INSTITUT FÜR ENERGIE- UND UMWELTFORSCHUNG HEIDELBERG

Meta Study of Life Cycle Assessment of Tetra Pak® carton packages and alternative packaging systems for beverages based on selected studies of the European market.

Meta Study of Environmental Impacts besides Climate Change of selected studies for European countries

commissioned by Tetra Pak

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1 Background

Tetra Pak has for several decades worked with Life Cycle Assessments (LCAs) as a tool to understand environmental impact of development decisions and relative to alternative solutions. Over time, the LCA method has become the preferred tool since it is based on scientific principles, including full transparency of sources and assumptions. Tetra Pak will only use LCAs for external purposes that have also undergone a rigorous peer review by independent experts in order to secure credibility of results.

The meta study at hand is based on LCA studies specifically commissioned by Tetra Pak which have been conducted by ifeu between 2018 and 2020. These are [ifeu 2018], [ifeu 2019a], [ifeu 2019b]. It includes various environmental impacts of **dairy**-, **JNSD**- (juices, nectars and still drinks) and **water** packages in selected European countries (**Austria**, **Belgium**, **Denmark**, **Finland**, **Ireland**, **Netherlands**, **Norway**, **Sweden**, **Switzerland** and **United Kingdom**.

To understand the differences between product systems, a holistic approach is taken by including several environmental impacts in the LCA. This meta study covers the impact categories Acidification, Photo-oxidant formation, Stratospheric ozone depletion, Eutrophication (terrestrial and aquatic), Particulate matter and the Use of nature. Regarding Climate change a separate meta study is conducted which covers in detail only the impact category climate change [ifeu 2021].

The packages included within the product segments are **beverage cartons with plant-based polymers**, **beverage cartons with fossil-based polymers**, **rPET**, **PET** and **HDPE bottles**. The term “plant-based beverage carton” refers to either beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or top/closure. The term “standard beverage carton” refers to beverage cartons with only fossil-based polymers in sleeve and closure/top. rPET bottles are further classified into PET bottle 30 % - 100 % recycled content (JNSD Family Pack) as well as 50 % recycled content and 100 % recycled content (Water Portion Pack).

1.1 Main Purpose

The main purpose of this report is to transparently present environmental impacts of competing beverage packaging systems in relation to product types and pack volumes. By doing this, trends as well as outliers can be identified which is of great importance when producing and marketing products.

1.2 Method

The results presented in this report are based on data that have formally been reviewed by external experts. In this report, mean values regarding environmental impacts per analysed package are explained.

At the impact assessment level, it must be decided which system allocation approach is applied. Since the authors in the present study consider allocation 50% relevant, only the allocation factor 50% was chosen. In contrast, allocation factors 100% and 50% were considered in all the individual studies. In case of allocation 50%, half of the emissions from recovery are attributed to the examined system and half of the emissions from recovery are attributed to the following system, for example the incineration plants with thermal recovery.

When applying the allocation 50% approach the benefit regarding the LCA results for 'Climate Change' of packaging systems containing regenerative materials can promote the increase of use of regenerative materials in packaging system.

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

1.2.1 Method I

The results of the meta study include for each impact category comparisons of types of packaging systems based on cross-country averages per segment. It should be noted, that these cross-country averages can differ in one and the same type of packaging system and segment. Depending on the comparison, they are based on different studies, which include both compared types of packaging systems. The included packaging systems cover 10 countries[1] from 3 LCA studies, all of which fulfil the following criteria:

- Critically reviewed LCA studies according to ISO 14040 and 14044
- Comparative approach
    - comparison of different products, i.e. a beverage carton and at least one other packaging type)
    - comparison of plant-based and standard beverage cartons only is valid and comparable when data for both types of cartons are available in the same study/country (otherwise country specific parameters like the energy mix might affect total averages unilaterally)

In order for the meta study to achieve robust comparative conclusions and to exclude statistical uncertainties, some results (from the analysed LCA studies) were excluded from interpretation:

[1] Austria, Belgium, Denmark, Finland, Ireland, Netherlands, Norway, Sweden, Switzerland and United Kingdom

- Packaging systems of countries that are analysed by less than 2 packaging systems of the same category (plant-based beverage cartons, standard beverage cartons, rPET, PET or HDPE) within a segment.
    - for example: at least 2 HDPE bottles are needed in one and the same product category (e.g. Dairy Family Pack chilled) in one and the same country (e.g. Greece).
- Types of packaging systems for which data from less than 5 packaging systems within a segment is available.
    - for example: at least 5 HDPE bottles are needed in one and the same product category (e.g. Dairy Family Pack chilled) across all the studies in scope.

