ifeu -
Institut für Energie-
und Umweltforschung
Heidelberg GmbH

Comparative Life Cycle Assessment of beverage cartons combibloc*Slimline* and combibloc*Slimline EcoPlus* for UHT milk

(LCA SIG / CB-100730)

Final report

commissioned by SIG Combibloc

Heidelberg, October 2012

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Table of contents

Table of contents **II**

Abbreviations **IV**

1 Goal and scope definition **1**

1.1 Background and objectives 1

1.2 Organisation of the study 2

1.3 Use of the study, target audience and critical review 2

1.4 Functional unit 2

1.5 System boundaries 3

1.6 Data gathering and data quality 4

1.7 Modelling and calculation of inventories 5

1.8 Allocation 5

1.9 Environmental impact assessment and interpretation 12

1.10 Optional elements 15

2 Packaging systems and scenarios **16**

2.1 Packaging specifications 16

2.2 End-of-life settings 17

2.3 System models and material flows 19

2.4 Scenarios 20

3 Life cycle inventory **24**

3.1 Manufacture of plastics 25

3.2 Production of primary material for aluminium bars and foils 27

3.3 Production of liquid packaging board (LPB) 27

3.4 Corrugated board and cardboard trays 27

3.5 Beverage carton converting 28

3.6 Filling 28

3.7 Recovery and recycling 29

3.8 Transport settings for distribution 29

3.9 Background data 32

4 Results of the life cycle inventory and impact assessment 34

4.1 Presentation of results 35

4.2 Description by systems 40

4.3 Comparison between systems 41

5 Interpretation and discussion 44

5.1 Base scenarios: significant parameters and characteristic patterns 44

5.2 Scenario variants 48

5.3 Sensitivity analysis 57

5.4 Limitations, completeness and consistency 61

6 Normalisation 62

7 Conclusions and recommendations 65

7.1 Most significant parameters of the ‘*cb3 EcoPlus’* system 65

7.2 Comparison of the two examined beverage carton systems 66

7.3 Evaluation of the scenario variants 67

7.4 Evaluation of the sensitivity analysis 68

7.5 Recommendations 68

8 References 70

Appendix A: Impact indicators 73

A.1 Climate change 73

A.2 Photo-oxidant formation (photosmog or summer smog) 75

A.3 Eutrophication and oxygen-depletion 77

A.4 Acidification 78

A.5 Human toxicity 79

A.6 Resource consumption 82

A.7 References (for Appendix A) 86

Appendix B: Cradle-to-gate excerpt 88

B.1 Background 88

B.2 Comparison between systems 88

B.3 Remarks and recommendation 89

Appendix C: Critical review 90

C.1 Members of critical review panel 90

C.2 Report of critical review panel 92

Abbreviations

ACE	Alliance for Beverage Cartons & the Environment (Brussels, Belgium)
BC	beverage carton
BOD	biological oxygen demand
CED	cumulative energy demand
COD	chemical oxygen demand
EAA	European Aluminium Association
EAFA	The European Aluminium Foil Association e.V.
EFTA	European Free Trade Association
e-o-l	end-of-life
FEFCO	Fédération Européenne des Fabricants de Carton Ondulé (Brussels)
FKN	Fachverband Kartonverpackungen (Wiesbaden, Germany) (Association for carton packaging for liquid foods)
FSC	Forest Stewardship Council
G	gramme(s)
GHG	greenhouse gas
HDPE	high density polyethylene
HBEFA	Handbuch für Emissionsfaktoren (Handbook for Emission Factors)
IFEU	Institut für Energie- und Umweltforschung Heidelberg GmbH (Institute for Energy and Environmental Research)
kg	kilogramme(s)
km	kilometre(s)
L	litre(s)
LCA	life cycle assessment
LCI	life cycle inventory
LDPE	low density polyethylene
LPB	liquid packaging board
MP	material production
MSWI	municipal solid waste incineration
NMVOC	non-methane volatile organic compounds
NO_X	nitrogen oxides
PE	primary energy
POCP	photochemical ozone creation potential
PP	Polypropylene
t	tonne(s)
TRS	total reduced sulphur
UBA	Umweltbundesamt (German Federal Environment Agency)
US-EPA	United States Environmental Protection Agency
VOC	volatile organic compounds

1 Goal and scope definition

1.1 Background and objectives

SIG Combibloc is one of the world's leading system suppliers of carton packaging and filling machines for beverages and food. In 2008 the company achieved a turnover of 1,249 million Euro with around 4,100 employees in 40 countries. SIG Combibloc is part of the New Zealand-based *Rank Group*.

For more than 20 years, SIG Combibloc has been actively working to address major environmental issues. As environment is an integral part of the corporate strategy it is of high importance for SIG Combibloc to gain credible knowledge about the environmental performance of its product portfolio. This will on the one hand serve as a basis for further improvements of the packing system. On the other hand such knowledge is of high importance and interest for various stakeholders, as environmental concerns are increasing and politics, NGOs, customers as well as consumers are increasingly demanding such information.

SIG Combibloc recently developed a new beverage carton with a new barrier technology for the packaging of UHT milk. The main difference to the already established beverage cartons on the European market besides a slightly different share of the raw materials in the liquid packaging board and low-density polyethylene is that its sleeve does not contain any aluminium but a small amount of polyamide as a barrier layer. The new packaging system bears the name affix *EcoPlus* as it is expected by SIG Combibloc that it will show an improved environmental profile compared to an alternative "conventional" beverage carton with aluminium layer.

With this study, SIG Combibloc would like to investigate some of the environmental impacts of their new *EcoPlus* beverage carton and compare its environmental profile to the one of an already established beverage carton from their product range.

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

- to provide knowledge of environmental strengths and weaknesses of the newly developed combibloc*Slimline*[1] *EcoPlus* 1000 mL beverage carton for the packaging of 1 litre of UHT milk under European market conditions and
- to compare its environmental performance with that of the firmly established "conventional" beverage carton combibloc*Slimline*[1] 1000 mL, SIG Combibloc's beverage carton with the highest market relevance in Europe for 1 litre of UHT milk.

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

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[1] This version of the final report dated October 2012 the packaging's names under study had been changed due to trademark issues. However, goal and scope, packaging specifications and scenarios, respective results, conclusions and recommendations are still valid, as published in the final report and summaries of this LCA dated July 30th, 2010.

1.2 Organisation of the study

This study was commissioned by the SIG Combibloc based in Linnich, Germany in 2010. It is being conducted by *ifeu – Institut für Energie- und Umweltforschung Heidelberg GmbH* (IFEU).

The members of the project panel are:

- Udo Felten (SIG Combibloc)
- Ralf Mosbacher (SIG Combibloc)
- Axel Meier (SIG Combibloc)
- Frank Wellenreuther (*IFEU*)
- Eva von Falkenstein (*IFEU*)

1.3 Use of the study, target audience and critical review

Results of this study will be used in both internal and external communication, i.e. retailers, authorities and NGOs. The commissioner specifically plans to derive figures from this report for the purpose of developing an on-pack declaration regarding its ‘cradle-to-gate carbon footprint’ aimed at SIG Combibloc’s customers (e.g. beverage fillers) and end consumers. According to the ISO standards on LCA [ISO 14040 and 14044 (2006), this demands that a critical review will be carried out. In SIG Combibloc’s and *IFEU*’s experience, the most cost- and time-efficient way to run the critical review is in parallel with the study. Thus the critical reviewers will be able to comment on the project from the time this goal and scope paper is finalised.

The members of the critical review panel are:

- Prof. Walter Klöpffer (chairman), Frankfurt, Germany
- Hans-Jürgen Garvens (co-reviewer), Berlin, Germany
- Dr. Fredy Dinkel (co-reviewer), Basel, Switzerland

1.4 Functional unit

The functional unit for this study is defined as the packaging and delivery to the point of sale of 1000 L UHT milk.

The reference flow of the product system regarded here includes all packaging elements, i.e. beverage carton and caps as well as the transport packaging, (corrugated cardboard trays, pallets), which is necessary for the filling and delivery of 1000 L UHT milk.

1.5 System boundaries

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

In general, the study covers the following steps:

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

Not included are:

- production and disposal of the infrastructure (machines, transport media, roads, etc.) and their maintenance (spare parts, heating of production halls)
- beverage production
- environmental effects related to storage phases
- environmental effects of beverage losses due to breakability of packages
- environmental effects from accidents
- losses of beverage at different points in the supply chain (losses might occur at several points in the supply and consumption chain, for instance in the filling process, during handling and storage, etc.) These losses would mostly be accidental.

The excluded aspects are not included in this LCA as no relevant differences between the systems under examination are to be expected.

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 means of credits obtained for secondary products. The credits given are based on the environmental loads of the corresponding primary energy generation process or material (see section 1.8).

Cut-off criteria

In order to ensure the symmetry of the packaging systems to be examined and in order to maintain the study within a feasible scope, a limitation on the detail in system modelling is necessary. So-called cut-off criteria are used for that purpose. According to ISO standards [ISO 14044], cut-off criteria shall consider mass, energy and environmental significance. Regarding mass-related cut-off, pre-chains with an input material share of less than 1% of the total mass input of a considered process were excluded. However, total cut-off is not to be more than 5% of input materials as referred to the functional unit. All energy inputs are considered (no cut-off), except the energy related to the material inputs from pre-chains which are cut off. 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. Environmental relevance of material input flows was assessed based on expert judgement.

1.6 Data gathering and data quality

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

Geographic scope

In terms of the geographic scope, the LCA study focuses on the production, distribution and disposal of beverage cartons in Western Europe (EU15 & Switzerland), which is considered by the commissioner as a market for the new *EcoPlus* beverage cartons. Beyond analysing the “average” situation in this world region, indications are sought regarding the differences between results calculated for country-specific scenarios.

Time scope

The reference time period for the comparison of packaging systems is 2009/2010. 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.

Most of the applied data refer to the period between 1999 and 2009. The process-specific data gathered specifically for this study (such as converting data for beverage cartons) refer to 2009. The datasets for transportation, energy generation and waste treatment processes are taken from the *IFEU* internal database in the most recent version (time reference between 2000 and 2009). The data for plastic production originates from the Plastics Europe dataset and refer to 1999.

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 operation in the reference period.

1.7 Modelling and calculation of inventories

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

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

1.8 Allocation

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

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

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

Process-related allocation

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

Multi-output processes

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

Multi-input processes

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

Transport processes

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

System-related allocation

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

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

General notes regarding figures 1-1 to 1-4

The following graphs (figures 1-1 to 1-4) are intended to support a general understanding of the allocation process and for that reason they are strongly simplified. The graphs serve

- to illustrate the difference between the 0% allocation method, the 50% : 50% allocation method and the 100% allocation method
- to show which processes are allocated[2]:

– primary material production

– recovery processes

– waste treatment of final residues (here represented by MSWI)

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

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

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

The allocation of final waste treatment is consistent with UBA LCA methodology and additionally this approach – beyond the UBA methodology – is also in accordance with [ISO 14044].

For simplification some aspects are not explicitly documented in the mentioned graphs, among them the following:

- Material losses occur in both systems A and B, but are not shown in the graphs. These losses are of course taken into account in the calculations, their disposal being included within the respective systems.
- Hence not all material flows from system A are passed on to system B, as the simplified material flow graphs may imply. Consequently only the effectively recycled material's life cycle steps are allocated between systems A and B.
- The graphs do not show the individual process steps relevant for the waste material flow out of packaging system A, which is sorted as residual waste, including the respective final waste treatment.
- For simplification, a substitution factor of 1 underlies the graphs. However, in the real calculations smaller values are used where appropriate. For example if a material's properties after recycling are different from those of the primary material it replaces, this translates to a loss in material quality. A substitution factor < 1 accounts for such 'down-cycling' effects. For further details regarding substitution factors please see subsection 'Application of allocation rules' (p.13)
- Furthermore, the material which is replaced by the recycled material may be a completely different one (e.g. plastic substituting for wood). This case, even if not relevant in this study, is not addressed in the graphs either.
- The final waste treatment for the materials from both systems A and B is represented in the graphs only as municipal solid waste incineration (MSWI). However, the LCA model implemented by means of Umberto® software applications comprehends a final waste management 'mix' made up of both landfilling and MSWI processes.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Application of allocation rules

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

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

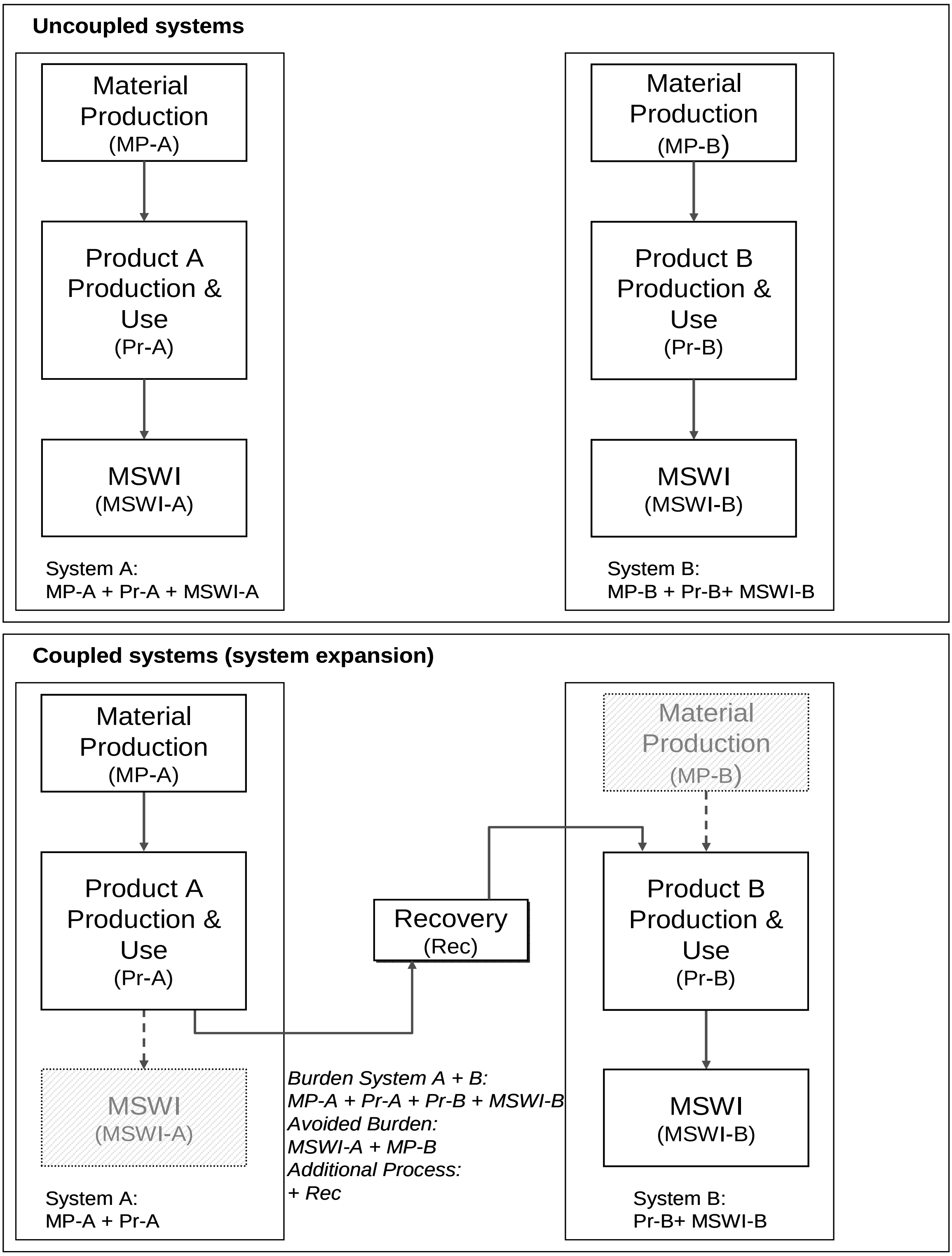

Figure 1-1: Additional system benefit/burden through recycling (schematic flow chart)

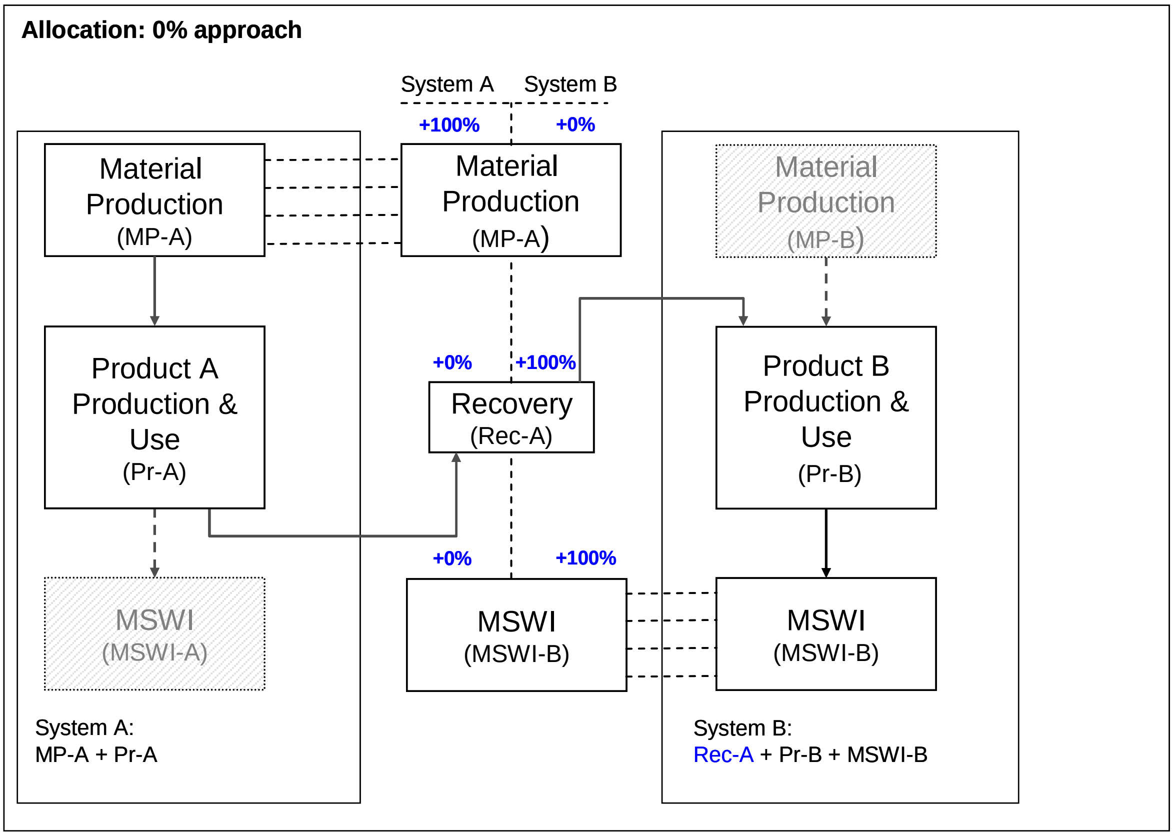

Figure 1-2: Principles of 0% allocation (schematic flow chart)

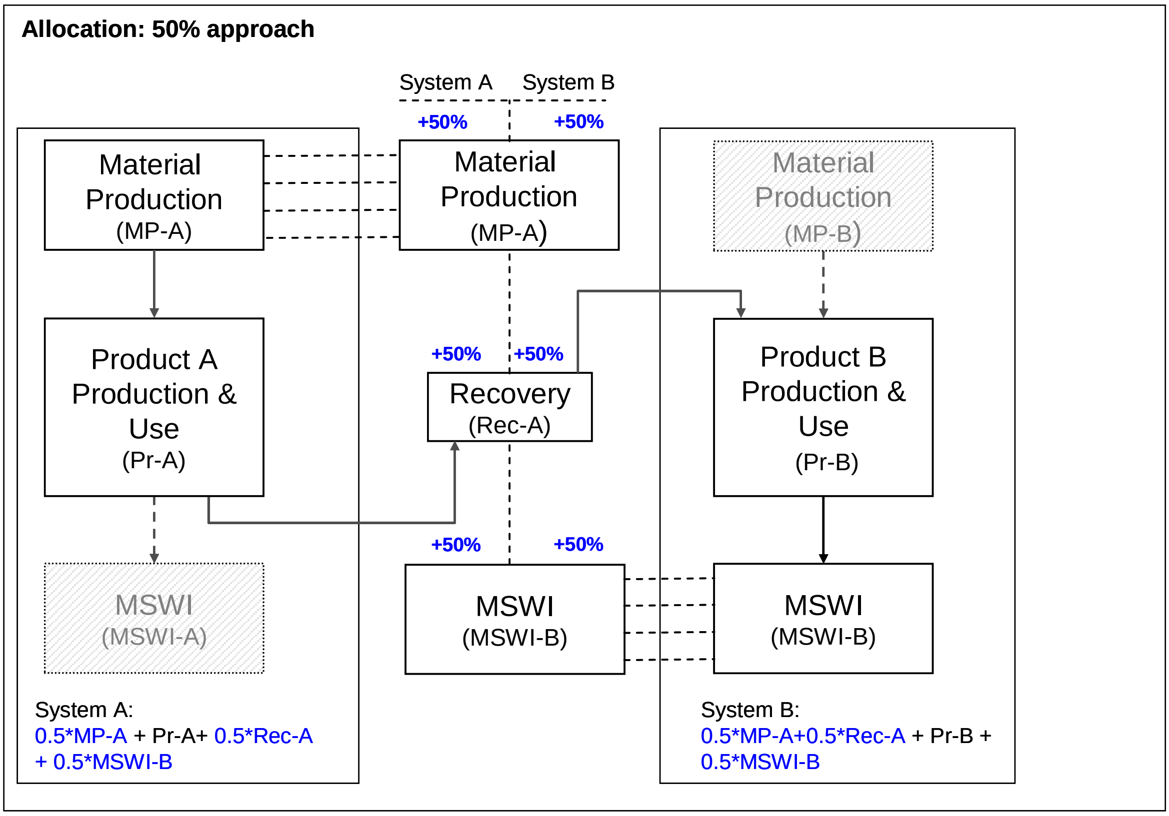

Figure 1-3: Principles of 50% allocation (schematic flow chart)

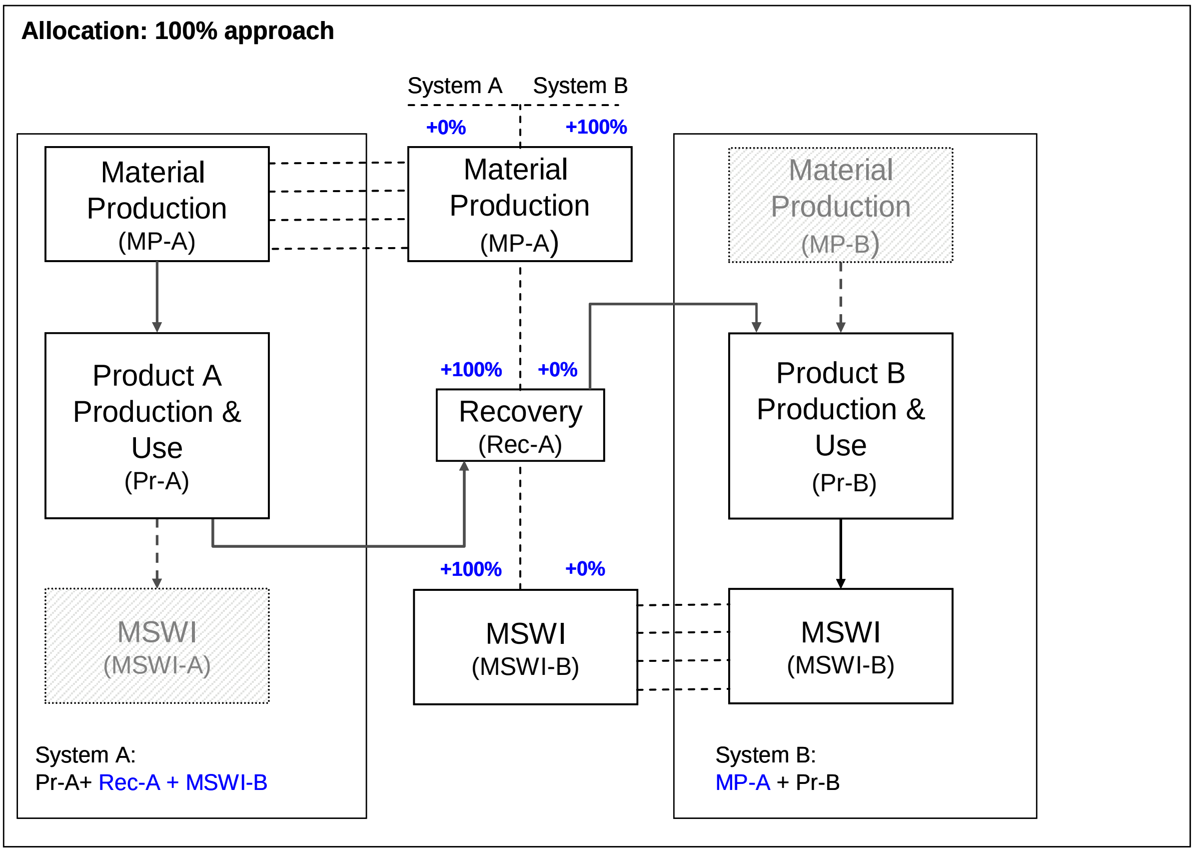

Figure 1-4: Principles of 100% allocation (schematic flow chart)

1.9 Environmental impact assessment and interpretation

To assess the environmental performance of the examined packaging system, a set of environmental impact categories according to current practice in LCA is used. They are listed and briefly addressed below. In this study midpoint indicators are applied. Midpoint indicators represent environmental issues, for example acidification, whereas the fate of the substances causing the environmental problems is not taken into account

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

Impact indicators related to emissions

- **Acidification**
  Acidification affects aquatic and terrestrial eco-systems by changing the acid-basic-equilibrium through the input of acidifying substances. The acidification potential is applied here as characterisation factor.

