable PE [GJ]	Burdens	5,07	4,09	6,58	9,87	9,49	11,34
	Credits	-0,39	-0,31	-0,36	-0,62	-1,25	-1,53
	Net results (∑)	4,69	3,78	6,22	9,25	8,24	9,81
Transport intensity (Lorry) [km]	Burdens	16,68	13,63	68,32	67,15	22,25	92,64
	Credits	-0,20	-0,17	-0,05	-1,05	-0,01	-0,12
	Net results (∑)	16,48	13,46	68,28	66,10	22,24	92,52

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[12] All figures are rounded to two decimal places. In some cases the 'net result' will deviate from the difference of the burdens and the credits by 0.01 due to the rounding. However all figures represent correct (rounded) values.

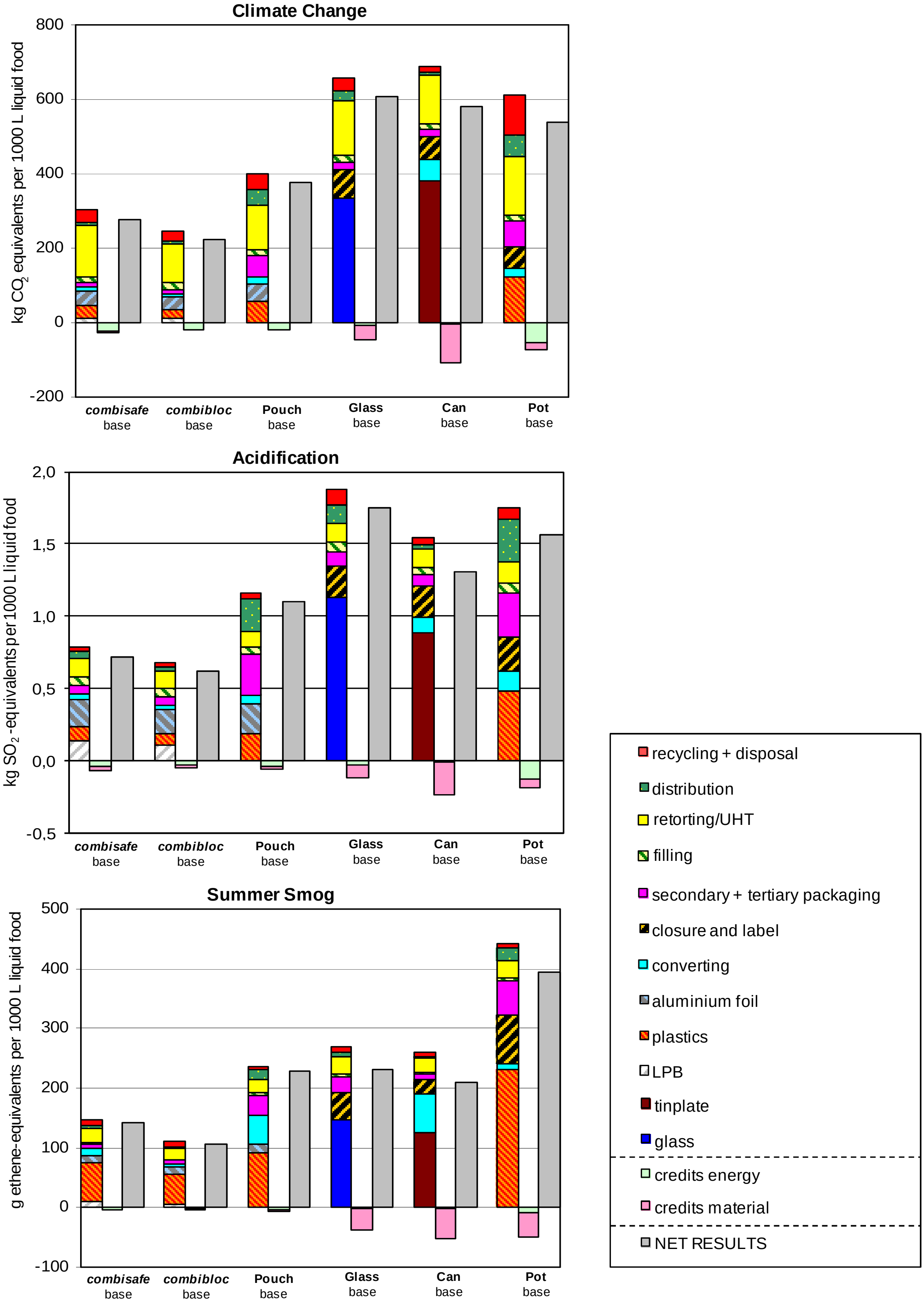


Figure 4-2: Impact indicator results for **base scenarios**, allocation factor 50% (Part I)

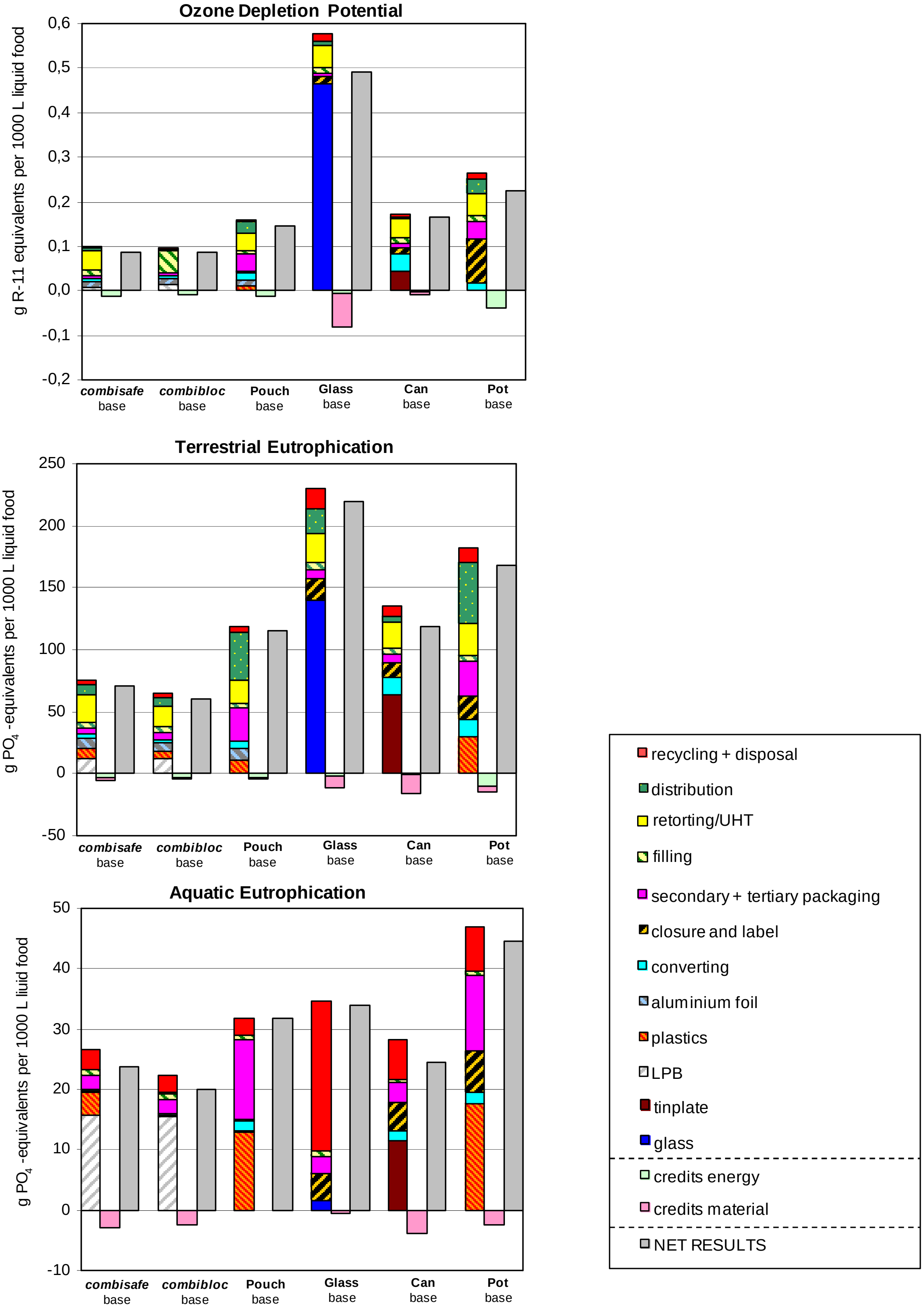
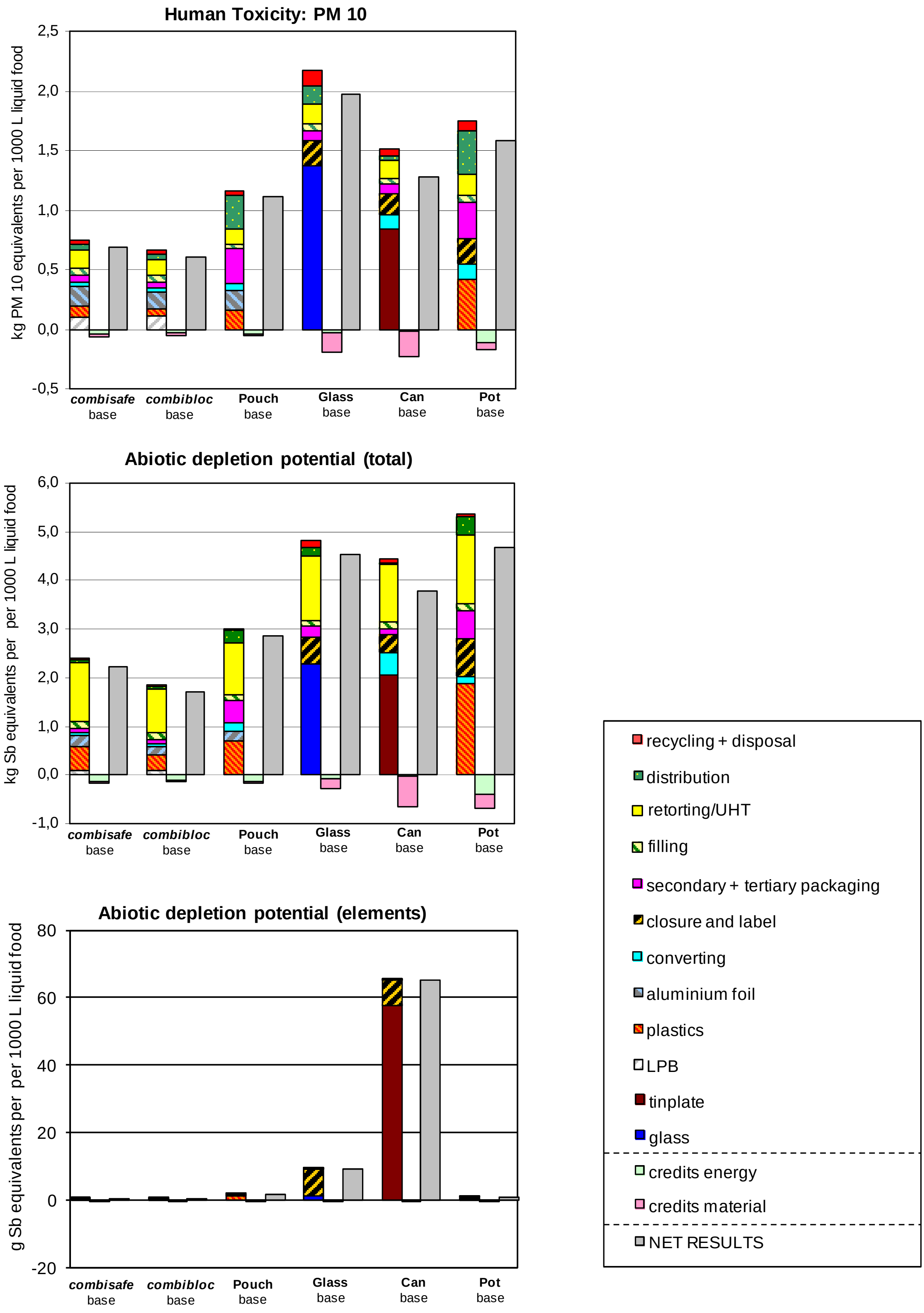


Figure 4-3: Impact indicator results for **base scenarios**, allocation factor 50% (Part II)


Human Toxicity: PM 10

Abiotic depletion potential (total)

Abiotic depletion potential (elements)

Figure 4-4: Impact indicator results for **base scenarios**, allocation factor 50% (Part III)

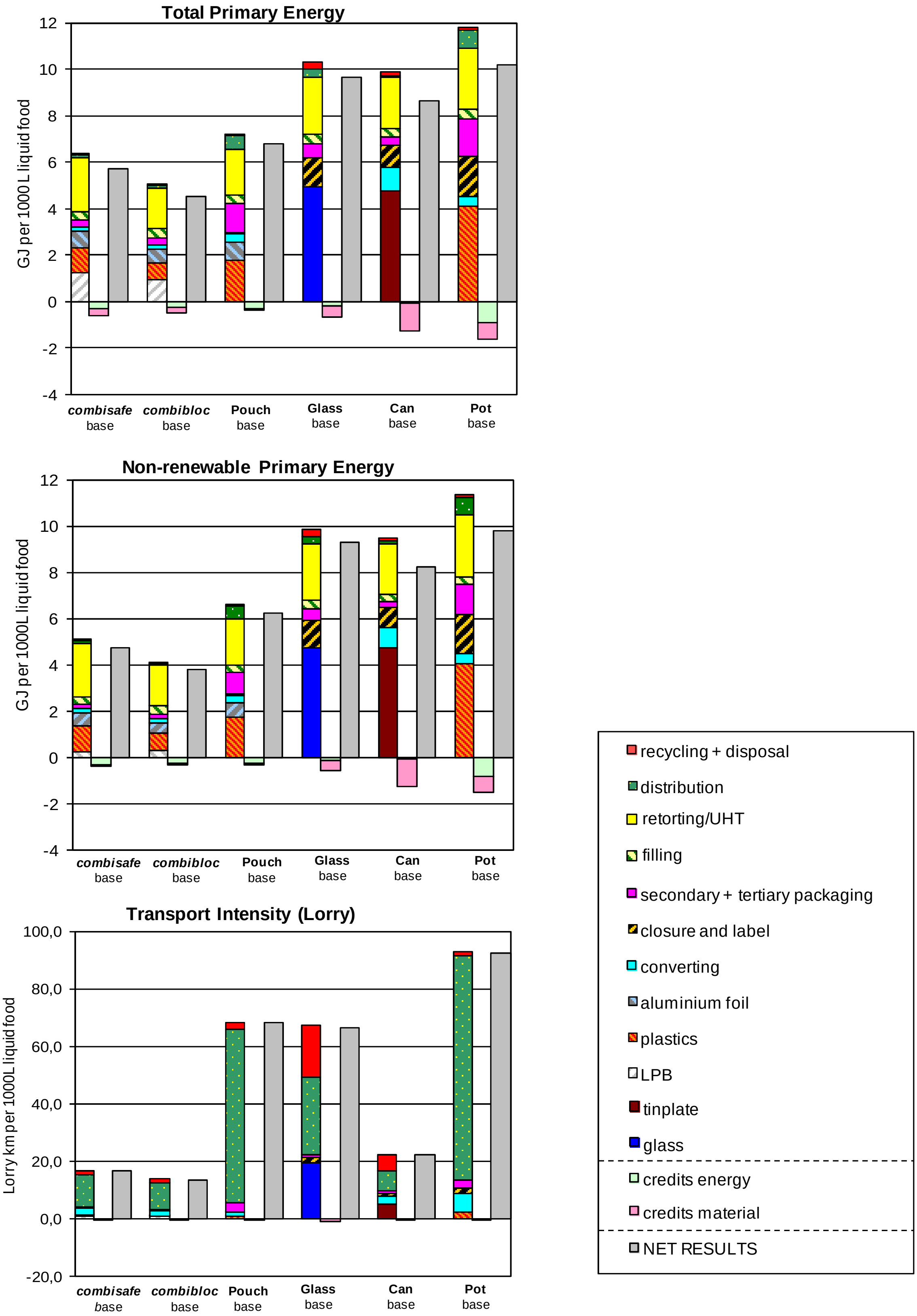


Figure 4-5: Results of **indicators at inventory level** for **base scenarios**, allocation factor 50%

4.2 Description by systems

In the following the graphical results of the base scenarios are described by system. Table 4-2 illustrates the dominant sectors (marked orange) on the life cycle results for the examined categories.

Food carton *combisafe*

In all analysed indicator categories the biggest part of the environmental burdens originates either from the production of the material components of the food carton or the retorting process.

The production of the liquid packaging board is the main contributor to the total burdens in *Aquatic Eutrophication*. In the categories *Terrestrial Eutrophication*, *Acidification*, *Total Primary Energy* and *Human Toxicitiy: PM10* the share of the LPB amount to about one sixth of the overall burdens.

In the analysed categories *Summer Smog*, *Abiotic Resource Depletion* and both total and non-renewable *primary energy demand* a high share on the environmental burdens for the plastics production is observed.

The production and provision of aluminum foil contribute visibly to the results in the indicators *Acidification*, *Climate Change* and *Human Toxicity: PM10*.

The converting does not show high impacts in any of the regarded impact categories.

The secondary & tertiary packaging does not contribute considerably to the total burdens of any category.

The filling process does not show high impacts in any of the regarded impact categories

The retorting process is the main contributor to the total burdens in the categories *Climate Change, Ozone Depletion, Terrestrial Eutrophication* and *Abiotic Resource Depletion* as well as for the inventory categories *Total* and *Non-renewable energy.*

The distribution only plays a considerable role for the inventory category *Transport Intensity (Lorry*), where it is the main contributor.

The recycling & disposal processes indicate a major contribution in *Climate change* and *Aquatic Eutrophication*.

Food carton *combibloc*

The results of the *combibloc* carton generally show a very similar pattern than those of *combisafe*. For all analysed impact and inventory categories the highest share of impacts is related to the same life cycle steps as for the *combisafe* carton. The UHT process shows similar result shares as the retorting process of the *combisafe* packaging.

Retortable Pouch

The impact and inventory category results of the pouch show many different life cycle steps as the important sector.

The production of base materials plastics and aluminium is a main contributor to the total burdens of the categories *Summer Smog* and *Aquatic Eutrophication*.

The converting process does not contribute considerably to any of the regarded categories except *Summer Smog*.

The secondary and tertiary packaging plays a major role in *Acidification, Ozone Depletion, Terrestrial* and *Aquatic Eutrophication* and *Human Toxicity: PM 10.*

The filling process does not show high impacts in any of the regarded impact categories.

The retorting process is a major contributor to the total burdens in the categories *Climate Change, Ozone Depletion, Terrestrial Eutrophication*, *Abiotic Resource Depletion* as well as for the inventory categories *Total* and *Non-renewable energy.*

The distribution contributes considerably to the impact categories *Acidification, Ozone Depletion, Terrestrial Eutrophication* and *Human Toxicity: PM 10 as well as to the Transport intensity (Lorry*) inventory category.

The recycling & disposal processes indicate a no major contributions to any of the regarded impact and inventory categories.

Glass jar

The results for the regarded glass jar are clearly determined by the material provision and production of the jar in all categories, except *Aquatic eutrophication*.

The converting process contributes considerably to the categories *Summer Smog*, *Ozone Depletion, Terrestrial Eutrophication, Abiotic Resource Depletion* and to a lesser extent to all the inventory categories.

For the closure and label production process no dominant impacts are observed in any of the examined categories, however contributions are visible in most indicators.

The secondary & tertiary packaging does not contribute considerably to the total burdens of any category.

The filling process does not show high impacts in any of the regarded impact categories.

The retorting process contributes considerably to the impact categories *Climate Change, Summer Smog, Terrestrial Eutrophication, Abiotic Resource Depletion* and the inventory categories *Total* and *Non-renewable energy*.