The following table shows the numbers of the packaging systems considered for the results with Method I:

Table 1

Presenting product types and package segments, number of beverage cartons and competing packages used for the results with Method I.

Product type and package segment		Number of beverage cartons	Number of competing packages
	Dairy Family Pack *CHILLED*	35	-
	Dairy Portion Pack *AMBIENT*	8	8
	JNSD Family Pack *AMBIENT*	25	11
	JNSD Portion Pack *AMBIENT*	8	8
	Water Portion Pack *AMBIENT*	42	51

1.2.2 Method II

As the individual packaging specifications (especially weight and volume) have a strong influence on the net results, the above mentioned exclusions were implemented in Method I.

However, alternative packaging systems examined in the individual LCA studies are intended to represent products relevant on the regarded markets or relevant in perspective of Tetra Pak. In the LCA studies beverage carton systems in some segments are often only compared to one alternative packaging system. As this leads to the exclusions of specific segments, which are of substantial importance for Tetra Pak, a further method was used.

In this Method II excluded from interpretation are:

- Types of packaging systems for which data from less than 3 packaging systems within a segment is available.
    - for example: at least 3 HDPE bottles are needed in one and the same product category (e.g. Dairy Family Pack chilled) across all the studies in scope.

Packaging systems of countries that are analysed by only one packaging system of the same category (standard beverage cartons, rPET, PET or HDPE) within a segment, were considered. It should be noted that this method is more case specific and therefore general conclusions are less robust.

It should be noted, that these cross-country averages can differ in one and the same type of packaging system and segment. Depending on the comparison, they are based on different studies, which include both compared types of packaging systems.

This Method II has been applied additionally to the comparisons with alternative packaging systems in all segments. These include 10 countries[1] from 3 LCA studies.

The following table shows the numbers of the packaging systems considered for the results with Method II:

[1] Austria, Belgium, Denmark, Finland, Ireland, Netherlands, Norway, Sweden, Switzerland and United Kingdom

Table 2

Presenting product types and package segments, number of beverage cartons and competing packages used for the results in detailed segments with Method II.

Product type and package segment		Number of beverage cartons	Number of competing packages
	Dairy Family Pack *CHILLED*	23	15
	Dairy Portion Pack *CHILLED*	8	8
	Dairy Family Pack *AMBIENT*	6	3

2 Results Method I

Acidification [kg SO_2-e/1000 L]

Acidification affects aquatic and terrestrial eco-systems by changing the acid-basic-equilibrium through the input of acidifying substances. It causes disruption of ecosystems, suppresses growth of living organisms, and reduces species diversity.

Table 3

Acidification [kg SO_2-e/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	0.22	0.15
JNSD Family Pack *AMBIENT*	0.34	0.29
Water Portion Pack *AMBIENT*	0.50	0.41

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 1.2 to 1.5 times higher Acidification impacts than standard beverage cartons in all regarded segments.

Table 4

Acidification [kg SO_2-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	0.52	0.87

Acidification [kg SO_2-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	0.23	0.24
JNSD Portion Pack *AMBIENT*	0.43	0.61
Water Portion Pack *AMBIENT*	0.44	0.31

Acidification [kg SO_2-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	0.23	0.23

Acidification [kg SO_2-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	0.44	0.26

Acidification [kg SO_2-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	0.44	0.21

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 4 segments, standard beverage cartons show lower Acidification impacts than all regarded alternative packaging systems.

In the segment JNSD Family Pack *AMBIENT* standard beverage cartons show similar Acidification impacts as PET bottles without recycled content as well as PET bottles (30 % - 100 % recycled content).

In the segment Water Portion Pack *AMBIENT* standard beverage cartons show higher Acidification impacts than PET bottles without recycled content as well as PET bottles with recycled content (50 % and 100 %).

