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Life Cycle Assessment of **SIG**NATURE PACK: a beverage carton containing polymers based on the mass balanced renewable material approach

Final report

LCA SIG / CB-100732

commissioned by SIG Combibloc

Heidelberg, March 2nd, 2018

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Executive summary

Background, goal and scope

The "Life Cycle Assessment of **SIG**NATURE PACK: a beverage carton containing polymers based on the mass balanced renewable material approach" conducted by *ifeu* investigates the environmental performance of two variants of the newly developed aseptic beverage carton SIGNATURE PACK from SIG Combibloc in comparison to two alternative beverage cartons from the same producer.
The study covers the European market situation for the EU countries & Switzerland & Norway as well as the German market situation in 2018.

The study was performed in accordance with the relevant ISO standards (ISO 14040 and ISO 14044) and accompanied by a critical review process.

A wide range of environmental impact categories and inventory level indicators is covered. The considered emission-related impact categories are '*Climate Change', 'Stratospheric Ozone Depletion*', '*Summer Smog*', '*Acidification*' and '*Terrestrial*' as well as '*Aquatic Eutrophication*', furthermore '*Human toxicity: PM2.5'.* The regarded impact category related to the consumption of resources is *Abiotic Resource Depletion*. The following inventory indicators are also included: *Primary Energy Consumption* – both *Total* and *Non-renewable* . The assessment of the environmental impacts of *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 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 and Germany respectively 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.

The four packaging solutions examined are:

a. *cb3 1000 EcoPlus* with combiCap opening
   - a beverage carton with LDPE and PA as additional barrier materials, it does not contain aluminium foil. Its closure is made from PP.
b. *cb3 1000 SIGNATURE PACK 100%* with combiCap opening containing mass balance polymers
   - a beverage carton with the same specifications as the *cb3 1000 EcoPlus* apart from the source of polymers. It contains mass balance based LDPE, PA and PP. Its closure is made from PP.
c. *cb3 1000 Standard* with combiSwift opening
   - a beverage carton with LDPE and aluminium as additional barrier materials. Its closure is made from PP and HDPE.
d. *cb3 1000 SIGNATURE PACK high barrier* with combiSwift opening containing mass balance polymers
   - a beverage carton with the same specifications as the *cb3 1000 Standard* apart from the source of polymers. It contains mass balance based LDPE and PP. Its closure is made from PP and HDPE.

Key objective of the study is the comparison of the SIGNATURE PACKS containing mass balance based polymers with the other packs that use "conventional" fossil polymers.

Mass balance based polymers are polymers that are produced by using both, fossil and biogenic resources as input materials for the same production process. In practice the input of biogenic materials (in this case tall-oil, a by-product of the paper production processes) to the polymerisation process is done at the same production process where mainly fossil based ethylene and naphta is used. This leads to only one final product per production process which is neither 100% fossil-based nor 100% bio-based material. To allocate the specific characteristics of fossil-based or bio-based input materials to the final product the producers declare a certain share of their production as linked to renewable resources. That share, of course is dependent on the share of biogenic input material.

It is important to understand that in reality (in a physical sense) the (C2H4)n and (C3H6)n molecules of the tall oil based polymers are in fact mainly non bio-based, as the share of bio-based ethylene is below 1% of the total production. But as the polymers in the SIGNATURE PACKS are the ones to which the tall-oil input is allocated to, they are modelled as if they would be 100% tall-oil based for the purpose of this study.

The LCA results for the packaging solutions *cb3 1000 SIGNATURE PACKS 100% and high-barrier* within this study are therefore not directly connected to the physical products examined, but to the production technology concept that lies behind them. In the authors' view the application of the mass balance approach in the production of polymers is an important driver to facilitate an increasing substitution of fossil resources by biogenic resources for the production of polymers. To model the examined products strictly on their physical properties would mean to not acknowledge this function of the mass balance approach.

Results and conclusions

The comparison between the *cb3 1000 SIGNATURE PACK high barrier* with the *cb3 1000 Standard* and the comparison of the *cb3 1000 SIGNATURE PACK 100%* with the *cb3 1000 EcoPlus* shows that the use of tall-oil based polymers in the sleeve and closures results into lower results for *'Climate change', 'Aquatic Eutrophication'* and *'Abiotic Depletion Potential'* as well as *'Summer Smog'* in the latter comparison. It leads to no significant differences for the remaining impact categories.

A comparison of the *cb3 1000 SIGNATURE PACK 100%* (without aluminium foil) with the *cb3* 1000 Standard containing aluminium foil shows lower environmental impacts of the *cb3 1000 SIGNATURE PACK 100%* in all examined impact categories.

These observations are true for both markets examined.

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 summarised in the previous sections the authors developed the following recommendations:

- As the environmental results of the beverage cartons are significantly influenced by the production of its main components for the sleeve and closure - LPB, Al, PE, PA6, and PP - measures to ensure the same functionality by the use of less material are recommended.
- The substitution of fossil polymers by mass balanced polymers based on tall oil leads to lower results in some environmental impact categories including *'Climate Change'* and no higher impacts in any of the other categories. The implementation of polymers based on tall oil via a mass balance system is therefore recommended.

- It is also recommended to actually achieve a more significant physical share of tall oil based input materials for the production of polymers. The utilisation and demand of mass balanced polymers by SIG Combibloc might be a driver to do so.

1 Goal and Scope

1.1 Background and Objectives

The newly developed SIGNATURE PACK is a beverage carton packaging produced by SIG Combibloc that contains polymers that originate from renewable European wood sources via a mass balance system. These replace conventional fossil based polymers, which are usually contained in most aseptic beverage cartons. SIG Combibloc commissioned ifeu to conduct a life cycle assessment study that:

- shall provide knowledge about the environmental strengths and weaknesses of the two SIGNATURE PACK variants *cb3 1000 SIGNATURE PACK 100%* and *cb3 1000 SIGNATURE PACK high-barrier* for the packaging of 1 litre of UHT milk at German and European market conditions and
- shall compare the environmental performance of these pack solutions with the beverage cartons *cb3 1000 Ecoplus* and *cb3 1000 Standard* within the geographic scopes of Germany and Europe.

The main comparisons are:

- *cb3 1000 SIGNATURE PACK 100%* versus *cb3 1000 Ecoplus*, as both of these do not contain aluminium foil and use the same closure solution. They are basically identical apart from the source of polymers used.
- *cb3 1000 SIGNATURE PACK high-barrier* versus *cb3 1000 Standard*, as both of these contain aluminium and use the same closure solution. They are basically identical apart from the source of polymers used.
- *cb3 1000 SIGNATURE PACK 100%* is also compared to *cb3 1000 Standard*, as this carton is the most usual beverage carton from SIG for the packaging of UHT milk on the European market, whereas the *cb3 1000 Ecoplus* can be considered as an already optimised packaging solution due to its substitution of aluminium foil by polyamide [IFEU 2014].

A note on the mass balance approach applied for the production of polymers in the *cb3* 1000 *SIGNATURE PACKS*:

Mass balance based polymers are polymers that are produced by using both, fossil and biogenic resources as input materials for the same production process. In practice the input of biogenic materials (in this case tall-oil, a by-product of the paper production processes) to the polymerisation process is done at the same production process where mainly fossil based ethylene and naphta is used. This leads to only one final product per production process which is neither 100% fossil-based nor 100% bio-based material. To allocate the specific characteristics of fossil-based or bio-based input materials to the final product the producers declare a certain share of their production as linked to renewable resources. That share, of course is dependent on the share of biogenic input material.

It is important to understand that in reality (in a physical sense) the (C2H4)n and (C3H6)n molecules of the tall oil based polymers are in fact mainly non bio-based, as the share of bio-based ethylene is below 1% of the total production. But as the polymers in the SIGNATURE PACKS are the ones to which the tall-oil input is allocated to, they are modelled as if they would be 100% tall-oil based for the purpose of this study. The allocation of inputs is certified by ISCC PLUS (International Sustainability & Carbon Certification) [ISSC 2018] and CMS 71 (TÜV SÜD certification standard) [TÜV SÜD 2017] respectively.

The LCA results for the packaging solutions *cb3 1000 SIGNATURE PACKS 100% and high-barrier* within this study are therefore not directly connected to the physical products examined, but to the production technology concept that lies behind them. In the authors' view the application of the mass balance approach in the production of polymers is an important driver to facilitate an increasing substitution of fossil resources by biogenic resources for the production of polymers. To model the examined products strictly on their physical properties would mean to not acknowledge this function of the mass balance approach.

The study is conducted according to the requirements of ISO applicable standards [ISO 14040] and [ISO 14044]. As the results of this study shall be used for internal and external communication, the study is also critically reviewed. The external review is conducted by Dominik Müller, Senior Sustainability Consultant at TÜV Rheinland. The review report can be found in Appendix A.

1.2 Organisation of the study

This study was commissioned by SIG Combibloc in 2017. It is being conducted by ifeu.

The members of the project panel are:

- Udo Felten (SIG Combibloc)
- Frank Wellenreuther (ifeu)
- Stefanie Markwardt (ifeu)

1.3 Functional unit

The function examined in this LCA study is the packaging of milk for retail. The functional unit for this study is the provision of 1000 L of ambient milk at the point of sale. (i.e. packed in 1000 beverage cartons)

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

The reference flow of the product system regarded here refers to the actually filled volume of the containers and includes all packaging elements, i.e. beverage carton and closures as well as the transport packaging (corrugated cardboard trays and shrink foil, pallets), which are necessary for the packaging, filling and delivery of 1000 L beverage.

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

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 beverage and transport to fillers as no relevant differences between the systems under examination are to be expected
- distribution of beverage from the filler to the point-of-sale (distribution of packages is included).
- environmental effects from accidents
- losses of beverage at different points in the supply and consumption chain which might occur for instance in the filling process, during handling and storage, etc. as they are considered to be roughly the same for all examined packaging systems. Significant differences in the amount of lost beverage between the regarded packaging systems might be conceivable only if non-intended uses or product treatments are considered as for example in regard to different breakability of packages or potentially different amount of residues left in an emptied package due to the design of the package/closure.
  Further possible losses are directly related to the handling of the consumer in the use phase, which

is not part of this study as handling behaviours are very different and difficult to assess. Therefore these possible beverage loss differences are not quantifiable as almost no data is available regarding these issues. In consequence a sensitivity analysis regarding beverage losses would be highly speculative and is not part of this study. This is indeed not only true for the availability of reliable data, but also uncertainties in inventory modelling methodology of regular and accidental processes and the allocation of potential beverage waste treatment aspects.

- transport of filled packages from the point of sale to the consumer as no relevant differences between the systems under examination are to be expected and the implementation would be highly speculative as no reliable data is available.
- use phase of packages at the consumers as no relevant differences between the systems under examination are to be expected (for example in regard to cleaning before disposal) and the implementation would be highly speculative as no reliable data is available.

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.

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 (significant impact on any impact category) of material input flows was determined based on ifeu's expert judgement based on previous studies. An example for excluded input materials based on a mass-related cut-off is the amount of printing ink used on the surface of beverage cartons.

1.5 Data gathering and data quality

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

Geographic scope

In terms of the geographic scope, the LCA study focuses on the production, distribution and disposal of beverage carton packages in Europe (EU27+2)[1] and Germany respectively. A certain share of the raw material production for packaging systems takes place in specific European countries. For these,

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[1] Geographic scope is EU27+2 as applied electricity mix refers to the year 2012. More recent data are currently not available. Therefore, a geographic scope of EU28 cannot be considered within this study.

country-specific data is used as well as European averages depending on the availability of datasets. Examples are the liquid packaging board production process (country-specific) and the production of plastics (available only as an European average).

Time scope

The reference time period for the comparison of packaging systems is 2018, as the packaging specifications listed in section 2 refer to 2018. Where no figures are available for these years, the used data shall be as up-to-date as possible. Particularly with regard to data on end-of-life processes of the examined packages, the most current information available is used to correctly represent the recent changes in this area. As some of these data are not yet publicly available, expert judgements are applied in some cases, for example based on confidential exchanges with representatives from the logistics sector and retailers regarding distribution distances.
Most of the applied data refer to the period between 2005 and 2018.

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.

1.6 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.

1.7 Allocation

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

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

Both approaches are further explained in the subsequent sections.

1.7.1 Process-related allocation

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

Multi-input processes

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

Multi-output processes

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

Transport processes

An allocation between the packaging and contents was carried out for the transportation of the filled packages to the point-of-sale. Only the share in environmental burdens related to transport, which is assigned to the package, has been accounted for in this study. That means the burdens related directly to the beverage is excluded. The allocation between package and filling good is based on mass criterion.

1.7.2 System-related allocation

The approach chosen for system-related allocation is illustrated in figure 1: both graphs show two example product systems, referred to as product system A and product system B. System A shall represent systems under study in this LCA. In figure 1 (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. 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 to 4

The following graphs (figures 1 to 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:
- primary material production
- recovery processes (e.g. material recycling, energy recovery as refuse-derived fuel (RDF))
- waste treatment of final residues (here represented by MSWI)

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

The allocation of final waste treatment is consistent with UBA LCA methodology [UBA 2000] and [UBA 2016a] 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 simplified graphs. These losses are of course taken into account in the calculations, their disposal is included within the respective systems.
- Hence not all material flows from system A are passed on to system B, as the simplified material flow graphs may imply. Consequently only the effectively recycled material's life cycle steps are allocated between systems A and B.
- The graphs do not show the individual process steps relevant for the waste material flow out of packaging system A, which is sorted as residual waste, including the respective final waste treatment.

- For simplification, a substitution factor of 1 underlies the graphs. However, in the real calculations smaller values are used where appropriate. For example if a material's properties after recycling are different from those of the primary material it replaces, this translates to a loss in material quality. A substitution factor < 1 accounts for such effects. For further details regarding substitution factors please see subsection 'Application of allocation rules'.

Figure 1 illustrates the general allocation approach used for uncoupled and coupled systems. The allocation methods used in this study are shown in figures 2 to 3. 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 2 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 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 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] and [UBA 2016a].

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

Allocation with the 100% method (figure 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 'downcycling' effects, which describe a recycling process in which waste materials are converted into new materials of lesser quality.

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. According to [ISO 14044] one sensitivity analysis has to be applied in order to check the uncertainty of results due to subjective choices.

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 [UBA 2000] and [UBA 2016a]. To verify how a different approach regarding system related allocation would influence LCA results, one sensitivity analysis is added to the study. For this a 100% allocation factor is applied.

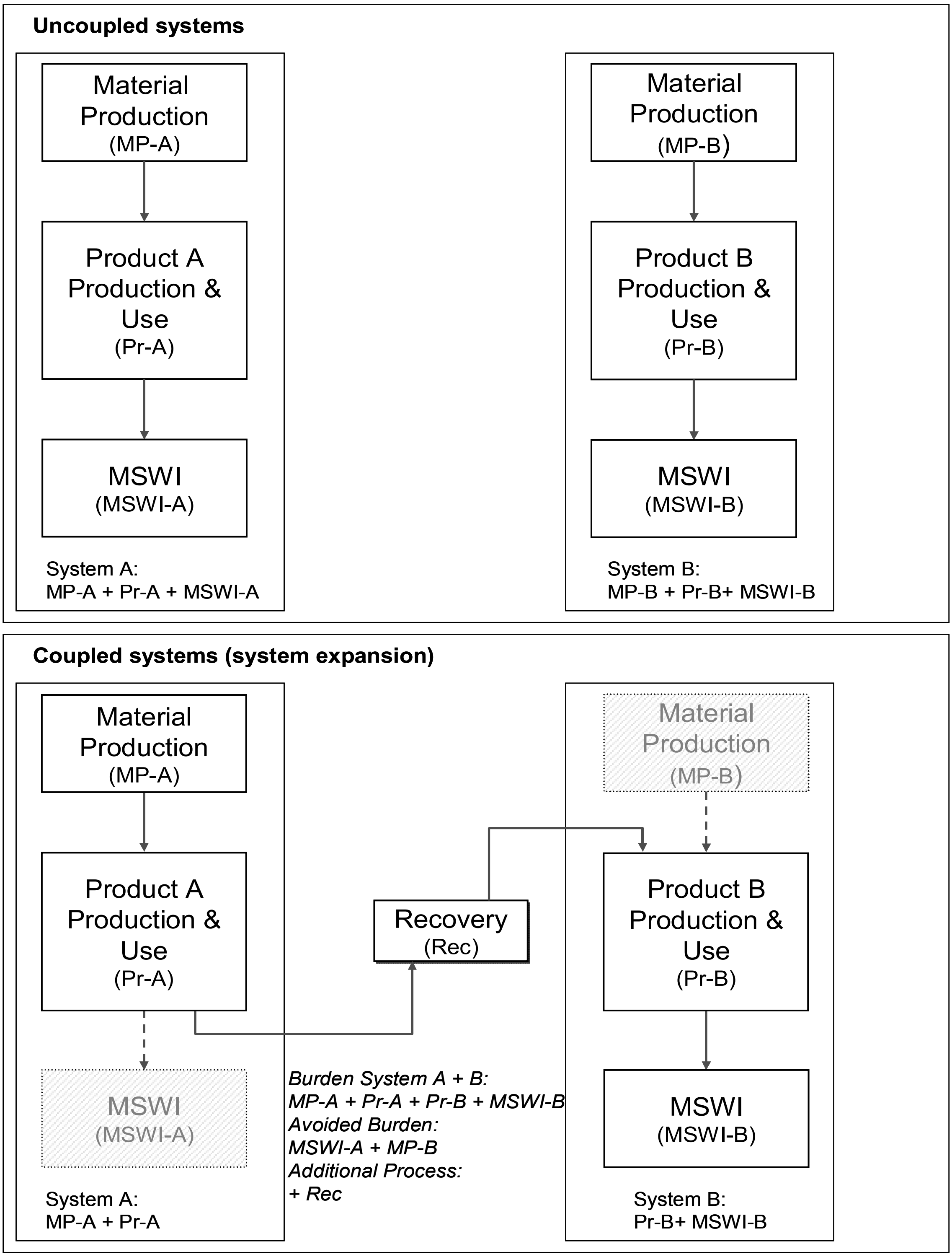

Figure 1: Additional system benefit/burden through recycling (schematic flow chart)