The distribution only plays a considerable role for the inventory category *Transport Intensity (Lorry)*, where it is the main contributor.

The recycling & disposal processes indicate a major contribution in *Aquatic Eutrophication* and *Transport Intensity (Lorry).*

Steel can

The results for the steel can are clearly determined by the tinplate production which is the main contributor to all impact and inventory categories except *Transport Intensity (Lorry).*

The converting process contributes considerably to the categories *Summer Smog*, *Ozone Depletion, Terrestrial Eutrophication, Abiotic Resource Depletion* and to a lesser extent to all the inventory categories.

For the closure and label production process no dominant impacts are observed in any of the examined categories, however contributions are visible in most indicators.

The secondary & tertiary packaging only contributes considerably to the total burdens of *Aquatic Eutrophication.*

The filling process does not show high impacts in any of the regarded impact categories.

The retorting process contributes considerably to the impact categories *Climate Change, Summer Smog, Ozone Depletion, Terrestrial Eutrophication, Human Toxicity: PM10 and Abiotic Resource Depletion* as well as to the inventory categories *Total* and *Non-renewable energy*.

The distribution only plays a considerable role for the inventory category *Transport Intensity (Lorry)*, where it is the main contributor.

The recycling & disposal processes indicate a major contribution in *Aquatic Eutrophication* and *Transport Intensity (Lorry).*

Plastic Pot

The results for the plastic pot are clearly determined by the plastic production and to a lesser extent the retorting process.

The production of plastic is a main contributor to all impact and inventory categories except *Ozone Depletion* and *Transport Intensity (Lorry).*

The closure and label production process is the dominant impact for *Ozone Depletion* and shows lower shares of burdens for all other categories apart from *Transport Intensity (Lorry).*

The secondary & tertiary packaging contributes considerably to the burdens of any category, apart from *Transport Intensity (Lorry).*

The filling process does not show high impacts in any of the regarded impact categories.

The retorting process is the contributor to *Climate Change* and also shows considerable impacts to the impact categories *Ozone Depletion, Terrestrial Eutrophication, Human Toxicity: PM10* and *Abiotic Resource Depletion* as well as to the inventory categories *Total* and *Non-renewable energy*.

The distribution only plays a considerable role for the inventory category *Transport Intensity (Lorry)*, where it is the main contributor.

The recycling & disposal processes indicate a major contribution in *Climate Change Aquatic Eutrophication*.

Table 4-2: Dominant sectors of the life cycle for the examined packaging systems regarding the considered impact categories. Given values represent percentage of sector in total burdens [%].

Base scenarios allocation factor 50%	***combisafe***	***combibloc***	**pouch**	**glass**	**can**	**pot**
Impact indicators: *emissions*						
Climate change						
glass				**51**		
tinplate					**55**	
LPB	4	5				
plastics	11	9	15			20
aluminium foil	13	14	11			
converting	3	4	5		8	4
closure and label				12	9	10
secondary + tertiary packaging	4	5	15	3	2	11
filling	6	8	4	3	3	3
retorting/UHT	**44**	**41**	**29**	22	19	**26**
distribution	3	3	11	4	1	9
recycling + disposal	12	11	10	5	2	18
Acidification						
glass				**60**		
tinplate					**57**	
LPB	17	16				
plastics	13	11	16			**27**
aluminium foil	**24**	**24**	18			
converting	5	5	5		7	8
closure and label				12	14	13
secondary + tertiary packaging	7	8	**25**	5	5	18
filling	**8**	9	4	4	4	4
retorting/UHT	16	17	9	7	8	8
distribution	6	6	20	7	2	17
recycling + disposal	4	4	3	6	3	4
Summer Smog						
glass				**55**		
tinplate					**48**	
LPB	7	5				
plastics	**43**	**44**	**39**			**52**
aluminium foil	9	11	6			
converting	7	4	21		25	2
closure and label				17	9	18
secondary + tertiary packaging	5	7	14	10	4	13
filling	1	2	2	1	1	1
retorting/UHT	18	17	9	10	10	7
distribution	2	**2**	7	3	1	5
recycling + disposal	7	8	2	4	3	2
Ozone Depletion Potential						
glass				**81**		
tinplate					**26**	
LPB	6	16				
plastics	1	0	6			0
aluminium foil	14	13	10			
converting	7	6	11		22	6
closure and label				2	9	**38**
secondary + tertiary packaging	7	7	**25**	2	6	14
filling	12	13	6	2	7	5
retorting/UHT	**43**	**37**	24	8	24	19
distribution	5	4	17	2	2	13
recycling + disposal	5	4	3	2	5	4

Table 4-2 – continued

Base scenarios allocation factor 50%	***combisafe***	***combibloc***	**pouch**	**glass**	**can**	**pot**
Terrestrial Eutrophication						
glass				**61**		
tinplate					**48**	
LPB	17	19				
plastics	10	8	9			16
aluminium foil	11	11	7			
converting	5	5	5		10	8
closure and label				7	9	10
secondary + tertiary packaging	7	7	22	3	5	15
filling	6	8	3	2	3	3
retorting/UHT	**29**	**27**	16	10	16	14
distribution	10	10	**32**	9	4	**27**
recycling + disposal	6	5	4	7	5	7
Aquatic Eutrophication						
glass				5		
tinplate					**41**	
LPB	**59**	**69**				
plastics	14	0	40			**37**
aluminium foil	1	1	1			
converting	1	1	5		5	4
closure and label				12	17	15
secondary + tertiary packaging	9	10	**42**	8	12	26
filling	3	4	2	3	2	1
retorting/UHT	0	1	0	0	0	0
distribution	0	0	0	0	0	0
recycling + disposal	13	12	9	**72**	23	16
Human Toxicity: PM 10						
glass				**63**		
tinplate					**56**	
LPB	14	16				
plastics	13	10	13			**24**
aluminium foil	**21**	**21**	15			
converting	5	5	5		8	8
closure and label				10	12	12
secondary + tertiary packaging	7	8	**24**	4	5	17
filling	8	9	4	3	4	3
retorting/UHT	20	20	11	8	10	10
distribution	7	7	**24**	7	3	21
recycling + disposal	4	4	3	6	4	5
Impact indicators: *use / consumption of resources*						
Abiotic Depletion Potential (total)						
glass				**48**		
tinplate					**46**	
LPB	4	5				
plastics	21	17	23			**35**
aluminium foil	9	10	7			
converting	3	3	5		10	3
closure and label				11	8	14
secondary + tertiary packaging	4	5	15	5	3	11
filling	5	7	4	3	3	2
retorting/UHT	**51**	**49**	**35**	28	26	27
distribution	2	3	9	3	1	7
recycling + disposal	1	1	1	3	2	1

Table 4-3: Dominant sectors of the life cycle for the examined packaging systems regarding the considered inventory level categories. Given values represent percentage of sector in total burdens [%].

Base scenarios allocation factor 50%	***combisafe***	***combibloc***	**pouch**	**glass**	**can**	**pot**
Categories at inventory level						
Total Primary Energy						
glass				**48**		
tinplate					**48**	
LPB	19	18				
plastics	17	14	25			**35**
aluminium foil	11	13	11			
converting	3	4	5		10	4
closure and label				12	10	15
secondary + tertiary packaging	4	5	18	6	4	14
filling	6	7	5	4	4	3
retorting/UHT	**36**	**35**	**27**	24	22	23
distribution	2	3	8	3	1	7
recycling + disposal	1	1	1	3	2	1
Non-renewable Primary Energy						
glass				**48**		
tinplate					**49**	
LPB	5	7				
plastics	21	18	26			**36**
aluminium foil	11	12	9			
converting	3	4	5		10	3
closure and label				12	9	15
secondary + tertiary packaging	4	5	15	5	3	12
filling	7	9	5	4	4	3
retorting/UHT	**45**	**42**	**30**	25	23	23
distribution	2	2	9	3	1	7
recycling + disposal	1	1	1	3	2	1
Transport Intensity (Lorry)						
glass				29		
tinplate					22	
LPB	4	4				
plastics	3	2	1			2
aluminium foil	0	0	0			
converting	13	13	2		14	7
closure and label				3	3	2
secondary + tertiary packaging	3	4	4	1	3	3
filling	0	0	0	0	0	0
retorting/UHT	0	0	0	0	0	0
distribution	**68**	**68**	**89**	**40**	**32**	**85**
recycling + disposal	8	9	4	27	26	1

4.3 Comparison between systems

In the following the net results of the examined food cartons *combisafe* and *combibloc* are compared to each other as well as to those of the analysed alternative packaging solutions.

Comparison of food carton *combisafe* to *combibloc*:

	Impact indicators *emissions*	**Impact indicators *use / consumption of resources***	**Categories at inventory level**
The food carton *combisafe* shows lower net results compared to the food carton *combibloc*			
The food carton *combisafe* shows higher net results compared to the food carton *combibloc*	Climate Change Acidification Summer Smog Terrestrial Eutrophication Aquatic Eutrophication Human Toxicity: PM 10	Abiotic Resource Depletion	Total Primary Energy Non-renweable primary energy Transport Intensity (Lorry)

Comparison of food cartons *combisafe* and *combibloc* to retortable pouch:

	Impact indicators *emissions*	**Impact indicators *use / consumption of resources***	**Categories at inventory level**
The food cartons *combisafe* and *combibloc* show lower net results compared to the pouch in	Climate Change Acidification Summer Smog Ozone Depletion Potential Terrestrial Eutrophication Aquatic Eutrophication Human Toxicity: PM 10	Abiotic Resource Depletion	Total Primary Energy Non-renweable primary energy Transport Intensity (Lorry)
The food cartons *combisafe* and *combibloc* show higher net results compared to the pouch in			

Comparison of food cartons *combisafe* and *combibloc* to one-way glass jar

	Impact indicators *emissions*	**Impact indicators *use / consumption of resources***	**Categories at inventory level**
The food cartons *combisafe* and *combibloc* show lower net results compared to the glass jar in	Climate Change Acidification Summer Smog Ozone Depletion Potential Terrestrial Eutrophication Aquatic Eutrophication Human Toxicity: PM 10	Abiotic Resource Depletion	Total Primary Energy Non-renweable primary energy Transport Intensity (Lorry)
The food cartons *combisafe* and *combibloc* show higher net results compared to the glass jar in			

Comparison of food cartons *combisafe* and *combibloc* to steel can

	Impact indicators *emissions*	**Impact indicators *use / consumption of resources***	**Categories at inventory level**
The food cartons *combisafe* and *combibloc* show lower net results compared to the steel can in	Climate Change Acidification Summer Smog Ozone Depletion Potential Terrestrial Eutrophication Aquatic Eutrophication Human Toxicity: PM 10	Abiotic Resource Depletion	Total Primary Energy Non-renweable primary energy Transport Intensity (Lorry)
The food cartons *combisafe* and *combibloc* show higher net results compared to the steel can in			

Comparison of food cartons *combisafe* and *combibloc* to plastic pot

	Impact indicators *emissions*	**Impact indicators *use / consumption of resources***	**Categories at inventory level**
The food cartons *combisafe* and *combibloc* show lower net results compared to the plastic pot in	Climate Change Acidification Summer Smog Ozone Depletion Potential Terrestrial Eutrophication Aquatic Eutrophication Human Toxicity: PM 10	Abiotic Resource Depletion	Total Primary Energy Non-renweable primary energy Transport Intensity (Lorry)
The food cartons *combisafe* and *combibloc* show higher net results compared to the plastic pot in			

5 Interpretation and discussion

In the following the results presented in section 4 are interpreted and discussed. In section 5.1 significant parameters and characteristic patterns shown in the base scenarios are explained and evaluated. In section 5.2 the results of the sensitivity analyses regarding system allocation factor, recycling rates and recycling rates and eutrophication potential according to ReCiPe are discussed. A look at the consistency and completeness of data and methodologies used and an overview of the current LCA's limitations (5.3) complete the discussion.

5.1 Base scenarios: significant parameters of packaging systems

For most impact indicators the results of the ***combisafe*** and ***combibloc*** system are predominantly related to the manufacture of packaging base materials with strong influence of aluminium and plastic production with the exception of *Aquatic Eutrophication* which is clearly dominated by LPB production. In many impact categories, especially *Climate Change* and *Abiotic Resource Depletion* also the retorting /UHT process is responsible for a large share of the impact results.

Results of the **pouch** system are heavily related to different life cycle steps in different impact categories. While the results of *Climate Change* and *Abiotic Resource Depletion* are predominantly related to the retorting process, the impact categories *Acidification* and *Aquatic Eutrophication* are mainly influenced by the production of secondary and tertiary production. This is due to high relevant emissions from the paperboard production process. For the impact categories *Acidification, Terrestrial Eutrophication* and *Human Toxicity: PM 10* the results are heavily related to the Distribution step which plays a bigger role for the *Pouch* system than for most of the other examined systems due to its disadvantageous pallet configuration with much less packages per pallet and therefore per lorry than the food cartons, the glass jar and the steel can. The manufacture of plastics and aluminium as base materials for the production of plays an important role in almost all impact categories as well.

The results of the **glass jar** system are predominantly related to the glass production, the closure production and the retorting process. The high impact of the glass production in the indicator *Ozone Depletion Potential* results from nitrous oxide emissions during limestone mining. For the impact category *Aquatic Eutrophication* the recycling and disposal sector shows high impacts. This high impact of the glass jar's end of life phase on *Aquatic Eutrophication* however may seem surprising. The reason for these high results lies in the applied landfill model, in which the glass waste is responsible for a part of the PO4eq. emissions from percolating water in landfills. As it is impossible to define which material generates these PO4eq emissions (in contrast to CO2eq emissions to air for example) they are allocated by mass to avoid not allocating them to any kind of waste at all. Apart from this percolating water can only be formed in landfills that are not completely covered due to a continuous delivery of new waste and therefore the glass waste is responsible for the formation of percolating water as well.

It must be noted, that the landfill model is applied equally to all packaging systems examined, although it may be seen as simplification. However, as there are no specific information available which enables an allocation of emissions to different materials, this model is still be evaluated as the best available approach.

The results of the **steel can** system are predominantly related to the manufacture of tinplate for most indicators. Besides the tinplate production, also converting as well as the retorting step are of importance.

5.2 Significant parameters of life cycle steps

Production of primary packaging materials

The results of the base scenarios (see sections 4.1 and 4.2) show that the production of base materials for the primary package is a predominant life cycle step in all examined packaging systems. Obviously the impact originating from the production of base materials is dependant of the demand of base materials per primary packaging. It is therefore directly related to the weight and filling volume of the examined packages. While the glass jar, steel can and plastic pot are heavier than the food cartons (with a similar filling volume) the pouch is the lightest of the examined packages. As it made almost exclusively from plastics and aluminium its impacts from the production of base materials is still higher than those of the food cartons in many impact categories as the food cartons' main component is the renewable base material LPB.

The production of LPB plays an important role for the results of the *Aquatic Eutrophication* though. This is due to the generation of emissions to water at the production of paperbased materials. For the separation of the cellulose needed for paper production from the ligneous wood fibres, the so called 'Kraft process' is applied, in which sodium hydroxide and sodium sulphide are used. This leads to additional emissions of SO_2, thus contributing significantly to the acidifying potential as well. The impact of the production of LPB on *Climate Change* and *Abiotic Resource Depletion* is relatively small as the energy sources for the production processes taking place in Finland and Sweden are mainly non-fossil. This renewable energy mainly originates from the burning of black liquor and bark at the paper mills.

Sterilization (Retorting/ UHT process)

The retorting and UHT step is the largest or one of the largest contributor to indicator results for all examined packaging systems in the impact categories: *Climate Change, Terrestrial Eutrophication*, *Ozone Depletion* and *Abiotic Resource Depletion* as well as in the energy related inventory categories. When looking at more detail it reveals that the energy demand of the retorting process is the key parameter for this life cycle step.

Converting

Energy consumption is also the key parameter for the impacts resulting from the converting process. The converting step includes the production of composites and packages in case of *combisafe* and *combibloc* and pouch systems, and the manufacture of plastic pot and can bodies and lids. As the converting of the steel can body and lid demands more energy that the converting processes of all other packaging systems the converting process only plays an important role on impact category results of the steel can system.

Secondary + tertiary packaging

The production of secondary and tertiary packaging, especially of corrugated cardboard boxes is responsible for considerable impacts in the categories *Acidification, Ozone Depletion, Terrestrial* and *Aquatic Eutrophication* and *Human Toxicity: PM 10.* This is especially true for the pouch and plastic pot systems. Both of these systems need a relatively high amount of cardboard for trays due to their shape and the fact that only 6 of the primary packages are packed per tray. This is also true for the glass jar, but much less paperboard is used for the jar as the secondary packages also consist of PE-foil in this case.

Distribution

The high influence of the distribution sector on Transport Intensity (Lorry) for the systems pouch and plastic pot can be explained by their pallet configuration with only 600 packages per pallet which leads to a higher demand of lorry space for the transportation of 1000 L liquid food products.

Recycling and Disposal

The end-of-life phase of the examined food cartons show relevant contributions to the results of the emission-related impact indicators *Climate Change* and *Aquatic Eutrophication*. In Europe almost half of the food cartons are disposed by landfilling. Due to the conversion of degraded carbon a high amount of methane emissions are generated, which causes emissions to a higher extent to the global warming potential. Those emissions have a stronger climatic effect, than those caused by the incineration of the plastic components included in the sleeve and the use of the rejects from the recycling process as fuel in cement kilns. However, these emissions contribute significantly to *Climate Change* as well. The ammonium and nitrate emissions having an impact on the *Aquatic Eutrophication* originate from landfills.

The recycling and disposal of both the retortable pouch and the plastic pot show significant contributions to the same categories compared to the food cartons The incineration of plastic causes higher greenhouse gas and NO2 emissions than the end of life treatment of the food cartons. Although plastic components behave inert on a landfill, the nitrate and ammonium emissions of the leakage water are allocated to the amount of the waste, which is finally landfilled.

5.3 Results of sensitivity analyses

5.3.1 Sensitivity analysis on system allocation: Allocation factor 100%

With the application of an allocation factor of 100%, all burdens and credits from recovery processes are allocated to the examined systems. For systems, which deliver more secondary products or receive energy credits from thermal recovery processes, the allocation factor has a stronger effect on the results.

The net results of the sensitivity analysis show only slight differences to the results of the base scenarios. The most significant changes can be observed at the results of the packaging systems glass jar and steel can as these systems benefit from higher additional credits from material recycling processes than the other regarded systems. The food cartons material credits do not play such a significant role as the production of their primary base materials does not show impacts as high as the other packaging systems. This is due to the fact, that the production of the main component of the food carton - LPB - takes place in Finland and Sweden, where the energy sources are mainly non-fossil. Therefore, the received material credits are not as high as for replaced processes carried out with mainly fossil based energy sources As all burdens of the recycling process are allocated to the system, when an allocation factor of 100% is applied, the impact caused by the recycling process of the food cartons increases. This process is carried out with a mainly fossil based electricity grid mix (EU27+2). Therefore, the net results, e.g. in Climate Change and Summer Smog, even slightly increase. The additional received material credits of the food cartons cannot offset the additional burdens.

Due to relatively low recycling rates, the pouch and pot packages' do not generate much additional credits even with an allocation factor of 100%.

Compared to the base scenarios of the present study, the ranking order among the food cartons and alternative packaging systems is not affected by the application of a 100% allocation factor.

The result graphs for the sensitivity analysis with allocation factor 100% - Figure 5-1 to 5-4 and the numerical values Table 5-1 (are presented on the following pages.