Photo-oxidant formation [kg O_3-e/1000 L]

The photochemical creation of reactive substances (mainly ozone) affecting human health and ecosystems. Ground-level ozone is formed in the atmosphere by nitrogen oxides and volatile organic compounds in the presence of sunlight.

Table 5

Photo-oxidant formation [kg O_3-e/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	3.74	2.45
JNSD Family Pack *AMBIENT*	4.72	3.71
Water Portion Pack *AMBIENT*	7.41	5.32

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 1.3 to 1.5 times higher Photo-oxidant formation impacts than standard beverage cartons in all regarded segments.

Table 6

Photo-oxidant formation [kg O_3-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	6.63	11.49

Photo-oxidant formation [kg O_3-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	3.14	2.95
JNSD Portion Pack *AMBIENT*	5.56	7.52
Water Portion Pack *AMBIENT*	5.67	4.24

Photo-oxidant formation [kg O_3-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	3.14	2.79

Photo-oxidant formation [kg O_3-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	5.61	3.61

Photo-oxidant formation [kg O_3-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	5.67	2.98

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 4 segments, standard beverage cartons show lower Photo-oxidant formation impacts than all regarded alternative packaging systems.

In the segment JNSD Family Pack *AMBIENT* standard beverage cartons show similar Photo-oxidant formation impacts than PET bottles without recycled content and higher impacts than PET bottles (30 % - 100 % recycled content).

In the segment Water Portion Pack *AMBIENT* standard beverage cartons show higher Photo-oxidant formation impacts impacts than PET bottles without recycled content as well as PET bottles with recycled content (50 % and 100 %).

Stratospheric ozone depletion [g R11-e/1000 L]

The anthropogenic impact on the earth's atmosphere leading to the decomposition of naturally present ozone molecules. The consequence of this disequilibrium is that an increased amount of UV-B radiation reaches the earth's surface causing damage to certain natural resources or human health.

Table 7

Stratospheric ozone depletion [g R11-e/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	0.21	0.04
JNSD Family Pack *AMBIENT*	0.19	0.06
Water Portion Pack *AMBIENT*	0.40	0.09

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 3.2 to 5.3 times higher Stratospheric ozone depletion impacts than standard beverage cartons in all regarded segments.

Table 8

Stratospheric ozone depletion [g R11-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	0.09	0.23

Stratospheric ozone depletion [g R11-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	0.04	0.38
JNSD Portion Pack *AMBIENT*	0.08	0.71
Water Portion Pack *AMBIENT*	0.09	0.49

Stratospheric ozone depletion [g R11-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	0.04	0.27

Stratospheric ozone depletion [g R11-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	0.09	0.36

Stratospheric ozone depletion [g R11-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	0.09	0.15

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 4 out of 4 segments, standard beverage cartons show lower Stratospheric ozone depletion impacts than all regarded alternative packaging systems.

Terrestrial Eutrophication [g PO_4-e/1000 L]

The excessive supply of nutrients and can apply to soils. Increased levels of nutrients stimulate primary the growth of biomass, which may in case of excess production disrupt the future functioning of the food web and lead to consequences for plant and animal species and the functioning of these ecosystems.

Table 9

Terrestrial Eutrophication [g PO_4-e/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	31.58	18.90
JNSD Family Pack *AMBIENT*	39.44	29.49
Water Portion Pack *AMBIENT*	62.40	41.78

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 1.3 to 1.7 times higher Terrestrial Eutrophication impacts than standard beverage cartons in all regarded segments.

Table 10

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	50.35	83.86

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	23.97	22.42
JNSD Portion Pack *AMBIENT*	42.70	57.68
Water Portion Pack *AMBIENT*	44.51	31.83

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	23.97	21.67

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	44.21	27.24

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	44.68	23.10

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 4 segments, standard beverage cartons show lower Terrestrial Eutrophication impacts than all regarded alternative packaging systems.

In the segment JNSD Family Pack *AMBIENT* standard beverage cartons show similar Terrestrial Eutrophication impacts than PET bottles without recycled content as well as PET bottles (30 % - 100 % recycled content).

In the segment Water Portion Pack *AMBIENT* standard beverage cartons show higher Terrestrial Eutrophication impacts than PET bottles without recycled content as well as PET bottles with recycled content (50 % and 100 %).