- **Climate change ('Global Warming')**
  Climate change is the impact of emissions from human activities on the radiative forcing of the atmosphere. Greenhouse gas emissions enhance the radiative forcing, resulting in an increase of the earth's temperature. The characterisation factors applied here are based on the Global Warming Potential for a 100 year time horizon [IPCC 2007].

- **Summer Smog ('Photo-Oxidant Formation')**
  Photo-oxidant formation is the photochemical creation of reactive substances (mainly ozone) which affect human health and ecosystems. This ground-level ozone is formed in the atmosphere by nitrogen oxides and volatile organic compounds in the presence of sunlight. Another name for this problem is 'summer smog'. The characterisation factor applied here is the 'Photochemical Ozone Creation Potential' (POCP).

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

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

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

The eutrophication potential of emissions to air and to water is applied here as characterisation factor.

- **Human toxicity**
  In recent years, series of different approaches have been developed for characterizing these categories in order to determine the related environmental impact. In this study two human toxicity categories have been differentiated and applied. In analogy to the other impact categories, they can be measured at a midpoint indicator level.

– ***Human toxicity: PM10***
This category covers effects of fine primary and secondary particles, where a correlation has been shown with respiratory deseases by epidemological studies. Following an approach proposed by EEA[3], secondary fine particulates are quantified and aggregated with primary fine particulates as PM10 equivalents[4].

– ***Human toxicity: Carcinogenic risk***
Carcinogenic risk includes impacts from air emissions that threaten human health without a threshold value. Those are especially emissions with carcinogenic properties. Based on inhalation unit risk values for carcinogenic substances which are published by US-EPA[5], various emissions are aggregated and expressed as As equivalents.

Impact indicators related to the use/consumption of resources

- **Fossil resource consumption** (limited to the consumption of energy resources).
  This category refers to the depletion of fossil energy resources. The resources are

---

[3] EEA: European Environment Agency

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

[5] US-EPA: United States Environmental Protection Agency

aggregated using individual scarcity factors.

Depletion of other abiotic resources such as metal ores, sand and quartz has been omitted from this impact category as these resources are not considered to be scarce. This procedure complies with the above mentioned UBA method.

- **Use of nature**

  Regarding the assessment of 'use of nature' (often referred to as land use) several methodological approaches have emerged in recent years. The method developed by *IFEU* is based on an ordinal scale of seven area-based categories, or classes, describing the 'proximity to nature' (e.g. class I: nature without direct anthropogenic influences, class II: forest managed in a near-natural way, class VII: sealed areas like landfill sites, roads)[6].

  For the purpose of this study a simplified approach was used, considering only the use of ***forest*** and ***sealed*** areas.

Additional categories at the inventory level

Additional categories for information purposes examined in this study are the total Primary Energy Demand (CED total; the non-renewable Primary Energy Demand (CED non-renewable) and water use.

- **Total Primary Energy (Cumulative Energy Demand, total)**

  The Total Cumulative Energy Demand is a parameter to quantify the primary energy consumption of a system. It is calculated by adding the energy content of all used fossil fuels, nuclear and renewable energy (including biomass). This indicator is described in [VDI 1997]. It is a measure for the overall energy efficiency of a system, regardless the type of energy resource which is used.

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

  The category non-renewable primary energy (CED non-renewable) considers the primary energy consumption based on non-renewable, i.e. fossil and nuclear energy sources.

- **Transport intensity: Lorry**

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

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[6] Aspects considered for the classification of an area into one of the seven classes include e.g. degradation of soils and ecosystems, fragmentation, loss of biodiversity etc. A distinction is also made between current land status and transformation, i.e. activities in order to change its quality.

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

Impact Categories	**Elementary Flows**								**Unit**
Land Use (forestry)	forest area								cm² * year
Fossil Resources	crude oil	natural gas	brown coal	hard coal					kg crude oil eq.
Climate Change	CO_2*	CH_4**	N_2O	$C_2F_2H_4$	CF_4	CCl_4	C_2F_6	R22	kg CO_2 eq.
Summer Smog (POCP)	CH4	NMVOC	Benzene	Formaldehyde	Ethyl acetate	VOC	C-total	Ethanol	kg ethene eq.
Acidification	NOx	NH_3	SO_2	TRS	HCl	H_2S	HF		kg SO_2 eq.
Terrestrial Eutrophication	NOx	NH_3	N_2O						kg PO_4 eq.
Aquatic Eutrophication	COD	N	NH_4^+	NO_3^-	NO_2^-	P			kg PO_4 eq.
Human toxicity: PM10	PM10	SO_2	NO_X	NH_3	NMVOC				kg PM10 eq.
Human toxicity: Carcinogenic risk	As	B(a)P	Cd	Cr VI	Ni	Dioxin	Benzene	PCB	kg As eq.
Total Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore	hydro energy	Other renewable		MJ
Non-renewable Primary Energy	hard coal	brown coal	crude oil	natural gas	uranium ore				MJ
Transport intensity	lorry distance								km

* CO_2 fossil ** CH_4 fossil and CH_4 regenerative included

1.10 Optional elements

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

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

In the present study, normalisation will be applied.

2 Packaging systems and scenarios

In general terms packaging systems can be defined based on the primary, secondary and tertiary packaging elements they are made up of. The composition of each of these individual packaging elements and their components' masses depend strongly on the function they are designed to fulfil, i.e. on requirements of the filler and retailer as well as the distribution of the beverage product to the point-of-sale.

All packaging systems examined in this study are presented in the following section (2.1), including the applied end-of-life settings (2.2). Flow charts of the respective systems (2.3) illustrate their life cycles as analysed and finally, a condensed overview of all regarded scenarios, including those chosen for sensitivity analyses, is provided in section 2.4.

2.1 Packaging specifications

The present study compares the following packaging systems intended for the delivery of milk to the consumer:

1. SIG Combibloc beverage carton combibloc*Slimline*[7] *EcoPlus* 1000 mL with closure *cCap*
2. SIG Combibloc beverage carton combibloc*Slimline*[7] *EcoPlus* 1000 mL without a closure
3. SIG Combibloc beverage carton combibloc*Slimline*[7] 1000 mL with closure *cSwift*
4. SIG Combibloc beverage carton combibloc*Slimline*[7] 1000 mL without a closure

The packaging systems examined in the LCA study are specified below in table 2-1 based on information provided by SIG Combibloc.

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[7] In the following sections the beverage cartons 'combibloc*Slimline EcoPlus* 1000 mL*' and '*combibloc*Slimline* 1000mL' are marked with their working names 'cb3 *EcoPlus* 1000 mL*' and '*cb3 1000mL' respectively.

Table 2-1: Packaging specifications for regarded beverage carton variants: packaging components and masses

Packaging components	**cb3 EcoPlus** w/ cCap	**cb3 EcoPlus** w/o closure	**cb3** w/ cSwift	**cb3** w/o closure
volume	1000 mL	1000 mL	1000 mL	1000 mL
primary packaging (sum per carton)	**29.473 g**	**27.623 g**	**30.333 g**	**27.623 g**
composite material (sleeve)	27.623 g	27.623 g	27.623 g	27.623 g
- liquid packaging board	*22.878 g*	*22.878 g*	*20.336 g*	*20.336 g*
- LDPE	*4.237 g*	*4.237 g*	*5.931 g*	*5.931 g*
- aluminium	–	–	*1.356 g*	*1.356 g*
- PA	*0.508 g*	*0.508 g*	–	–
closure	1.85 g	–	2.71 g	–
- PP spout	–	–	*1.41 g*	–
- HDPE cap	–	–	*1.3 g*	–
- PP cap	*1.85 g*	–	–	–
secondary packaging (sum per tray)	**133.83 g**	**133.83 g**	**133.83 g**	**133.83 g**
tray (corrugated cardboard)	133.83 g	133.83 g	133.83 g	133.83 g
tertiary packaging (sum per pallet)	**20,627 g**	**20,627 g**	**20,627 g**	**20,627 g**
pallet (25 use cycles)	20,000 g	20,000 g	20,000 g	20,000 g
type of pallet	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 layer	12	12	12	12
layers per pallet	5	5	5	5
cartons per pallet	720	720	720	720

2.2 End-of-life settings

For each packaging system regarded in the study, a base scenario is modelled and calculated assuming an average recycling rate for post-consumer packaging and an average final waste disposal split (landfill/incineration) for Western Europe (EU15 & Switzerland). In order to provide indications of how certain end-of-life framework conditions influence the results, for example in one specific country, additional scenario variants will be calculated using country-specific settings for the key end-of-life parameters (see also section 2.4.2). These average and country-specific figures will be based on data obtained from *ACE* (the *Alliance for Beverage Cartons & the Environment*) and *Eurostat*, for the reference year 2008. Table 2-2 lists the average recovery and final disposal quotas, and Table 2-3 provides an overview of the country-specific values as well as a classification based on the countries' recycling rates and referred to in the result graphs.

Table 2-2: Recycling rate and disposal split as well as collection rate of beverage cartons – West European (EU15 & Switzerland) averages used in base scenarios (based on [ACE 2010] and [Eurostat 2010])

End-of-life rates (EU15 & CH average)	
Recycling rate (material recycling)	**36.7 %**
collection rate	41 %
- recovery at sorting process (share of collection rate)	*89.5 %*
- residues at sorting process (share of collection rate)	*10.5 %*
Final waste disposal (total)	**63.3 %**
- *landfill rate (share of total final waste)*	55.5 %
- *incineration rate* (MSWI w/ energy recovery, share of total final waste)	*44.5 %*

Table 2-3: Recycling and disposal rates of beverage cartons – recycling rates applied for scenario variants and country-specific landfill rates (based on [ACE 2010] and taken from [Eurostat 2010], respectively) as well as classification in two groups (based on recycling rate)

Country	**(Material) Recycling rate** (per country group; % of BC's total e-o-l material flow)	**Landfill rate** (per country; % of country's specific final waste for BCs)
***Group H* – High recycling rate** (> 36.7 % of total e-o-l material flow)		
Austria	53.3 % (average recycling rate of countries in this group, weighted based on total e-o-l material flow)	10.44 %
Belgium		13.16 %
France		52.88 %
Germany		1.53 %
Luxemburg		100.00 %
Spain		86.05 %
Sweden		5.66 %
***Group L* – Low recycling rate** (< 36.7 % of total e-o-l material flow)		
Denmark	11.7 % (average recycling rate of countries in this group, weighted based on total e-o-l material flow)	7.48 %
Finland		74.65 %
Greece		100.00 %
Ireland		95.86 %
Italy		80.00 %
Netherlands		3.33 %
Portugal		77.14 %
United Kingdom		84.85 %
Switzerland		0.00 %

2.3 System models and material flows

The following flow charts are simplified illustrations of the material flows in the examined systems of the base scenarios. Numerical data regarding masses/quantities has not been included for reasons of confidentiality.

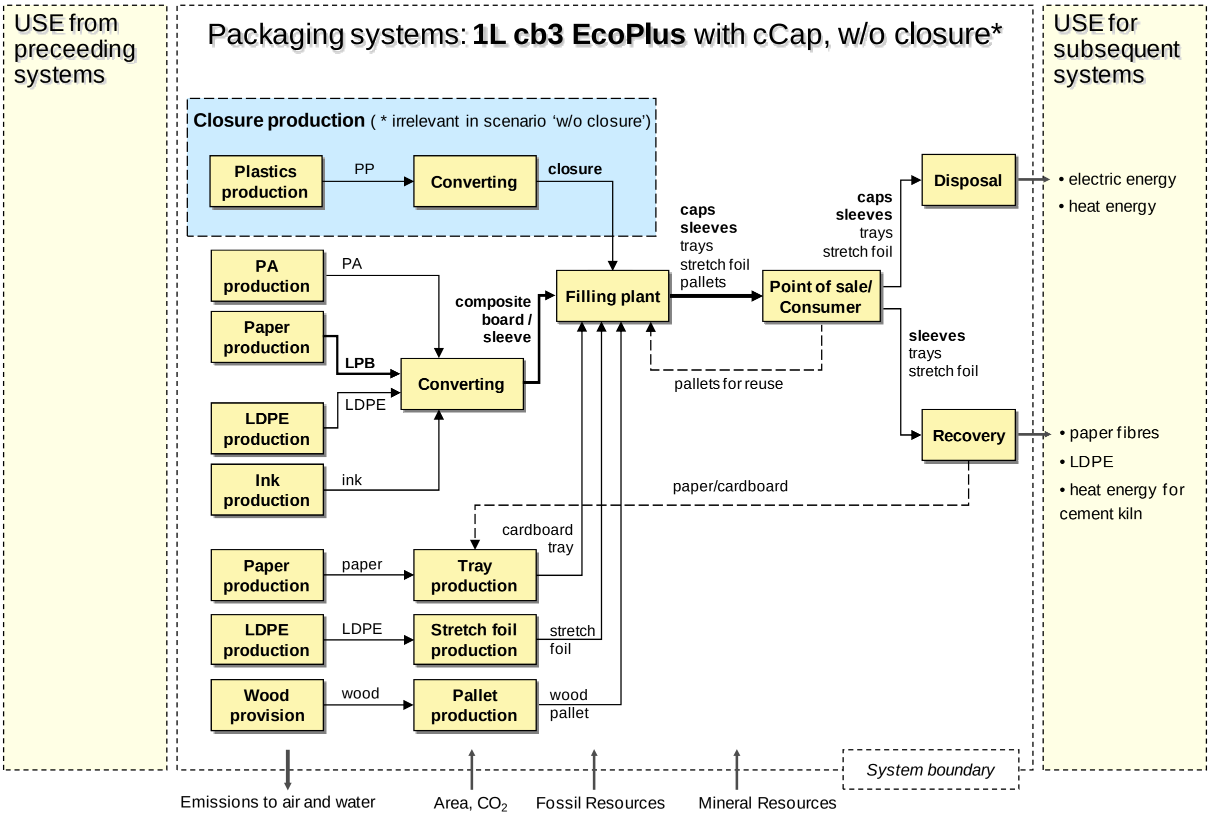

Figure 2-1: System flow chart for the beverage carton *cb3 Ecoplus* (1000 mL) for UHT milk – thicker arrows indicate major material flows

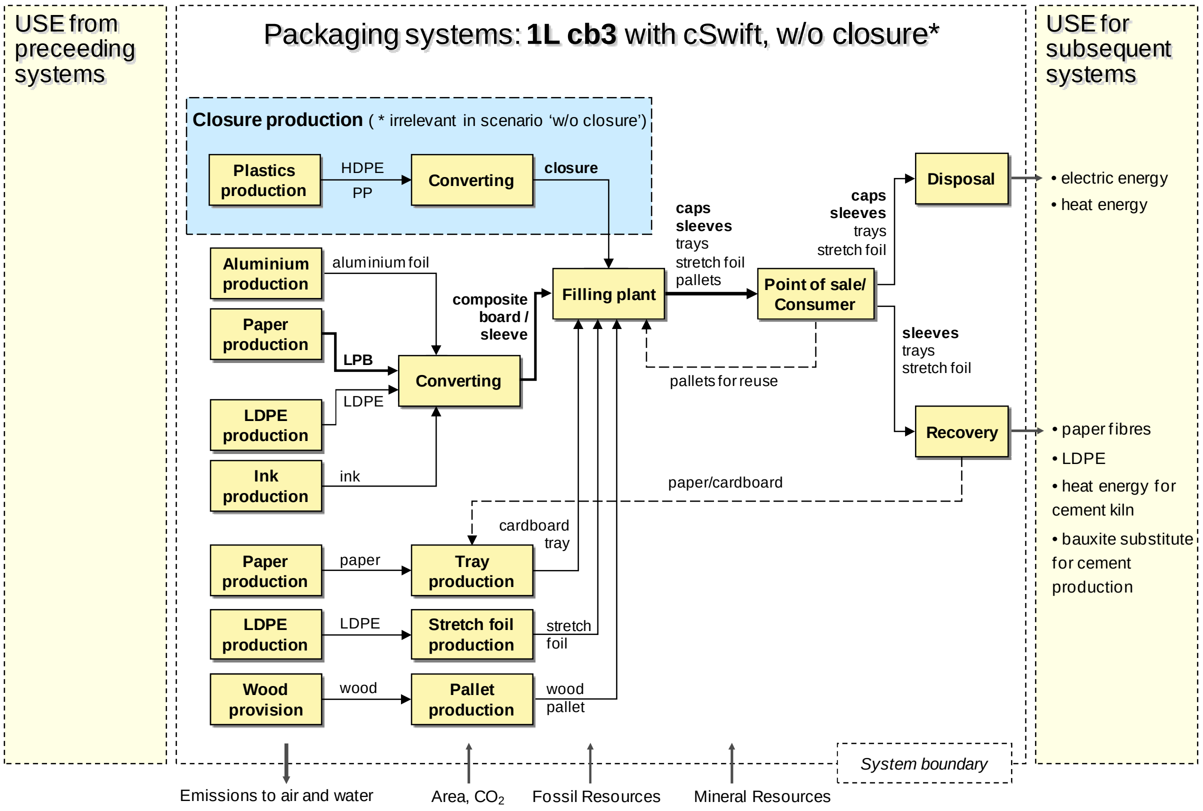

Figure 2-2: System flow chart for the beverage carton cb3 (1000 mL) for UHT milk – thicker arrows indicate major material flows

2.4 Scenarios

Apart from the base scenarios that are modelled according to the described system boundaries and scope described in section 1, this study also includes the evaluation of scenario variants considering different end-of-life parameters in order to reflect respective differences between countries in Western Europe. In addition to these variants two sensitivity analyses concerning system allocation will be conducted for the base scenarios.

2.4.1 Base scenarios

For each of the studied packaging systems, a base scenario is defined, which is intended to reflect the most realistic situation under the described scope. End-of-life conditions are modelled and calculated with West European average settings.

The following Table 2-4 shows an overview of the base scenarios that are modelled and lists their short names. In these base scenarios, the allocation factor applied for open-loop-recycling is 50%.

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

Base scenario	Short name
cb3 1000 mL EcoPlus with cCap, **29.473**g	cb3 EcoPlus cCap (base)
cb3 1000 mL EcoPlus without closure, **27.623** g	cb3 EcoPlus w/o closure (base)
cb3 1000 mL with cSwift, 30.333 g	cb3 cSwift (base)
cb3 1000 mL without closure, 27.623 g	cb3 w/o closure (base)

2.4.2 Scenario variants

While in the base scenarios average end-of-life conditions for Western Europe (EU15 & Switzerland) are assumed, the scenario variants modelled and calculated in this study shall provide indications of the picture arising for the single countries. The key question here is how the specific end-of-life settings influence the respective results. The methodology chosen is briefly described in the following.

Basic assumptions

a) For the regarded countries, there are two key elements that determine how the end of life of packaging products influences the results: the share of materials recovered in recycling processes and the final waste treatment or so-called ‘landfill/incineration split’. With this, two concrete parameters (e.g. the recycling and landfill rates) are sufficient to define specific end-of-life ‘scenarios’.

b) The relation between the key parameters and the calculated results is of linear nature.

Definition of variants (and presentation of results)

1) Based on their recycling rates, the 16 regarded countries are classified in two *groups*: one with ‘high’ recycling rates > 36.7% and another with ‘low’ recycling rates < 36.7% (*Group H* and *Group L*, respectively – see also Table 2-3).

2) The theoretically possible range of landfill rates that may occur is modelled by applying 3 different settings: high and low extremes (0% and 100%, respectively) as well as one intermediate (50%).

3) For both (recycling rate-based) country *groups*, each of the three (theoretical) landfill rate settings is calculated, leading to six distinct scenario variants (see Table 2-5 and Table 2-6).

4) The results are presented in linear graphs, in which the values between the calculated end-of-life scenarios, i.e. the six variants described in step 3), are interpolated, thus providing approximations of the outcomes for every possible disposal split.

5) These result graphs (see section 5.2) allow readings of approximations for country-specific results based on the classification of the country of interest in *Group H* and *Group L* and the respective landfill rate, both of which are listed in Table 2-3.

Overview of scenario variants

The following tables (2-5 and 2-6) give an overview of the scenario variants that are modelled and the corresponding short names used in the report and result graphs. As in the base scenarios, the allocation factor applied for open-loop-recycling is 50%.

Table 2-5: Scenario variants with low recycling rate: primary packaging element, mass and short name (as used e.g. in the result graphs)

Scenario variant L-0: low recycling rate, 0% landfill rate	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; low recycling rate – 0% landfill rate	cb3 EcoPlus cCap (L-0)
cb3 1000 mL EcoPlus without closure, 27.623 g; low recycling rate – 0% landfill rate	cb3 EcoPlus w/o closure (L-0)
cb3 1000 mL with cSwift, 30.333 g; low recycling rate – 0% landfill rate	cb3 cSwift (L-0)
cb3 1000 mL without closure, 27.623 g; low recycling rate – 0% landfill rate	cb3 w/o closure (L-0)
Scenario variant L-50: low recycling rate, 50% landfill rate	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; low recycling rate – 50% landfill rate	cb3 EcoPlus cCap (L-50)
cb3 1000 mL EcoPlus without closure, 27.623 g; low recycling rate – 50% landfill rate	cb3 EcoPlus w/o closure (L-50)
cb3 1000 mL with cSwift, 30.333 g; low recycling rate – 50% landfill rate	cb3 cSwift (L-50)
cb3 1000 mL without closure, 27.623 g; low recycling rate – 50% landfill rate	cb3 w/o closure (L-50)
Scenario variant L-100: low recycling rate – 100% landfill rate	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; low recycling rate – 100% landfill rate	cb3 EcoPlus cCap (L-100)
cb3 1000 mL EcoPlus without closure, 27.623 g; low recycling rate – 100% landfill rate	cb3 EcoPlus w/o closure (L-100)
cb3 1000 mL with cSwift, 30.333 g; low recycling rate – 100% landfill rate	cb3 cSwift (L-100)
cb3 1000 mL without closure, 27.623 g; low recycling rate – 100% landfill rate	cb3 w/o closure (L-100)

Table 2-6: Scenario variants with high recycling rate: primary packaging element, mass and short name (as used e.g. in the result graphs)

Scenario variant H-0: high recycling rate, 0% landfill rate	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; high recycling rate – 0% landfill rate	cb3 EcoPlus cCap (H-0)
cb3 1000 mL EcoPlus without closure, 27.623 g; high recycling rate – 0% landfill rate	cb3 EcoPlus w/o closure (H-0)
cb3 1000 mL with cSwift, 30.333 g; high recycling rate – 0% landfill rate	cb3 cSwift (H-0)
cb3 1000 mL without closure, 27.623 g; high recycling rate – 0% landfill rate	cb3 w/o closure (H-0)
Scenario variant H-50: high recycling rate, 50% landfill rate	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; high recycling rate – 50% landfill rate	cb3 EcoPlus cCap (H-50)
cb3 1000 mL EcoPlus without closure, 27.623 g; high recycling rate – 50% landfill rate	cb3 EcoPlus w/o closure (H-50)
cb3 1000 mL with cSwift, 30.333 g; high recycling rate – 50% landfill rate	cb3 cSwift (H-50)
cb3 1000 mL without closure, 27.623 g; high recycling rate – 50% landfill rate	cb3 w/o closure (H-50)
Scenario variant H-100: high recycling rate, 100% landfill rate	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; high recycling rate – 100% landfill rate	cb3 EcoPlus cCap (H-100)
cb3 1000 mL EcoPlus without closure, 27.623 g; high recycling rate – 100% landfill rate	cb3 EcoPlus w/o closure (H-100)
cb3 1000 mL with cSwift, 30.333 g; high recycling rate – 100% landfill rate	cb3 cSwift (H-100)
cb3 1000 mL without closure, 27.623 g; high recycling rate – 100% landfill rate	cb3 w/o closure (H-100)

2.4.3 Sensitivity analyses

In the base scenarios of this study, open-loop allocation is calculated with an allocation factor of 50% (see section 1.8). Following the ISO recommendation on subjective choices, sensitivity analyses are conducted in this study to verify the influence of the allocation method on the final results. For that purpose, an allocation factor of 100% is applied in a ‘sensitivity analysis 100’. The following table (2-7) gives an overview of the respective scenario models and the corresponding short names used in the report and result graphs.

