LCA of plastic & paper straws for portion-sized carton packages

On behalf of Tetra Pak

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On behalf of thinkstep AG and its subsidiaries

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List of Acronyms

EoL	End-of-Life
FU	Functional Unit
GaBi	Ganzheitliche Bilanzierung (German for holistic balancing)
GHG	Greenhouse Gas
ILCD	International Cycle Data System
ISO	International Organization for Standardization
LPB	Liquid Packaging Board
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
NMVOC	Non-Methane Volatile Organic Compound
PEF	Product Environmental Footprint
VOC	Volatile Organic Compound

Glossary

Life cycle

A view of a product system as "consecutive and interlinked stages … from raw material acquisition or generation from natural resources to final disposal" (ISO 14040:2006, section 3.1). This includes all material and energy inputs as well as emissions to air, land and water.

Life Cycle Assessment (LCA)

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle" (ISO 14040:2006, section 3.2)

Life Cycle Inventory (LCI)

"Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle" (ISO 14040:2006, section 3.3)

Life Cycle Impact Assessment (LCIA)

"Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product" (ISO 14040:2006, section 3.4)

Life cycle interpretation

"Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations" (ISO 14040:2006, section 3.5)

Functional unit

"Quantified performance of a product system for use as a reference unit" (ISO 14040:2006, section 3.20)

Allocation

"Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems" (ISO 14040:2006, section 3.17)

Closed-loop and open-loop allocation of recycled material

"An open-loop allocation procedure applies to open-loop product systems where the material is recycled into other product systems and the material undergoes a change to its inherent properties."

"A closed-loop allocation procedure applies to closed-loop product systems. It also applies to open-loop product systems where no changes occur in the inherent properties of the recycled material. In such cases, the need for allocation is avoided since the use of secondary material displaces the use of virgin (primary) materials."

(ISO 14044:2006, section 4.3.4.3.3)

Foreground system

“Those processes of the system that are specific to it … and/or directly affected by decisions analysed in the study.” (JRC, 2010, p. 97) This typically includes first-tier suppliers, the manufacturer itself and any downstream life cycle stages where the manufacturer can exert significant influence. As a general rule, specific (primary) data should be used for the foreground system.

Background system

“Those processes, where due to the averaging effect across the suppliers, a homogenous market with average (or equivalent, generic data) can be assumed to appropriately represent the respective process … and/or those processes that are operated as part of the system but that are not under direct control or decisive influence of the producer of the good….” (JRC, 2010, pp. 97-98) As a general rule, secondary data are appropriate for the background system, particularly where primary data are difficult to collect.

Critical Review

“Process intended to ensure consistency between a life cycle assessment and the principles and requirements of the International Standards on life cycle assessment” (ISO 14044:2006, section 3.45).

Executive Summary

A high-profile debate is currently taking place regarding the use of plastic packaging, particularly in relation to how such packaging is managed at end of life and the associated littering and pollution problems. In response to this, Tetra Pak has announced plans to develop paper straws for its portion-sized carton packages, offering its customers an alternative to the current plastic straws. However, the company recognises the importance of having a full understanding of the relative environmental performance of plastic and paper straws so as to avoid problems such as burden shifting and to ensure that the optimal choices are made for the environment when selecting packaging materials.

As such, Tetra Pak has commissioned thinkstep, a sustainability consultancy, to undertake an LCA to evaluate and compare the environmental impacts of the following alternative straw options, which have been assessed over their full life cycle, from cradle-to-grave:

- plastic straw with plastic wrapping
- paper straw with plastic wrapping
- paper straw with paper wrapping

The burdens associated with portion-sized pack itself have also been assessed to put those of the straw and wrapping in context.

It is acknowledged that, due to limitations in our current understanding of the science, this study does not assess the potential burdens resulting from littering of packaging and associated impacts on the marine environment linked to the use of plastics. Tetra Pak is addressing these issues through separate activities.

The functional unit (FU) for this study is

the provision of beverage packaging for storing, accessing and consuming the beverage contained within 1000 portion-sized servings

As this study is focused on cartons and straws, the reference flows for each option relate to 1000 portion-sized carton packs including the straws and straw wrapping.

The top-level results are presented in Table E-1. These show that the impact categories assessed in this study can be split into two groups:

- those that show an increase in burden as the proportion of paper increases: acidification, eutrophication (freshwater, marine, terrestrial), photochemical ozone formation and water scarcity[1]
- and those that show a decrease in burden: climate change and non-renewable resource use.

The impact categories where burdens are seen to *increase* with increasing paper content are generally those that have dominant contributions from specific polluting emissions (particularly NO_x

[1] The results for water scarcity are less robust than for other impact categories due to uncertainties in the methodology and to limitations in the background datasets. These issues are described in more detail in section 4.2.6.

but also SO_2), which are produced in greater amounts during paper production than polymer production and are also associated with energy consumption required for manufacturing straws. As paper straws are produced less efficiently than plastic straws, this results in higher burdens for the paper option. Water scarcity also increases with increasing paper content and this is partially due to the higher burdens from paper production (although the data here are less reliable[2]) but, again, is mainly a result of the much higher energy consumption associated with straw manufacture.

It seems likely that manufacturing impacts associated with paper straws will be reduced over time as the process is optimised. If production impacts were the same for both paper and plastic straws the difference between their performance in these categories would be greatly reduced (but would not become equivalent as production of the paper raw material itself has higher burdens than production of plastic).

Table E-1: LCIA results per FU for the three straw and wrap scenarios and for the portion-sized pack

Impact category	Unit	Plastic straw & plastic wrap	Paper straw and plastic wrap	Paper straw and paper wrap	Portion-sized pack (excl. straw and wrap)
Acidification	Mole of H^+ eq.	1.00E-03	2.24E-03	2.32E-03	0.0462
Climate change, fossil emissions	kg CO_2 eq.	0.969	0.704	0.598	10.7
Climate change, biogenic emissions	kg CO_2 eq.	4.10E-03	-0.0585[3]	-0.0710	-0.877[3]
Climate change (fossil + biogenic)	kg CO_2 eq.	0.973	0.646	0.527	9.858
Eutrophication (freshwater)[4]	kg P eq.	3.51E-06	1.29E-05	1.42E-05	1.95E-04
Eutrophication (marine)	kg N eq.	2.51E-04	6.40E-04	6.81E-04	0.0115
Eutrophication (terrestrial)	Mole of N eq.	2.63E-03	6.18E-03	6.53E-03	0.115
Photochemical ozone formation	kg NMVOC eq.	8.99E-04	1.59E-03	1.69E-03	0.0316
Non-renewable energy resource use	MJ	18.9	11.6	9.42	168
Water scarcity	m^3 world eq.	0.131	0.217	0.217	4.14

[2] Due to several factors including the lack of reliable input/output information on water in background data, the lack of regional specificity of water flows in background data, the lack of granularity in characterisation factors (may have a single waster scarcity value for an entire country, rather than broken down by watershed) and that this is a new methodology that has not been widely tested and evaluated.

[3] Negative value is due to the fraction of waste that is landfilled. Not all of this biodegrades so over the full life cycle, there is some net carbon storage when considering the standard 100 year timescale used for climate change assessments. Over longer timescales more of this material may biodegrade, there are quite large uncertainties associated with the behaviour of paper and card materials in landfills.

[4] These three eutrophication potentials are considered in isolation. No attempt has been made to assess the fraction of contributing emissions that end up in each environmental compartment.

Those impact categories where burdens *decrease* with increasing paper content are both strongly correlated with use of fossil fuels. Polymer production uses a lot of fossil fuel both for process energy during manufacture and as feedstock within the finished product. In contrast, paper production uses much less fossil fuel as most of its energy requirements are sourced from biomass (woodchips, bark and black liquor) derived from the same forestry operations that supply the raw material for pulping.

On this basis alone, it is difficult to make recommendations about which material is preferable to use for straws and wrapping. There are trade-offs associated with each choice. Normalisation is an approach that can help decision-making in these circumstances and involves comparing LCA results against an external reference. Impacts across different categories can then be compared and their relative significance (compared to the reference) can be evaluated.

When using a normalisation reference based on the impact caused by an average global citizen over a year, the most significant impact categories were found to be non-renewable resource use followed by climate change, both of which decrease as paper content increases. The relevance of the other impact categories was much lower in comparison.

Given that climate change is generally regarded as the most challenging environmental issue of our time, this finding supports the conclusion that paper straws and wrapping should be recommended over plastic straws and wrapping from an environmental perspective.

It is also important to consider the context in which this study has been carried out. The issue of marine litter is currently extremely prominent and of very great interest to both environmental specialists and the general public and has been a key driver for Tetra Pak to develop paper alternatives to plastic straws. This study does not address marine litter as no LCA metrics have yet been developed for this issue, and our current understanding of how much, and by what pathways, littered material ends up in our oceans is still rudimentary. Nevertheless, it is clear that, due to being readily biodegradable, paper will inevitably have a much lower contribution to the marine litter problem than non-biodegradable plastics. In addition, once degraded into micro- and nano-particles, plastic materials are persistent in the environment, can bioaccumulate, and may have further toxicological effects; this is not an issue for paper.

1. Goal of the Study

Tetra Pak is a food processing and packaging solutions company best known for its aseptic packaging technology and associated products. There is a high-profile debate on-going regarding the use of plastic packaging, with particular focus on how such packaging is managed at end of life and the associated littering and pollution problems.

In response to this issue, Tetra Pak has announced plans to develop paper straws for its portion-sized carton packages, offering its customers an alternative to the current plastic straws. However, the company recognises the importance of having a full understanding of the relative environmental performance of plastic and paper straws so as to avoid problems such as burden shifting and to ensure that the optimal choices are made for the environment when selecting packaging materials. As such, Tetra Pak has commissioned thinkstep, a sustainability consultancy, to undertake an LCA to evaluate and compare the environmental impacts of these different straws from a cradle to grave perspective.

It is acknowledged that, due to limitations in our current understanding of the science, this study does not assess the potential burdens resulting from littering of packaging and associated impacts on the marine environment linked to the use of plastics. Tetra Pak is addressing these issues through separate activities.

Three alternative straw options have been assessed:

- plastic straw with plastic wrapping
- paper straw with plastic wrapping
- paper straw with paper wrapping.

The environmental burdens associated with the portion-sized carton to which the straws are attached have also been assessed to put the impacts associated with the straws in context.

The results of this study will be used to build and develop Tetra Pak's internal understanding regarding the relative environmental performance of these different production options. The results may also be used in external communications with customers, consumers or other stakeholders.

The study has been conducted in line with the requirements of ISO 14040/44, the international standards on LCA (ISO 14040, 2006; ISO 14044, 2006).

The study has been critically reviewed by Håkan Stripple of the IVL Swedish Environmental Research Institute.

2. Scope of the Study

The following sections describe the general scope of the project to achieve the stated goals. This includes, but is not limited to, the identification of specific product systems to be assessed, the product function(s), functional unit and reference flows, the system boundary, allocation procedures, and cut-off criteria of the study.

2.1. Product Systems

Tetra Pak is a leading manufacturer of beverage cartons. Many beverage cartons are supplied as portion-sized units that are suitable for school lunches, picnics, etc. Such portion-sized packs usually come with a straw attached to allow easy access to the contents of the packaging.

To ensure hygiene is maintained, the straw is contained within a wrapping layer that keeps it clean and protects it from dirt until it is ready for use. Typically, the straw, contained within this wrapping, is then glued to the portion-sized package using hot melt adhesive.

This study is focused on assessing the environmental performance of different material choices for the straw and wrapping.

1. Current option: polymer straw with polymer film wrapping
2. New option 1: paper straw with polymer film wrapping
3. New option 2: paper straw with paper wrapping

The packaging specifications for each option and for the portion-sized pack to which they are attached are given in Table 2-1.

Table 2-1: Packaging specifications

Packaging element	Dimensions (outer diameter)	Materials	Mass/unit
Plastic straw	100 mm x 5 mm	Polymer	0.400 g
		TOTAL	**0.400 g**
Paper straw	100 mm x 5 mm	Liquid packaging board Polymer	0.378 g 0.0120 g
		TOTAL	**0.390 g**
Plastic wrapping	n/a	Polymer film	0.0735 g
		TOTAL	**0.0735 g**
Paper wrapping	n/a	Paper Polymer	0.0675 g 0.00675 g
		TOTAL	**0.0743 g**
Aseptic portion package (excl. straw and wrapping), 200ml	0.03 m^2	Liquid packaging board Polymers Aluminium foil Ink	5.90 g 1.75 g 0.500 g 0.050 g
		TOTAL	**8.20 g**

2.2. Product Functions and Functional Unit

Portion-sized carton packages usually come with an attached straw, contained within a protective outer wrapping. This straw can be inserted through a small foil opening in the carton to allow the user to access and imbibe the beverage contained within. This is very convenient for the user, allowing easy access to the contents without requiring additional tools, such as scissors, to open the pack. The straw gives the user access to all of the beverage, thereby minimising waste while the tight fit between the straw and opening reduces the risk of spillages.

The paper and plastic straws assessed in this study are assumed to have identical functionality, being of similar dimensions and with equivalent ease of use for accessing the portion-sized carton package. Both paper and plastic straws are assumed to be discarded with the portion-sized carton package and so have equivalent lifetimes in use.

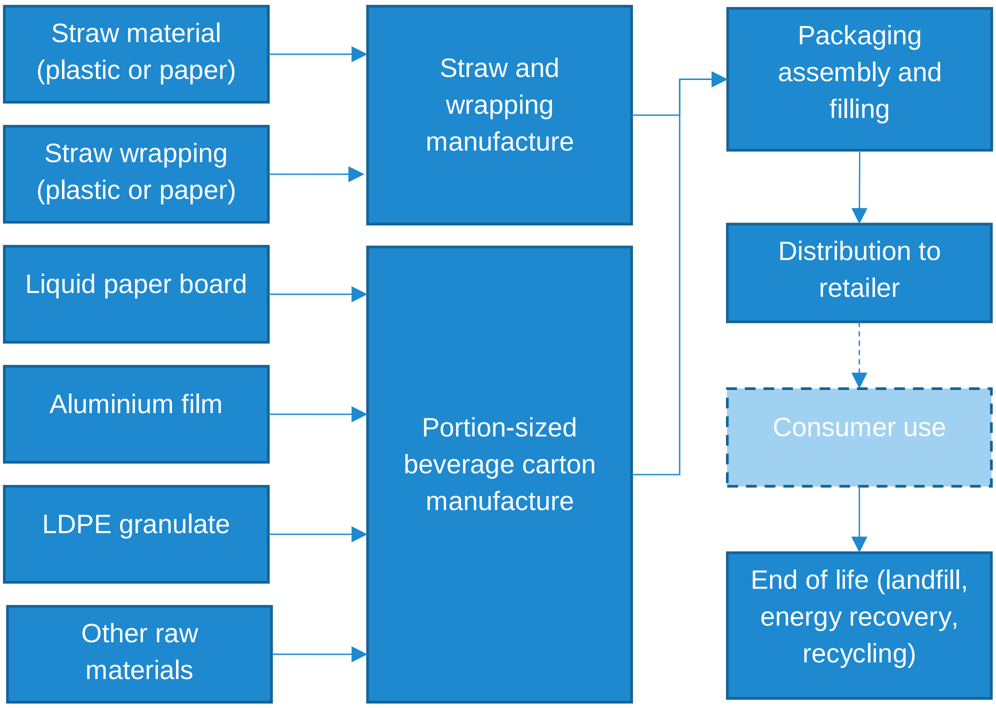
The functional unit for this study is

the provision of beverage packaging for storing, accessing and consuming the beverage contained within 1000 portion-sized servings

This functional unit is consistent with the goals of the study, which aim to evaluate the environmental performance of the different straw and wrapping options. The corresponding reference flows for each packaging component are therefore:

- 1000 plastic straws in plastic wrapping = 0.474 kg
- 1000 paper straws in plastic wrapping = 0.464 kg
- 1000 paper straws in paper wrapping = 0.464 kg
- 1000 portion-sized carton packages = 8.20 kg.

2.3. System Boundary



Dashed lines indicate process stage not assessed
Transport is included for all materials and process steps
Energy inputs and waste treatment associated with each process step have been modelled but not shown

Figure 2-1: Scope of product system assessed in this study

The full product life cycle has been considered, from cradle-to-grave. That is, from the point at which raw materials are extracted from the environment through to the point at which waste materials are disposed of or recycled at end of life.