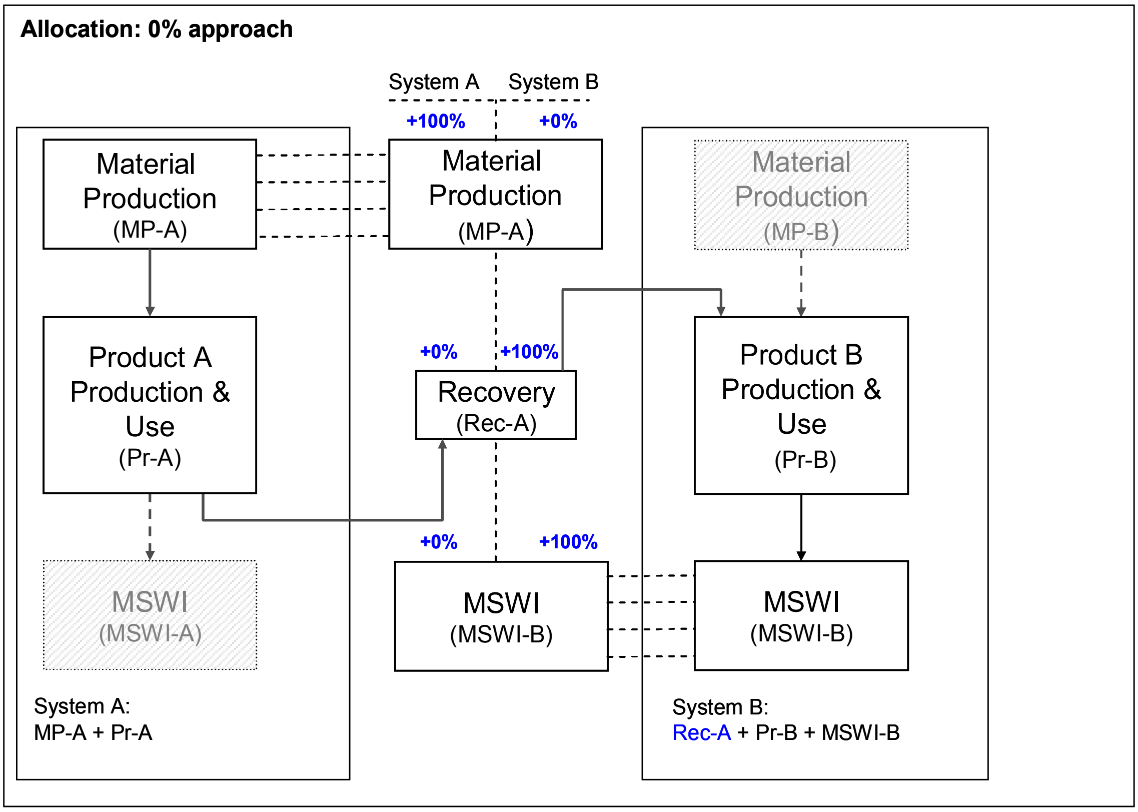

Figure 2: Principles of 0% allocation (schematic flow chart)

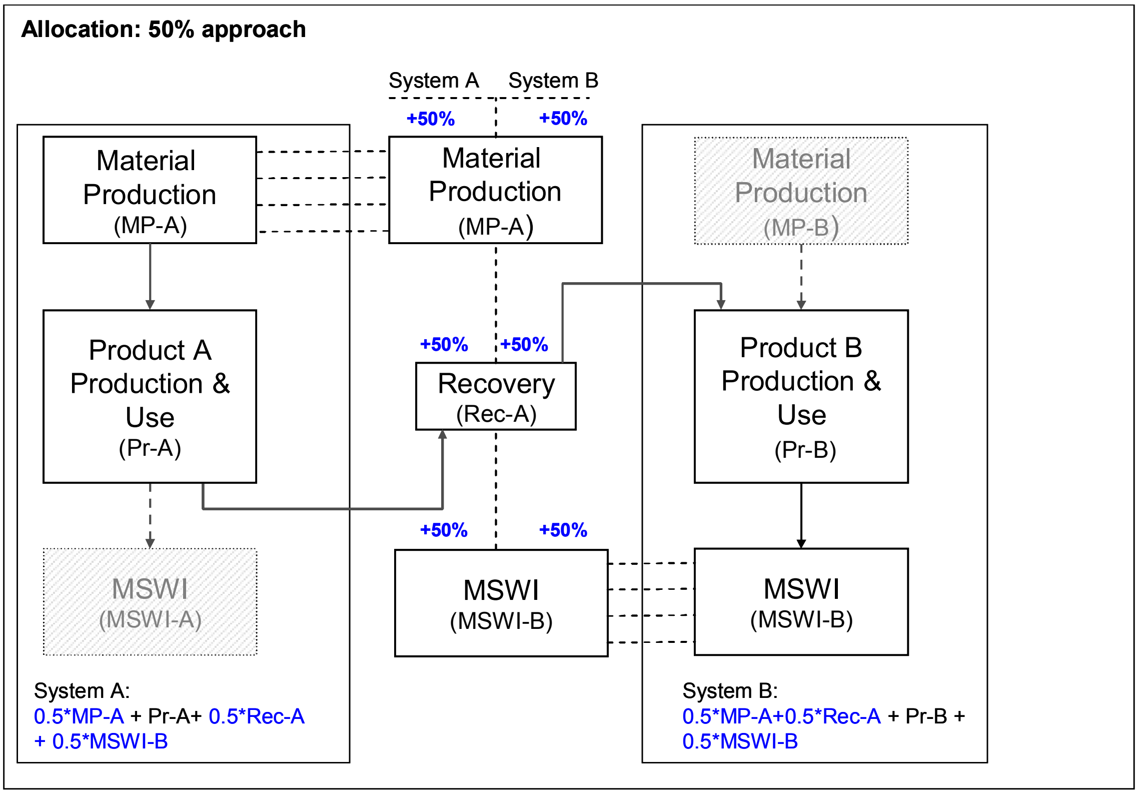

Figure 3: Principles of 50% allocation (schematic flow chart)

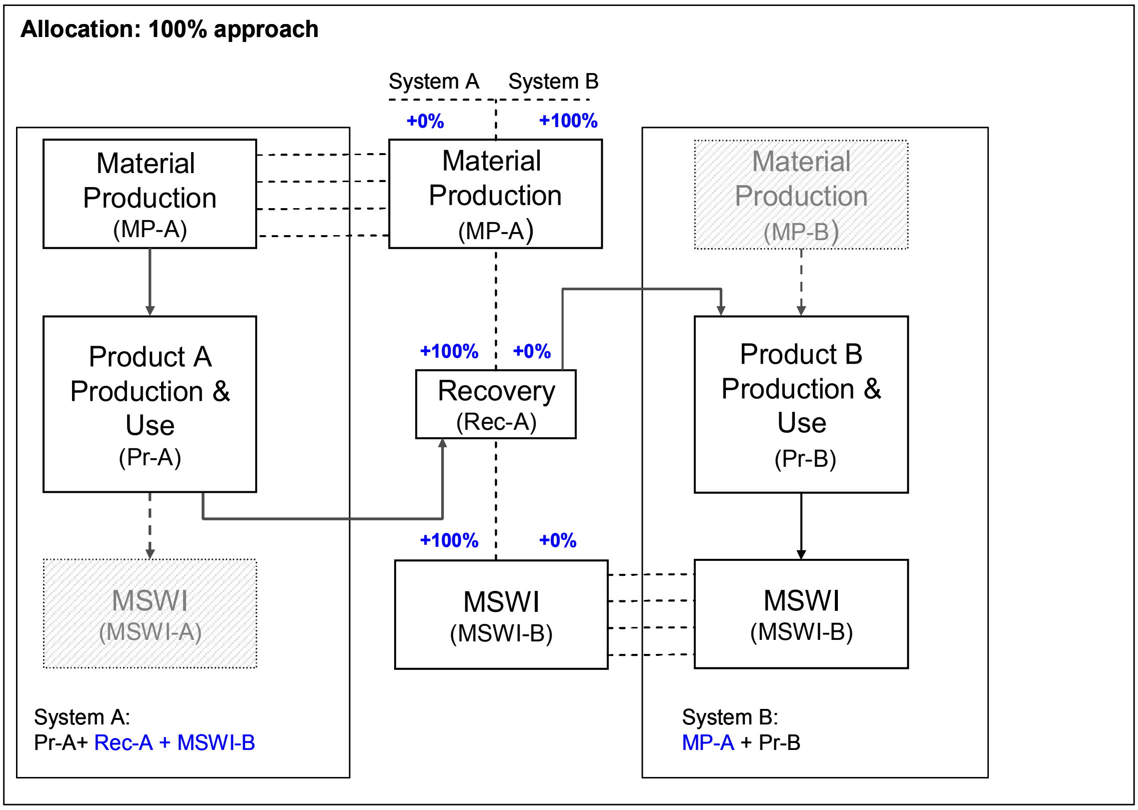

Figure 4: Principles of 100% allocation (schematic flow chart)

1.8 Environmental Impact Assessment

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

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

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

The description of the different inventory categories and their indicators is based on the terminology by [ISO 14044]. It has to be noted; that the impact categories, represent the environmental issues of concern, to which life cycle inventory analysis results per functional unit are assigned, but do not reflect actual environmental damages.

The selected impact categories and additional inventory categories to be assessed and presented in this study are listed and briefly addressed below.

Impact categories related to emissions

Climate change

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

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 former approach has been applied for the impact assessment, as due to the application of an allocation factor of 50% the carbon balance can't be closed for the examined system. The allocation affects the emissions and credits from incineration plants but not the uptake of CO_2 by plant growth. The carbon balance is closed in the sensitivity analyses with an allocation factor of 100%. Please see section 1.7.2 for an explanation of the different allocation approaches.

Stratospheric Ozone Depletion

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

Photo-Oxidant Formation / Summer Smog

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

In this study, 'Maximum Incremental Reactivity' (MIR) developed in the US by William P. L. Carter is applied as category indicator for the impact category photo-oxidant formation. MIRs expressed as [kg O3-e / emission i] are used in several reactivity-based VOC (Volatile Organic Compounds) regulations by the California Air Resources Board (CARB 1993, 2000). The recent approach of William P. L. Carter includes characterisation factors for individual VOC, unspecified VOC and NOx. The 'Nitrogen-Maximum Incremental Reactivity' (NMIR) for NOx is introduced for the first time in 2008 (Carter 2008). The MIRs and NMIRs are calculated based on scenarios where ozone formation has maximum sensitivities either to VOC or NOx inputs. The recent factors applied in this study were published by [Carter 2010]. According to [Carter 2008], "MIR values may also be appropriate to quantify relative ozone impacts of VOCs for life cycle assessment analyses as well, particularly if the objective is to assess the maximum adverse impacts of the emissions of the compounds involved." The results reflect the potential where VOC or NOx reductions are the most effective for reducing ozone.

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

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

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

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

Acidification

Acidification affects aquatic and terrestrial ecosystems by changing the acid-basic-equilibrium through the input of acidifying substances. The acidification potential expressed as SO2-equivalents according to [Heijungs et al. 1992] is applied here as category indicator.

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

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

The unit for the Acidification potential is kg SO_2-e/fu.

Eutrophication and oxygen-depletion

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

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

Compounds containing nitrogen and phosphorus are among the most eutrophicating elements. The eutrophication of surface waters also causes oxygen-depletion. A measure of the possible perturbation of the oxygen levels is given by the Chemical Oxygen Demand (COD). In order to quantify the magnitude of this undesired supply of nutrients and oxygen depletion substances, the eutrophication potential by [Heijungs et al. 1992, CML 2002] category was chosen as impact indicator. The unit for both types of Eutrophication is kg PO_4-e/fu.

Human toxicity: PM2.5 / Particulate Matter

The category covers effects of fine particulates with an aerodynamic diameter of less than 2.5 µm (PM 2.5) emitted directly (primary particles) or formed from precursors as NOx and SO2 (secondary particles). Epidemiological studies have shown a correlation between the exposure to particulate matter and the mortality from respiratory diseases as well as a weakening of the immune system. Following an approach of [De Leeuw 2002], the category indicator aerosol formation potential (AFP) is applied. Within the characterisation model, secondary fine particulates are quantified and aggregated with primary fine particulates as PM2.5 equivalents[2]. This approach addresses the potential impacts on human health and nature independent of the population density.

The characterisation models suggested by [ReCiPe 2008] and [JRC 2011] calculate intake fractions based on population densities. This means that emissions transported to rural areas are weighted lower than transported to urban areas. These approaches contradict the idea that all humans independent of their residence should be protected against potential impacts. Therefore, not the intake

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[2] In previous LCA studies commissioned by SIG and conducted by ifeu the contribution to the fine particulate matter potential was calculated by summing the products of the amounts of the individual harmful substances and the respective PM10 equivalent. According to UBA (2016) the characterisation factors of De Leeuw (2002) shall now be related to PM 2.5 equivalent. This recommendation is based on the respective guidelines of WHO (2005): It states that the fraction 2.5 is mainly responsible for toxic effects.

potential, but the formation potential is applied for the impact category particulate matter. In reference to the functional unit, the unit for Particulate Matter is kg PM 2.5-e/fu.

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

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

Figure 5: Model uncertainty estimates for USEtox characterisation factors (reference: [Rosenbaum et al. 2008])

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

Table 1.1: Examples of elementary flows and their classification to emission related impact categories

Impact categories	**Elementary flow examples**								**Unit**
Climate Change	CO_2*	CH_4**	N2O	$C_2F_2H_4$	CF_4	CCl_4	C_2F_6	HCFC-22	kg CO_2-e
Stratospheric Ozone Depletion	CFC-11	N_2O	HBFC-123	HCFC-22	Halon-1211	Methyl Bromide	Methyl Chloride	CCl_4	kg CFC-11-e
Photo-Oxidant Formation	CH4	NMVOC	Benzene	Formaldehyde	Ethyl acetate	VOC	TOC	Ethanol	kg O_3-e
Acidification	NO_x	NH_3	SO_2	TRS***	HCl	H_2S	HF		kg SO_2-e
Terrestrial Eutrophication	NO_x	NH_3	SO_x						kg PO_4-e
Aquatic Eutrophication	COD	N	NH^{4+}	NO^{3-}	NO^{2-}	P			kg PO_4-e
Particulate matter	PM2.5	SO_2	NO_X	NH_3	NMVOC				kg PM2.5-e
*** CO_2 fossil and biogenic / ** CH_4 fossil and CH_4 biogenic included / *** Total Reduced Sulphur**									

Impact categories related to the use/consumption of resources

Abiotic resource depletion (ADP)

Abiotic resource depletion (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 Sb-e/fu.

The latest developed method by CML [CML 2013] to separate ADP into two single impact categories, one for fossil resource depletion is not applied as the authors think that this leads to two separate impact indicators to assess an environmental impact with the same area of protection which should be avoided. Therefore the previous CML method without separating ADP in two categories is applied.

Table 1.2: Examples of elementary flows and their classification to resource related impact category

Impact categories	Elementary flow examples							Unit
ADP	Crude oil	Natural gas	Hard coal	Soft coal	Al	Ab	Fe	kg Sb-e

<u>A note on use of nature:</u>

Regarding the assessment of ‘use of nature’ (often referred to as land use) several methodological approaches have emerged in recent years. In the authors’ view none of these achieve to deliver robust assessment results on the basis of the limited land use data available. Therefore no assessment of the use of nature is included in this study. A presentation at the inventory level is not considered helpful, as non-characterised area of land does not give any indication on actual environmental impact.

Additional categories at the inventory level

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

Primary Energy (Cumulative Energy Demand)

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

Total Primary Energy (Cumulative Energy Demand, total)

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

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

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

Table 1.3: Examples of elementary flows and their classification to inventory level categories

Categories at inventory level	Elementary flow examples							Unit
Total Primary Energy	hard coal crude oil	brown coal natural gas	uranium ore	hydro energy	solar energy	wind energy	biomass	MJ
Non-renewable Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore			MJ

2 Packaging systems and scenarios

The Packaging systems examined in this study are:

e. *cb3 1000 EcoPlus* with combiCap opening
   - a beverage carton with LDPE and PA as additional barrier materials, it does not contain aluminium foil. Its closure is made from PP.

f. *cb3 1000 SIGNATURE PACK 100%* with combiCap opening containing mass balance polymers
   - a beverage carton with the same specifications as the *cb3 1000 EcoPlus* apart from the source of polymers. It contains mass balance based LDPE, PA and PP. Its closure is made from PP.

g. *cb3 1000 Standard* with combiSwift opening
   - a beverage carton with LDPE and aluminium as additional barrier materials. Its closure is made from PP and HDPE.

h. *cb3 1000 SIGNATURE PACK high barrier* with combiSwift opening containing mass balance polymers
   - a beverage carton with the same specifications as the *cb3 1000 Standard* apart from the source of polymers. It contains mass balance based LDPE and PP. Its closure is made from PP and HDPE.

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

All packaging systems examined in this study are presented in the following sections (2.1), including the applied end-of-life settings (2.2). Section 2.3 gives an overview of all regarded scenarios.