Table 2-7: ‘Sensitivity analysis 100’ regarding allocation factor 100% for open-loop recycling: primary packaging element, mass and short name (as used e.g. in the result graphs)

Sensitivity analysis 100	Short name
cb3 1000 mL EcoPlus with cCap, **29.473** g; allocation factor 100%	cb3 EcoPlus cCap (SA-AF100)
cb3 1000 mL EcoPlus without closure, 27.623 g; allocation factor 100%	cb3 EcoPlus w/o closure (SA-AF100)
cb3 1000 mL with cSwift, 30.333 g;’ allocation factor 100%	cb3 cSwift (SA-AF100)
cb3 1000 mL without closure, 27.623 g; allocation factor 100%	cb3 w/o closure (SA-AF100)

3 Life cycle inventory

Process data on packaging material production and converting were either collected at the industry or taken from literature and *IFEU*’s internal database respectively. Data on background processes on energy generation, transportation as well as for waste treatment and recycling are continuously updated internally by *IFEU*; for this study the most recent format was drawn upon. On the next page, Table 3-1 gives an overview on packaging raw materials and process and background datasets that were used, followed by short descriptions of datasets relevant for the present study.

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

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

Material / Process step	Source	Reference period
Raw materials		
LDPE	Plastics Europe, published online March 2005	1999
HDPE	Plastics Europe, published online March 2005	1999
PP	Plastics Europe, published online March 2005	1999
PA 6	Plastics Europe, published online March 2005	1999
Aluminium	EAA Environmental Profile report 2008	2005
Corrugated cardboard	[FEFCO 2006]	2005
LPB	IFEU data, obtained from ACE [ACE 2009]	2002/2004
Production		
BC converting	SIG Combibloc 2009	2008
closure production	SIG Combibloc 2010	2008
Filling		
filling process	SIG Combibloc 2009	2008
Recovery		
Beverage carton	[ACE 2009], [Eurostat 2010]	2008
Background data		
electricity production, Finland	IFEU database, based on statistics and power plant models	2004
electricity production, Sweden	IFEU database, based on statistics and power plant models	2004
electricity production, EU15 + Switzerland	IFEU database, based on statistics and power plant models	2007
MSWI	IFEU database, based on statistics and incineration plant models	2008
Landfills	IFEU database, based on statistics and landfill models	2008
lorry transport	IFEU database, based on statistics and transport models, emission factors based on HBEFA 3.1 [INFRAS 2010].	2009
rail transport	[Borken et al. 1999]	1999
sea ship transport	[Buhaug et al. 2008]	

3.1 Manufacture of plastics

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

- Low density polyethylene (LDPE)
- High density polyethylene (HDPE)
- Polypropylene (PP)
- Polyamide (PA)

3.1.1 Low density polyethylene

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

The data set covers the production of LDPE granulates from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the 1999 time period and were acquired from a total of 27 polymerisation plants producing 4,480,000 tonnes of LDPE annually. The total production in Europe in 1999 was ca. 4,790,000 tonnes. The data set hence represented 93.5% of LDPE production in Western Europe.

3.1.2 High density polyethylene

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 (data last calculated March 2005) [Plastics Europe 2005b].

The data set covers the production of HDPE granulates right from the extraction of the raw materials from the natural environment, including processes associated with this. The data refer to the 1999 time period and were acquired from a total of 24 polymerisation plants producing 3,870,000 tonnes of HDPE annually. The total production in Europe in 1999 was ca. 4,310,000 tonnes. The data set hence represented 89.7% of HDPE production in Western Europe.

3.1.3 Polypropylene

Polypropylene (PP) is produced by catalytic polymerisation of propylene into long-chained polypropylene. The two important processing methods are low pressure precipitation polymerisation and gas phase polymerisation. In a subsequent processing stage the polymer powder is converted to granulate using an extruder.

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

3.1.4 Polyamide (PA 6)

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

3.2 Production of primary material for aluminium bars and foils

The data set for primary aluminium covers the manufacture of aluminium ingots starting from bauxite extraction, via aluminium oxide manufacture and on to the manufacture of the final aluminium bars. This includes the manufacture of the anodes and the electrolysis. The data set is based on information acquired by the European Aluminium Association (EAA) covering the year 2005. Respectively, this represented 90% to 92% of the single production steps alumina production, past and anode production, as well as electrolysis and casthouse of the primary aluminium production in Europe [EAA 2008].

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

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

3.3 Production of liquid packaging board (LPB)

The production of liquid packaging board (LPB) was modelled using data gathered from Nordic board producers. It covers data from four different production sites where more than 95% of European LPB is produced.

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

3.4 Corrugated board and cardboard trays

For the manufacture of corrugated cardboard and corrugated cardboard packaging the data sets published by FEFCO in 2006 [FEFCO 2006] were used. More specifically, the data sets for the manufacture of ‘Kraftliners’ (predominantly based on primary fibres), ‘Testliners’ and ‘Wellenstoff’ (both based on waste paper) as well as for corrugated cardboard packaging were used. The data sets represent weighted average values from European locations recorded in the FEFCO data (see also Table 3-2). They refer to the year 2005.

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

Cardboard material	Publication date	Reference year	Representative-ness	Production countries covered
Kraftliner	2006	2005	>80%	AT, FI, FR, PL, SK, SE
Testliner	2006	2005	51%	AT, BE, CZ, FR, DE, IT, NL, ES, GB
Wellenstoff	2006	2005		
Corrugated cardboard and trays	2006	2005	24% (162 plants)	AT, BE, CZ, DK, EE, FI, FR, DE; GR, HU, LV, IT, LT, NL, NO, PL, RU, ES, SE, CH, GB

In order to ensure stability, a fraction of fresh fibres is often used for the corrugated cardboard trays. According to [FEFCO 2006] this fraction on average is 18% in Europe. Due to a lack of more specific information, this split was also used for the present study.

3.5 Beverage carton 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. 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.

3.6 Filling

Filling processes are similar for beverage cartons and bottles regarding 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 will be conducted with filling data from *IFEU*'s internal database, which relies on information from different fillers and filling machine manufacturers.

3.7 Recovery and recycling

Beverage cartons

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 or incineration in a MSWI plant. Related process data used are taken from *IFEU*'s internal database, referring to the year 2008.

Substitution factors

As indicated in section 1.8 (Allocation), 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: as a material is recycled after a (first) use, it often loses some of its original qualities.

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 *IFEU*'s contacts with the respective material branches and information gathered through previous work:

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

3.8 Transport settings for distribution

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 400 km has been selected in context of the present study for all types of packages examined.

The 400 km transport distance is implemented in the model as a two-stage delivery to retailers, where the first step indicates the transport to a central warehouse, and the second represents the delivery from a central warehouse to the supermarket (point-of-sale).

The overall structure of the distribution model is shown in Figure 3-1 and distances and assumed lorry types are summarized in Table 3-4. It is aimed to include typical lorry specifications in this study.

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

In the life cycle model, environmental loads related to distribution have been allocated between 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 3-3: Transport distances and means

		Transport defined by distance and mode [km / mode]		
Packaging element		**Material producer to converter**	**Converter to filler**	**Filler to point of sale (retailer)**
cb3, cb3 EcoPlus				
Plastic granulates for caps and composite board		500 / road		
Aluminium for composite board		350 / road 300 / river 100 / rail		
Paper board for composite board		100 / 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		
Converted carton sleeves			700 / road	
Caps			700 / road	
LDPE stretch foil		500/road (material production site = converter)		
Trays			500 / road	
Pallets			100 / road	
Distribution / pallet configuration				400 / road

Table 3-4 also shows numbers for an ‘empty transport distance’, which is to be understood as the part of the lorry’s return trip, during which the vehicle is not carrying a load. For example in case of distribution step 1, the lorry travels a distance of 100 km without carrying any goods, after that it is assumed to be loaded with other products. In other words, only environmental loads for the ‘empty’ part return trip (100 km in this example) of the lorry are assigned to the analysed beverage carton systems. The remaining part of the return trip, during which the lorry is transporting other goods, would be assigned to these products.

Table 3-4: Overview on transport distances and lorry types for distribution to point of sale

	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	**300 km**	**100 km**	50 %	50 %	0 %	0 %
Distribution – Step 2	**100 km**	**60 km**	34 %	0 %	33 %	33 %
Total distance	**400 km**	**160 km**				

Based on internally available (but confidential) distribution data an empty return trip with 33% of the distance of the fully loaded trip was assumed. However, these data indicate that for short-distance transports, the 33% rule typically underestimates the empty return trip. As a consequence, based on expert estimate, a minimum empty transport distance of 60 km is applied if the full trip distance is smaller than 180 km. For example in the case of distribution step 2, an empty return trip of 60 km is assumed although the full trip distance is only 100 km. Figure 3-2 shows a graphic overview of the empty return trip model applied.

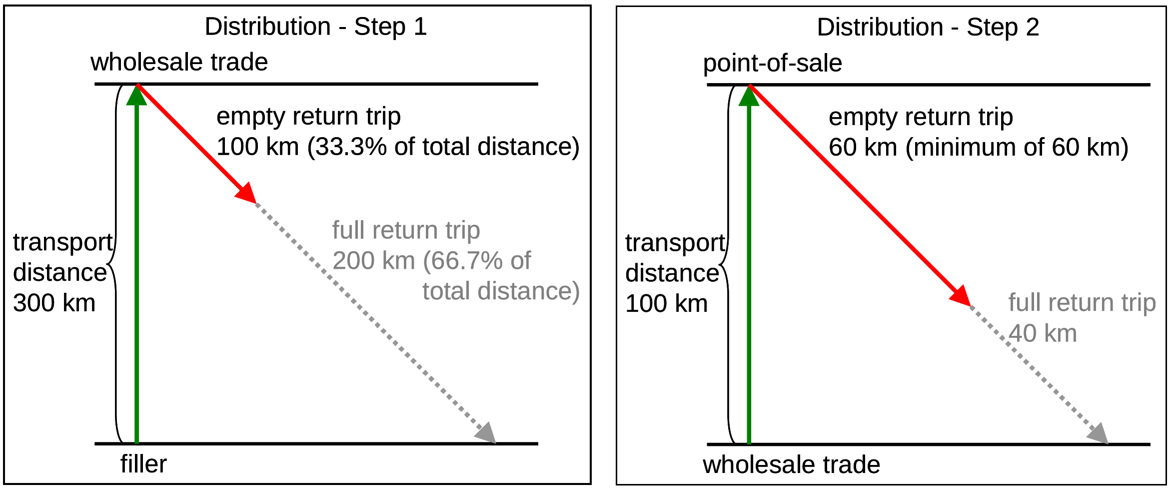

Figure 3-2: Overview on empty return trips allocated to the different distribution steps

3.9 Background data

3.9.1 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 2004]. The 'Handbook' is a database application referring to the year 2004 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 2003.

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

Rail transport

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

Ship transport

The dataset mentioned in the previous section on rail transport represents freight transport with an overseas container ship capacity between 9,000 and 23,000 tonnes. Energy use is based on an average fleet composition of this ship category and is based on data taken from [Borken et al. 1999]. Emission factors based on fuel consumption have been applied. Heavy fuel oil is the fuel used in container ship transports and its elemental composition is based on international average values. Similar to other diesel-fuelled transport operations, CO_2 and SO_2 emissions are calculated based on elemental composition of heavy fuel oil. Other emission factors are related to fuel consumption. More recent data on ship transport is available from [Buhaug et al. 2008]. As this source only lists CO_2 emissions it is only used to crosscheck the data used for the modelling of this study. This crosscheck of data resulted in a confirmation of the assumed emissions based on [Borken et al. 1999].

3.9.2 Electricity generation

Modelling of electricity generation is particularly relevant for the production of base materials as well as for converting and filling processes. Electricity generation is considered using Swedish and Finnish mix of energy suppliers in the year 2004 for the production of paperboard and the West European mix of energy suppliers (EU15 + Switzerland) in the year 2007 for converting and filling processes.

The mix of energy suppliers to the respective electricity networks was determined by using data from the Statistical Office of the European Communities. [EUROSTAT 2004].

3.9.3 Landfills

The landfill model accounts for the emissions and the consumption of resources for the deposition of domestic wastes on a sanitary landfill site. As information regarding an average landfill standard in Europe is currently not available, assumptions regarding the equipment with and the efficiency of the landfill gas capture system (the two parameters which determine the net methane recovery rate) had to be made.

Besides the parameters determining the landfill standard, another relevant system parameter is the degree of degradation of the food carton material on a landfill. Empirical data regarding degradation rates of laminated 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.

3.9.4 Municipal waste incineration

It is assumed that from the energy content in the incinerated waste, 11% is recovered as electricity and 30% as thermal energy. 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 European grid electricity (EU27 grid). Thermal energy recovered in MSWI plants is assumed to serve as process heat, replacing process heat generated by light fuel oil (50%) and natural gas (50%). The latter mix of energy sources is an assumption made by *IFEU*, as official data regarding this aspect are not available according to the knowledge of the authors of this study.

4 Results of the life cycle inventory and impact assessment

In this section the results of the examined packaging systems are presented (a) in graphic form and (b) in tables with numerical data, but always separately for the different indicators. The methodology of the life cycle impact assessment is documented in Appendix A.

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

- the production and transport of liquid packaging board (**‘liquid packaging board’**)
- the production and transport of LDPE for the beverage carton sleeves (**‘plastics for sleeve’**)
- the production and transport of aluminium (**‘aluminium’**)
- the production and transport of closures (**‘closure’**)
- the converting processes of sleeve composite for beverage cartons (**‘converting’**)
- the production of secondary and tertiary packaging: wooden pallets, LDPE shrink foil and corrugated cardboard trays (**‘secondary & tertiary packaging’**)
- the filling process including packaging handling (**‘filling’**)
- retail of the packages from filler to the point-of-sale (**‘distribution’**)
- sorting, recycling and disposal processes (**‘recycling & disposal’**)

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

The credits are shown in form of separate bars in the LCA result graphs (figures 4-1, 4-2 and 4-3). They are broken down into:

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

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

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

- sectoral results of the packaging system itself (stacked bar ‘**system results**’)
- 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 indicator results refer to the primary and transport packaging material flows required for the delivery of 1000 L milk to the point of sale including the end-of-life of the packaging materials.

Note that in the following sections (description, comparison and interpretation of results), differences ≤ 10% are considered as insignificant in accordance with the common practice for LCA studies comparing different product systems.

4.1 Presentation of results

Figure 4-1, Figure 4-2 and Figure 4-3 on the following pages illustrate the quantitative results for the base scenarios regarded in the current LCA study by impact/inventory level category. The stacked bar graphs allow the identification of the relative contribution of certain parts of the packaging system (life cycle 'elements') as well as credits to the respective final result. Table 4-1 subsequently provides corresponding numerical result values in cumulated form in order to facilitate attribution to selected parts of the life cycle.

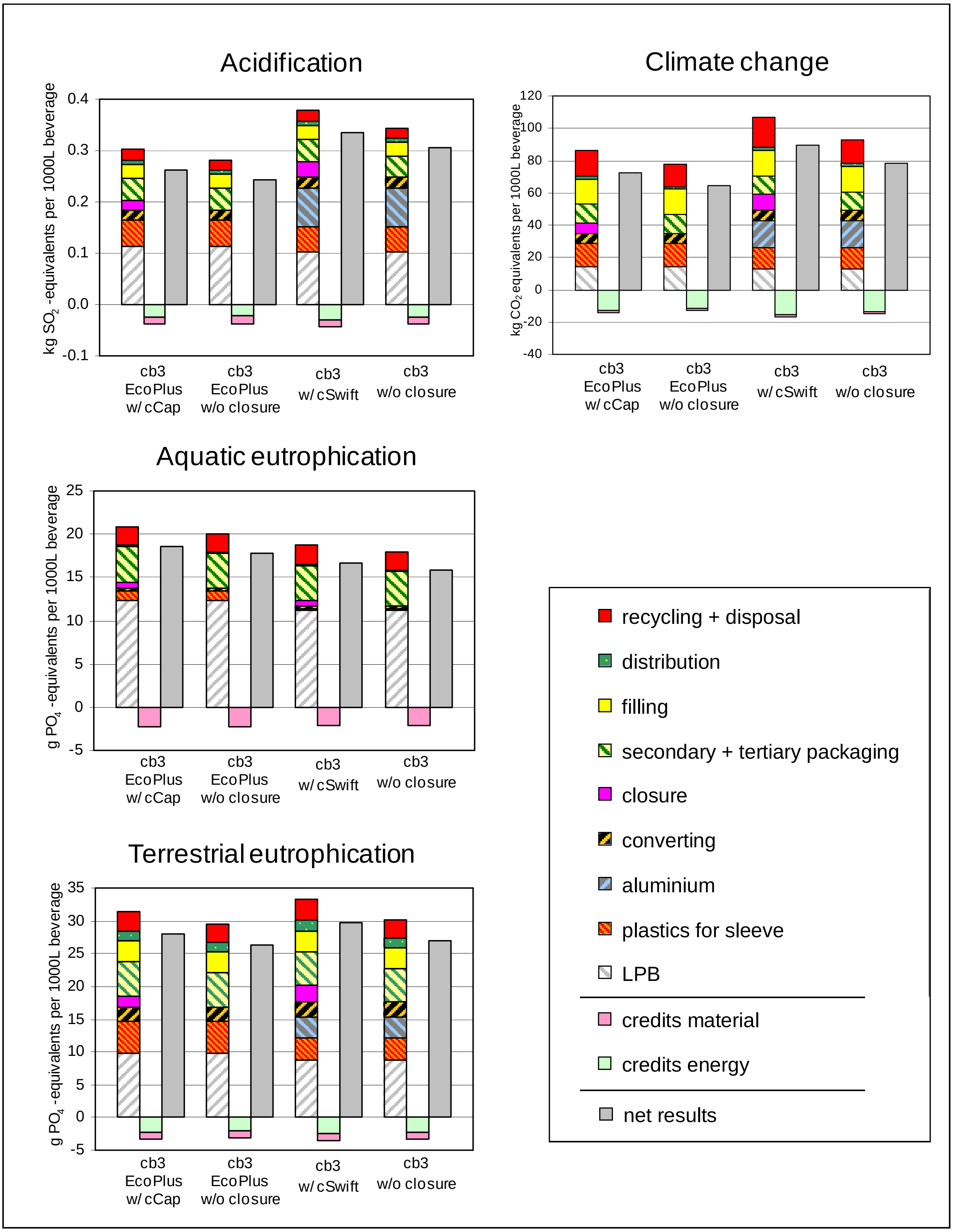

Figure 4-1: Indicator results for base scenarios, allocation factor 50% (Part I)

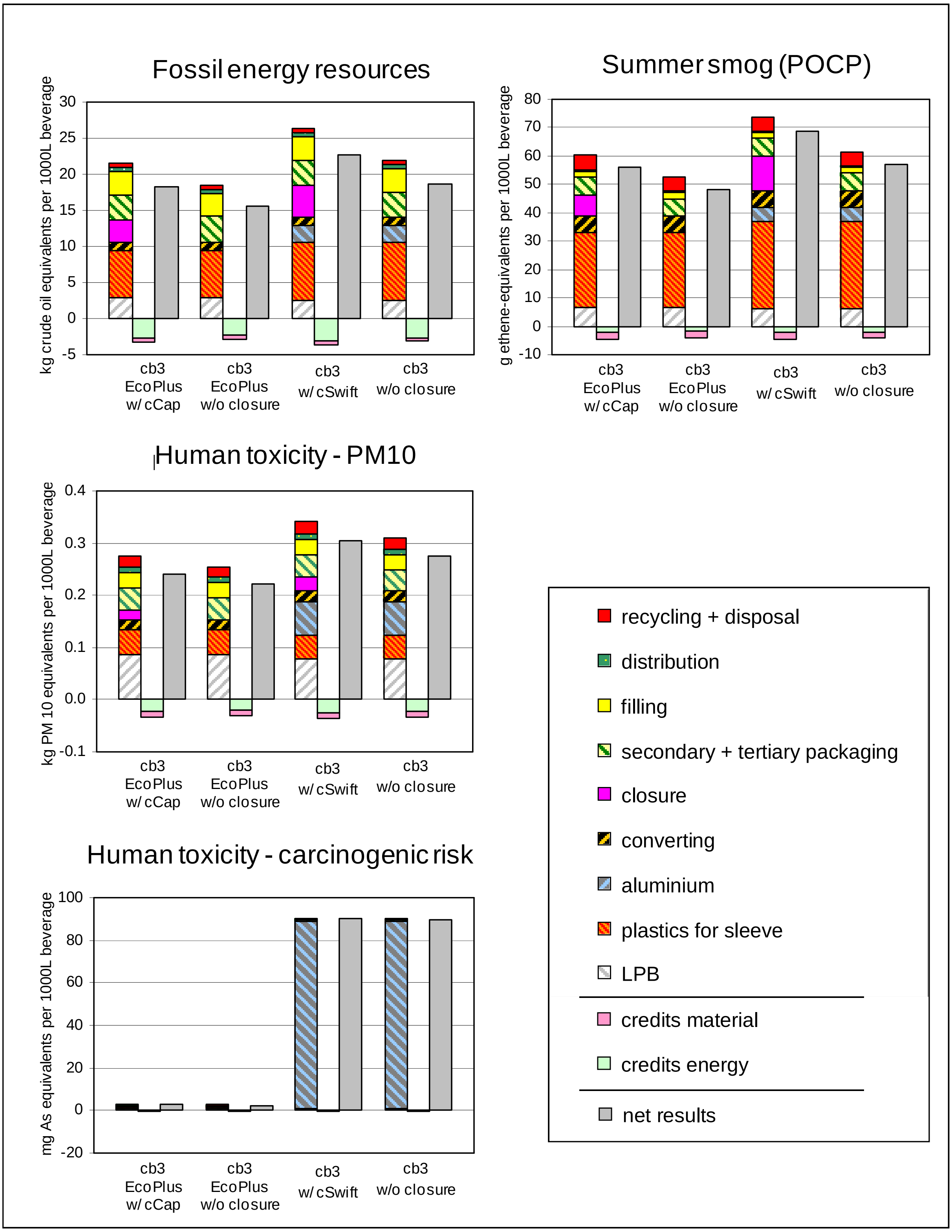

Figure 4-2: Indicator results for base scenarios, allocation factor 50% (Part II)