Table 5-1: Results for sensitivity analysis with allocation factor 100% - burdens, credits and net results (per 1000 L liquid food)[13]:

Sensitivity analysis allocation factor 100%		***combisafe***	***combibloc***	**pouch**	**glass**	**can**	**pot**
Impact indicators: *emissions*							
Climate change [kg CO_2 equivalents]	Burdens	321,43	257,90	404,75	663,13	691,16	630,59
	Credits	-42,26	-32,87	-25,37	-88,42	-213,32	-102,56
	Net results (∑)	279,17	225,03	379,39	574,71	477,84	528,03
Acidification [kg SO_2 equivalents]	Burdens	0,79	0,68	1,16	1,88	1,56	1,77
	Credits	-0,11	-0,09	-0,08	-0,23	-0,47	-0,28
	Net results (∑)	0,69	0,59	1,08	1,65	1,09	1,49
Summer Smog [g ethene equivalents]	Burdens	150,12	114,07	236,45	270,20	260,51	444,19
	Credits	-7,59	-6,56	-9,27	-74,28	-101,36	-90,13
	Net results (∑)	142,53	107,51	227,19	195,92	159,15	354,06
Ozone Depletion Potential [g R11 equivalents]	Burdens	0,10	0,10	0,16	0,58	0,17	0,27
	Credits	-0,02	-0,01	-0,02	-0,16	-0,01	-0,05
	Net results (∑)	0,08	0,08	0,14	0,41	0,16	0,22
Terrestrial eutrophication [g PO_4 equivalents]	Burdens	77,08	65,64	119,39	231,47	136,51	184,81
	Credits	-8,29	-6,96	-5,20	-21,87	-31,86	-20,70
	Net results (∑)	68,79	58,68	114,19	209,60	104,65	164,10
Aquatic eutrophication [g PO_4 equivalents]	Burdens	27,48	23,10	32,00	42,60	31,71	47,92
	Credits	-5,80	-5,04	-0,28	-1,30	-7,61	-4,68
	Net results (∑)	21,68	18,06	31,72	41,30	24,10	43,24
Human toxicity – PM10 [kg PM10 equivalents]	Burdens	0,76	0,67	1,16	2,17	1,52	1,77
	Credits	-0,10	-0,08	-0,07	-0,36	-0,45	-0,25
	Net results (∑)	0,66	0,59	1,10	1,81	1,08	1,52
Impact indicators: *use / consumption of resources*							
Abiotic Resource Depletion (total) [kg Sb equivalents]	Burdens	2,41	1,85	3,01	4,81	4,45	5,37
	Credits	-0,26	-0,21	-0,20	-0,54	-1,29	-1,06
	Net results (∑)	2,15	1,64	2,81	4,27	3,15	4,31
Categories at inventory level							
Total primary energy (PE) [GJ]	Burdens	6,38	5,04	7,16	10,32	9,93	11,85
	Credits	-1,07	-0,89	-0,54	-1,21	-2,45	-2,46
	Net results (∑)	5,31	4,15	6,63	9,10	7,48	9,40
Non-renewable PE [GJ]	Burdens	5,10	4,11	6,59	9,88	9,52	11,38
	Credits	-0,59	-0,47	-0,46	-1,14	-2,44	-2,34
	Net results (∑)	4,52	3,64	6,13	8,74	7,09	9,04
Transport intensity (Lorry) [km]	Burdens	17,85	14,04	68,39	67,15	24,52	92,95
	Credits	-0,37	-0,32	-0,05	-2,09	-0,02	-0,15
	Net results (∑)	17,48	13,72	68,34	65,06	24,50	92,80

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[13] All figures are rounded to two decimal places. In some cases the 'net result' will deviate from the difference of the burdens and the credits by 0.01 due to the rounding. However all figures represent correct (rounded) values.

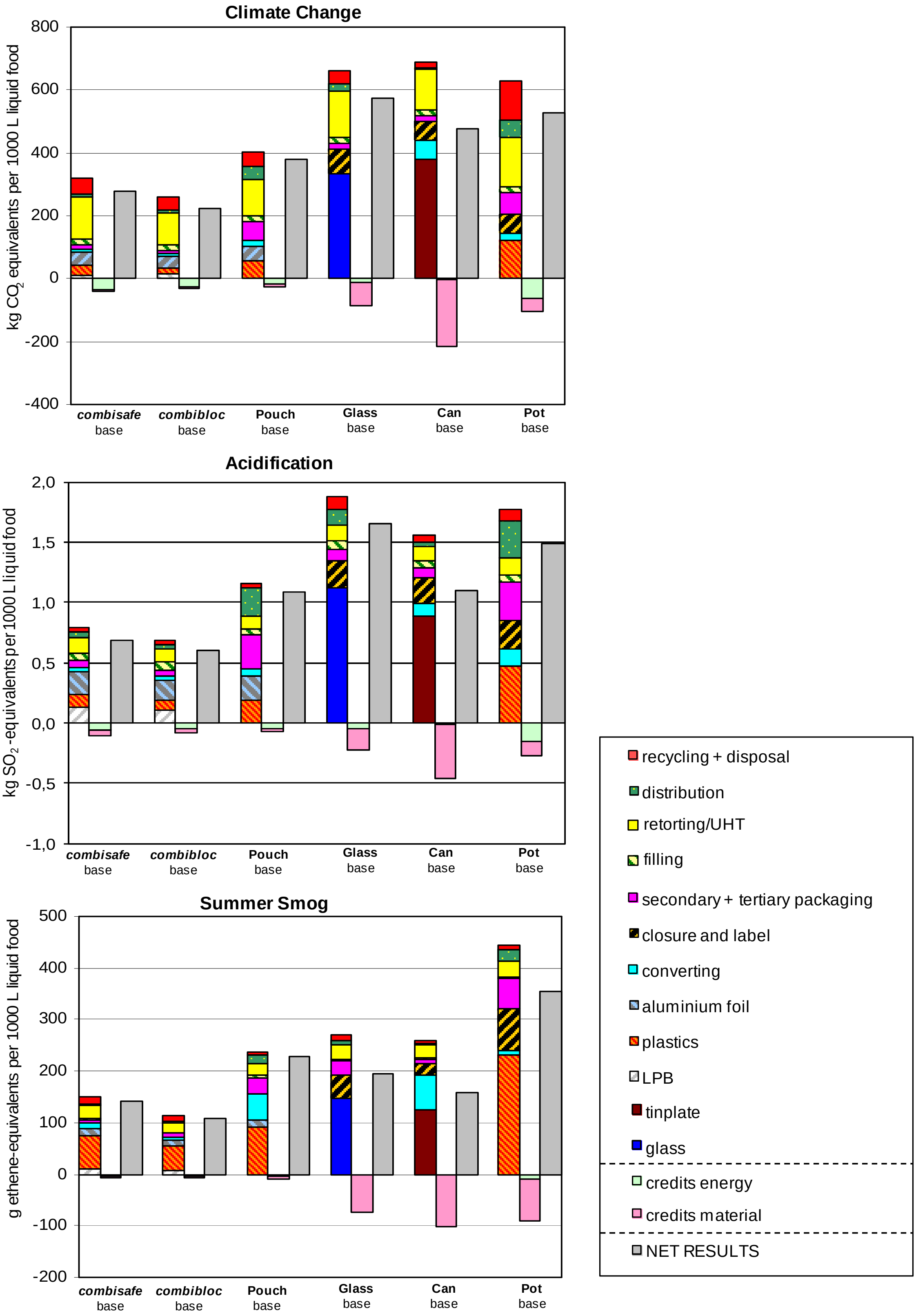

Figure 5-1: Impact indicator results for **sensitivity analysis allocation factor 100%** for materials (Part I)

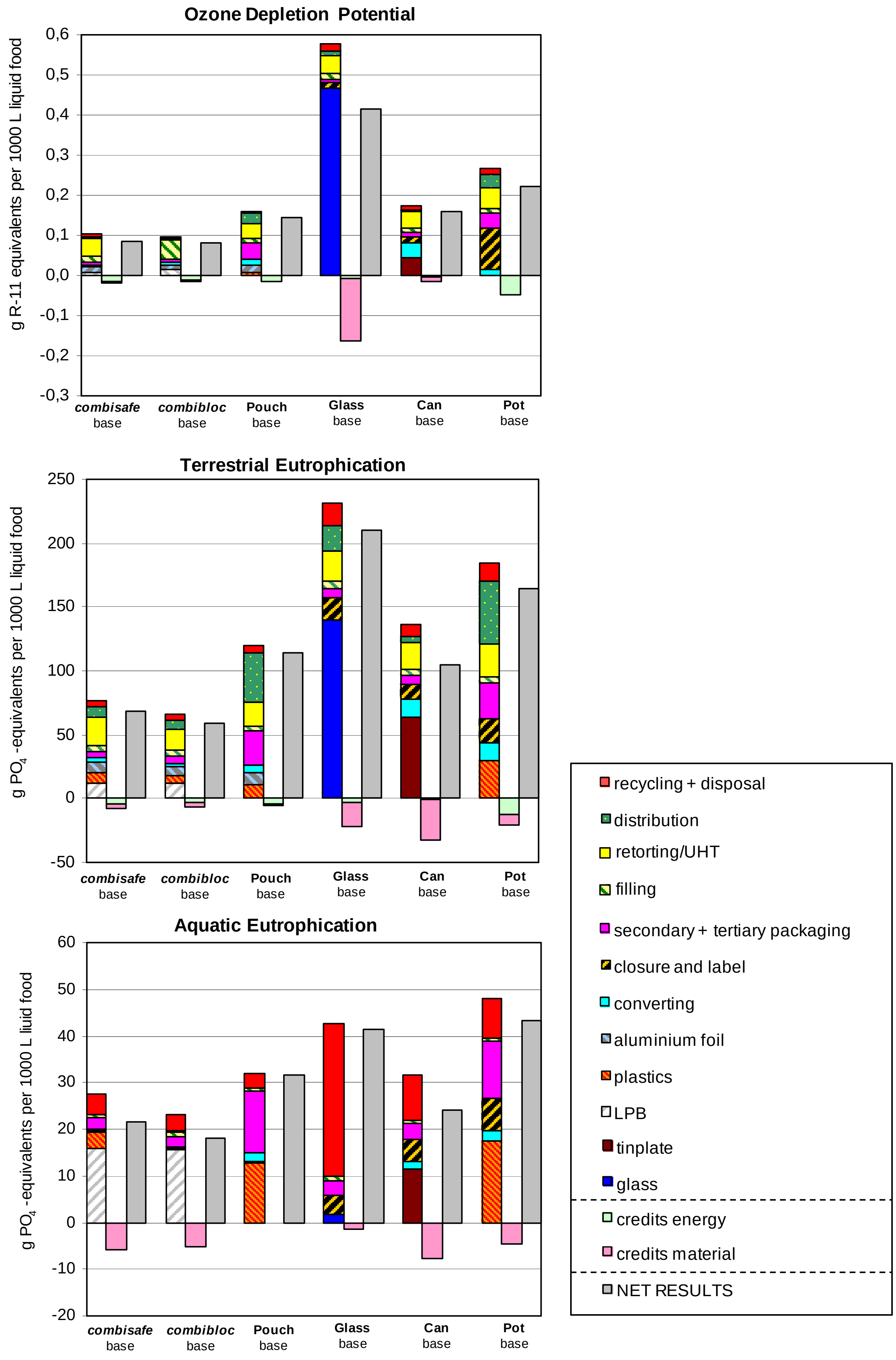

Figure 5-2: Impact indicator results for **sensitivity analysis allocation factor 100%** for materials (Part II)

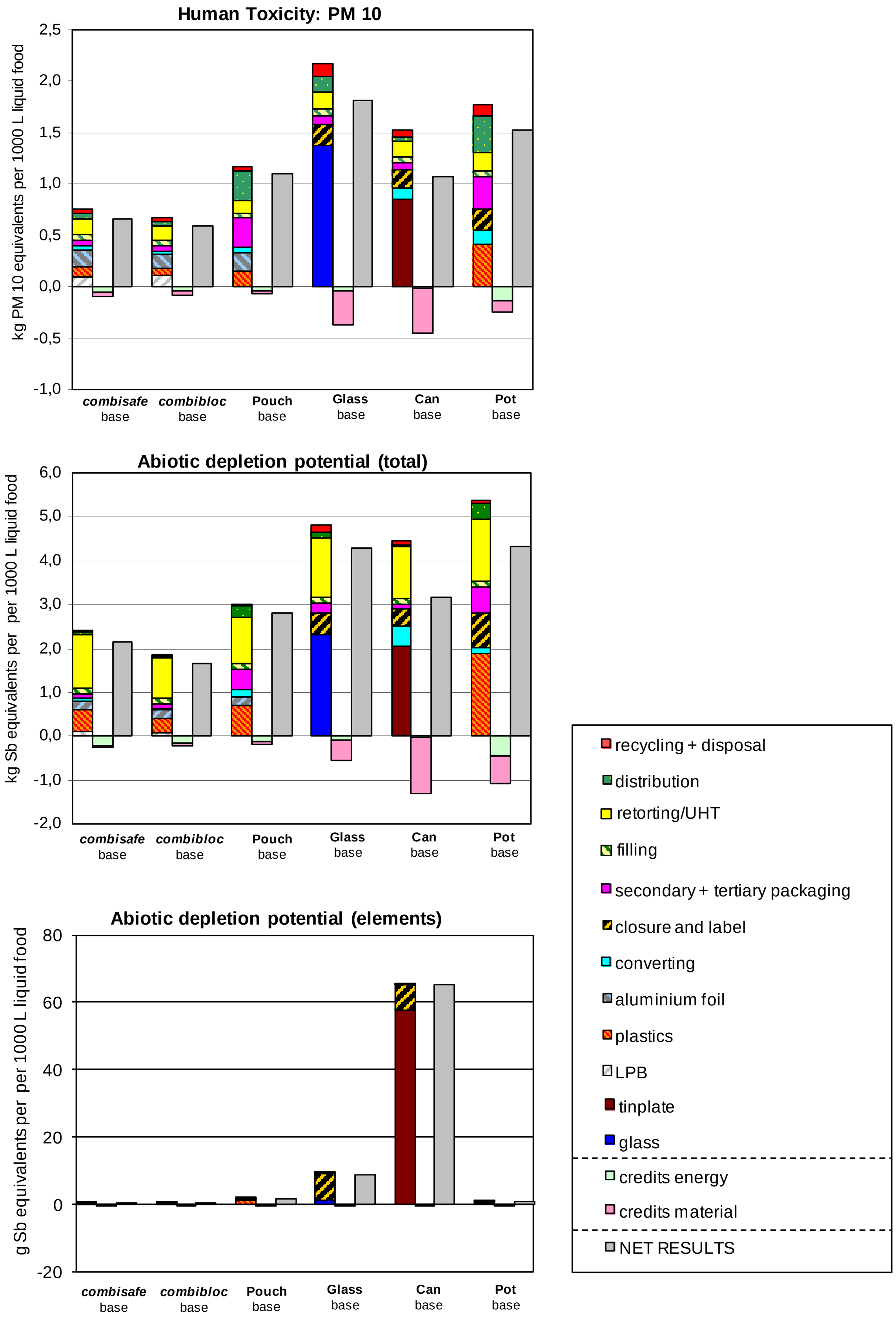

Figure 5-3: Impact indicator results for **sensitivity analysis allocation factor 100%** for materials (Part III)

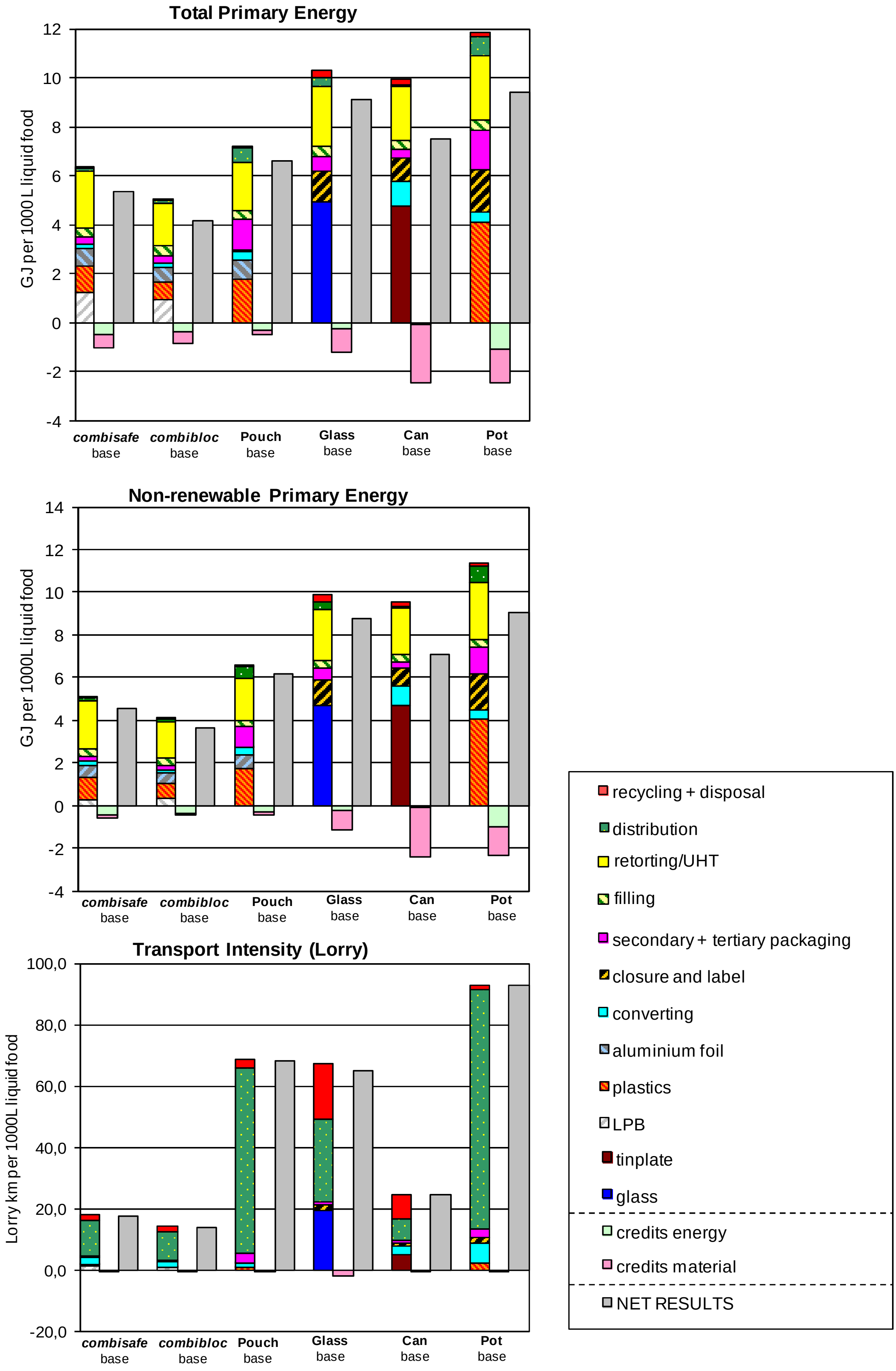

Figure 5-4: Results of **indicators at inventory level for sensitivity analysis 100% allocation factor** for materials

5.3.2 Sensitivity analyses with focus on recycling rates

The present LCA study shall provide indications of the environmental performance of food cartons compared to those of the competing packaging systems for the packaging of liquid food. With this sensitivity analysis the effects of varying recycling rates within a certain value range on the results shall be examined, to extent the picture analysed in the base scenarios relying on average recycling rates. For that reason scenario settings with recycling rates of 0%, 35% and 70% were calculated and interpolated in linear graphs. In such cases in which the actual recycling rate of a specific packaging system, as used for the calculation of the base scenarios, is close to 35% or 70% the actual rate is used for this sensitivity analysis. E.g. the food cartons are calculated with 37% instead of 35% and the glass jar and steel can with a recycling rate of 69% and 71% respectively instead of 70%. In this sensitivity analyses an allocation factor of 50% is applied for all scenarios.

The result graphs for the sensitivity analysis with focus on recycling rates are presented in Figure 5-5 to 5-7. The respective numerical values are shown in Table 5-2 and 5-3 on the following pages behind the description of the main findings.