Aquatic Eutrophication [g PO_4-e/1000 L]

The excessive supply of nutrients and can apply to surface waters. Increased levels of nutrients stimulate primary the growth of biomass, which may in case of excess production disrupt the future functioning of the food web and lead to consequences for plant and animal species and the functioning of these ecosystems. Most aquatic ecosystems are primary affected by excessive production of primary biomass (algae growth), which could lead to secondary effects like oxygen depletion.

Table 11

Aquatic Eutrophication [g PO_4-e/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	59.77	21.42
JNSD Family Pack *AMBIENT*	60.47	30.86
Water Portion Pack *AMBIENT*	109.00	41.62

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 2 to 2.8 times higher Aquatic Eutrophication impacts than standard beverage cartons in all regarded segments.

Table 12

Aquatic Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	41.38	95.69

Aquatic Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	24.43	29.32
JNSD Portion Pack *AMBIENT*	37.95	70.76
Water Portion Pack *AMBIENT*	42.56	32.52

Aquatic Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	24.43	28.32

Aquatic Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	43.36	26.54

Aquatic Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	43.92	13.97

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 3 out of 4 segments, standard beverage cartons show lower Aquatic Eutrophication impacts than all regarded alternative packaging systems.

In the segment Water Portion Pack *AMBIENT* standard beverage cartons show higher Aquatic Eutrophication impacts than PET bottles without recycled content as well as PET bottles with recycled content (50 % and 100 %).

Particulate matter [g PM 2.5-e/1000 L]

It covers effects of fine particulates with an aerodynamic diameter of less than 2.5 µm (PM 2.5) emitted directly or formed from precursors. There is a correlation between the exposure to particulate matter and the mortality from respiratory diseases and weakening of the immune system.

Table 13

Particulate matter [g PM 2.5-e/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	254.28	156.37
JNSD Family Pack *AMBIENT*	346.71	270.08
Water Portion Pack *AMBIENT*	454.05	332.37

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 1.3 to 1.6 times higher Particulate matter impacts than standard beverage cartons in all regarded segments.

Table 14

Particulate matter [g PM 2.5-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	240.88	392.17

Particulate matter [g PM 2.5-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	222.43	220.44
JNSD Portion Pack *AMBIENT*	276.49	563.75
Water Portion Pack *AMBIENT*	415.67	301.99

Particulate matter [g PM 2.5-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	222.43	210.75

Particulate matter [g PM 2.5-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	409.34	256.97

Particulate matter [g PM 2.5-e/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	415.10	208.10

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 4 segments, standard beverage cartons show lower Particulate matter impacts than all regarded alternative packaging systems.

In the segment JNSD Family Pack *AMBIENT* standard beverage cartons show similar Particulate matter impacts as PET bottles without recycled content as well as PET bottles (30 % - 100 % recycled content).

In the segment Water Portion Pack *AMBIENT* standard beverage cartons show higher Particulate matter impacts than PET bottles without recycled content as well as PET bottles with recycled content (50 % and 100 %).

Use of nature (land use) [m²-e*year/1000 L]

It covers preservation of biodiversity and ecosystems. The methodology is based on the hemeroby concept (distance to nature) and classifies different land use types based on their occupation impact. That means that forest area receives a lower characterisation factor than agricultural systems. A sustainably managed area, like FSC certified forest, shows the lowest characterisation factor apart from untouched natural land. The highest factor is used for sealed roads or coal mining pits.

Table 15

Use of nature [m²-e*year/1000 L]		
Segment	Plant-based beverage carton[1] [average]	Standard beverage carton[2] [average]
Dairy Family Pack *CHILLED*	28.66	18.85
JNSD Family Pack *AMBIENT*	31.91	23.55
Water Portion Pack *AMBIENT*	45.62	26.42

[1] Beverage cartons with only plant-based polymers in sleeve and closure/top, or beverage cartons with shares of plant-based polymers in sleeve and or closure/top

[2] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Plant-based beverage cartons show 1.4 to 1.7 times higher Use of nature impacts than standard beverage cartons in all regarded segments.