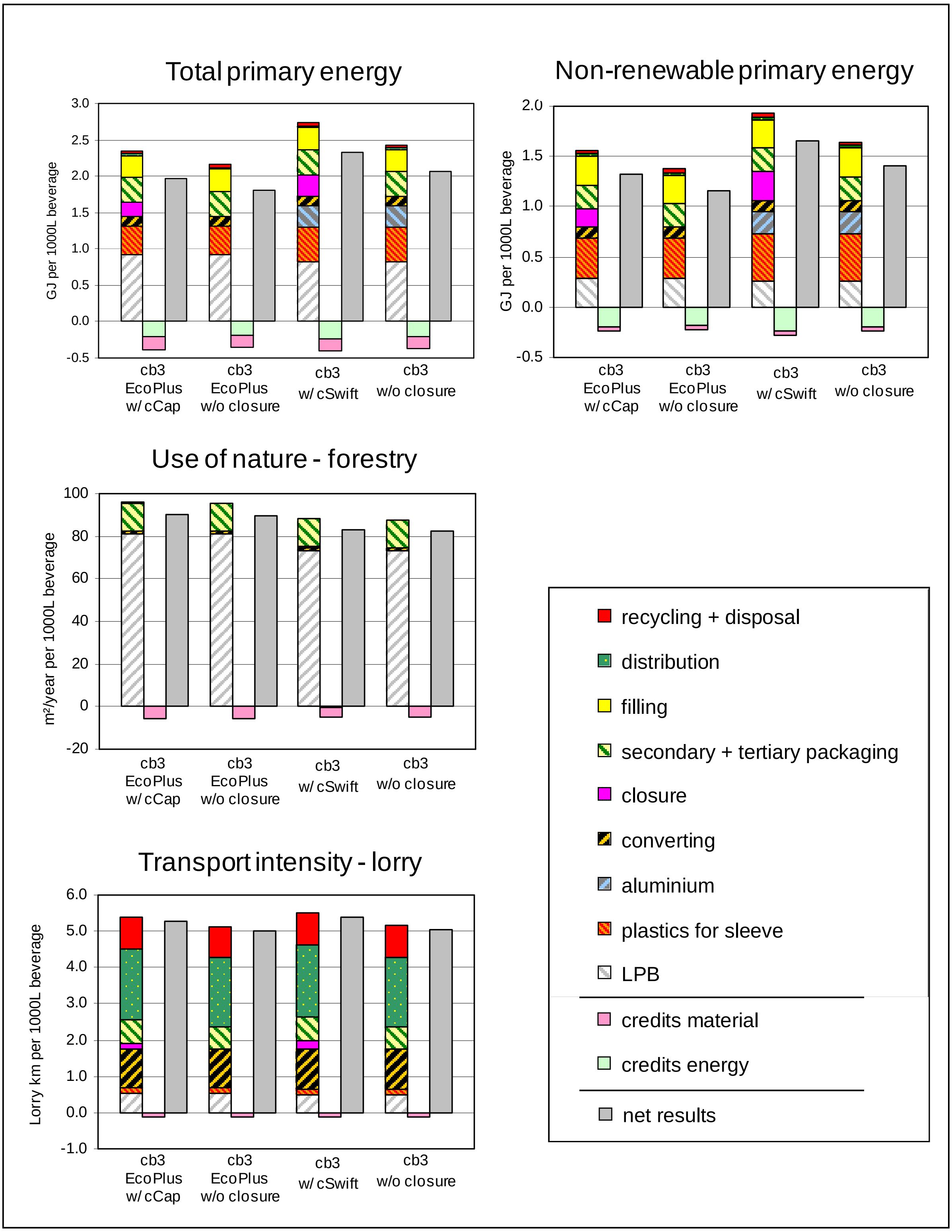

Figure 4-3: Indicator results for base scenarios, allocation factor 50% (Part III)

Table 4-1 provides result values for the base scenarios, cumulated for 2 parts of the life cycle and for the respective credits. The reason for dividing the life cycle into 2 parts is that the commissioner specifically plans to derive figures from this report for the purpose of developing an on-pack declaration regarding its ‘cradle-to-gate carbon footprint’ (see also section 1.3 *Use of the study, target audience and critical review*). *Part A* therefore covers the steps referred to in the graphs as ‘*liquid packaging board*’, ‘*plastics for sleeve*’, ‘*aluminium foil*’, ‘*closure*’ (where applicable) and ‘*converting*’. *Part B* includes ‘*secondary & tertiary packaging*’, ‘*filling*’, ‘*distribution*’ and ‘*recycling & disposal*’. *Credits* refers to the benefits from end-of-life processes leading to the recovery of material and/or energy, i.e. the figures represent the sum of ‘*credits material*’ and ‘*credits energy*’.

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,
Credits: Benefits from end of life processes (material and energy recovery)

Base scenarios		**cb3 EcoPlus cCap**	**cb3 EcoPlus w/o closure**	**cb3 cSwift**	**cb3 w/o closure**
Acidification [kg SO_2 equivalents]	*LC part A*	0.20	0.18	0.28	0.25
	LC part B	0.10	0.10	0.10	0.10
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.26	0.24	0.33	0.31
Climate change [kg CO_2 equivalents]	*LC part A*	41.39	34.97	59.00	48.95
	LC part B	45.20	42.52	47.83	43.89
	Credits	-14.48	-12.98	-16.97	-14.58
	Net results (∑)	72.11	64.51	89.87	78.26
Aquatic eutrophication [g PO_4 equivalents]	*LC part A*	14.45	13.71	12.29	11.61
	LC part B	6.43	6.31	6.50	6.32
	Credits	-2.29	-2.28	-2.09	-2.08
	Net results (∑)	18.60	17.74	16.70	15.85
Terrestial eutrophication [g PO_4 equivalents]	*LC part A*	18.55	16.90	20.17	17.59
	LC part B	12.87	12.59	13.03	12.63
	Credits	-3.31	-3.10	-3.59	-3.24
	Net results (∑)	28.11	26.39	29.62	26.99
Summer smog [g ethene equivalents]	*LC part A*	46.36	38.77	60.00	47.75
	LC part B	13.93	13.82	13.68	13.52
	Credits	-4.49	-4.24	-4.76	-4.36
	Net results (∑)	55.81	48.36	68.92	56.91
Human toxicity – PM10 [kg PM10 equivalents]	*LC part A*	0.17	0.15	0.24	0.21
	LC part B	0.10	0.10	0.10	0.10
	Credits	-0.03	-0.03	-0.04	-0.03
	Net results (∑)	0.24	0.22	0.30	0.28
Human toxicity – carcinogenic risk [mg As equivalents]	*LC part A*	1.79	1.67	89.14	88.93
	LC part B	1.09	1.06	1.12	1.07
	Credits	-0.26	-0.23	-0.31	-0.27
	Net results (∑)	2.63	2.50	89.95	89.73

(Table 4-1 continued)

Base scenarios		**cb3 EcoPlus cCap**	**cb3 EcoPlus w/o closure**	**cb3 cSwift**	**cb3 w/o closure**
Fossil resource consumption [kg crude oil equivalents]	*LC part A*	13.60	10.64	18.46	14.05
	LC part B	7.89	7.84	7.91	7.85
	Credits	-3.20	-2.92	-3.60	-3.16
	Net results (∑)	18.29	15.55	22.77	18.74
Use of nature - forestry [m² * year]	*LC part A*	82.66	82.17	75.24	74.51
	LC part B	13.13	13.13	13.13	13.13
	Credits	-5.56	-5.53	-5.10	-5.04
	Net results (∑)	90.23	89.78	83.27	82.60
Total primary energy (PE) [GJ]	*LC part A*	1.64	1.45	2.02	1.72
	LC part B	0.71	0.71	0.72	0.71
	Credits	-0.38	-0.36	-0.40	-0.36
	Net results (∑)	1.97	1.80	2.33	2.07
Non-renewable PE [GJ]	*LC part A*	0.98	0.80	1.35	1.06
	LC part B	0.58	0.58	0.58	0.58
	Credits	-0.24	-0.22	-0.27	-0.24
	Net results (∑)	1.32	1.16	1.66	1.41
Transport intensity (lorry) [km]	*LC part A*	1.92	1.76	2.00	1.76
	LC part B	3.48	3.37	3.52	3.39
	Credits	-0.13	-0.13	-0.12	-0.12
	Net results (∑)	5.26	5.00	5.40	5.03

4.2 Description by systems

New beverage carton ‘*cb3 EcoPlus*’

In all impact/indicator categories covered in this study, the biggest part of the environmental loads originate from the production, provision and/or recycling of the (material) components of the beverage carton (and closure). While for ‘*Aquatic eutrophication*’ and ‘*Use of nature - forestry*’ the LPB clearly dominates the results, in most other categories, the other components are more determining. However it still plays the relatively greatest role regarding ‘*Acidification*’, ‘*Terrestrial eutrophication*’, ‘*Total primary energy*’ and, but for the *EcoPlus* variant only, ‘*Human toxicity - PM10*’. The closure has a minor influence on the results for ‘*Aquatic entrophication*’, ‘*Human toxicity - carcinogenic risk*’, ‘*Use of nature - forestry*’ and ‘*Transport intensity - lorry*’. In all categories except ‘Human toxicity - *carcinogenic risk*’ the secondary (and tertiary) packaging also contribute visibly to the environmental loads determined for the regarded systems, however to a lesser extent.

The filling process causes the relatively largest contribution for ‘*Climate change*’; it also causes visible environmental loads regarding the consumption of ‘*Primary energy*’ (both total and non-renewable) as well as of ‘*Fossil energy* resources’.

While the distribution of the final good dominates the '*Transport intensity - lorry*' its contribution to the environmental loads of the other regarded categories are much less significant, or even insignificant.

The packaging's end of life, i.e. recycling and disposal processes, contributes most significantly to the final results in the categories '*Climate change*' and '*Transport intensity - lorry*'. It is also relevant for both the aquatic and terrestrial *eutrophication* potentials as well as '*Summer smog*' and '*Human toxicity - PM10*'. For '*Acidification*' as well as the consumption of '*Fossil energy resources*' and both total and non-renewable '*Primary energy*', its influence is still visible, however to a (much) lesser extent.

Depending on the specific environmental impact/indicator level category, the regarded packaging systems receive credits for material and/or energy recovery in different shares.

Established beverage carton '*cb3*'

All of the observations described in the previous section for the newly developed *EcoPlus* variant are also valid for the established *cb3* beverage carton system. Here, however, the aluminium foil included in the sleeve generally plays a visible role for the results, with the exception of the categories '*Aquatic eutrophication*', '*Use of nature - forestry*' and '*Transport intensity - lorry*'.

4.3 Comparison between systems

Several general differences between the two variants of the cb3 beverage carton system are apparent from the result graphs:

- In those categories, where the 'plastics for sleeve' play a visible role for the results, they are relatively more significant in the '*cb3 EcoPlus*' system.
- As the *EcoPlus* variant contains no aluminium, this material only appears in the balance of the established '*cb3'* beverage carton.
- The closure '*cCap*' used for the newly developed *EcoPlus* variant generally has smaller environmental loads than the closure 'c*Swift*' – except for 'A*quatic eutrophication*', where the difference is insignificant, however.

Acidification

The results regarding this impact category show the *EcoPlus* variant to have the more favourable results, i.e. the lower numerical values (net results about 1/4 lower). In both regarded systems, the production and provision of materials that make up the primary packaging play the relatively largest role: for the newly developed *EcoPlus* variant, the sleeve (LPB + plastics) accounts for less harmful emissions than it does in the established *cb3* system (where it additionally contains aluminium). For the latter, the LPB and aluminium shares of the sleeve are of very similar importance. Both beverage cartons receive almost the same amount of the total credits, with energy recovery playing a (slightly) greater role than material credits, which is more clear for the established *cb3* system.

Climate change

The comparison between the regarded packaging systems shows clearly more favourable results for the 'cb3 EcoPlus' variant: the environmental load of the established cb3 beverage carton is almost 1/4 higher. As is the case for the acidifying potential, the sleeve's contribution to the total greenhouse gas emissions is slightly greater in the established *cb3* system (approximately 50% versus 55% for the *EcoPlus* variant). In this category both systems receive a significant amount of credits, almost exclusively for energy recovered from the respective end-of-life treatments.

Aquatic eutrophication

In this category, the established *cb3* system accounts for less emissions than the newly developed *EcoPlus* variant. The difference is relatively small, however: taking the beverage carton's closure into account, the total environmental burden of the former is merely 10% lower than that of the latter. In analogy, the sleeve of the *EcoPlus* variant also accounts for a higher load than that of the established *cb3* beverage carton. In this category, only material credits play a role in both systems (slightly higher for the *EcoPlus* variant).

Terrestrial eutrophication

In contrast to '*Aquatic eutrophication*', the numerical results for '*Terrestrial eutrophication*' are lower for the *EcoPlus* variant, indicating a more favourable performance of the newly developed beverage carton in this category. However the difference is very small and may therefore be considered insignificant: the established *cb3*'s total emissions are merely 5% higher than those of the *EcoPlus* variant. In accordance with this picture, the load caused by the sleeve is also very similar for both regarded systems. The benefits from end-of-life processes support the reversed picture (as compared to that of the aquatic eutrophication potential): the *EcoPlus* variant receives slightly lower credits. For both systems energy credits play a relatively greater role.

Summer smog

In this category the *EcoPlus* variant clearly shows more favourable results than the established *cb3* system: its total emissions are approximately 20% lower than those of the latter. Although the sleeve's contribution to the total emissions is only insignificantly greater in the *cb3 EcoPlus* system (64% versus 65% for the established *cb3* system), the newly developed pack has the lower absolute values, especially visible for the plastic components (in sleeve and closure). In terms of credits, the results hardly differ for the two regarded systems (the *EcoPlus* variant receives insignificantly less credits); in both cases material recovery plays a slightly more important role.

Human toxicityy - PM10

The results for this impact category show a similar picture to that of '*Acidification'*. The *EcoPlus* variant delivers more favourable results, i.e. lower numerical values, with the net results for the established *cb3* system about 1/4 higher. Both beverage cartons receive very similar amounts of total credits; with energy recovery playing a greater role.

Human toxicity - carcinogenic risk

Here, the calculated values seem to indicate an extraordinary, almost exclusive relevance of aluminium. It must be noted, however, that an important data asymmetry exists between inventories used for different materials: the databases used for paper and plastic do not list the substances that are crucial in this impact category while the one applied for aluminium does. With this, the results in this category are not suited for conclusive interpretations and therefore not discussed further in this report.

Fossil resource consumption

The base scenario analysed for the *EcoPlus* variant is related with a clearly lower consumption of fossil (energy) resources than the established one *cb3* system (scenarios with closures: nearly 1/4 less total consumption). In terms of the credits, the two regarded systems do not differ significantly: in both cases, energy recovery is clearly more relevant than material recycling.

Use of nature - forestry

The comparison of the two packaging systems reveals that in correspondence with its higher LPB content, the *EcoPlus* variant requires more forest than established *cb3* (8% larger area demand). For the credits, only material recycling plays a (relatively small) role, with barely visible differences between the systems.

Total primary energy demand

The base scenario with the lowest primary energy (PE) demand is the one analysed for the *EcoPlus* variant (taking into account the closures: 18% lower than for established *cb3* system). It also receives slightly fewer credits, however the difference can be regarded as insignificant. While for the established *cb3* system, the recovery of energy plays a slightly greater role than material recycling, the difference is harly visible for the *EcoPlus* variant.

Non-renewable primary energy demand

A focus specifically on the non-renewable share of the systems' PE demands broadly confirms the overall picture and ranking of the individual systems for the total PE demand. The main difference is that a larger result range is covered: the *EcoPlus* variant's demand is 22% lower than that of the established *cb3* system. However the latter receives slightly more credits, which for both systems result mostly from energy recovery.

Transport intensity: Lorry

In this inventory category, the difference between the two regarded packaging systems is barely visible and insignificiant. This is also true for the minimal (material) credits, i.e. 'saved' lorry kilometres. Ultimately, the *EcoPlus* variant's performance is slightly more favourable.

5 Interpretation and discussion

In the following, the results presented in the previous sections are interpreted and discussed. After significant parameters and characteristic patterns shown in the base scenarios are evaluated and explained (5.1), variants and sensitivity analyses serve the purpose of verifying specific aspects, such as the significance of assumptions made in the study (5.2 and 5.3). A look at the consistency and completeness of data and methodologies used and an overview of the current LCA's limitations (5.4) complete the discussion.

5.1 Base scenarios: significant parameters and characteristic patterns

The results presented for the regarded packaging systems in the previous chapter allow the identification of specific parameters that are more or less significant for certain environmental impact/indicator categories as well as revealing some overall patterns. In the following, these observations are shortly listed (in summary from sections 4.2 and 4.3), and explanations are provided based on knowledge of processes and interrelations.

(a) For '*Aquatic eutrophication*' and the inventory category '*Use of nature: forest area*' the LPB appears to be of special importance. It is also clearly relevant (> 1/4) for the outcomes regarding '*Acidification'*, '*Terrestrial eutrophication*' and '*Total primary energy*'.

- The LPB is made practically entirely from paper fibres (cellulose).
- The production of paper (and cardboard) generates emissions that cause '*Aquatic eutrophication*' and, in a second measure and thus to a lesser extent, also '*Terrestrial eutrophication*'. With trees being the key source of primary paper fibres, land area is required to provide this raw material, which is reflected in the comparably high demand of the LPB for forest area (in this case in Northern Europe). The use of cardboard trays as secondary packaging likely increases the respective effects.
- For the separation of the cellulose needed for paper production from the lignous wood fibres, the so-called 'Kraft process' is applied, in which sodium hydroxide and sodium sulphide are used. A certain share of the sulphur input remains in the by-product that contains the lignin (black liquor), which undergoes an energy recovery process. Here, it is partly emitted as SO_2, thus contributing significantly to the *acidifying* potential.
- The energy required for paper production from wood is recovered from process-internal residues (hemicellulose and lignin soluted in black liquor), i.e. here, a certain amount of the process energy comes from renewable sources. However, additional input of electricity is needed, which becomes visible in the results for '*Total primary energy demand*'.

(b) Plastics (sleeve and closure) appear as especially relevant for '*Summer smog*' as well as for the consumption of '*Fossil energy resources*' and, to a lesser extent, '*Non-renewable primary energy*'.

  - Plastics contain fossil resources (crude oil) as a key raw material. Furthermore, plastic production processes are known to be quite energy-intensive. An increased consumption of '*Fossil energy resources*' is therefore likely to result from the use of electricity generated to a high share with fossil fuels This is also reflected in the results for '*Non-renewable primary energy*'.
  - The production of electricity generally generates relatively large amounts of emissions which cause '*Summer smog*', and as stated above, the production of plastics requires considerable electricity inputs as process energy.

(c) Regarding the '*Non-renewable primary energy demand*', plastics are clearly the most relevant material share in all regarded packaging systems.

  - As explained in the first point above under (b), plastic production relies primarily on non-renewable energy carriers. In contrast, the process energy needed for LPB production is partly generated on-site from renewable energy carriers such as wood. Both the renewable and non-renewable shares are included in the '*Total primary energy demand*'.

(d) For the regarded packaging systems, the end-of-life phase of is clearly most relevant in the impact category '*Climate change*' and '*Transport intensity - lorry'*, however it also visibly contributes to the emissions leading to '*Acidification'* and (both terrestrial and aquatic) *'Eutrophication'*.

  - A great share of the greenhouse gases (GHGs) generated during the regarded product life cycles come from the generation of energy 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*'.
  - The majority of transports connected to the end-of-life processes (e.g. municipal waste collection and transport to sorting/recycling facilities, cement kilns and MSWI plants) take place with lorries.
  - The contributions to the impact indicators *'Acidification'*, and '*Terrestrial eutrophication'* are mainly caused by NO_2 emissions from incineration plants.

(e) For the established *cb3* beverage carton system, the aluminium foil included in its sleeve plays a visible role in most regarded categories except ‘*Aquatic eutrophication*’, ‘*Use of nature - forestry*’ and ‘*Transport intensity - lorry*’.

- Compared to the other materials used in the regarded packaging systems, the production of aluminium ingots and the converting to aluminium foil is very energy-intensive, thus its visible influence on energy-related categories incl. ‘*Climate change*’.
- Being a metallic element, aluminium contains no organic substances and with its reliance on fossil energy resources, it causes no waterborne emissions that would have a eutrophicating effect.
- Even though nearly half of distance covered for the upstream transports of aluminium ingots and foils take place by lorry, the respective results (aluminium contribution to ‘*Transport intensity - lorry*’) is invisible due to the very light weight of this metal.

(f) In most cases, the closure *cCap* appears to have smaller environmental loads in the regarded categories than the *cSwift.* ‘*Aquatic eutrophication*’ is the exception to this rule.

- Although the two different closure systems are made from similar materials (PP for *cCap* and PP and HDPE for *cSwift) cCap* is about 1/3 lighter than *cSwift.*
- In contrast, the material composition likely is more relevant than the packaging weight for ‘*Aquatic eutrophication*’.

(g) Overall, the majority of credits are ‘energy credits’. ‘*Aquatic eutrophication*’ represents the most obvious exception: here, only material credits play a role. ‘*Use of nature - forestry*’ and ‘*Transport intensity - lorry*’ are similar cases.

- Energy credits originate from the use of materials as fuel in cement kilns at their end of life as well as from their final disposal in waste incineration plants where energy recovery takes place. In this context, the material characteristics are significant: the heating value determines the quantity of energy credits that it receives. Material credits are only given for material that is effectively recycled.
- Furthermore, while for material recycling, a 50% allocation factor comes into effect, none is applied to end-of-life incineration, because no consecutive product system uses the material. This further increases the relative significance of the energy credits in the result graphs.
- As pointed out in the second point above under (a), ‘*Aquatic eutrophication*’ is caused by waterborne emissions from processes, and paper production plays a major role here. More specifically, the transformation of raw wood to paper fibres is the determining step. Because the post-consumer recycling of paper fibres from the LPB reduces the need for this process (as secondary paper fibres substitute for primary fibres), this leads to (material) credits. Accordingly, the results of ‘*Use of nature: forestry*’ show a similar effect, as do those for ‘*Transport intensity - lorry*’ because the transports or recycled fibres are less long than those that would be necessary to provide the equivalent in primary fibres.

(h) In comparison between the two regarded packaging systems, the LPB generally plays a more significant role in the *cb3 EcoPlus* variant. Regarding the plastics integrated in the sleeve, the pattern varies. In most categories, their contribution are higher for the *cb3 EcoPlus* system, however for ‘*Terrestrial eutrophication*’, ‘*Summer smog*’ and the consumption of ‘*Fossil energy resources*’ as well as both *non-renewable* and *total ‘Primary energy*’ the established *cb3* is affected more – in spite of the fact that its sleeve contains less plastic.

- The *cb3 EcoPlus* beverage carton contains a greater share of LPB and less LDPE than the established *cb3* packaging, but additionally also PA. It appears likely that the latter is responsible for the respective higher specific results of the *EcoPlus* variant (5 categories listed above).
- ‘*Plastics for sleeve*’ include LDPE for all regarded packaging systems and additionally PA for the ‘*cb3 EcoPlus*’ system.

5.2 Scenario variants

While in the base scenarios average end-of-life conditions for Western Europe (EU15 & Switzerland) are assumed, the scenario variants modelled and calculated in this study shall provide indications of the picture arising for the single countries. The key question here is how the specific end-of-life settings influence the respective results. The methodology chosen is briefly summarised in the following. For more details see section 2.4.2.

1) Based on their recycling rates (% of BC's total e-o-l material flow), the 16 regarded countries are classified in two *groups*: *Group H* (countries with 'high' recycling rates > 36.7%) and *Group L* ('low' recycling rates < 36.7%) – for classification see Table 2-3.

2) Three different settings for landfill rates (% of country's specific final waste for BCs) are modelled: high and low extremes (100% and 0%, respectively) as well as one intermediate value (50%).

3) For both (recycling rate-based) country *groups*, each of the three (theoretical) landfill rate settings is calculated, leading to six distinct scenario variants (see Table 2-5 and Table 2-6).

4) The results are presented in linear graphs, in which the values between the calculated end-of-life scenarios, i.e. the six variants described in step 3), are interpolated, thus providing approximations of the outcomes for every possible disposal split.

5) These result graphs allow readings of approximate country-specific results based on the classification in *Group H* or *Group L* and the country's landfill rate (both listed in Table 2-3).

For an overview of the scenario variants that are modelled and the corresponding short names used in the report and result graphs, please see Table 2-5 and Table 2-6 in section 2.4.2. As in the base scenarios, the allocation factor applied for open-loop-recycling is 50%.

Several basic patterns that become visible in the results are described and discussed in the following. '*Human toxicity – carcinogenic risk*' is excluded from the evaluation for the reasons given in section 4.3.