Main findings for regarded food cartons

For both analysed food cartons no significant influence of the recycling rate on the net results of all impact categories can be observed except in *Aquatic Eutrophication* in which a higher recycling rate leads to significantly lower results, due to the fact that less food cartons are landfilled and more material credits are received. However, a decreased share of food cartons being landfilled doesn’t necessarily lead to lower burdens of the “recycling and disposal” sector within the indicator *Climate Change*. Although less methane is emitted, caused by the degradation of food cartons in landfills, the burdens stay more or less stable. This is due to the fact that the recycling process of the food cartons is quite energy intensive and is carried out with a mainly fossil based electricity grid mix (EU27+2), which is reflected in the energy-related indicator, e.g. *Climate Change.*
A higher recycling rate leads to slightly lower net results for the ‘*Total Primary Energy Demand’,* but not for the *‘Non-renewable Energy Demand’*, as almost only renewable energy is saved by the replacement of primary production through recycled fibres.

Main findings for the regarded alternative packaging systems

For the glass jar and to a lesser extent for the steel can and the plastic pot as well the application of a higher recycling rate leads to lower net results in all regarded impact and inventory categories except Transport Intensity (Lorry) where the net results increase due to the additional transports related to the recycling processes.

With a higher recycling rate the emission- and energy-intensive production processes for glass and tinplate are substituted, which considerably decrease the contributions to the impact categories *Climate Change, Acidification, Human Toxicity: PM10, Abiotic Resource Depletion* and *Summer Smog* as well as to the inventory categories related to energy consumption. The same is mainly valid for the results of the plastic pot, however to a lesser extent as the production processes of the base materials are not as emission- and energy-intensive as they are for the glass jar and steel can. Therefore, the effect on the net results is lower compared to the glass jar and steel can however, still higher when compared with the results of the food cartons.

The application of a higher recycling rate for the packaging system pouch causes only slight changes in each indicator regarded. While in the base scenario no recovery of post-consumer waste is assumed, in this sensitivity analysis the recovery of pouch packages via the pyrolysis route is assumed. However, while with a recycling rate of 0% the pouch system receives more energy credits, the material credits increase with an increasing recovery rate. However, the latter does not offset the burdens to a considerable extent.

Within the indicator *Ozone Depletion Potential* the analysed glass jar show a considerable decrease in the net results, while the other packaging systems don’t. This is due to the fact, that the nitrous oxide emissions caused by the limestone mining are substituted by an increasing recycling rate.

Comparison of food cartons and alternative packaging systems

Although the environmental performance of glass jar, steel can and plastic pot improves in the described categories above, when a higher recycling rate is assumed and the performance of the food cartons and the pouch stays mainly stable, no changes in the ranking for all indicators can be observed among the food cartons and the alternative packaging systems. Therefore, it can be stated, that even with an applied recycling rate of 70% for the competing packages and a recycling rate of 0% for the regarded food cartons, the latter would still perform better in all of the analysed impact/indicator categories.

Non linear results for the glass jar

A certain effect which is visible to a greater extent in the results of *Aquatic Eutrophication* shall be explained as well: For the production of glass 59% of external cullet is considered. With an assumed recycling rate of 0%, the supply with this cullet is no longer ensured and additional primary glass has to be produced to cover the required amount of glass. Therefore, the respective emissions increase, as less substituted glass can be used, therefore the respective graphs are no longer linear. With a decreasing recycling rate, the amount of glass which is finally landfilled increases. As explained in section 5.1., the landfill model is applied equally to all packaging systems examined. Therefore, the caused emissions on a landfill are allocated by mass to avoid not allocating them to any kind of waste at all.

Table 5-2: Net indicator results of the regarded **food cartons *combisafe* and *combibloc* as well as pouch** for the sensitivity analysis with different recycling rates (per 1000L of liquid food)

Sensitivity analysis recycling rate Net results (∑)	***combisafe***			***combibloc***			**pouch**		
	Recycling rate								
	0%	**37%**	**70%**	**0%**	**37%**	**70%**	**0%**	**35%**	**70%**
Impact indicators: ***emissions***									
Climate change [kg CO_2 equivalents]	278,30	277,72	277,19	223,61	223,78	223,94	377,90	380,15	382,40
Acidification [kg SO_2 equivalents]	0,72	0,72	0,71	0,63	0,61	0,61	1,10	1,09	1,08
Summer smog [g ethane equivalents]	142,29	141,87	141,50	107,43	106,99	106,60	229,93	230,06	230,19
Ozone Depletion Potential [g R11 equivalents]	0,08	0,09	0,09	0,08	0,09	0,09	0,15	0,15	0,15
Terrestial eutrophication [g PO_4 equivalents]	70,99	70,42	69,92	60,68	60,12	59,62	114,74	114,72	114,69
Aquatic eutrophication [g PO_4 equivalents]	27,12	23,75	20,74	22,75	19,89	17,33	31,74	31,04	30,34
Human toxicity – PM10 [kg PM10 equivalents]	0,69	0,69	0,68	0,61	0,61	0,60	1,11	1,10	1,10
Impact indicators: ***consumption of resources***									
Abiotic Resource Depletion (total) [kg Sb equivalents]	2,23	2,23	2,23	1,70	1,70	1,71	2,85	2,86	2,87
Categories at inventory level									
Total primary energy (PE) [GJ]	5,88	5,71	5,57	4,63	4,49	4,36	6,75	6,72	6,70
Non-renewable PE [GJ]	4,68	4,69	4,70	3,77	3,79	3,79	6,22	6,23	6,23
Transport intensity (Lorry) [km]	16,00	16,48	16,90	13,10	13,46	13,79	68,28	68,54	68,81

Table 5-3: Net indicator results of the regarded **glass jar, steel can and plastic pot** for the sensitivity analysis with different recycling rates (per 1000L of liquid food)

Sensitivity analysis recycling rate Net results (∑)	**Glass**			**Can**			**Pot**		
	Recycling rate								
	0%	**35%**	**69%**	**0%**	**35%**	**71%**	**0%**	**35%**	**70%**
Impact indicators: *emissions*									
Climate change [kg CO_2 equivalents]	707,36	653,09	609,53	658,75	617,18	579,65	554,48	529,09	503,68
Acidification [kg SO_2 equivalents]	2,00	1,84	1,75	1,47	1,38	1,31	1,58	1,54	1,51
Summer smog [g ethane equivalents]	331,31	276,63	232,17	247,55	227,12	208,67	414,88	378,23	341,58
Ozone Depletion Potential [g R11 equivalents]	0,82	0,64	0,49	0,17	0,17	0,16	0,22	0,23	0,23
Terrestial eutrophication [g PO_4 equivalents]	241,52	228,89	219,00	128,05	122,89	118,24	169,20	166,86	164,53
Aquatic eutrophication [g PO_4 equivalents]	63,52	43,47	33,95	30,30	27,19	24,38	46,91	42,68	38,45
Human toxicity – PM10 [kg PM10 equivalents]	2,49	2,20	1,98	1,43	1,35	1,28	1,60	1,56	1,53
Impact indicators: *consumption of resources*									
Abiotic Resource Depletion (total) [kg Sb equivalents]	4,93	4,70	4,52	4,24	4,00	3,77	4,80	4,56	4,32
Categories at inventory level									
Total primary energy (PE) [GJ]	10,45	10,00	9,64	9,47	9,03	8,63	10,46	9,98	9,50
Non-renewable PE [GJ]	10,05	9,60	9,25	9,08	8,64	8,23	10,09	9,59	9,09
Transport intensity (Lorry) [km]	53,06	60,75	66,10	20,33	21,33	22,24	92,06	92,87	93,68

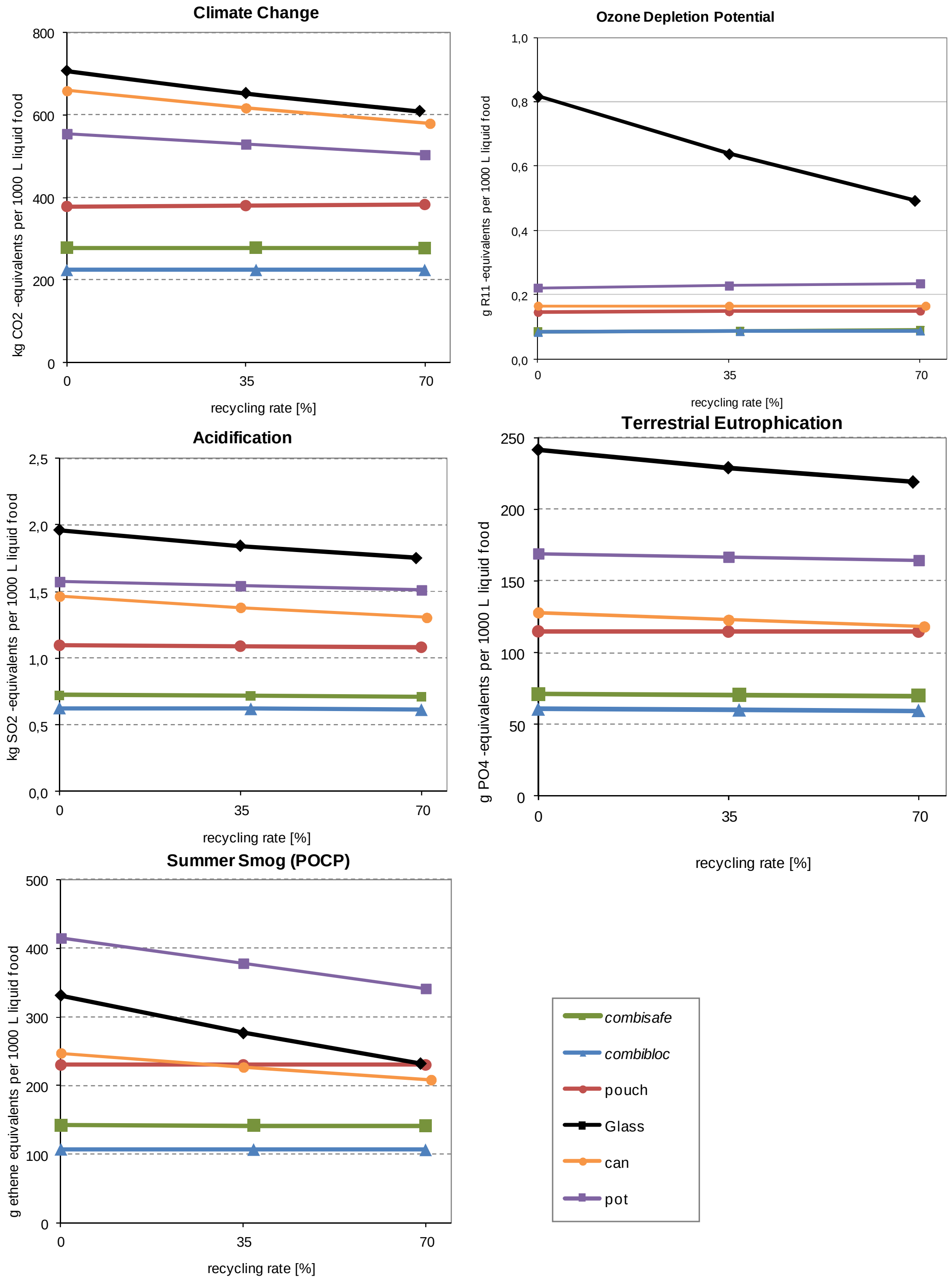

Figure 5-5: Impact indicator results for sensitivity analysis with different recycling rates (Part I)

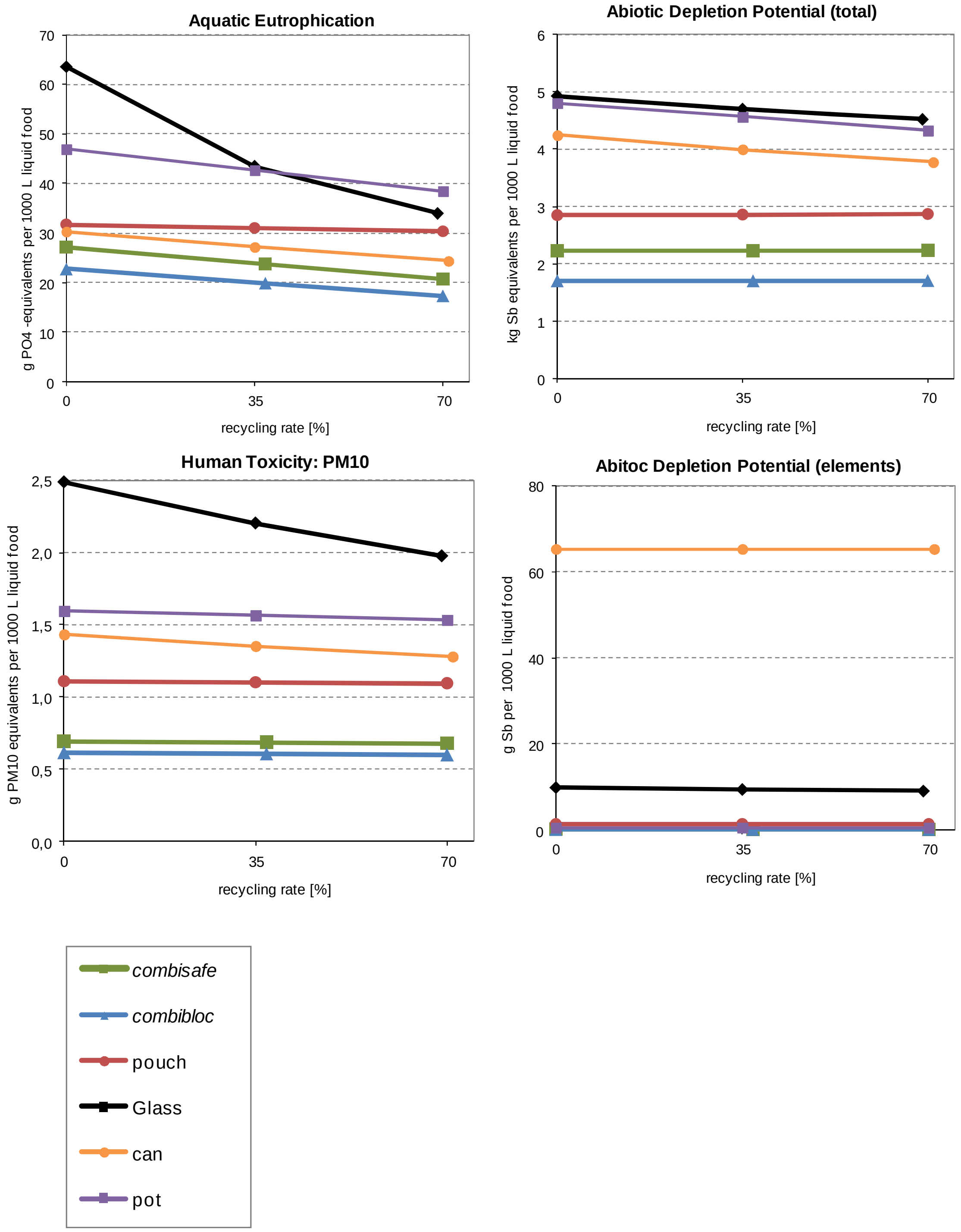

Figure 5-6: Impact indicator results for sensitivity analysis with different recycling rates (Part II)

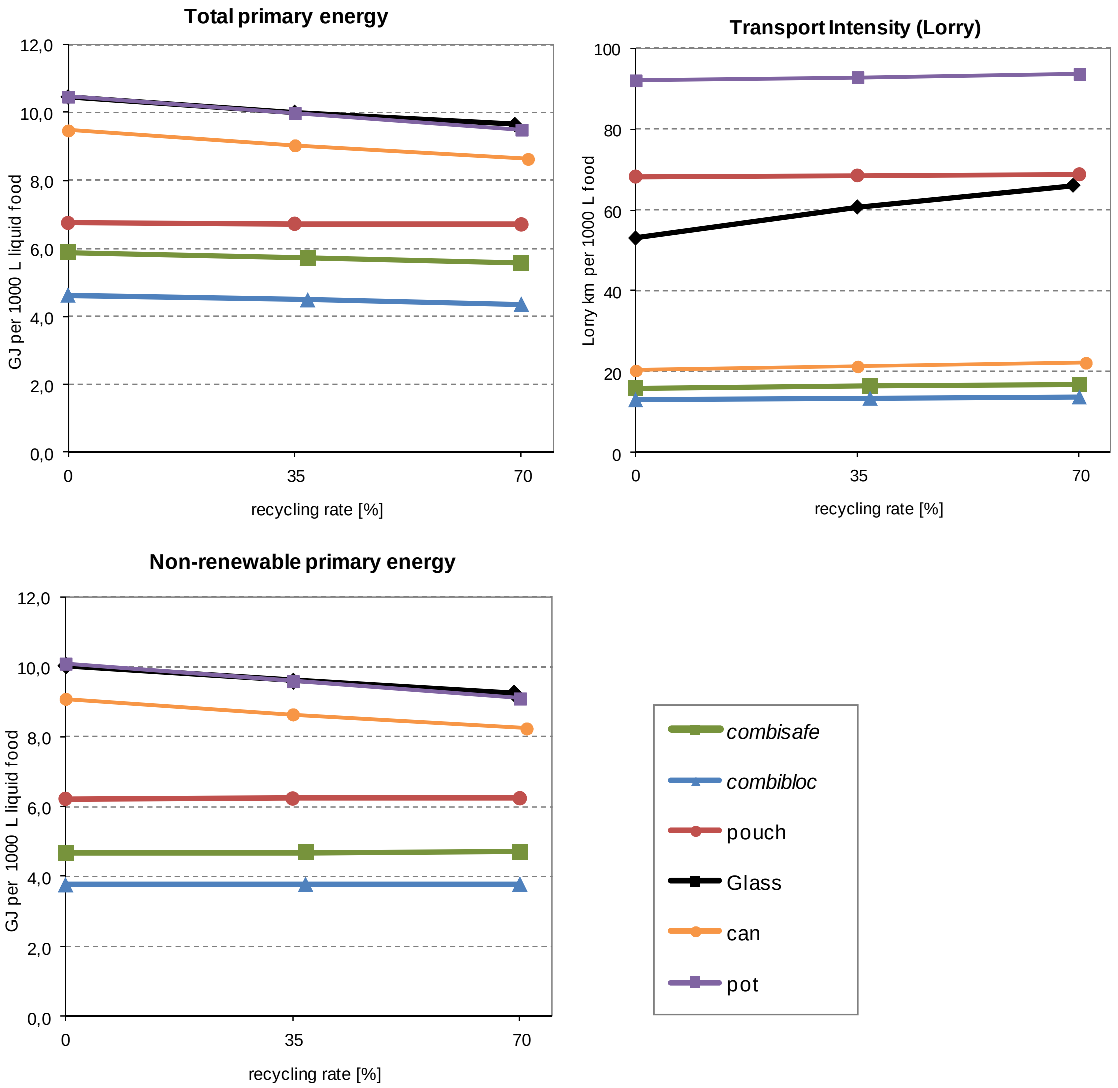

Figure 5-7: Results of indicators at inventory level for sensitivity analysis with different recycling rates

5.3.3 Sensitivity analysis eutrophication potential according to ReCiPe

As described in section 1.9 IFEU recently conducted an internal cradle-to-gate study to exemplarily examine different LCA methods recommended by the JRC and their impacts on the results of selected beverage or food cartons and plastic bottles. It shows that a change in ranking between the examined packaging systems only changed in the eutrophication potential, when the ReCiPe approach is compared to the CML approach. While the CML method differentiate the eutrophication by its target media (aquatic eutrophication: emissions into water; terrestrial eutrophication: emissions into air), the ReCiPe methodology divides the eutrophication into two indicators considering the limited nutrient of the respective aquatic systems (freshwater eutrophication: P-emissions in freshwater and soil; marine eutrophication: N-emissions in sea water and soil/air. Therefore, the authors decided to assess the emissions occurring in the life cycle of the regarded similar packaging systems a second time by applying the ReCiPe method recommended by the JRC. The results are shown in the graphic below.

