Anthesis

Comparative Life Cycle Assessment: D-PAK™ Carton refill system vs pouch refill system

1L D-PAK™ Elopak carton compared to an LDPE pouch as part of a detergent refill system for a 1L plastic container.

Disclaimer

Anthesis Consulting Group Ltd has prepared this report for the sole use of the client and for the intended purposes as stated in the agreement between Anthesis and the client under which this report was completed. Anthesis has exercised due and customary care in preparing this report but has not, save as specifically stated, independently verified information provided by others. No other warranty, express or implied, is made in relation to the contents of this report. The use of this report, or reliance on its content, by unauthorised third parties without written permission from Anthesis shall be at their own risk, and Anthesis accepts no duty of care to such third parties. Any recommendations, opinions or findings stated in this report are based on facts and circumstances as they existed at the time the report was prepared. Any changes in such facts and circumstances may adversely affect the recommendations, opinions or findings contained in this report.

Comparative Life Cycle Assessment

Prepared for:

Elopak

Website: https://www.elopak.com/

Report written by:

Rebecca Furlong

Principal Analyst

Anais Beninger

Analyst

Website: www.anthesisgroup.com

Company Registration: 08425819

Quality Assurance

Peter Slorach

Principal Analyst

Report approved by:

Peter Slorach

Principal Analyst

September 2024

Signature ……………………………………………………………………

Contents

Executive summary

Anthesis Consulting Group Limited has prepared this report for the sole use of Elopak and for the intended purposes as stated in the agreement between the Anthesis and Elopak under which this report was completed. The Life Cycle Assessment described in this summary has been conducted according to the requirements of BS EN ISO 14040:2006 and BS EN ISO 14044:2006. This published International Standard provides the globally agreed criteria for the quantification and reporting of a Life Cycle Assessment.

Elopak commissioned Anthesis to conduct a comparative LCA of 3 detergent refill systems, one of which uses their D-PAK™ carton. The systems are as follows:

1. System 1: 1L PP detergent bottle refilled with 1L D-PAK™ carton.
2. System 2: 1L PP detergent bottle refilled with 1.8L LDPE pouch.
3. System 3: 1L PP detergent bottle refilled with 1L LDPE pouch.

This study employs a cradle-to-gate plus end-of-life system boundary to assess the environmental profiles associated with these stages in the life cycle of the products; this includes the acquisition of ingredients, acquisition of packaging, manufacturing of the finished packaging format, distribution to filling site, distribution of filled packaging to retail/distribution centre, transport to end-of-life, and end-of-life. The full set of impact categories in ReCiPe v1.08/ World (2016) (100 year Mid-point Hierarchical) were applied in this LCA.

According to ISO standard, a comparative assertion must be based on the function delivered by the studied products. For this study, the chosen functional unit is defined as: "The packaging required to provide 11 litres of detergent to a customer". This study considers the environmental profile of the 3 refill packaging systems outlined above, presenting the results for each separately.

The results show that System 1 is estimated to have a lower environmental impact than System 2 across 11 impact categories, and a lower environmental impact than System 3 across 14 impact categories. Table 1 presents the percentage difference between the impact of System 1 compared to systems 2 and 3. A positive percentage denotes System 1 having a higher environmental impact.

Table 1: Impact difference between System 1 and Systems 2 and 3 across all impact categories. Negative percentages signify a lower environmental impact result for System 1 compared to systems 2 or 3, and positive percentage signify higher environmental impact results compared to systems 2 or 3.

Impact category	% difference between System 1 and System 2	% difference between System 1 and System 3
Global warming	-24%	-28%
Stratospheric ozone depletion	13%	-1%
Ionizing radiation	6%	8%
Ozone formation, Human health	3%	-2%
Fine particulate matter formation	-19%	-17%
Ozone formation, Terrestrial ecosystems	0%	-4%
Terrestrial acidification	-10%	-10%

Freshwater eutrophication	-26%	-31%
Marine eutrophication	-21%	-31%
Terrestrial ecotoxicity	14%	5%
Freshwater ecotoxicity	-36%	-40%
Marine ecotoxicity	-32%	-37%
Human carcinogenic toxicity	-12%	-13%
Human non-carcinogenic toxicity	-35%	-39%
Land use	575%	425%
Mineral resource scarcity	-11%	-12%
Fossil resource scarcity	-38%	-33%
Water consumption	3%	2%

Figure 1, Figure 2, Figure 3, and Figure 4 display results across refill systems for global warming, water consumption, land use, and fossil resource scarcity. Overall, it can be observed that across these impact categories, the main contributor across all refill systems' life cycle impacts is the material acquisition phase.