- For all indicators, the ranking of the examined packaging systems amongst each other is the same as in the comparison of the base scenarios.
- The line graphs for the scenario variants (both of *Group H* and of *Group L*) illustrate that in most of the regarded environmental categories, the landfill rate has a certain influence on the packaging system's overall performance. How strong this influence (i.e. how big the gradient of the respective line) is, differs per category. For '*Terrestrial eutrophication'*, '*Human toxicity - PM10*', '*Use of nature - forestry'* and '*Transport intensity - lorry'* the line is nearly level, in other words, the share of final waste that is landfilled plays (almost) no role for the regarded packaging systems' performances in these categories. The strongest influence emerges for the consumption of '*Fossil energy resources'* and '*Non-renewable primary energy'*: in *Group L*, the net results calculated for a landfill rate of 100% are more than 40% higher than those for a 0% landfill rate (and the respective lines have the highest gradients). For the *cb3 EcoPlus* system, the landfill rate also plays an important role (difference still >30%) in these two inventory categories if the recycling rate is high (*Group H*). Regarding '*Climate change'*, this applies regardless of the recycling rate.

- The comparison between the results calculated for countries with higher recycling rates (*Group H*) and those with lower recycling rates (*Group L*) shows that this parameter is also more relevant in some of the regarded environmental categories (e.g. '*Terrestrial eutrophication'* and '*Use of nature - forestry'*) than in others.
- As mentioned in the first point above, regarding the packaging system's impact on climate change material recycling affects the results to a much lesser extent than the final disposal in a landfill. The explanation is related to the fact that the majority of carbon (C) contained in LPB is sourced from wood (i.e. a renewable resource) and originates from carbon dioxide (CO_2) drawn from the atmosphere during tree growth. In a landfill, a certain share of this biogenic C is re-emitted not only as CO_2 – which is not accounted for in the GWP calculation (for further explanation see the note on biogenic carbon in Appendix A, section A.1) – but also as methane (CH_4), which considerably increases the GWP per single C atom and therefore must be taken into account. If instead the carton is incinerated, then the contained C is of course also re-emitted, however mostly as CO_2, which is not valuated in the GWP calculation as its source is biogenic.

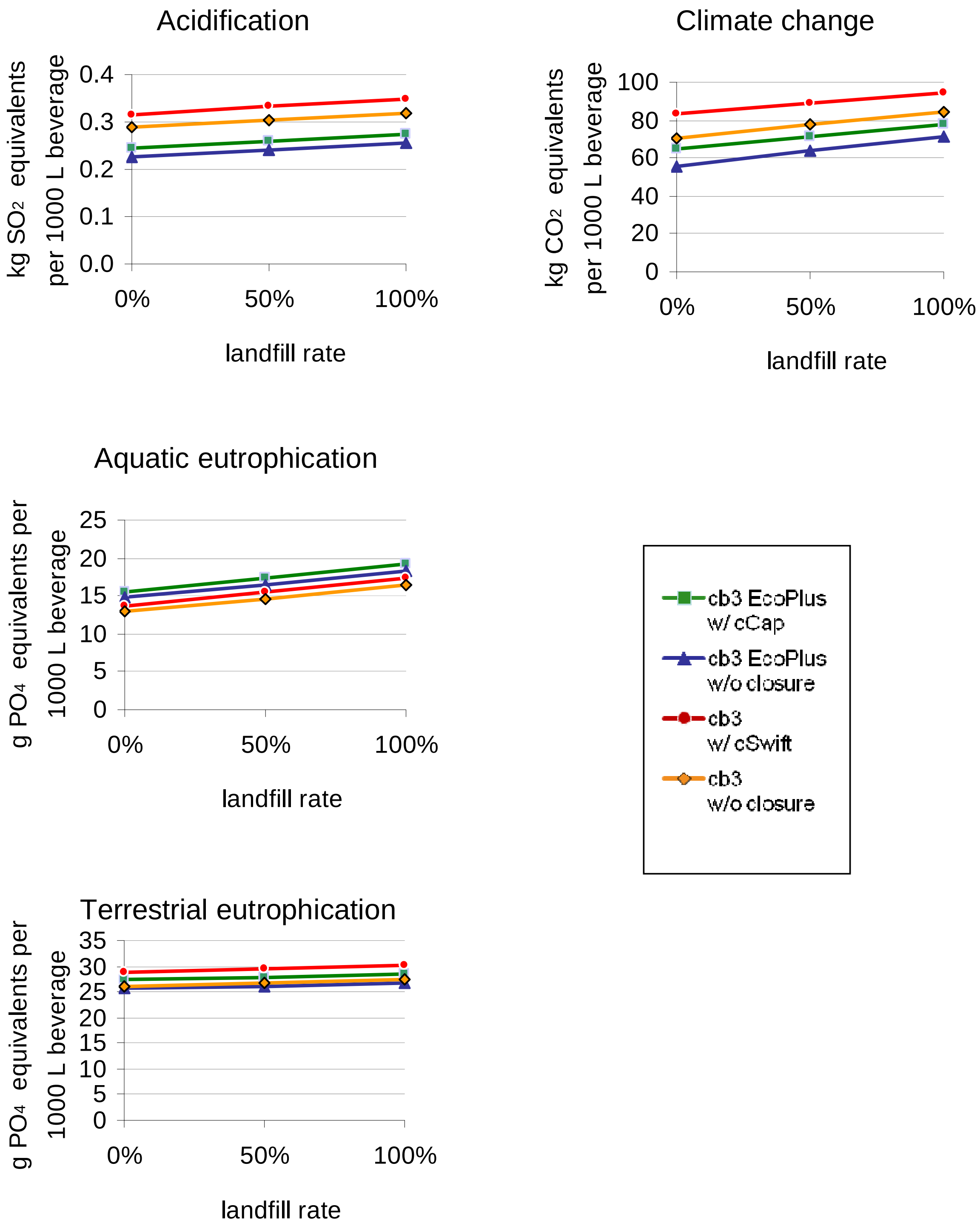

Figure 5-1: Net indicator results for scenario variants – Group H / recycling rate > 36.7% (Part I)

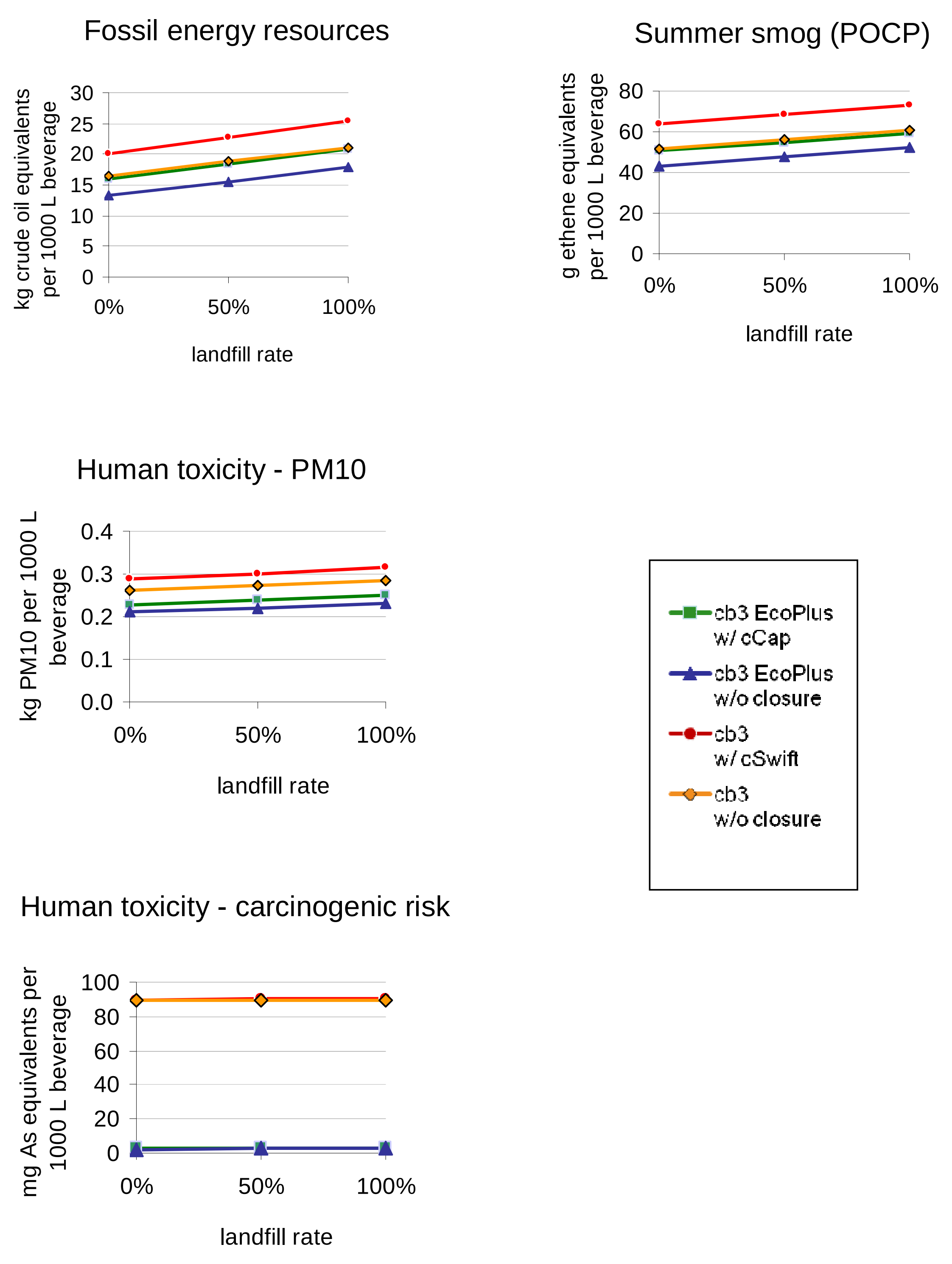

Figure 5-2: Net indicator results for scenario variants – Group H / recycling rate > 36.7% (Part II)

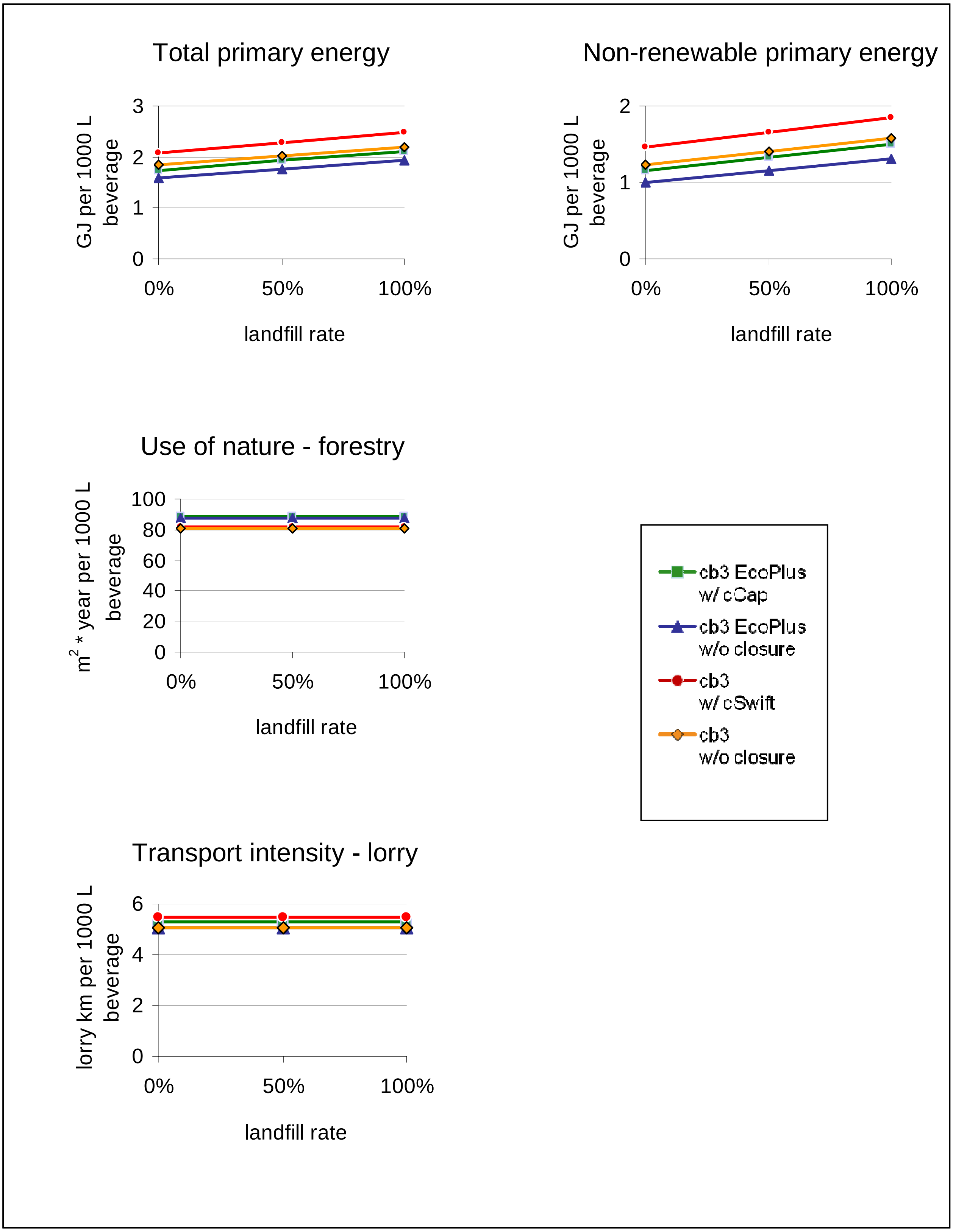

Figure 5-3: Net indicator results for scenario variants – Group H / recycling rate > 36.7% (Part III)

The result graphs for the scenario variants of *Group L* are presented on the following pages.

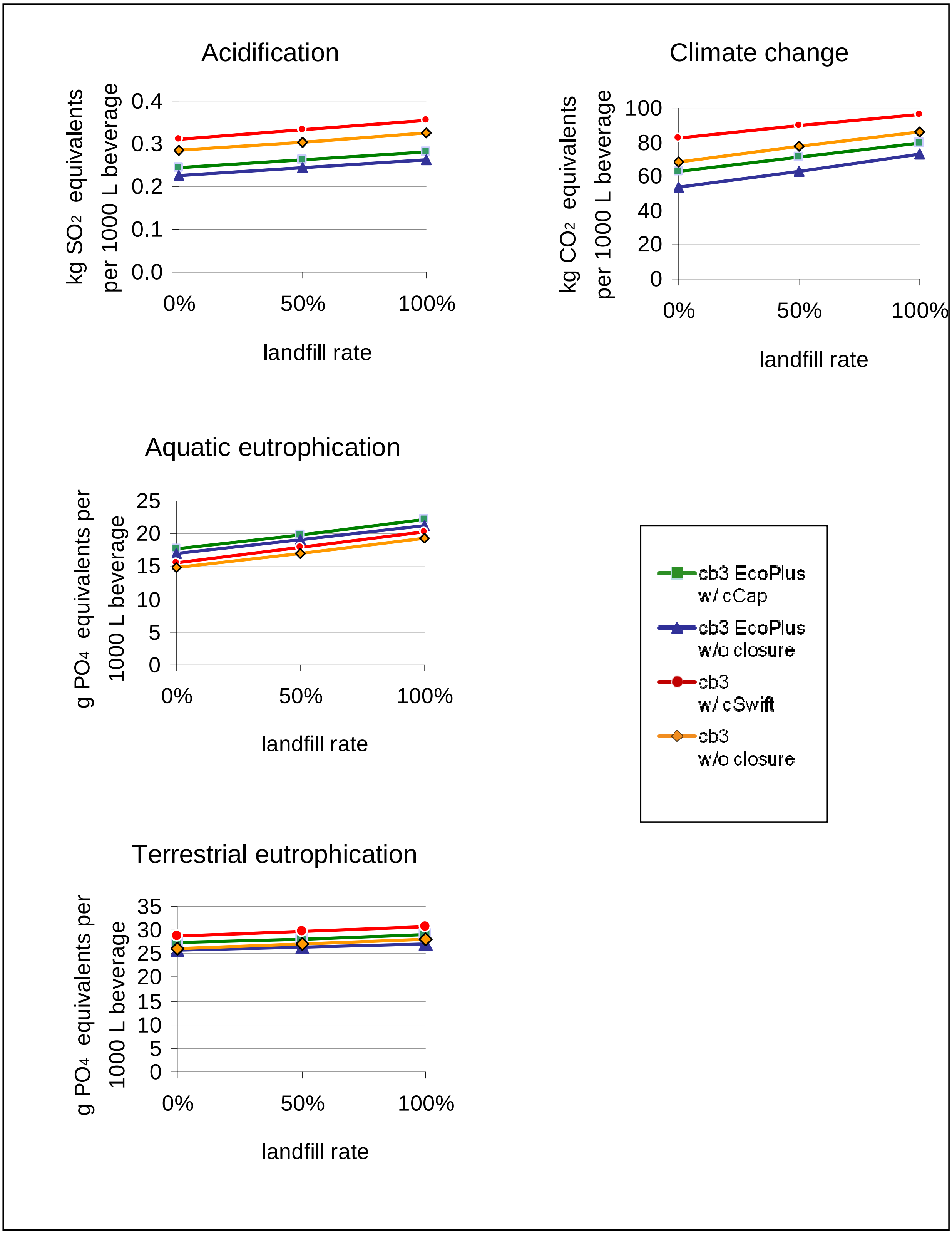

Figure 5-4: Net indicator results for scenario variants – Group L / recycling rate < 36.7% (Part I)

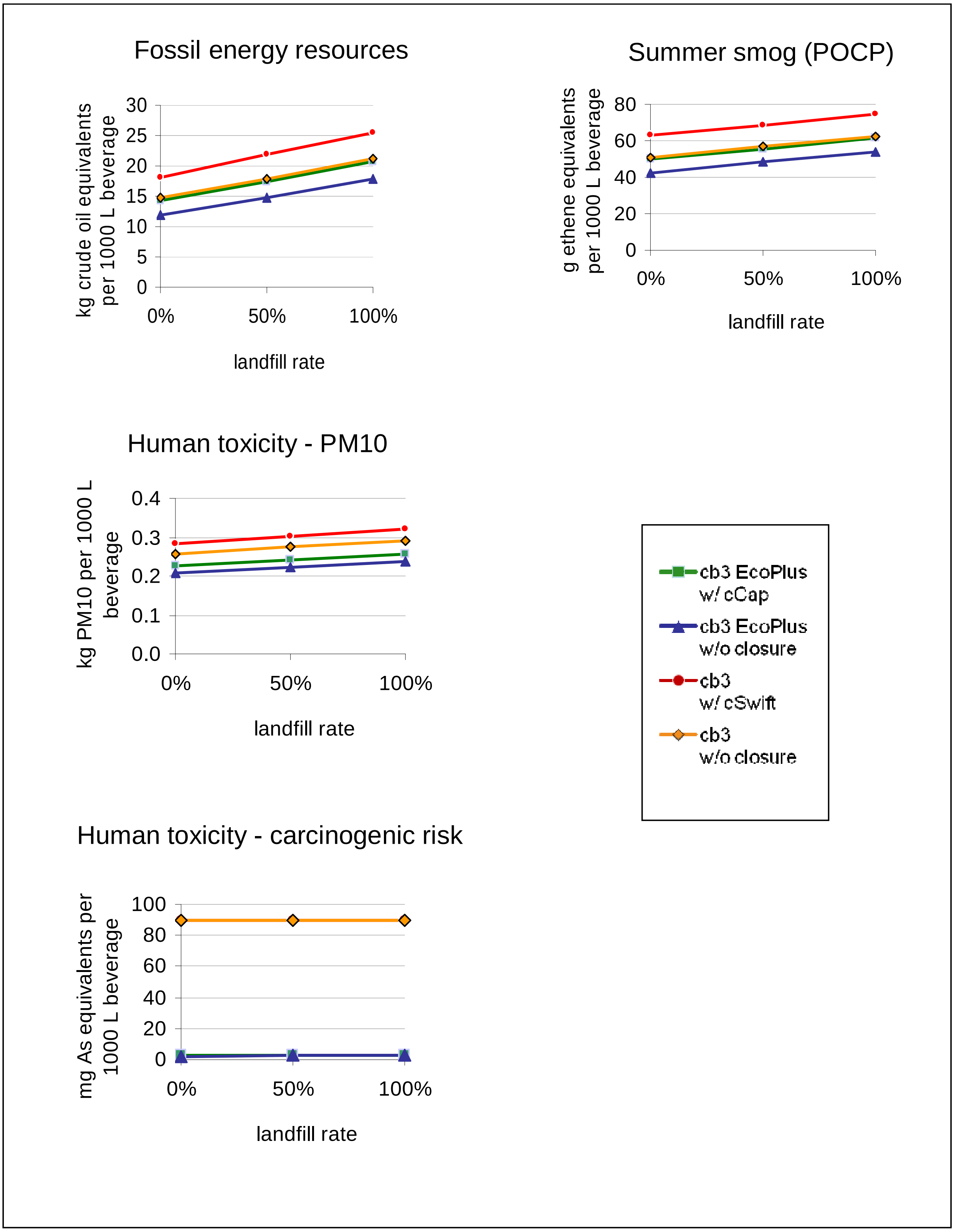

Figure 5-5: Net indicator results for scenario variants – Group L / recycling rate < 36.7% (Part II)

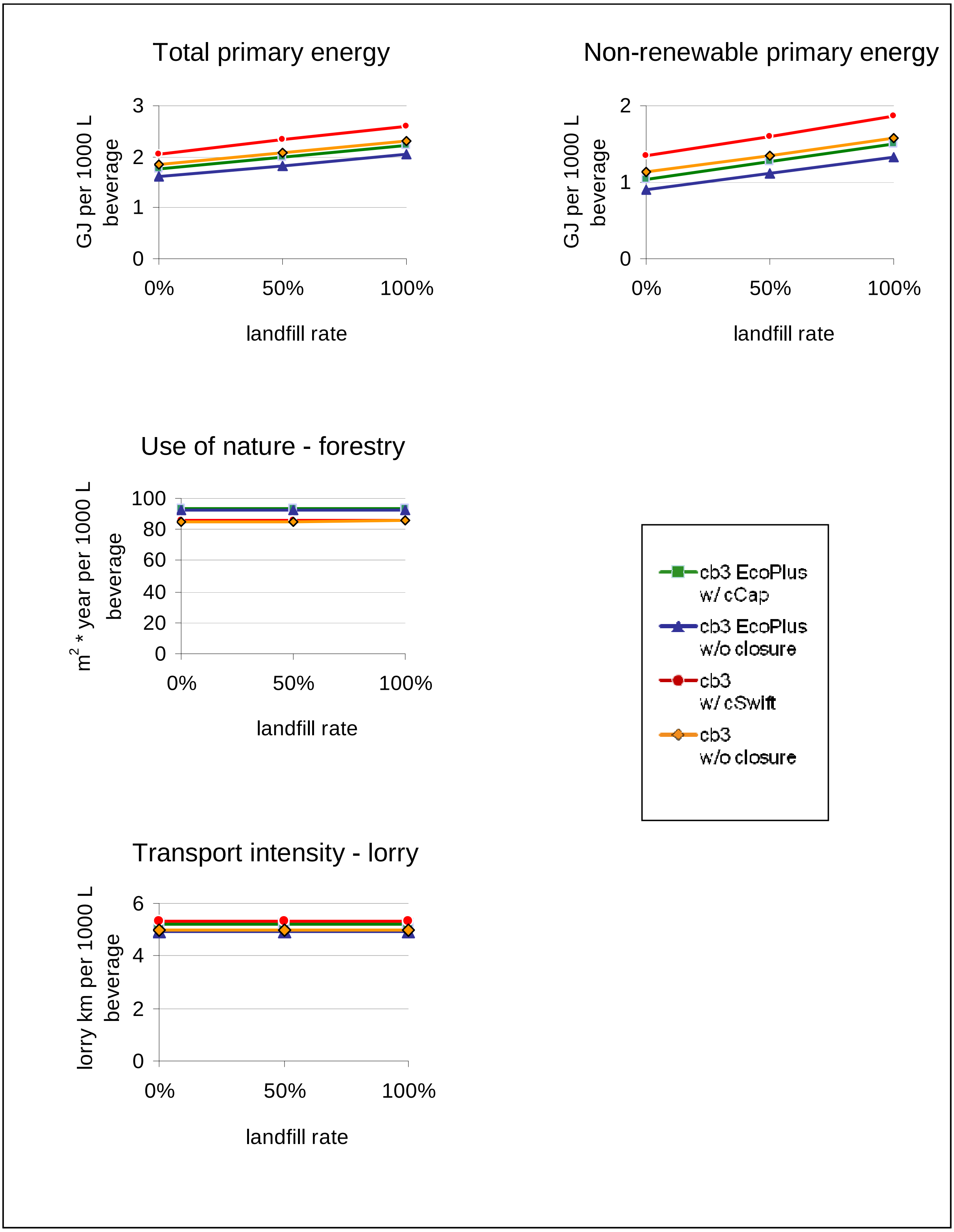

Figure 5-6: Net indicator results for scenario variants – Group L / recycling rate < 36.7% (Part III)

5.3 Sensitivity analysis

Figure 5-7, Figure 5-8 and Figure 5-9 on the following pages illustrate the quantitative results for the sensitivity analysis in which an allocation factor of 100% is used for the modelling and calculation of open-loop recycling processes.