The net results in marine eutrophication show the highest value for the glass jar, followed by the plastic pot and the pouch. The examined food cartons *combisafe* and *combibloc* show the lowest emissions in this indicator. The main contributors to the burdens of the food cartons, the pouch, steel can and plastic pot are the nitrogen dioxide emissions into the air caused by the production and provision of the packaging systems's main components (i.e. LPB, tinplate, plastics). Due to their shape and the applied pallet configuration the systems pouch and pot require a relatively high amount of cardboard for trays. The resulting burdens are therefore especially visible in the sector secondary and tertiary packaging. The production and recycling of glass causes high nitrogen dioxide emissions as well. Additionally ammonium emissions into water resulting from landfilling exceed the impacts and lead to even higher contributions in the end-of-life sector within the marine Eutrophciation according to ReCiPe.

The freshwater eutrophication potential is much lower when applying the ReCiPe method instead of the CML approach, applied for the base scenarios (see Figure 4.3 in section 4). The reason for these big differences between both methods is that in contrast to the CML method applied ReCiPe does not consider N-emissions and the Chemical Oxygen Demand (COD) as relevant for the freshwater eutrophication potential. Therefore, the ammonium emissions arising from the landfilling of e.g. the glass jar and steel can are not accounted to this indicator (however are considered in the marine eutrophication) and hence, the respective emissions decrease to an extent, which leads to a more favourable performance of the glass jar and steel can in the freshwater eutrophication compared to the result in the base scenario. The burdens in the end-of-life phase of the plastic pot decrease as well as ammonium emissions are not taken into account. However, the lower net results for the plastic pot are mainly caused due to the consideration of nitrate dioxide emissions in the marine eutrophication instead in the freshwater potential.

As the COD is not considered in the freshwater eutrophication as it is in the aquatic eutrophication potential according to the CML method, the emissions especially of the LPB production for the food cartons *combisafe* and *combibloc* are decreased to a high extent, which leads to a change in ranking between steel can and the food cartons. Due to the organic pollution load of the wastewater from the production of virgin fibre paper the COD plays the crucial role when the CML method is applied.

Due to the time-consuming determination of the BOD, the data sets mostly include the COD as parameter for eutrophication. As the COD represents all the available potential for oxygen depletion, the COD is normally higher than the BOD. The respective equivalence factor in the CML approach is therefore very high and used as a conservative estimate for the eutrophication. As a high COD however means less oxygen availability in aquatic systems, it therefore shortens the availability of oxygen for the decomposition of biomass.

This consideration of the COD and therefore the inclusion of the oxygen depletion into the eutrophication potential raises a scientific discussion which cannot be finally solved within this study. While the ReCiPe approach of limited nutrients may underestimate the impact on the eutrophication potential by considering only a limited number of substances with regard to their limnological function, the CML approach may overestimate the results with the consideration of the COD.

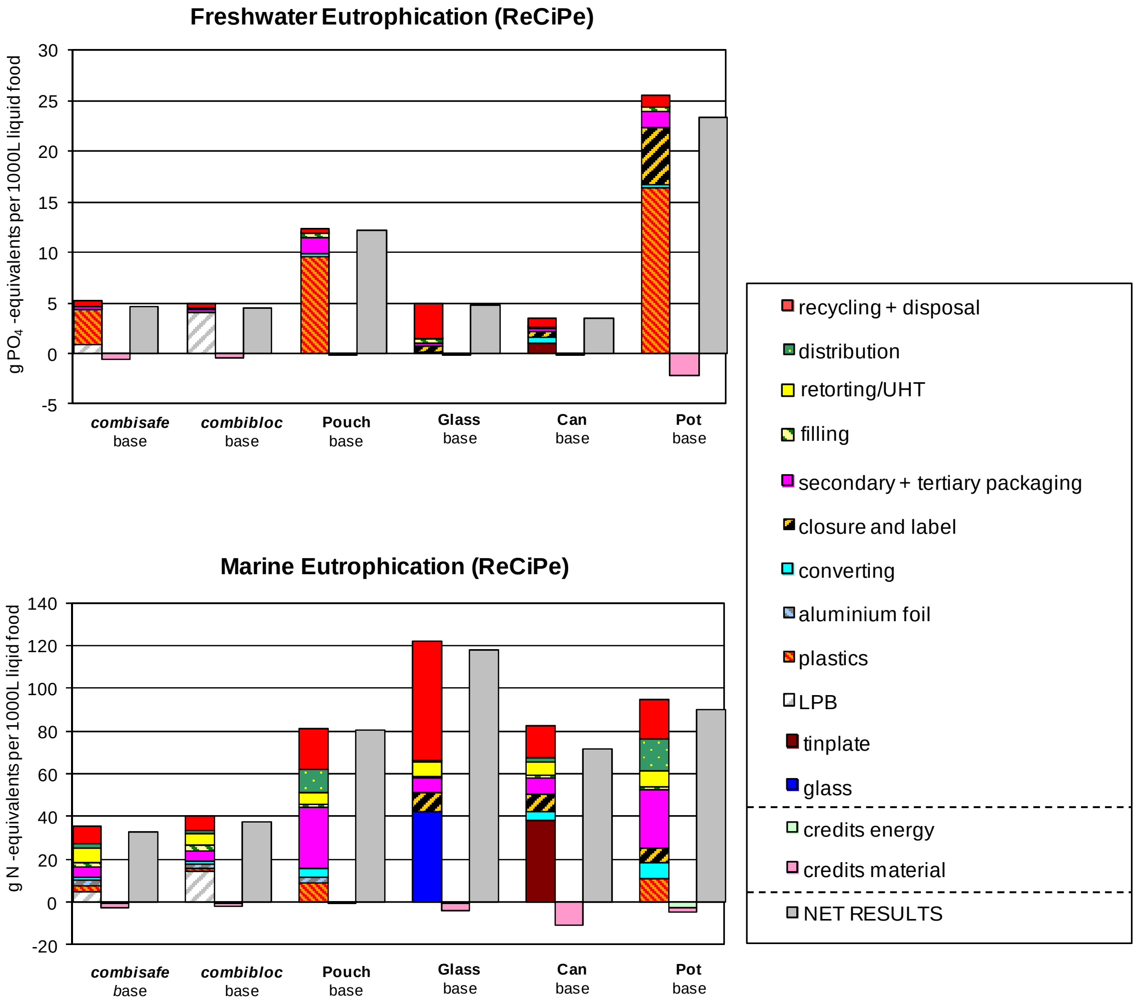

Figure 5-8: Indicator results of freshwater and marine eutrophication for sensitivity analysis eutrophication potential according to ReCiPe methodology; allocation factor 50%

Table 5-4: Results for sensitivity analysis eutrophication potential according to ReCiPe methodology - burdens, credits and net results (per 1000L of liquid food):

Sensitivity analysis eutrophication potential according to ReCiPe		***combisafe***	***combibloc***	**pouch**	**glass**	**can**	**pot**
Impact indicators: *emissions*							
Freshwater eutrophication [g PO_4 equivalents]	Burdens	5,23	4,93	12,32	4,96	3,55	25,51
	Credits	0,51	0,45	0,02	0,05	0,08	2,06
	Net results (∑)	4,72	4,48	12,30	4,91	3,47	23,45
Marine eutrophication [g N equivalents]	Burdens	35,28	39,84	81,06	121,75	82,52	94,50
	Credits	2,87	2,47	0,39	4,06	11,35	4,57
	Net results (∑)	32,41	37,37	80,67	117,69	71,17	89,93

5.4 Limitations, completeness and consistency

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 ambient liquid food with particulate contents. Even though carton packaging systems, steel cans or glass jars 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 **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 were provided by SIG Combibloc 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 impacts** and applied **assessment method**:
The selection of the environmental indicators applied in this study covers impact categories that are widely accepted within the LCA practitioner community. 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 **indicators**:
The results are valid only for the environmental impact indicators, which were examined. They are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

Limitations concerning **geographic boundaries**:
The results are valid only for the indicated geographic scope and cannot be assumed to be valid in geographic regions other than Europe (EU27+2), even for the same packaging systems.

This applies particularly for the end-of-life settings as the mix of waste treatment routes (recycling, landfills, and incineration) and specific technologies used within these routes may differ, e.g. among European 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 regarding **retail distances**:
The distances of the two transport steps – empty packaging from converter to filler and filled packs from filler to point of sale – are based on expert judgements. Individual logistic and supply chains can therefore deviate from transport distances applied.

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 indicators.

6 Discussion: land use and water consumption

As described in section 1.9 the assessment of land use and water consumption is not realised in this LCA study. The following section shall show results on the inventory level, describe the current state of assessment possibilities for these potential impact categories and explain why none of these could be applied for this study.

6.1 Discussion assessment of use of forest land

The largest type of land use found in the inventory results of this study is related to forest land. The amount of forest area per packaging system is shown in table 6.1.

Table 6-1: Forest land area used in the compared packaging systems

package	*combisafe*	*combibloc*	retortable pouch	glass jar	steel can	plastic pot
m2*a	105.99	153.33	29.37	11.65	18.47	28.33

However, the amount of land area used does not give information on the potentially associated environmental impacts. For this latter purpose the quality of land use has to be known. In addition, in order to assess the land use within LCIA a characterization method is required.

Life Cycle Impact Assessment

Research on method development has been subject of a dedicated working group within UNEP/SETAC Life Cycle Initiative [Köllner, T. and Geyer, R. 2013], [Köllner, T. et al. 2013]. From this work only recently, methods and characterization factors have been published, addressing the safeguard subjects of biodiversity [De Baan, L. et al. 2013] on the one hand and of ecosystem services on the other. Regarding the latter different approaches are proposed by the LCI initiative by differentiating between biotic production (i.e. capacity of ecosystems to produce biomass) [Brandão, M. and Milà i Canals, L. 2013] and regulative functions (freshwater regulation, erosion regulation, water purification). Characterization factors are derived by comparing a given land use situation with a reference situation. As for the latter the potential natural vegetation concept is applied.

The method usually used by IFEU looks at the "degree of naturalness" of areas in use. It is based on the hemerobic levels concept by [Klöpffer & Renner 1995] and was operationalised for forest systems in a life cycle assessment of graphical papers of the German Environment Agency [UBA 1998]. In contrast to the methods mentioned in the previous paragraph this method intends to take into account all land-related environmental impacts such as the reduction in biodiversity, soil erosion, adverse effects on the landscape, etc. together and not as separate impact indicators. This is also the reason why the impact category is named with "use of nature" instead of using the term "land use".

It is beyond the scope of this present LCA study to analyse and compare the named methods in detail. Each is associated with advantages and disadvantages and the decision of which method to take also implies value choice. For instance it can be questioned whether the restriction of an assessment to the mere biotic production using soil organic content as a measure is adequate to reflect sufficient aspects of a complex system like e.g. a forest production system.

Overall the authors of this present study think that all of the methods mentioned still require further work to be suitable to produce meaningful results and provide a robust basis for LCA based decision making. For instance the land use classes and characterization factors presented by [Köllner, T. et al. 2013] and [De Baan, L. et al. 2013] do not differentiate between different types of forest uses and management types. The method according to [UBA 1998] needs further development of characterization factors on a global scale.

On top of that, the described shortcomings of the methods are usually reflected by shortcomings regarding land use data in the currently available life cycle inventories.

Forest Certification

As visible from table 6.1 use of forest land is larger for food cartons than for the compared packaging systems. This is related to the fact that LPB is the main packaging base material of food cartons. As a consequence the wood resources used in LPB have a high attention within SIG Combibloc’s environmental policy, as shows the following text parts taken from SIG Combibloc’s environmental brochure and information available on the SIG website[14]:

“SIG Combibloc…places great emphasis on ensuring that…only woodfibres originating from legal and accepted sources are used….to manufacture the unprocessed paperboard…to make our beverage cartons, guaranteeing full traceability all the way back to the forests of origin…..To make certain that this can be done, we have implemented a certified chain of custody (CoC) verification according to the FSC® standard.

We are making sure that as long as availability remains limited, in addition to already certified raw paperboard we only use raw paperboard from other controlled sources. This ensures that the use of wood from illegal or genetically modified sources, and from protected forests, is avoided. We have set ourselves the ambitious goal of increasing the percentage of our carton packs that are FSC®-labelled to 40 per cent by 2015. At the end of June 2012, the proportion of FSC®-labelled carton packs from SIG Combibloc had already reached 16 per cent.”

The Forest Stewardship Council (FSC) is an international not for-profit, multi-stakeholder organisation established in 1993 to promote responsible management of the world’s forests. Its main tools for achieving this are standard setting, certification and labeling of forest products [Wikipedia]. According to Greenpeace this responsibility consists in an

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[14] http://www.sig.biz/sig-global/en/environment/fsccertification/

ecologically sustainable, socially supportive and economically viable management of forests on a global scale[15].

Environmental Relevance

Life cycle impact assessment (LCIA) and forest certification in principle are two quite different instruments with different objectives. While impact assessment of land use is not yet reliably applicable for wood based products, it's the authors' opinion that FSC certification certainly is helpful to ascertain that a product is made from wood produced under the most advanced forest management standard.

On the other hand FSC certification cannot replace impact assessment. FSC criteria are the result of a consensus-oriented stakeholder process bringing together environmental, societal and economic interests. LCIA in first line has a clear focus on environment and underlying methods must stand scientific scrutiny. This does not exclude the option that environmental FSC criteria might be usable within an LCIA method. In fact there already seems to be a certain match of criteria of FSC and [UBA 1998].

The circumstances described lead to the following conclusions:

1. It is not helpful to give a special weight to mere inventory results of area used, for drawing conclusions in this present study
2. Existing impact assessment methods are still not sufficiently mature and operational to be implemented in this study
3. As wood is a renewable but not infinite resource, it should be aimed at sourcing this raw material from forests with state-of-the-art management systems. In the view of IFEU, FSC certification is strongly preferable above other available forest certification schemes.

6.2 Discussion assessment of water use and consumption

6.2.1 Evaluation of freshwater use on inventory level

In Table 6.2 and Table 6.3 the freshwater input for the base scenario of each packaging system differentiated in process and cooling water is illustrated. An evaluation of these figures is hardly feasible and may lead to misleading conclusions as the available data on water are reported on different levels of detail. Most of the datasets are provided in an aggregated format, which does not enable an allocation of the water use to the respective prechains or unit processes. Furthermore, it can be doubted that for example the production of tinplate does not require cooling water as the energy demand for this production process is very high. This number may be included in the given number of process water or may be excluded from the inventory. However, as long as there are such lacks and asymmetries in the available inventories an evaluation of the freshwater use on inventory level is omitted.

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[15] http://www.greenpeace.de/themen/waelder/oekologische_waldnutzung/artikel/der_fsc_forest_stewardship_council/

Furthermore, most of the inventories do not include the water discharged from the technosphere. Therefore, the amount of water integrated into the product or evaporated during the production process 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.

Table 6 -2: Freshwater use with focus on input pocess water for regarded packaging systems in the base scenario

Freshwater use: Input process water [m³]						
	combisafe	***combibloc***	**Pouch**	**Glass**	**Can**	**Pot**
Glass				0.72		
Tinplate					1.32	
LPB	1.78	2.15				
Plastics	0.07	0.03	1.05			0.29
Aluminium foil	0.24	0.20	0.26			
Converting	0.02	0.02	0.29		0.27	0.09
Closure & label				0.33	0.36	0.12
Sec. & tert. packaging	0.10	0.10	0.55	0.13	0.14	0.53
Filling	0.45	0.50	0.13	0.31	0.30	0.06
Retorting/UHT	0.51	0.17	0.44	0.51	0.51	0.59
Distribution	0.00	0.00	0.00	0.00	0.00	0.00
Recycling & disposal	0.01	0.01	0.00	0.01	0.02	0.01
sum	**3.18**	**3.18**	**2.71**	**2.01**	**2.92**	**1.69**

Table 6-3: Freshwater use with focus on input cooling water for regarded packaging systems in the base scenario

Freshwater use: Input cooling water [m³]						
	combisafe	*combibloc*	Pouch	Glass	Can	Pot
Glass				4.21		
Tinplate					0.00	
LPB	0.29	0.71				
Plastics	0.66	0.44	1.14			2.13
Aluminium foil	0.00	0.00	0.00			
Converting	0.46	0.40	0.23		1.70	0.56
Closure & label				0.67	0.35	1.47
Sec. & tert. packaging	0.12	0.11	0.51	0.33	0.14	0.77
Filling	1.10	1.12	0.70	1.18	1.01	1.11
Retorting/UHT	0.12	0.54	0.16	0.14	0.13	0.17
Distribution	0.00	0.00	0.00	0.00	0.00	0.00
Recycling & disposal	0.11	0.09	0.03	0.16	0.24	0.16
sum	**2.85**	**3.42**	**2.78**	**6.69**	**3.59**	**6.38**

6.2.2 Methodological issues for the impact assessment of water use and consumption

As explained in the previous section, the impact assessment of water use and water consumption requires reliable inventory data. Furthermore, the assessment of inventory figures without the consideration of water scarcity of different regions leads to misleading results as well.

As there is no common definition yet, in the following the terms “water use” and “water consumption” are applied in the following, based on [Pfister et al. 2009]:

- All types of water use; in industrial and agricultural processes, households; not including in-stream processes (e.g. turbinated water in hydropower).
- Part of the water use that is not released into the same water shed due to evaporation, evapotranspiration, product incorporation, discharge into another watershed. The water is “lost” to the watershed, i.e. it is no more available to ecosystems and humans or only in a changed quality.

In the LCA community, three different categories of water consumption are often applied:

- Extraction of freshwater from surface and groundwater, also called “blue water” by [Hoekstra et al. 2011]

- Rain water that is stored as soil moisture and lost by the evaporation through the soil and the uptake through the plants, also called “green water” [Hoekstra et al. 2011].
- Degradative water, which describes the amount of water needed to dilute the load of pollutants to reach natural background concentrations, also called “grey water by [Hoekstra et al. 2011].

Due to the growing awareness of the impacts caused by the use and consumption of water, efforts to develop comprehensive impact assessment methods are increasing in the life cycle community. Water footprint methods focusing on spatial factors and use patterns at the specific location have recently been reviewed in terms of their applicability and methodological challenges (e.g. [Kounina et al. 2013]). The required level of differentiation at the inventory level for these methods differs significantly. In the following methodological issues for the assessment of water use and consumption shall be shortly explained, exemplified by selected recently published impact assessment methods.

In general, the available methods 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.

While most of the assessment methods at the midpoint level target the impact caused by the extraction of freshwater, methods for the assessment of water consumed by the ecosystem and for the degradative water use have been recently developed.

A widely applied method for the quantification of water use and consumption is the water footprint concept of [Hoekstra et al. 2011]. This concept addresses the freshwater use along the supply chains and is regarded by the Water Footprint Network (WFN) as a comprehensive indicator of freshwater resources appropriation. In this concept, the water footprint of a product is the volume of freshwater used to produce the product, measured over the full supply chain. A distinction between the blue, green and grey water footprint is made. The water footprint as such is a volumetric measure of water consumption and pollution. However, a simple summation of the volumes consumed without the consideration of spatial water scarcity does not assess the related environmental impacts of the water consumption and is therefore not suitable and for the application in this study.

Beside the lack in the inventories applied in this study, the exclusion of the regional water scarcity would lead to disadvantageous results for production processes which take place in regions where no water scarcity occurs, as for example the LPB production for the food cartons in Sweden and Finland.

On the European level the ILCD Handbook [JRC-IES 2011], the Joint Research Centre (JRC) of the European Commission recommends the application of the Ecological Scarcity method for the calculation of water use and consumption at the midpoint level. This approach is based on the relation of water consumption and water availability.

These figures are available for OECD countries. The quality of water is not considered in this approach. The figures are normalised to the so called eco-factors for the scope of Switzerland and therefore, may not be adequate for an impact assessment of water use and consumption on the European level.

For a further regionalisation, the JRC recommends the application of the Water Stress Index published by [Pfister et al. 2009].