2.1 Packaging specifications

Table 2.1: Packaging specifications

Packaging components	cb3 1000 EcoPlus w/ cCap	cb3 1000 SIGNATURE PACK 100% w/ cCap	cb3 1000 Standard w/ cSwift	cb3 1000 SIGNATURE PACK high barrier w/ cSwift
volume	1000 mL	1000 mL	1000 mL	1000 mL
primary packaging (sum per carton)	**29.7g**	**29.7 g**	**30.3 g**	**30.3 g**
composite material (sleeve)	**27.7 g**	**27.7 g**	**27.6 g**	**27.6 g**
- liquid packaging board	*22.9 g*	*22.9 g*	*20.3 g*	*20.3 g*
- LDPE	*4.24 g*		*5.93 g*	
- ISCC Plus mass balanced green LDPE		*4.24 g*		*5.93 g*
- aluminium			*1.36 g*	*1.36 g*
- PA	*0.51 g*			
- CMS71 mass balanced green PA		*0.51 g*		
closure	**2.01 g**	**2.01 g**	**2.71 g**	**2.71 g**
- PP spout			*1.41 g*	
- ISCC Plus mass balanced green PP				*1.41 g*
- HDPE cap			*1.30 g*	
- ISCC Plus mass balanced green HDPE				*1.30 g*
- PP cap	*2.01 g*			
- ISCC Plus mass balanced green PP		*2.01 g*		
Secondary packaging (tray)	**134g**	**134g**	**134 g**	**134 g**
Tertiary packaging (sum)	**20,627 g**	**20,627 g**	**20,627 g**	**20,627 g**
pallet	20,000 g	20,000 g	20,000 g	20,000 g
type of pallet (trip rate 25)	EURO	EURO	EURO	EURO
Stretch foil per pallet (LDPE)	627 g	627 g	627 g	627 g
Pallet configuration				
Cartons per tray	12	12	12	12
Trays per pallet	12	12	12	12
Layers per pallet	5	5	5	5
Cartons per pallet	720	720	720	720

Table 2.1 shows the packaging specifications of the examined packaging. It shows that the specifications of *cb3 1000 EcoPlus w/ cCap* and *cb3 1000 SIGNATURE PACK 100% w/ cCap*, and those of *cb3 1000 Standard w/ cSwift* and *cb3 1000 SIGNATURE PACK high barrier w/ cSwift* repectively are very similar.

Liquid packaging board, aluminium, the masses of all components, secondary packaging and pallet configuration are the same for the compared packs. Also the mass of the used polymers does not show any difference between the compared packs. The only difference lies in the kind of polymer that is used. While *cb3 1000 EcoPlus w/ cCap* and *cb3 1000 Standard w/ cSwift* contain only “conventional” fossil-based polymers the two SIGNATURE PACKS utilise polymers that are linked to renewable resources via the mass balance approach.

These polymers are produced by using both, fossil and biogenic resources as input materials for the same production process. In practice the input of biogenic materials (in this case tall-oil , a by-product of paper production processes) to the polymerisation process is done at the same production process where mainly fossil based ethylene and naphta is used. This leads to only one final product per production process which is neither 100% fossil-based nor 100% bio-based material. To allocate the specific characteristics of fossil-based or bio-based input materials to the final product the producers declare a certain share of their pro-duction as linked to renewable resources. That share, of course is dependent on the share of bio-genic input material.

It is important to understand that in reality (in a physical sense) the (C2H4)n and (C3H6)n molecules of the tall oil based polymers are in fact mainly non bio-based, as the share of bio-based ethylene is below 1% of the total production. But as the polymers in the SIGNATURE PACKS are the ones to which the tall-oil input is allocated to, they are modelled as if they would be 100% tall-oil based for the purpose of this study. The allocation of inputs is certified by ISCC PLUS (International Sustainability & Carbon Certification) [ISSC 2018] and CMS 71 (TÜV SÜD certification standard) [TÜV SÜD 2017] respectively.

2.2 End-of-life

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

Europe:

The applied collection quota of 48.5 % is based on the recovery quota of 44% published by ACE (2015). According to [Eurostat 2016] the remaining share is incinerated in MSWI plants (40%) or landfilled (60%).

Germany:

The applied collection quota of 84.5 % is based on the recovery quota of 76.8% published by UBA (2016). In Germany the remaining share is incinerated in MSWI plants to [Eurostat 2016].

2.3 Scenario modelling

2.3.1 Base scenarios

For each of the studied packaging systems a base scenario for the German and European market is defined, which is intended to reflect the most realistic situation under the described scope.

In the base scenarios the allocation factor applied for open-loop-recycling is 50%.

2.3.2 Sensitivity analysis with focus on the allocation factor

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

2.3.3 Sensitivity analyses with focus on recycling rates

In the base scenarios for Europe the average recycling rate of 44% for Europe (EU27 & Switzerland and Norway) is applied. However, throughout Europe the recycling rates vary. Although the specific end-of-life situations are not within the scope of this study (apart from Germany) the following sensitivity analyses shall provide indications about the environmental performance of the different packaging systems, if the recycling rate varies within a certain value range.

The sensitivity analyses include the calculation of scenarios with a

- recycling rate 0%
- recycling rate 44% (as applied in base scenario)
- recycling rate 80%

The range is chosen, as the highest recycling rate determined in Europe is about 77% representing the recycling rate of beverage cartons in Germany.

Furthermore an allocation factor of 50% is applied. The results are interpolated in linear graphs.

3 Life cycle inventory

Data on processes for packaging material production and converting were either collected in cooperation with the industry or taken from literature and the ifeu database. Concerning background processes (energy generation, transportation as well as waste treatment and recycling), the most recent version of ifeu's internal, continuously updated database was used. Table 2.1 gives an overview of important datasets applied in the current study.

Table 2.1: Overview on inventory/process datasets used in the current study

Material / Process step	Source	Reference period	Geographic scope
Plastics			
PP	Plastics Europe, published online April 2014	2011	Europe
HDPE	Plastics Europe, published April 2014	2011	Europe
LDPE	Plastics Europe, published April 2014	2011	Europe
PA 6	From producer, confidential	2015	Europe
Bio-PE (mass balance)	Based on information provided by SIG Combibloc, literature and ifeu database	2016	Finland/Europe
Bio-PP (mass balance)	Based on information provided by SIG Combibloc, literature and ifeu database	2016	Finland/Europe
Bio-PA 6 (mass balance)	Based on information provided by SIG Combibloc & literature data and ifeu database	2016	Finland/Europe
Board			
Corrugated cardboard	[FEFCO 2012]	2012	Europe
Liquid packaging board	ifeu data, obtained from ACE [ACE 2012]	2009	Finland/Sweden
Converting			
BC converting	SIG Combibloc	2009	Europe
Injection moulding of caps	SIG Combibloc	2009	Europe
Filling			
Filling of beverage cartons	Data provided by SIG Combibloc	2014	Europe
Recovery			
Beverage carton recycling	ifeu database, based on data from various European recycling plants	2008	Europe
Background data			
electricity production, Finland & Sweden, Ger-	ifeu database, based on statistics and power plant models	2012	Sp.

Material / Process step	Source	Reference period	Geographic scope
many, Europe			
municipal waste incineration	ifeu database, based on statistics and incineration plant models	2008	Europe
Cement kiln	ifeu database, based on data provided by German cement industry association (VDZ)	2006	Europe
lorry transport	ifeu database, based on statistics and transport models, emission factors based on HBEFA 3.1 [INFRAS 2010].	2009	Europe
rail transport	[EcoTransIT 2010]	2010	Europe
sea ship transport	[EcoTransIT 2010]	2010	Europe

3.1 Manufacture of plastic raw materials

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

3.1.1 Polypropylene (PP)

Polypropylene (PP) is produced by catalytic polymerisation of propylene into long-chained polypropylene. The two important processing methods are low pressure precipitation polymerisation and gas phase polymerisation. In a subsequent processing stage the polymer powder is converted to granulate using an extruder.
The present LCA study utilises data published by Plastics Europe [PlasticsEurope 2014a]. The dataset covers the production of PP from cradle to the polymer factory gate. The polymerisation data refer to the 2011 time period and were acquired from a total of 35 polymerisation plants producing. The total PP production in Europe (EU27+2) in 2011/2012 was 8,500,000 tonnes. The Plastics Europe data set hence represented 77% of PP production in Europe.

3.1.2 Low Density Polyethylene (LDPE)

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

3.1.3 High Density Polyethylene (HDPE)

High density polyethylene (HDPE) is produced by a variety of low pressure methods and has fewer side-chains than LDPE. The present LCA study uses the ecoprofile published on the website of Plastics Europe [Plastics Europe 2014b].

The dataset covers the production of HDPE-granulate from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the 2011 time period and were acquired from a total of 21 participating polymerisation units. The data set represented 68% of HDPE production in Europe (EU27+2).

3.1.4 PA 6

Polyamide 6 is manufactured from the precursors benzene and hydroxylamine. The present LCA study uses an ecoprofile provided by a specific supplier within Europe. The applied datset covers the production of Polyamide granulates right from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the year 2015 and is specific for the supplier of SIG Combibloc. Due to confidentiality reason the data cannot disclosed within this study.

3.1.5 Mass balanced PE and mass balanced PP dataset based on tall oil pitch

The production processes of LDPE and PP are based on tall oil. These plastics are produced by cracking and polymerization of renewable diesel. The renewable diesel is based on tall oil pitch. It is a distillation product of crude tall oil, gained through acidulation of black liquor soap which is a by- product of paper pulp production.

The production of tall oil pitch is modelled as described in Cashman (2015) covering the production steps kraft pulping, acidulation and distillation and their related transportation. Allocation was necessary in the main processes of pulping and distillation. This is done on mass basis. Because crude tall oil produced from black liquor soap is a useful output a share of the pulping burdens is assigned to the tall oil.

For kraft pulping a kraftliner pulp process based on FEFCO (2012) is used. The share of Black Liquor Soap (BLS) in kraft pulp production is 4% (Cashman et al. 2015). By applying mass allocation 4% of pulp production’s burdens are taken for BLS.

The acidulation step to produce crude tall oil from black liquor soap is modelled with the in- and outputs of Table 2 in Cashman et al. (2015).

Tall oil pitch is only one output of the tall oil distillation process. 27% of the total output mass of all distillation products is tall oil pitch. The distillation process is modelled with the in-and outputs of Table 1b in Cashman et al. (2015). As these in- and outputs apply for the sum of all distillation products they are multiplied in this study with the mass allocation factor of 0.27 in order to account only the burdens of the tall oil pitch production

Renewable diesel is then produced from tall oil pitch by hydrotreatment. The dataset of this process is based on the studies ifeu (2006) and Nikander (2008). Both studies provide process data of the so-called NExBTL process of Neste Oil. If two different values existed, the average of both was used. The co-products fuel gas and bio-gasoline are produced as well. Bio-gasoline is internally used as thermal energy.

Allocation was done by mass and calorific value of renewable diesel and fuel gas. Renewable diesel accounts for 93.5% of the processes in- and outputs. According to several press releases[3] of Neste Oil renewable diesel based on tall oil pitch is produced in its plant in Finland. The location of the plant was therefore set accordingly.

The cracking and polymerization processes for LDPE and PP are taken from the ifeu database. They are based on data representing the average from several polymerisation units in Europe.

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[3] https://www.neste.com/en/neste-oil-uses-tall-oil-pitch-produce-traffic-fuel

3.1.6 Mass balanced PA 6

The applied dataset of mass balanced Nylon 6 (PA6) refers to the production of PA6 based on tall oil. At this time, there is no official LCA dataset available for this tall oil based PA6. Tall oil based PA6 is produced similar to fossil PA6. The difference is the input of distilled tall oil instead of naphta.

In this study tall oil based PA6 was preliminarily modelled as described in the following:

The dataset of fossil PA6 was extended with the processes to produce tall oil pitch. The dataset for the production of tall oil pitch is modelled as described in Cashman (2015) covering the production steps kraft pulping, acidulation and distillation and their related transportation (see also section 3.1.5).

The replaced amount of naphtha was taken into account by subtracting its impacts during the life cycle impact assessment (LCIA). The dataset used for calculating the impacts of naphtha is taken from the ecoinvent database 2.2.

The amount of naphtha needed for 1kg of PA6 was calculated based on the used oil feedstock in MJ for the production of 1kg of PA6 and the used oil feedstock in MJ for the production of 1kg of naphtha [PlasticsEurope 2014] as shown in equation 1.

$$\frac{22.01\,\frac{MJ\ oil\ feedstock}{kg\ PA6}}{45\,\frac{MJ\ oil\ feedstock}{kg\ naphtha}} = 0.489\ \frac{kg\ naphtha}{kg\ PA6} \tag{1}$$

The corresponding amount of tall oil pitch was calculated by equating the input of naphtha with the replacing tall oil pitch based on their energy values (equations 2 to 4). For this purpose the following lower heating values were used:

Table 3.2: lower heating values of naphtha and tall oil pitch

	lower heating value	Reference
Naphtha	41.8 kg/MJ	[IPCC 2006]
Tall oil pitch	38 kg/MJ	[U.C.Y. Energy n.d.]

$$0.489\ \frac{kg\ naphtha}{kg\ PA6} * 41\ \frac{MJ\ naphtha}{kg\ naphtha} = 20.45\ \frac{MJ\ naphtha}{kg\ PA6} \tag{2}$$

$$20.45\ \frac{MJ\ naphtha}{kg\ PA6} = 20.45\ \frac{MJ\ tall\ oil\ pitch}{kg\ PA6} \tag{3}$$

$$\frac{20.45\,\frac{MJ\ tall\ oil\ pitch}{kg\ PA6}}{38\,\frac{MJ\ tall\ oil\ pitch}{kg\ tall\ oil\ pitch}} = 0.538\ \frac{kg\ tall\ oil\ pitch}{kg\ PA6} \tag{4}$$

This approach of modeling the production of tall oil based PA6 is still preliminary. Limitations exist especially by using ecoinvent data for calculating the subtracted impacts of naphtha. There is no certainty and information which data is used for the naphtha input in the fossil PA6 dataset. When official data for tall oil based PA6 is available, this preliminary approach should be cross-checked and adapted if necessary.

3.2 Production of liquid packaging board (LPB)

The production of liquid packaging board (LPB) 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. The forest model is based on [Giegrich et al. 1996].

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

3.3 Corrugated board and manufacture of cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2012 [FEFCO 2012] were used. More specifically, the data sets for the manufacture of ‘Kraftliners’ (predominantly based on primary fibres), ‘Testliners’ and ‘Wellenstoff’ (both based on waste paper) as well as for corrugated cardboard packaging were used. The data sets represent weighted average values from European locations recorded in the FEFCO data (see also Table 3.3). The representativeness for Corrugated Cardboard and trays is relatively low. This data set is still considered the best one available. The data refer to the year 2012.

Table 3.3 FEFCO datasets used for corrugated cardboard

Cardboard material	Publication date	Reference year	Representativeness
Kraftliner	2012	2012	>80%
Testliner	2012	2012	66%
Wellenstoff	2012	2012	66%
Corrugated cardboard and trays	2012	2012	38% (221 plants)

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

3.4 Converting

The manufacture of composite board was modelled using data provided by the commissioner of the current study, SIG Combibloc, and refers to the year 2009. Process data has been collected from the converting site in Linnich, Germany. Due to very similar technology at other (and smaller) converting sites the collected data is considered as representative for all European converting sites by SIG.The converting process covers the lamination of LPB, LDPE and aluminium or PA respectively, printing, cutting and packing of the composite material. The examined combibloc beverage cartons are produced at European production sites of SIG Combibloc and printed with a rotogravure process. The packaging materials used for shipping of beverage 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.

3.5 Closure production

The closures made of fossil and mass balanced PP and HDPE are produced by injection moulding. The data for the production were provided by SIG Combibloc and are based on values measured in SIG's plant in Switzerland. The process data were coupled with required prechains such as the production of PE and grid electricity.

3.6 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. Energy prechain data refer to 2011. As the production of pallets has only extremely limited impact on overall results (due to their reuse, see table 2.1) the data is considered to be usable besides its early reference year.

3.7 Filling

Filling processes for all examined beverage cartons are very similar in regard to material and energy flows. The respective data for this study was provided by SIG Combibloc, distinguishing between the consumption of electric and thermal energy as well as of water and air demand. A cross-check has been conducted with filling data from ifeu's internal database, which relies on information from different fillers and filling machine manufacturers.

3.8 Transport settings

The following Table 3.4 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 3.4 Transport distances and means: Transport defined by distance and mode [km/mode]

Packaging element	Material producer to converter	Converter to filler
HDPE, LDPE, PP granulate for all packages	500 / road	
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)	
Trays		500 / road
Pallets		100 / road
Converted carton sleeves		700 / road

3.9 Distribution of filled packs from filler to point of sale

Large dairies (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. Therefore, according to expert judgements by retailers and fillers, a transport distance of 300 km for Germany and 400 km for Europe has been selected in context of the present study for all types of packages examined.

The 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). In the life cycle model, environmental loads related to distribution have been allocated between beverage 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 3.5 Applied distribution distances in km for the examined packaging systems

	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	225 km DE 300 km EU	75 km DE 100 km EU	50 %	50 %	0 %	0 %
Distribution – Step 2	75 km DE 100 km EU	60 km DE 60 km EU	34 %	0 %	33 %	33 %
Total distance	300 km DE 400 km EU	135 km DE 160 km EU				

3.10 Recovery and recycling

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

Substitution factors

Substitution factors were used to model material recycling (where appropriate in combination with the allocation factors). These substitution factors express the mass relation between a secondary (recycled) material and the primary material it replaces in a (new) product. For example, a substitution factor of 0.8 (or 80%) means that 1 kg recycled (secondary) material replaces 0.8 kg primary material, thus receiving a corresponding credit. A substitution factor < 1 also reflects so-called 'down-cycling' effects which describes a recycling process in which waste materials are converted into new materials of lesser quality.

