INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

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

Addendum for beverage cartons with closure cSwift Plus

LCA SIG / CB-100732c

commissioned by SIG Combibloc

Heidelberg, October 31st, 2018

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Frank Wellenreuther

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1 Background

This document is an addendum to the Life Cycle Assessment study “Life Cycle Assessment of SIGNATURE PACK: a beverage carton containing polymers based on the mass balanced renewable material approach.” that was finalised in March 2018. In this study two variants of the newly developed SIGNATURE PACK are compared with two other beverage cartons from SIG Combibloc with a geographical scope of Germany and Europe. In June 2018 an addendum extending the scope to the Dutch market was added.

This second addendum to these Life Cycle Assessments introduces a different closure system for two of the regarded beverage cartons. The cartons that featured a cCap closure in the original studies, are now modelled with the cSwift Plus closure for all three markets i.e. Germany, Europe and Netherlands. Apart of the specification of this closure no other input data are different from those of the original studies. As also the goal and scope, the methodologies applied and the way the LCA is conducted shows no differences to the original studies, an additional critical review is not considered necessary. The original study and its first addendum have been critically reviewed by Dominik Müller, Senior Sustainability Consultant at TÜV Rheinland. In the view of the authors the confirmed compliancy to the ISO 14040 and ISO 14044 standards for LCA is also valid for the current addendum.

The description of goal and scope and life cycle inventory of the original study report is valid for this addendum as well and is therefore not repeated here. Only the regarded packaging systems and scenarios are slightly different and therefore are described in the following section.

2 Packaging systems and scenarios

The Packaging systems examined in this study are:

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

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

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

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

2.1 Packaging specifications

The following table 2-1 shows the packaging specifications of the regarded beverage cartons. The only difference compared to the specifications of the beverage cartons examined in the original study is the choice and therefore composition and weight of the closures of the cb3 1000 EcoPlus and the cb3 1000 SIGNATRE PACK 100% cartons.

Table 2.1: Packaging specifications

Packaging components	cb3 1000 EcoPlus w/ cSwift Plus	cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus	cb3 1000 Standard w/ cSwift	cb3 1000 SIGNATURE PACK high barrier w/ cSwift
volume	1000 mL	1000 mL	1000 mL	1000 mL
primary packaging (sum per carton)	**30.5g**	**30.5 g**	**30.3 g**	**30.3 g**
composite material (sleeve)	**27.7 g**	**27.7 g**	**27.6 g**	**27.6 g**
- liquid packaging board	*22.9 g*	*22.9 g*	*20.3 g*	*20.3 g*
- LDPE	*4.24 g*		*5.93 g*	
- ISCC Plus mass balanced green LDPE		*4.24 g*		*5.93 g*
- aluminium			*1.36 g*	*1.36 g*
- PA	*0.51 g*			
- CMS71 mass balanced green PA		*0.51 g*		
closure	**2.80 g**	**2.80 g**	**2.71 g**	**2.71 g**
- PP spout	*1.46 g*		*1.41 g*	
- ISCC Plus mass balanced green PP		*1.46 g*		*1.41 g*
- HDPE cap	*1.34 g*		*1.30 g*	
- ISCC Plus mass balanced green HDPE		*1.34 g*		*1.30 g*
- PP cap				
- ISCC Plus mass balanced green PP				
Secondary packaging (tray)	**134 g**	**134 g**	**134 g**	**134 g**
Tertiary packaging (sum)	**20,627 g**	**20,627 g**	**20,627 g**	**20,627 g**
pallet	20,000 g	20,000 g	20,000 g	20,000 g
type of pallet (trip rate 25)	EURO	EURO	EURO	EURO
Stretch foil per pallet (LDPE)	627 g	627 g	627 g	627 g
Pallet configuration				
Cartons per tray	12	12	12	12
Trays per pallet	12	12	12	12
Layers per pallet	5	5	5	5
Cartons per pallet	720	720	720	720

2.2 Scenario modelling

2.2.1 Base scenarios

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

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

2.2.2 Sensitivity analysis with focus on the allocation factor

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

3 Results

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

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

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

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

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

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

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

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

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

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

3.1 Results base scenario GERMANY

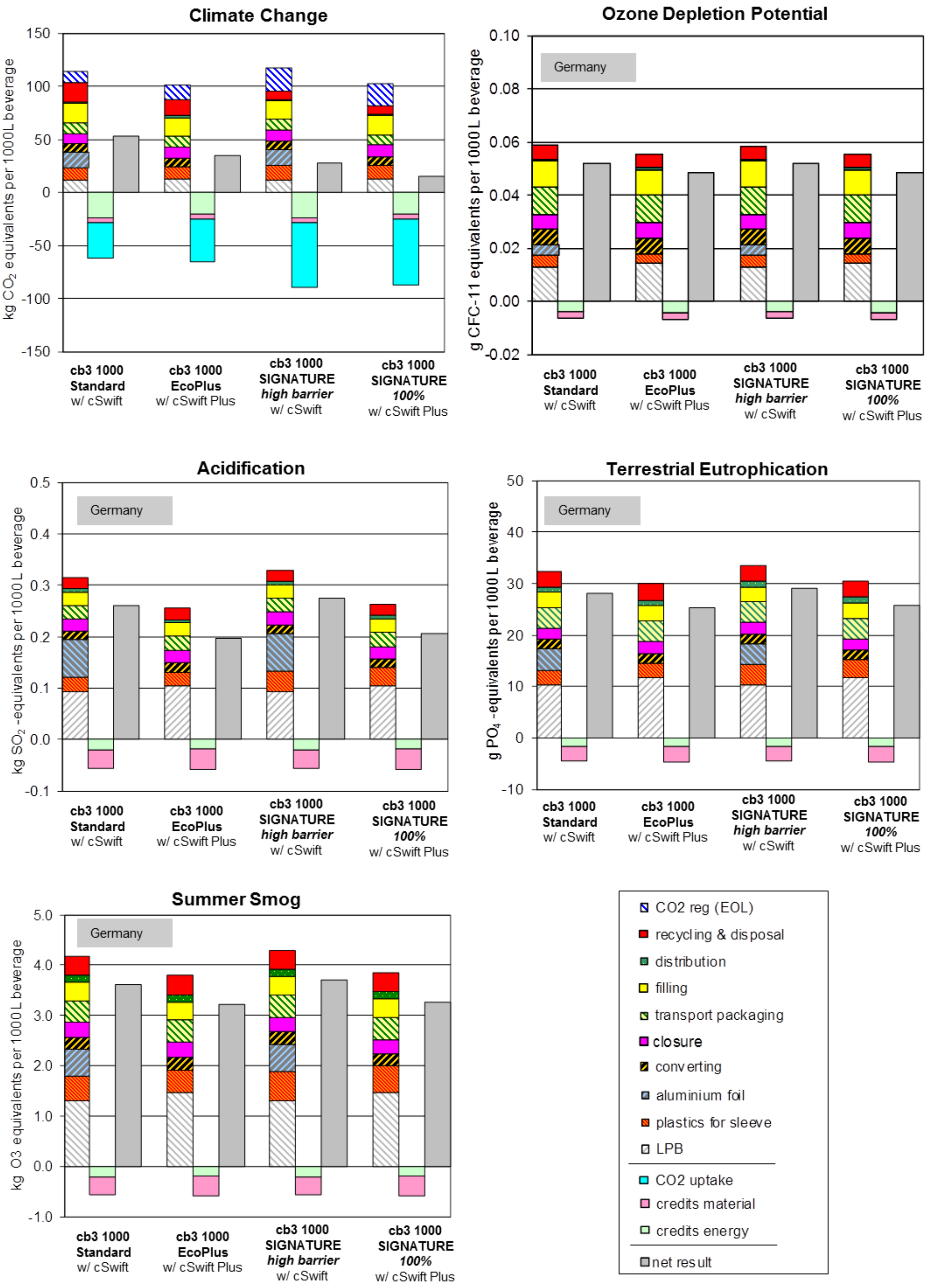

Figure 3.1: Indicator results for base scenario GERMANY with allocation factor 50% (Part 1)