The impact assessment method of [Pfister et al. 2009] aims to prevent regional water scarcity. The consumptive water use (CWU) requires the Water Stress Index (WSI) at the specific geographic location and the quantity of water consumed, according to the definition mentioned above. In the meanwhile, the approach has been further developed by Ridoutt & Pfister (2013), which address the degradative water use (DWU) as well. The DWU assessment requires information regarding emissions into water covered by the ReCiPe (2008) assessment framework. As mentioned in the previous section, most of the inventories do not include the amount of water released. The determination of the water consumed and polluted according to this method is therefore hardly possible. Additionally, most of the available inventory data within this study do not include information regarding the specific geographic location or are provided as average data set for Europe. The application of this impact assessment method in the present study is therefore not recommended by the authors. However, as this approach has minor requirements on the differentiation of the inventory data it may be the most promising to become applicable in the future.

The water flow inventory of [Boulay, A.-M et al. 2011] seeks to prevent regional water scarcity caused by pollution. To allocate the water use to the specific categories developed in this approach, the quantity, quality and geographic location of water extracted and released as well as water quality requirements of downstream water users are required. As the amount of water released is not included in most of the inventories applied in the present study, an application of this approach is hardly possible as well.

However, once those data are available this approach could provide reliable information on water consumed by pollution. For the production of the LPB for the food cartons the consideration of degradative water may be already possible, as the amount of water released is reported in the inventory. With the knowledge, that most of the LPB is produced in Sweden and Finland within a watershed of a broad extension and therefore low natural background concentrations in which the water is released, the consideration of the degradative water would be a benefit from the life cycle perspective. However, the effort in applying the approach of [Boulay, A.-M et al. 2011] is of high extent and not yet affordable by practitioners. Furthermore, due to the data asymmetries a comparative assertion is omitted.

To summarise, most of the methods to assess water use and consumption require geographical information as they address regional water scarcity. This information is not provided in most of the available inventories. Furthermore, not only the amount of water withdrawal but also the amount of water discharged is requisite for the determination of the impact caused by water consumption. Some of the available methods require a high effort to receive reliable data on water consumption, which can only be invested within research projects.

7 Normalisation

The aim of normalisation is to better understand the relative magnitude of each indicator result of the systems under study. The indicator results of each impact category are normalised into so-called “resident-equivalents (REQs)” by division by a normalisation factor, and scaled to total production of sterilised soup and sauce products per year.

Normalisation factors

The normalisation factors were obtained by dividing the total environmental load per environmental metric within a dedicated geographical boundary by the number of inhabitants within this boundary. In this study the data for Europe were used because the study focuses on the European market, it has to be noted though that no data for the geographic boundary of EU27+2 is available, therefore mainly data referring to EU25+3 (NO,CH,IS). Table 6-1 shows the total environmental loads for Europe valid for the year ~2000 and the statistical environmental impacts per inhabitant.

Calculation of REQs and their scaling to European consumption of conserved food products

To calculate resident-equivalents (REQs), the net impact indicator results of base scenarios given in Table 4-1 (and illustrated in figures 4-1 to 4-4) are divided by the respective impact per resident. The resulting number has the same unit for all metrics (REQs/1000 Litre liquid food) allowing comparison between different metrics.

The normalised results are then scaled to the same boundaries – the total European consumption of sterilised food products per year. Data from year 2009 was used, when 2,280,560,000 l of soup were consumed in Europe [Innova 2013]. The original value is given as kg soup and sauces. It was transferred into liquid food volume using an assumed product density of 0.983 kg/L.

To scale the results to European production, the REQ value have to be calculated per 1 L liquid food first. By multiplying this value by total European consumption per year, one gets the indicator value relating to the total European sterilised food production per year. In other words, one gets indicator values corresponding to the environmental loads that would be caused by each package system if all sterilised liquid food products produced in Europe per year were filled in the respective packaging system only.

Table 7-1 Basic data for Europe used to calculate REQs

	Impact per year **Europe**			Impact per resident and year **Europe**	
Residents					
Residents	464 036 294	c)			
Resources					
Lignite	3.26E+06	c)	TJ/year	7.02E+03	MJ/resident and year
Natural gas	1.01E+07	c)	TJ/year	2.19E+04	MJ/resident and year
Crude oil	1.37E+07	c)	TJ/year	2.96E+04	MJ/resident and year
Hard coal	3.67E+06	c)	TJ/year	7.91E+03	MJ/resident and year
Emissions (Air)					
Ammonia	2.53E+05	a)	t/year	5.45E-01	kg/resident and year
Arsenic	3.70E+02	a)	t/year	7.97E-04	kg/resident and year
Benzene	4.25E+06	a)	t/year	9.17E+00	kg/resident and year
Benzo(a)pyrene	4.05E+02	a)	t/year	8.73E-04	kg/resident and year
Cadmium	2.26E+02	a)	t/year	4.87E-04	kg/resident and year
Chromium	1.29E+03	a)	t/year	2.78E-03	kg/resident and year
Dioxins (I-TEQ)	3.55E+00	b)	kg/year	7.35E+00	µg/resident and year
Dinitrous oxide	1.34E+06	a)	t/year	2.89E+00	kg/resident and year
Carbon dioxide, fossil	4.02E+09	a)	t/year	8.67E+03	kg/resident and year
Methane	2.16E+07	a)	t/year	4.64E+01	kg/resident and year
Nickel	1.93E+03	a)	t/year	4.16E-03	kg/resident and year
NMVOC	1.17E+07	a)	t/year	2.52E+01	kg/resident and year
NOx (as NO_2)	1.18E+07	a)	t/year	2.55E+01	kg/resident and year
PCB	3.38E+00	a)	t/year	7.27E-06	kg/resident and year
Sulfur dioxide	8.75E+06	a)	t/year	1.89E+01	kg/resident and year
Dust (PM10)	2.50E+06	a)	t/year	5.39E+00	kg/resident and year
Emissions (Water)					
Nitrogen (freshwater)	2.70E+06	a)	t/year	5.83E+00	kg/resident and year
Aggregated values for impact categories					
Abiotic Resource Depletion	19,255,030		t Sb-Eq/year	41.49	kg SB-Eq /resident and year
Climate change	5,017,944,690		t CO_2-Eq/year	10,814	kg CO_2-Eq/resident and year
Acidification	18,160,803		t SO_2-Eq/year	39.1	kg SO_2-Eq /resident and year
Eutrophication (terrestrial)	1,628,360		t PO_4-Eq/year	3.51	kg PO_4-Eq /resident and year
Eutrophication (aquatic)	1,136,069		t PO_4-Eq/year	2.45	kg PO_4-Eq /resident and year
Summer smog (POCP)	2,656,784		t Eth-Eq/year	5.73	kg Eth-Eq /resident and year
Human Toxicity: PM10	17,950,982		t PM10-Eq/year	38.7	Kg PM10-Eq/ resident and year
Ozone depletion	32971638,571	a)	kg	71,054	g/resident and year

a) Reference normalisation emissions "EU25+3 2000" ; CML Dec 2007

b) European Dioxin Inventory - Stage II, refers to EU15 + Norway + Switzerland + Poland + Estonia + Latvia + Greek Rep.

c) Database Eurostat, 2008, reference year 2000, EU25

Note: If not specified otherwise, numbers given in this table refer to EU25+3 (Norway, Switzerland, Iceland) countries.

Figure 7-1 shows the normalised impact indicator results of the base scenarios. This gives an indication how much each system would contribute to the overall European environmental impact under the assumptions made.

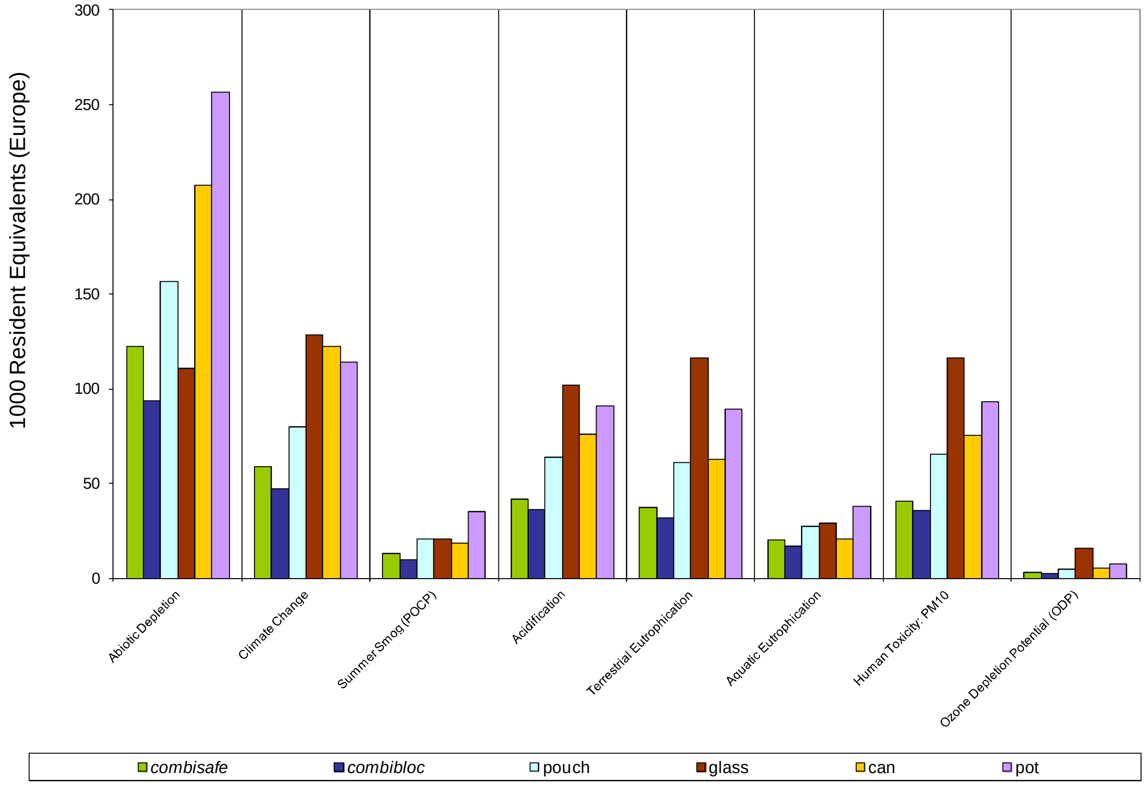

Fig. 7-1: Normalised indicator results of base scenarios (all environmental indicators)

How the comparison of regarded base scenarios, expressed here in resident equivalents (REQs) can be 'read' shall be exemplified for the impact indicator Climate Change. For the geographic reference scope 'Europe', the *combibloc* packaging would be responsible for approximately 47,000 REQs. With this, it ranks lower than all other packaging systems examined. The highest result is shown by the glass jar, which would be responsible for approximately 129,000 REQs if all soups and sauces consumed in Europe would be packaged this way. By bringing the entire quantity of soups and sauces consumed in Europe within one year to the market exclusively in *combibloc* packages, the total greenhouse gas (GHG) emissions could be influenced. Compared to the exclusive use of the regarded glass jar, it would lead to a decrease of the GHG emissions by (129,000-47,000=) 82,000 REQs.

Apart from the result comparisons between packaging systems the comparison of the results of different impact categories is also useful for the assessment of the environmental performance of the examined packaging systems as it allows the identification of impact categories with high relevance regarding the overall environmental impact in Europe. The choice of packaging system for the packaging of liquid food plays a significantly bigger role for the environmental impacts *Abiotic Resource Depletion, Climate Change, Acidification, Terrestrial Eutrophication* and *Human Toxicity: PM 10* than for the impacts *Summer Smog, Aquatic Eutrophication and Ozone Depletion.*

8 Conclusions and Recommendations

In the following sections, conclusions and recommendations are drawn from the results presented, interpreted and discussed in the previous sections. After a short summary of the significant system parameters (8.1), characteristic patterns are highlighted for the comparison of the food cartons with the alternative packages (8.2). Subsequently, the outcomes of the sensitivity analyses addressing the applied allocation factor and different recycling rates are discussed (sections 8.3 and 8.4). Finally, recommendations are drawn from the LCA study presented in the current report (8.5).

A note on significance: For studies intended to be used in comparative assertions intended to be disclosed to the public ISO 14044 asks for an analysis of results for sensitivity and uncertainty. It’s often not possible to determine uncertainties of datasets and assumed 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.

8.1 Most significant parameters

The major impact in most of the examined environmental impact indicators originates from the production of the base materials used for the primary packaging. This is especially true for the production of plastics and aluminium as well as for the production of tinplate and glass. The production of LPB for food cartons plays a somewhat less important role in many impact categories though it still is a main contributor to the net results in the impact categories *Aquatic Eutrophication* and *Acidification*.

Apart from the production of base materials the sterilizing (retorting & UHT) process also demands high amounts of energy and therefore is responsible for high results in the impact categories *Climate Change, Terrestrial Eutrophication* and *Abiotic Resource Depletion*.

High contributions to the net results in the impact categories *Aquatic Eutrophication* and to a lesser extent *Acidification* also arise from the production of LPB and corrugated cardboard for secondary packaging.

Transport related impacts can be found in the impact categories *Acidification, Terrestrial Eutrophication* and *Human Toxicity PM 10* for the examined packaging systems pouch, plastic pot and glass jar, which all have either a disadvantageous pallet configuration that leads to a lesser number of packages per lorry or a high packaging weight respectively.

8.2 Comparison of the food cartons with the alternative packaging systems

Comparison of food cartons *combisafe* and *combibloc* with the retortable pouch

The pouch shows higher environmental impacts in all impact categories than both of the food cartons.

Though the pouch is of lower weight than the food cartons the impacts related to the production of base materials are similar or even higher than those for the food cartons in most categories. This is due to the higher amount of plastics and aluminium than the food cartons, whose main component is LPB which generally shows lower impacts as plastics and aluminium.

The impacts of the retail related sectors *secondary + tertiary packaging* and *distribution* of the pouch show higher results than those of the food cartons due to the high amount of corrugated cardboard used in the secondary packaging and the pallet configuration with much less packages per pallet than for the pallet configuration of the food cartons.

Comparison of food cartons *combisafe* and *combibloc* with the glass jar

The glass jar shows higher environmental impacts in all impact categories than both of the food cartons.

This is mainly due the high impact of the glass production itself, while the additional tinplate closure leads to further environmental impacts as well.

Comparison of food cartons *combisafe* and *combibloc* with the steel can

The steel can shows higher environmental impacts in all impact categories than both of the food cartons except *Aquatic Eutrophication* where the results of the can match those of the *combisafe* (i.e no significant difference) while still being considerable higher than those of *combibloc*.

Especially in the energy related impact categories the high burdens of the production of tinplate for body and closure is responsible for the high environmental impact of the steel can.

Comparison of food cartons *combisafe* and *combibloc* with the plastic pot

The plastic pot shows higher environmental impacts in all impact categories than both of the food cartons.

The impacts of the retail related sectors *secondary + tertiary packaging* and *distribution* of the pot show higher results than those of the food cartons due to the high amount of corrugated cardboard used in the secondary packaging and the pallet configuration with much less packages per pallet than for the pallet configuration of the food cartons.

The production of plastics for the pot body and the additional closure causes high loads that lead to an overall high environmental impact of the plastic pot compared to those of the food cartons.

The following tables illustrate the comparative results by showing percental differences between impact category base scenario results of the food cartons and the alternative packaging systems.

Table 8-1: percental differences of base scenario results of *combisafe* and alternative packaging systems

	The net results of ***combisafe*** are lower than those of the **retortable pouch** by	The net results of ***combisafe*** are lower than those of the **glass jar** by	The net results of ***combisafe*** are lower than those of the **steel can** by	The net results of ***combisafe*** are lower than those of the **plastic pot** by
Climate change [kg CO_2 equivalents]	27%	54%	52%	49%
Acidification [g SO_2 equivalents]	35%	59%	45%	54%
Summer smog [g ethane equivalents]	38%	39%	32%	64%
Ozone Depletion Potential [g R11 equivalents]	40%	82%	47%	61%
Terrestial eutrophication [g PO_4 equivalents]	39%	68%	40%	58%
Aquatic eutrophication [g PO_4 equivalents]	25%	30%	insignificant (3%)	47%
Human toxicity – PM10 [g PM10 equivalents]	38%	65%	46%	56%
Abiotic Resource Depletionl [kg Sb equivalents]	22%	51%	41%	52%

Table 8-2: percental differences of base scenario results of *combibloc* and alternative packaging systems

	The net results of ***combibloc*** are lower than those of the **retortable pouch** by	The net results of ***combibloc*** are lower than those of the **glass jar** by	The net results of ***combibloc*** are lower than those of the **steel can** by	The net results of ***combibloc*** are lower than those of the **plastic pot** by
Climate change [kg CO_2 equivalents]	41%	63%	61%	59%
Acidification [g SO_2 equivalents]	44%	65%	53%	60%
Summer smog [g ethane equivalents]	53%	54%	49%	73%
Ozone Depletion Potential [g R11 equivalents]	41%	83%	48%	62%
Terrestial eutrophication [g PO_4 equivalents]	48%	73%	49%	64%
Aquatic eutrophication [g PO_4 equivalents]	37%	41%	18%	55%
Human toxicity – PM10 [g PM10 equivalents]	45%	69%	52%	61%
Abiotic Resource Depletion [kg Sb equivalents]	11%	51%	79%	80%

8.3 Evaluation of the sensitivity analyses regarding the allocation factor

The sensitivity analyses applying the allocation factor 100% for the open-loop recycling of the regarded packaging systems' material components is modelled to verify the influence the choice of the allocation method applied has on the results.

As the application of the allocation factor 100% leads to only slight changes in the net results for all regarded packaging systems, the overall ranking between the packaging systems in each indicator is not changed compared to the base scenarios. The choice of system allocation therefore plays no decisive role for the environmental assessment of the examined packaging systems.Evaluation of the sensitivity analysis regarding recycling rates

8.4 Evaluation of the sensitivity analysis regarding recycling rates

While in the base scenarios average end-of-life conditions are assumed, the sensitivity analysis with focus on recycling rates shall provide indications how different recycling rates would effect the results of the examined packaging systems.

Although the modelling with different recycling rates shows differences regarding the net results of the examined packages its influence is not high enough to change the ranking between the food cartons and the alternative packaging systems regardless which recycling rate between 0% and 70% is applied.

8.5 Recommendations

Based on the findings of this study, summarised in section 8-1 to 8-5, the authors developed the following recommendations:

- From an environmental point of view the food cartons *combisafe* and *combibloc* clearly show a better performance compared to the examined retortable pouch, glass jar, steel can and plastic pot not only in the base scenarios but also in the analysed sensitivity scenarios regarding an allocation factor of 100%, different recycling rates and the different method for the assessment of the eutrophication potential. For the packaging of sterilised liquid food on the European market (EU27+2) the authors therefore recommend to prefer food cartons over the alternative packages examined.
- The results of this study show that of both examined food cartons the *combibloc* has slightly bigger competitive advantages over the regarded alternative packages than the *combisafe*. It is therefore recommended to prefer *combibloc* over *combisafe* in case an UHT treatment combined with an aseptic filling is technically viable for a dedicated product application. If a retortable packaging system is necessary due to

requirements of the food to be packed, *combisafe* is the best option of all the examined packaging systems from an environmental point of view.