The net results of this sensitivity analysis (all credits and burdens from recovery processes are allocated to the examined packaging systems) differ visibly from those of the base scenarios in all categories except '*Climate change*'*,* where the difference is minimal. In the others the changes are more or less obvious, the biggest differences appear regarding the credits. The ranking of the regarded packaging systems among each other, however, is not affected by the use of a 100% allocation factor.

Both the burdens and energy credits are (slightly) higher than when the '50/50 approach' is used, but as the former are reduced to a greater extent, the net results end up being lower. This is more or less visible for '*Summer smog'*, '*Use of nature - forestry'* as well as *aquatic* and *terrestrial 'Eutrophication'* and '*Human toxicity - PM10'*, where the benefits – primarily the material credits (from recycling processes) – are higher than in the base scenarios. The general trend also applies for the consumption of '*Fossil energy resources'* as well as '*Non-renewable'* and *'Total primary energy'*, however here, the use of a 100% allocation factor for open-loop recycling also visibly increases the energy credits.

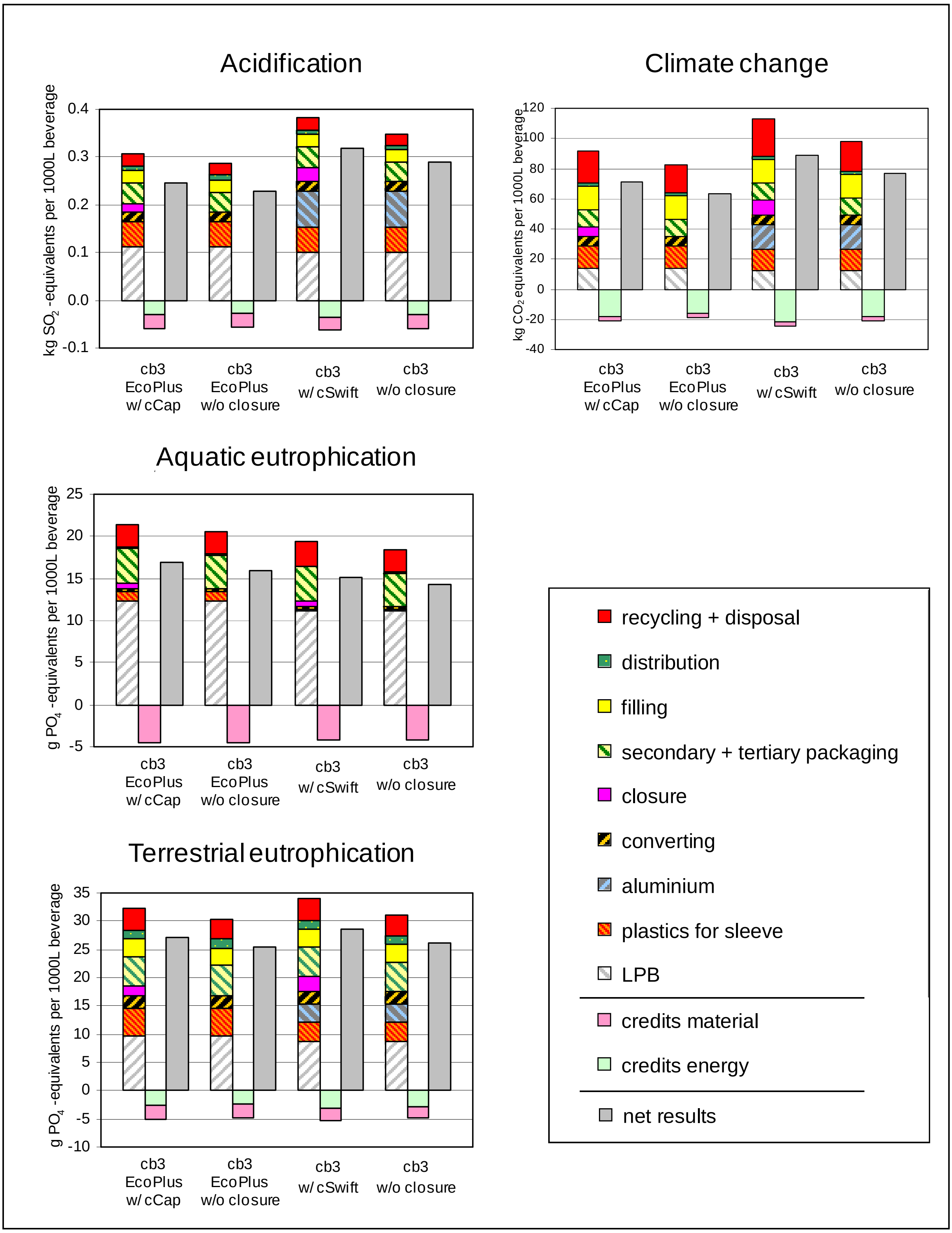

Figure 5-7: Indicator results for sensitivity analysis – 100% allocation factor for materials (Part I)

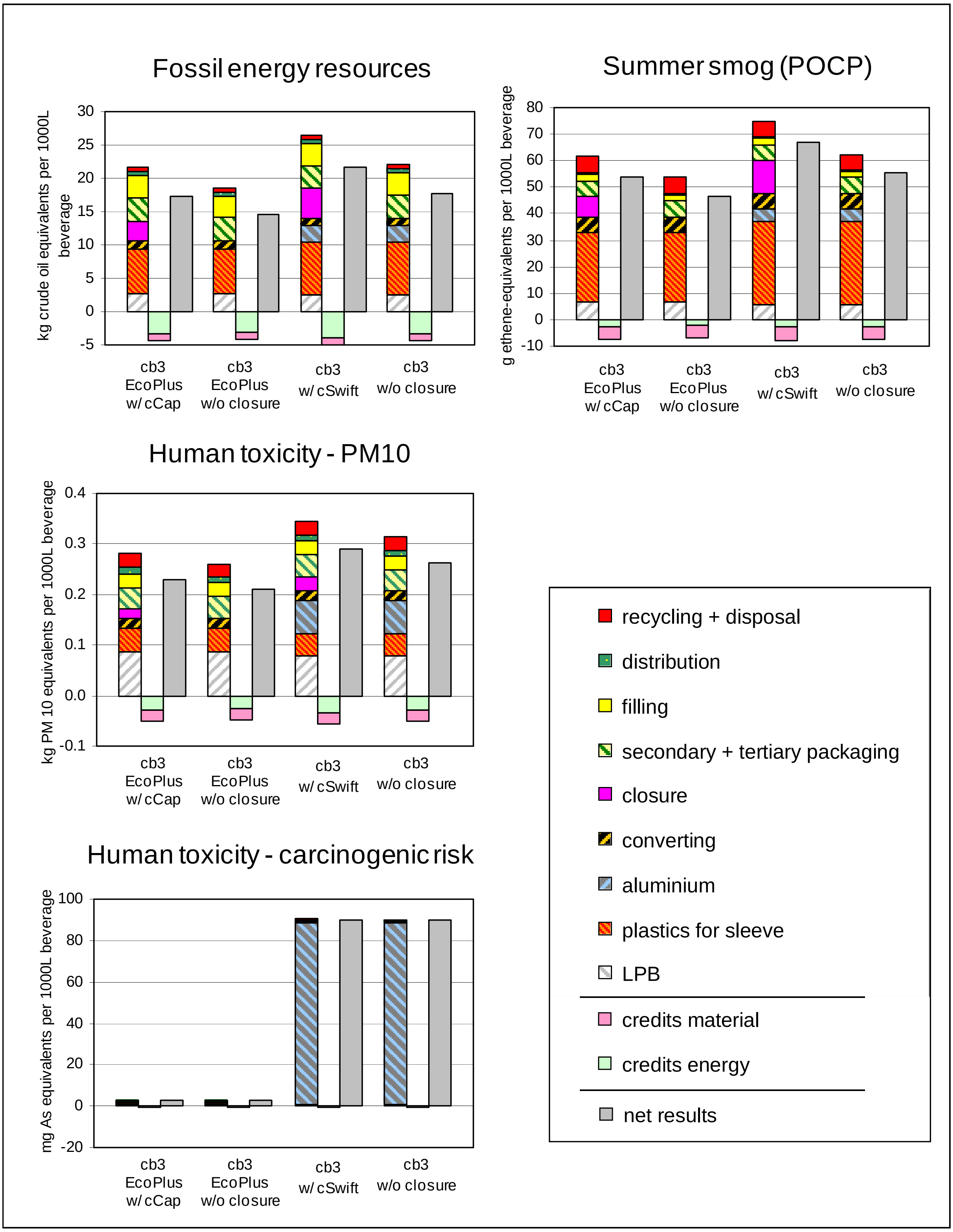

Figure 5-8: Indicator results for sensitivity analysis – 100% allocation factor for materials (Part II)

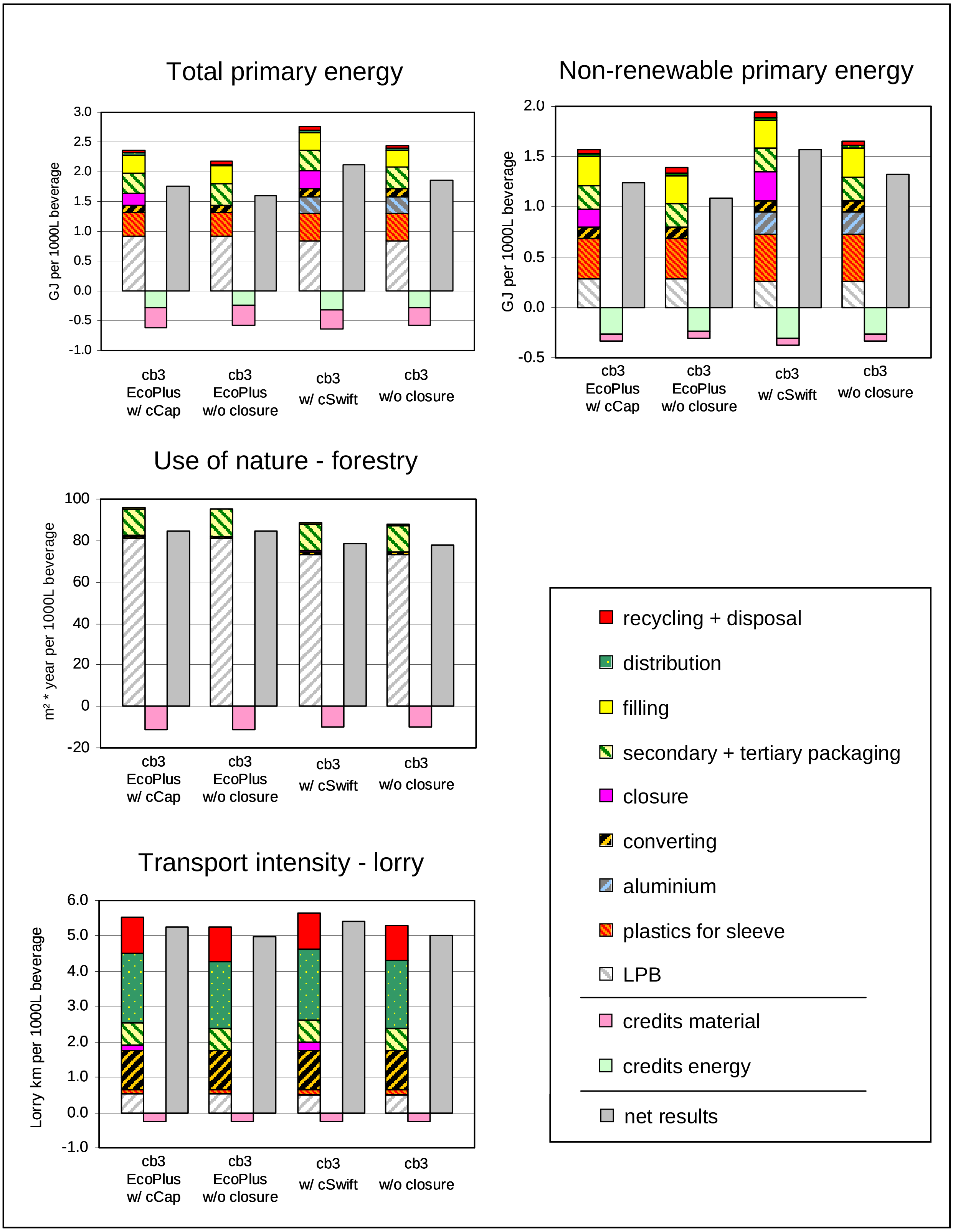

Figure 5-9: Indicator results for sensitivity analysis – 100% allocation factor for materials (Part III)

5.4 Limitations, completeness and consistency

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

Limitations arising from the selection of **market segments**:
The results are valid only for the filling product UHT (ambient) milk. Even though beverage carton packaging systems are common in other market segments, e.g. fresh milk, other filling products create different requirements towards their packaging and thus certain characteristics may differ strongly, e.g. barrier functions.

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

The established *cb3* packaging system analysed in this study was proposed by *SIG Combibloc* based on its benchmark function for the producer regarding the European milk market in 2009/2010). For the innovative system '*cb3 EcoPlus*', the commissioner provided data according to the latest available stage of the product development project.

The filling volume and weight of a certain type of packaging can vary considerably for all packaging types that were studied. The volume chosen for this study (1000 mL) represents the predominant packaging size on the market. It is not possible to transfer the results of this study to packages with other filling volumes or weight specifications.

Each packaging system is defined by multiple system parameters which may potentially alter the overall environmental profile. All packaging specifications were provided by *SIG Combibloc* and are to represent the typical packaging systems used in the analysed market segment. They have been cross-checked both by *IFEU* and the critical reviewers.

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 **valuation method**:
The selection of the environmental indicators applied in this study covers impact categories that are widely accepted within the LCA practitioner community. It should be noted that the use of different impact assessment methods could lead to other results concerning the environmental ranking of packaging systems. The results are valid only for the specific valuation method used for the step from inventory data to impact assessment.

Limitations concerning the analysed **indicators**:
The results are valid only for the environmental impact indicators, which were examined.

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 West Europe, even for the same packaging systems.

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

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

Limitations regarding **retail distances**:
The distances of the two transport steps – empty packaging from converter to filler and filled packs from filler to point of sale – are based on expert judgements. Individual logistic and supply chains can therefore deviate from transport distances applied.

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

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

6 Normalisation

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

Normalisation factors

The normalisation factors used in the current study were obtained by dividing the total environmental load per environmental metric within a dedicated geographical boundary by the number of inhabitants within this boundary. In this study the data for Europe were used because the study focuses on the European market. It has to be noted though that the geographical boundary for the appliance of normalisation is EU 25+3 as no recent and robust data for the calculation of REQs for EU 15 & Switzerland was available. Table 6-1 shows the total environmental loads for Europe valid for the year ~2000 and the statistical environmental impacts per inhabitant

Calculation of REQs and their scaling to European consumption of UHT milk

To calculate resident equivalents (REQs), the net indicator results of base scenarios given in Table 4-1 (and illustrated in figures 4-1 to 4-3) are divided by the respective average impact per resident. The resulting number has the same unit for all metrics (REQs/1,000 litres milk) allowing comparison between different metrics.

Table 6-1: Basic data for Europe used to calculate REQs

	Impact per year			Impact per resident and year	
	Europe			**Europe**	
Residents					
Residents	464 036 294	c)			
Resources					
Lignite	3.26E+06	c)	TJ/year	7.02E+03	MJ/resident and year
Natural gas	1.01E+07	c)	TJ/year	2.19E+04	MJ/resident and year
Crude oil	1.37E+07	c)	TJ/year	2.96E+04	MJ/resident and year
Hard coal	3.67E+06	c)	TJ/year	7.91E+03	MJ/resident and year
Total area	4.44E+06	d)	km^2	9.57E+03	m^2/resident
Emissions (Air)					
Ammonia	2.53E+05	a)	t/year	5.45E-01	kg/resident and year
Arsenic	3.70E+02	a)	t/year	7.97E-04	kg/resident and year
Benzene	4.25E+06	a)	t/year	9.17E+00	kg/resident and year
Benzo(a)pyrene	4.05E+02	a)	t/year	8.73E-04	kg/resident and year
Cadmium	2.26E+02	a)	t/year	4.87E-04	kg/resident and year
Chromium	1.29E+03	a)	t/year	2.78E-03	kg/resident and year
Dioxins (I-TEQ)	3.55E+00	b)	kg/year	7.35E+00	µg/resident and year
Dinitrous oxide	1.34E+06	a)	t/year	2.89E+00	kg/resident and year
Carbon dioxide, fossil	4.02E+09	a)	t/year	8.67E+03	kg/resident and year
Methane	2.16E+07	a)	t/year	4.64E+01	kg/resident and year
Nickel	1.93E+03	a)	t/year	4.16E-03	kg/resident and year
NMVOC	1.17E+07	a)	t/year	2.52E+01	kg/resident and year
NOx (as NO_2)	1.18E+07	a)	t/year	2.55E+01	kg/resident and year
PCB	3.38E+00	a)	t/year	7.27E-06	kg/resident and year
Sulfur dioxide	8.75E+06	a)	t/year	1.89E+01	kg/resident and year
Dust (PM10)	2.50E+06	a)	t/year	5.39E+00	kg/resident and year
Emissions (Water)					
Nitrogen (freshwater)	2.70E+06	a)	t/year	5.83E+00	kg/resident and year
Aggregated values for impact categories					
Crude oil equivalents	461,295,277		t COE-Eq/year	1079	kg COE-Eq /resident and year
Climate change	5,017,944,690		t CO_2-Eq/year	10,814	kg CO_2-Eq/resident and year
Acidification	18,160,803		t SO_2-Eq/year	39.1	kg SO_2-Eq /resident and year
Eutrophication (terrestrial)	1,628,360		t PO_4-Eq/year	3.51	kg PO_4-Eq /resident and year
Eutrophication (aquatic)	1,136,069		t PO_4-Eq/year	2.45	kg PO_4-Eq /resident and year
Summer smog (POCP)	2,656,784		t Eth-Eq/year	5.73	kg Eth-Eq /resident and year
Human Toxicity: PM10	17,950,982		t PM10-Eq/year	38.7	Kg PM10-Eq/ resident and year
Transport Intensity: Lorry	282,781		Mio Lorry km/year	609	Lorry km/ resident and year
Primary Energy Total	49,285,966	c)	TJ/year	106	GJ/ resident and year
Primary Energy Non-renewable	42,563,985	c)	TJ/year	92	GJ/ resident and year
Forest area Europe	1,293,980	d)	km^2	2,789	m^2/resident

a) Reference normalization emissions "EU25+3 2000" ; CML Dec 2007
b) European Dioxin Inventory - Stage II, refers to EU15 + Norway + Switzerland + Poland + Estonia + Latvia + Greek Rep.
c) Database Eurostat, 2008, refernce year 2000
d) EAA report 2007 Europes Environment the fourth assessment

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

The thus normalized results are then scaled up to the yearly total European consumption of UHT milk. Data from the year 2007 was used, when approximately 19,336,400,000 L of UHT milk were distributed in Europe [IDF 2007].

To scale the results up to desired scope, the REQ value is first determined for 1 L milk, and then multiplied by the yearly total German market volume. By normalizing the results in this way, one gets an indication of the environmental loads that each packaging system would cause if all UHT milk distributed in Europe within one year were filled exclusively in the respective packaging system.

Figure 6-1 shows the normalised indicator results of the base scenarios. It illustrates how much each of the regarded packaging systems would contribute to the overall European picture for each regarded environmental impact and resource consumption category if it were the only packaging system used for ambient milk. The findings are valid for the assumptions made in the base scenarios of this LCA.

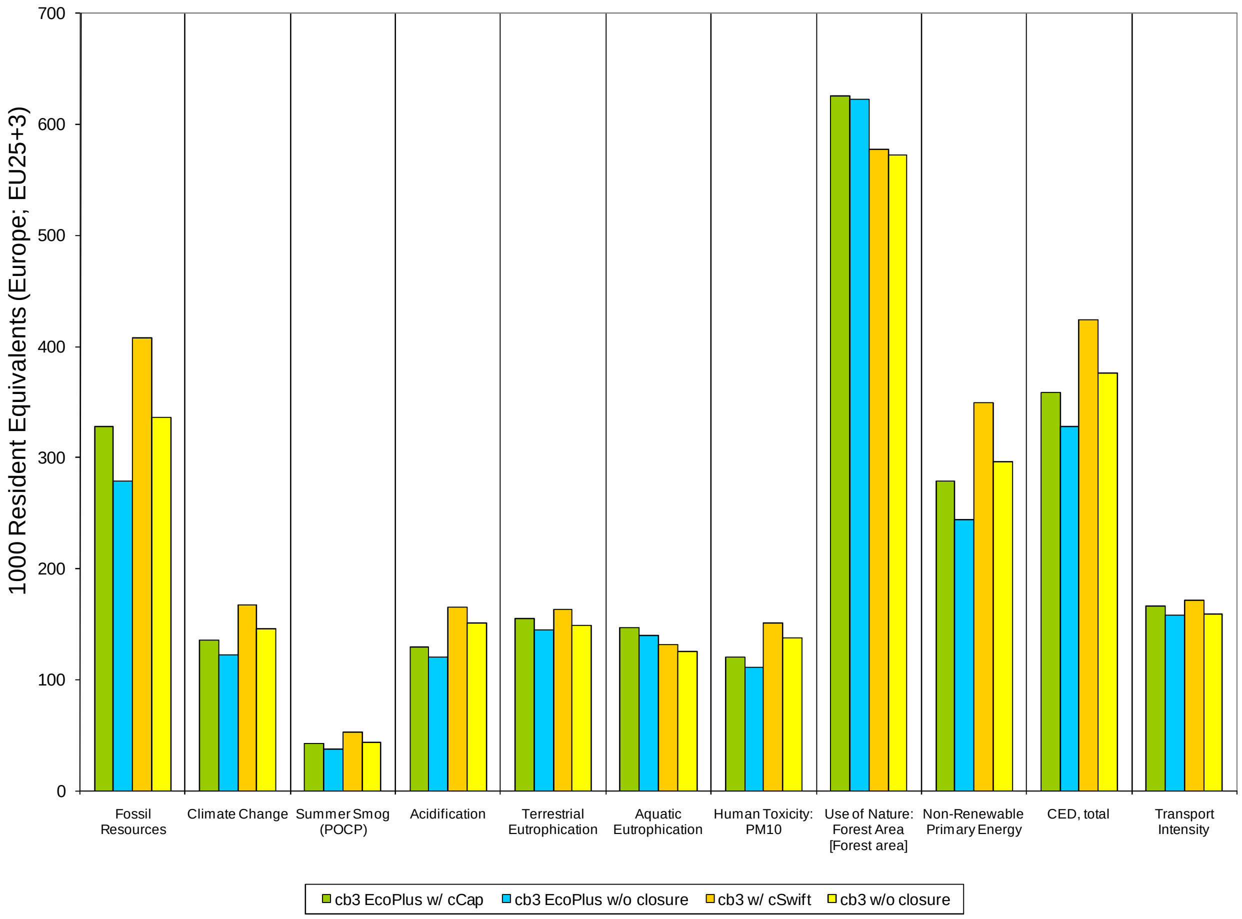

Figure 6-1: Normalised indicator results of base scenarios

Each of the regarded environmental categories reflects the result pattern shown by the respective (base scenario) net results in section 4.1. The normalised results thus confirm the previously described ranking of the different packaging systems analysed in this study.