Hence, the study includes:

- Raw material production
- Converting processes
- Filling operations (excluding production of beverage)
- Distribution
- End-of-life

The focus of this study is the life cycle burdens associated with the straws and of the portion-sized packaging (which is included for context). As such, consideration of secondary and tertiary packaging is outside the scope of the study. Similarly, storage at the retailer and consumer is also excluded since products stored in Tetra Pak beverage cartons often do not require refrigeration. Even if refrigeration were required, this would be a property of the packaged product and not of the packaging itself.

Impacts associated with the beverage product itself are also excluded – so no burdens are given to manufacturing or distributing the beverage (reported distribution impacts only consider the mass of packaging required).

Aspects relating to production of capital equipment and infrastructure have also be excluded from the assessment as these are very likely to be negligible when allocated over the output from such equipment over its full lifetime. Employee transport has also been excluded from the study and with similar justification.

The geographical scope of the study is Europe so European-average data have been used as far as such information is available.

Table 2-2: System boundaries

Included	Excluded
✓ Raw material production	× Capital equipment
✓ Inbound transport to manufacturing sites	× Infrastructure
✓ Converting into straws, wrapping and portion-sized carton packages	× Beverage product
	× Retail storage
✓ Assembly and filling	× Consumer transport and storage
✓ Distribution to retailers	× Employee transport
✓ Transport to end of life	
✓ Waste management options	

2.3.1. Time Coverage

The intended time reference for the study was to use primary data from Tetra Pak production processes for 2018.

Background datasets with different time horizons have been used to model the raw material inputs as documented in section 3.3.

2.3.2. Technology Coverage

The study is intended to focus on the current technologies used for manufacturing paper and plastic straws and portion-sized beverage cartons.

2.3.3. Geographical Coverage

The intended geographical focus of the study is production and use within Europe.

2.4. Allocation

2.4.1. Multi-output Allocation

Production processes with more than one output do not occur in this product system with the exception of liquid packaging board (LPB) production, which has an output of 1.33 kg turpentine alongside the production of each 1000 kg of LPB (Alliance for Beverage Cartons and the Environment, 2009). As the quantity of this co-product relative to the main product is so low

(0.133% w/w), no allocation has been applied. Instead the worst case option has been modelled with all burdens being assigned to the LPB.

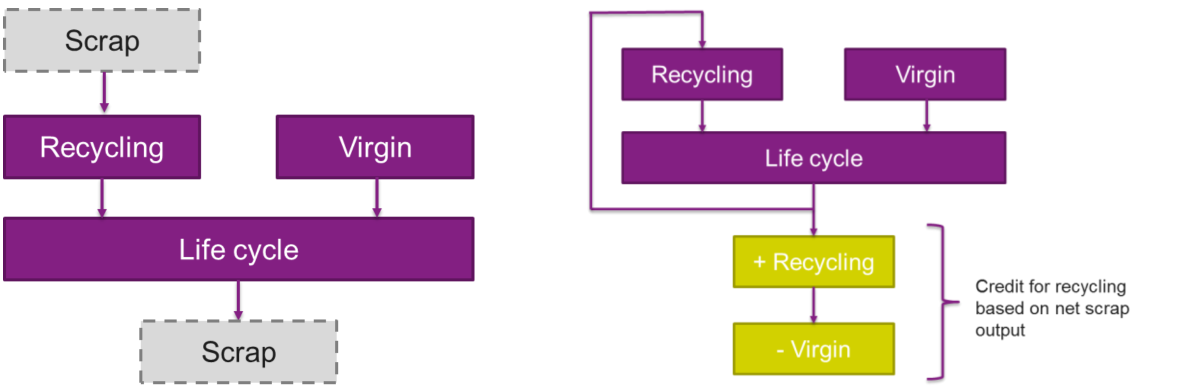
Allocation of background data (energy and materials) taken from the GaBi 2018 databases is documented online (thinkstep, 2018).

2.4.2. End-of-Life Allocation

End-of-Life allocation follows the requirements of ISO 14044, section 4.3.4.3. Such allocation approaches address the question of how to assign impacts from virgin production processes to material that is recycled and used in future product systems.

Two main approaches are commonly used in LCA studies to account for end of life recycling and recycled content.

- Cut-off approach – burdens or credits associated with material from previous or subsequent life cycles are not considered i.e., are “cut-off”. Therefore, scrap input to the production process is considered to be free of burdens but, equally, no credit is received for scrap available for recycling at end of life. Hence, this approach rewards the use of recycled content but does not reward end of life recycling.
- Substitution approach – this approach is based on the perspective that material that is recycled at end of life will substitute for an equivalent amount of virgin material. A credit is given to account for the benefits of this substitution. However, this also means that burdens equivalent to this credit should be assigned to scrap used as an input to the production process, with the overall result that the impact of recycled granulate is the same as the impact of virgin material. Hence, this approach rewards end of life recycling but does not reward the use of recycled content.



i. Cut off approach (scrap inputs and outputs are not considered)

ii. Substitution approach (credit given for net scrap arising)

Figure 2-2: Schematic representations of the cut-off and substitution approaches

The substitution approach is used as the default option in this study as we consider this to be most appropriate for materials where the market for post-consumer recycled material market is not saturated (i.e. demand for post-consumer recycled material exceeds supply), which is the case for paper and card and commonly recycled plastics such as PP and HDPE. This follows the recommendations provided in the *GHG Protocol Product Life Cycle Accounting and Reporting Standard* (WRI, 2011). Nevertheless, the cut-off approach has been included as a sensitivity analysis to examine the influence of methodological choices on the results of the study. An explanation of how the two approaches have been implemented in the LCA model is provided below.

Material recycling (substitution approach): Open scrap inputs from the production stage are subtracted from scrap to be recycled at end of life to give the net scrap output from the product life cycle. This remaining net scrap is sent to material recycling. The original burden of the primary material input is allocated between the current and subsequent life cycle using the mass of recovered secondary material to scale the substituted primary material, i.e., applying a credit for the substitution of primary material so as to distribute burdens appropriately among the different product life cycles. These subsequent process steps are modelled using industry average inventories.

Energy recovery (substitution approach): In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. Credits are assigned for power and heat outputs using the regional grid mix and thermal energy from natural gas. The latter represents the cleanest fossil fuel and therefore results in a conservative estimate of the avoided burden.

Landfilling (substitution approach): In cases where materials are sent to landfills, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilisation rates (flaring vs. power production). A credit is assigned for power output using the regional grid mix.

Material recycling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary at end of life is drawn after scrap collection to account for the collection rate, which generates an open scrap output for the product system. The processing and recycling of the scrap is associated with the subsequent product system and is not considered in this study.

Energy recovery and landfilling (cut-off approach): Any open scrap inputs into manufacturing remain unconnected. The system boundary includes the waste incineration and landfilling processes. In cases where materials are sent to waste incineration, they are linked to an inventory that accounts for waste composition and heating value as well as for regional efficiencies and heat-to-power output ratios. In cases where materials are sent to landfill, they are linked to an inventory that accounts for waste composition, regional leakage rates, landfill gas capture as well as utilisation rates (flaring vs. power production). No credits for power or heat production are assigned.

2.5. Cut-off Criteria

No cut-off criteria are defined for this study. As summarized in section 2.3, the system boundary was defined based on relevance to the goal of the study. For the processes within the system boundary, all available energy and material flow data have been included in the model. In cases where no matching life cycle inventories are available to represent a flow, proxy data have been applied based on conservative assumptions regarding environmental impacts.

The choice of proxy data is documented in Chapter 3. The influence of these proxy data on the results of the assessment has been carefully analysed and is discussed in Chapter 5.

2.6. Selection of LCIA Methodology and Impact Categories

The impact assessment categories and other metrics considered to be of high relevance to the goals of the project are shown in Table 2-3. The methodologies for evaluating the different impact categories are based on those used by the European Commission's Product Environmental Footprint (PEF) initiative. These methods have been thoroughly evaluated and are considered to be the most robust available for European-focused studies.

Global warming potential and non-renewable primary energy demand were chosen because of their relevance to climate change and energy efficiency, both of which are strongly interlinked, of high public and institutional interest, and deemed to be the most pressing environmental issues of our time. The global warming potential impact category is assessed based on the current IPCC characterisation factors taken from the 5th Assessment Report (IPCC, 2013) for a 100-year timeframe (GWP100) as this is currently the most commonly used metric[5]. The global warming potential results include the photosynthetically bound carbon (also called *biogenic carbon*) as well as the release of that carbon during the use or end-of-life phase as CO_2 and/or CH_4.

Eutrophication, acidification, and photochemical ozone creation potentials were chosen because they are closely connected to air, soil, and water quality and capture the environmental burdens associated with commonly regulated emissions such as NO_x, SO_2, VOC, and others.

The *Montreal Protocol on Substances that Deplete the Ozone Layer* was implemented in 1989 with the aim of phasing out emissions of ozone depleting gases. The protocol has been ratified by *all* members of the United Nations – an unprecedented level of international cooperation. With a few exceptions use of CFCs, the most harmful ozone-depleting chemicals, has been eliminated, while complete phase out of less active HCFCs will be achieved by 2030. As a result, it is expected that the ozone layer will return to 1980 levels between 2050 and 2070. In addition, no ozone-depleting substances are emitted in the foreground system under study. For these reasons, ozone depletion potential is not considered in this study.

Water scarcity has also been selected due to its high political relevance. The UN estimates that roughly a billion people on the planet don't have access to improved drinking water, which entails a variety of problems around ecosystem quality, health, and nutrition. However, if the water supply is not a limiting factor in the region, then the water supply also does not pose an environmental problem.

It shall be noted that the selected impact categories represent impact *potentials*, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) actually follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the functional unit (relative approach). LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

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[5] PEF also uses data from the IPCC 5th Assessment Report but it includes emission factors that also consider climate carbon feedback (CCFB), which increases the emission factors associated with GHGs. At this time, most external reporting of GHG emissions does not include CCFB, so we have not included CCFB effects in the results of this study.

Table 2-3: Impact category descriptions

Impact Category	Description	Unit	Method & Reference	Robustness[6]
Acidification Potential	A measure of emissions that cause acidifying effects to the environment. The acidification potential is a measure of a molecule's capacity to increase the hydrogen ion (H^+) concentration in the presence of water, thus decreasing the pH value. Potential effects include fish mortality, forest decline, degradation of agricultural crop quality and the deterioration of building materials.	mol H+ equivalent	Accumulated Exceedance (Seppälä J., 2006; Posch, 2008)	II
Climate change	A measure of greenhouse gas emissions, such as carbon dioxide, nitrous oxide, and methane. These emissions are causing an increase in the absorption of radiation emitted by the earth, increasing the natural greenhouse effect. In turn, this has, adverse impacts on ecosystem health, human health and material welfare due to sea level change and higher incidence of extreme weather events, drought, flooding and wildfires.	kg CO_2 equivalent	Baseline model of 100 years of the IPCC (IPCC, 2013)	I
Eutrophication Potential	Eutrophication covers all potential impacts of excessively high levels of macronutrients, the most important of which are nitrogen (N) and phosphorus (P). Nutrient enrichment may cause an undesirable shift in species composition and elevated biomass production in both aquatic and terrestrial ecosystems. In aquatic ecosystems, increased biomass production may lead to depressed oxygen levels, because of the additional consumption of oxygen in biomass decomposition.	kg P equivalent, kg N equivalent, mol N equivalent	Accumulated Exceedance (Seppälä J., 2006; Posch, 2008; Struijs, 2009)	II

[6] Based on an assessment by the European Commission for the Product Environmental Footprint initiative. I = most robust, II = intermediate, III = least robust (European Commission, 2017)

Impact Category	Description	Unit	Method & Reference	Robustness[6]
Photochemical Ozone Formation	A measure of emissions of precursors that contribute to ground level smog formation (mainly ozone, O_3), produced by the reaction of VOC and carbon monoxide in the presence of nitrogen oxides under the influence of UV light. Ground level ozone may be injurious to human health and ecosystems and may also damage crops.	kg NMVOC equivalent	LOTOS-EUROS model (Van Zelm R., 441-453)	II
Non-renewable energy resource use	The consumption of non-renewable energy resources leads to a decrease in the future availability of the functions supplied by these resources.	MJ (net calorific value)	CML 2002 Abiotic resource depletion – fossil fuels (van Oers, de Koning, Guinée, & Huppes, 2002)	III
Water scarcity	A measure of the stress on a region due to water consumption. The result represents the relative available water remaining per area in a watershed, after the demand of humans and aquatic ecosystems has been met. Hence, it assesses the potential for water deprivation to either humans or ecosystems, building on the assumption that the less available water remaining per area, the more likely another user will be deprived.	m^3 world equivalent	AWARE (Boulay, 2017)	III

The study applies normalisation relative to the impacts caused by an average global citizen over a year to establish the order of magnitude in which each product system would contribute for the assessed impact categories. The chosen geographic reference corresponds to the scope of the chosen impact assessment methodologies and is the most recent baseline available.

As this study intends to support comparative assertions to be disclosed to third parties, no grouping or further quantitative cross-category weighting has been applied. Instead, each impact is discussed in isolation, without reference to other impact categories, before final conclusions and recommendations are made.

2.7. Interpretation to Be Used

The results of the LCI and LCIA were interpreted according to the Goal and Scope. The interpretation addresses the following topics:

- Identification of significant findings, such as the main process step(s), material(s), and/or emission(s) contributing to the overall results
- Evaluation of completeness, sensitivity, and consistency to justify the exclusion of data from the system boundaries as well as the use of proxy data.
- Conclusions, limitations, and recommendations

Note that in situations where no product outperforms all of its alternatives in each of the impact categories, some form of cross-category evaluation is necessary to draw conclusions regarding the environmental superiority of one product over the other. Since ISO 14044 rules out the use of quantitative weighting factors in comparative assertions to be disclosed to the public, this evaluation will take place qualitatively and the defensibility of the results therefore depend on the authors' expertise and ability to convey the underlying line of reasoning that led to the final conclusion.

2.8. Data Quality Requirements

The data used to create the inventory model shall be as precise, complete, consistent, and representative as possible with regards to the goal and scope of the study under given time and budget constraints.

- Measured primary data are considered to be of the highest precision, followed by calculated data, literature data, and estimated data. The goal is to model all relevant foreground processes using measured or calculated primary data.
- Completeness is judged based on the completeness of the inputs and outputs per unit process and the completeness of the unit processes themselves. The goal is to capture all relevant data in this regard.
- Consistency refers to modelling choices and data sources. The goal is to ensure that differences in results reflect actual differences between product systems and are not due to inconsistencies in modelling choices, data sources, emission factors, or other artefacts.
- Reproducibility expresses the degree to which third parties would be able to reproduce the results of the study based on the information contained in this report. The goal is to provide enough transparency with this report so that third parties are able to approximate the

reported results. This ability may be limited by the exclusion of confidential primary data and access to the same background data sources.

- Representativeness expresses the degree to which the data matches the geographical, temporal, and technological requirements defined in the study's goal and scope. The goal is to use the most representative primary data for all foreground processes and the most representative industry-average data for all background processes. Whenever such data were not available (e.g., no industry-average data available for a certain country), best-available proxy data were employed.

An evaluation of the data quality with regard to these requirements is provided in Chapter 5 of this report.

2.9. Type and format of the report

In accordance with the ISO requirements (ISO, 2006) this document aims to report the results and conclusions of the LCA completely, accurately, and without bias to the intended audience. The results, data, methods, assumptions, and limitations are presented in a transparent manner and in sufficient detail to convey the complexities, limitations, and trade-offs inherent in the LCA to the reader. This allows the results to be interpreted and used in a manner consistent with the goals of the study.

2.10. Software and Database

The LCA model was created using the GaBi 8 Software system for life cycle engineering, developed by thinkstep AG. The GaBi 2018 LCI database provides the life cycle inventory data for most of the raw and process materials in the background system (thinkstep, 2018).

2.11. Critical Review

The study has been critically reviewed by Håkan Stripple of the IVL Swedish Environmental Research Institute.

3. Life Cycle Inventory Analysis

3.1. Data Collection Procedure

Primary data were supplied by Tetra Pak in a spreadsheet. Upon receipt, these data were cross-checked for completeness and plausibility using mass balance, stoichiometry, as well as internal and external benchmarking. Where gaps, outliers, or other inconsistencies occurred, thinkstep engaged with the Tetra Pak to resolve these issues.

3.2. Packaging production

3.2.1. Overview of Product System

Figure 2-1 describes the overall production process for the packaging assessed in this study. The straws (paper or plastic) are manufactured from raw materials and inserted into the wrapping material (paper or plastic). The carton-board used for the beverage packaging is manufactured separately and supplied to Tetra Pak, which then converts this into the finished portion-sized pack, fills it and attaches the straw and wrapping.