- Though, as described in the discussion in section 6.1, the assessment of the consumption of wood and the use of forest area is difficult to accomplish in the scope of a LCA study, it is recommended to aim at sourcing wood from forests with state-of-the-art management systems. In this context, the authors recommend the Forest Stewardship Council's (FSC) criteria for orientation and would like to point out that SIG Combibloc has been making special efforts to achieve FSC certification at different levels of the company and of the chain of custody. The authors appreciate the continuous pursuing of these endeavours by SIG Combibloc and recommend to further put an effort into that aspect. A continuous close cooperation between SIG Combibloc and the company's LPB suppliers may be one crucial element of a successful strategy for further achievements.
- The normalisation performed with the results of the base scenarios allows a conclusion on where a reduction of the examined packaging systems' environmental loads could be most effective in order to improve the quality of the environment at the European level. These are the impact categories *Abiotic Resource Depletion, Climate Change, Acidification, Terrestrial Eutrophication* and *Human Toxicity: PM 10.* In all of these both examined food cartons show considerably better environmental performances than the pouch, glass jar, steel can and plastic pot. This confirms the recommendation to prefer food cartons over the alternative packages for the packaging of sterilised liquid food products.
- Due to the potential generation of methane emissions on landfills, diversion of residual waste streams of all fibre-based products (both food cartons and subsequent products made of recycled fibres) from landfill should still be the goal of SIG Combibloc – as producer of *combisafe* and *combibloc* to further reduce the environmental impact of the food carton packaging systems. SIG Combibloc - as well as its customers, mainly the retorted food producers as well as the retailers should contribute to the development of an infrastructure which avoids that food cartons or products made of recycled fibres end up in landfills.
- 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 emissions relevant for the assessment of impact indicators as *Human Toxicity: Carcinogenic Risk*) and to allow recently developed methods as for the assessment of water consumption to be successfully applicable.

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Appendix A: Impact indicators

The impact indicators 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 is given at the end of each sub-section.

A.1 Climate change

Climate Change is the adverse environmental effect caused by anthropogenic heating of the Earth's atmosphere; it is described in detail in the relative references [IPCC 1995]. The indicator 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.

The 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)
Carbon dioxide (CO_2). fossil	1
Methane (CH_4)[16] fossil	27.75
Methane (CH_4). regenerative	25
Nitrous oxide (N_2O)	298
Tetrafluoromethane	7390
Hexafluoroethane	12200
Halon 1301	7140
R22	1810
Tetrachlormethane	1400
Trichlorethane	146
Source: [IPCC 2007]	

Table A-1: Global warming potential for 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. The non-fossil 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.

In the present study, the latter approach has been applied for the impact assessment. The CO_2 uptake has been documented at the inventory level.

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[16] According to [IPCC 2007], indirect effects such as oxidation of CH_4 to CO_2 are not considered in the GWP values given in the IPPC report. Therefore one CO_2 equivalent has been added per one CH_4 molecule.

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 (photosmog or summer smog)

Due to the complex reactions during the formation of near-ground ozone (photosmog or summer smog), the modelling of the relationships between the emissions of unsaturated hydrocarbons and nitrogen oxides is extremely difficult. A method which has been frequently used by LCA practitioners for assessing the respective effects is referred to as the Photochemical Ozone Creation Potential (POCP) [CML 1992]; the results expressed in Ethene equivalents. It is viewed controversially among experts because it is based on changes to existing ozone concentrations and also because it was originally developed for calculating the effects over broad regions.

A weakness is that it is based on the ozone creation potential of hydrocarbons and completely ignores the contribution of nitrogen oxides to the ozone forming reactions. However, as there is no commonly accepted indicator including the contribution of nitrogen oxides, the POCP assessment method is used in this study.

The table below shows the gases and their ozone creation potential (POCP) as used in this study.

Harmful gas	POCP [kg ethene equivalents]
Ethene	1
Methane	0.006
Carbon monoxide	0.027
Formaldehyde	0.519
Benzene	0.218
Acetylene	0.085
Ethanol	0.399
Ethylbenzene	0.73
Ethylacetate	0.209
Hexane	0.482
Toluene	0.637
Xylene	1.108
Aldehydes unspec.*	0.563
Butane	0.352
Butene	1.079
Ethane	0.123
Heptane	0.494
Propene	1.123
MTBE	0.175
Acetaldehyde	0.641
Methanol	0.14
Styrene	0.142
Dichlorethene	0.447
Ethene glycol	0.373
Hydrocarbons:	
• NMVOC from diesel emissions**	0.7
• NMVOC (average)*	1.0
• VOC*	1.0
Source: [Jenkin+Hayman 1999. Derwent et al. 1998] taken from [CML 2010]. *[IFEU 2008]. **[UBA 1995]	

Table A-2: Ozone creation potential of substances considered in this project

In [CML 2010], only individual substances having a defined equivalent value relative to ethane are considered. However within emissions relevant for POCP, often the group parameters (NMVOC, VOC) are predominant on a mass basis. As the composition of those is not known in many inventory data sets, they were treated similar to ethene emissions (POCP = 1). This represents a conservative approach.

Note: Older publications by CML [CML 1992] specified characterisation factors for VOC and NMVOC, however those were derived on grounds of characterisation factors for individual substances taken from the same [CML 1992] publication. In the opinion of the authors of this study, the most consistent way to deal with the group parameters would be to derive updated characterisation factors based on the most current factors for individual substances, as taken from [CML 2010]. However, it could not be clarified in communication with Jerone Guinee [Guinee 2008], which individual substances with which weights had been used for the calculation of VOC and NMVOC in [CML 1992]. That is the reason why we use a characterisation factor of 1 for the group parameters in this study.

The POCP was calculated using the following equation:

$$POCP = \sum_i (m_i * POCP_i)$$

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 impact 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 impact of an emission 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:

$$ozone\_depletion = \sum_i (m_i \times ODP_i)$$

A.4 Eutrophication and oxygen-depletion

Eutrophication means the excessive supply of nutrients. and can apply to both surface waters and soils. As these two different media are affected in very different ways, a distinction is made between water-eutrophication and soil-eutrophication. It is assumed here for simplification that all nutrients emitted via the air cause enrichment of the soil and that all nutrients emitted via water cause enrichment of the water. As the nutrient input into surface waters via air emissions is small compared to the nutrient input via wastewater, this assumption does not give rise to noteworthy error.

The eutrophication of surface waters also causes oxygen-depletion. If there is an over-abundance of oxygen-consuming reactions taking place, this can lead to oxygen shortage in the water. A measure of the possible perturbation of the oxygen levels is given by the Bio-chemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). As the BOD is only defined by a reaction time and the COD essentially represents all the available potential for oxygen-depletion. COD is used as a conservative estimate[17] for the eutrophication in the parameter list.

In order to quantify the magnitude of this undesired supply of nutrients, the eutrophication potential indicator was chosen. This indicator is expressed as phosphate equivalents [CML 2002, Klöpffer 1995]. The table below shows the harmful substances and nutrients that were considered in this study, along with their respective characterisation factors:

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] taken from [CML 2010]	

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

Regarding the supply of nutrients, the contribution to the eutrophication potential is calcu-lated separately for soil and water. 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.

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[17] 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.

The following equation is used for terrestrial or aquatic eutrophication:

$$EP = \sum_i (m_i \times EP_i)$$

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 indicator 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 Human toxicity: Fine particulate matter (PM10)

Concerning the impact category “human toxicity”, a generally accepted approach covering the whole range of toxicological concerns is not available. The indicator chosen for this assessment examines the potential threat to human health due to the emission of fine particulates (primary particulates as well as precursors).

Fine particulates (PM10) are subsuming primary particulates and precursors of secondary particulates. They are characterised according to an approach by the European Environment Agency (EEA).

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 can not be absorbed by protection mechanisms and thus deeply penetrate into the lung and cause damage.

Fine particulate matter can be formed from emissions by different mechanisms: On the one hand carbon-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).

As an indicator for the category “Human Toxicity: Particulate matter”, the absolute quantity of dust particles and secondary particles smaller than 10 micrometers (PM10) measured in kg of PM10 equivalent has been chosen. Characterisation factors (shown in table below) supplied by the European Environmental Agency [Leeuw 2002] are used to quantify compounds such as SO_2, NOx and NH_3 as secondary particles. They are regarded to be representative for Europe. Regarding NMVOC emissions, only the knowledge of exact organic compounds would allow a quantification as secondary particles. As however, related information is missing in most of the inventory data sets. an average value derived by [Heldstab et al. 2003] has been applied in this study (0.012). For Diesel particles, neither of the two named references include a quantification. It has been (conservatively) assumed that Diesel particles completely consist of the fraction with less than 10 µm in diameter. They have therefore been classified with a factor of 1.

Harmful substance	**PM10 equivalents ($PM10_i$) (Air)** [kg PM10 equivalents/kg]
PM10	1
SO_2	0.54
NO_X as NO_2	0.88
NMVOC (unspecified. hydrocarbons and from Diesel emissions)	0.012*
NH_3	0.64
Diesel particles	1**
Source: [Leeuw 2002]; *[Heldstab et al. 2003]. ** Assumption IFEU	

Table A-5: PM10 equivalents of substances considered in this study

The contribution to the fine particulate matter potential is calculated by summing the products of the amounts of the individual harmful substances and the respective PM10 equivalent values using the following equation:

$$PM10 = \sum_i (m_i \times PM10_i)$$

Please note: The newly developed assessment method USEtox requires great amounts and high quality of inventory data. The inventories currently used for different materials are clearly asymmetric and not yet harmonised regarding the emissions in water and air. Therefore, the authors do not apply the USEtox method for the evaluation of the carcinogenic risk, as incomplete inventory data may lead to misinterpretation of the results in the study.

A.6 Abiotic resource depletion

Abiotic resources are natural resources such as iron ore, crude oil and other mineral or fossil resources which are regarded as non-living. The consumption of resources is deemed adverse for human society. In all considerations regarding sustainable, environmentally-compatible commerce, the conservation of resources plays a key role.

When evaluating resource requirements within an LCA study. the scarcity of the resource is usually used as the criterion. The relationship between the factors – consumption, possible regeneration and reserves – is used to determine the scarcity of a resource, relative to a particular geographical unit. The result is a scarcity factor that is then considered in conjunction with the resource data in the life cycle inventory and aggregated into an overall parameter for the resource consumption.

For this study the approach of [CML 2002] based on parameters on ultimate reserves and extraction rates by [Guineé & Heijungs 1995] is used. The following table lists the ADP factors used.

Natural resource	ADP (in kg antimony eq./kg)
actinium (Ac)	6.33E13
aluminium (Al)	1E–8
antimony (Sb)	1
argon (Ar)	4.71E–7
arsenic (As)	0.00917
barium (Ba)	1.06E–10
beryllium (Be)	3.19E–5
bismuth (Bi)	0.0731

boron (B)	0.00467
bromine (Br)	0.00667
cadmium (Cd)	0.33
calcium (Ca)	7.08E–10
cerium (Ce)	5.32E–9
cesium (Cs)	1.91E–5
chlorine (Cl)	4.86E–8
chromium (Cr)	0.000858
cobalt (Co)	2.62E–5
copper (Cu)	0.00194
dysprosium (Dy)	2.13E–6
erbium (Er)	2.44E–6
europium (Eu)	1.33E–5
fluorine (F)	2.96E–6
gadolinium (Gd)	6.57E–7
gallium (Ga)	1.03E–7
germanium (Ge)	1.47E–6
gold (Au)	89.5
hafnium (Hf)	8.67E–7
helium (He)	148
holmium (Ho)	1.33E–5
indium (In)	0.00903
iodine (I)	0.0427
iridium (Ir)	32.3
iron (Fe)	8.43E–8
kalium (K;potassium)	3.13E–8
krypton (Kr)	20.9
lanthanum (La)	2.13E–8
lead (Pb)	0.0135
lithium (Li)	9.23E–6
lutetium (Lu)	7.66E–5
magnesium (Mg)	3.73E–9
manganese (Mn)	1.38E–5

mercury (Hg)	0.495
molybdenum (Mo)	0.0317
neodymium (Nd)	1.94E–17
neon (Ne)	0.325
nickel (Ni)	0.000108
niobium (Nb)	2.31E–5
osmium (Os)	14.4
palladium (Pd)	0.323
phosphorus (P)	8.44E–5
platinum (Pt)	1.29
polonium (Po)	4.79E14
praseodymium (Pr)	2.85E–7
protactinium (Pa)	9.77E6
radium (Ra)	2.36E7
radon (Rn)	1.2E20
rhenium (Re)	0.766
rhodium (Rh)	32.3
rubidium (Rb)	2.36E–9
ruthenium (Ru)	32.3
samarium (Sm)	5.32E–7
scandium (Sc)	3.96E–8
selenium (Se)	0.475
silicium (Si; silicon)	2.99E–11
silver (Ag)	1.84
Sodium (Na)	8.24E–11
strontium (Sr)	1.12E–6
sulfur (S)	0.000358
tantalum (Ta)	6.77E–5
tellurium (Te)	52.8
terbium (Tb)	2.36E–5
thallium (Tl)	5.05E–5
thorium (Th)	2.08E–7
thulium (Tm)	8.31E–5

tin (Sn)	0.033
titanium (Ti)	4.4E–8
tungsten (W); wolfraam	0.0117
uranium (U)	0.00287
vanadium (V)	1.16E–6
xenon (Xe)	17500
ytterbium (Yb)	2.13E–6
yttrium (Y)	3.34E–7
zinc (Zn)	0.000992
Zirconium (Zr)	1.86E–5
crude oil	0.0201
natural gas*	0.0187
hard coal	0.0134
soft coal	0.00671
* In kg antimony/m^3 natural gas	
Source: [CML 2002]	

Table A-6: ADPs of abiotic resources considered in this study

The following equation was used to calculate the abiotic resource depletion:

$$abiotic\_depletion = \sum_i (m_i \times ADP_i)$$

The indicator result is expressed in kg of the reference resource antimony. ADP_i is the Abiotic Depletion Potential of resource i, while m_i is the quantity of resource i used.

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Appendix B: Fossil resources

In the previous LCA study on food cartons and alternative packagings [IFEU 2008] the consumption of fossil resources has been assessed by applying a method based on static ranges that serve as indicators for the scarcity of fossil resources. The scarcity values are converted to Crude Oil Equivalents. To allow an easier comparison of the results of the previous and the present study Crude Oil Equivalents of fossil resources used are presented below.

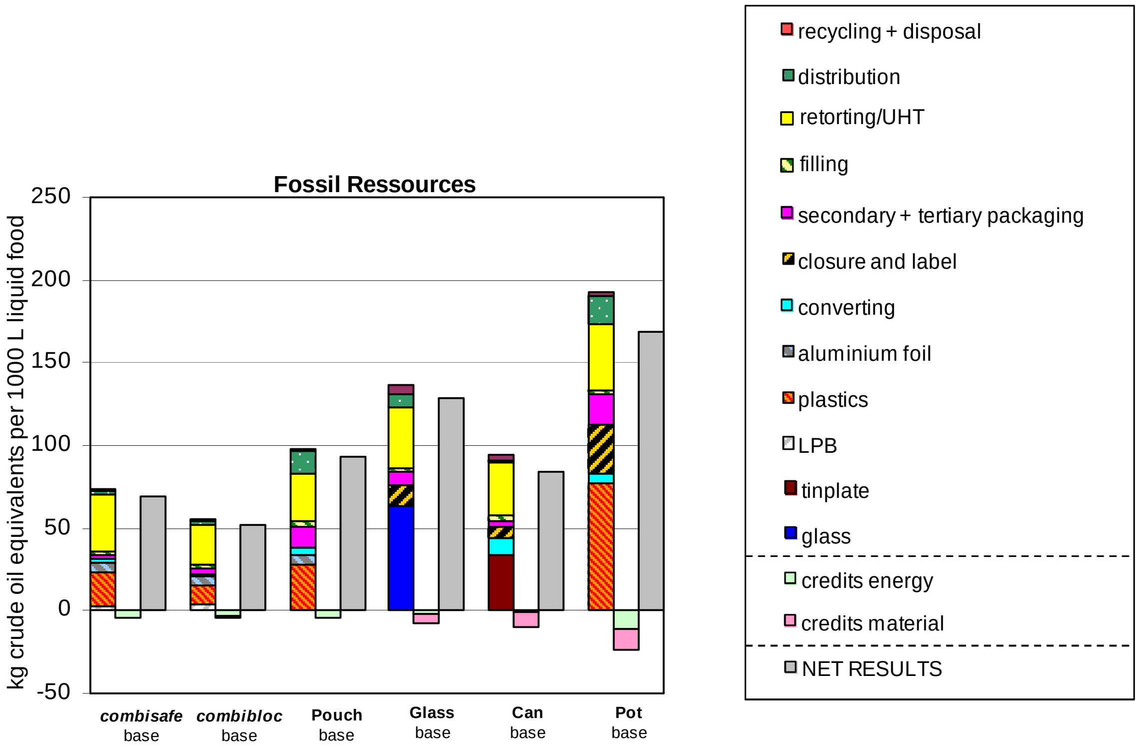

Figure B.1: Fossil resource consumption using crude oil equivalents

Appendix C: Critical review report

Critical Review Report according to ISO 14040 and 14044

of the study

Comparative Life Cycle Assessment of sterilized food packaging systems on the European market

Conducted by IFEU - Institut für Energie- und Umweltforschung
Heidelberg GmbH (the “Practitioner”)

Performed for SIG International Services GmbH, D-Linnich
(the “Commissioner”)

by

Birgit Grahl (chair)
Richard Murphy
Philippe Osset

September 2013

Content

1. Procedural Aspects of the Critical Review

The Critical Review was commissioned by SIG International Services GmbH, D-Linnich 14th May 2013 as a three-stage process. The reviewers received the initial goal and scope of the study 2nd May 2013, a First Draft including the inventory and first results 29th May 2013 and the Final Draft Report containing all relevant chapters 22nd July 2013. In all thee steps of the review process the reviewers sent a list of detailed comments to the practitioner in order to prepare for the respective telephone conferences on 10th May, 5th June and 26th July. During the conference calls the comments were elaborated by the panel members and discussed with the practitioner and the commissioner in detail. An online data model check was performed by one panel member (Richard Murphy) on 25th July 2013.

A few queries of the panel which could not be clarified during the conference calls where answered by the practitioner a few days later either in written form or by telephone call.

The review panel received the Final Report 13th August 2013 and the statements and comments below are based on this final version.

Formally this critical review is a review by “interested parties” (panel method) according to ISO 14040 section 7.3.3 [1] and ISO 14044 section 4.2.3.7 and 6.3 [2] because the study includes comparative assertions of different packaging systems.

Despite this title, however, the inclusion of further representatives of "interested parties" is optional and was not explicitly foreseen in this study. The review panel is neutral with regard to and independent from particular commercial interests. The panel had to safeguard other interested parties issues, even if governmental or non governmental organisations or other interested parties e.g. from competitors or the consumer side have not been invited due to the time scale of the project and the limited budget.

The reviewers emphasise the open and constructive atmosphere of the project. All necessary data were presented to the reviewers and all issues were discussed openly. All comments of the panel have been treated by the practitioner with sufficient detail in the final report. The resulting critical review report represents the consensus between the reviewers.

Note: The present CR report is delivered to SIG International Services GmbH. The CR panel cannot be held responsible of the use of its work by any third party. The conclusions of the CR panel cover the full report from the study for SIG entitled “Comparative Life Cycle Assessment of sterilized food packaging systems on the European market – Final Report – August 2013” and no other report, extract or publication which may eventually be undertaken. The CR panel conclusions are given with regard to the current state of the art and the information which has been received. The conclusions expressed by the CR panel are specific to the context and content of the present study only and shall not be generalised any further.

2. General Comments

In the study different food packaging variants for liquid food products are investigated in the context of European market conditions. In the goal definition two aspects are addressed:

- provide knowledge of the environmental strengths and weaknesses of the SIG food carton packs *combibloc* and *combisafe* for the packaging of sterilised liquid food products under European market conditions (EU 27 and Norway & Switzerland)
- compare the environmental performance of the food carton packs *combibloc* and *combisafe* with those of competing packaging systems with a high market relevance in Europe (e.g. steel can, glass jar, retortable pouch, plastic pot).

The competing variants chosen are the four packaging systems named in the goal definition. Thus the study contains comparative assertions which may be used for internal and external communication. The selection of the specific competing products considered is meaningful and is deduced transparently from market data to safeguard the relevance of investigated packaging variants.

The report is well structured and conforms to the requirements for a third-party-report including comparative assertions intended to be disclosed to the public according to ISO 14044 clause 5.2 and 5.3.

The executive summary concentrates the results in a meaningful manner and highlights the recommendations. These are plausible according to the arguments made and all statements are substantiated in the report.