Table 16

Use of nature [m²-e*year/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Portion Pack *AMBIENT*	23.39	3.08

Use of nature [m²-e*year/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
JNSD Family Pack *AMBIENT*	20.15	0.57
JNSD Portion Pack *AMBIENT*	23.10	1.33
Water Portion Pack *AMBIENT*	26.59	0.78

Use of nature [m²-e*year/1000 L]	Standard beverage carton[1] [average]	PET bottle 30 % - 100 % recycled content[2] [average]
JNSD Family Pack *AMBIENT*	20.15	0.57

Use of nature [m²-e*year/1000 L]	Standard beverage carton[1] [average]	PET bottle 50 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	26.72	1.12

Use of nature [m²-e*year/1000 L]	Standard beverage carton[1] [average]	PET bottle 100 % recycled content[3] [average]
Water Portion Pack *AMBIENT*	27.53	1.13

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 4 out of 4 segments, standard beverage cartons show higher Use of nature impacts than all regarded alternative packaging systems. Even though the land used for the growth of trees shows a relatively low occupation impact compared to other uses like open-pit mining, the much greater area needed leads to high results in this category for beverage cartons.

Use of water

In the LCA studies on which this metastudy is based the use of water is only reported on an inventory level. That means no assessment of the environmental impact has been done. This is due to the lack of data on water inputs and outputs in many of the underlying process datasets. Thus it is unclear, if water is only used or consumed (f.e. via evaporation,

integration into a product or release into a different drainage basin. Also the consideration of spatial scarcity is necessary to assess the related environmental impacts of potential water consumption. For example a certain amount of water would show much lower impacts on water scarcity if it is consumed within a humid area like the Nordic countries than in arid areas like the south of Spain. As the inventory-only data that is presented in the respective LCA studies do not give any information on the environmental impact at all, these “results” are not considered for this meta study to avoid misleading conclusions.

3 Results Method II

In this chapter comparisons of standard beverage cartons and alternative packaging systems are shown for the segments dairy family pack (chilled) and dairy portion pack (chilled). As described in chapter 1.2.2, packaging systems of countries that are analysed by only one packaging system of the same category (standard beverage cartons, rPET, PET or HDPE) within a segment, were also considered. It should be noted that this method is more case specific and therefore general conclusions are less robust.

Acidification [kg SO_2-e/1000 L]

Acidification affects aquatic and terrestrial eco-systems by changing the acid-basic-equilibrium through the input of acidifying substances. It causes disruption of ecosystems, suppresses growth of living organisms, and reduces species diversity.

Table 17

Acidification [kg SO_2-e/1000 L]		
Segment	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	0.16	0.29
Dairy Portion Pack *CHILLED*	0.33	0.63
Dairy Family Pack *AMBIENT*	0.24	0.23

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Acidification [kg SO_2-e/1000 L]		
Segment	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	0.15	0.31

In 2 out of 3 segments, standard beverage cartons show lower Acidification impacts than all regarded alternative packaging systems.

In the segment Dairy Family Pack *AMBIENT* standard beverage cartons show similar Particulate matter impacts as HDPE bottles.

Photo-oxidant formation [kg O_3-e/1000 L]

The photochemical creation of reactive substances (mainly ozone) affecting human health and ecosystems. Ground-level ozone is formed in the atmosphere by nitrogen oxides and volatile organic compounds in the presence of sunlight.

Table 18

Photo-oxidant formation [kg O_3-e/1000 L]		
Segment	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	2.52	3.96
Dairy Portion Pack *CHILLED*	5.02	8.45
Dairy Family Pack *AMBIENT*	3.13	3.15

Photo-oxidant formation [kg O_3-e/1000 L]		
Segment	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	2.42	3.85

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 3 segments, standard beverage cartons show lower Photo-oxidant formation impacts than all regarded alternative packaging systems.

In the segment Dairy Family Pack *AMBIENT* standard beverage cartons show similar Particulate matter impacts as HDPE bottles.

Stratospheric ozone depletion [g R11-e/1000 L]

The anthropogenic impact on the earth's atmosphere leading to the decomposition of naturally present ozone molecules. The consequence of this disequilibrium is that an increased amount of UV-B radiation reaches the earth's surface causing damage to certain natural resources or human health.