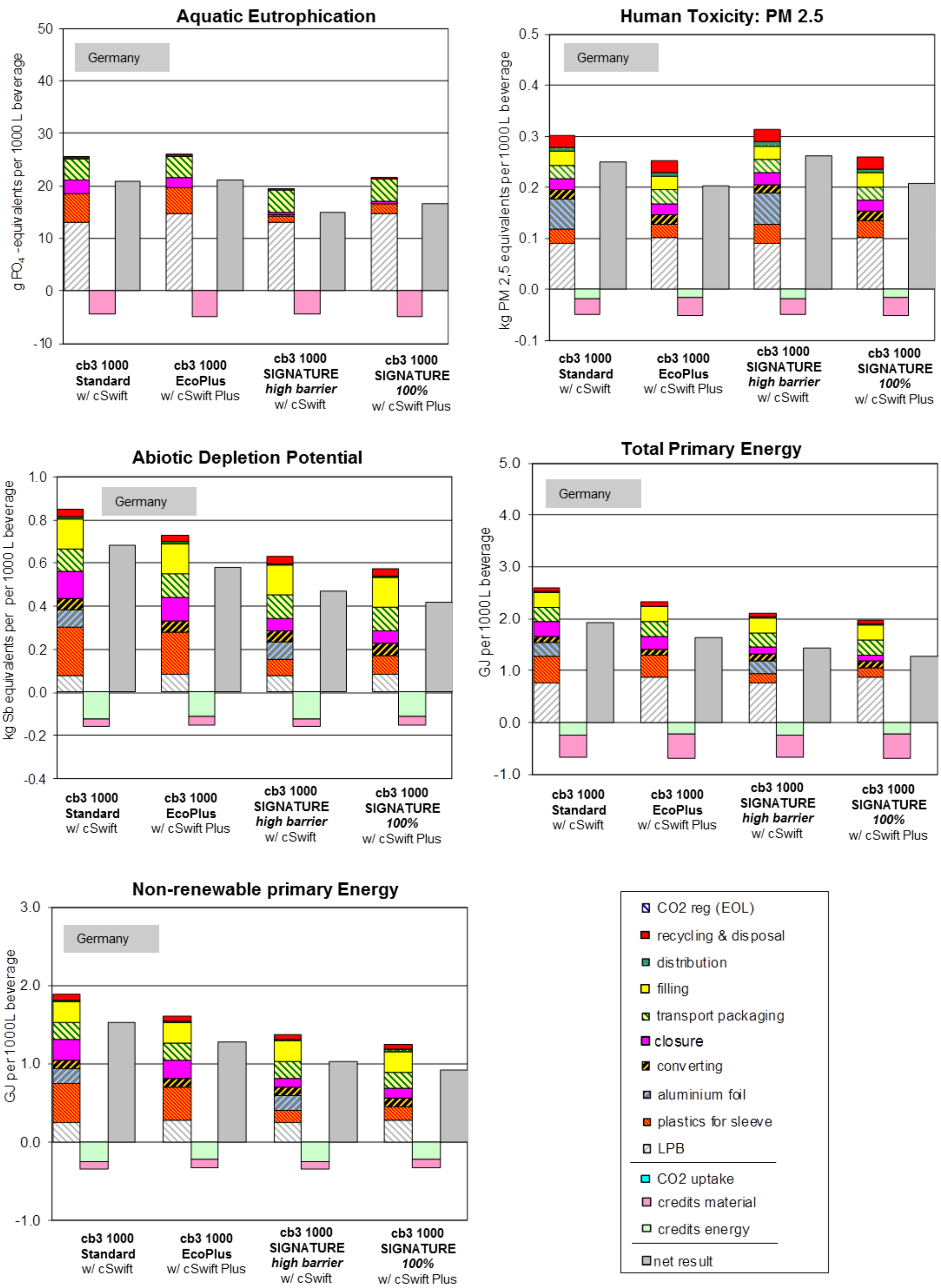

Figure 3.2: Indicator results for base scenario GERMANY with allocation factor 50% (Part 2)

Table 3.1: Results for base scenarios – cumulated life cycle (LC) phases:
LC part A: Share of production processes for primary packaging (to producer gate out),

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

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

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

Base scenarios GERMANY		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	55.67	42.32	58.25	44.26
	LC part B	47.96	44.83	36.60	37.40
	CO_2 reg (EOL)	10.69	13.53	22.04	20.95
	Credits	-28.24	-25.56	-28.24	-25.56
	CO_2-uptake	-33.49	-40.24	-61.08	-61.65
	Net results (∑)	52.58	34.89	27.57	15.42
Acidification [kg SO_2 equivalents]	*LC part A*	0.23	0.17	0.25	0.18
	LC part B	0.08	0.08	0.08	0.08
	Credits	-0.06	-0.06	-0.06	-0.06
	Net results (∑)	0.26	0.20	0.27	0.20
Summer Smog [kg O_3 equivalents]	*LC part A*	2.86	2.48	2.97	2.52
	LC part B	1.32	1.33	1.32	1.33
	Credits	-0.58	-0.60	-0.58	-0.60
	Net results (∑)	3.60	3.20	3.71	3.25
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.03	0.03	0.03	0.03
	Credits	-0.007	-0.007	-0.007	-0.007
	Net results (∑)	0.05	0.05	0.05	0.05
Aquatic eutrophica-tion [g PO_4 equivalents]	*LC part A*	21.01	21.54	14.94	17.14
	LC part B	4.27	4.27	4.27	4.27
	Credits	-4.34	-4.83	-4.34	-4.83
	Net results (∑)	20.94	20.98	14.87	16.58
Terrestial eutrophi-cation [g PO_4 equivalents]	*LC part A*	21.28	18.66	22.38	19.24
	LC part B	11.13	11.20	11.13	11.20
	Credits	-4.44	-4.61	-4.44	-4.61
	Net results (∑)	27.97	25.25	29.07	25.83
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.56	0.44	0.34	0.28
	LC part B	0.29	0.29	0.29	0.29
	Credits	-0.16	-0.15	-0.16	-0.15
	Net results (∑)	0.68	0.57	0.47	0.42

(Table 3.1 continued)

Base scenarios GERMANY		cb3 1000 w/ cSwift 1000 mL	cb3 EcoPlus 1000 w/ cSwift Plus 1000 mL	cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL	cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.22	0.17	0.23	0.17
	LC part B	0.08	0.08	0.08	0.09
	Credits	-0.05	-0.05	-0.05	-0.05
	Net results (∑)	0.25	0.20	0.26	0.21
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.62	1.44	1.26
	LC part B	0.66	0.66	0.66	0.66
	Credits	-0.67	-0.68	-0.67	-0.68
	Net results (∑)	1.93	1.60	1.44	1.25
Non-renewable PE [GJ]	*LC part A*	1.31	1.04	0.81	0.67
	LC part B	0.57	0.56	0.57	0.56
	Credits	-0.34	-0.33	-0.34	-0.33
	Net results (∑)	1.53	1.27	1.03	0.91

3.2 Description of results GERMANY

3.2.1 Description by system

cb3 1000 Standard w/ cSwift 1000 mL

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

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

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

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

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

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

The transport packaging contributes to almost all examined categories.

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

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

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

cb3 1000 EcoPlus w/ cSwift Plus 1000 mL

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

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

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

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

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

The transport packaging contributes to almost all examined categories.

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

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

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

cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL

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

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

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

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

cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL

As the *cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus* is identical to the *cb3 1000 EcoPlus w/ cSwift Plus* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, closure, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 EcoPlus w/ cSwift Plus.*

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

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

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

3.2.2 Comparison between systems

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

Table 3.2: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 Standard w/ cSwift in **GERMANY**

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

Table 3.3: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 EcoPlus w/ cSwift Plus in **GERMANY**

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL					
are **LOWER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		are **HIGHER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cSwift Plus**	
Climate Change	-21%	Summer Smog	+16%	Ozone Depletion	+8%
Aquatic Eutrophication	-29%	Acidification	+39%		
Abiotic Depletion	-19%	Terrestrial Eutrophication	+15%		
Total Primary Energy	-12%	PM 2.5	+29%		
Non-renewable primary energy	-19%				

Table 3.4: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus with cb3 1000 Standard w/ cSwift in **GERMANY**

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus 1000 mL			
are **LOWER** than those of **cb3 1000 Standard c/Swift**		show **no significant differences** compared to those of **cb3 1000 Standard c/Swift**	
Climate Change	-71%	Terrestrial Eutrophication	-8%
Acidification	-21%	Summer Smog	-10%
Aquatic Eutrophication	-21%	Ozone Depletion	-7%
PM 2.5	-17%		
Abiotic Depletion	-39%		
Total Primary Energy	-34%		
Non-renewable primary energy	-41%		

Table 3.5: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus with cb3 1000 EcoPlus w/ cSwift Plus in **GERMANY**

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus 1000 mL			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cSwift Plus**	
Climate Change	-56%	Acidification	+4%
Aquatic Eutrophication	-21%	Ozone Depletion	0%
Abiotic Depletion	-27%	Terrestrial Eutrophication	+2%
Total Primary Energy	-22%	PM 2.5	+3%
Non-renewable primary energy	-29%	Summer Smog	+1%