How the comparison of regarded base scenarios, expressed here in resident equivalents (REQs) can be ‘read’ shall be exemplified for ‘Climate change’. For the geographic reference scope ‘Europe’, the *cb3 EcoPlus* beverage carton with *cCap* (as modelled for the purpose of this study) would be responsible for approximately 136,000 REQs. With this, it ranks lower than the cb3 with SwiftCap with approximately 167,000 REQs. By bringing the entire quantity of ambient milk consumed in Europe within one year to the market exclusively in cb3 EcoPlus cCap packages, the total greenhouse gas (GHG) emissions could be influenced. Compared to the exclusive use of the regarded cb3 with SwiftCap packaging system, it would lead to a decrease of the GHG emissions by (167,000-136,000=) 31,000 REQs.

The highest reduction potential is visible in the categories related to the consumption of fossil resources (incl. energy carriers) and the respective greenhouse gas emissions. While the acidification potential is also an area in which optimisations to the regarded packaging systems are most likely to improve the situation in Europe, 'Terrestrial Eutrophication' and 'Summer Smog' show less significant differences between packaging systems.

As the normalised results mirror the result pattern of the respective net results of the base scenarios, the results for 'Use of Nature: Forest Area' and 'Aquatic Eutrophication' show higher normalised results for the cb3 Ecoplus packaging compared to the established cb3 carton. The reason for this is the higher share of liquid packaging board in the EcoPlus packagings systems, which is the element contributing most significantly to the respective balance of these indicators.

7 Conclusions and recommendations

In the following sections, conclusions and recommendations are drawn from the results presented, interpreted and discussed in the previous sections, with a focus on the newly developed *cb3 EcoPlus* packaging system. After a short summary of the significant system parameters (7.1), characteristic patterns are highlighted both for the comparison between the two regarded beverage carton variants (7.2). Subsequently, the outcomes of the scenario variants addressing the role of country-specific end-of-life paths as well as the sensitivity analysis conducted to verify consistency of the results are discussed (sections 7.3 and 7.5, respectively). Finally, recommendations are drawn from the LCA study presented in the current report (7.5).

Note that in the following sections (description, comparison and interpretation of results), differences ≤ 10% are considered as insignificant in accordance with the common practice for LCA studies comparing different product systems.

7.1 Most significant parameters of the '*cb3 EcoPlus*' system

As indicated in section 4.2, the results of this LCA conducted for the use of *cb3 EcoPlus* packs on the European ambient milk market show that overall the major impact in all examined environmental indicators originate from the production – and in some cases also the recycling – of the primary packaging's (material) components. The carton's major material component is liquid packaging board (LPB), but the plastic elements (sleeve component and closure) also contribute significantly to the results in most regarded categories. The end of life is especially relevant concerning '*Climate change*' and '*Transport intensity - lorry*'.

7.2 Comparison of the two examined beverage carton systems

This study examines two beverage carton systems, which differ only regarding the primary packaging, namely the sleeve compositions and closures used. The following table shows that in most of the environmental impact categories that are regarded, the *cb3 EcoPlus* has a (slightly) more favourable performance. The exception is '*Aquatic eutrophication*', although here the difference in results is only barely above the 10% significance threshold. Regarding the analysed inventory categories, the picture is similar: in four out of five cases, the *cb3 EcoPlus* variant has slightly more favourable (i.e. lower) results while the established *cb3*'s performance is less favourable (however insignificantly by about 8%) regarding '*Use of nature - forestry*'. The differences in performance are mainly related to the different (shares of) materials used in the sleeves.

How to read the following table 7-1:

- The packaging system named first in the table's title as well as in the table itself (here: '*cb3 EcoPlus w/ cCap')* is compared against a reference system (here: '*cb3 w/ cSwift'*).
- Percentages listed in the table express the proportion between the net results of the first-named packaging system and those of the reference system named at the top of the respective column.

For quicker orientation, the relative results of this system comparison are listed in two different columns, distinguishing cases of environmentally more favourable performances from the less favourable ones. This distinction is visually reinforced by a colour code using green and brown, respectively. Percentages lower than 10% are considered to be insignificant and marked by a grey shading of the respective fields.

Explanation:

Column headed 'more': The packaging system named first in the table (and table title) has lower indicator values (i.e. an environmentally more favourable performance) than the alternative packaging system listed in the second row of the respective column.	**Column headed 'less': The packaging system named first in the table (and table title) has higher indicator values (i.e. an environmentally less favourable performance) than the alternative packaging system listed in the second row of the respective column.**
Note: Percentages shaded in grey are smaller than 10% and thus considered insignificant.	

Exemplification for Table 7-1:
The indication '"by 17%" in the middle column ("more favourable than …") means the net indicator results of '*cb3 EcoPlus w/ cCap*' are 17% lower than the net indicator results of '*cb3 w/ cSwift*' for the respective environmental indicator.

- Note that the table covers all environmental impact indicators and inventory categories that were examined in the current LCA, with the exception of '*Human toxicity – carcinogenic risk*'. The reason for this exclusion is given in section 4.3 (p. 41).

Table 7-1: Net indicator results (impact indicator and inventory level categories) of '*cb3 EcoPlus'* system with closure *cCap* related to those of '*cb3'* system with closure *cSwift*

The net results of *'cb3 EcoPlus'* are	**more**	**less**
	favourable than those of *'cb3'* *(=100%)*	
Acidification	by 22%	
Climate change	by 20%	
Aquatic eutrophication		by 12%
Terrestrial eutrophication	by 7%	
Summer smog (POCP)	by 19%	
Human toxicity - PM10	by 20%	
Fossil resource consumption	by 22%	
Use of nature - forestry		by 8%
Total primary energy demand	by 15%	
Non-renewable primary energy demand	by 20%	
Transport intensity – lorry	by 3%	

Left column (green fields):
'*cb3 EcoPlus w/ cCap'* has lower indicator values (i.e. a more favourable performance) than '*cb3 w/ cSwift'*
Right column (brown fields):
'*cb3 EcoPlus w/ cCap*' has higher indicator values (i.e. a less favourable performance) than '*cb3 w/ cSwift'*

Note: Percentages shaded in grey are smaller than 10% and thus considered insignificant.

7.3 Evaluation of the scenario variants

While in the base scenarios average end-of-life conditions for Western Europe (EU15 & Switzerland) are assumed, the scenario variants modelled and calculated in this study provide indications of the picture arising for specific countries. The findings allow conclusions on the influence of certain parameters for the environmental performance of the examined packaging systems.

For an overview of the scenario variants that are modelled and the corresponding short names used in the report and result graphs, please see Table 2-5 and Table 2-6 in section 2.4.2. As in the base scenarios, the allocation factor applied for open-loop-recycling is 50%. Further details are also given in section 5.2.

Several basic patterns that become visible in the results are described and discussed in section 5.2. They show that two scenarios may have similar (net) results in spite of very different end-of-life settings. However, in most of the regarded environmental impact / indicator categories landfilling has a more or less unfavourable effect. Overall, the difference between recycling and incineration of the packaging after use is minimal.

It must also be noted that the methodology chosen here, i.e. the classification of countries in two groups based on their recycling rates, is not suitable to determine exactly quantified country-specific results. As stated in section 2.4.2. it can only provide indications of respective trends or relative performances.

7.4 Evaluation of the sensitivity analysis

The sensitivity analysis applying a 100% allocation factor for the open-loop recycling of the regarded packaging systems' material components reveals a mostly (however insignificantly) favourable effect on the results. Compared to the base scenarios, for which a 50% allocation factor is applied, the overall picture is confirmed, i.e. the ranking of the regarded packaging systems among each other, is not affected.

7.5 Recommendations

As summarized in section 7.2, the LCA study presented here delivered an advantageous picture for the newly developed *cb3 EcoPlus* system than for the established *cb3* beverage carton regarding the examined environmental impacts and inventory categories. Exceptions are '*Aquatic eutrophication*', where the established *cb3* system is found to be less impacting, and *Terrestrial eutrophication'* as well as *'Use of nature – forestry'* and '*Transport intensity – lorry'*, where the differences are smaller than 10% (and therefore are considered insignificant in this study).

Based on the findings, the authors have developed the following recommendations:

- The results of this LCA study provide conclusive reasons to prefer the newly developed '*cb3 EcoPlus*' beverage carton over the established '*cb3*' system when choosing a packaging solution for ambient milk on the European market.
- The results indicate that of the three regarded end-of-life treatment options, landfilling is the least favourable. From this finding, the recommendation can be derived to aim at reducing the landfill rate – and thus to increase the amount of *cb3 EcoPlus* beverage cartons that are recycled and/or incinerated with energy recovery. This would also be in line with requirements of the EU's so-called 'Landfill Directive' [EC 1991], thus reducing the landfilling of biodegradable waste and the treatment of any waste prior to landfilling (e.g. in municipal waste incineration plants).
- For the majority of the regarded environmental indicators, the *EcoPlus* variant appears as more favourable than the established *cb3* system, or within an insignificant range of difference. A focus on (further) reducing this packaging system's aquatic eutrophicating potential (the only category in which the former has significantly higher net results) is advisable.
- A higher share of LPB in order to avoid using aluminium in the sleeve means that an increased use of land area for forestry can hardly be avoided. It is therefore even more important to aim at sourcing all required wood / paper fibres from forests managed in an environmentally sustainable way according to knowledge on best practice.
- Wood is the major resource in the production of liquid packaging board (LPB), which itself is the major component of beverage cartons, and makes up an increased share of the new *cb3 EcoPlus* pack developed by SIG Combibloc. All LPB used in the examined carton-based packaging systems is produced in Sweden and Finland and the wood input mostly comes from Nordic forests. As wood is a renewable but not infinite resource, it should be aimed at sourcing this raw material from forests with state-of-the-art

management systems: in this context, the FSC certification scheme is a sound standard to apply, however we recommend going beyond the respective requirements. This task is likely to require special efforts, especially in view of the increasing competition in the demand for wood as a resource. A close cooperation between SIG Combibloc and the company's LPB suppliers may be one crucial element of a successful strategy for achieving this goal.

- The normalisation performed with the results of the base scenarios allow a conclusion on where a reduction of the examined packaging systems' environmental loads could be most effective in order to improve the quality of the environment at the European level. The categories related to the consumption of fossil resources and the demand of both, renewable and total energy are clearly most promising here, as well as use of forest area of the packaging systems.

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Appendix A: Impact indicators

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

A.1 Climate change

Climate Change is the adverse environmental effect caused by anthropogenic heating of the Earth's atmosphere; it is described in detail in the relative references [IPCC 1995]. The indicator most used in life cycle assessments up to now is the radiative forcing [CML 2002, Klöpffer 1995] and is given as CO_2 equivalents. The characterisation method is a generally recognised method.

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

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

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

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

Greenhouse gas	**CO_2 equivalents (GWP_i)**
Carbon dioxide (CO_2), fossil	1
Methane (CH_4)[8] fossil	27.75
Methane (CH_4), regenerative	25
Nitrous oxide (N_2O)	298
Tetrafluoromethane	7390
Hexafluoroethane	12200
Halon 1301	7140
R22	1810
Tetrachlormethane	1400
Trichlorethane	146
Source: [IPCC 2007]	

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

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

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

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

Note on biogenic carbon:

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

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

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

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

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

A.2 Photo-oxidant formation (photosmog or summer smog)

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

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

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

Harmful gas	POCP [kg ethene equivalents]
Ethene	1
Methane	0.006
Formaldehyde	0.519
Benzene	0.218
Acetylene	0.085
Ethanol	0.399
Ethylbenzene	0.73
Ethyl acetate	0.209
Hexane	0.482
Toluene	0.637
Xylene	1.108
Aldehydes unspec.*	0.563
Butane	0.352
Butene	1.079
Ethane	0.123
Heptane	0.494
Propene	1.123
MTBE	0.175
Acetaldehyde	0.641
Methanol	0.14
Styrene	0.142
Dichlorethene	0.447
Ethene glycol	0.373
Hydrocarbons:	
• NMVOC from diesel emissions**	0.7
• NMVOC (average)*	1.0
• VOC*	1.0
Source: [Jenkin+Hayman 1999, Derwent et al. 1998] taken from [CML 2007], *[IFEU 2008], **[UBA 1995]	

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

In [CML 2007], only individual substances having a defined equivalent value relative to ethane are considered. However within emissions relevant for POCP, often the group parameters (NMVOC, VOC) are predominant on a mass basis. As the composition of those is not known in many inventory data sets, they were treated similar to ethene emissions (POCP = 1). This represents a conservative approach.

Note: Older publications by CML [CML 1992] specified characterisation factors for VOC and NMVOC, however those were derived on grounds of characterisation factors for individual substances taken from the same [CML 1992] publication. In the opinion of the authors of this study, the most consistent way to deal with the group parameters would be to derive updated characterisation factors based on the most current factors for individual substances, as taken from [CML 2007]. However, it could not be clarified in communication with Jerone Guinee [Guinee 2008], which individual substances with which weights had been used for the calculation of VOC and NMVOC in [CML 1992]. That is the reason why we use a characterisation factor of 1 for the group parameters in this study.

The POCP was calculated using the following equation:

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

A.3 Eutrophication and oxygen-depletion

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

The eutrophication of surface waters also causes oxygen-depletion. If there is an overabundance of oxygen-consuming reactions taking place, this can lead to oxygen shortage in the water. A measure of the possible perturbation of the oxygen levels is given by the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). As the BOD is only defined by a reaction time and the COD essentially represents all the available potential for oxygen-depletion, COD is used as a conservative estimate[9] for the eutrophication in the parameter list.

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

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[9] The COD is (depending on the degree of degradation) higher than the BOD_5, which is why the equivalence factor is deemed relatively unreliable and too high.

Harmful substance	PO43- equivalents (EPi) in kg PO43-equiv./kg
Eutrophication potential (terrestrial)	
Nitrogen oxides (NO_X as NO_2)	0.13
Ammonia (NH_3)	0.35
Dinitrogen oxide (N_2O)	0.27
Eutrophication potential (aquatic) (+ oxygen depletion)	
Phosphate ($PO4^{3-}$)	1
Total phosphorus	3.06
Chemical Oxygen Demand (COD)	0.022
Ammonium (NH_4^+)	0.33
Nitrate (NO_3^{2-})	0.1
N-compounds, unspec.	0.42
P as P_2O_5	1.34
P-compounds unspec.	3.06
Source: [Heijungs et al 1992] taken from [CML 2007]	

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

Regarding the supply of nutrients, the contribution to the eutrophication potential is calculated separately for soil and water. In each case, that contribution is obtained by summing the products of the amounts of harmful substances that are emitted and the respective EP values.

The following equation is used for terrestrial or aquatic eutrophication:

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

A.4 Acidification

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

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

Harmful substance	SO_2 equivalents (AP_i)
Sulphur dioxide (SO_2)	1
Nitrogen oxides (NO_X)	0.7
Hydrochloric acid (HCl)	0.88
Hydrogen sulphide (H_2S)	1.88
Hydrogen fluoride (HF)	1.6
Hydrogen cyanide (HCN)	1.6
Ammonia (NH_3)	1.88
Nitric acid (HNO_3)	0.51
Nitrogen oxide (NO)	1.07
Phosphoric acid (H_3PO_4)	0.98
Sulphur trioxide (SO_3)	0.8
Sulphuric acid (H_2SO_4)	0.65

Source: [Hauschild und Wenzel 1998] taken from [CML 2007] *: Assumption: Propanethiol used as a proxy.

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

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

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

A.5 Human toxicity

Concerning the impact category “human toxicity”, a generally accepted approach covering the whole range of toxicological concerns is not available. In this assessment, two indicators have been chosen to represent human toxic effects: carcinogenic pollutants and fine particulates (primary particulates as well as precursors).

A.5.1 Carcinogenic risk

Generally toxicological evaluations are conducted on a site specific local scale within a risk analysis or an environmental impact assessment (EIA). Within a clearly defined spatial unit an exposition analysis can be applied which allows an evaluation of potential toxicological impacts on human. In contrast, LCA is a system specific method without local reference of emission inventory data, thus the generally accepted tools for toxicological evaluations can not be applied.

A commonly accepted assessment method for the variety of potential toxicological impacts does not exist. Nevertheless, in order not to exclude such environmental impacts of a LCA study, a simplified approach based on toxic pollutants without effect threshold can be applied. Pollutants with effect threshold are recorded on inventory level but not further aggregated within an impact category, as only pollutants without effect threshold are suitable to use for the characterisation step of LCAs. Especially carcinogenic pollutants with effects being already caused at very low concentration levels can be used in this impact category, because these effects are independent of local dilution processes, specific pathways or exposure. This approach has been developed and applied in several Life cycle assessments [IFEU 1997; UBA 1998].

The carcinogenic substances are aggregated by characterisation factors based on inhalation unit risk values of the Integrated Risk Information System (IRIS) of the U.S. EPA which is regularly revised and published. With these unit risk values all carcinogenic pollutants can be expressed as “Arsenic equivalents”. The characterization factors applied are shown in the table below. In case of chromium, the carcinogenic risk depends on the degree of oxidation. As often only Chromium, unspecified is given in inventory data, it is assumed that 10% of Chromium, unspecified actually is carcinogenic chromium VI.

	Carcinogenic Risk Potential (CRP_i) (Air) [kg Arsenic equivalents/kg]
Arsenic (As)	1
Benzo(a)pyren (BaP)	20.9
Benzene	0.0019
Cadmium (Cd)	0.42
Chromium, unspecified	0.279
Dioxins	3020
Nickel (Ni)	0.056
PCB	0.0233
Source: [IRIS 2006], Assumption: 10% of Chromium, unspecified is Chromium (VI)	

Table A-7: Carcinogenic risk potential of selected substances relevant in this study

The contribution to the carcinogenic risk potential (CRP) is calculated by summing the products of the amounts of the individual harmful substances and the respective As equivalent values using the following equation:

$$CRP = \sum_i (m_i \times CRP_i)$$

A.5.2 Fine particulate matter (PM10)

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

Epidemiological studies have shown a correlation between the exposure to particulate matter and the mortality from respiratory diseases as well as a weakening of the immune system. Relevant are small particles with a diameter of less than 10 and especially less than 2.5 µm (in short referred to as PM10 and PM2.5).These particles can not be absorbed by protection mechanisms and thus deeply penetrate into the lung and cause damage.

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

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

	PM10 equivalents ($PM10_i$) (Air) [kg PM10 equivalents/kg]
PM10	1
SO_2	0.54
NO_X as NO_2	0.88
NMVOC (unspecified, hydrocarbons and from Diesel emissions)	0.012*
NH_3	0.64
Diesel particles	1**

Source: [Leeuw 2002]; *[Heldstab et al. 2003], ** Assumption IFEU

Table A-8: PM10 equivalents of substances considered in this study

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

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

A.6 Resource consumption

The consumption of resources is deemed adverse for human society. In all considerations regarding sustainable, environmentally-compatible commerce, the conservation of resources plays a key role. The term resources is often limited in use to finite mineral or fossil resources but is at other times interpreted very widely to include for example genetic diversity, agricultural land, etc.

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

Despite supposedly systematic transparency of the data for the "resource consumption" impact category, some fundamental aspects still remain to be clarified. This in particular concerns sensible classification of types of resources and the definition of scarcity. Only then will understandable and accepted measuring procedures and evaluation principles be possible.

The difficulties delimiting the resource types arise due to the fact that materials can also be energy resources and vice-versa, that biotic resources under certain conditions are not renewable, that water can be a renewable material and a renewable energy resource, etc. In addition, there are problems associated with the life cycle inventory: If the growth of a biotic resource is part of the system, it is not the biological material that is an input to the system but rather the area of ground where it is grown. As such, ground area is the resource that must be considered in estimating and evaluating the environmental impact and not the biotic resource itself.

Against this background, there are assumed to be three resource categories:

- Energy resources
- Material resources
- Use of nature

Based on the selection of primary impact categories for this study, only the two resource categories *energy resources* and use *of nature* are discussed below.

A.6.1 Energy resources

Various energy resources, for example crude oil and wood, can be used as both material resources (so-called feedstock) and energy resources. Due to the many conversion processes within a life cycle, it is tricky to set system boundaries.

These characteristics of energy resources have resulted up until now in some cases in proposals to represent the energy resources as materials. This has made it difficult to include non-material energy resources such as wind power, hydroelectric power, tidal energy and photovoltaic energy, etc. in a single concept. In other studies, materials that can be considered as both a material resource and an energy resource are represented by their energy content. This necessarily brings the problem that these materials cannot be included with non-energetic materials. For example, when replacing glass with plastic, the used mass cannot be compared with the amount of energy. Instead of relating this to the energy content of the plastic, conversion to a weight-related scenario is necessary.

Energy reserves on Earth are finite – as long as people continue using them. This applies in particular for the exhaustible energy resources such as fossil fuels and also uranium, the raw material for nuclear energy generation. For that reason, it is important to consider fossil resources and uranium when evaluating environmental impact. In addition, information about the total amount of energy[10] in a system is important, because it describes the fundamental energetic efficiency of this system, including other forms of energy such as solar energy and geothermal energy.

The aggregation of the energy resources is carried out in two ways in this study: Firstly, the concept of fossil primary energy resource consumption is introduced. Secondly, evaluation of the finite nature of the primary energy resources is undertaken.

The term CED (cumulative primary energy demand) is used as a category description for the primary energy evaluation. It is a life cycle inventory parameter and expresses the sum of the energy contents of all primary energy resources up to the system boundaries. The term *CED fossil* refers to the sum of the fossil primary energy resources considered in this way. The term *CED nuclear* refers to the consumption of uranium. The calculation of *CED nuclear* is carried out by taking the atom flow consumed in the systems under study and assuming a degree of efficiency of 33%. Both *CED fossil* and *CED nuclear* are summarized to *CED non-renewable*. In addition, the *CED hydroelectric power, CED regenerative* and *CED Other* as well as the *CED total* obtained by summing all the CED values are recorded in the life cycle inventory results. Furthermore, *CED hydroelectric power* and *CED regenerative* are summarized as *CED renewable.* The *CED hydroelectric power* is determined assuming a degree of efficiency of 85%. *CED regenerative* is calculated from biomass (e.g. wood) input.

In accordance with the method of the UBA [UBA 1995], the static range of the energy resources serves as indicator for the scarcity of fossil fuels[11]. The static range here is derived from data on available global reserves and the current consumption of the respective resource. The static range expresses how many years an energy resource will be available from global reserves in the future, if the consumption level remains stable at the current level. The scarcity values are converted to Crude Oil Equivalents (COE) [UBA 1995]. The table below shows the conversion factors for calculating the crude oil equivalents.

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[10] The total energy requirements of the systems under study here are represented by the LCI parameter CED (the sum of the energy contents of the primary energy resources) and CED (total)

[11] The reliability of the static range as a scarcity factor is adversely affected by the uncertainties in the status of known, commercially viable reserves of the resources.

INPUT	Static range	Energy content, fossil	Crude oil equivalent (COE_i)
Fossil resources	**[a]**	**[kJ/kg]**	**[kg crude oil eq.]**
Brown coal	200	8303	0.0409 (kg COE/kg)
Natural gas	60	37718	0.6205 (kg COE/kg)
Crude oil	42	42622	1 (kg COE/kg)
Mineral coal	160	29809	0.1836 (kg COE/kg)
Source: [UBA 1995]			

Table A-5: Crude oil equivalents of fossil resources considered in this study

The following equation was used to calculate the crude oil equivalent values:

$$COE = \sum_i (m_i \times COE_i)$$

A.6.2 Use of nature

Land can be considered a finite resource when evaluating environmental impact. It is however not helpful to consider land as merely an available area. Land has to be defined by the environmental state of this land.

When the environmental status of an area of land is being considered, this takes into account all land-related environmental impact such as the reduction in biodiversity, soil erosion, adverse effects on the landscape, etc. It seems appropriate to include all such natural interrelationships in the term "use of nature" – in contrast to the term "land".