The substitution factors used in the current LCA study to calculate the credits for recycled materials provided for consecutive (down-stream) uses are based on expert judgments from German waste sorting operator "Der Grüne Punkt – Duales System Deutschland GmbH" from the year 2002 [DSD 2000]

- LDPE from foils: 0.94
- Paper fibres
  - from LPB (carton-based primary packaging): 0.9
  - in cardboard trays (secondary packaging): 0.9

  It could be argued that the substitution factor for paper fibres from cardboard trays may be lower than that for LPB, because in trays mainly secondary fibres are used. As there is no robust data on different substitution factors available, and all the examined packaging systems show the use of the same cardboard tray, no specific factor is used for this study, though.

3.11 Background data

3.11.1 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. An update of the transport model is currently done at ifeu, but will not make it into this report in time. As transport processes play only a minor role for overall results, in the view of the authors it is justified to use the data described above.

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

Ship transport

The data used for the present study represent freight transport with an overseas container ship (10,5 t/TEU[4]) and a utilisation of capacity by 55%. Energy use is based on an average fleet composition of this ship category with data taken from [EcoTransIT World 2011]. The Ecological Transport Information Tool (EcoTransIT) calculates environmental impacts of any freight transport. Emission factors and fuel consumption have been applied for direct emissions (tank-to-wheel) based on [EcoTransIT World 2011]. For the consideration of well-to-tank emissions data were taken from ifeu's internal database.

Rail transport

The data used for rail transport for the present study also is based on data from [EcoTransIT World 2011]. Emission factors and fuel consumption have been applied for direct emissions based on [EcoTransIT World 2011].

3.11.2 Electricity generation

Modelling of electricity generation is particularly relevant for the production of base materials as well as for converting and filling processes. Electric power supply is modelled using country specific grid electricity mixes, since the environmental burdens of power production varies strongly depending on the electricity generation technology. The country-specific electricity mixes are obtained from a master network for grid power modelling maintained and annually updated at ifeu as described in [IFEU 2013]. It is based on national electricity mix data by [EUROSTAT 2013]. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2012 for the production of paperboard and the European mix of energy suppliers in the year 2012 for all other processes depending on their location.

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[4] Twenty-foot Equivalent Unit

3.11.3 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. Those numbers are derived from Eurostat data on amounts of waste incinerated and electricity and thermal energy sold by MSWI plants. The numbers are also 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 German or European grid electricity (EU27 grid) respectively. 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.

3.11.4 Landfill

The landfill model accounts for the emissions and the consumption of resources for the deposition of domestic wastes on a sanitary landfill site. As information regarding an average landfill standard in 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 beverage 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 20% of methane generated is actually recovered via landfill gas capture systems. This recovery rate is according to [ETC/RWM 2008] considered a maximum technically achievable recovery rate. Also the IPCC Guideline estimates a default value of 20% methane recovery [IPCC 2006].
- regarding the degradation of the beverage carton board under landfill conditions, it is assumed that it behaves like coated paper-based material in general. According to [Micales and Skog 1996], 30% of paper is decomposed anaerobically on landfills
- it is assumed that the degraded carbon is converted into landfill gas with 50% methane content (by volume).

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

3.11.5 Cement kiln

On the German market all rejects from beverage cartons are modelled to undergo a thermal treatment including energy recovery in cement kilns. In reality a certain small share is already undergoing a material recycling where the PE and aluminium are separated from each other. As no process data for this recycling process is available, a conservative approach (100% to cement kilns) has been chosen. The related process data refer to the year 2006 and are taken from ifeu's database based on information provided by the German cement industry association (VDZ). The applied process data cover emissions from the treatment in the clinker burning process Parameters are restricted to those which change compared to the use of primary fuels. The output cement clinker is a function of the energy potential of the fuel and considers the demand of base material.

All data used meet the general requirements and characteristics regarding data gathering and data quality as summarised in section 1.4.

4 Results

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

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

- production and transport of liquid packaging board (‘**LPB**’)
- production and transport of plastics and additives for beverage carton (‘**plastics for sleeve’**)
- converting processes of cartons **(‘converting’**)
- production and transport of base materials for closure (**‘closure’**)
- production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays (**‘transport packaging’**)
- filling process including packaging handling **(‘filling’**)
- retail of the packages from filler to the point-of-sale including cooling during transport if relevant **(‘distribution’**)
- sorting, recycling and disposal processes **(‘recycling & disposal’**)
- regenerative CO_2 emissions from incineration of biobased materials (‘**CO_2 reg. (EOL)**’

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

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

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

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

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

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

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

4.1 Results base scenario GERMANY

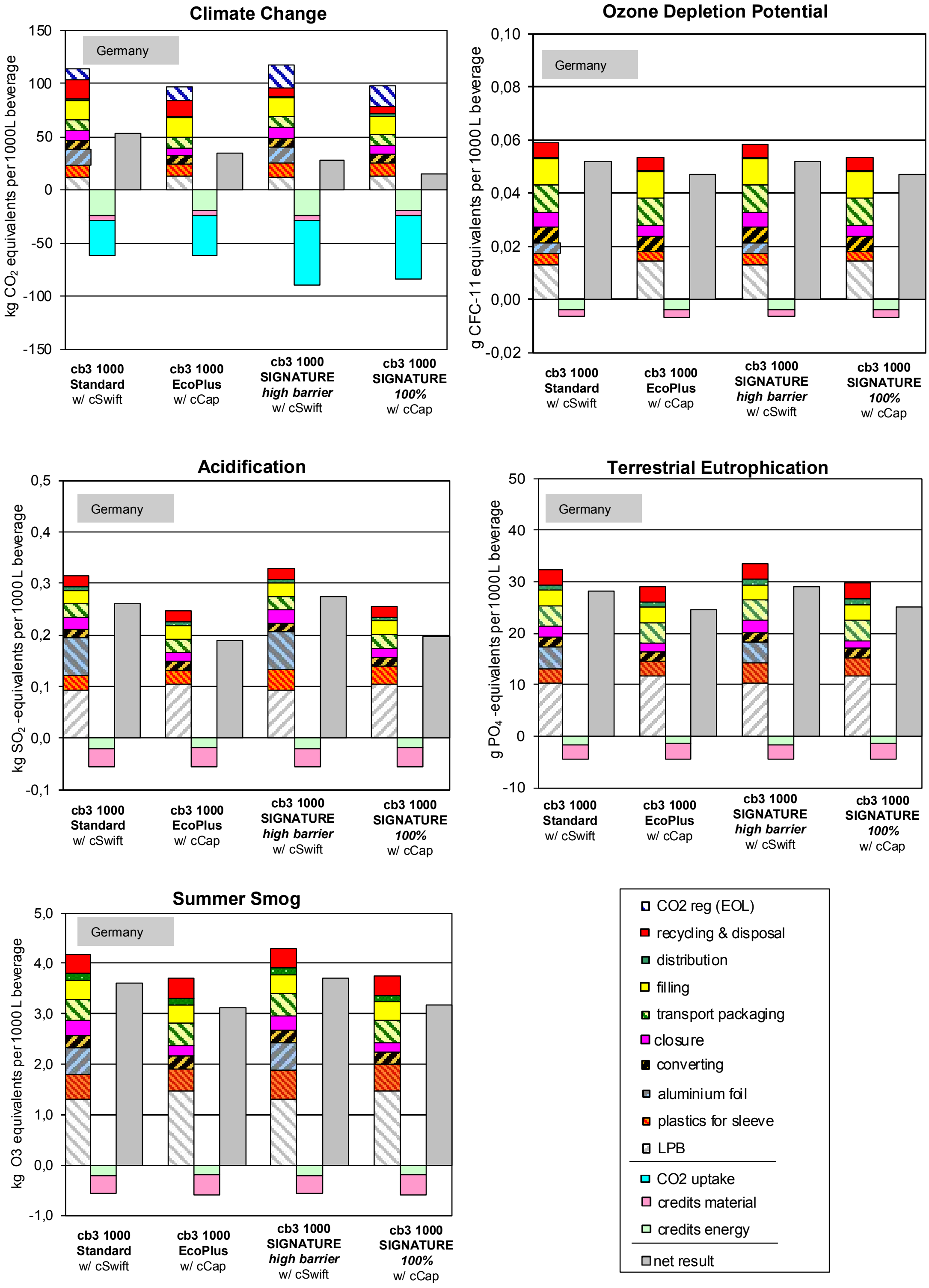

Figure 4.1: Indicator results for base scenario GERMANY with allocation factor 50% (Part 1)

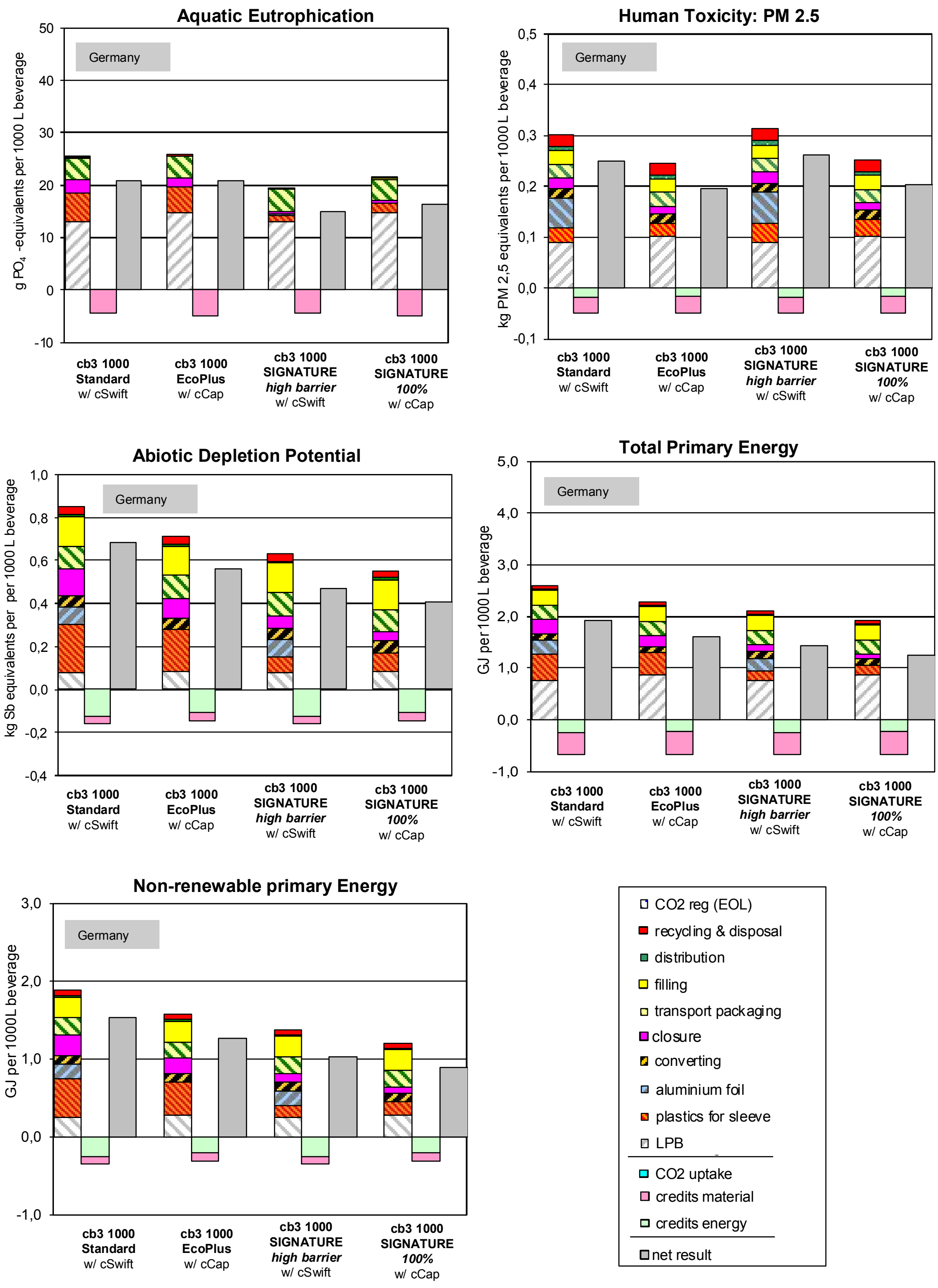

Figure 4.2: Indicator results for base scenario GERMANY with allocation factor 50% (Part 2)

Table 4.1: Results for base scenarios – cumulated life cycle (LC) phases:
LC part A: Share of production processes for primary packaging (to producer gate out),

LC part B: Share of filling, distribution (to point of sale), secondary/tertiary packaging and end of-life processes,

CO_2 reg (EOL): regenerative CO_2 emissions from incineration of biobased materials,
Credits: Benefits from end of life processes (material and energy recovery),

CO_2-uptake: Uptake of athmospheric CO_2 during the plant growth phase,

Base scenarios GERMANY		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	55.67	39.25	58.25	41.19
	LC part B	47.96	44.47	36.60	37.05
	CO_2 reg (EOL)	10.69	12.43	22.04	19.85
	Credits	-28.24	-24.31	-28.24	-24.31
	CO_2-uptake	-33.49	-37.68	-61.08	-59.09
	Net results (∑)	52.58	34.16	27.57	14.69
Acidification [kg SO_2 equivalents]	*LC part A*	0.23	0.16	0.25	0.17
	LC part B	0.08	0.08	0.08	0.08
	Credits	-0.06	-0.06	-0.06	-0.06
	Net results (∑)	0.26	0.19	0.27	0.20
Summer Smog [kg O_3 equivalents]	*LC part A*	2.86	2.38	2.97	2.43
	LC part B	1.32	1.32	1.32	0.94
	Credits	-0.58	-0.59	-0.58	-0.59
	Net results (∑)	3.60	3.11	3.71	2.78
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.03	0.03	0.03	0.03
	Credits	-0.007	-0.007	-0.007	-0.007
	Net results (∑)	0.05	0.05	0.05	0.05
Aquatic eutrophication [g PO_4 equivalents]	*LC part A*	21.01	21.37	14.94	16.97
	LC part B	4.27	4.27	4.27	4.27
	Credits	-4.34	-4.82	-4.34	-4.82
	Net results (∑)	20.94	20.82	14.87	16.41
Terrestial eutrophication [g PO_4 equivalents]	*LC part A*	21.28	17.96	22.38	18.53
	LC part B	11.13	11.10	11.13	11.10
	Credits	-4.44	-4.50	-4.44	-4.50
	Net results (∑)	27.97	24.56	29.07	25.14
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.56	0.42	0.34	0.26
	LC part B	0.29	0.29	0.29	0.29
	Credits	-0.16	-0.15	-0.16	-0.15
	Net results (∑)	0.68	0.56	0.47	0.40

(Table 4.1 continued)

Base scenarios GERMANY		**cb3 1000 w/ cSwift 1000 mL**	**cb3 EcoPlus 1000 w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.22	0.16	0.23	0.17
	LC part B	0.08	0.08	0.08	0.08
	Credits	-0.05	-0.05	-0.05	-0.05
	Net results (∑)	0.25	0.20	0.26	0.20
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.62	1.44	1.26
	LC part B	0.66	0.66	0.66	0.66
	Credits	-0.67	-0.68	-0.67	-0.68
	Net results (∑)	1.93	1.60	1.44	1.25
Non-renewable PE [GJ]	*LC part A*	1.31	1.01	0.81	0.64
	LC part B	0.57	0.56	0.57	0.56
	Credits	-0.34	-0.31	-0.34	-0.31
	Net results (∑)	1.53	1.25	1.03	0.89

4.2 Description of results GERMANY

4.2.1 Description by system

cb3 1000 Standard w/ cSwift 1000 mL

In all analysed impact/indicator categories, the major part of the environmental burdens originate from the production, provision and/or recycling of the (material) components of the beverage carton (and closure).

The LPB shows the largest contribution in the results of *'Aquatic Eutrophication', 'Acidification'*, *'Terrestrial eutrophication'*, *'Summer smog'*, *'Total primary energy demand'* and *'Human toxicity: PM 2.5'*.

For the plastic composites the highest share on the environmental loads can be observed in *'Abiotic Depletion Potential'* and *'Non-renewable primary energy'* demand.

The production of aluminium foil shows considerable impacts in most categories. The largest contributions are to *'Climate Change'*, *'Acidification'*, *'Terrestrial eutrophication'*, *'Summer smog'* and *'Human toxicity: PM 2.5'*

For the converting process low contributions to the environmental burdens can be observed in all impact and inventory categories.

The closure plays a visible role in *'Climate Change'*, *'Abiotic Depletion Potential'*, *'Total primary energy demand'*, *'Non-renewable primary energy'* and *'Climate change'*. In the other categories the contribution of the closure to the environmental burdens is of minor importance.

The transport packaging contributes to almost all examined categories.

The largest contribution by the filling process is observed in *'Climate change'*, *'Abiotic Depletion Potential'* and *'Total- and non-renewable primary energy'*.

The recycling & disposal processes indicate a major contribution in *'Climate change'* For the categories aquatic and terrestrial *eutrophication* potentials and *'Summer Smog'* the influence on the results are of less extent. Depending on the specific environmental impact/indicator level, the examined packaging systems receive credits for material and/or energy recovery in different shares.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

cb3 1000 EcoPlus w/ cCap 1000 mL

Throughout most analysed impact categories covered in the present study the biggest part of the environmental burdens is caused by the production of the components of the beverage carton.