3.3 Results base scenario EUROPE

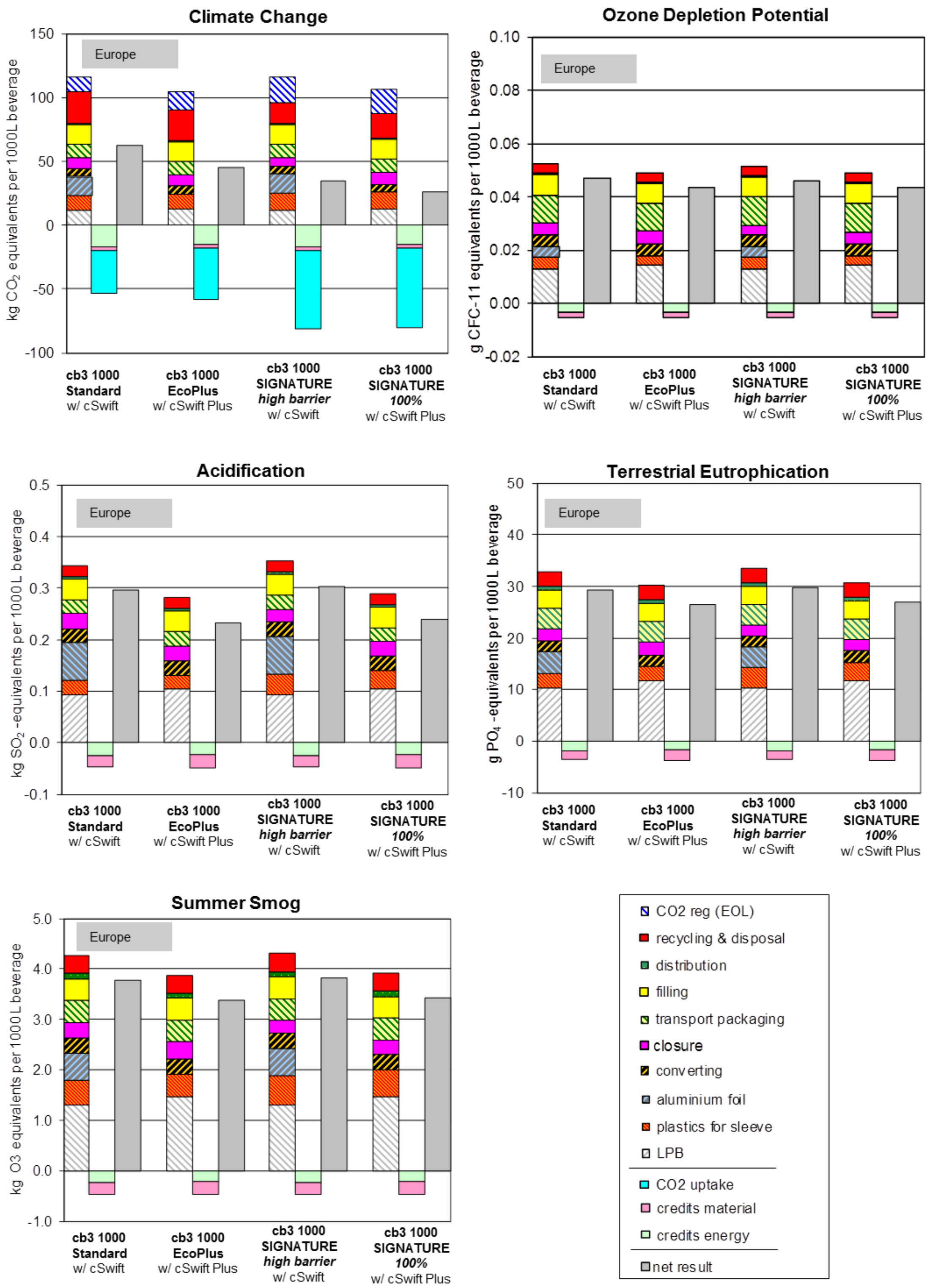

Figure 3.3: Indicator results for base scenario EUROPE with allocation factor 50% (Part 1)

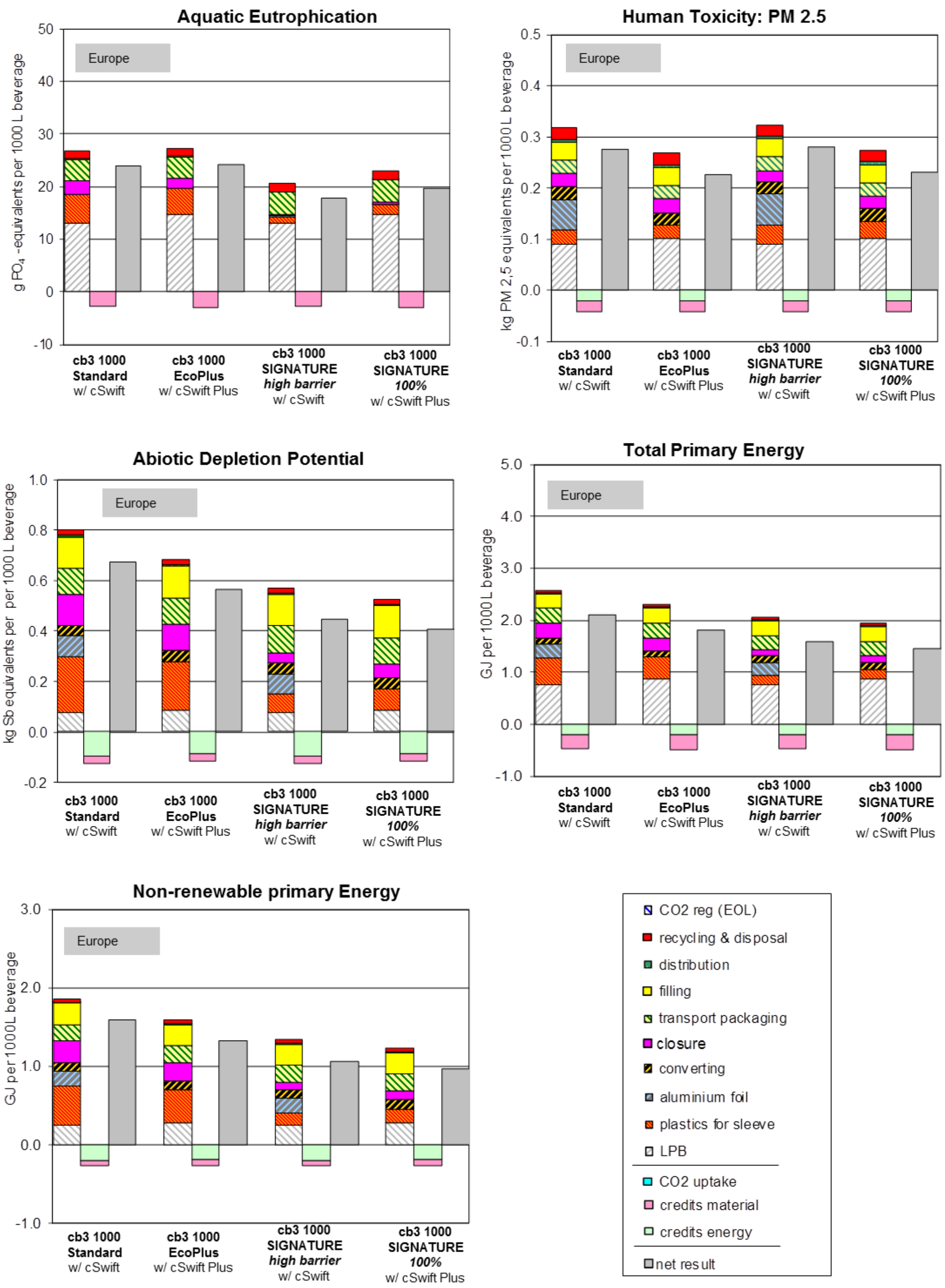

Figure 3.4: Indicator results for base scenario EUROPE with allocation factor 50% (Part 2)

Table 3.6: Results for base scenarios **EUROPE**– cumulated life cycle (LC) phases:
LC part A: Share of production processes for primary packaging (to producer gate out),

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

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

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

Base scenarios Europe		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	52.93	39.55	52.66	41.52
	LC part B	51.79	50.80	43.60	45.87
	CO_2 reg (EOL)	11.57	13.84	19.75	18.77
	Credits	-20.33	-18.55	-20.33	-18.55
	CO_2-uptake	-33.49	-40.24	-61.08	-61.65
	Net results (∑)	62.45	45.40	34.60	25.96
Acidification [kg SO_2 equivalents]	*LC part A*	0.25	0.19	0.26	0.20
	LC part B	0.09	0.09	0.09	0.09
	Credits	-0.05	-0.05	-0.05	-0.05
	Net results (∑)	0.30	0.23	0.30	0.24
Summer Smog [kg O_3 equivalents]	*LC part A*	2.94	2.55	2.98	2.59
	LC part B	1.32	1.32	1.32	1.32
	Credits	-0.48	-0.49	-0.48	-0.49
	Net results (∑)	3.78	3.38	3.82	3.43
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.02	0.02	0.02	0.02
	Credits	-0.005	-0.006	-0.005	-0.006
	Net results (∑)	0.0468	0.0434	0.0460	0.0433
Aquatic eutrophica-tion [g PO_4 equivalents]	*LC part A*	21.00	21.54	14.78	17.14
	LC part B	5.72	5.73	5.72	5.73
	Credits	-2.82	-3.12	-2.82	-3.12
	Net results (∑)	23.90	24.15	17.68	19.75
Terrestial eutrophi-cation [g PO_4 equivalents]	*LC part A*	21.83	19.18	22.49	19.70
	LC part B	10.98	11.00	10.98	11.00
	Credits	-3.63	-3.71	-3.63	-3.71
	Net results (∑)	29.19	26.46	29.84	26.98
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.54	0.42	0.31	0.27
	LC part B	0.26	0.26	0.26	0.26
	Credits	-0.13	-0.12	-0.13	-0.12
	Net results (∑)	0.67	0.56	0.44	0.40

(Table 3.6 continued)

Base scenarios Europe		cb3 1000 Standard w/ cSwift 1000 mL	cb3 1000 EcoPlus w/ cSwift Plus 1000 mL	cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL	cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.23	0.18	0.23	0.18
	LC part B	0.09	0.09	0.09	0.09
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.27	0.23	0.28	0.23
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.66	1.43	1.31
	LC part B	0.64	0.64	0.64	0.64
	Credits	-0.48	-0.49	-0.48	-0.49
	Net results (∑)	2.09	1.80	1.58	1.45
Non-renewable PE [GJ]	*LC part A*	1.32	1.04	0.79	0.68
	LC part B	0.54	0.54	0.54	0.54
	Credits	-0.28	-0.27	-0.28	-0.27
	Net results (∑)	1.58	1.32	1.06	0.96

3.4 Description of results EUROPE

3.4.1 Description by system

cb3 1000 Standard w/ cSwift 1000 mL

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

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

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

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

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

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

The transport packaging contributes to almost all examined categories.

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

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

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

cb3 1000 EcoPlus w/ cSwift Plus 1000 mL

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

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

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

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

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

The transport packaging contributes to almost all examined categories.