Specific details relating to the product specifications and the manufacturing process are confidential to Tetra Pak. These have been included in Appendix B so they are available to the critical reviewer but can be removed if this report is made available to the public.

3.2.2. Distribution

For road transport, it is assumed that deliveries use a 28-32 t capacity lorry (gross weight). Only the one-way distance has been modelled as it is assumed that material delivery will be managed by a third-party logistics provider that would optimise routing and loads to minimise empty returns. The utilisation factor (55%) used for road transport is an average for European trucks of the selected size and so already accounts for some empty and under-utilised transport.

The transport distances and modes assumed in this study are given in Table 3-1.

Table 3-1: Distribution (based on values recommended by ACE (Alliance for Beverage Cartons and the Environment, 2011)).

Material/product	Transport mode	Distance	Unit
INBOUND TRANSPORT			
Polymers for straws	Truck	200	km
Paper for straws	Truck	200	km
Polymers for wrap	Truck	200	km
Paper for wrap	Truck	200	km
Liquid packaging board	Truck	200	km
	Train	400	km
	Ship	1300	km
Polymers for carton	Truck	400	km
Aluminium foil for carton	Truck	250	km
Printing ink for carton	Truck	200	km
Carton rolls to filler	Truck	400	km
Transport of finished product to retailer	Truck	200	km

3.2.3. Use

Impacts associated with the use stage are outside the scope of this assessment, as explained in section 2.3.

3.2.4. End-of-Life

At end of life, the portion-sized packaging carton is assumed to be sent for recycling, energy recovery or landfill. The straw and wrapping are assumed to go to the same waste treatment destination as the portion-sized packaging carton. For carton recycling, it is assumed that each component material can be separated and recycled separately. This is representative of some recycling facilities in Europe, but this can vary, in other recycling plants the polymer fraction may be used for on-site energy generation.

The proportion of product that goes to each waste treatment option is given in Table 3-2. The recycling rate is based on the latest available European data from ACE (year 2017) (Alliance for Beverage Cartons and the Environment, 2019). The split between landfill and energy recovery for the remaining waste is based on the average for municipal waste in the European Union in 2017 (Eurostat, 2019).

Table 3-2: Split of waste treatment options for packaging in the EU

Waste treatment route	Proportion
Recycling rate	48%
Energy recovery	28%
Landfill	24%

3.3. Background Data

Documentation for all GaBi datasets can be found online (thinkstep, 2018).

3.3.1. Fuels and Energy

Regional averages for fuel inputs and electricity grid mixes were obtained from the GaBi 2018 databases. Table 3-3 shows the most relevant LCI datasets used in modelling the product systems. Electricity consumption was modelled using the regional grid mix that accounts for imports from neighbouring countries/regions.

Table 3-3: Key energy datasets used in inventory analysis

Dataset	Location	Dataset	Data Provider	Reference Year
Compressed air	EU-28	Compressed air	thinkstep	2014
Electricity	EU-28	Electricity grid mix	thinkstep	2014
Diesel	EU-28	Diesel mix at filling station	thinkstep	2014
Heavy fuel oil	EU-28	Heavy fuel oil at refinery (1.0wt.% S)	thinkstep	2014
Light fuel oil	EU-28	Light fuel oil at refinery	thinkstep	2014
LPG	EU-28	Liquefied Petroleum Gas (LPG) (70% propane, 30% butane)	thinkstep	2014
Natural gas	EU-28	Natural gas mix	thinkstep	2014
Process steam	EU-28	Process steam from natural gas 90%	thinkstep	2014

3.3.2. Raw Materials and Processes

The choice of materials used in Tetra Pak's packaging is commercially sensitive so this section has been moved to Annex B, where it can be removed before being shared externally.

3.3.3. Transportation

Average transportation distances and modes of transport are included for the transport of the raw materials, operating materials, and auxiliary materials to production and assembly facilities.

The GaBi 2018 database was used to model transportation. Transportation was modelled using the GaBi global transportation datasets. Fuels were modelled using the geographically appropriate datasets.

Table 3-4: Transportation and road fuel datasets

Mode / fuels	Location	Dataset	Data Provider	Reference Year
Ship	GLO	Container ship, 27500 dwt payload capacity, ocean going	thinkstep	2017
Rail	GLO	Rail transport cargo - average, average train, gross tonne weight 1000t / 726t payload capacity	thinkstep	2017
Truck	GLO	Truck, Euro 6, 26 - 28t gross weight / 18,4t payload capacity	thinkstep	2017

4. LCIA Results

This chapter contains the results for the impact categories and additional metrics defined in section 2.6. It shall be reiterated at this point that the reported impact categories represent impact potentials, i.e., they are approximations of environmental impacts that could occur if the emissions would (a) follow the underlying impact pathway and (b) meet certain conditions in the receiving environment while doing so. In addition, the inventory only captures that fraction of the total environmental load that corresponds to the chosen functional unit.

LCIA results are therefore relative expressions only and do not predict actual impacts, the exceeding of thresholds, safety margins, or risks.

4.1. Overall Results

The overall life cycle results for the assessed impact categories are presented in Table 4-1 and Figure 4-1.

Table 4-1: LCIA results for the different straw and wrap scenarios and for the portion-sized pack

Result category	Unit	Plastic straw & plastic wrap	Paper straw and plastic wrap	Paper straw and paper wrap	Portion-sized pack (excl. straw and wrap)
Acidification	Mole of H^+ eq.	1.00E-03	2.24E-03	2.32E-03	0.0462
Climate change, fossil emissions	kg CO_2 eq.	0.969	0.704	0.598	10.7
Climate change, biogenic emissions	kg CO_2 eq.	4.10E-03	-0.0585	-0.0710	-0.877
Climate change (fossil + biogenic)	kg CO_2 eq.	0.973	0.646	0.527	9.858
Eutrophication (freshwater)	kg P eq.	3.51E-06	1.29E-05	1.42E-05	1.95E-04
Eutrophication (marine)	kg N eq.	2.51E-04	6.40E-04	6.81E-04	0.0115
Eutrophication (terrestrial)	Mole of N eq.	2.63E-03	6.18E-03	6.53E-03	0.115
Photochemical ozone formation	kg NMVOC eq.	8.99E-04	1.59E-03	1.69E-03	0.0316
Non-renewable energy resource use	MJ	18.9	11.6	9.42	168
Water scarcity*	m^3 world eq.	0.131	0.217	0.217	4.14

*Due to uncertainties in the methodology and limitations in the background datasets used for modelling the product life cycle, the water scarcity results should be regarded as less robust than for other impact categories (see section 4.2.6 for more details).

Products that include paper or board components exhibit negative values for biogenic climate change. This is because a proportion of the packaging is sent to landfill at end of life. Not all of this landfilled material will biodegrade within the 100 year timescale of the assessment, so some of the biogenic carbon contained in the material will end up being sequestered over the long term.

Consideration of emissions over a 100 year time period is usual practice in LCA studies, but this is an arbitrarily selected time scale. Over longer periods it is reasonable to assume that there would be increased degradation and further emissions. Plastics may also degrade to some extent, given enough time. However, the science and understanding of degradation rates of different materials in landfills is not very certain and is the focus of a lot of research. This uncertainty should be borne in mind when interpreting these results.

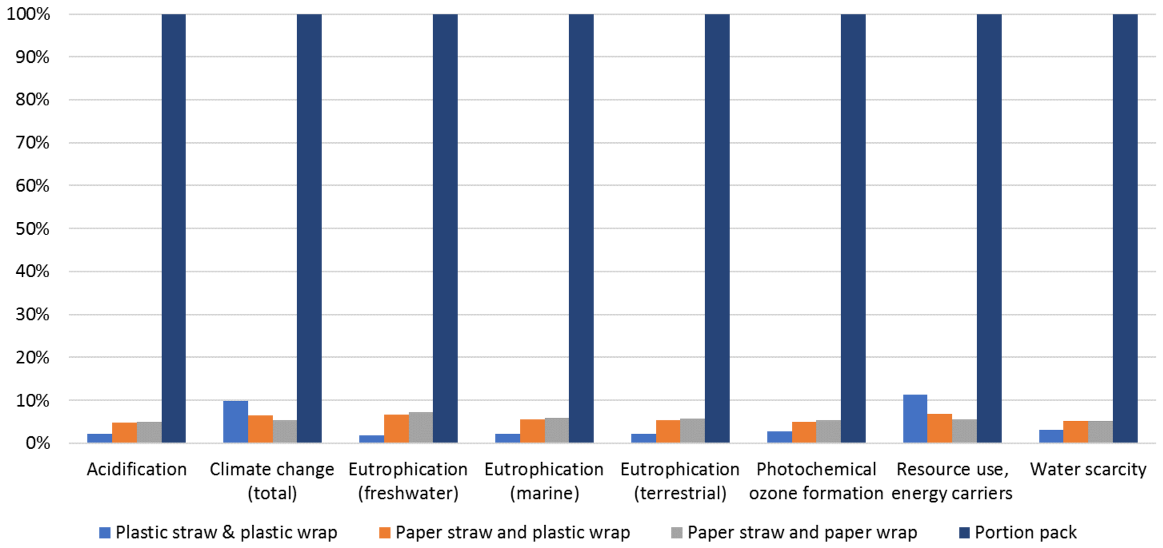

Figure 4-1: Comparison of results for each scenario

Figure 4-1 shows that the environmental burdens of the straws are very small compared to those of the portion-sized carton pack, for every impact category assessed.

4.2. Detailed Results

For each impact category, charts are presented (1) comparing the overall results for each scenario across the product lifecycle and (2) showing the contribution to the total impact from different component materials, processes, and life cycle stages. Some additional charts are presented for the climate change impact category, as this is the most widely discussed metric.

The results for the portion pack are not shown as the burdens associated with this are so large compared to the straws and wraps that it would be difficult see the detail in and make comparisons among the different straw scenarios.

4.2.1. Acidification Potential

Figure 4-2 and Figure 4-3 show the results for acidification potential.

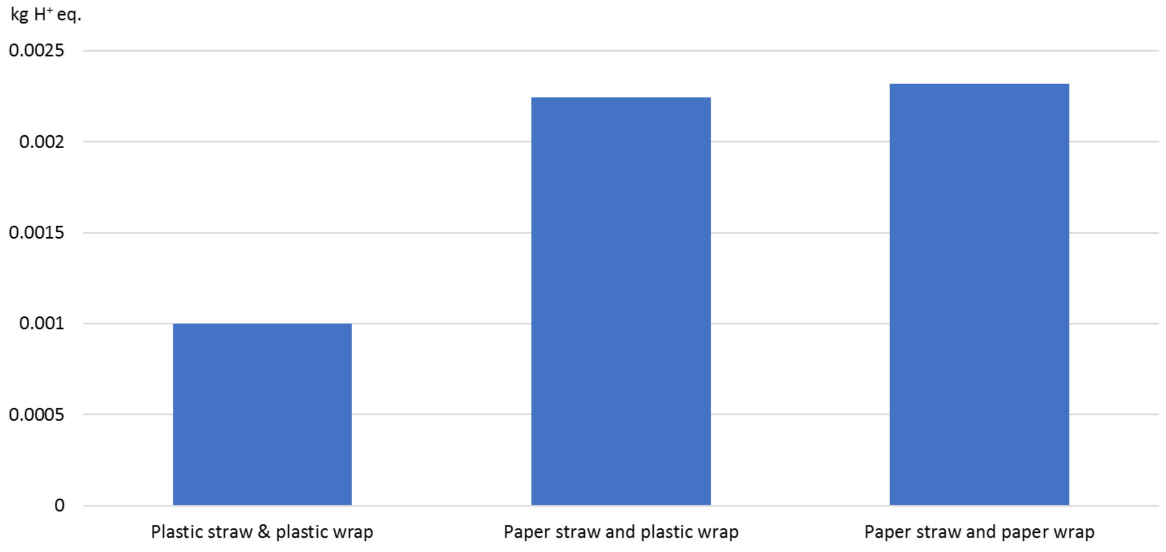

Figure 4-2: Net life cycle results for acidification potential

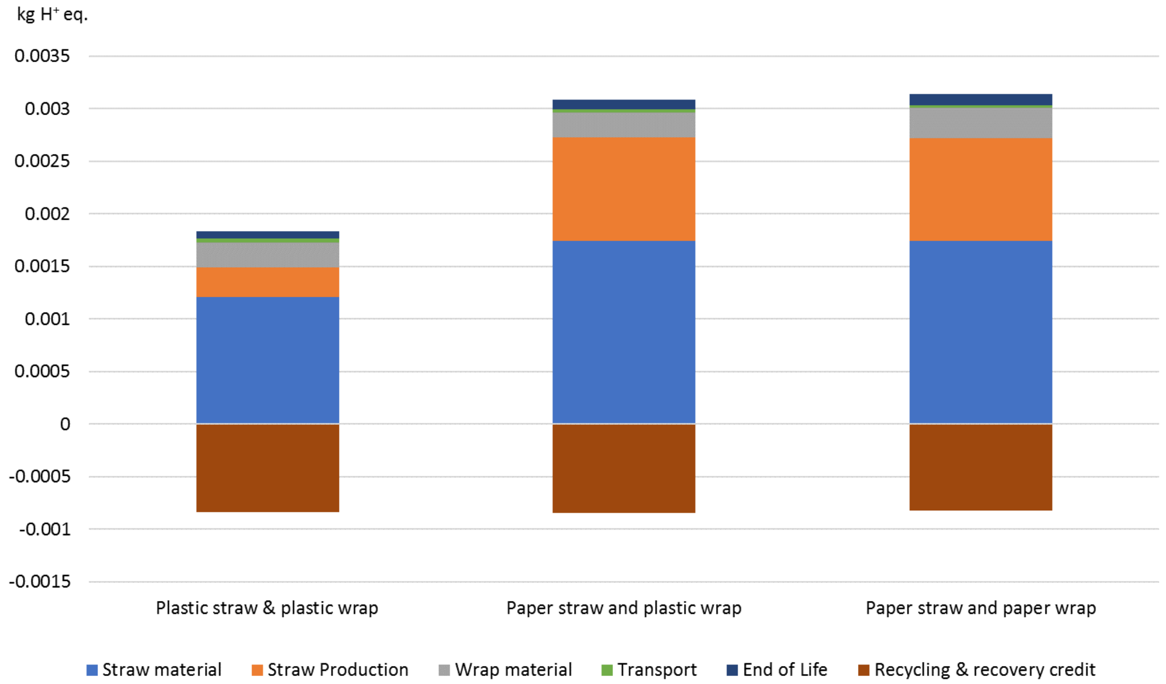

Figure 4-3: Life cycle results for acidification potential showing contribution from different life cycle stages/production processes

Acidification is dominated by sulphur dioxide (ca. 50-53%) and nitrogen oxide emissions (40-45%) that are mainly associated with fuel combustion. The burdens increase as the amount of paper present increases (considering both the straw and wrap).

The contribution analysis shows that production of straws, including production of the raw materials, has the largest overall contribution to this impact category and that paper straws have a greater acidifying impact than for plastic straws. However, the main difference between the two is due to the straw production process. The paper straw takes much longer to make than the plastic straw, so the energy consumption per straw is more than 3.5 times greater. Another notable finding is that a large acidification credit is received for energy recovery and recycling at end of life, regardless of material choice.

In contrast, burdens associated with producing the wrap are relatively minor in all scenarios – reflecting the low mass of this packaging component. Transport and waste treatment processes at end of life processes have a negligible contribution to this impact category.

4.2.2. Climate Change

Figure 4-4 shows overall results for climate change, including the split between biogenic and fossil carbon), while Figure 4-5 shows the contribution due to fossil GHG emissions only and Figure 4-6 shows the contribution due to biogenic GHG emissions only.