Table 19

Stratospheric ozone depletion [g R11-e/1000 L]		
Segment	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	0.04	0.04
Dairy Portion Pack *CHILLED*	0.08	0.11
Dairy Family Pack *AMBIENT*	0.04	0.04

Stratospheric ozone depletion [g R11-e/1000 L]		
Segment	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	0.04	0.46

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

Standard beverage cartons show lower Stratospheric ozone depletion impacts than HDPE bottles in Dairy Portion Pack *CHILLED* and PET bottles in Dairy Family Pack *CHILLED*.

In the segment Dairy Family Pack *AMBIENT* and Dairy Family Pack *CHILLED* standard beverage cartons show similar Stratospheric ozone depletion impacts as HDPE bottles.

Terrestrial Eutrophication [g PO_4-e/1000 L]

The excessive supply of nutrients and can apply to soils. Increased levels of nutrients stimulate primary the growth of biomass, which may in case of excess production disrupt the future functioning of the food web and lead to consequences for plant and animal species and the functioning of these ecosystems.

Table 20

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	19.52	28.09
Dairy Portion Pack *CHILLED*	38.49	61.18
Dairy Family Pack *AMBIENT*	24.30	22.50

Terrestrial Eutrophication [g PO_4-e/1000 L]	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	18.76	29.25

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 3 segments, standard beverage cartons show lower Terrestrial Eutrophication impacts than all regarded alternative packaging systems.

In the segment Dairy Family Pack *AMBIENT* standard beverage cartons show higher Terrestrial Eutrophication impacts than HDPE bottles.

Aquatic Eutrophication [g PO_4-e/1000 L]

The excessive supply of nutrients and can apply to surface waters. Increased levels of nutrients stimulate primary the growth of biomass, which may in case of excess production disrupt the future functioning of the food web and lead to consequences for plant and animal species and the functioning of these ecosystems. Most aquatic ecosystems are primary affected by excessive production of primary biomass (algae growth), which could lead to secondary effects like oxygen depletion.

Table 21

Aquatic Eutrophication [g PO_4-e/1000 L]		
Segment	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	21.81	33.77
Dairy Portion Pack *CHILLED*	43.04	71.17
Dairy Family Pack *AMBIENT*	23.37	26.42

Aquatic Eutrophication [g PO_4-e/1000 L]		
Segment	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	21.63	29.32

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 3 out of 3 segments, standard beverage cartons show lower Aquatic Eutrophication impacts than all regarded alternative packaging systems.

Particulate matter [g PM 2.5-e/1000 L]

It covers effects of fine particulates with an aerodynamic diameter of less than 2.5 µm (PM 2.5) emitted directly or formed from precursors. There is a correlation between the exposure to particulate matter and the mortality from respiratory diseases and weakening of the immune system.

Table 22

Particulate matter [g PM 2.5-e/1000 L]		
Segment	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	161.66	278.43
Dairy Portion Pack *CHILLED*	257.37	464.72
Dairy Family Pack *AMBIENT*	226.31	218.39

Particulate matter [g PM 2.5-e/1000 L]		
Segment	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	153.71	287.99

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 2 out of 3 segments, standard beverage cartons show lower Particulate matter impacts than all regarded alternative packaging systems.

In the segment Dairy Family Pack *AMBIENT* standard beverage cartons show higher Terrestrial Eutrophication impacts than HDPE bottles.

Use of nature (land use) [m²-e*year/1000 L]

It covers preservation of biodiversity and ecosystems. The methodology is based on the hemeroby concept (distance to nature) and classifies different land use types based on their occupation impact. That means that forest area receives a lower characterisation factor than agricultural systems. A sustainably managed area, like FSC certified forest, shows the lowest characterisation factor apart from untouched natural land. The highest factor is used for sealed roads or coal mining pits.

Table 23

Use of nature [m²-e*year/1000 L]		
Segment	Standard beverage carton[1] [average]	HDPE bottle [average]
Dairy Family Pack *CHILLED*	19.54	0.28
Dairy Portion Pack *CHILLED*	26.32	1.71
Dairy Family Pack *AMBIENT*	20.15	0.63

Use of nature [m²-e*year/1000 L]		
Segment	Standard beverage carton[1] [average]	PET bottle [average]
Dairy Family Pack *CHILLED*	19.32	0.39

[1] Beverage cartons with only fossil-based polymers in sleeve and closure/top

In 3 out of 3 segments, standard beverage cartons show higher Use of nature impacts than all regarded alternative packaging systems. Even though the land used for the growth of trees shows a relatively low occupation impact compared to other uses like open-pit mining, the much greater area needed leads to high results in this category for beverage cartons.