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

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

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

cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL

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

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

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

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

cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL

As *the cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus* is identical to the *cb3 1000 EcoPlus w/ cSwift Plus* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, closure, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 EcoPlus w/ cSwift Plus.*

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

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

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

3.4.2 Comparison between systems

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

Table 3.7: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 Standard w/ cSwift in **EUROPE**

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

Table 3.8: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 EcoPlus w/ cSwift Plus in **EUROPE**

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		are **HIGHER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**	
Climate Change	-24%	Summer Smog	+13%
Aquatic Eutrophication	-27%	Acidification	+31
Abiotic Depletion	-21%	Terrestrial Eutrophication	+13%
Total Primary Energy	-13%	PM 2.5	+24%
Non-renewable primary energy	-26%		
		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cSwift Plus**	
		Ozone Depletion	+6%

Table 3.9: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus with cb3 1000 Standard w/ cSwift in in **EUROPE**

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus 1000 mL			
are **LOWER** than those of **cb3 1000 Standard c/Swift**		show **no significant differences** compared to those of **cb3 1000 Standard c/Swift**	
Climate Change	-58%	Terrestrial Eutrophication	-8%
Acidification	-19%	Ozone Depletion	-7%
Aquatic Eutrophication	-17%	Summer Smog	-9%
PM 2.5	-16%		
Abiotic Depletion	-40%		
Total Primary Energy	-31%		
Non-renewable primary energy	-40%		

Table 3.10: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus with cb3 1000 EcoPlus w/ cSwift Plus in **EUROPE**

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus 1000 mL			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cSwift Plus**	
Climate Change	-43%	Acidification	3%
Aquatic Eutrophication	-18%	Summer Smog	1%
Abiotic Depletion	-28%	Ozone Depletion	0%
Total Primary Energy	-20%	Terrestrial Eutrophication	2%
Non-renewable primary energy	-28%	PM 2.5	2%

3.5 Results base scenario NETHERLANDS

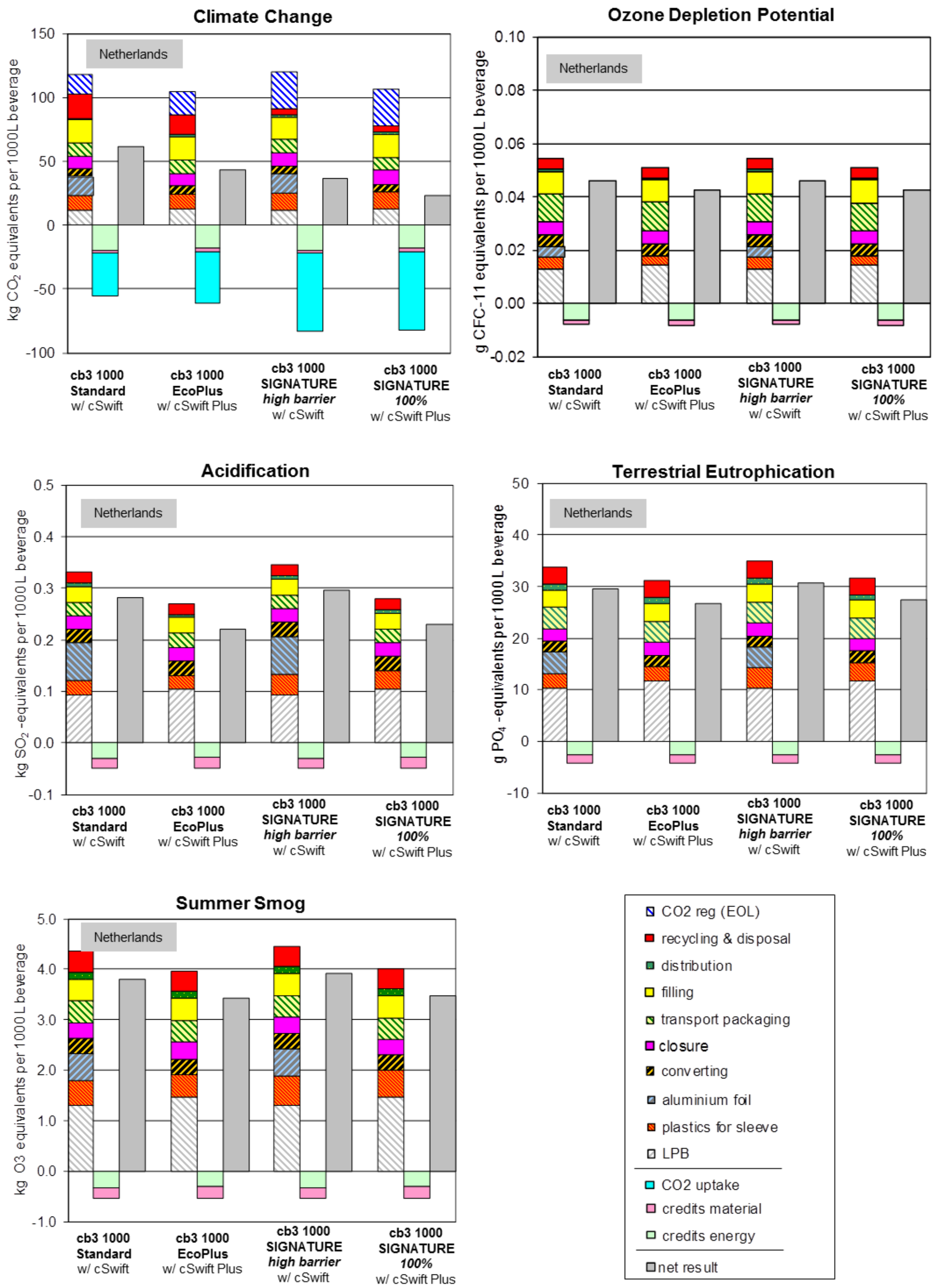

Figure 3.5: Indicator results for base scenario with allocation factor 50% (Part 1)

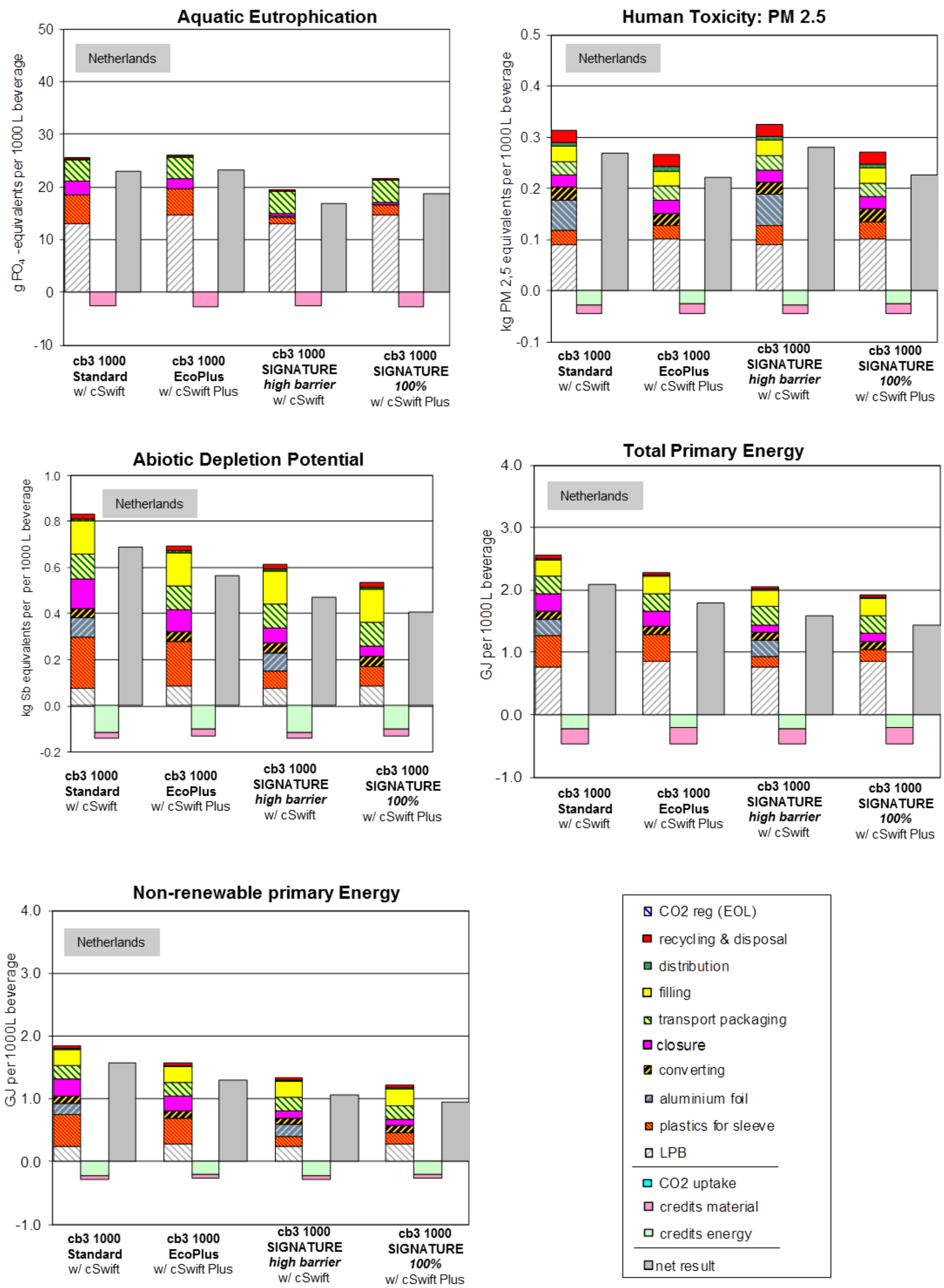

Figure 3.6: Indicator results for base scenario with allocation factor 50% (Part 2)

Table 3.11: Results for base scenarios – cumulated life cycle (LC) phases:
LC part A: Share of production processes for primary packaging (to producer gate out),

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

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

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

Base scenarios Netherlands		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	54.07	40.80	56.65	42.73
	LC part B	48.66	45.39	34.90	35.40
	CO_2 reg (EOL)	14.75	17.85	28.50	27.85
	Credits	-22.38	-20.82	-22.38	-20.82
	CO_2-uptake	-33.49	-40.24	-61.08	-61.65
	Net results (∑)	61.61	42.98	36.60	23.51
Acidification [kg SO_2 equivalents]	*LC part A*	0.25	0.18	0.26	0.19
	LC part B	0.09	0.09	0.09	0.09
	Credits	-0.05	-0.05	-0.05	-0.05
	Net results (∑)	0.28	0.22	0.30	0.23
Summer Smog [kg O_3 equivalents]	*LC part A*	2.94	2.56	3.05	2.61
	LC part B	1.41	1.40	1.41	1.40
	Credits	-0.54	-0.55	-0.54	-0.55
	Net results (∑)	3.81	3.41	3.91	3.46
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.02	0.02	0.02	0.02
	Credits	-0.008	-0.008	-0.008	-0.008
	Net results (∑)	0.0461	0.0427	0.0461	0.0427
Aquatic eutrophica-tion [g PO_4 equivalents]	*LC part A*	21.00	21.54	14.94	17.14
	LC part B	4.37	4.37	4.37	4.37
	Credits	-2.49	-2.75	-2.49	-2.75
	Net results (∑)	22.88	23.16	16.82	18.76
Terrestial eutrophi-cation [g PO_4 equivalents]	*LC part A*	21.86	19.26	22.97	19.83
	LC part B	11.83	11.82	11.83	11.82
	Credits	-4.23	-4.30	-4.23	-4.30
	Net results (∑)	29.46	26.78	30.57	27.35
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.55	0.41	0.33	0.26
	LC part B	0.28	0.28	0.28	0.28
	Credits	-0.14	-0.13	-0.14	-0.13
	Net results (∑)	0.69	0.56	0.47	0.40