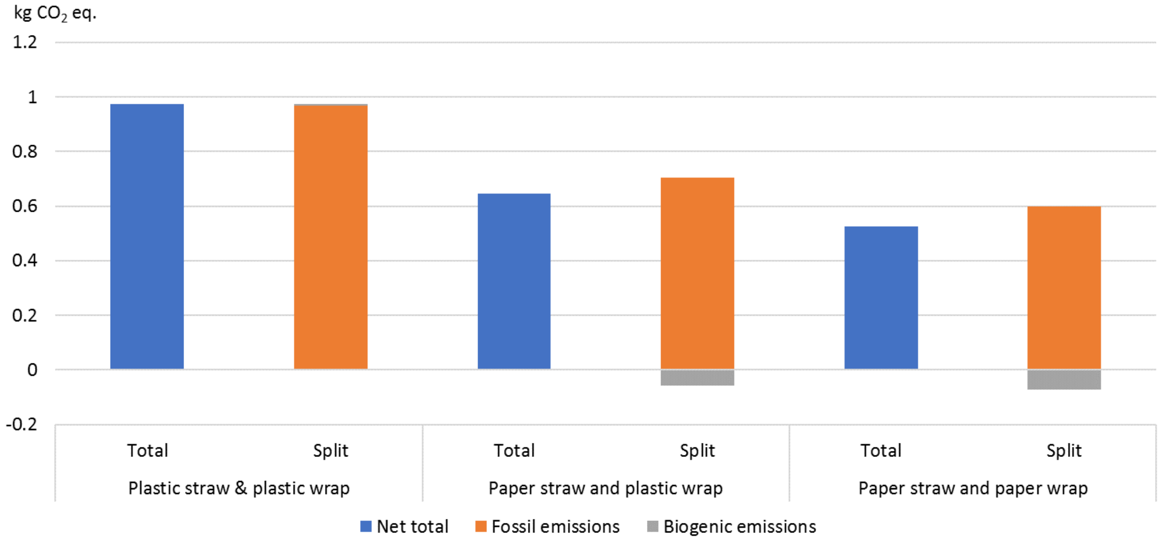

Figure 4-4: Net life cycle results for climate change

The dominant source of climate change impact is emission of carbon dioxide, with most of the remainder coming from methane (6% for plastic straws and 15-18% for paper straws). For this impact category, burdens decrease as the amount of paper used in the straw and wrap increases, and this is seen for both biogenic and fossil emissions.

Fossil GHG emissions

The contribution analysis for fossil emissions shows large differences among the plastic and paper straw scenarios. For the plastic straw, the profile is dominated by the granulate production process. Emissions at end of life and credits for energy recovery and recycling are also substantial (but more or less cancel each other out). Other life cycle stages have minor contributions in comparison.

The fossil-only climate change results profile of the paper straw for is very different. Here the burdens associated with paper production are very low (since integrated paper and pulp mills are predominantly fuelled by biomass), but, as with acidification, the burdens associated with processing the paper into straws has the largest contribution to the total impact.

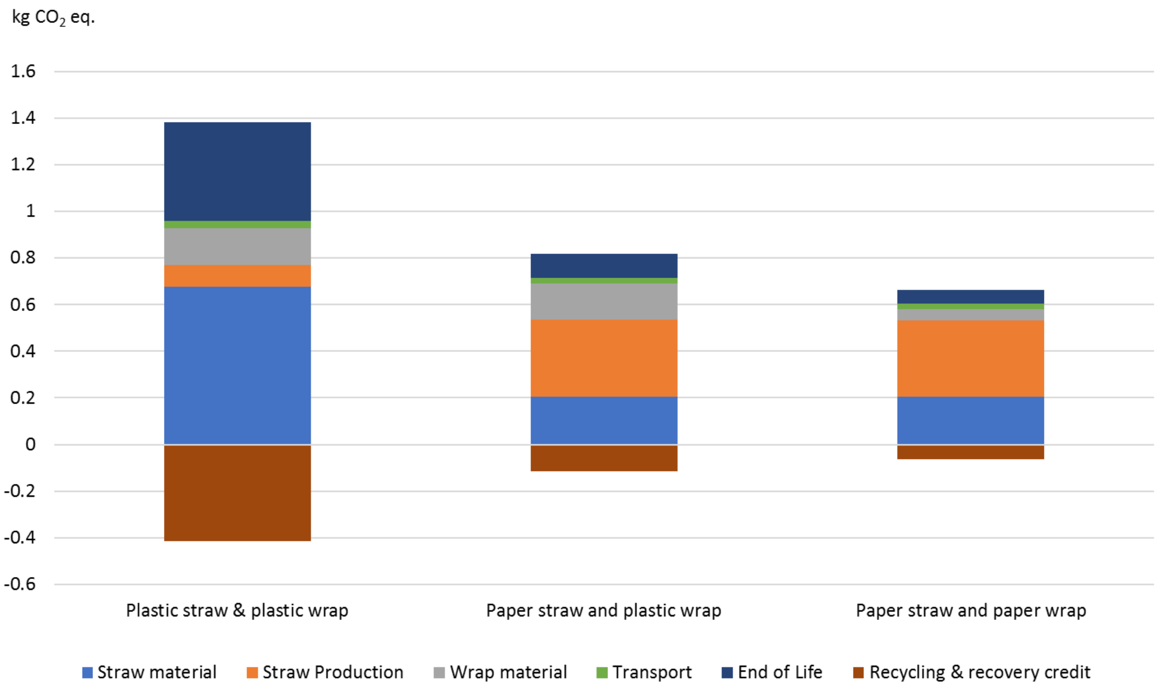

Figure 4-5: Life cycle results for climate change (fossil emissions) showing contribution from different life cycle stages/production processes

Biogenic GHG emissions

The contribution analysis for *biogenic* climate change shows the difference between the plastic and paper straws even more starkly (Figure 4-6).

There are almost no sources of biogenic carbon emissions in the plastic straw life cycle (for transport there will be some uptake due to the use of biodiesel in the fuel mix but this is emitted again once the fuel is burnt. As these processes both occur in the same category, the net emission is near zero). For the paper straw, a large amount of biogenic carbon is taken up and stored within plant fibres during forest growth and some of this remains stored within the paper that is subsequently manufactured. It is also interesting to note that the recycling and recovery credit is positive for the paper straws (indicating that it is adding to the total burden rather than reducing it). This is a consequence of using the substitution methodology to calculate the potential benefits of paper recycling. Here, the burdens from the recycling process are modelled while those associated with producing an equivalent quantity of virgin material are subtracted from the life cycle total. However, as can be seen from the chart, production of virgin paper takes up biogenic carbon dioxide, so by recycling paper, less carbon dioxide is stored than if all the paper used were obtained from virgin sources.

Despite this, the net biogenic carbon burden is negative for the paper straws. This is because 24% of the straws get sent to landfill at end of life. Only a portion of this landfilled paper biodegrades into carbon dioxide and methane. Much of this landfill gas is captured and combusted with energy recovery. The remaining non-biodegraded paper is modelled as being stored in the landfill over the long term. The results presented in this study follow the usual assumption of a 100 year time horizon. If a longer time period was considered, it is likely that more of the paper would biodegrade and GHG emissions would be larger. However, there is a lot of uncertainty over the behaviour of paper and card materials in landfills. Some recent studies indicate that degradation rates may be a lot lower than previously assumed, but this is likely to vary a lot depending on specific landfill conditions.

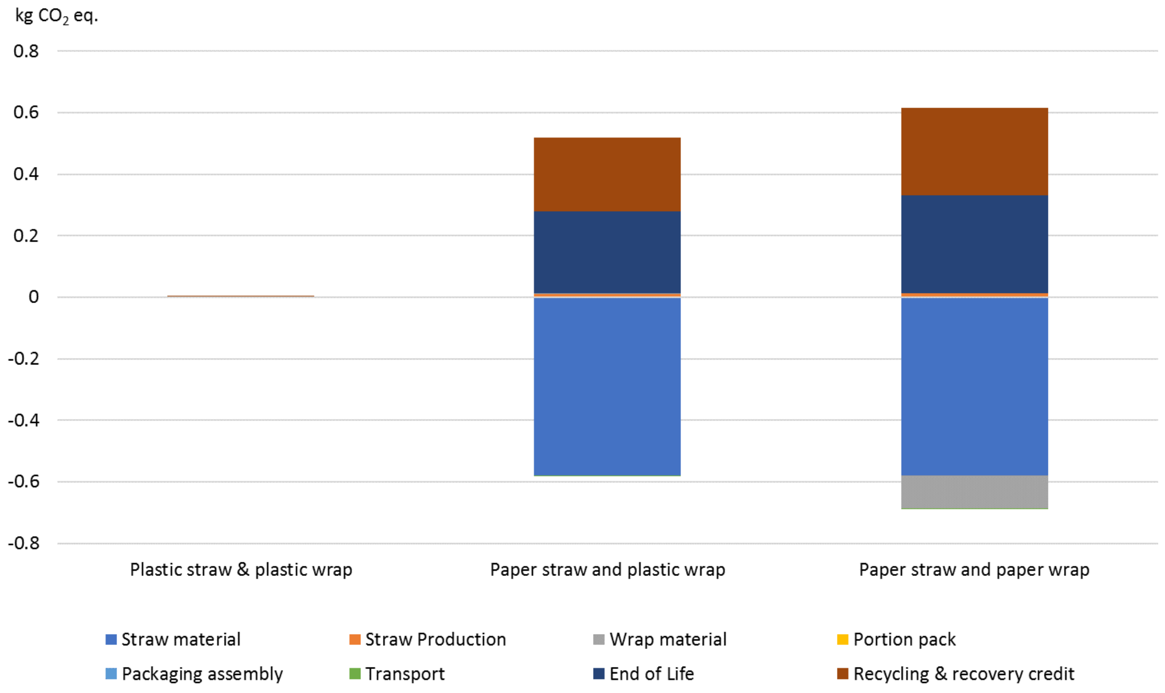

Figure 4-6: Life cycle results for climate change (biogenic emissions only) showing contribution from different life cycle stages/production processes

Presented below are some additional ways to present the climate change results. Figure 4-7 shows the relative contributions from each scenario compared to a baseline where the plastic straw and wrap = 100%. Figure 4-8 does the same but also includes the package itself in the comparison. Figure 4-9 shows what fraction of the total climate change impact is due to the package and to the straw and wrap for each scenario.

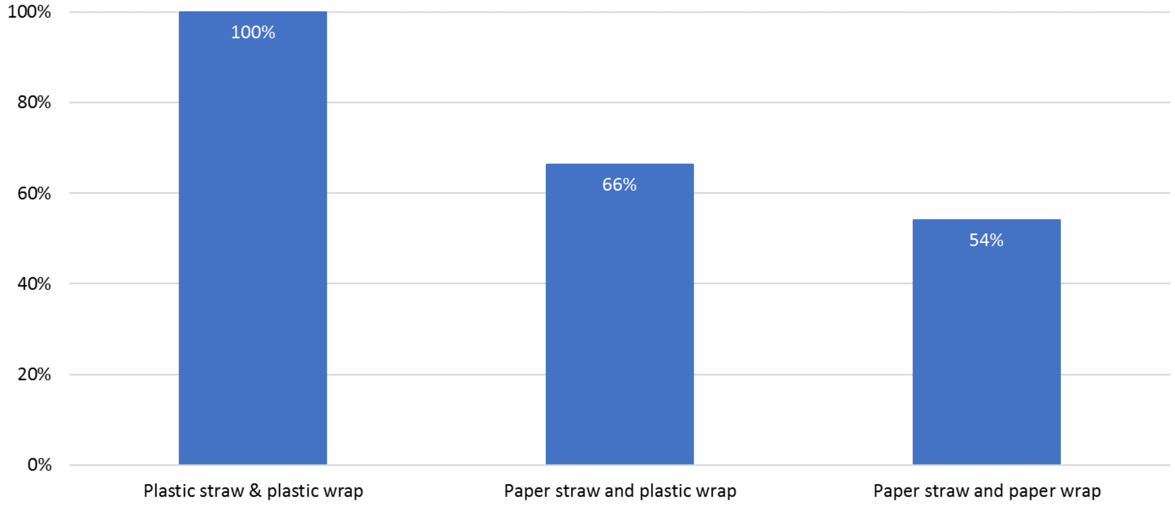

Figure 4-7: Relative climate change impacts (fossil and biogenic) for each straw and wrap combination (with plastic straw, and wrap = 100%)

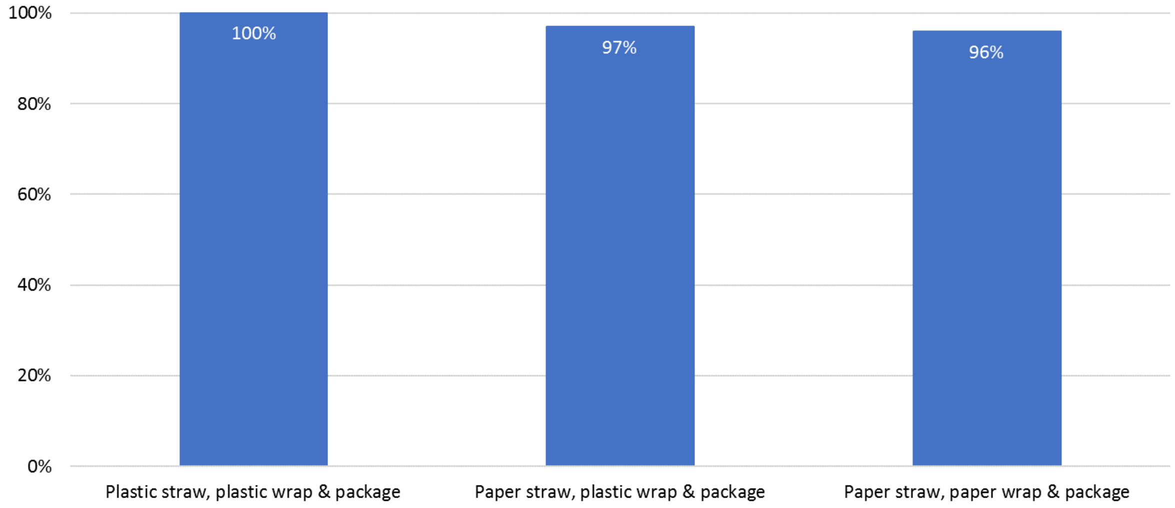

Figure 4-8: Relative climate change impacts (fossil and biogenic) for each straw and wrap combination including the packaging (with plastic straw, wrap and package = 100%)

Figure 4-9: Contribution analysis showing the proportion of fossil and biogenic climate change impacts associated with the package and with the straw and wrap for each scenario

4.2.3. Eutrophication Potential

Figure 4-10 and Figure 4-11 show the results for eutrophication potential in freshwater, Figure 4-12 and Figure 4-13 show results for marine eutrophication potential, and Figure 4-14 and Figure 4-15 show the results for eutrophication potential in terrestrial environments.

These different impact categories represent the potential burdens resulting from all emissions from the product system for each environmental compartment (freshwater, marine and terrestrial) in isolation. No attempt has been made to allocate specific fractions of the total emissions to each compartment (this would be an extremely complex undertaking, outside the scope of the study).

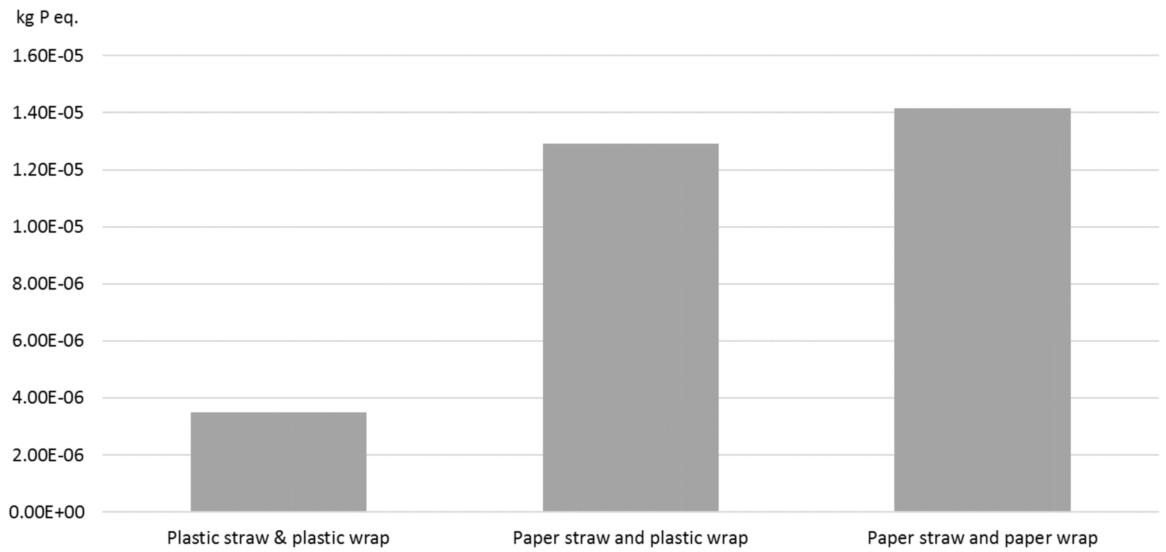

Figure 4-10: Life cycle results for eutrophication potential (freshwater)

The dominant source of freshwater eutrophication potential is phosphate emissions to water (as phosphorus is usually the limiting nutrient in freshwater bodies).