For this purpose, the UBA life cycle assessment of graphical papers [UBA 1998] developed a method for assessing environmental impact based on describing the "degree of naturalness" (hemerobic levels) of natural areas [Klöpffer & Renner 1995]. This was first of all used for forest ecosystems. The key feature of the method is the classification of the quality of the land into seven quality classes, with decreasing degree of naturalness (see table A-6). All areas of land must be able to be ranked. Forest areas can be classified in the first five classes. Class I corresponds to "unperturbed nature", which may not be used for any purpose for the foreseeable future. The next four classes are for forest practices ranging from "close to nature" to "distant to nature". Classes III, IV, V and VI cover agricultural use. Three classes (III, IV and V) hence over-lap with forestry use. Class VII corresponds to land sealed by paving or land which has degraded over a long period of time such as waste disposal sites.

Table A-6: Land use classes based on level of proximity to nature [UBA 1999]

Class	Level of proximity to nature	Type of land use
I	Natural	Ecosystem without anthropogenic management, natural forests
II	Close to natural	Close to natural forest management and use
III	Semi-close to natural	Semi-close to natural forest and agricultural management and use
IV	Semi-natural	Semi-natural forest and agricultural management and use
V	Semi-distant to natural	Semi-distant to natural forest and agricultural management and use
VI	Distant to natural	Distant to natural agricultural management and use
VII	Artificial / non-natural	Long-term sealed areas

The method is described in detail in [UBA 1999]. It is pointed out there that the development of the method is not yet complete. In particular, apart from forestry use, there is no general classification of all the uses of land relevant to LCA studies into degree of naturalness classes. This is due, amongst other things, to the fact that the available data sets do not as a rule provide the required information and for use of nature outside Germany the indicators for forming classes still have to be defined. Within the context of this study, forest land use (classes IV – V), agricultural land use (class VI) and sealed area (class VII) are most relevant and have been selected to serve as environmental indicators representing the impact category “Use of Nature”.

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Appendix B: Cradle-to-gate excerpt

B.1 Background

As mentioned in the section about the use of the current study (1.3), the commissioner has a special interest in the ‘cradle-to-gate carbon footprint’ of the *cb3 EcoPlus* beverage carton. In the course of the project, the authors of this report were informed of plans to derive respective findings from this report for use in on-pack declaration aimed at *SIG Combibloc*’s customers (e.g. beverage fillers) and end consumers. This information can be extracted from the study which is presented in the current report and underwent a critical review.

In order to facilitate a quick verification, e.g. for readers referring to the report following an indication they may have found on the *cb3 EcoPlus* pack, this appendix provides a summary specifically of the so-called ‘cradle-to-gate’ results. This term refers to the first part of the life cycle, covering the production processes of the primary packaging and the provision of the necessary material and energy inputs (i.e. the steps referred to in the result graphs as ‘*liquid packaging board*’, ‘*plastics for sleeve*’, ‘*aluminium foil*’, ‘*closure*’ where applicable and ‘*converting*’).

In accordance with the presentation of results in the main report, this so-called **‘cradle-to-gate’** part of the life cycle is referred to as ***Part A*** (see also section 4.1 and Table 4-1).

B.2 Comparison between systems

The following table provides an overview of the relative cradle-to-gate performance of the *SIG Combibloc*‘s beverage carton systems *cb3* and the *EcoPlus* variant in terms of the environmental aspects covered in this LCA. The presentation corresponds with the form used in Table 7-1 for the net results. Note that the table covers all environmental impact indicators and inventory categories examined in the current LCA, except ‘*Human toxicity – carcinogenic risk*’. The reason for this exclusion is given in section 4.3 (p. 41).

How to read the following table B–1:

- The packaging system named first in the table’s title as well as in the table itself (here: ‘*cb3 EcoPlus’)* is compared against a reference system (here: ‘*cb3’*).
- Percentages in the table express the proportion between the results of the first-named packaging system (here: ‘*cb3 EcoPlus’* with or without cap*)* and those of the reference system named at the top of the column (here: ‘*cb3’* with or without cap, respectively*)*.

For quicker orientation, the relative results of each system comparison are listed in two different columns, distinguishing cases of environmentally more favourable performances from the less favourable ones. This distinction is visually reinforced by a colour code using green and brown, respectively. Percentages lower than 10% are considered to be insignificant and marked by a grey shading of the respective fields.

Explanation:

Column headed ‘more’: The packaging system named first in the table (and table title) has lower indicator values (i.e. an environmentally <u>more</u> favourable performance) than the alternative packaging system listed in the second row of the respective column.	**Column headed ‘less’:** The packaging system named first in the table (and table title) has higher indicator values (i.e. an environmentally <u>less</u> favourable performance) than the alternative packaging system listed in the second row of the respective column.
Note: Percentages shaded in grey are smaller than 10% and thus considered insignificant.	

Exemplification for Table B–1:

The indication ‘“by 17%” in the middle column (“more favourable than …”) means the indicator results of ‘*cb3 EcoPlus w/ cCap*’ are 17% <u>lower</u> than those of ‘*cb3 w/ cSwift*’ for the respective environmental indicator.

Table B-1: Indicator results of the ‘*cb3 EcoPlus’* system with and without *cCap* related to those of the ‘*cb3’* system with and without *cSwift*, respectively (‘cradle-to-gate’ excerpt)

The indicator results of *Part A* of the *‘cb3 EcoPlus’* system’s life cycle are	***w/ cap***		***w/o cap***	
	more	**less**	**more**	**less**
	favourable than those of *‘cb3’* *(=100%)*			
Acidification	by 28.6%		by 28.0%	
Climate change	by 29.8%		by 28.6%	
Aquatic eutrophication		by 17.6%		by 18.1%
Terrestrial eutrophication	by 8.0%		by 4.0%	
Summer smog (POCP)	by 22.7%		by 18.8%	
Human toxicity - PM10	by 29.2%		by 28.6%	
Fossil resource consumption	by 26.3%		by 24.3%	
Use of nature - forestry		by 9.9%		by 10.3%
Total primary energy demand	by 18.8%		by 15.7%	
Non-renewable primary energy demand	by 27.4%		by 24.5%	
Transport intensity – lorry	by 4.0%		by 0.0%	

Per system comparison:
Left column (green fields): ‘*cb3 EcoPlus’* has lower indicator values (i.e. a more favourable performance) than ‘*cb3’*
Right column (brown fields): ‘*cb3 EcoPlus*‘ has higher indicator values (i.e. a less favourable performance) than ‘*cb3’*
Note: Percentages shaded in grey are smaller than 10% and thus considered insignificant.

B.3 Remarks and recommendation

This restricted view on the life cycle implies several additional limitations beyond those that apply to the complete LCA study (for more details see section 5.4). Regarding this ‘excerpt’ with a cradle-to-gate focus, it must be kept in mind that

- the results presented are not ‘full life cycle results’ – however according to the ISO standards on LCA, the LCA technique established there could also be applied for ‘cradle-to-gate studies’ (ISO 14040, Annex A, §A.1.2) and
- as the end of life of the regarded packaging systems is not included, these results include no credits.

The authors of the study recommend taking these points into account in any customer- and/or consumer-oriented communication that is based on cradle-to-gate figures.

Appendix C: Critical review

C.1 Members of critical review panel

Prof. Walter Klöpffer

Prof. Dr. Walter Klöpffer was born June 6, 1938 in Graz, Austria. After completion of his studies of chemistry at the Karl-Franzens-University in Graz, he joined 1964 the Battelle Institute in Frankfurt am Main, Federal Republic of Germany, where he has been living since that time.

His main field of research in the first 10 to 15 years at Battelle was the spectroscopy and photophysics of aromatic polymers and monomeric model compounds. After this period he switched to the study of environmental processes of chemicals and the assessment of chemicals. Since 1975 he has also been a professor for physical chemistry at the Jo-hannes-Gutenberg-University in Mainz. In 1995, three years after joining C.A.U. GmbH, he was appointed as the editor-in-chief of the newly founded „International Journal of Life Cycle Assessment“. The renewed international interest in persistent organic pollut-ants (POPs) induced a revival of older work on exposure modelling and, more general, in applying the precautionary principle to the assessment of organic chemicals.

Retired from C.A.U. GmbH, Dreieich, he is now free consultant and critical reviewer according to ISO 14040/44.

Hans-Jürgen Garvens

Hans-Jürgen Garvens (1966) studied at the University of Applied Technology and Technical University of Berlin in Chemical-, Energy- and Environmental Engineering. At that time he was also lecturer on contaminated sites, soil and groundwater purification and surface water protection. Mr. Garvens worked for Der Grüne Punkt (DSD Germany) a major packaging waste collection system in Germany until 2005 as packaging and LCA expert. His main task was to analyse the complete waste collection and treatment system in environmental terms (system to grave modelling). Results were used for publications as well as to steer the system (LCM). From that time he joined most of the packaging and waste LCA-Projects conducted in Germany in the project panel as representative of one of the interested parties. From 2005 he joined Umweltbundesamt (German Environment Protection Agency) in Berlin. He there works at the German Emissions Trading Authority. Aside of that he is free LCA Consultant. As such he conducts LCA Reviews according to ISO 14040/14044, mainly on packaging, waste management or near-related issues. Since 2009 he is subject editor “Packaging Systems including Recycling” of The International Journal of Life Cycle Assessment.

Dr. Fredy Dinkel

- Date of Birth: 8.4.1957
- Education

Master in theoretical physics, ETH, Zurich
Doctorate at the Institute of Polymers at the Swiss Federal Institute of Technology, Zurich

- Employment history

Research work on renewable materials

Partner in an engineering company, involved in renewable energy

For nearly twenty years partner of Carbotech Inc. as consultant in the field of environment and sustainable development, director for the department decision support: Life Cycle Assessment and mass flow analysis for cleaner production and environmental management

Director of the board of Carbotech Inc.

More than ten years of experience as lecturer in different universities and trainer for international companies in the fields of Life cycle analysis, environmental management, cleaner production and hazardous wastes.

Lectures on Live cycle assessment in CP, in different CP centres, like Vietnam, Sri Lanka, Costa Rica, Brazil and Jordan

- Professional experiences

Project leader for different national and international projects, e.g.:

- Decision support in environmental management systems, finding relevant impacts, option evaluation and communication for different companies like Die Post, Sarnafil or Schindler
- Consultancy in sustainable reporting according to GRI for different companies like Straumann or Die Post
- Decision support for the Jordanian government concerning the environmental impact of energy supply
- Different Life cycle assessments concerning recycling systems for companies like PET Recycing Schweiz, Tetrapak, SIG Combibloc, Vetroswiss, Alcan, Igora
- Different Life cycle projects on bio fuels and renewable materials for the Federal office of agriculture, energy and environment in Switzerland, 1993 – 2007
- Reviewing the study “life cycle assessment of bio fuels” according to ISO 14040, expert for the *Federal office of environment, 2006*
- Life cycle assessment of transportation systems in the construction sector, *Administration of the canton Basel, 2003*
- Different LCA projects in the construction sector for companies like *Holcim, Lafrage, Sarnafil, UBS*
- Evaluating different possibilities of waste treatment in Mexico, *expert for the CP Centre Mexico, 2003*

- Improving sustainable benefits of jute and allied fibres in West Bengal, *together with IBF inc. 2002*
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- Conception and realisation of the software EMIS for live cycle assessment

C.2 Report of critical review panel

Comparative Life Cycle Assessment of beverage cartons cb3 and cb3 EcoPlus for UHT milk

Critical Review Report

according to ISO 14040 and 14044

prepared for

SIG Combibloc

by

Walter Klöpffer (Chair)

Hans-Jürgen Garvens

and

Fredy Dinkel

August 2010

1 Procedural Aspects of the Critical Review

This critical review was ordered by SIG Combibloc (the "commissioner") in May 2010 and started with the examination of the model and the substance flows (May 31st, 2010) by one of us (HJG) and a telephone conference attended by the project team and the review panel (June 2nd, 2010). At that time a preliminary Draft Final Report had been produced by IFEU, Heidelberg (the "practitioner"). The critical review can therefore be considered only partly as an accompanying or interactive review [1, 2]. On the other hand it was still possible for the review team to propose major improvements which partly were accepted, partly not. This study was inserted into another LCA study (same commissioner, same practitioner and review team) at short notice so that a certain pressure with regard to the time available seems to have hindered a deeper treatment of some aspects of this study.

Formally, this critical review is a review by a "panel of interested parties" according to ISO 14040 section 7.3.3 [3] and ISO 14044 section 6.3 [4]. This most demanding form of critical review shall be performed if comparative assertions are expected that are "intended to be disclosed to the public". The two product systems compared in this LCA study have been developed by the same company so that the LCA can also be considered as an improvement assessment. It is therefore not necessary to include competitors or any other "interested parties" in the critical review.

The final report has been submitted by the practitioner July 28th, 2010. The critical review is based on this document.

The critical review process took place in an open and constructive atmosphere. The reports were read and extensively commented by all members of the panels; the review report is based on a synthesis of the comments and consensus among them.

2 General Comments

The LCA study scrutinized aims to compare two carton systems by SIG Combibloc under Western European conditions. Western Europe is defined as EU15 + CH. Since the end-of-live (EOL) phase was expected to play a major role, statistical data for the 16 states were collected and made available to the reviewers. Recycling, energetic use and controlled land filling are supposed to add up to 100% in all countries (i.e. any kind of littering and illegal waste removal is considered to negligible). Even if this is correct, there remains the problem that the three main routes of EOL play a different role in each of the 16 countries included in the study. There are examples for nearly 100% landfill and nearly 100% energetic use. Since it is difficult to present three parameters in a well understandable form, the practitioner defined – somewhat arbitrarily - two groups of countries: those with “high recycling rate” (> 36,7%) and the rest with less recycling. The transport distances involved in the packaging production constitute another not fully documented problem, but it can be argued that they are (or will be in the future) identical for the existing system (cb3) and the new one (cb3 EcoPlus). The data not documented in the report were open for the system check and found to be fully satisfactory.

All in all it can be said the complex European situation has been treated properly and a method has been developed to interpolate the results graphically for individual countries. Remaining open questions are treated in section 3.

The system modelling of the packaging systems using the UMBERTO® software was carefully checked (see section 3.3).

The problem of allocation in open-loop recycling was solved by the application of two (the minimum required by ISO 14044) allocation rules: 50/50 as the base allocation and 100% (all material credit to the secondary material supplying system). The not obligatory component normalization was included, using European system boundaries.

3. Statements by the reviewers as required by the international standards

3.1 Introduction

The LCA-framework standard ISO EN 14040 states [3]:

"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with the 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;*
- *the study report is transparent and consistent."*

In the following sections 3.2 to 3.6 these items are discussed to our best judgement in the light of the final report (version of 30th July, 2010), based on the international LCA-standards ISO 14040 and 14044 [3-5].

3.2 Consistency of the methods with the ISO standards

This LCA study follows closely the general structure of LCA prescribed in ISO 14040 [3] and also the requirements laid down in ISO 14044 [4]. The structure of the report reflects the sequence Goal & Scope – Life cycle inventory analysis (LCI) – Life cycle impact assessment (LCIA) – and Interpretation. Normalisation, an optional step of LCIA, is presented separately as chapter 6 after "Interpretation and discussion".

Despite of several details to be criticized below, there can be no doubt that this study has been conducted according to the international standards cited.

3.3 Scientific and technical validity of the methods applied

The methods applied in this study follow in general to the procedure developed for the German packaging studies by UBA and IFEU, but now (not for the first time) extended for the enlarged (Western) European system boundaries. Some essential features of the methods are described in the report, but the full complexity can only be considered using the computer programme (UMBERTO®) developed for LCA and Mass flow analysis.

The system check for the two LCAs in this project, performed by one of us (HJG), brought the following results:

"The system modelling of all packaging systems using the UMBERTO® software (including the different scenarios) was checked May 31st, 2010. About 20% of the models were under closer investigation. Most tests results were to the complete satisfaction. Obviously most of the models were already carefully checked internally by the practitioner prior to the presentation of the results in the final draft review. Only minor problems were found, which were corrected by the practitioner prior to the preparation of the final report. The reviewer was provided with all requested original data and all questions could be answered if not at the time of the investigation, they were answered the following days by

mail. Transparency was complete to the reviewer, even if the report's transparency lacks significantly due to confidentiality reasons."

The Life cycle inventory (LCI) models established are scientifically and technically valid.

The Life cycle impact assessment (LCIA) method follows the one used in previous packaging studies by IFEU. The international standard ISO 14044 does not prescribe specific impact categories and indicators, not even a default list. Most impact categories and indicators used in this study belong to the common ones used in nearly all LCIAs, e.g. the impact category "Climate change" and the indicator Global warming potential for a time horizon of 100 years (GWP_{100}). These impact categories are commonly attributed to CML, Leiden [6,7].

As indicated clearly in the report, some indicators consist of LCI data properly related to the functional unit. The indicator "transport intensity", e.g., is used as a proxy for noise impacts. It quantifies the amount of lorry kilometres required in a product system (an indicator for the impact category noise (road traffic) is still under development [8, 9 and 10]). In this study the transport intensity also summarizes rail and ship transport. Furthermore the effected population intensity was not considered. Having the same transport distances in all scenarios, "transport intensity" gives only an idea on the effects of the different packaging weights on the need of transportation.

Also the indicator "Cumulative Energy Demand" [11] does not strictly obey to the rules by ISO, but is frequently used and gives relevant information about the total and renewable primary energy consumed per functional unit. The same is true for the category indicator "forest area" quantifying the land occupied for producing the raw material of the main material used in the manufacture of the cartons (LPB). This indicator can be considered as a proxy for a set of indicators to be developed for the impact category "land use" [7].

Normalisation is an important voluntary step of LCIA. As already mentioned above, the results have been reported in a separate chapter. Since data necessary for calculating the "resident-equivalents" (REQs) were not available for EU15+CH, the system boundary chosen for calculating these values was EU25+3. Although this difference in the system boundaries may somewhat influence the results, the main features should be similar.

As a result of the normalization step, the packaging cb3 EcoPlus without closure turns out to be best in most categories/indicators with exception of Forest area and aquatic eutrophication. The relatively low normalised indicator values (GWP_{100}) in the important impact category Climate change are caused by the use of renewable raw materials. Aquatic eutrophication always gives a relatively high potential for products consisting mainly of cellulose. This shows a need for further decreasing the water emissions caused during production of LPB.

All in all, the results of the LCIA of the two product systems (both with and without plastic closure) compared are not surprising. The methods used should nevertheless be adjusted to the scientific progress, e.g. [8, 9, 10, 12] in the future. It is clear, however, that the new methods pose higher demands with regard to the quality of LCI data. At the time being we can assert that the LCIA methods used in this study correspond to the methods mostly used in the literature and go beyond the average in several impact categories.

The methods used are scientifically and technically valid.

3.4 Appropriateness of data

The functional unit (f.u.) is (together with “cradle-to-grave”) the basic concept of Life Cycle Assessment [7]. If the f.u. is not properly defined, all data are related in a wrong way. In the definition of the f.u. one has to assume and prove in critical cases the technical equivalence of the systems compared. In the case of the two cartons we can assume that the replacement of the aluminium barrier foil by polyamide does provide the same protection function for the contained milk. The reviewers asked for some technical documentation about studies performed to prove this equivalence, but did not obtain any direct information about this item. The test samples provided by the commissioner as well as samples bought by one of the reviewers showed the same best before-date than conventional (LPB-based) packagings. It is thus safeguarded, that at least the same results at storage stability tests were obtained by the milk filler using EcoPlus already.

Most data used in the foreground and in the background are appropriate (see also system check in section 3.3). Data symmetry problems are mentioned in particular regarding human toxicity (carcinogenic risks); in this indicator, the benzo[a]pyrene emissions reported by the European Aluminium Association (EAA) [13] – but not by most competing material producers – invariably distorts the results. The practitioner has considered this problem in the interpretation of the results.

3.5 Assessment of the interpretation in view of limitations and goal and scope

The core problem in the section "Interpretation" concerns the question: are the conclusions drawn from the numerical results robust? Or do the results of sensitivity analyses and other considerations shed doubts on the results. Since the differences in the results obtained for the four systems are relatively small, the reviewers recommended performing a significance analysis. This was not done, but a 10% significance rule was applied instead for all impact categories (except human toxicity/carcinogenicity, see above), as in several comparative packaging LCAs before. This requires some comment, since 10% is a significance which can be obtained for primary energy and (less certainly) for energy-dominated impact categories. Other categories/indicators may require a higher significance level, but of course there cannot be a consensus in the LCA community about the values to be taken generally, because the significance level depends from a variety of factors like quality of the data, uncertainty of the models to describe the system or to calculate the impacts. E. g. in this study the category land use has a very small uncertainty because it is nearly proportional to the differences in the use of cardboard. On the other hand impact categories like terrestrial eutrophication will have higher uncertainty than 10%.

Considering the long experience with packaging LCA studies, performed with a continuously improved data set and only slow adaptation of the LCA method, we may safely conclude that there is a high degree of comparability which is certainly higher than the accuracy which can be calculated with mathematical models. Since the reviewers are furthermore convinced that the results obtained in this study are essentially correct (consensus, see below), we accept the 10% significance in this study, even if a significance analysis would have given more reliable results.

Since the four systems compared are quite similar and have several steps in common, the so-called "black box" method can/could be used extensively. Black box means to consider only those process steps providing differences between the scenarios and leaving all other to the "black box". There was a discussion within the review team about this topic, since a broader, as well as a minor use of the black box method has advantages as well as disadvantages. The main advantage of a broader use of black box (less process steps considered) consists in a clearer demonstration of the differences between the systems.

These differences may, however, concern only an insignificant part of the whole system, which cannot be observed, since the whole system is not considered (disadvantage). It depends finally on Goal & Scope, i.e. on the main questions to be answered, how extensive the black box method should be applied. From an environmental point of view, it is in general better to optimise the whole system and this is why LCA gained general acceptance. In this study, the Goal and Scope asked to answer the following two questions:

1: "*to provide knowledge of environmental strengths and weaknesses of the newly developed cb3 1000 mL EcoPlus beverage carton*".

2.: "*to compare its environmental performance with that of the firmly established 'conventional' beverage carton cb3*"

Especially in the first question the whole packaging is moved into focus, it was thus necessary to minimise the black box-use (considering most, if not all process steps). This has been very well done in the study pointing out the relevance of the different parts of the systems. Concerning this relevance analysis there is also no doubt about the significance.

On the other hand the second question can be understood that the answer should provide information, if the changes lead to a *significant* environmental improvement. To give a clear answer to this question using a broad black box approach could be very helpful. This is especially true, if the differences are small and not all indicators lead to the same conclusion. To check, if the differences are significant, an estimation focusing only on the differences (broader use of the black box method) has been performed on CED, GWP and other selected CML indicators by one member of the review team (FD). These calculations have shown differences by factors of two and more. These results convinced us, that the results are significant in these impact categories.

As discussed before not all indicators show the same results. To check the overall conclusions FD has also performed calculations using methods valuating the different impacts to one single indicator as it usual in Europe outside Germany. Ecological Scarcity [14] and Recipe [15] was used for additional valuations of the results given in the LCA report. The review team is fully aware that these methods are not well accepted in Germany and also the norm ISO 14'040 does not accept the use of these methods for comparatives studies disclosed to the public. Nevertheless the results of such methods can give a valuable decision base for internal use [16].

The results of these calculations give a strong indication that the results and the conclusions concerning the second goal are correct and significant.

All our considerations indicate, that the interpretation well reflects goal and scope and that the results sufficiently consider the limitations from data and methods.

3.6 Transparency and consistency of study report

The report is complete and contains all main elements of a life cycle assessment report. The structure with the main headers is sensible.

The transparency of the report is not very high, since evidently some data have not been reported for confidentiality reasons. However, the needed details were laid open to the review during the system and data check, see section 3.3.

The report has been read carefully by all of us. No major contradictions could be found. The report is also well printed; the quality of the diagrams is excellent.

4 Résumé and recommendations

- The study has been performed in accordance with the international standards ISO EN 14040 + 14044
- 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
- The study report is transparent and consistent

The results should be used to further improve all packaging systems. Minimization of the use of plastics in the carton is as well promising as the use of wood from sustainably managed forests. For the various countries it remains a task to reduce direct landfilling for all biodegradable materials – in accordance with EU legislation.

The Life cycle impact assessment methods should be further improved. For internal use also other valuation methods are recommended.

The review team appreciates the intended publication of the full report. Such a publication would be further improved, if an executive summary is added. However, such summary was not disclosed to the review panel and is not part of the review.

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