(Table 3.11 continued)

Base scenarios Netherlands		cb3 1000 w/ cSwift 1000 mL	cb3 EcoPlus 1000 w/ cSwift Plus 1000 mL	cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL	cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.22	0.18	0.24	0.18
	LC part B	0.09	0.09	0.09	0.09
	Credits	-0.04	-0.04	-0.04	-0.04
	Net results (∑)	0.27	0.22	0.28	0.23
Total primary energy (PE) [GJ]	*LC part A*	1.93	1.66	1.44	1.30
	LC part B	0.62	0.62	0.62	0.62
	Credits	-0.46	-0.47	-0.46	-0.47
	Net results (∑)	2.08	1.80	1.59	1.44
Non-renewable PE [GJ]	*LC part A*	1.31	1.04	0.81	0.68
	LC part B	0.53	0.53	0.53	0.53
	Credits	-0.28	-0.27	-0.28	-0.27
	Net results (∑)	1.56	1.30	1.06	0.94

3.6 Description of results NETHERLANDS

3.6.1 Description by system

cb3 1000 Standard w/ cSwift 1000 mL

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

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

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

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

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

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

The transport packaging contributes to almost all examined categories.

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

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

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

cb3 1000 EcoPlus w/ cSwift Plus 1000 mL

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

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

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

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

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

The transport packaging contributes to almost all examined categories.

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

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

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

cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL

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

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

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

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

cb3 1000 SIGNATURE PACK 100% w/ cSwift 1000 mL

As the *cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus* is identical to the *cb3 1000 EcoPlus w/ cSwift Plus* apart from the polymers, the results of all life cycle steps apart from plastics for sleeve, recycling & disposal, CO_2 reg (EOL) and the credits are the same as for *cb3 1000 EcoPlus w/ cSwift Plus.*

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

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

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

3.6.2 Comparison between systems

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

Table 3-12: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 Standard w/ cSwift

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL			
are **LOWER** than those of **cb3 1000 Standard w/ cSwift**		show **no significant differences** compared to those of **cb3 1000 Standard w/ cSwift**	
Climate Change	-41%	Summer Smog	+3%
Aquatic Eutrophication	-27%	Acidification	+5%
Abiotic Depletion	-32%	Ozone Depletion	±0%
Total Primary Energy	-24%	Terrestrial Eutrophication	+4%
Non-renewable primary energy	-32%	PM 2.5	+4%

Table 3.13: Comparison of net results cb3 1000 SIGNATURE Pack high barrier w/ cSwift with cb3 1000 EcoPlus w/ cSwift Plus

RESULTS OF cb3 1000 SIGNATURE Pack high barrier w/ cSwift 1000 mL			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		are **HIGHER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**	
Climate Change	-15%	Summer Smog	+15%
Aquatic Eutrophication	-27%	Acidification	+34%
Abiotic Depletion	-16%	Terrestrial Eutrophication	+14%
Total Primary Energy	-11%	PM 2.5	+27%
Non-renewable primary energy	-19%		
		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cSwift Plus**	
		Ozone Depletion	+8%

Table 3.14: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus with cb3 1000 Standard w/ cSwift

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus 1000 mL			
are **LOWER** than those of **cb3 1000 Standard c/Swift**		show **no significant differences** compared to those of **cb3 1000 Standard c/Swift**	
Climate Change	-62%	Summer Smog	-9%
Acidification	-19%	Terrestrial Eutrophication	-7%
Aquatic Eutrophication	-18%	Ozone Depletion	-7%
PM 2.5	-16%		
Abiotic Depletion	-41%		
Total Primary Energy	-31%		
Non-renewable primary energy	-40%		

Table 3.15: Comparison of net results cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus with cb3 1000 EcoPlus w/ cSwift Plus

RESULTS OF cb3 1000 SIGNATURE Pack 100% w/ cSwift Plus 1000 mL			
are **LOWER** than those of **cb3 1000 EcoPlus w/ cSwift Plus**		show **no significant differences** compared to those of **cb3 1000 EcoPlus w/ cSwift Plus**	
Climate Change	-45%	Acidification	+4%
Aquatic Eutrophication	-19%	Ozone Depletion	±0
Abiotic Depletion	-28%	Terrestrial Eutrophication	+2%
Total Primary Energy	-20%	PM 2.5	+3%
Non-renewable primary energy	-28%	Summer Smog	+1%

4 Interpretation

4.1 Base scenarios GERMANY, EUROPE and NETHERLANDS

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

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

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

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

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

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

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

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

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

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

4.2 Sensitivity analysis on system allocation GERMANY

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

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

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

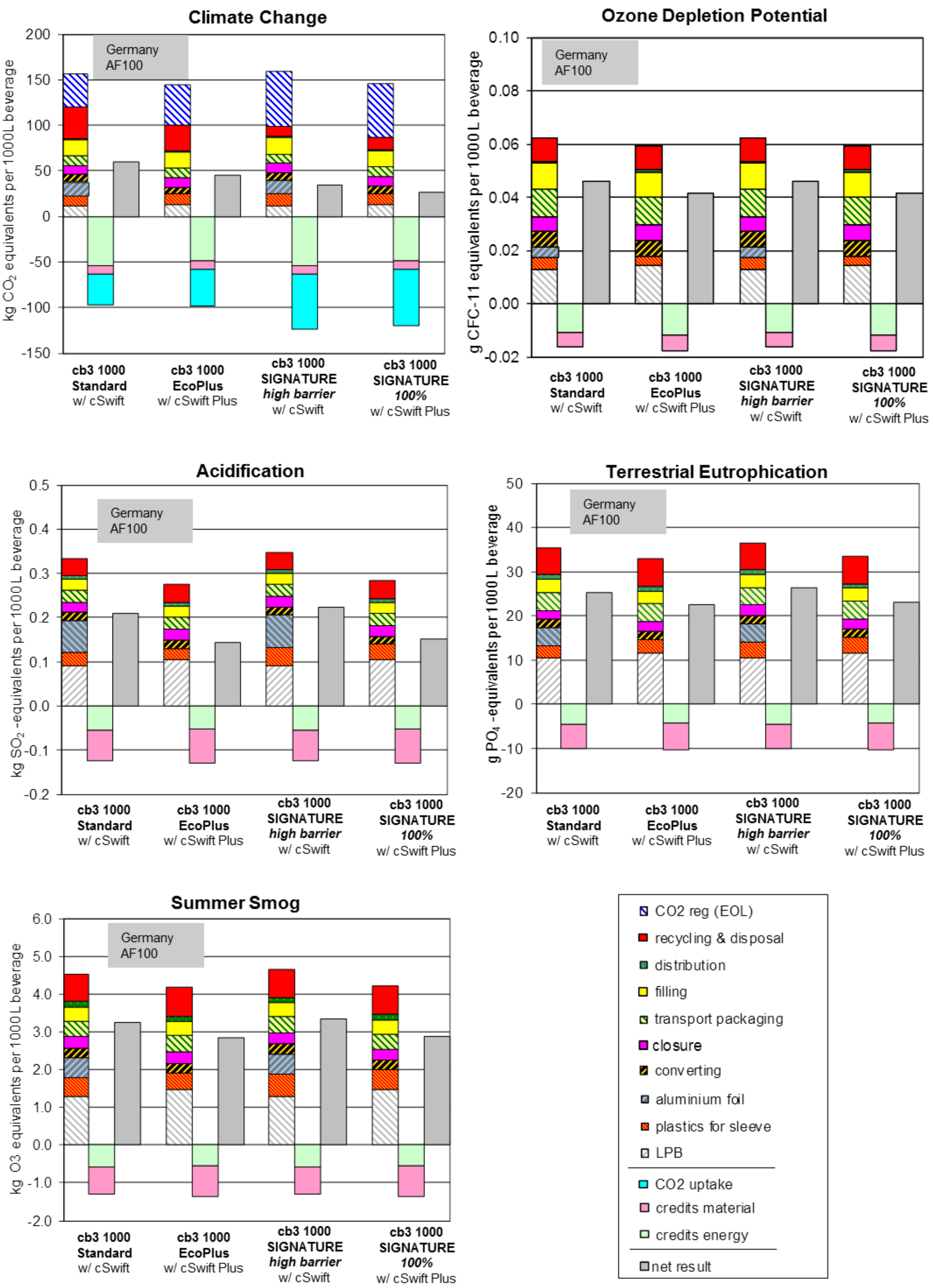

Figure 4.1: Indicator results for sensitivity analysis with allocation factor 100%, **GERMANY** (Part 1)