Results in Figure 4-10 and Figure 4-11 show that the paper straw scenarios have much higher impacts for freshwater eutrophication than the plastic straw scenario and this is mainly due to the production of the paper itself. The pulp production process is associated with high phosphate emissions. Eutrophication is one of the major environmental issues associated with paper making.

Recycling and recovery credits are also noticeable for paper straws while other process stages have only minor contributions. For plastic straws, the largest contributor to freshwater eutrophication is waste treatment.

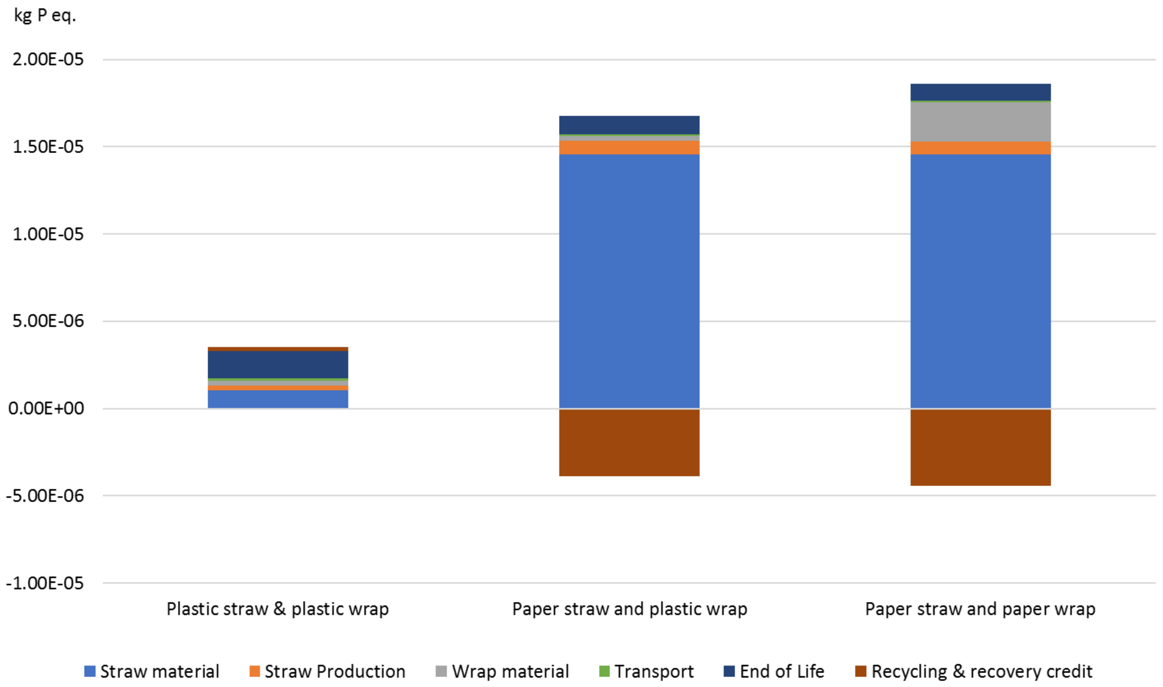

Figure 4-11: Life cycle results for eutrophication potential (freshwater) showing contribution from different life cycle stages/production processes

Figure 4-12 and Figure 4-13 show marine eutrophication potential results for the three scenarios.

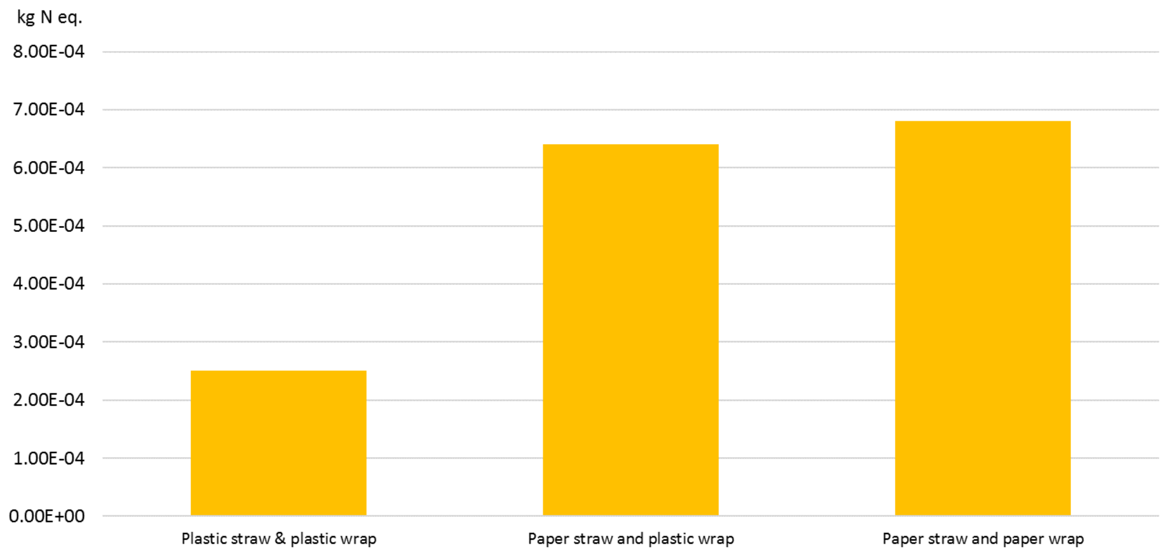

Figure 4-12: Net life cycle results for eutrophication potential (marine)

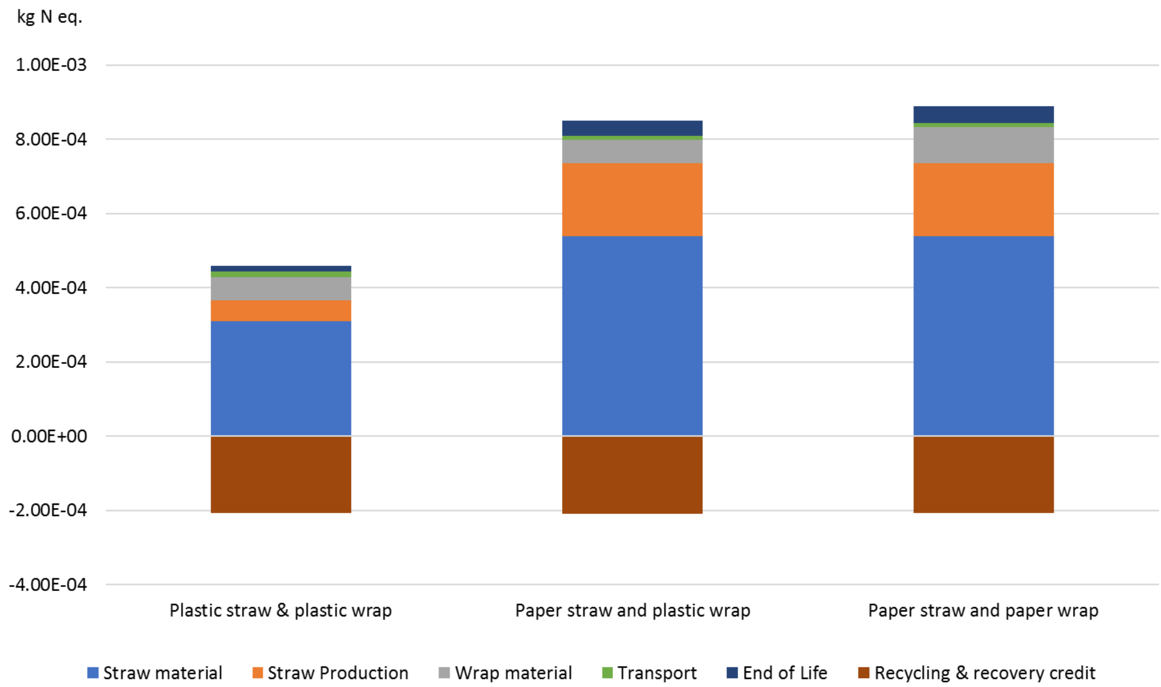

Figure 4-13: Life cycle results for eutrophication potential (marine) showing contribution from different life cycle stages/production processes

Nitrogen is usually the limiting nutrient in the marine environment. The biggest source of marine eutrophication in all scenarios is emission of nitrogen oxides (NO_x) to air. These enter the marine environment through the water cycle – getting washed out with rainfall. NO_x air emissions are mainly generated from combustion of fuels (both fossil and biomass fuels).

The charts show that the paper straw options have higher impacts in this category than the plastic straw and this is due to both the paper making process and to the straw manufacturing step, which is much more energy intensive for paper straws.

Recycling and recovery credits are also significant for all three scenarios, but other life cycle stages have only a minor contribution to marine eutrophication.

Figure 4-14 and Figure 4-15 show the results for terrestrial eutrophication potential.

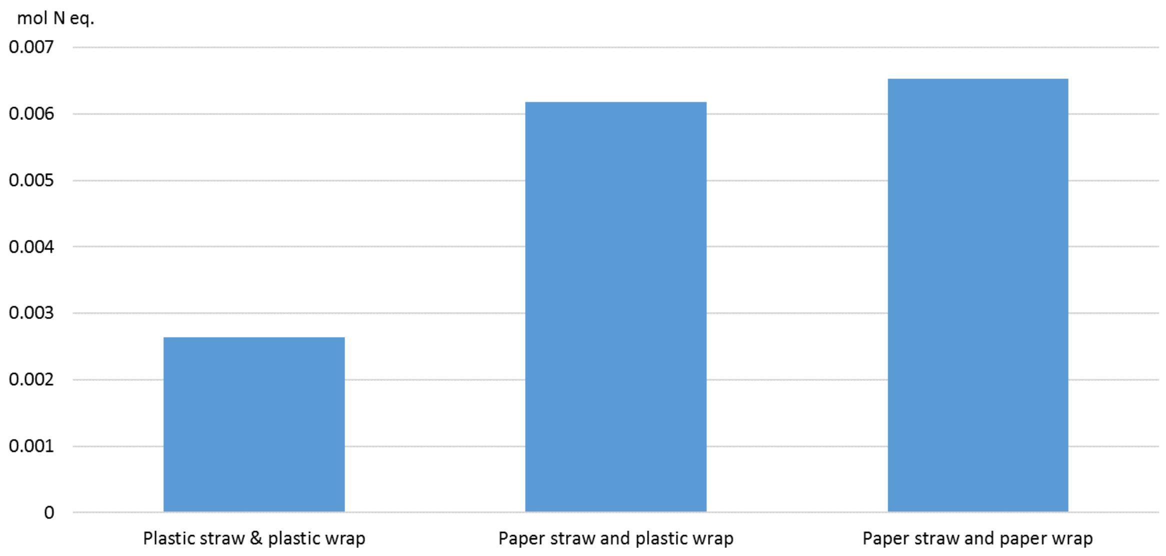

Figure 4-14: Net life cycle results for eutrophication potential (terrestrial)

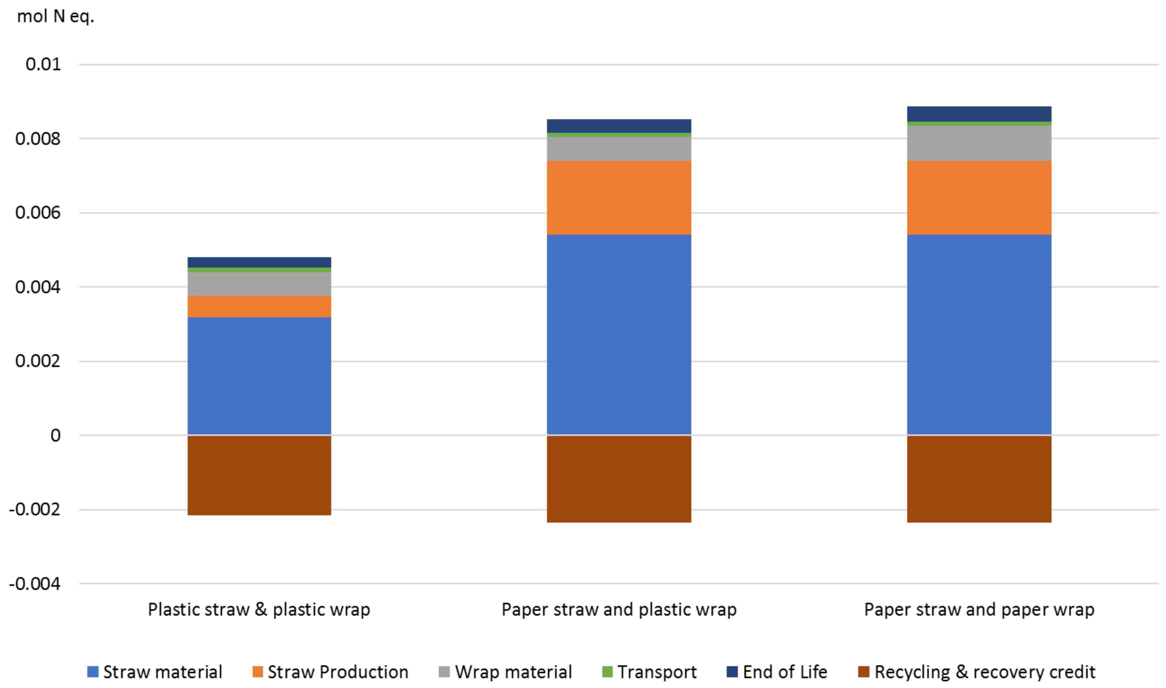

Figure 4-15: Life cycle results for eutrophication potential (terrestrial) showing contribution from different life cycle stages/production processes

Terrestrial eutrophication, like marine eutrophication, is primarily driven by NO_x air emissions so the results profiles and findings are very similar to those for marine eutrophication.

4.2.4. Photochemical Ozone Formation

Figure 4-16 and Figure 4-17 show the results for photochemical ozone formation (smog).

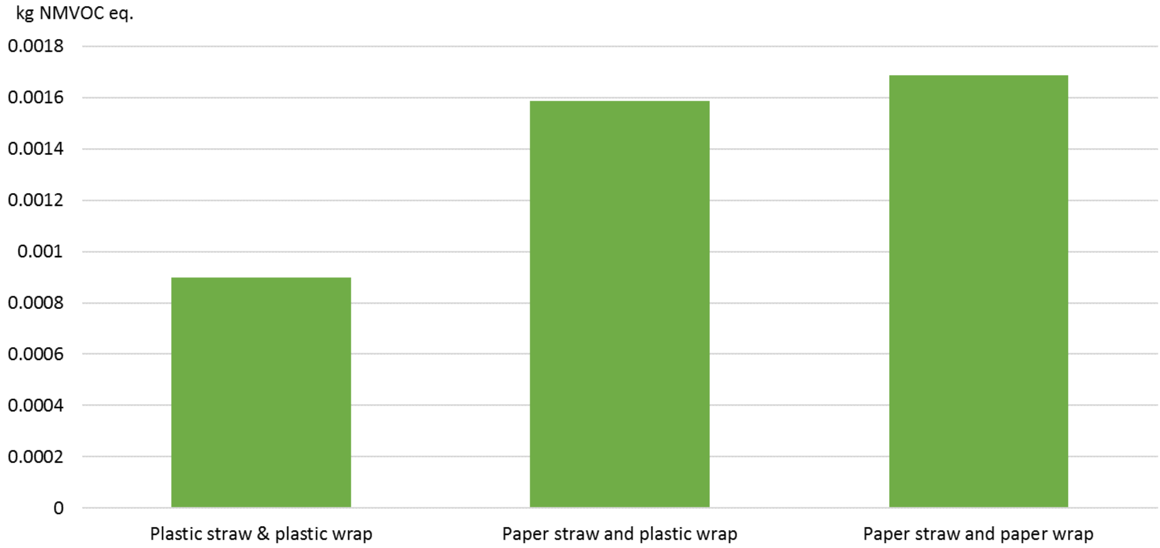

Figure 4-16: Net life cycle results for photochemical ozone formation

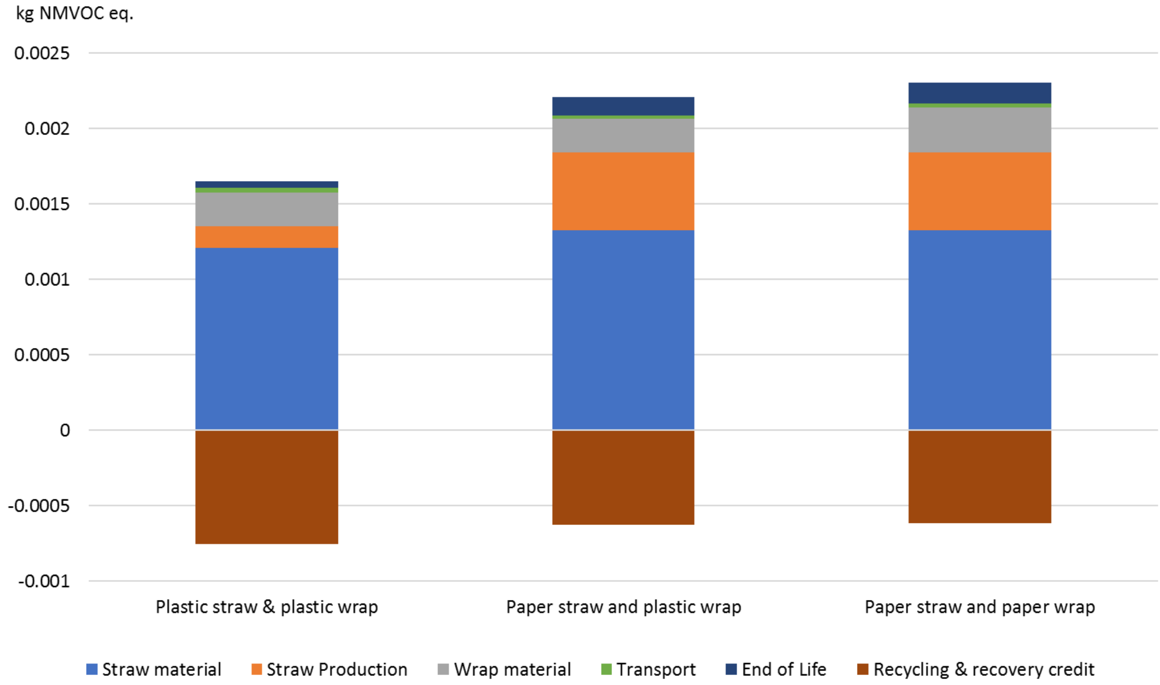

Figure 4-17: Life cycle results for photochemical ozone formation showing contribution from different life cycle stages/production processes

Photochemical ozone formation is another impact category that is dominated by emissions of nitrogen oxides to air, which arise mainly from fuel combustion. For the plastic straw scenario, there is also a large contribution from VOC emissions linked to the upstream extraction, refining and processing required for plastic production. Given these additional sources of photochemical ozone formation potential for plastics, the choice of plastic or paper as the raw material in the straw is not a large differentiator.