3. Statements by the reviewers as required by ISO 14044

According to ISO 14044 section 6.1
"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with this International Standard,*
- *the methods used to carry out the LCA are scientifically and technically valid,*
- *the data used are appropriate and reasonable in relation to the goal of the study,*
- *the interpretations reflect the limitations identified and the goal of the study and*
- *the study report is transparent and consistent."*

In the following sections 3.1 to 3.5 these items are discussed according to our best judgement and considering the ISO standards 14040 and 14044.

3.1 Consistency of the methods with ISO 14040 and 14044

The study has been performed according to the general structure of LCA required in ISO 14040 and also to the requirements laid down in ISO 14044. The structure of the report reflects the general structure of LCA (Goal & Scope definition– Life cycle inventory analysis (LCI) – Life cycle impact assessment (LCIA) and Interpretation). The functional unit and the system boundary are defined and elaborated thoroughly and according to the goal of the study.

The inventory analysis methods applied are consistent with the ISO standards 14040 and 14044. The use of the Umberto® software facilitates an appropriate modelling of the systems at issue.

The problem of allocation in open-loop recycling was solved by the application of two (the minimum required by ISO 14044) allocation rules: 50:50 as the base allocation and 100:0 as a sensitivity analysis. The allocation procedures and consequences for the results are described transparently.

The impact categories and characterisation models as well as the inventory level indicators are meaningful and well explicated. They are critically discussed, emphasising weaknesses and shortcomings. The impact assessment methods chosen are in line with the ISO 14044 standards. Normalization as optional element of LCIA was included in the analysis of the results.

Sensitivity analyses were performed in order to check the robustness of the base scenario results. Three aspects were investigated: the relevance of the open-loop allocation rule, the influence of recycling rates in the end-of-life phase and the relevance of the characterisation model for the impact category eutrophication. The choice of the analysed base scenario and of the parameters considered in the sensitivity analyses are comprehensible and meaningful within the context of the study.

The CR panel concludes that the methods used are consistent with the international standards.

3.2 Scientific and technical validity of the methods used

The methods used represent the scientific and technical state-of-the-art for such analyses. Some specific aspects performed in the study are highlighted below:

Within the critical review, a data model check was conducted. In particular, the model structure and its organisation within the LCA software and the organisation and example values for LCIA characterisation factors were assessed. Basic datasets in the model were explored, including a number of' drill-downs' to understand sub-structure, level of disaggregation and data options available. The data choices selected were examined by means of different examples and system processes/models were explored at the whole life cycle level. The model, software and the organisation of the product systems for the LCA were of a very high standard and meet the requirements of ISO 14040 and ISO 14044. The session was conducted with full openness and transparency and the practitioner addressed all questions and challenges with competence and completeness.

The international standard ISO 14044 does not prescribe specific impact categories and indicators, not even a default list. However, the choice of impact categories has to be defined and justified according to the goal of the study. This is carefully elaborated in the study. Regarding the selection of impact categories the study refers to the German Federal Environmental Agency (UBA) approach 2000 [3] as a basis, discusses exceptions to this approach, derives the categories chosen and includes a thorough reflection of impact categories used in former studies as well as the current discussion on newer categories and characterisation models. A sensitivity analysis regarding the characterisation model of eutrophication, referring to the current method discussion provides a good example of the careful conduct of the study. Three inventory parameters complement the evaluated data. Data for the indicator Crude Oil Equivalents of fossil resources not considered in this but in a previous study is also presented in an Appendix and this facilitates comparison with previous research.

The exclusion or non-consideration of certain possible impact categories is justified and substantiated. It is explained comprehensively how the inclusion of USEtox as a characterisation model for human toxicity may lead to misleading results due to substantial asymmetries between the data sets at the inventory level. Additionally, the reasons for excluding the impact categories of land use and water consumption are scientifically sound and well justified, leading to improvement opportunities within further studies.

The influence of recycling rates to the burdens of the end-of-life phase of the considered products is investigated in detail. The base scenario models the end-of-life with material specific recycling rates deduced from literature and the European average split for landfilling and incineration for the remaining fraction. The three scenarios that vary the recycling rate and thus change the remaining fractions for landfilling and incineration from the base data in order to understand the implications of different waste management types are meaningful and aid understanding of the results. The results are carefully analysed and in a critical discussion the reasons and relevance of results are evaluated comprehensively.

The CR panel concludes that the methods used are scientifically and technically valid.

3.3 Appropriateness of data in relation to the goal of the study

Data gathering for packaging specification is a crucial aspect of the inventory, because data uncertainty has a multiplicative effect via reference flow. The method of data gathering is described and in deeper discussions in the conference calls the panel was convinced that data of SIG products as well as for competing products are gathered carefully and consistently.

As is usual practice for Critical Reviews, the correctness of all items of primary and other data was not checked but the data used in the study were reviewed for appropriateness and plausibility.

All data sets used for the unit processes are well characterised according to data source, reference period, and geographical and technical system boundaries. The table and short descriptions of the considered unit processes allow a deeper insight. The data used are meaningful and appropriate to the objective as defined in the goal and scope of the study.

Specific data of the commissioner were used for the packaging specifications (both for SIG's own products and competing products), some transport distances and the food carton converting.

The distribution model is described in detail and is differentiated as a two-step distribution considering empty trips and degree of utilisation. The burdens are allocated between food and packaging by mass. Although the transparency of documented transport distances involved in packaging production, distribution to filler and to point of sale is limited, the data are nevertheless plausible.

A complete review of every item of data and calculations in the study is not included in the critical review process. This is not possible because of the amount of data to be considered. Therefore, it was important to examine the data horizontally (general plausibility, plausibility of the relevance of certain impacts to the results) as well as vertically (detailed checks of parts of the calculation model). The handling of data and sensitivity analyses demonstrate a sufficient robustness of the calculated data. The data and calculation methods were judged to be appropriate for the goal of the study.

Furthermore it can be stated that no over-interpretation of the data has been detected.

The CR panel concludes that the data used are appropriate and reasonable in relation to the goal of the study.

3.4 Assessment of interpretation referring to limitations and goal of the study

The interpretation is based on a detailed data analysis, is transparently deduced from inventory data and impact assessment results and is meaningfully considered with due regard to the limitations and the goal of the study.

Clearly arranged tables including numerical results complement the charts of contribution analysis presented so that the interpretation of data is comprehensible, and remains in the scope of a consistent significance limit. According to the goal of the study, on the one hand a comparison of the two product systems of the commissioner (*combibloc* and *combisafe*) is analysed, on the other hand the interpretation discuses these results in comparison with the competing products. The analyses and particularly the contribution analyses are executed in an exemplary manner and comprehensible conclusions are presented why certain results were obtained.

A careful elaboration of the interpretation of the sensitivity analyses is also given. The detailed analysis of the dependence of results according to the recycling rate leads to interesting insights.

In order to analyse the relative importance of the various impact categories, a normalisation step was included for the base scenario and the results are meaningfully reflected in the interpretation.

It was also noted by the reviewers that the impact categories Land Use and Water Use/Consumption were excluded. This is explained and justified clearly by the practitioners. Further information and practitioner viewpoint concerning forest certification and the FSC scheme is provided as supplementary information related to the wood fibre source. However, this is not directly linked to an LCA impact category and as such this information falls outside the scope of this Critical Review.

The derivation of the conclusions and recommendations of the study are comprehensible from the interpretation undertaken. Where subjective views of the practitioner are presented they are clearly delineated from those recommendations directly deducible from the results. Because a critical review neither shall validate the goal of a study nor subjective views if they are characterised as such, the CR panel considers this representation is exemplary.

The report’s interpretation chapters deal with all issues from goal and scope sufficiently. Thus, the CR panel concludes that the interpretations reflect the limitations identified and the goal of the study.

3.5 Transparency and consistency of study report

The report is clearly presented and follows the specification in ISO 14040 and 14044. Inconsistencies in the report could not be identified. The same is true for the well written and concise executive summary.

The presentation of the four LCA phases Goal & Scope Definition, Inventory Analysis, Impact Assessment and Interpretation is well balanced and enables understanding of the credibility of results. The line of argument is transparent and comprehensible. This is supported by visualisation of advantages and disadvantages of calculated product systems as well as for scenarios in charts and tables. The reader-friendly configuration of the tables facilitates the comparison of results. Any value judgements of the practitioner are transparently mentioned, including the additional information provided on FSC label use (this outside the scope of this Critical Review).

The CP panel concludes that the report is transparent and consistent.

4 Conclusions and recommendations

The CR panel considers that this LCA study has been conducted according to and in compliance with the ISO standards 14040 and 14044. The quality of this study is a very good example of a scientifically-based, state-of-the-art LCA.

The study is foreseen for publication and this can be recommended by the reviewers.

References:

[1] DIN EN ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework

[2] DIN EN ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines

[3] [UBA 2000]: Umweltbundesamt. Berlin (Hrsg.): Ökobilanz für Getränkeverpackungen II. Hauptteil, UBA-Texte 37/00,Berlin, 2000.

Heidekamp, 10.9.2013

Prof. Dr. Birgit Grahl (chair)
on behalf of the CR review panel

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Prof. Dr. Birgit Grahl
Birgit Grahl studied Chemistry at University of Hamburg and after dissertation she worked as head of chemistry department at Öko-Institut Freiburg followed by some years as co-owner and director of a commercial laboratory (measurement of pollution in environmental media and food). Than she started as a free consultant in the field of industrial ecology: Life Cycle Assessment and Applications, Critical Reviews; Life Cycle-/ Supply Chain Management; Environmental Labelling / ISO Type III. Clients are industry, government and NGOs. She was involved in the development of the ISO 14040 series, is member of the editorial board of “The International Journal of Life Cycle Assessment” and professor for Industrial Ecology at University of Applied Sciences in Lübeck.

Dr Richard James MURPHY

Date of Birth:	10 October 1956
Current Posts:	Professor of Life Cycle Assessment, Centre for Environmental Strategy, University of Surrey (*from 1 Feb 2013*) Distinguished Research Fellow, Imperial College London (honorary) - previously Reader in Plant Science, Division of Biology, Imperial College London) Director and Senior LCA Practitioner, LCAworks Ltd Chief Scientific Officer, Mycologix Ltd (*to January 2013*)
Degrees:	1978 BSc (Hons.) Botany w/ Zoology, Kings College, University of London 1982 PhD, Pure & Applied Biology, Imperial College, University of London

Career Summary

1982/3	Post-Doctoral research School of Forestry, University of Canterbury, Christchurch, New Zealand Forest Research Institute, Rotorua, New Zealand
1983	Post Doctoral Research, Imperial College London
1985	Lecturer, Imperial College London (incl. 1987 Visiting Scientist, TNO, Delft, NL)
1989	Senior Lecturer, Imperial College London
2007	Reader in Plant Science, Imperial College London
2012	Distinguished Research Fellow, Imperial College London

Professional memberships/roles:

IWSc/IoM3	Institute of Wood Science, President (1998-2000), Chairman Education Committee (2003-2007), now part of IoM3,
IRG-WP	International Research Group on Wood Protection, Stockholm - Member Executive Council (1999-2003), member since 1982
BMS	British Mycological Society, member since 1982
Vice-Chairman	COST-Action E9 LCA Forestry/Forest Products (1997-2001).
BRE Advisory Panel	Member since 2011
NNFCC	National Non-Food Crops Centre Programme Advisory Committee (PAC) member and Strategy Group member (2004 -2005).
DEFRA	Peer reviewer/assessor - Research grant competition on Renewable Industrial Materials and Bioenergy (2003)
IFS	Reviewer panel International Foundation for Science, Stockholm (2002 -)
External Examiner	BSc in Biology, University of Portsmouth (2012-) MSc in Green Biotechnology & Innovation, University of Aberystwyth (2012-)
FRIM	Forest Research Institute Malaysia - Programme Advisory Committee (2000)
Reviewer	Holzforschung, Annals of Botany, Forest Products Journal, International Journal of LCA, Biomass and Bioenergy, Energy & Environmental Science, Plant Physiology.
Critical LCA Reviews	Member of Critical Review Panels for LCAs to the ISO 14040 series and as an individual reviewer for other LCA studies.
BSI committee	PKW 0 Packaging (2006 -), co-chair biodegradability working group

Research Grant Support - examples

BBSRC BSRC Sustainable BioEnergy research Centre (BSBEC), Perennial Biomass Programme 2009 – 2014, £680,200 (IC component). Funding Renewed Dec 2011, ***2009 to 2014***

EU FP7 – Project ENERGYPOPLAR £150,799 (Total consortium project Euro 4,156,45), ***2008 - 2012.***

TSB/EPSRC FarmPULP – Farm produced ultrathin lightweight packaging £128,370, ***2009 – 2011***

NERC TSEC-BIOSYS - a whole-systems approach to analysing bioenergy demand and supply: mobilising the long-term potential of bioenergy, £110,000 to IC (Murphy) (Total IC budget £450,000), ***2006 - 2010***

BERR - Bio Based Lightweight Sandwich Structures for Packaging Applications £71,500 to IC/Total consortium costs £1,752,000, ***2008 – 2010***.

DTI/BERR Lightweight Eco-composites £78,600, ***2005-2009***,

EU FP 6 Project LENSE – methodology development towards a label for environmental, social and economic buildings, £70,000, ***2006 – 2007***

+ launched **2 spin-out companies** (Mycologix Ltd, late 2009; LCAworks Ltd, spring 2011), several smaller grants and an extensive range of corporate (e.g. BT, BP, The Coca Cola Company, Braskem) and government (e.g. DECC, Defra, WRAP, ITTO) **consultancies**.

Examples of Recent/Principal Publications

Littlewood J, Murphy RJ, Wang L, (2013). Importance of policy support and feedstock prices on economic feasibility of bioethanol production from wheat straw in the UK, *Renewable and Sustainable Energy Reviews*, 17, 291-300 http://dx.doi.org/10.1016/j.rser.2012.10.002

Guo, M., Stuckey, D. C., Murphy, R. J. (2013) End-of-life of starch-polyvinyl alcohol biopolymers. *Bioresource Technology* 127, 256-266 http://dx.doi.org/10.1016/j.biortech.2012.09.093

Guo, M. and Murphy R.J. (2012). LCA data quality: Sensitivity and uncertainty analysis. *Science of the Total Environment* 435/436, 230-243. http://dx.doi.org/10.1016/j.scitotenv.2012.07.006

Gonzalez-Garcia,S., Iribarren, D., Susmozas, A., Dufour, J. and Murphy R.J. (2012). Life cycle assessment of two alternative bioenergy systems involving Salix spp. biomass: Bioethanol production and power generation. *Applied Energy* 95,111-122 http://dx.doi.org/10.1016/j.apenergy.2012.02.022

González-García, S., Bacenetti, J., Murphy, R.J. & Fiala, M. (2012). Present and future environmental impact of poplar cultivation in the Po Valley (Italy) under different crop management systems. *Journal of Cleaner Production* 26, 56-66. http://dx.doi.org/10.1016/j.jclepro.2011.12.020

Wang, L., Templer, R. and Murphy, R.J. (2012). Environmental sustainability of bioethanol production from waste papers: sensitivity to the system boundary. *Energy & Environmental Science* 5 (8), 8281-8293. http://dx/doi.org/10.1039/c2ee21550k

Wang, L., Sharifzadeh, M., Templer, R. & Murphy, R.J. (2012). Technology performance and economic feasibility of bioethanol production from various waste papers. *Energy & Environmental Science* 5 (2), 5157-5730

Guo, M., Li, C., Bell, J.N.B & Murphy, R.J. (2011). The influence of agro-ecosystem modelling approach on the greenhouse gas profiles of wheat-derived biopolymer products. *Environmental Science & Technology* 46 (1), 320−330.

Whittaker,C., Mortimer, N., Murphy, R.J. & Matthews, R.(2011). Energy and greenhouse gas balance of the use of forest residues for bioenergy production in the UK. *Biomass & Bioenergy* 35 (11), 4581-4594.

Brandt, A., Ray, M. J., To, T. Q., Leak, D. J., Murphy, R. J., & Welton, T. (2011). Ionic liquid pretreatment of lignocellulosic biomass with ionic liquid-water mixtures. *GREEN CHEM*, *13*(9), 2489-2499. doi:10.1039/c1gc15374a).

Woods, J., Williams, A., Hughes, J. K., Black, M., & Murphy, R. J. (2010).Energy and the Food System. *Phil Trans Royal Soc B*. 365, 2991-3006 doi: 10.1098/rstb.2010.0172 *(this paper is part of UK gov. Foresight project Global Food & Farming Futures)*

Murphy, R., Woods, J., Black, M., & McManus, M. (2011). Global developments in the competition for land from biofuels. *Food Policy*, *36*, S52-S61. doi:10.1016/j.foodpol.2010.11.014 *(this paper is part of UK go.t Foresight project Global Food & Farming Futures)*

Brereton, N. J. B., Pitre, F. E., Hanley, S. J., Ray, M. J., Karp, A., & Murphy, R. J. (2010). QTL Mapping of Enzymatic Saccharification in Short Rotation Coppice Willow and Its Independence from Biomass Yield. *Bioenerg Res*, *3* (3), 251-261. doi:10.1007/s12155-010-9077-3

Hillier, J., Whittaker, C., Dailey, G., Aylott, M., Casella, E., Richter, G.M., Riche, A., Murphy, R.J., Taylor, G. and Smith, P. (2009). Greenhouse gas emissions from four bioenergy crops in England and Wales: Integrating spatial estimates of yield and soil carbon balance in life cycle analyses. Global Change Biology Bioenergy, 1, 267-281. doi: 10.1111/j.1757-1707.2009.01021.x

Ragauskas, A.J., Williams, C.K., , Davison, B.H., Britovsek, G., Cairney, J., Eckert, C.A., Hallett, J.F.J.P, Leak, D., Liotta, C.L., Mielenz, J.R., Murphy, R.J., Templer, R., and T.Tschaplinski (2006). The Path Forward for Biofuels and Biomaterials. *Science* 311, 484-489. *(has received 1100+ citations)*

Recent Invited conference presentations 2012/2011

Murphy R.J. (2012). “Closing Summary of Forum”. *Bloomberg New Energy Finance Leadership Forum Bioenergy, London, 23/24 October 2012.*

Murphy, R.J. ‘Biomass composition for biofuels and life cycle environmental impact’. *Umeå Renewable Energy Conference* 14-16 March 2012

Murphy, R.J. ‘Assessing optimum biomass composition for the production of bioenergy and biomaterials’. *International Symposium for Green Chemistry and Biomass Energy,* National Cheng-Kung University, Tainan, Taiwan; 3 & 4 November 2011.

Murphy R.J. ‘Life Cycle Assessment (LCA) of bio-based products: A perspective’. *19th BioEnvironmental Polymer Society Annual Meeting*, Vienna, Austria 28-30 September 2011.

Notable activities and achievements

Advisor to UK Climate Change Committee of LCA for bioenergy systems (2011/12)
Imperial College London, Rector’s Award for Excellence in Teaching 2011
Defra Hazardous Substances Advisory Committee (2013 -)

Dpl. Eng. Philippe Osset

Philippe Osset is an engineer of the Ecole Centrale de Paris (ECP92). After graduation, is started working at Ecobilan, a French LCA consultancy, in January 1994. From 1997, he has created a branch of Ecobilan in Japan. From 2002, he became the responsible of the Ecobilan activities within the sustainable development services of PwC, and has provided consultancy within mainly fields, including packaging. In 2010, he created his own environmental consultancy, Solinnen, with other partners. He is member of SETAC. He represents France at ISO when dealing with LCA standardisation: he is the convenor of the ISO TC207/SC/WG9 work on the Critical Review practice (ISO/NP TS 14071). Since 2012, he is also the Scientific Director of SCORELCA, a French consortium of private companies, together with the French EPA (ADEME), funding LCA research studies, mainly focusing on LCA methodologies. He has written a book on “LCA applications” published by AFNOR Edition.