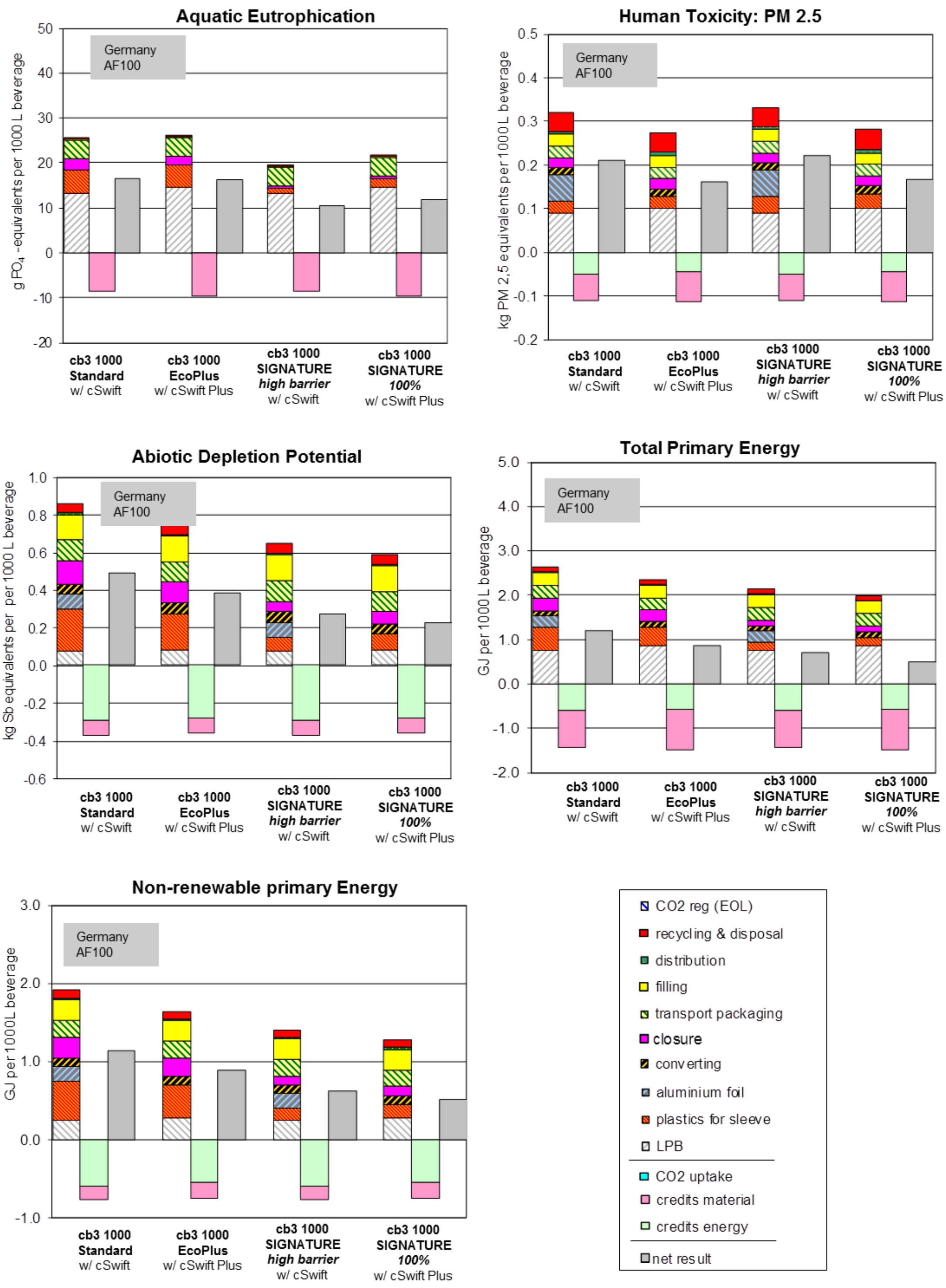

Figure 4.2: Indicator results for sensitivity analysis with allocation factor 100%, GERMANY (Part 2)

Table 4.1: Results for **sensitivity analysis allocation factor 100% GERMANY**– cumulated life cycle (LC) phases:

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

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

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

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

Sensitivity analysis allocation factor 100% Germany		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	55.67	42.32	58.25	44.26
	LC part B	64.59	58.42	41.01	42.55
	CO_2 reg (EOL)	35.96	43.22	59.54	59.09
	Credits	-62.93	-58.30	-62.93	-58.30
	CO_2-uptake	-33.49	-40.24	-61.08	-61.65
	Net results (∑)	59.79	45.43	34.78	25.96
Acidification [kg SO_2 equivalents]	*LC part A*	0.23	0.17	0.25	0.18
	LC part B	0.10	0.10	0.10	0.10
	Credits	-0.12	-0.13	-0.12	-0.13
	Net results (∑)	0.21	0.14	0.22	0.15
Summer Smog [kg O_3 equivalents]	*LC part A*	2.86	2.48	2.97	2.52
	LC part B	1.67	1.70	1.67	1.70
	Credits	-1.29	-1.35	-1.29	-1.35
	Net results (∑)	3.24	2.83	3.35	2.88
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.03	0.03	0.03	0.03
	Credits	-0.016	-0.018	-0.016	-0.018
	Net results (∑)	0.0458	0.0413	0.0458	0.0413
Aquatic eutrophica-tion [g PO_4 equivalents]	*LC part A*	21.01	21.54	14.94	17.14
	LC part B	4.29	4.29	4.29	4.29
	Credits	-8.68	-9.66	-8.68	-9.66
	Net results (∑)	16.61	16.17	10.54	11.76
Terrestial eutrophi-cation [g PO_4 equivalents]	*LC part A*	21.28	18.66	22.38	19.24
	LC part B	14.01	14.25	14.01	14.26
	Credits	-9.95	-10.41	-9.95	-10.41
	Net results (∑)	25.33	22.50	26.44	23.08
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.56	0.44	0.34	0.28
	LC part B	0.30	0.30	0.30	0.30
	Credits	-0.37	-0.36	-0.37	-0.36
	Net results (∑)	0.49	0.39	0.27	0.23

(Table 4.1 continued)

Sensitivity analysis allocation factor 100% Germany		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.22	0.17	0.23	0.17
	LC part B	0.10	0.11	0.10	0.11
	Credits	-0.11	-0.11	-0.11	-0.11
	Net results (∑)	0.21	0.16	0.22	0.17
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.66	1.44	1.30
	LC part B	0.69	0.69	0.69	0.69
	Credits	-1.43	-1.49	-1.43	-1.49
	Net results (∑)	1.20	0.86	0.71	0.51
Non-renewable PE [GJ]	*LC part A*	1.31	1.04	0.81	0.67
	LC part B	0.60	0.60	0.60	0.60
	Credits	-0.78	-0.76	-0.78	-0.76
	Net results (∑)	1.13	0.88	0.62	0.51

4.3 Sensitivity analysis on system allocation EUROPE

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

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

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

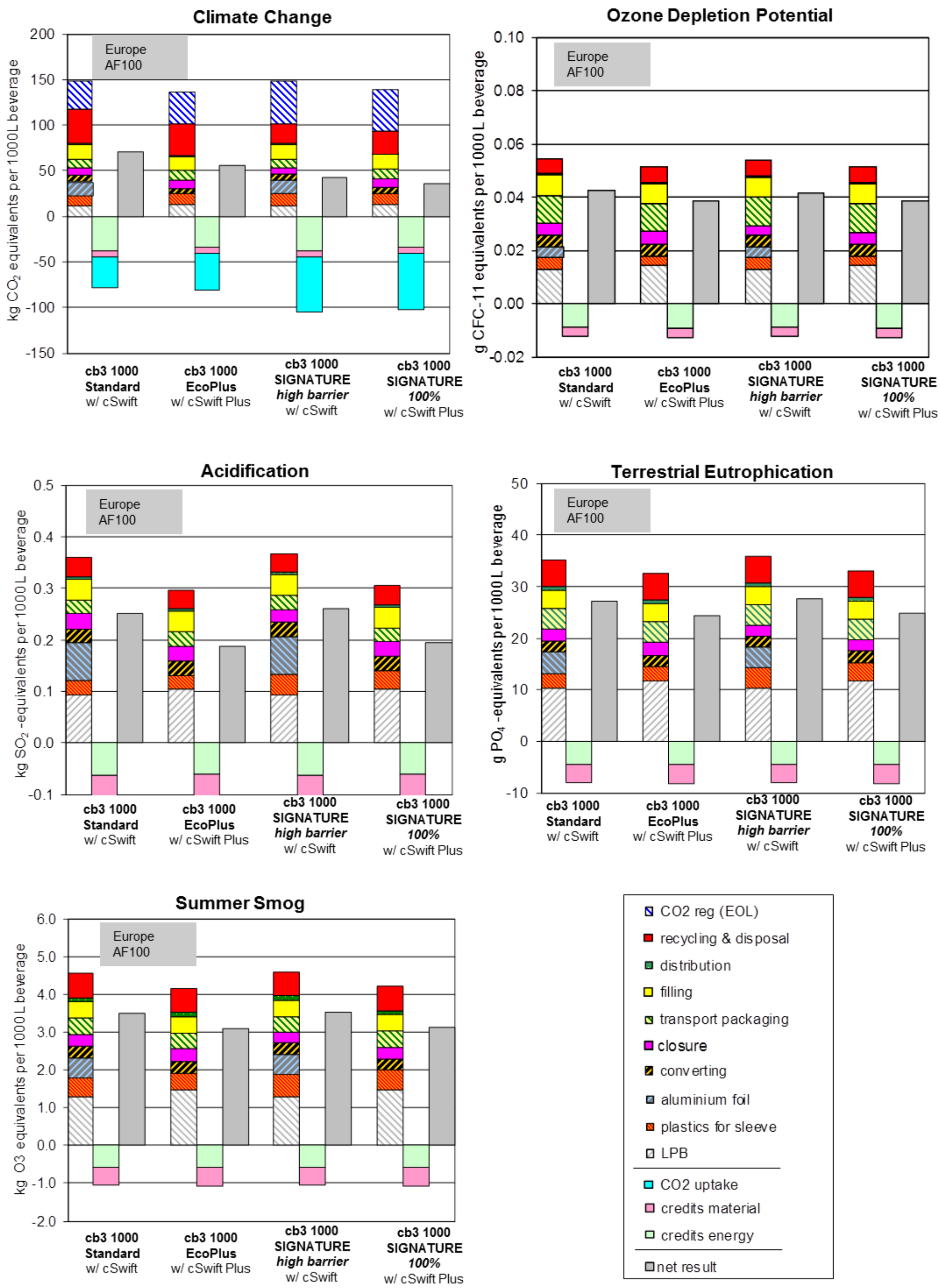

Figure 4.3: Indicator results for sensitivity analysis with allocation factor 100%, Europe (Part 1)