The main driver of differences in smog formation potential among the three scenarios is the straw production process, which is due to the higher energy demand for manufacturing paper straws compared to plastic straws.

4.2.5. Non-renewable Resource Use

Figure 4-18 shows overall results and Figure 4-19 shows the life-cycle breakdown for non-renewable resource use.

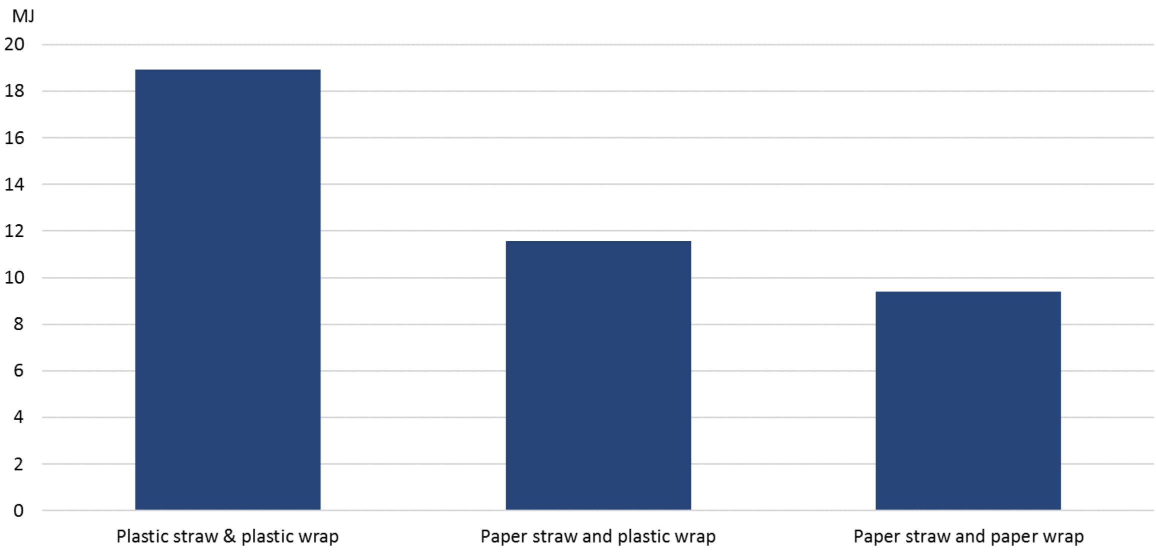

Figure 4-18: Net life cycle results for non-renewable resource use per primary pack

This impact category assesses the consumption of non-renewable fuels (fossil and nuclear fuels), so it is not surprising to see big reductions in moving from plastic to paper straws.

Paper production uses only small amounts of non-renewable fuels as integrated pulp and paper mills are predominantly fuelled by biomass (bark, chips and offcuts from forestry as well as black liquor generated as part of the pulping process). Plastic production, in contrast, is heavily dependent upon fossil fuels. These are used to fuel the manufacturing process but also constitute the feedstock of the plastic itself.

The plastic straws receive large recycling and recovery credits at end of life, but these are not sufficient to offset higher fossil fuel use during manufacturing and embodied within the product, as shown in Figure 4-19.

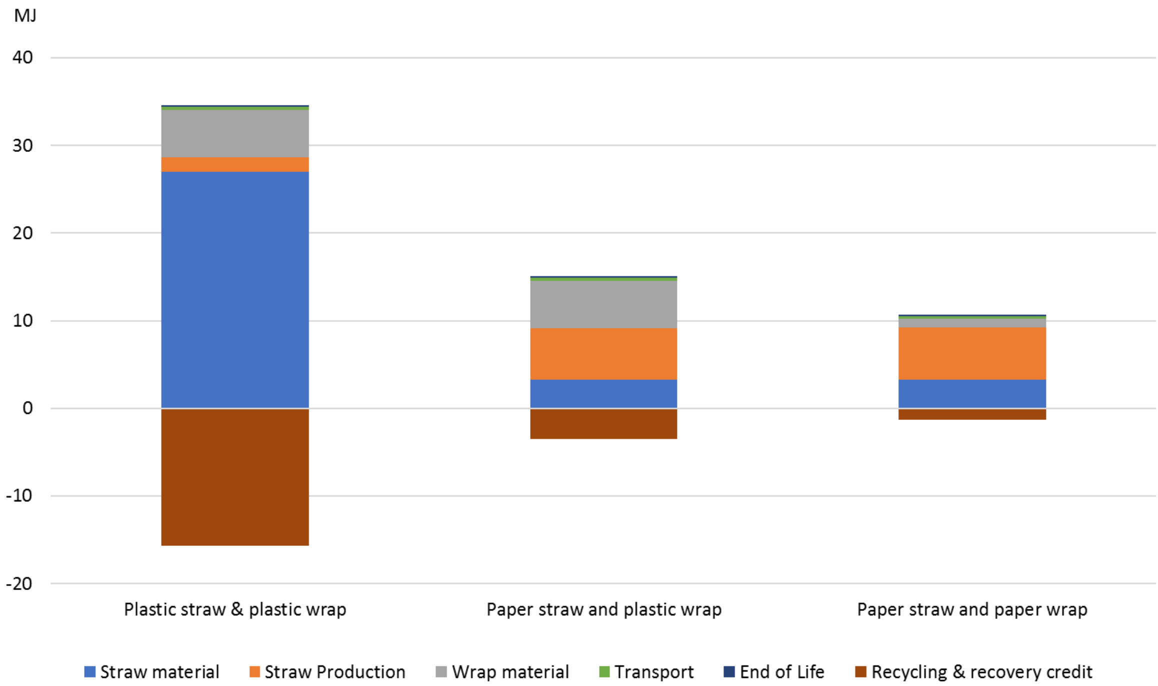

Figure 4-19: Life cycle results for non-renewable resource use showing contribution from different life cycle stages/production processes

4.2.6. Water Scarcity

Figure 4-20 shows overall results and Figure 4-21 shows the contribution breakdown for water scarcity.

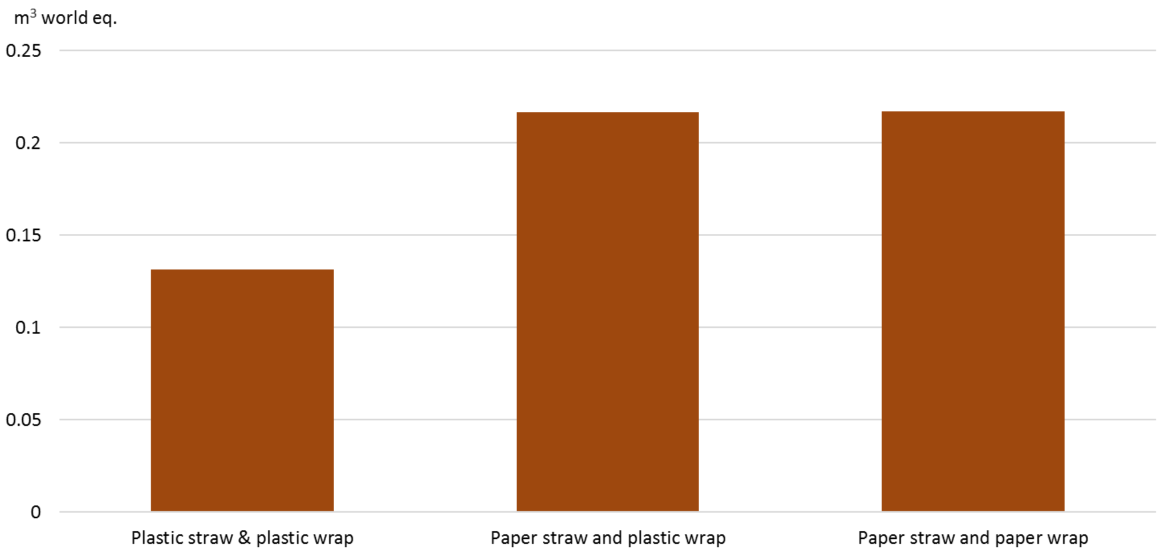

Figure 4-20: Net life cycle results for water scarcity

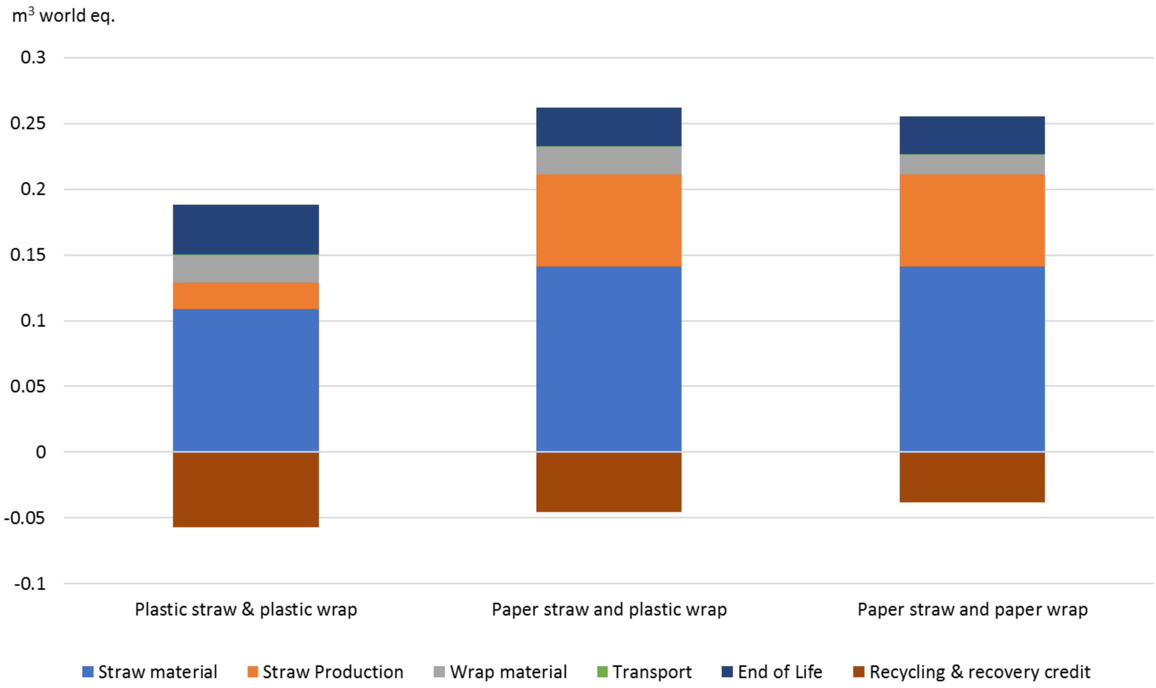

Figure 4-21: Life cycle results for water scarcity showing contribution from different life cycle stages/production processes

Water scarcity accounts for the availability of water remaining for use by other stakeholders within the region relevant to the product system. Regions where water availability is more limited will have a higher characterisation factor for water consumption, and will report a higher score per litre of water consumed than regions where water is more plentiful.

The results show that the paper straw scenarios result in significantly higher water scarcity than the plastic straw scenario. This is partially due to the production of raw materials (paper or plastic) but mainly a result of the much higher energy consumption associated with straw manufacture. Water is consumed in energy generation as combustion power stations have cooling towers where considerable quantities of water are evaporated and lost from the local watershed.

It should be noted that, at present, water scarcity is not a very robust metric – it is graded as III (the lowest rank) in the Product Environmental Footprint guidance (European Commission, 2017). This is for several reasons including:

- Background data may not include reliable information on water. As water scarcity is a relatively new area of concern, older datasets often do not include robust data on water inputs and outputs. This is the case for the ACE dataset on beverage board converting, which did not include an output flow of water (this was assumed to equal the input to close the mass balance, but some portion of this water is likely to be lost to evaporation).
- It is region-specific, water consumption in arid areas has a bigger impact than that in tropical regions. However, background datasets for LCA modelling are not fully regionalised. GaBi datasets have regionalised information on water for most energy datasets (e.g. grid mixes) but not for general processes (if country-specific versions of every dataset were provided, the database would become unworkably large).
- The methodology itself is relatively new and untested. The accuracy of background data relating to water availability within a given region should be checked and verified through application over the coming years.

- Regionalisation is generally carried out at the country level. However, watersheds do not map exactly to national boundaries and large countries can have a wide diversity of biomes/climates, each with very different levels of water availability.

These uncertainties should be borne in mind when interpreting the results for water scarcity. The differences in impact between plastic and paper raw materials may not be robust. However, the differences due to energy consumption for straw manufacturing are more meaningful as these relate to the same background dataset in all scenarios (the EU grid mix).

4.3. Normalised Results

Normalisation is the process of comparing LCA results against an external reference to help judge the significance of different impact categories. This can help the reader to compare across impact categories and prioritise those that have the largest relative impacts.

The normalisation reference used in this study is the impact caused by an average global citizen over a year. This is calculated as the global impact in each category over a year, divided by the global population (as shown in Table 4-2). The base year for the assessment is 2010 and these data are as provided by the European Commission for the Product Environmental Footprint initiative (European Commission, 2017).

The normalised results are obtained by dividing the burdens associated with the assessed packaging elements (straw, wrapping and portion-sized pack) by the reference values. This gives an indication of the magnitude of each impact category relative to that of the total global impact scaled per person.

Table 4-2: Reference values used for normalisation (European Commission, 2017)

Packaging element	Unit	Annual impact per person
Acidification potential	Mole of H^+ eq.	55.5
Climate change	kg CO_2 eq.	7,760
Eutrophication potential (freshwater)	kg P eq.	2.55
Eutrophication potential (marine)	kg N eq.	28.3
Eutrophication potential (terrestrial)	Mole of N eq.	177
Photochemical ozone formation	kg NMVOC eq.	40.6
Non-renewable resource use	MJ	65,300
Water scarcity	m^3 world equiv.	11,500

The normalised results presented Table 4-3,

Figure 4-22 and

Figure 4-23 indicate that resource use is the most significant environmental issue, followed by climate change. The normalised results for acidification, photochemical ozone formation and marine and terrestrial eutrophication and water scarcity all have a similar order of magnitude but are considerably less relevant than resource use or climate change. Freshwater eutrophication is the least significant impact category by a considerable margin.