The LPB accounts considerably for the burdens of the following impact and inventory categories: *'Aquatic Eutrophication'*, *'Acidification'*, *'Summer Smog', 'Terrestrial Eutrophication'*, '*Human Toxicity: PM 2.5' and 'Total Primary Energy'.*

For the plastic composites the highest share on the environmental loads can be observed in *'Abiotic Depletion Potential'* and *'Non-renewable primary energy'* demand.

For the converting process low contributions to the environmental burdens can be observed in all impact and inventory categories.

The closure plays a visible role in *'Climate Change'*, *'Abiotic Depletion Potential'*, *'Total primary energy demand'*, *'Non-renewable primary energy'* and *'Climate change'*. In the other categories the contribution of the closure to the environmental burdens is of minor importance.

The transport packaging contributes to almost all examined categories.

The filling process accounts to *'Climate Change', 'Abiotic Depletion Potential', 'Terrestrial Eutrophication', 'Acidification', 'Summer Smog'*, '*Human Toxicity: PM 2.5' ,'Non-renewable Primary Energy'* and *'Total Primary Energy'.*

The recycling & disposal process indicates a visible share in the category *'Climate Change'.*
Main impact on *'Climate Change'* comes from the uptake of carbon dioxide from the atmosphere.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL

As the *cb3 1000 SIGNATURE PACK high barrier w/ cSwift* is identical to the *cb3 1000 Standard w/ cSwift* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 Standard w/ cSwift.*

Plastics for sleeves show the highest environmental loads in, '*Human Toxicity: PM 2.5'* and *'Summer Smog'.*

The recycling & disposal process indicates a visible share in the category *'Climate Change'.*
Main impact on *'Climate Change'* comes from the uptake of carbon dioxide from the atmosphere.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL

As the *cb3 1000 SIGNATURE PACK high barrier w/ cSwift* is identical to the *cb3 1000 EcoPlus w/ cCap* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 EcoPlus w/ cCap.*

Plastics for sleeves show the highest environmental loads in, '*Human Toxicity: PM 2.5'* and *'Summer Smog'.*

The recycling & disposal process indicates a visible share in the category *'Climate Change'.*
Main impact on *'Climate Change'* comes from the uptake of carbon dioxide from the atmosphere.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

4.2.2 Comparison between systems

The following tables show comparisons of both SIGNATURE PACKS with the cb3 1000 Standard and cb3 1000 EcoPlus packs.

Table 4.2: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 Standard w/ cSwift in **GERMANY**

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL			
are **LOWER** than those of **cb3 1000 Standard w/ cSwift**		show **no significant differences** compared to those of **cb3 1000 Standard w/ cSwift**	
Climate Change	-48%	Summer Smog	+3%
Aquatic Eutrophication	-29%	Acidification	+5%
Abiotic Depletion	-32%	Ozone Depletion	0%
Total Primary Energy	-25%	Terrestrial Eutrophication	+4%
Non-renewable primary energy	-33%	PM 2.5	+4%

Table 4.3: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 EcoPlus w/ cCap in **GERMANY**

<table>
<tr><th colspan="4">RESULTS OF
cb3 1000 SIGNATURE Pack high barrier w/ cSwift
1000 mL</th></tr>
<tr><th colspan="2">are LOWER
than those of
cb3 1000 EcoPlus w/ cCap</th><th colspan="2">are HIGHER
than those of
cb3 1000 EcoPlus w/ cCap</th></tr>
<tr><td>Climate Change</td><td>-19%</td><td>Summer Smog</td><td>+19%</td></tr>
<tr><td>Aquatic Eutrophication</td><td>-29%</td><td>Acidification</td><td>+44%</td></tr>
<tr><td>Abiotic Depletion</td><td>-17%</td><td>Ozone Depletion</td><td>+11%</td></tr>
<tr><td>Total Primary Energy</td><td>-10%</td><td>Terrestrial Eutrophication</td><td>+18%</td></tr>
<tr><td>Non-renewable primary energy</td><td>-18%</td><td>PM 2.5</td><td>+34%</td></tr>
</table>

Table 4.4: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cCap with cb3 1000 Standard w/ cSwift in **GERMANY**

<table>
<tr><th colspan="4">RESULTS OF
cb3 1000 SIGNATURE Pack 100% w/ cCap
1000 mL</th></tr>
<tr><th colspan="2">are LOWER
than those of
cb3 1000 Standard c/Swift</th><th colspan="2">are HIGHER
than those of
cb3 1000 Standard c/Swift</th></tr>
<tr><td>Climate Change</td><td>-72%</td><td></td><td></td></tr>
<tr><td>Summer Smog</td><td>-23%</td><td></td><td></td></tr>
<tr><td>Acidification</td><td>-24%</td><td></td><td></td></tr>
<tr><td>Terrestrial Eutrophication</td><td>-10%</td><td></td><td></td></tr>
<tr><td>Aquatic Eutrophication</td><td>-22%</td><td></td><td></td></tr>
<tr><td>PM 2.5</td><td>-20%</td><td></td><td></td></tr>
<tr><td>Ozone Depletion</td><td>-10%</td><td></td><td></td></tr>
<tr><td>Abiotic Depletion</td><td>-41%</td><td></td><td></td></tr>
<tr><td>Total Primary Energy</td><td>-35%</td><td></td><td></td></tr>
<tr><td>Non-renewable primary energy</td><td>-42%</td><td></td><td></td></tr>
</table>

Table 4.5: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cCap with cb3 1000 EcoPlus w/ cCap in **GERMANY**

RESULTS OF **cb3 1000 SIGNATURE Pack 100% w/ cCap** **1000 mL**			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cCap**		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cCap**	
Climate Change	-57%	Acidification	+4%
Summer Smog	-11%	Ozone Depletion	0%
Aquatic Eutrophication	-21%	Terrestrial Eutrophication	+2%
Abiotic Depletion	-28%	PM 2.5	+3%
Total Primary Energy	-22%		
Non-renewable primary energy	-29%		

4.3 Results base scenario EUROPE

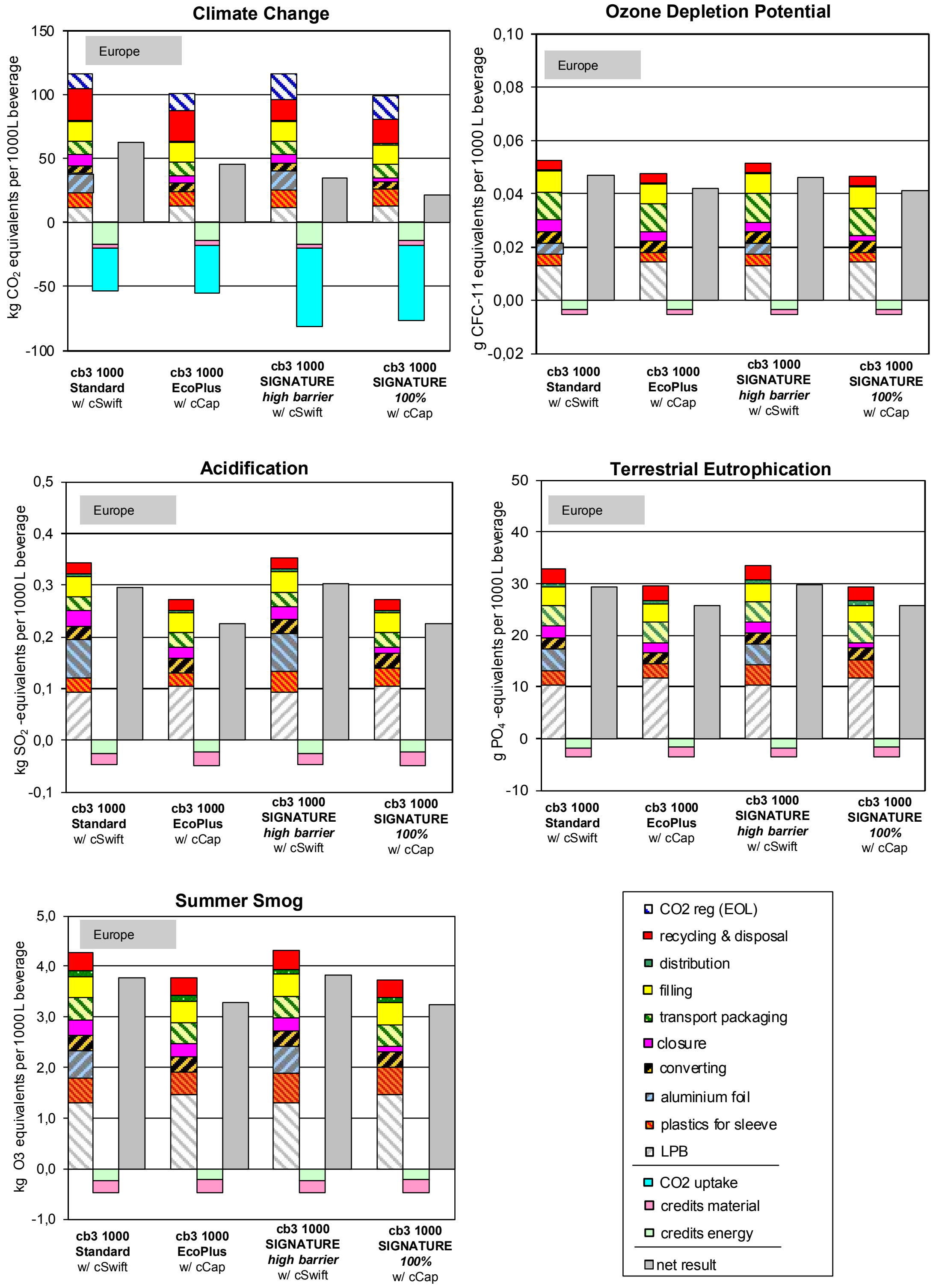

Figure 4.3: Indicator results for base scenario EUROPE with allocation factor 50% (Part 1)

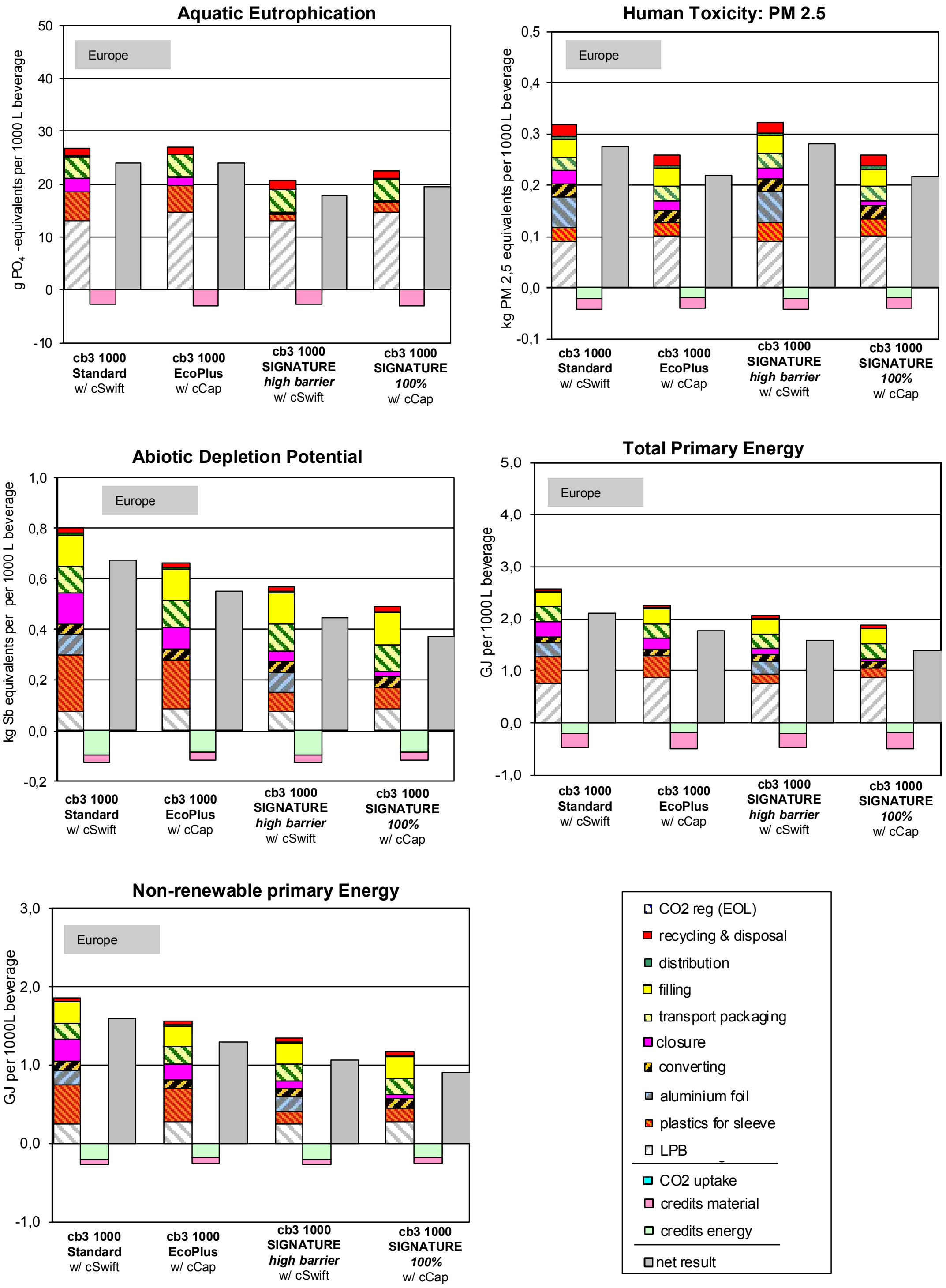

Figure 4.4: Indicator results for base scenario EUROPE with allocation factor 50% (Part 2)

Table 4.6: Results for base scenarios **EUROPE**– cumulated life cycle (LC) phases:
LC part A: Share of production processes for primary packaging (to producer gate out),

LC part B: Share of filling, distribution (to point of sale), secondary/tertiary packaging and end of-life processes,

CO_2 reg (EOL): regenerative CO_2 emissions from incineration of biobased materials,
Credits: Benefits from end of life processes (material and energy recovery),

CO_2-uptake: Uptake of athmospheric CO_2 during the plant growth phase,

Base scenarios Europe		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	52.93	36.79	52.66	34.67
	LC part B	51.79	50.56	43.60	45.63
	CO_2 reg (EOL)	11.57	13.18	19.75	18.11
	Credits	-20.33	-17.84	-20.33	-17.84
	CO_2-uptake	-33.49	-37.68	-61.08	-59.09
	Net results (∑)	62.45	45.00	34.60	21.47
Acidification [kg SO_2 equivalents]	*LC part A*	0.25	0.18	0.26	0.18
	LC part B	0.09	0.09	0.09	0.09
	Credits	-0.05	-0.05	-0.05	-0.05
	Net results (∑)	0.30	0.22	0.30	0.22
Summer Smog [kg O_3 equivalents]	*LC part A*	2.94	2.46	2.98	2.41
	LC part B	1.32	1.31	1.32	0.96
	Credits	-0.48	-0.48	-0.48	-0.48
	Net results (∑)	3.78	3.29	3.82	2.90
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.02
	LC part B	0.02	0.02	0.02	0.02
	Credits	-0.005	-0.005	-0.005	-0.005
	Net results (∑)	0.0468	0.0420	0.0460	0.0409
Aquatic eutrophication [g PO_4 equivalents]	*LC part A*	21.00	21.37	14.78	16.74
	LC part B	5.72	5.68	5.72	5.68
	Credits	-2.82	-3.11	-2.82	-3.11
	Net results (∑)	23.90	23.94	17.68	19.31
Terrestial eutrophication [g PO_4 equivalents]	*LC part A*	21.83	18.46	22.49	18.39
	LC part B	10.98	10.93	10.98	10.93
	Credits	-3.63	-3.64	-3.63	-3.64
	Net results (∑)	29.19	25.75	29.84	25.68
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.54	0.41	0.31	0.23
	LC part B	0.26	0.26	0.26	0.26
	Credits	-0.13	-0.12	-0.13	-0.12
	Net results (∑)	0.67	0.55	0.44	0.37

(Table 4.6 continued)

Base scenarios Europe		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.23	0.17	0.23	0.17
	LC part B	0.09	0.09	0.09	0.09
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.27	0.22	0.28	0.22
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.62	1.43	1.23
	LC part B	0.64	0.63	0.64	0.63
	Credits	-0.48	-0.49	-0.48	-0.49
	Net results (∑)	2.09	1.77	1.58	1.38
Non-renewable PE [GJ]	*LC part A*	1.32	1.01	0.79	0.61
	LC part B	0.54	0.54	0.54	0.54
	Credits	-0.28	-0.26	-0.28	-0.26
	Net results (∑)	1.58	1.29	1.06	0.90

4.4 Description of results Europe

4.4.1 Description by system

cb3 1000 Standard w/ cSwift 1000 mL

In all analysed impact/indicator categories, the major part of the environmental burdens originate from the production, provision and/or recycling of the (material) components of the beverage carton (and closure).

The LPB shows the largest contribution in the results of *'Aquatic Eutrophication', 'Acidification', 'Terrestrial eutrophication', 'Summer smog', 'Total primary energy demand'* and *'Human toxicity: PM 2.5'*.

For the plastic composites the highest share on the environmental loads can be observed in *'Abiotic Depletion Potential'* and *'Non-renewable primary energy'* demand.

The production of aluminium foil shows considerable impacts in most categories. The largest contributions are to *'Climate Change', 'Acidification', 'Terrestrial eutrophication', 'Summer smog'* and *'Human toxicity: PM 2.5'*

For the converting process low contributions to the environmental burdens can be observed in all impact and inventory categories.