The error bars represent the highest and lowest impact results for each refill system according to the sensitivity scenario results outlined in Section 4.4.2, excluding the results of the single use sensitivity scenario. The single use sensitivity scenario was excluded from the error bars as it represents a different packaging system to the refill systems outlined in the figures.

The results from Figure 1 show that in the baseline modelling of the refill systems, System 1 has the lowest global warming impact, with impacts 24-28% lower than the other two refill systems. However, the error bars show that certain sensitivity scenarios could lead to System 2 having lower global warming impacts than System 1. Indeed, as discussed in Section 4.4.2.1, when the 1.8L LDPE Pouch has 100% recycled content, it directionally changes the results of this LCA.

The results from Figure 2 show that all three refill systems have similar baseline water consumption impacts, with System 1 having 2-3% higher water consumption impacts than system 2 and 3. However, certain sensitivities according to the error bars lead to System 2 and 3 having lower water consumption impacts than System 1, namely recycled content variation in the LDPE pouches (see Section 4.4.2.1). One of the limitations of this impact category is an error in the wastewater treatment process in ecoinvent 3.10 which leads to an underestimation of the water consumption impacts (this is further explained in Section 4.5).

The results of Figure 3 show that System 1 has 425-575% higher land use impacts compared to System 2 and 3. Sensitivity analyses did not lead to directional changes in the comparison between the refill systems. The higher land use impacts of System 1 are due to the fibre-based raw material that is used to produce D-PAK^{TM} cartons.

The results of Figure 4 show that among the baseline impacts of the refill systems, System 1 has 33-38% lower fossil resource scarcity impacts. However, the error bars show that there are sensitivity scenarios which lead to directional changes in the comparison between the refill scenarios. Indeed, the sensitivity scenario which leads to system 2 having 11% lower fossil resource scarcity impacts than system 1 is a result of variation in the LDPE Pouches' recycled content to 100% recycled content.

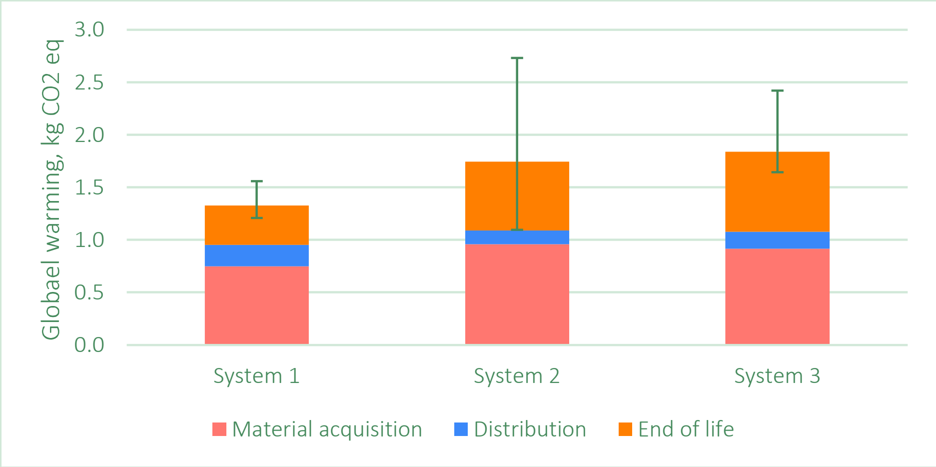

Figure 1: Global warming impact across packaging systems. System 1 refers to 1L PP detergent bottle refilled with 1L D-PAK™ carton, System 2 refers to 1L PP detergent bottle refilled with 1.8L LDPE pouch, and System 3 refers to 1L PP detergent bottle refilled with 1L LDPE pouch.