Table 4-3: Normalised results for the different straw and wrap scenarios and for the portion-sized pack

Impact category	Plastic straw & plastic wrap	Paper straw and plastic wrap	Paper straw and paper wrap	Portion-sized pack
Acidification	1.81E-05	4.04E-05	4.18E-05	8.32E-04
Climate change	1.25E-04	8.32E-05	6.79E-05	1.27E-03
Eutrophication (freshwater)	1.37E-06	5.06E-06	5.56E-06	7.67E-05
Eutrophication (marine)	8.88E-06	2.26E-05	2.41E-05	4.05E-04
Eutrophication (terrestrial)	1.49E-05	3.49E-05	3.69E-05	6.51E-04
Photochemical ozone formation	2.22E-05	3.91E-05	4.16E-05	7.79E-04
Non-renewable resource use	2.90E-04	1.77E-04	1.44E-04	2.58E-03
Water scarcity	1.14E-05	1.88E-05	1.89E-05	3.60E-04

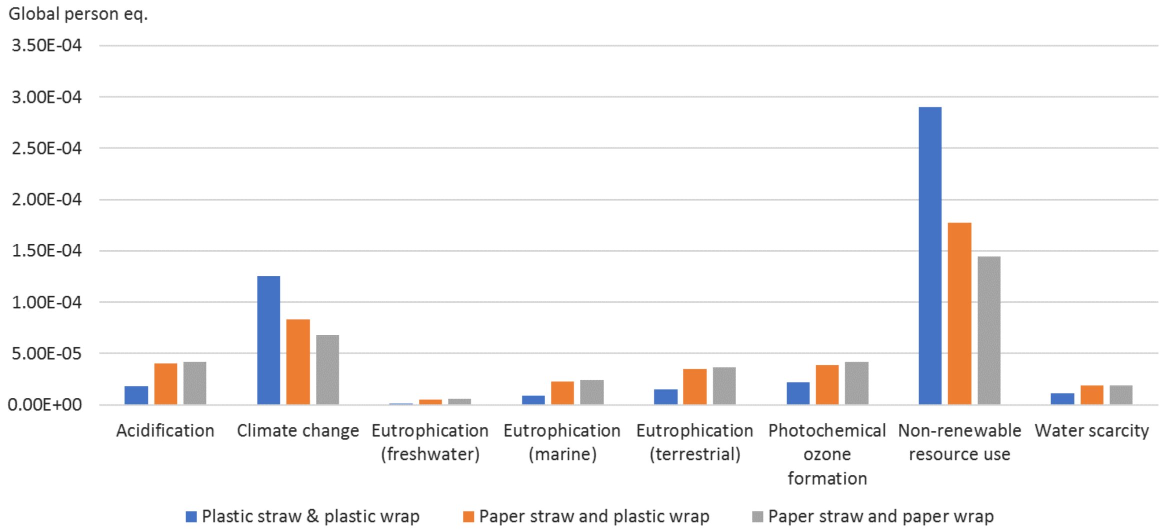

Figure 4-22: Normalised results for the straw and wrap scenarios

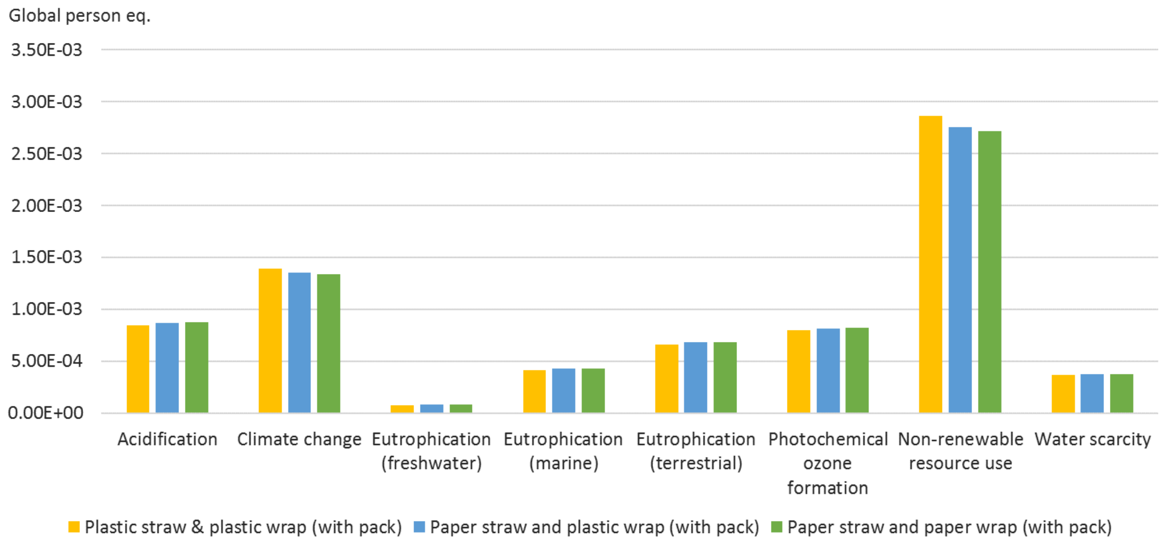

Figure 4-23: Normalised results for the straw and wrap scenarios including the portion-sized pack

4.4. Sensitivity Analysis

A sensitivity analysis has been conducted to examine the influence of the choice of recycling methodology on the results of the study. The substitution approach has been used for the results presented previously. As noted in section 2.4.2, we believe that this is the most appropriate methodology for the materials used in the assessed products. However, it is also important to evaluate the sensitivity of the results on this choice and understand whether different conclusions would be drawn if alternative methodologies, such as the "cut-off" approach, were applied. The results of the main assessment have been re-run using the cut-off allocation methodology and the results for both approaches are presented numerically and as a heatmap in

Table 4-4.

These results show that the absolute values reported using each methodology can vary significantly. However, more striking is the observation that the rank ordering of the results is almost entirely unaffected by the choice of recycling methodology. The result for water scarcity is the only one that differs when changing methodology from substitution to cut off approach.

Figure 4-24 shows how the results for climate change vary depending upon the choice of allocation methodology. For the plastic and paper straw the cut-off approach gives higher burdens than the substitution approach because only virgin raw materials are used (no recycled content) and because, in the substitution approach, credits are received for energy recovery and material recycling at end of life.

Table 4-4: Heatmap showing scenario results using the substitution and cut-off allocation methods (green = lowest impact, red = highest impact)

Environmental Indicator	Substitution			Cut-off		
	Plastic straw & plastic wrap	Paper straw & plastic wrap	Paper straw & paper wrap	Plastic straw & plastic wrap	Paper straw & plastic wrap	Paper straw & paper wrap
Acidification	1.00E-03	2.24E-03	2.32E-03	1.84E-03	3.09E-03	3.14E-03
Climate change	0.973	0.646	0.527	1.38	0.827	0.668
Eutrophication freshwater	3.51E-06	1.29E-05	1.42E-05	3.30E-06	1.68E-05	1.86E-05
Eutrophication marine	2.51E-04	6.40E-04	6.81E-04	4.59E-04	8.50E-04	8.88E-04
Eutrophication terrestrial	2.63E-03	6.18E-03	6.53E-03	4.80E-03	8.53E-03	8.87E-03
Photochemical ozone formation	8.99E-04	1.59E-03	1.69E-03	1.65E-03	2.21E-03	2.30E-03
Non-renewable resource use	18.9	11.6	9.42	34.6	15.1	10.7
Water scarcity	0.131	0.217	0.217	0.189	0.262	0.255

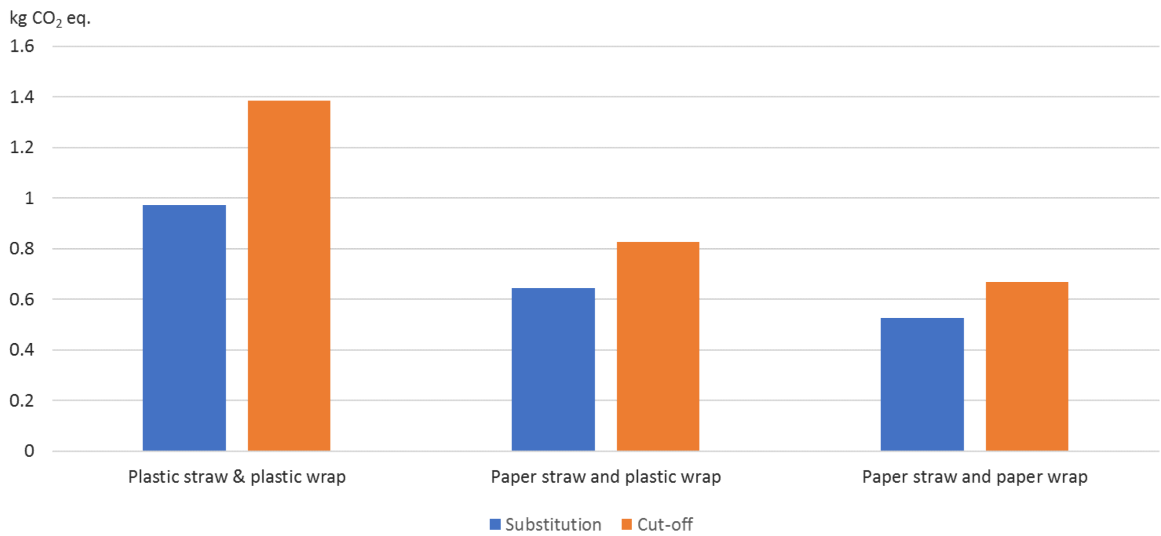

Figure 4-24: Comparison of climate change results for substitution and cut-off approaches

For the paper straw scenarios, the cut off approach also shows higher climate change impacts. Because the carbon content of paper is an inherent physical property of the material it must be handed over with the scrap paper to the next life cycle. To avoid double counting of sequestered carbon and ensure a closed carbon balance, a “virtual” emission of this carbon content must be included in the current life cycle[7]. Therefore, the cut-off approach shows a burden from recycling. that is very similar to that given under the substitution approach. The substitution methodology gives lower overall burdens because it also counts the credits received for energy recovery from incineration and from landfill gas combustion.

[7] This follows the guidance set out in EN 16485 on wood and wood-based products in environmental product declarations (CEN, 2014). This standard is specifically focused on construction materials, but we believe the principles outlined are relevant for all products made from biomass sources.

5. Interpretation

5.1. Identification of Relevant Findings

Key findings from this study are that:

- For most impact categories, raw material production accounts for the largest impacts for both plastic and paper straws. As expected, based on their relative masses, most raw material burdens are due to the straw with a much lower contribution from the wrap.
- Straw manufacturing also has a significant contribution to many impact categories. This is especially noticeable for paper straws due to a much lower production efficiency compared to plastic straws (requiring over 3.5 times as much energy to manufacture).
- Credits received from energy recovery and material recycling at end of life also often have a significant contribution to the total burden in a category.
- Impacts associated with waste treatment operations (the processes themselves, rather than credits from recovery) are generally not significant, with the exception of climate change.
- Impacts associated with transport are negligible in all categories.
- Compared to the burdens associated with manufacturing the portion-sized carton packages, the impacts of the straw and wrap are very low (between 2-11%). Again, this is expected given the large difference in mass.
- As the proportion of paper in the straw and wrap increases, the burdens associated with climate change and use of non-renewable energy resources decrease. This is due to carbon uptake within biomass during plant growth (that become part of the paper product), and the use of biomass energy in paper production.
- Conversely, the choice of paper in the straw and wrap increases the burdens associated with acidification, eutrophication (freshwater, marine, and terrestrial), photochemical oxidant formation, and water scarcity. To some extent, this is due to higher burdens from raw material production (e.g. phosphate water emissions and water consumption from pulping and paper making processes) but the main difference is often due to higher fuel combustion in the straw production process, leading to higher NO_x and SO_2 air emissions.
- When the results of the assessment are normalised against a reference of annual global emissions per person, the use of non-renewable energy resources is the most relevant category, followed by climate change. The other impact categories assessed in this study are less relevant in comparison.

5.2. Assumptions and Limitations

Much of the data used in this study has been obtained from secondary sources, and some of this is also relatively old (e.g. ACE datasets for LPB and beverage carton converting dating from 2009). As such, the results will not reflect any changes in manufacturing processes that may have occurred since these datasets were published. Moreover, the reliability and robustness of ACE datasets with respect to water use is considered to be poor as reporting of water flows was found to be incomplete. When correcting this, an assumption was made that there were no water losses associated with the ACE production processes.

In addition to these issues, the results for water scarcity should be regarded as less robust than for other impact categories due to uncertainties in the methodology and to limitations in the background datasets. These are described in more detail in section 4.2.6.

This study does not assess the impacts related to unintended releases (littering) of the straws or packaging, or potential effects of littered materials on the marine environment. At this point, although there is some indication of potential effects of microplastics on human and ecological health, the methodologies required to assess these effects within the context of LCA are still in the early stages of development.

5.3. Results of Scenario & Sensitivity Analysis

5.3.1. Scenario Analysis

The results of the scenario analysis focusing on end of life treatment options are discussed in Annex C.

5.3.2. Sensitivity Analysis

A sensitivity analysis was conducted to examine the influence on the results of the choice of methodology in modelling recycling (i.e., end-of-life allocation methodology, further described in section 2.4.2). The results for the waste treatment scenario analysis obtained using the substitution approach (Table C-1) were compared to those obtained using the alternative cut-off approach (

Table 4-4).

The main differences in findings relate to the choice of preferred waste treatment option within each product system, rather than to the performance of the plastic straw vs. paper alternatives. For paper straws with paper wrap, the preferred option to minimise climate change is energy recovery for the substitution approach, but using the cut-off approach, the preferred option is landfill (although this is based on the standard 100 year time horizon, emissions that occur after this point are neglected from the assessment). While findings concerning the best end-of-life treatment changed based on modelling methodology, the relative performance among the three straw and wrap options generally shows a similar pattern regardless of methodology. For the highest relevance impact categories (climate change and non-renewable energy consumption), the paper straw and paper wrap scenario is preferred over alternatives, whether using the substitution or cut-off approach.

Although there are differences between the results obtained for each method, they tend to trend in the same direction. For the average end of life mix used for the baseline results in this study, the ranking of the different straw and wrapping options in the climate change category would be unchanged. As such, although the absolute results may vary depending upon the choice of allocation methodology, the overall conclusions are unaffected.

5.4. Data Quality Assessment

Inventory data quality is judged by its precision (measured, calculated or estimated), completeness (e.g., unreported emissions), consistency (degree of uniformity of the methodology applied) and representativeness (geographical, temporal, and technological).

To cover these requirements and to ensure reliable results, first-hand industry data in combination with consistent background LCA information from the GaBi 2018 database were used. The LCI datasets from the GaBi 2018 database are widely distributed and used with the GaBi 6 Software. The datasets have been used in LCA models worldwide in industrial and scientific applications in internal as well as in many critically reviewed and published studies. In the process of providing these datasets they are cross-checked with other databases and values from industry and science.

5.4.1. Precision and Completeness

- ✓ **Precision:** The majority of the relevant foreground data are measured data or calculated based on primary information sources of the owner of the technology. Data for straw manufacturing was sourced from a single month in 2017 (March) and so may not be representative of average annual performance. However, the same months data has been applied to all assessed scenarios so the influence of any uncertainty with regards to the conclusions of this study are considered to be negligible. Accordingly, the precision of this study is considered to be high. Most background data are sourced from GaBi databases with the documented precision. Other datasets were sourced from ACE and EAA with the precision reported in their respective documentation.
- ✓ **Completeness:** Each foreground process was checked for mass balance and completeness of the emission inventory. No data were knowingly omitted. Completeness of foreground unit process data is considered to be high. Most background data are sourced from GaBi databases with the documented completeness. ACE datasets for LPB and carton converting were missing some data on water flows, these were corrected using estimates.

5.4.2. Consistency and Reproducibility

- ✓ **Consistency:** To ensure data consistency, all primary data were collected with the same level of detail, while most background data were sourced from the GaBi databases.
- ✓ **Reproducibility:** Reproducibility is supported as much as possible through the disclosure of input-output data, dataset choices, and modelling approaches in this report. Based on this information, any third party should be able to approximate the results of this study using the same data and modelling approaches.