The closure plays a visible role in *'Climate Change', 'Abiotic Depletion Potential', 'Total primary energy demand', 'Non-renewable primary energy'* and *'Climate change'*. In the other categories the contribution of the closure to the environmental burdens is of minor importance.

The transport packaging contributes to almost all examined categories.

The largest contribution by the filling process is observed in *'Climate change'*, *'Abiotic Depletion Potential'* and *'Total- and non-renewable primary energy'*.

The recycling & disposal processes indicate a major contribution in *'Climate change'* For the categories aquatic and terrestrial *eutrophication* potentials and *'Summer Smog'* the influence on the results are of less extent. Depending on the specific environmental impact/indicator level, the examined packaging systems receive credits for material and/or energy recovery in different shares.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

cb3 1000 EcoPlus w/ cCap 1000 mL

Throughout most analysed impact categories covered in the present study the biggest part of the environmental burdens is caused by the production of the components of the beverage carton.

The LPB accounts considerably for the burdens of the following impact and inventory categories: *'Aquatic Eutrophication'*, *'Acidification'*, *'Summer Smog', 'Terrestrial Eutrophication'*, '*Human Toxicity: PM 2.5' and 'Total Primary Energy'.*

For the plastic composites the highest share on the environmental loads can be observed in *'Abiotic Depletion Potential'* and *'Non-renewable primary energy'* demand.

For the converting process low contributions to the environmental burdens can be observed in all impact and inventory categories.

The closure plays a visible role in *'Climate Change'*, *'Abiotic Depletion Potential'*, *'Total primary energy demand'*, *'Non-renewable primary energy'* and *'Climate change'*. In the other categories the contribution of the closure to the environmental burdens is of minor importance.

The transport packaging contributes to almost all examined categories.

The filling process accounts to *'Climate Change', 'Abiotic Depletion Potential', 'Terrestrial Eutrophication', 'Acidification'*, *'Summer Smog'*, '*Human Toxicity: PM 2.5'* ,*'Non-renewable Primary Energy'* and *'Total Primary Energy'.*

The recycling & disposal process indicates a visible share in the category *'Climate Change'.*
Main impact on *'Climate Change'* comes from the uptake of carbon dioxide from the atmosphere.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL

As the *cb3 1000 SIGNATURE PACK high barrier w/ cSwift* is identical to the *cb3 1000 Standard w/ cSwift* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 Standard w/ cSwift.*

Plastics for sleeves show the highest environmental loads in, '*Human Toxicity: PM 2.5*' and *'Summer Smog'.*

The recycling & disposal process indicates a visible share in the category *'Climate Change'.*
Main impact on *'Climate Change'* comes from the uptake of carbon dioxide from the atmosphere.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL

As *the cb3 1000 SIGNATURE PACK high barrier w/ cSwift* is identical to *the cb3 1000 EcoPlus w/ cCap* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 EcoPlus w/ cCap.*

Plastics for sleeves show the highest environmental loads in, '*Human Toxicity: PM 2.5*' and *'Summer Smog'.*

The recycling & disposal process indicates a visible share in the category *'Climate Change'.*
Main impact on *'Climate Change'* comes from the uptake of carbon dioxide from the atmosphere.

The emission of biogenic C in the course of end-of-life processes (CO_2 reg (EOL) plays a considerable role for the burdens at the environmental impact category *'Climate Change'.*

4.4.2 Comparison between systems

The following tables show comparisons of both SIGNATURE PACKS with the cb3 1000 Standard and cb3 1000 EcoPlus packs.

Table 4.7: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 Standard w/ cSwift in **EUROPE**

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL			
are **LOWER** than those of **cb3 1000 Standard w/ cSwift**		show **no significant differences** compared to those of **cb3 1000 Standard w/ cSwift**	
Climate Change	-45%	Summer Smog	+1%
Aquatic Eutrophication	-26%	Acidification	+3%
Abiotic Depletion	-34%	Ozone Depletion	-2%
Total Primary Energy	-25%	Terrestrial Eutrophication	+2%
Non-renewable primary energy	-33%	PM 2.5	+2%

Table 4.8: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 EcoPlus w/ cCap in **EUROPE**

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cCap**		are **HIGHER** than those of **cb3 1000 EcoPlus w/ cCap**	
Climate Change	-23%	Summer Smog	+16%
Aquatic Eutrophication	-26%	Acidification	+36%
Abiotic Depletion	-19%	Terrestrial Eutrophication	+16%
Total Primary Energy	-11%	PM 2.5	+29%
Non-renewable primary energy	-18%		
		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cCap**	
		Ozone Depletion	+10%

Table 4.9: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cCap with cb3 1000 Standard w/ cSwift in in **EUROPE**

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cCap 1000 mL			
are **LOWER** than those of **cb3 1000 Standard c/Swift**		are **HIGHER** than those of **cb3 1000 Standard c/Swift**	
Climate Change	-66%		
Summer Smog	-23%		
Acidification	-24%		
Terrestrial Eutrophication	-12%		
Aquatic Eutrophication	-19%		
PM 2.5	-21%		
Ozone Depletion	-13%		
Abiotic Depletion	-45%		
Total Primary Energy	-34%		
Non-renewable primary energy	-43%		

Table 4.10: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cCap with cb3 1000 EcoPlus w/ cCap in **EUROPE**

RESULTS OF **cb3 1000 SIGNATURE Pack 100% w/ cCap** **1000 mL**			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cCap**		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cCap**	
Climate Change	-52%	Acidification	0%
Summer Smog	-12%	Ozone Depletion	-3%
Aquatic Eutrophication	-19%	Terrestrial Eutrophication	0%
Abiotic Depletion	-32%	PM 2.5	0%
Total Primary Energy	-22%		
Non-renewable primary energy	31%		

5 Interpretation

5.1 Base scenarios GERMANY and EUROPE

The biggest part of the environmental burdens in the beverage carton systems analysed is caused by the production of the components of the beverage carton sleeve and the closure.

For *'Aquatic Eutrophication'* the LPB appears to be of special importance. It is also significantly relevant regarding *'Acidification', 'Summer Smog', 'Terrestrial Eutrophication',* and *'Human toxicity: PM2.5'.*

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

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

The required energy for paper production mainly originates from recovered process internal residues (hemicellulose and lignin dissolved in black liquor). Therefore, the required process energy is mainly generated from renewable sources. That explains its relatively small influence on *'Climate Change'.*

Additionally the use of cardboard trays as secondary packaging raises the demand and the respective impacts.

The sectors plastics for sleeve and closure of the beverage cartons *cb3 1000 Standard* and *cb3 1000 EcoPlus* show considerable contributions in many impact categories. The share of plastic composites (sleeve and closure) in the beverage cartons shows a major impact in '*Summer Smog'* and *'Abiotic depletion potential'*. It also causes visible effects regarding the consumption of *'Primary energy'* (both total and non-renewable).

The key raw material for the plastic composites originates from fossil resources (crude oil). Additionally, the production processes show a high energy demand. As the source for energy recovery is mainly fossil fuels, the results show an increased consumption of *'Non-renewable primary energy''*.

For the SIGNATURE PACKS with mass balanced plastics in sleeve and closure the direct impacts from the production is considerably lower only in the impact categories *'Aquatic Eutrophication'* and *'Abiotic depletion potential'*. The significant benefit to the overall net result in *'Climate Change'* derives mainly from the additional uptake of regenerative CO_2.

The end-of-life phase of the regarded beverage cartons is clearly most relevant in the impact category *'Climate Change'.* A share of the greenhouse gases (GHGs) is generated from the energy production required in the respective processes. Material recycling processes are commonly run on electricity, thus this end-of-life treatment contributes directly to the result values for the impact on *'Climate change'*. When the packaging materials are used as fuel in cement kilns or incinerated in MSWI facilities, this also leads to GHG emissions. In the case of plastics made from fossil resources, the emitted CO_2 is fully reflected in the results for *'Climate change'*. For the SIGNATURE PACKS, whose mass balanced plastics are considered as renewable for the purpose of modelling, the biogenic CO_2 emissions from incineration are added to the separate sector CO_2 reg (EOL). As on the European market the applied landfill rate amount 3/5 of the disposal split, a further share of the GHGs originates from methane emissions, caused by the conversion of degraded carbon.

5.2 Sensitivity analysis on system allocation GERMANY

If an allocation factor of 100% is applied, all burdens and credits from recovery processes are allocated to the examined systems. For the examined systems this leads to slightly lower net results in all regarded environmental impact categories apart from *'Climate Change'.* For *'Climate Change'* the benefit from receiving more credits does not outweigh the extra burdens obtained. The main reason for this are the emissions of the waste incineration plants which are now fully allocated to the examined system. As regenerative CO_2 emissions are accounted for '*Climate* Change' in the same way as fossil CO_2 emissions, no significant difference is visible between beverage cartons with mass balanced plastics and those without.

Although net results differ as described, the choice of system allocation factor does not change the overall ranking between the different packaging systems when compared to each other.

The result graphs for the sensitivity analysis with allocation factor 100% for all segments are presented on the following pages.

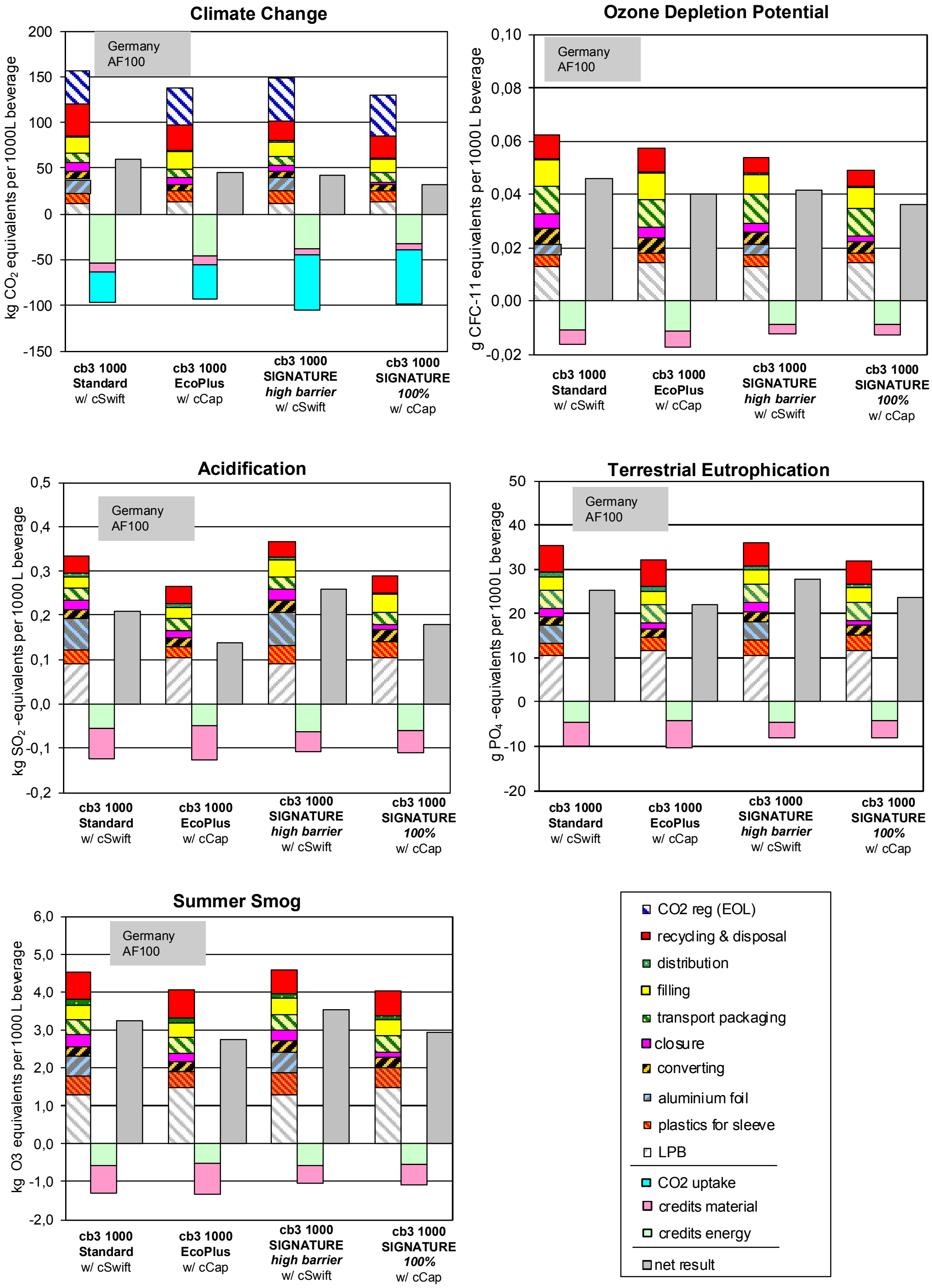

Figure 5.1: Indicator results for sensitivity analysis with allocation factor 100%, **GERMANY** (Part 1)

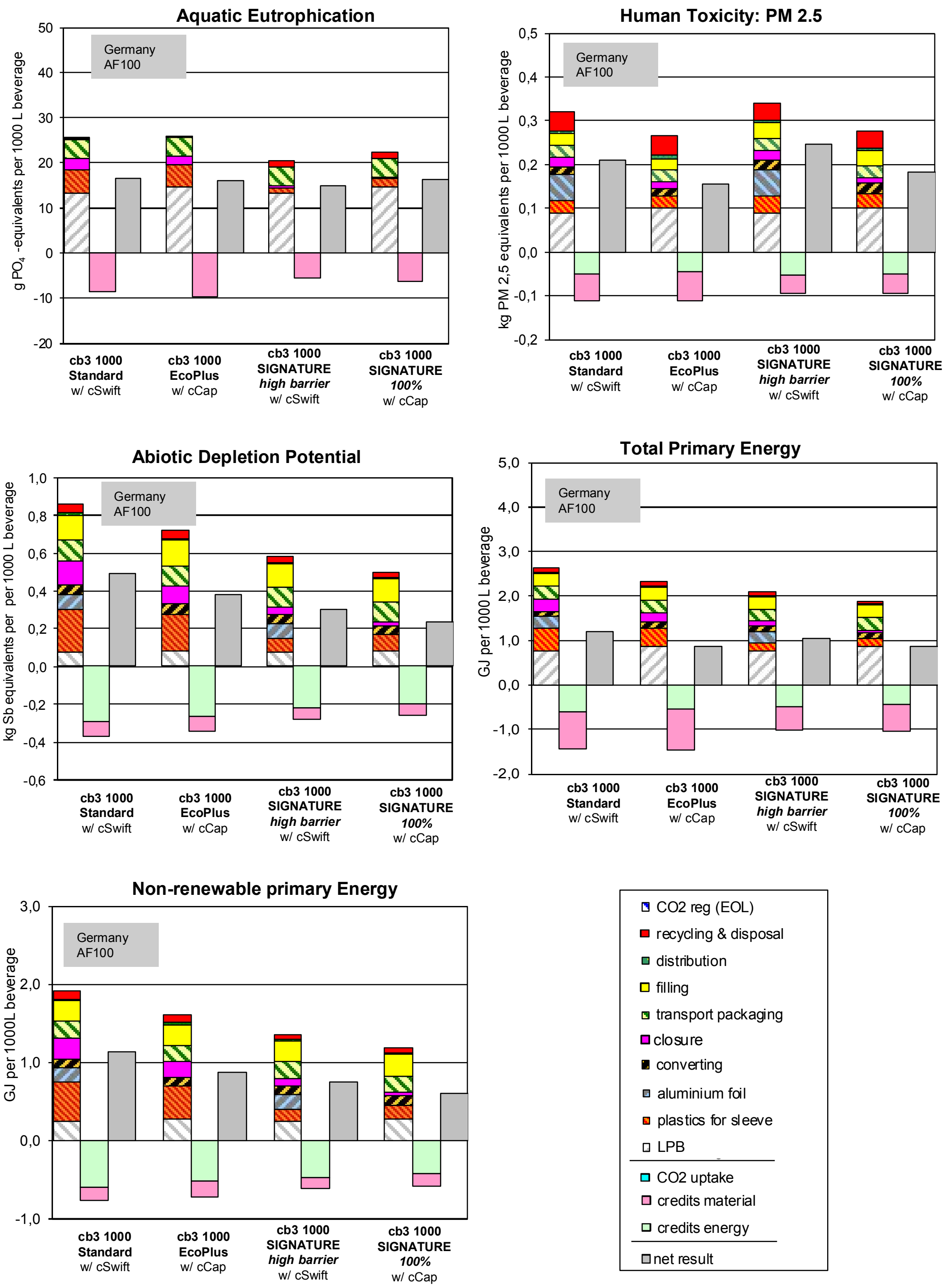

Figure 5.2: Indicator results for sensitivity analysis with allocation factor 100%, GERMANY (Part 2)

Table 5.1: Results for **sensitivity analysis allocation factor 100% GERMANY**– cumulated life cycle (LC) phases:

LC part A: Share of production processes for primary packaging (to producer gate out),

LC part B: Share of filling, distribution (to point of sale), secondary/tertiary packaging and end of-life processes,

CO_2 reg (EOL): regenerative CO_2 emissions from incineration of biobased materials,
Credits: Benefits from end of life processes (material and energy recovery),