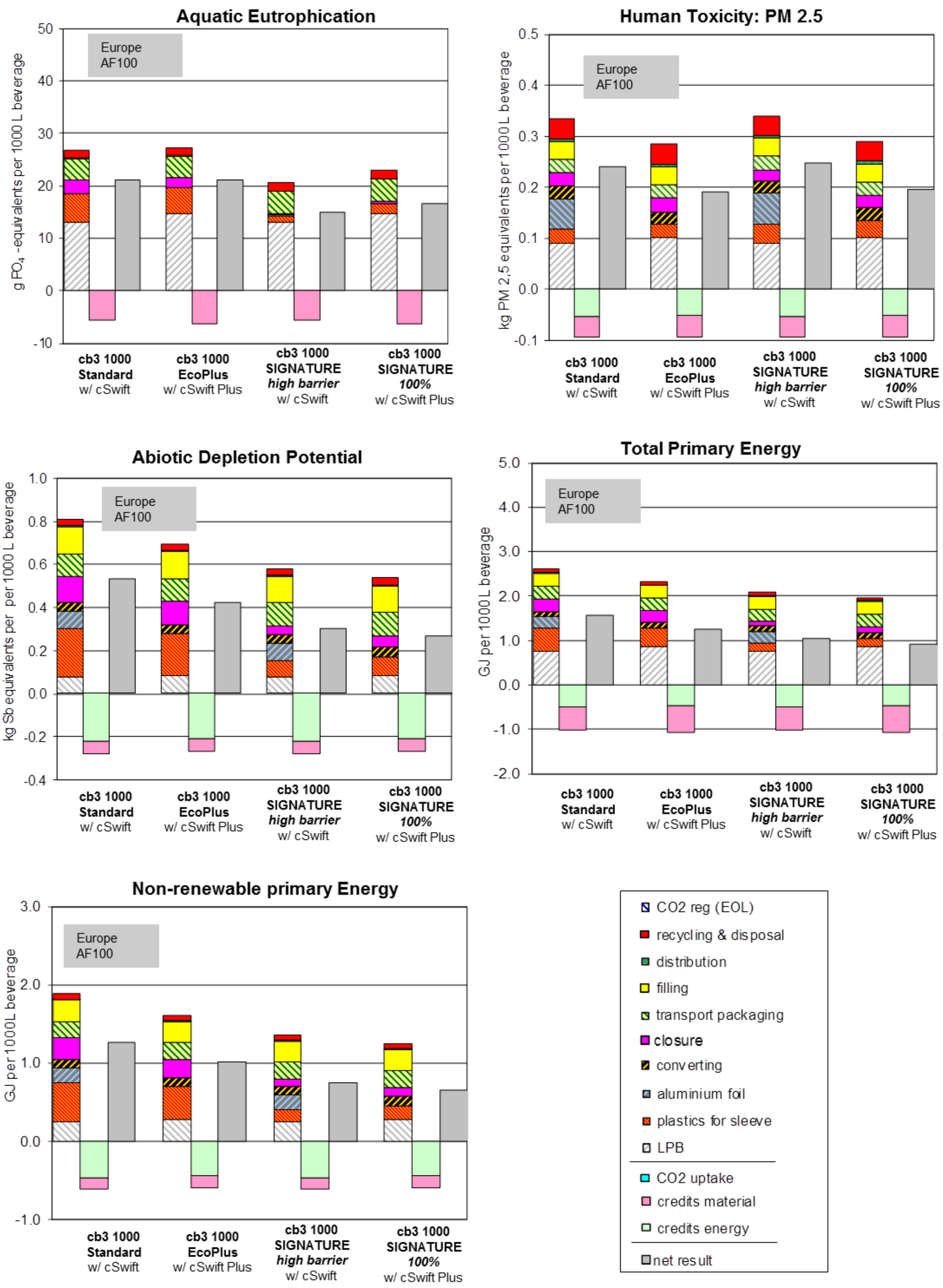

Figure 4.4: Indicator results for sensitivity analysis with allocation factor 100%, Europe (Part 2)

Table 4.2: Results for **sensitivity analysis allocation factor 100% EUROPE**– cumulated life cycle (LC) phases:

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

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

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

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

Sensitivity analysis allocation factor 100% Europe		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	52.93	39.55	52.66	41.52
	LC part B	64.81	61.45	48.71	51.75
	CO_2 reg (EOL)	30.48	35.82	46.58	45.52
	Credits	-44.40	-41.25	-44.40	-41.25
	CO_2-uptake	-33.49	-40.24	-61.08	-61.65
	Net results (∑)	70.32	55.33	42.47	35.89
Acidification [kg SO_2 equivalents]	*LC part A*	0.25	0.19	0.26	0.20
	LC part B	0.11	0.11	0.11	0.11
	Credits	-0.11	-0.11	-0.11	-0.11
	Net results (∑)	0.25	0.19	0.26	0.19
Summer Smog [kg O_3 equivalents]	*LC part A*	2.94	2.55	2.98	2.59
	LC part B	1.60	1.61	1.60	1.61
	Credits	-1.06	-1.09	-1.06	-1.09
	Net results (∑)	3.49	3.08	3.53	3.12
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.02	0.02	0.02	0.02
	Credits	-0.001	-0.013	-0.01	-0.013
	Net results (∑)	0.0422	0.0384	0.0414	0.0383
Aquatic eutrophica-tion [g PO_4 equivalents]	*LC part A*	21.00	21.54	14.78	17.14
	LC part B	5.73	5.74	5.73	5.74
	Credits	-5.64	-6.23	-5.64	-6.23
	Net results (∑)	21.09	21.04	14.87	16.64
Terrestrial eutrophi-cation [g PO_4 equivalents]	*LC part A*	21.83	19.18	22.49	19.70
	LC part B	13.30	13.40	13.30	13.40
	Credits	-8.08	-8.33	-8.08	-8.33
	Net results (∑)	27.06	24.24	27.71	24.76
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.54	0.42	0.31	0.27
	LC part B	0.27	0.27	0.27	0.27
	Credits	-0.28	-0.27	-0.28	-0.27
	Net results (∑)	0.53	0.42	0.30	0.26

(Table45.2 continued)

Sensitivity analysis allocation factor 100% Europe		cb3 1000 Standard w/ cSwift 1000 mL	cb3 1000 EcoPlus w/ cSwift Plus 1000 mL	cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL	cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.23	0.18	0.23	0.18
	LC part B	0.11	0.11	0.11	0.11
	Credits	-0.09	-0.09	-0.09	-0.09
	Net results (∑)	0.24	0.19	0.25	0.20
Total primary energy (PE) [GJ]	*LC part A*	1.94	1.66	1.43	1.31
	LC part B	0.66	0.66	0.66	0.66
	Credits	-1.03	-1.06	-1.03	-1.06
	Net results (∑)	1.57	1.26	1.06	0.91
Non-renewable PE [GJ]	*LC part A*	1.32	1.04	0.79	0.68
	LC part B	0.56	0.56	0.56	0.56
	Credits	-0.62	-0.60	-0.62	-0.60
	Net results (∑)	1.26	1.01	0.74	0.64