5.4.3. Representativeness

- ✓ **Temporal:** Primary data for straw manufacturing (both plastic and paper straws) was collected for a single month in 2018 (March). All other primary data were collected for the year 2017. Most secondary data come from the GaBi 2018 databases and are representative of the years 2014-2017. Other datasets come from ACE (2009), EAA (2010) and FEFCO (2015). As the study intended to compare the product systems for the reference year 2017, temporal representativeness is considered to be moderate, primarily due to the age of the ACE datasets that are important for modelling the paper straw and portion-sized carton.
- ✓ **Geographical:** All primary and secondary data were collected specific to the regions under study, and nearly all background data is representative of the European average. Where

European average data were not available, globally representative datasets were used in some instances (e.g. transport). In other cases, German-specific datasets were used. Geographical representativeness is considered to be high[8].

- ✓ **Technological:** All primary and secondary data were modelled to be specific to the technologies or technology mixes under study. Where technology-specific data were unavailable, proxy data were used. Technological representativeness is considered to be high.

5.5. Model Completeness and Consistency

5.5.1. Completeness

All relevant process steps for each product system were considered and modelled to represent each specific situation. The process chain is considered sufficiently complete and detailed with regards to the goal and scope of this study.

5.5.2. Consistency

All assumptions, methods and data are consistent with each other and with the study's goal and scope. Differences in background data quality were minimised by predominantly using LCI data from the GaBi 2018 databases, and by investigating and addressing deficiencies in background data from other sources. System boundaries, allocation rules, and impact assessment methods have been applied consistently throughout the study.

5.6. Conclusions, Limitations, and Recommendations

5.6.1. Conclusions and Recommendations

This study has assessed three alternative material combinations for straws and wrappings, ranging from a completely polymer option (plastic straw and wrap), through to an intermediate option (paper straw and plastic wrap) and then on to a completely paper option (paper straw and wrap). The impact categories assessed in this study can be split into two groups – those that show an increase in burden as the proportion of paper increases, and those that show a decrease in burden. These are summarised in Table 5-1.

[8] This study was focused on the European average situation. For information, Tetra Pak is currently planning for straw production to take place in Portugal.

Table 5-1: Table showing how burdens trend with increasing paper content in the straw and wrap.

Burdens increase	Burdens decrease
Acidification	Climate change
Eutrophication (freshwater, marine, terrestrial)	Non-renewable resource use
Photochemical ozone formation	
Water scarcity[9]	

The impact categories where burdens are seen to *increase* with increasing paper content are generally those that have dominant contributions from specific polluting emissions (particularly NO_x but also SO_2) or resource demands (e.g. water consumed in energy generation). These are most strongly associated with energy consumption required for manufacturing the straws and, to a lesser extent, the raw materials needed (paper and polymer production). As paper straws are produced less efficiently than plastic straws, with 3.5 times the energy demand, this results in higher burdens for the paper option.

It seems likely that manufacturing impacts associated with paper straws will be reduced over time as the process is optimised. If production impacts were the same for both paper and plastic straws the difference between their performance in these categories would be greatly reduced (but would not become equivalent as production of the paper raw material itself has higher burdens than production of plastic for these impact categories).

Those impact categories where burdens *decrease* with increasing paper content are both strongly correlated with use of fossil fuels. Polymer production uses a lot of fossil fuels both for process energy during manufacture, and as feedstock within the finished product. In contrast, paper production uses much less fossil fuel as most of its energy requirements are sourced from biomass (woodchips, bark and black liquor) derived from the forestry operations and paper pulping process itself.

On this basis alone, it is difficult to make recommendations about which material is preferable to use for straws and wrapping. There are trade-offs associated with each choice. Normalisation is an approach that can help decision-making in these circumstances and involves comparing LCA results against an external reference. Impacts across different categories can then be compared and their relative significance (compared to the reference) can be evaluated.

When using a normalisation reference based on the impact caused by an average global citizen over a year, the most significant impact categories were found to be non-renewable resource use followed by climate change, both of which decrease as paper content increases. The relevance of the other impact categories was much lower in comparison.

Given that climate change is generally regarded as the most challenging environmental issue of our time, this finding supports the conclusion that paper straws and wrapping should be recommended over plastic straws and wrapping from an environmental perspective.

[9] The results for water scarcity are less robust than for other impact categories due to uncertainties in the methodology and to limitations in the background datasets. These issues are described in more detail in section 4.2.6.

It is also important to consider the context in which this study has been carried out. The issue of marine litter is currently extremely prominent and of very great interest to both environmental specialists and the general public, and has been a key driver for Tetra Pak to develop paper alternatives to plastic straws. This study does not address marine litter as no LCA metrics have yet been developed for this issue, and our current understanding of how much, and by what pathways, littered material ends up in our oceans is still rudimentary. Nevertheless, it is clear that, due to being readily biodegradable, paper will inevitably have a much lower contribution to the marine litter problem than non-biodegradable plastics. In addition, once degraded into micro- and nano-particles, plastic materials are persistent in the environment, can bioaccumulate, and may have further toxicological effects; this is not an issue for paper.

5.6.2. Limitations

This study focuses on the geographic region of Europe and is based on European grid mixes, energy sources and transport distances and modes and waste treatment mixes. It may not be valid to extrapolate the results from this study to regions outside Europe or to specific countries within Europe that have substantially different grid mixes, etc.

This study also does not address all environmental issues associated with plastic and paper straws. In particular, it does not include an assessment of littering or marine pollution, both of which are currently topics of very high interest and certainly relevant to any general discussion regarding the sustainability performance of these products.

References

Alliance for Beverage Cartons and the Environment. (2009). *LCI dataset for Liquid Packaging Board Production.* ACE.

Alliance for Beverage Cartons and the Environment. (2011). *LCI dataset for converting of beverage carton packaging material.* ACE. Retrieved from http://www.ace.be/uploads/Modules/Publications/lci-dataset-for-bc-converting.pdf

Alliance for Beverage Cartons and the Environment. (2019). *Recycling Performance*. Retrieved from ACE Website: http://www.ace.be/ace-priorities/recycling-2/recycling-performance

Boulay, A.-M. J. (2017). The WULCA consensus characterization model for water scarcity footprints: assessing impacts of water consumption based on available water remaining (AWARE). *The International Journal of Life Cycle Assessment*.

CEN. (2014). *EN16485 - Round and sawn timber - Environmental Product Declarations - Product category rules for wood and wood-based products for use in construction.* Brussels: European Committee for Standardization.

European Commission. (2017). *Product Environmental Footprint Category Rules Guidance (Version 6.3, December 2017).* Brussels: European Commission.

Eurostat. (2019). *Municipal waste by waste management operations*. Retrieved from Eurostat: https://ec.europa.eu/eurostat/data/database

IPCC. (2013). *Climate Change 2013: The Physical Science Basis.* Geneva, Switzerland: IPCC.

ISO. (2006). *ISO 14040: Environmental management – Life cycle assessment – Principles and framework.* Geneva: International Organization for Standardization.

ISO. (2006). *ISO 14044: Environmental management – Life cycle assessment – Requirements and guidelines.* Geneva: International Organization for Standardization.

JRC. (2010). *ILCD Handbook: General guide for Life Cycle Assessment – Detailed guidance. EUR 24708 EN* (1st ed.). Luxembourg: Joint Research Centre.

Posch, M. S. (2008). The role of atmospheric dispersion models and ecosystem sensitivity in the determination of characterisation factors for acidifying and eutrophying emissions in LCIA. *International Journal of Life Cycle Assessment, 13*, 477-486.

Seppälä J., P. M. (2006). Country-dependent Characterisation Factors for Acidification and Terrestrial Eutrophication Based on Accumulated Exceedance as an Impact Category Indicato. *International Journal of Life Cycle Assessment, 11*(6), 403-416.

Struijs, J. B. (2009). *Aquatic Eutrophication. Chapter 6 in: ReCiPe 2008 A life cycle impact assessment method which comprises harmonised category indicators at the midpoint and the endpoint level. Report I: Characterisation factors, first edition. .*

thinkstep. (2018). *GaBi LCA Database Documentation*. Retrieved from thinkstep AG: http://www.gabi-software.com/international/databases/gabi-databases/

van Oers, L., de Koning, A., Guinée, J. B., & Huppes, G. (2002). *Abiotic resource depletion in LCA.* The Hague: Ministry of Transport, Public Works and Water Management.

Van Zelm R., H. M. (441-453). European characterisation factors for human health. *Atmospheric Environment, 42*.

Annex A: Critical Review Statement

Date
Gothenburg, 7 October 2019
Our reference.
Håkan Stripple

Your date

Your reference
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Tetra Pak Packaging Solutions AB
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Review of the study: LCA of plastic & paper straws for portion-sized carton packages

LCA study for review and verification
LCA of plastic & paper straws for portion-sized carton packages. Version 1.3.

Author(s)
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Study commissioned by:
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Date of the study:
3 October 2019

Verifier
Håkan Stripple, IVL Swedish Environmental Research Institute Ltd. is the verifier. Håkan Stripple is an independent individual verifier in the International EPD system[i].

Background and Scope
Tetra Pak is one of the world's largest manufacturers of beverage packaging systems, and especially packagings based on liquid packaging board (LPB). Tetra Pak also has high ambitions regarding the environmental performance of their products. Today, there is an extensive discussion about plastics as packaging material, especially regarding the debris of the oceans and other watercourses. Plastics are persistent materials that slowly decompose in the recipient and where it can form particles of microplastics that are now suspected to have an effect on the ecosystem in lakes and seas. As part of this work, the EU is therefore planning restrictions on the use of certain single use plastic products. Disposable straws are one such product that may be subject to restrictions. This has initiated

[i] http://www.environdec.com/sv/Creating-EPDs/List-of-verifiers/

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a work at Tetra Pak to investigate alternative materials to plastic for straws. Within the framework of this work, Tetra Pak wants to investigate and compare the environmental performance of plastic straws with alternative materials mainly based on paperboard. The present LCA study is part of this work.

The task of the verifier was to review the LCA report "LCA of plastic & paper straws for portion-sized carton packages", the LCA models, the LCA background information, underlying data, and general calculations. The verification is performed in order to check and verify the calculations and validity of the system boundaries chosen and model defined, as well as consistency with the steering documents, which mainly are; ISO14040:2006 and ISO 14044:2006.

Review process

Thinkstep in United Kingdom has developed this study according to their standardised procedures and with their updated databases covering the new straw products and its production with process data from Tetra Pak's production. The review is based on the written materials from the study (LCA report) and sample checks of other processes and materials. Thus, not all data and calculations are checked. The review statement and conclusions are given with regard to the current state of art and the information, which has been received from Thinkstep or Tetra Pak. The comments and corrections are documented direct in the documents. The information in the review process is thus traceable throughout the entire review process.

The report "LCA of plastic & paper straws for portion-sized carton packages." was reviewed as well as strategically selected parts of underlying materials and methodology. The documentation was sent to the verifier for review by e-mail. After reading and comments, the different remarks were discussed and commented by Thinkstep or Tetra Pak. A virtual review meeting was held 2 October 2019 where all remarks were discussed and underlaying data were reviewed.

The report explains the goal and scope, methodologies, and main assumptions. After discussions and request in the review process, including product specifications, the functional unit of the study, water resource use and water scarcity, impact categories such as biogenic CO_2, eutrophication and non-renewable energy resource use, littering of plastics and its calculation possibilities, system boundaries and included processes, classification of data set robustness, plastic and paper separation in waste handling, data for electricity, climate change calculations, end-of-life calculations, 100 years perspective for landfill calculations, degradation rates for paper and plastics in landfills, satisfactory changes were made. The reviewer has checked the entire product chain including upstream data, core processes, and downstream data. The reviewer has checked the product specifications, the GaBi product systems, the data gaps and cut offs, the methodology applied, the data used, and assumptions made for the products, electricity production, and end-of-life treatment. The procedure for calculations and the selection of studied product has also been checked. The review process also includes minor editorial changes.

The study thus includes the ordinary impact categories for an LCA study to assess the environmental performance and primary resource use. However, in the absence of reliable scientific methods to assess the effects of plastic and microplastic debris in the recipient, the study has not considered these effects.

All remarks were accounted for in a satisfactory manner in the revised versions of the LCA model and the LCA report.

Statement

The verification covers the LCA study and report "LCA of plastic & paper straws for portion-sized carton packages". The undersigned verifier to the International EPD System verifies that the attached LCA study is in consistency with the steering documents identified under the above-mentioned scope of this review and has relevant data sources. Also, the sample check of methodology and calculation are reasonable and acceptable.

IVL Swedish Environmental Research Institute Ltd.

/Håkan Stripple/

M.Sc.Chem.Eng. / LCA specialist

Annex C: Scenario Analysis

A scenario analysis has been conducted to evaluate the influence on the results of the choice of waste treatment option.

For each straw and wrap option, the results for three extreme scenarios have been assessed – for 100% landfill[12], 100% energy recovery and 100% recycling. This analysis will allow Tetra Pak to evaluate the environmental performance of packaging disposal for any mix of waste treatment options.

Results for each waste treatment scenario are presented numerically and as a heatmap in Table C-1. Each impact category is considered in isolation with the dark green cells indicating the lowest burdens and the red cells the highest burdens in each category.

Table C-1: Heatmap showing the results using the substitution allocation method (green = lowest impact, red = highest impact)

Environmental Indicator	Plastic straw & plastic wrap			Paper straw and plastic wrap			Paper straw and paper wrap		
	LF	ER	Rec	LF	ER	Rec	LF	ER	Rec
Acidification	1.88E-03	5.17E-04	8.47E-04	3.10E-03	2.54E-03	1.65E-03	3.15E-03	2.72E-03	1.68E-03
Climate change	0.994	1.67	0.553	0.620	0.641	0.631	0.484	0.393	0.579
Eutrophication freshwater	8.23E-06	7.58E-07	2.74E-06	2.01E-05	1.53E-05	7.97E-06	2.16E-05	1.73E-05	8.68E-06
Eutrophication marine	4.71E-04	1.36E-04	2.09E-04	8.88E-04	7.18E-04	4.72E-04	9.31E-04	7.90E-04	4.95E-04
Eutrophication terrestrial	4.82E-03	1.70E-03	2.09E-03	8.61E-03	7.38E-03	4.27E-03	8.95E-03	8.05E-03	4.44E-03
Photochemical ozone formation	1.69E-03	7.64E-04	5.85E-04	2.37E-03	1.83E-03	1.05E-03	2.48E-03	2.01E-03	1.11E-03
Non-renewable resource use	34.9	21.3	9.56	15.1	8.94	11.0	10.7	5.81	10.4
Water scarcity	0.150	0.210	0.0759	0.231	0.295	0.161	0.224	0.289	0.167

LF: landfill
ER: energy recovery (incineration)
Rec: recycling

For plastic straws, energy recovery and recycling are the preferred options in all cases. Landfill is never the best option, but it is not always the least favoured either. Energy recovery performs well for polypropylene and is preferred in most impact categories, although recycling has the lowest impacts for climate change, non-renewable resource use and water scarcity (covering both

[12] The landfill scenario assumes that 50% of potentially biodegradable material actually biodegrades within the 100 year time horizon of the LCA, in line in IPCC guidelines.

categories of highest relevance based on the normalised results). The relatively good performance of energy recovery for plastic straws reflects the high calorific value of the polypropylene polymer (resulting in high amounts of recovered energy) but also the low manufacturing burdens (which reduce the credit that is received from recycling). Energy recovery is the least favoured option for climate change as this releases all the fossil carbon within the polymer back to the atmosphere (as discussed previously, it is important to remember that landfill impacts have been assessed over a 100 year time horizon; if a longer period were assessed it there may be additional emissions).

For the paper straw options, recycling has the lowest impacts for most categories, followed by energy recovery, while landfill usually has the highest impacts. It is notable however, that for climate change and non-renewable resource use (the categories of highest relevance), energy recovery is preferred.

Paper has much lower energy content than polypropylene, so less energy is recovered from incineration, whereas the relatively intensive primary production process for paper means that recycling credits are comparatively large. The exception to this trend is climate change, where recycling has the highest impact and energy recovery the lowest. Energy recovery performs well in this impact category as incinerating paper does not release any additional fossil carbon into the atmosphere (it just rereleases the biogenic carbon taken up during tree growth). As explained in section 4.2.2, recycling shows high impacts because it substitutes for virgin paper that would otherwise sequester more carbon. Hence, by avoiding the production of more virgin paper, recycling has the effect of adding to the climate change burden, not reducing it.

Overall, this sensitivity analysis investigating waste treatment options indicates that recycling is generally the preferred option for paper straws, although for climate change and non-renewable resource use, energy recovery is preferred. For plastic straws, energy recovery is generally the preferred option, but recycling is a very close second place. However, for climate change recycling is preferred as combustion of plastics releases a lot of carbon dioxide into the atmosphere. These results suggest that a good policy for both plastic and paper straws would be to increase recycling as far as possible and send any remaining material to energy recovery.