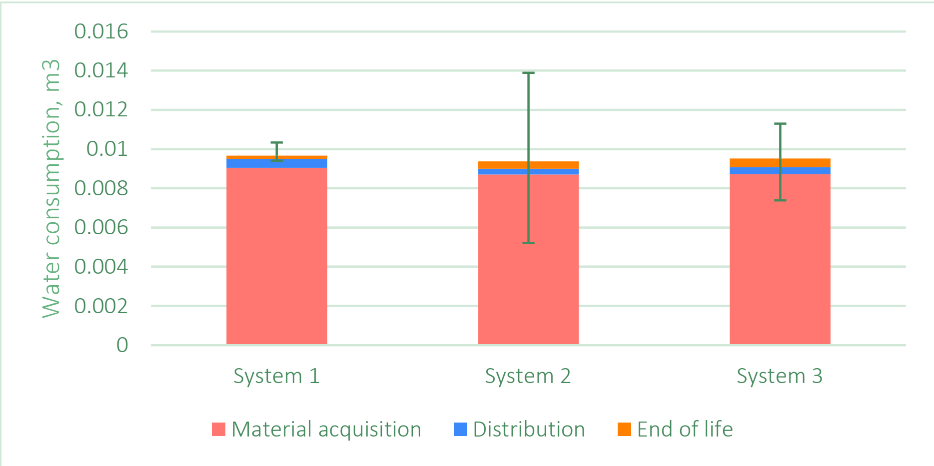

Figure 2: Water consumption impact across packaging systems studied. System 1 refers to 1L PP detergent bottle refilled with 1L D-PAK™ carton, System 2 refers to 1L PP detergent bottle refilled with 1.8L LDPE pouch, and System 3 refers to 1L PP detergent bottle refilled with 1L LDPE pouch.

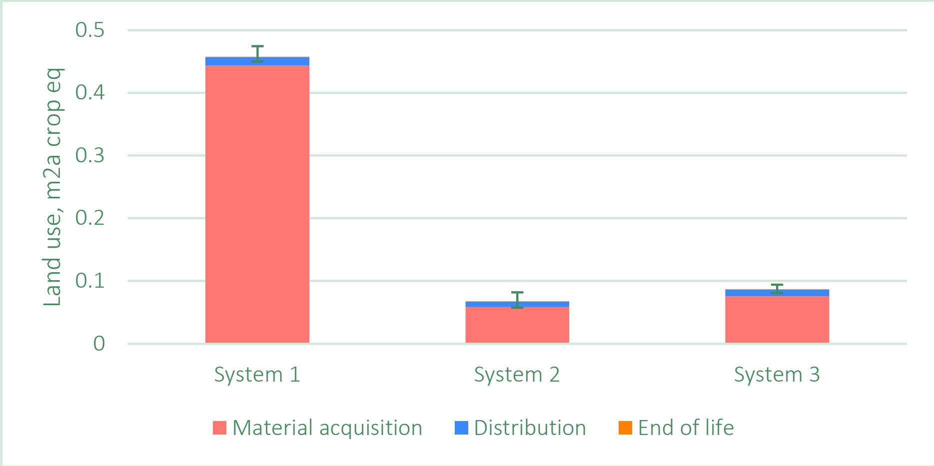

Figure 3: Land use impact across packaging systems. System 1 refers to 1L PP detergent bottle refilled with 1L D-PAK™ carton, System 2 refers to 1L PP detergent bottle refilled with 1.8L LDPE pouch, and System 3 refers to 1L PP detergent bottle refilled with 1L LDPE pouch.

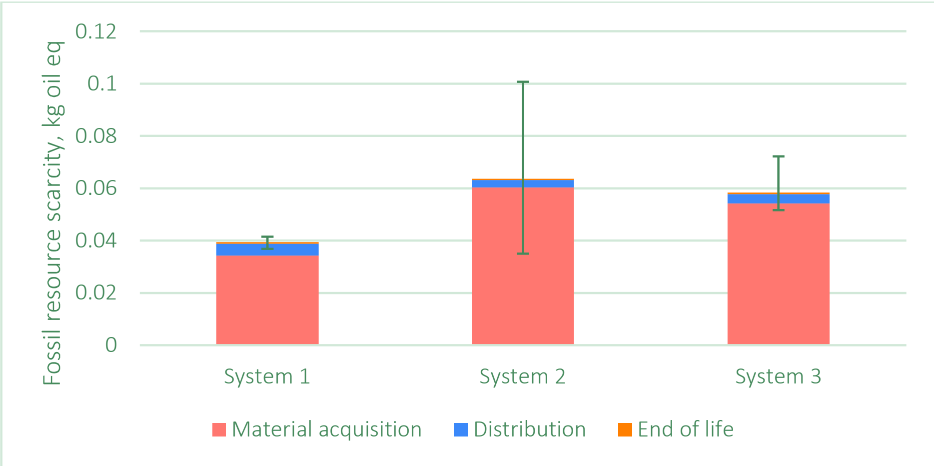

Figure 4: Fossil resource scarcity across packaging systems. System 1 refers to 1L PP detergent bottle refilled with 1L D-PAK™ carton, System 2 refers to 1L PP detergent bottle refilled with 1.8L LDPE pouch, and System 3 refers to 1L PP detergent bottle refilled.