4.4 Sensitivity analysis on system allocation NETHERLANDS

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

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

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

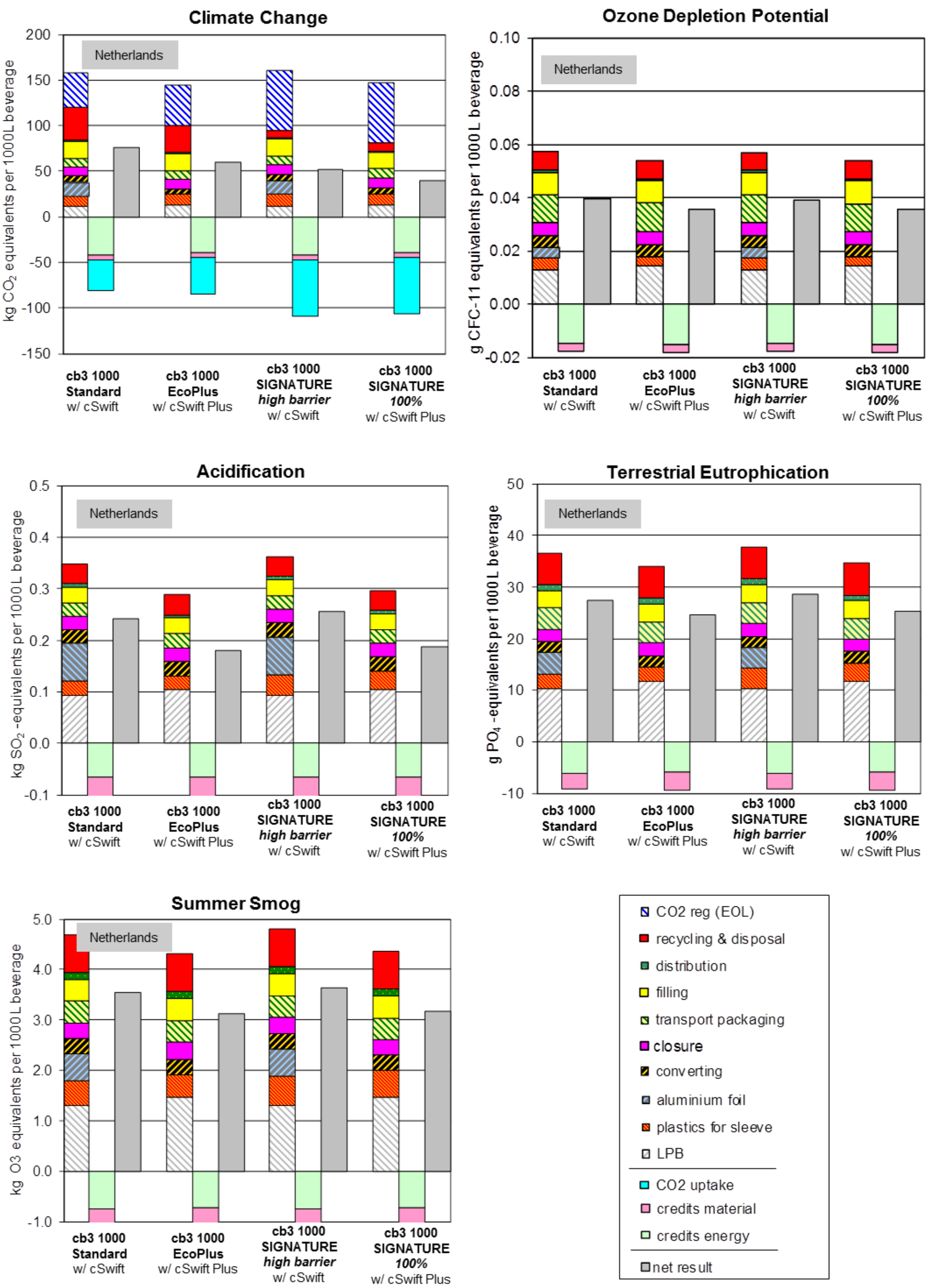

Figure 4.5: Indicator results for sensitivity analysis with allocation factor 100% (Part 1)

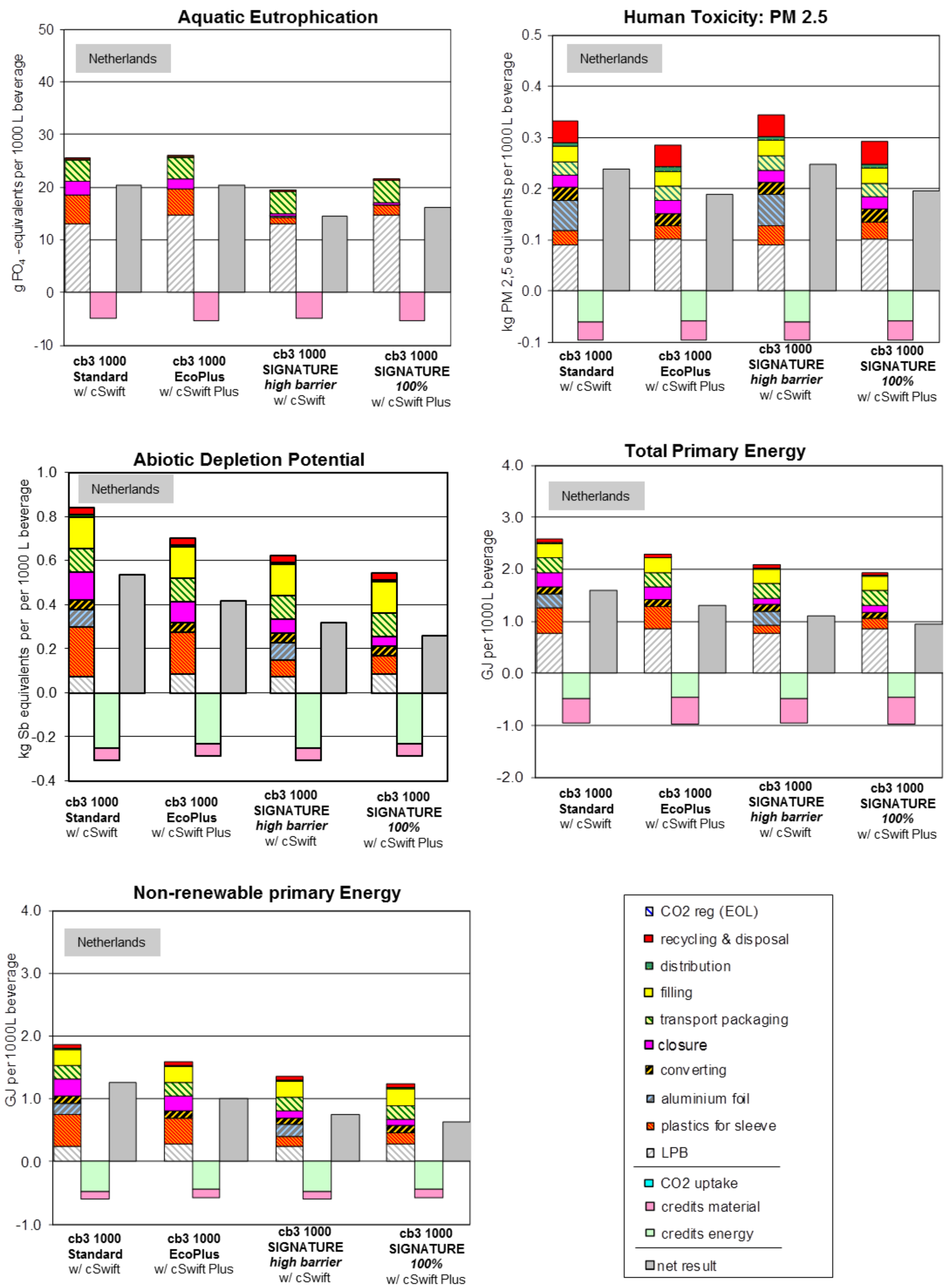

Figure 4.6: Indicator results for sensitivity analysis with allocation factor 100% (Part 2)

Table 4.3: Results for **sensitivity analysis allocation factor 100%**– cumulated life cycle (LC) phases:
LC part A: Share of production processes for primary packaging (to producer gate out),

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

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

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

Sensitivity analysis 100% Netherlands		**cb3 1000 Standard w/ cSwift 1000 mL**	**cb3 1000 EcoPlus w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Climate change [kg CO_2 equivalents]	*LC part A*	54.07	40.80	56.65	42.73
	LC part B	66.22	59.62	37.64	38.50
	CO_2 reg (EOL)	37.17	44.18	65.74	65.30
	Credits	-47.62	-44.77	-47.62	-44.77
	CO_2-uptake	-33.49	-40.24	-61.08	-61.65
	Net results (∑)	76.34	59.59	51.33	40.12
Acidification [kg SO_2 equivalents]	*LC part A*	0.25	0.18	0.26	0.19
	LC part B	0.10	0.10	0.10	0.10
	Credits	-0.11	-0.11	-0.11	-0.11
	Net results (∑)	0.24	0.18	0.26	0.19
Summer Smog [kg O_3 equivalents]	*LC part A*	2.94	2.56	3.05	2.61
	LC part B	1.75	1.76	1.75	1.76
	Credits	-1.16	-1.19	-1.16	-1.19
	Net results (∑)	3.53	3.13	3.64	3.18
Ozone Depletion potential [g R11 equivalents]	*LC part A*	0.03	0.03	0.03	0.03
	LC part B	0.03	0.03	0.03	0.03
	Credits	-0.018	-0.018	-0.018	-0.018
	Net results (∑)	0.0393	0.0355	0.0392	0.0354
Aquatic eutrophication [g PO_4 equivalents]	*LC part A*	21.00	21.54	14.94	17.14
	LC part B	4.40	4.41	4.40	4.41
	Credits	-4.99	-5.50	-4.99	-5.50
	Net results (∑)	20.42	20.44	14.35	16.04
Terrestial eutrophication [g PO_4 equivalents]	*LC part A*	21.86	19.26	22.97	19.83
	LC part B	14.70	14.73	14.70	14.73
	Credits	-9.11	-9.31	-9.11	-9.31
	Net results (∑)	27.44	24.67	28.55	25.25
Abiotic Depletion Potential [kg Sb equivalents]	*LC part A*	0.55	0.41	0.33	0.26
	LC part B	0.29	0.29	0.29	0.29
	Credits	-0.30	-0.28	-0.30	-0.28
	Net results (∑)	0.54	0.42	0.32	0.26

(Table 4.3 continued)

Sensitivity analysis 100% Netherlands		**cb3 1000 w/ cSwift 1000 mL**	**cb3 EcoPlus 1000 w/ cSwift Plus 1000 mL**	**cb3 1000 SIGNATURE PACK high barrier w/ cSwift 1000 mL**	**cb3 1000 SIGNATURE PACK 100% w/ cSwift Plus 1000 mL**
Human toxicity – PM2.5 [kg PM2.5 equivalents]	*LC part A*	0.22	0.18	0.24	0.18
	LC part B	0.11	0.11	0.11	0.11
	Credits	-0.10	-0.10	-0.10	-0.10
	Net results (∑)	0.24	0.19	0.25	0.19
Total primary energy (PE) [GJ]	*LC part A*	1.93	1.66	1.44	1.30
	LC part B	0.63	0.63	0.63	0.63
	Credits	-0.97	-0.99	-0.97	-0.99
	Net results (∑)	1.60	1.30	1.11	0.94
Non-renewable PE [GJ]	*LC part A*	1.31	1.04	0.81	0.68
	LC part B	0.55	0.55	0.55	0.55
	Credits	-0.61	-0.59	-0.61	-0.59
	Net results (∑)	1.26	1.01	0.75	0.64

5 Conclusions and Recommendations

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

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

A comparison of the *cb3 1000 SIGNATURE PACK 100% w/cSwift Plus*(without aluminium foil) with the *cb3 1000 Standard w/cSwift* containing aluminium foil also shows lower or insignificantly different environmental impacts of the *cb3 1000 SIGNATURE PACK 100%* in all examined impact categories.
These observations are true for all three markets examined.

5.2 Recommendations

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

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