Use of water

In the LCA studies on which this meta study is based the use of water is only reported on an inventory level. That means no assessment of the environmental impact has been done. This is due to the lack of data on water inputs and outputs in many of the underlying process datasets. Thus it is unclear, if water is only used or consumed (f.e. via evaporation, integration into a product or release into a different drainage basin. Also the consideration of spatial scarcity is necessary to assess the related environmental impacts of potential water consumption. For example a certain amount of water would show much lower impacts on water scarcity if it is consumed within a humid area like the Nordic countries than in arid areas like the south of Spain. As the inventory-only data that is presented in the respective LCA studies do not give any information on the environmental impact at all, these “results” are not considered for this meta study to avoid misleading conclusions.

4 Limitations and overall Conclusions

Limitations

- The results of this meta study include LCA studies covering 10 European countries. Nevertheless not all countries in Europe are included in this study.
- The conclusions of this meta study are based on the results of the considered countries. The impact of background settings of non-regarded countries cannot be addressed in this study.

Overall Conclusions Method I

- This meta study shows that standard beverage cartons show lower similar or higher environmental impacts compared to the regarded alternative packaging systems depending on the impact category and regarded segment:
    - Stratospheric ozone depletion:
        - All regarded standard beverage cartons show lower impacts than the regarded alternative packaging systems.
    - Aquatic Eutrophication:
        - In the regarded segments Dairy Portion Pack *AMBIENT,* JNSD Family Pack *AMBIENT* and JNSD Portion Pack *AMBIENT* standard beverage cartons show lower impacts than the regarded alternative packaging systems.
        - In the regarded segment Water Portion Pack *AMBIENT* standard beverage cartons show higher impacts than the regarded alternative packaging systems.
    - Acidification, Photo-oxidant formation, Terrestrial Eutrophication and Particulate matter:
        - In the regarded segments Dairy Portion Pack *AMBIENT* and JNSD Portion Pack *AMBIENT* standard beverage cartons show lower impacts than the regarded alternative packaging systems.
        - In the regarded segments JNSD Family Pack AMBIENT and Water Portion Pack *AMBIENT* standard beverage cartons show similar or higher impacts than the regarded alternative packaging systems.
    - Use of nature:

    - All regarded beverage cartons show higher impacts than the regarded alternative packaging systems.

- This meta study shows that plant-based beverage cartons show higher environmental impacts than standard beverage cartons throughout all regarded impact categories resulting from the emissions of the production of plant-based polymers, including its agricultural background.
- Due to the limited amount of data no comparative results for comparisons of plant-based beverage cartons and alternative packaging systems are available on the meta study level.
- Although the environmental impacts of packaging systems differ between the regarded countries, this meta study shows that the overall comparative result is not impacted by the local settings in the considered countries.

Overall Conclusions Method II

- This meta study shows that standard beverage cartons show lower similar or higher environmental impacts compared to the regarded alternative packaging systems depending on the impact category and regarded segment:
    - Stratospheric ozone depletion:
        - All regarded standard beverage cartons show lower or similar impacts than the regarded alternative packaging systems.
    - Aquatic Eutrophication:
        - In the regarded segments Dairy Family Pack *CHILLED,* Dairy Family Pack *AMBIENT* and Dairy Portion Pack *CHILLED* standard beverage cartons show lower impacts than the regarded alternative packaging systems.
    - Acidification, Photo-oxidant formation, Terrestrial Eutrophication and Particulate matter:
        - In the regarded segments Dairy Family Pack *CHILLED* and Dairy Portion Pack *CHILLED* standard beverage cartons show lower impacts than the regarded alternative packaging systems.
        - In the regarded segment Dairy Family Pack *AMBIENT* standard beverage cartons show similar or higher impacts than the regarded alternative packaging systems.
    - Use of nature:
        - All regarded beverage cartons show higher impacts than the regarded alternative packaging systems.
- Although the environmental impacts of packaging systems differ between the regarded countries, this meta study shows that the overall comparative result is not impacted by the local settings in the considered countries.

5 References

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