CO_2-uptake: Uptake of athmospheric CO_2 during the plant growth phase,

Sensitivity analysis allocation factor 100% Germany		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	55.67	39.25	52.66	34.67
	LC part B	64.59	57.79	48.71	51.35
	CO_2 reg (EOL)	35.96	41.17	46.58	44.23
	Credits	-62.93	-55.90	-44.40	-39.85
	CO_2-uptake	-33.49	-37.68	-61.08	-59.09
	Net results (∑)	59.79	44.63	42.47	31.31
Acidification [kg SO_2 equivalents]	*LC part A*	0.23	0.16	0.26	0.18
	LC part B	0.10	0.10	0.11	0.11
	Credits	-0.12	-0.13	-0.11	-0.11
	Net results (∑)	0.21	0.14	0.26	0.18
Summer Smog [kg O_3 equivalents]	*LC part A*	2.86	2.38	2.98	2.41
	LC part B	1.67	1.68	1.60	0.96
	Credits	-1.29	-1.32	-1.06	-1.07
	Net results (∑)	3.24	2.74	3.53	2.30
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.02
	LC part B	0.03	0.03	0.02	0.02
	Credits	-0.016	-0.017	-0.012	-0.013
	Net results (∑)	0.0458	0.0399	0.0414	0.0360
Aquatic eutrophication [g PO_4 equivalents]	*LC part A*	21.01	21.37	14.78	16.74
	LC part B	4.29	4.29	5.73	5.69
	Credits	-8.68	-9.65	-5.64	-6.23
	Net results (∑)	16.61	16.00	14.87	16.20
Terrestial eutrophication [g PO_4 equivalents]	*LC part A*	21.28	17.96	22.49	18.39
	LC part B	14.01	14.09	13.30	13.29
	Credits	-9.95	-10.21	-8.08	-8.20
	Net results (∑)	25.33	21.85	27.71	23.48
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.56	0.42	0.31	0.23
	LC part B	0.30	0.30	0.27	0.27
	Credits	-0.37	-0.34	-0.28	-0.26
	Net results (∑)	0.49	0.38	0.30	0.24

(Table 5.1 continued)

Sensitivity analysis allocation factor 100% Germany		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.22	0.16	0.23	0.17
	LC part B	0.10	0.11	0.11	0.11
	Credits	-0.11	-0.11	-0.09	-0.09
	Net results (∑)	0.21	0.15	0.25	0.18
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.62	1.43	1.23
	LC part B	0.69	0.69	0.66	0.66
	Credits	-1.43	-1.46	-1.03	-1.04
	Net results (∑)	1.20	0.85	1.05	0.85
Non-renewable PE [GJ]	*LC part A*	1.31	1.01	0.79	0.61
	LC part B	0.60	0.59	0.56	0.56
	Credits	-0.78	-0.73	-0.62	-0.58
	Net results (∑)	1.13	0.87	0.74	0.59

5.3 Sensitivity analysis on system allocation EUROPE

If an allocation factor of 100% is applied, all burdens and credits from recovery processes are allocated to the examined systems. For the examined systems this leads to slightly lower net results in all regarded environmental impact categories apart from *'Climate Change'.* For *'Climate Change'* the benefit from receiving more credits does not outweigh the extra burdens obtained. The main reason for this are the emissions of the waste incineration plants which are now fully allocated to the examined system. As regenerative CO_2 emissions are accounted for *'Climate* Change' in the same way as fossil CO_2 emissions, no significant difference is visible between beverage cartons with mass balanced plastics and those without.

Although net results differ as described, the choice of system allocation factor does not change the overall ranking between the different packaging systems when compared to each other.

The result graphs for the sensitivity analysis with allocation factor 100% for all segments are presented on the following pages.

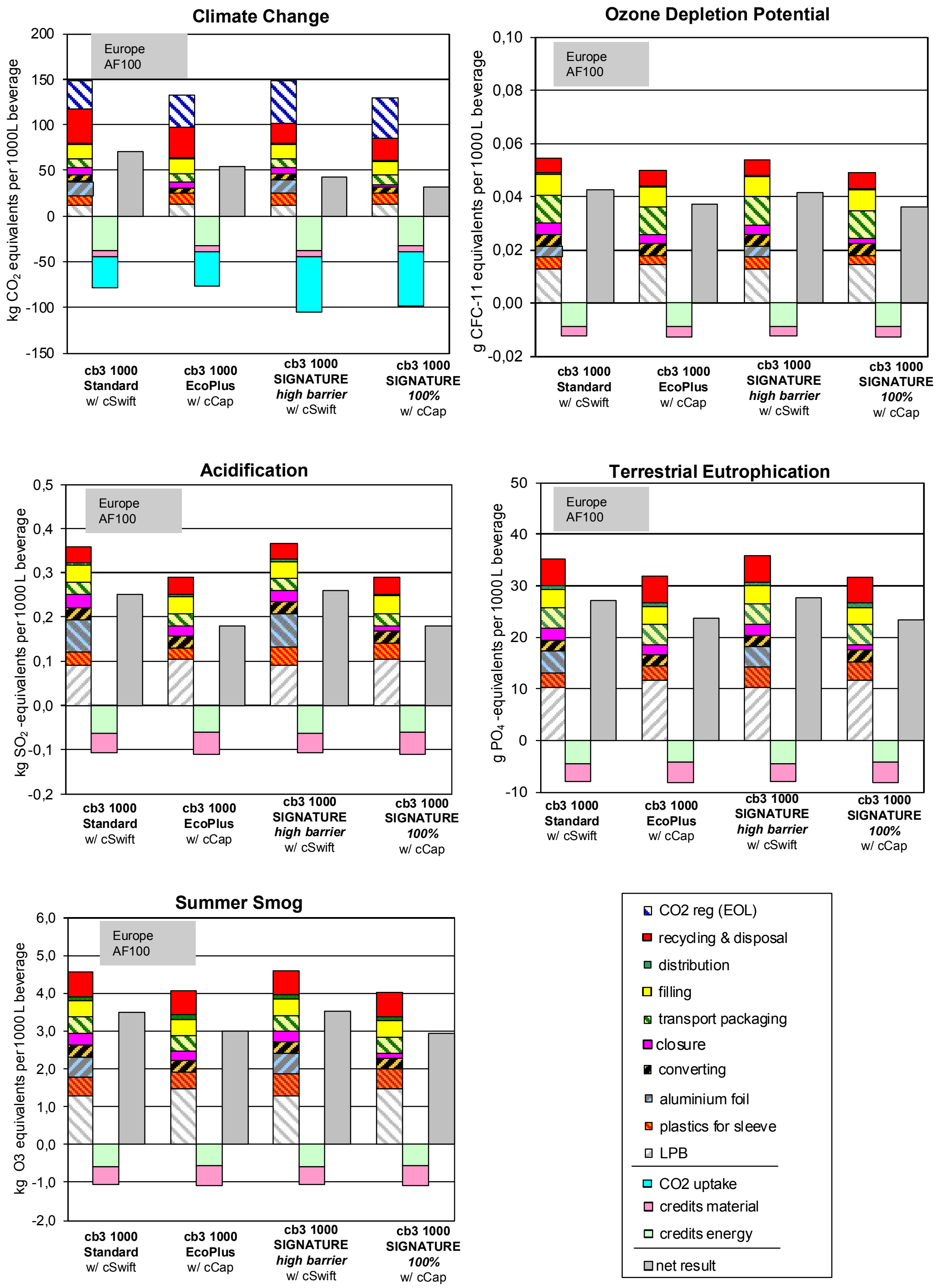

Figure 5.3: Indicator results for sensitivity analysis with allocation factor 100%, Europe (Part 1)

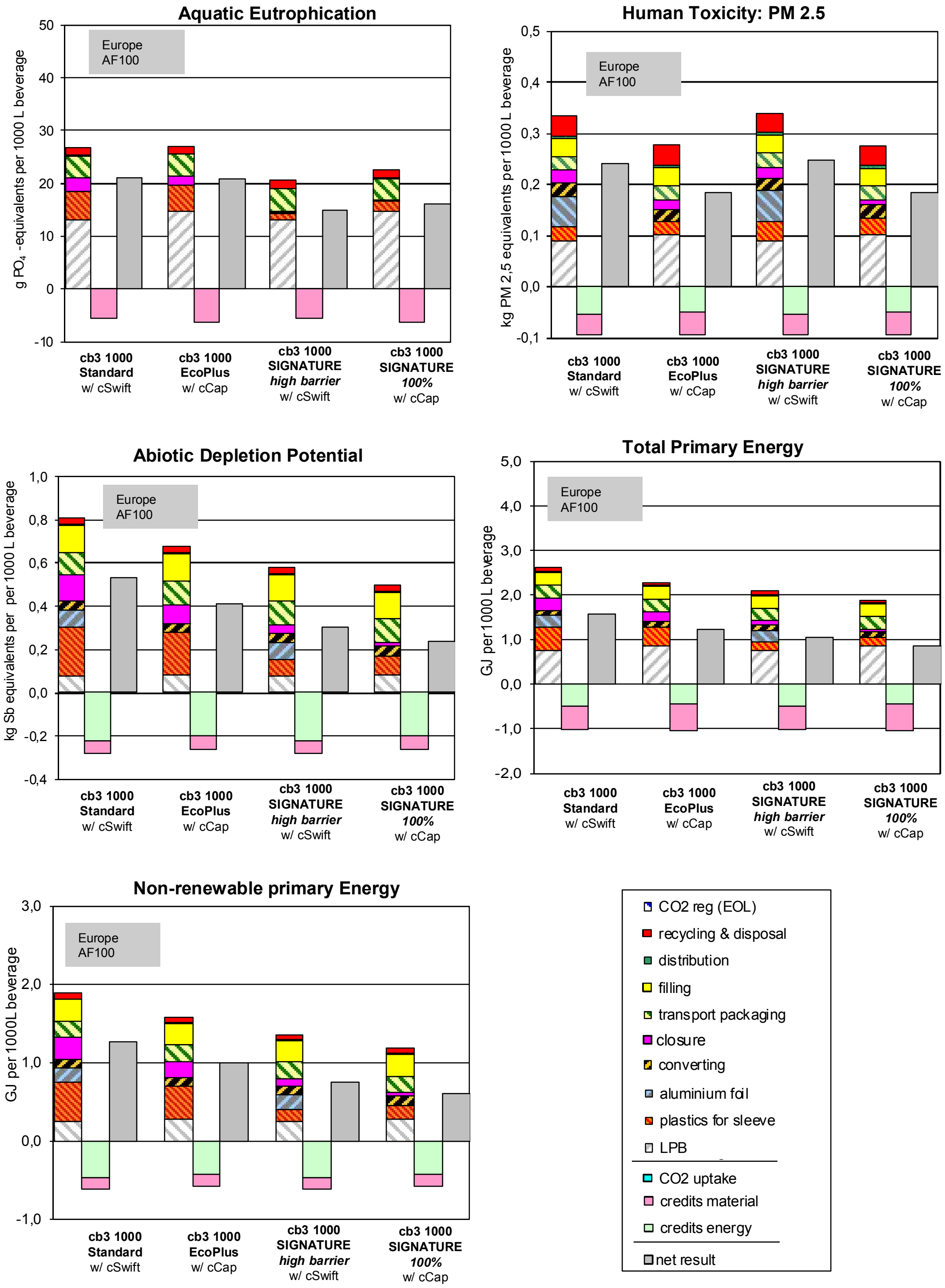

Figure 5.4: Indicator results for sensitivity analysis with allocation factor 100%, Europe (Part 2)

Table 5.2: Results for **sensitivity analysis allocation factor 100% EUROPE**– cumulated life cycle (LC) phases:

LC part A: Share of production processes for primary packaging (to producer gate out),

LC part B: Share of filling, distribution (to point of sale), secondary/tertiary packaging and end of-life processes,

CO$_2$ reg (EOL): regenerative CO$_2$ emissions from incineration of biobased materials,
Credits: Benefits from end of life processes (material and energy recovery),

CO$_2$-uptake: Uptake of athmospheric CO$_2$ during the plant growth phase,

Sensitivity analysis allocation factor 100% Europe		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Climate change [kg CO$_2$ equivalents]	*LC part A*	52.93	36.79	52.66	34.67
	LC part B	64.81	61.05	48.71	51.35
	CO$_2$ reg (EOL)	30.48	34.53	46.58	44.23
	Credits	-44.40	-39.85	-44.40	-39.85
	CO$_2$-uptake	-33.49	-37.68	-61.08	-59.09
	Net results (∑)	70.32	54.84	42.47	31.31
Acidification [kg SO$_2$ equivalents]	*LC part A*	0.25	0.18	0.26	0.18
	LC part B	0.11	0.11	0.11	0.11
	Credits	-0.11	-0.11	-0.11	-0.11
	Net results (∑)	0.25	0.18	0.26	0.18
Summer Smog [kg O$_3$ equivalents]	*LC part A*	2.94	2.46	2.98	2.41
	LC part B	1.60	1.60	1.60	0.96
	Credits	-1.06	-1.07	-1.06	-1.07
	Net results (∑)	3.49	2.98	3.53	2.30
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.02
	LC part B	0.02	0.02	0.02	0.02
	Credits	-0.005	-0.005	-0.005	-0.005
	Net results (∑)	0.0468	0.0420	0.0460	0.0409
Aquatic eutrophication [g PO$_4$ equivalents]	*LC part A*	21.00	21.37	14.78	16.74
	LC part B	5.73	5.69	5.73	5.69
	Credits	-5.64	-6.23	-5.64	-6.23
	Net results (∑)	21.09	20.83	14.87	16.20
Terrestrial eutrophication [g PO$_4$ equivalents]	*LC part A*	21.83	18.46	22.49	18.39
	LC part B	13.30	13.29	13.30	13.29
	Credits	-8.08	-8.20	-8.08	-8.20
	Net results (∑)	27.06	23.55	27.71	23.48
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.54	0.41	0.31	0.23
	LC part B	0.27	0.27	0.27	0.27
	Credits	-0.28	-0.26	-0.28	-0.26
	Net results (∑)	0.53	0.41	0.30	0.24

(Table 5.2 continued)

Sensitivity analysis allocation factor 100% Europe		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cCap 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cCap 1000 mL**
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.23	0.17	0.23	0.17
	LC part B	0.11	0.11	0.11	0.11
	Credits	-0.09	-0.09	-0.09	-0.09
	Net results (∑)	0.24	0.18	0.25	0.18
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.62	1.43	1.23
	LC part B	0.64	0.63	0.64	0.63
	Credits	-0.48	-0.49	-0.48	-0.49
	Net results (∑)	2.09	1.77	1.58	1.38
Non-renewable PE [GJ]	*LC part A*	1.32	1.01	0.79	0.61
	LC part B	0.56	0.56	0.56	0.56
	Credits	-0.62	-0.58	-0.62	-0.58
	Net results (∑)	1.26	0.99	0.74	0.59

5.4 Sensitivity analysis regarding recycling rates

With this sensitivity analysis the effects of varying recycling rates within a certain value range on the results shall be examined to extend the picture analysed in the base scenarios relying on average recycling rates. Therefore scenario settings with recycling rates of 0%, 44% (as in base scenario) and 80% were calculated and interpolated in linear graphs.

The result graphs for the sensitivity analysis with focus on recycling rates –Figure 5.5 and Figure 5.6 - are presented on the following pages behind the description of the results.

For the analysed beverage cartons no significant influence of the recycling rate on the net results of all impact indicators can be observed except in *Climate Change* and *Aquatic Eutrophication*. For the aquatic eutrophication potential a higher recycling rate leads to significantly lower results, due to the fact that less beverage cartons are incinerated or landfilled and more material credits are received.

A higher recycling rate leads to 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.

The choice of the applied recycling rate does not change the ranking between the two packaging systems when compared to each other.

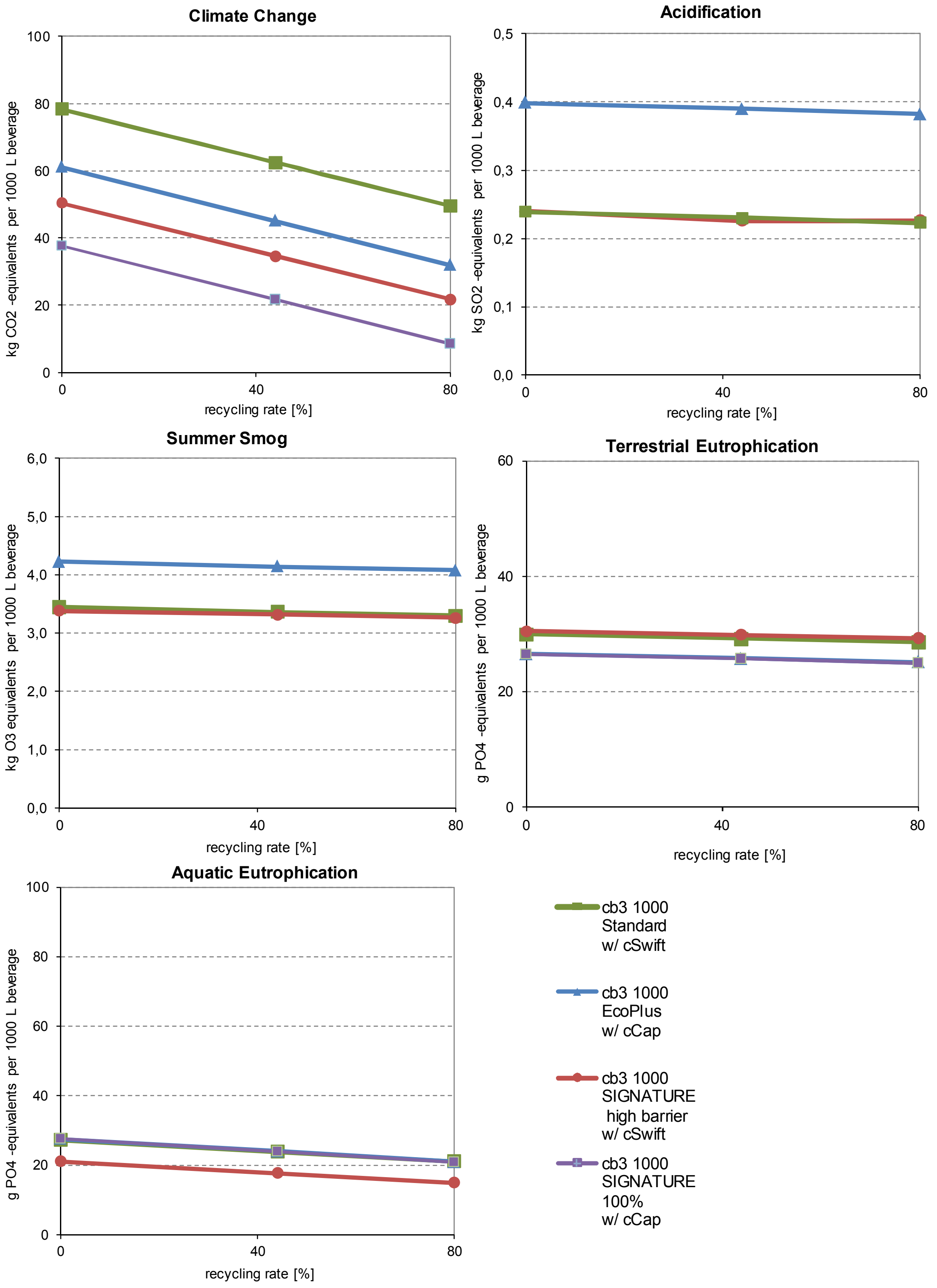

Figure 5.5 Indicator results for sensitivity analysis regarding recycling rates in Europe; allocation factor 50% (Part 1)

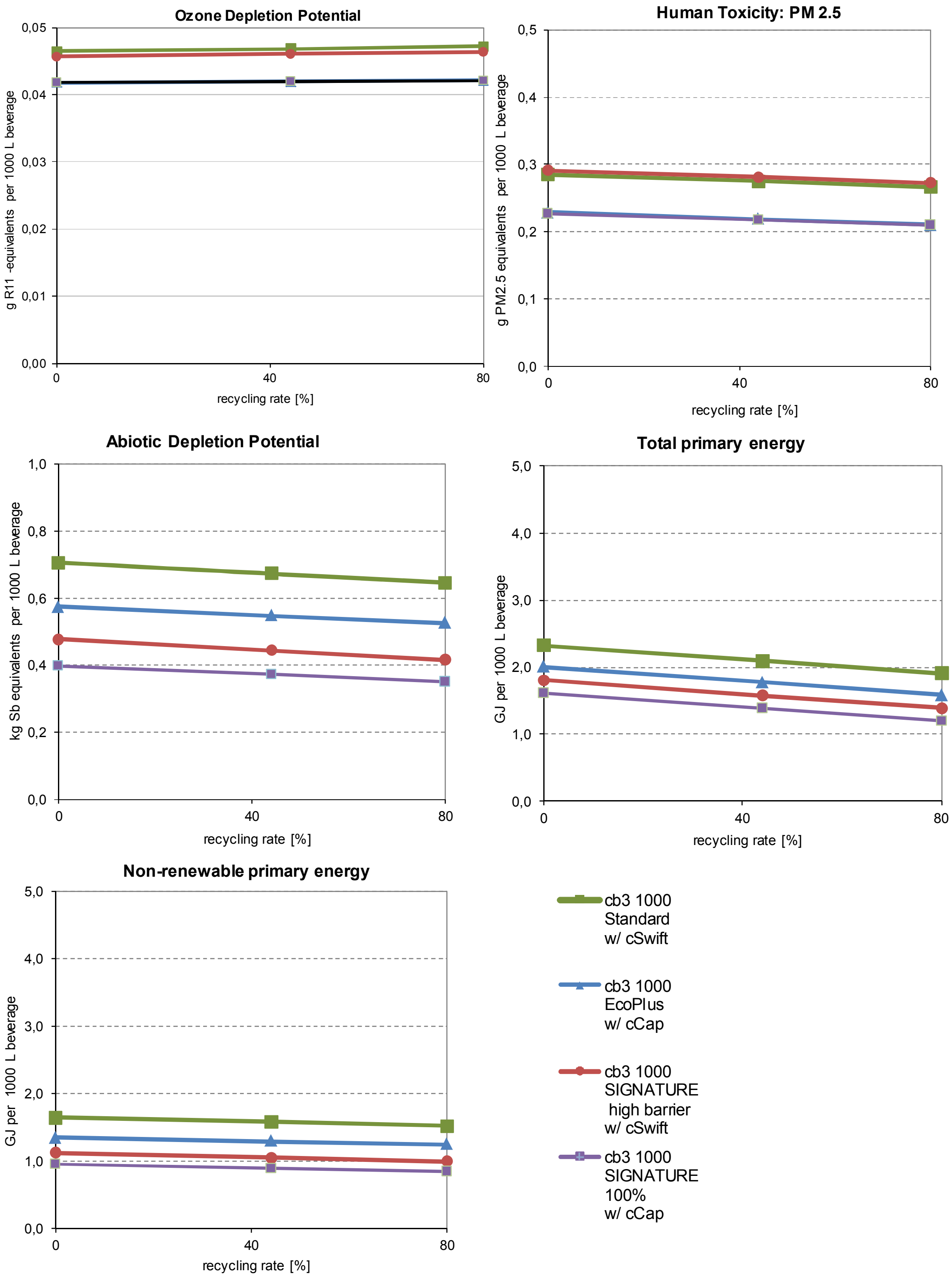

Figure 5.6: Indicator results for sensitivity analysis regarding recycling rates in **Europe**; allocation factor 50% (Part 2)

Table 3.3: Net indicator results of the regarded beverage cartons for the sensitivity analysis with different recycling rates in Europe; allocation factor 50%

Sensitivity analysis recycling rate **Net results (∑)**	cb3 1000 Standard w/ Swift 1000 mL			cb3 1000 EcoPlus w/ cCap 1000 mL			cb3 1000 SIGNATURE Pack high barrier w/ cSwift			cb3 1000 SIGNATURE Pack 100% w/ cCap		
	Recycling rate											
	0%	**44%**	**80%**	**0%**	**44%**	**80%**	**0%**	**44%**	**80%**	**0%**	**44%**	**80%**
Climate change [kg CO_2 equivalents]	78.25	62.45	49.53	61.03	45.00	31.88	50.40	34.60	21.68	37.51	21.47	8.35
Acidification [kg SO_2 equivalents]	0.31	0.30	0.29	0.24	0.22	0.21	0.31	0.30	0.29	0.24	0.22	0.21
Summer Smog [kg O_3 equivalents]	3.88	3.78	3.70	3.39	3.29	3.20	3.92	3.82	3.74	3.35	3.24	3.16
Terrestrial eutrophication [g PO_4 equivalents]	29.91	29.19	28.59	26.52	25.75	25.11	30.57	29.84	29.25	26.45	25.68	25.05
Aquatic eutrophication [g PO_4 equivalents]	27.28	23.90	21.14	27.54	23.94	20.98	21.06	17.68	14.91	27.54	23.94	20.98
Ozone Depletion [g R11 equivalents]	0.05	0.05	0.05	0.04	0.04	0.04	0.05	0.05	0.05	0.04	0.04	0.04
Human toxicity – PM2.5 [kg PM2.5 equivalents]	0.28	0.27	0.27	0.23	0.22	0.21	0.29	0.28	0.27	0.23	0.22	0.21
Abiotic Depletion [kg Sb oil equivalents]	0.71	0.67	0.65	0.57	0.55	0.53	0.48	0.44	0.42	0.40	0.37	0.35
Total Primary Energy [GJ]	2.32	2.09	1.91	2.01	1.77	1.58	1.80	1.58	1.39	1.62	1.38	1.19
Non-renewable Primary Energy [GJ]	1.65	1.58	1.53	1.35	1.29	1.25	1.12	1.06	1.00	0.95	0.90	0.85

6 Limitations, completeness and consistency

The results of the 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, UHT milk. Even though carton packaging systems are common in other market segments, other filling products create different requirements towards their packaging and thus certain characteristics may differ strongly, e.g. barrier functions.

Limitations concerning **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.

It is not possible to transfer the results of this study to packages with other filling volumes or weight specifications.

Each packaging system is defined by multiple system parameters which may potentially alter the overall environmental profile. All packaging specifications of the carton packaging systems were provided by SIG Combibloc.

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 categories applied in this study covers impact categories that are widely accepted within the LCA practitioner community. It should be noted that the use of other impact assessment methods could lead to different results. The results are valid only for the specific characterisation model used for the step from inventory data to impact assessment.

Limitations concerning the analysed **categories**:
The results are valid only for the environmental impact categories, which were examined. They are relative expressions and do not predict impacts on category endpoints, the exceeding of thresholds, safety margins or risks.

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

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

Regarding the production of tall oil based polymers the results are only valid as long as the tall oil originates from Finland as the tall oil related processes are modelled with Finnish electricity for this study.

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 categories.

7 Conclusions and Recommendations

7.1 Comparison of beverage cartons with and without mass-balanced polymers

The comparison between the *cb3 1000 SIGNATURE PACK high barrier* with the *cb3 1000 Standard* and the comparison of the *cb3 1000 SIGNATURE PACK 100%* with the *cb3 1000 EcoPlus* shows that the use of tall-oil based polymers in the sleeve and closures results into lower results for *'Climate change', 'Aquatic Eutrophication'* and *'Abiotic Depletion Potential'* and *'Summer Smog'* in the latter comparison. It leads to no significant differences for the remaining impact categories.
A comparison of the *cb3 1000 SIGNATURE PACK 100%* (without aluminium foil) with the *cb3 1000 Standard* containing aluminium foil shows lower environmental impacts of the *cb3 1000 SIGNATURE PACK 100%* in all examined impact categories.
These observations are true for both markets examined.

7.2 Recommendations

Based on the findings summarised in the previous sections the authors developed the following recommendations:

- As the environmental results of the beverage cartons are significantly influenced by the production of its main components for the sleeve and closure - LPB, Al, PE, PA6, and PP - measures to ensure the same functionality by the use of less material are recommended.
- The substitution of fossil polymers by mass balanced polymers based on tall oil leads to lower results in some environmental impact categories including *'Climate Change'* and no higher impacts in any of the other categories. The implementation of polymers based on tall oil via a mass balance system is therefore recommended.
- It is also recommended to actually achieve a more significant physical share of tall oil based input materials for the production of polymers. The utilisation and demand of mass balanced polymers by SIG Combibloc might be a driver to do so.

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8 Appendix: Critical review report

Dokumentation zur Kritischen Prüfung
Documentation for Critical Review

On behalf of
SIG Combibloc

Critical review of
“Life Cycle Assessment of SIGNATURE PACK: a beverage carton containing polymers based on the mass balanced renewable material approach”

was performed by:

TÜV Rheinland LGA Products GmbH
Dominik Müller

Berlin, 2nd of March 2018

Dokumentation zur Kritischen Prüfung
Documentation for Critical Review

Content

1 General Information and Background of the Study

SIG is one of the world’s leading solution providers for the food and beverage industry within the field of carton packs and filling technology.

ifeu conducts research and provides a worldwide consultancy service in relation to all major environmental and sustainability issues. With almost 40 years of experience, ifeu is one of the most important ecological research institutes in Germany.

Dominik Müller (reviewer) from TÜV Rheinland LGA Products GmbH was commissioned by SIG to carry out the critical review of “Life Cycle Assessment of SIGNATURE PACK: a beverage carton containing polymers based on the mass balanced renewable material approach”. The study considers the provision of 1,000 litre of milk at the point of sale in four beverage carton packaging alternatives at German and European market conditions:

- cb3 EcoPlus with combiCap opening
- cb3 SIGNATURE PACK 100% with combiCap opening containing mass balance polymers
- cb3 with combiSwift opening
- cb3 SIGNATURE PACK high barrier with combiSwift opening containing mass balance polymers

Originators of the study are Frank Wellenreuther, Stefanie Markwardt, Samuel Schlecht, Mirjam Busch und Andrea Drescher (ifeu). Client and provider of process information is Udo Felten (SIG Combibloc).

Since the present study claims to be in line with the international standards ISO 14040:2006 and ISO 14044:2006 a critical review is necessary. This has to be done in accordance with the mentioned standards, which means the study has to be reviewed by an independent expert/s. Because the international standards do not specify whether the critical review carried out concomitantly or a posteriori, both embodiments are in accordance with the standards. The reviewer was commissioned after the study was finished.

A preliminary report was delivered on 14th of February 2018. Recommendations concerning the report and open questions were discussed during a conference call on 19th of February 2018. The originators of the study have integrated the comments afterwards and provided a revised report on 27th of February 2018. The final version of the report was provided on 2nd of March 2018.

The aim of the critical review is to check the reliability, transparency, relevance and representativeness of the used methods and data in this Life Cycle Assessment (LCA) study.

2 Standards and Criteria

The critical review is carried out according to the international standards ISO 14040:2006 and ISO 14044:2006. The critical review shall ensure that (see ISO 14044:2006):

- „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.“

3 Results of the Critical Review

3.1 Objective and Use of the Study

SIG wants to understand the environmental strengths and weaknesses of the two SIGNATURE PACK variants cb3 SIGNATURE PACK 100% and cb3 SIGNATURE PACK high-barrier for the packaging of 1,000 litre of milk at German and European market conditions. Furthermore, SIG wants to compare the environmental performance of these pack solutions with the beverage cartons cb3 Ecoplus and cb3 within the geographic scopes of Germany and Europe.

The present study shall be used for internal and external communication.

3.2 Used Methods in this Analysis

ISO 14040:2006 and ISO 14044:2006 do not give any details about which environmental impact categories should be considered in an LCA. They do not even contain any minimum criteria for such a study.

Following impact categories are considered in this study:

- Climate change
- Stratospheric ozone depletion
- Summer smog
- Acidification
- Eutrophication and oxygen depletion
- Human toxicity and particulate matter
- Abiotic resource depletion

In addition to these impact categories the Life Cycle Inventory indicators Primary Energy Demand – total and Primary Energy Demand – non-renewable are considered.

The selected impact categories follow the requirements of the international standards ISO 14040:2006 and ISO 14044:2006. In addition, they are in line with the defined goal and scope of the LCA study. The used impact categories reflect a comprehensive set of environmental topics connected with the product system. The analysis uses a life cycle approach including all relevant life cycle steps from cradle to grave.

Allocation factors have been applied on a mass basis 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 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 used allocation methods in this study are state of the art and seem to be appropriate for the respective processes.

Sensitivity and scenario analysis are an accepted procedure to determine the effect of changes in data and choice of the methodological approach. The following scenarios were considered in the study:

- In the base scenarios of this study open-loop allocation is performed with an allocation factor of 50%. Following the ISO standards recommendation on subjective choices, a sensitivity analysis is conducted in this study to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% was applied in a ‘sensitivity analysis 100’ for German and European market
- In the base scenarios for Europe the average recycling rate of 44% for Europe was applied. However, throughout Europe the recycling rates vary. Although the specific end-of-life situations are not within the scope of this study (apart from Germany) sensitivity analyses shall provide indications about the environmental performance of the different packaging systems, if the recycling rate varies within a certain value range.

The individual analysis steps are justified on scientific basis and reflect the state of the art.

3.3 Used Data

Data on processes for packaging material production and converting were either collected in cooperation with the industry or taken from literature and the ifeu database. Concerning background processes (energy generation, transportation as well as waste treatment and recycling), the most recent version of ifeu's internal, continuously updated database was used. The data reflect the year 2016. Secondary data were selected to be as up-to-date as possible. Altogether the data quality of the data is high. It can be assumed that these data are appropriate. Nonetheless, a quality check in form of a factory inspection was not performed. To ensure the traceability of data, calculations and documentation were explained to the reviewer in detail. Thus, the data collection was examined by the reviewer. All data seem to be sufficiently and conclusive in itself and in relation to the objective of the study.

3.4 Transparency and Consistency of the Study

It was noted by the reviewer, that the report follows the requirements of ISO 14040:2006 and ISO 14044:2006. The ISO standards provide a framework for presenting an LCA study in a clear and understandable way. The final report itself is coherent, legible, and clear. The results were presented consistently and transparently. The calculation and presentation of the results are complete and understandable. Both, the tabular and graphical representations of results are clear and comprehensible. The explanations concerning assumptions and results are sufficient. Furthermore conclusions and recommendations are included, which outline the most important influence factors in a reasonable and transparent way.

4 Summary of the Critical Review

A critical review in accordance with the standards ISO 14040:2006 and ISO 14044:2006 was carried out for the LCA study called " Life Cycle Assessment of SIGNATURE PACK: a beverage carton containing polymers based on the mass balanced renewable material approach”. The present study is on behalf of SIG Combibloc and was calculated by Frank Wellenreuther, Stefanie Markwardt, Samuel Schlecht, Mirjam Busch und Andrea Drescher from ifeu.

All steps of the study were carried out according to the standards ISO 14040:2006 and ISO 14044:2006. They are scientifically based and reflecting the state of the art. Results and data are consistent. Used data are appropriate for the goal and scope of the study. Necessary recommendations for the report were discussed during the review. The presentation of results is transparent and consistent.

Literature

ISO 14040:2006: International Organisation for Standardisation:

Environmental Management – Life Cycle Assessment – Principles and Framework

ISO 14044:2006: International Organisation for Standardisation:

Environmental Management – Life Cycle Assessment – Requirements and Guidelines

Berlin, 2nd of March 2018

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