This study is limited by the technological representativeness of unit processes selected to represent the ingredient production. Where unit processes were not available in standard LCI databases, custom and proxy unit processes were employed. The results of this study may be improved by collecting primary data from suppliers relating to the production of raw materials.

Results from this LCA can be used to make comparative assertions between the studied products. Attention to detail and transparency is critical, particularly for comparative assertions. This study does not support comparison to other studies as system boundaries, functional units, and other key parameters and assumptions would not be consistent with this assessment. Life cycle assessment results are usually relative to specific products, and it is not possible to extrapolate specific products, and it is not possible to extrapolate specific results to general statements about product categories.

This study has undergone critical review by a panel of independent reviewers to ensure conformance to the BS EN ISO 14040:2006 and BS EN ISO 14044:2006 standards. The review was completed by the following panel members:

- Matt Fishwick
- Frank Wellenreuther
- Joris Simaitis

General aspects

Life Cycle Assessment (LCA) is a method used to measure the environmental impacts of a product or process throughout its entire life cycle. LCA can be used to analyse and compare the environmental impacts of different scenarios. LCA results can be used to identify hotspots for impact reduction and inform innovation and provide solutions for reducing impacts across a range of environmental indicators.

This LCA study was commissioned by Elopak and was conducted by Anthesis Group, an external sustainability consultancy. Elopak is a Norwegian company that produces cartons for both food and non-food liquids. In this LCA study Elopak want to explore the application of their 1L D-PAK™ carton for use in non-food (detergent) systems as a refill container to refill a 1L PP bottle.

Elopak are keen to fully understand the environmental impacts of the use of the D-PAK™ as a refill pack in a non-food refill system. This study focuses on understanding the environmental impacts of the D-PAK™ carton as a refill pack and comparing these impacts to an equivalent refill system that uses an LDPE pouch as the refill pack.

In this study Anthesis conducts a comparative LCA to understand how the environmental impacts of a refill system using a Elopak D-PAK™ carton compares to a refill system using an LDPE pouch product, and to use these results to communicate to customers and make claims on the carton refill system.

This LCA study aims to report the results and conclusions completely, accurately and without bias to the intended audience. The results, data, methods, assumptions, and limitations are transparent and are presented in sufficient detail to enable the reader to understand the complexities and trade-offs inherent in the study. This allows the results and interpretation to be used in a manner consistent with the goals of the study.

An attributional approach was used in this LCA, following the design support context known as "Situation A", defined in the ILCD handbook (JRC, 2010) with the following text: "Situation A refers to decision support directly or indirectly related to inform the purchase of products that are already offered in the market, or to inform the design/development of products that are foreseen to entering the market."

The LCA study described in this report has been conducted according to the requirements of the BS EN ISO 14040:2006+A1:2020 and BS EN ISO 14044:2006+A1+A2:2020. Conformance to standards, aside from the ISO 14040:2006+A1:2020 and ISO 14044:2006+A1+A2:2020, is not being claimed.

A critical panel review was undertaken at the end of the study.

This report contains some commercially sensitive information in the appendices. The appendices should only be accessed by Elopak, Anthesis (under NDA) and the review panel (under NDA and restricted to the period of the review). A third-party report will be made available and will comprise this report in its entirety except for primary data and any other information deemed to be commercially sensitive, which will be redacted.

1 Goal definition

1.1 Objectives of the study

This LCA was commissioned by Elopak with the goal to:

- Evaluate the environmental impact profiles of two different refill system options (refilling with plastic detergent bottle using a carton vs refilling with a pouch).

- Compare the environmental impact profiles of the refill systems, highlight the differences between the systems
- Identify environmental impact hotspots in the 1L D-PAK™ carton and recommend possible opportunities for environmental impact reduction.

1.2 Intended application

The intended application of the study is to act as scientific support for environmental impact claims made about using the Elopak D-PAK™ carton for a non-food detergent application.

In addition to supporting environmental impact claims the results of the study will be used inform future redesign and manufacturing choices of the Elopak D-PAK™ carton.

1.3 Target audience

Internal and external stakeholders at Elopak are the target audience of this study. External stakeholders include consumers and business-to-business contacts, while internal stakeholders include the team at Elopak.

1.4 Critical review

As an intended application of the study is to make public comparative assertions, a critical review was completed.

A critical review by the following panel of experts was carried out:

- Matt Fishwick

Matthew Fishwick is an environmental consultant at Fishwick Environmental Ltd. Matt has 17+ years of experience in life cycle assessment. Past clients include include 3M, Lonza, BP, , Honeywell, GSK, and Johnson & Johnson. He has PhD, MRes, MSc and BSc degrees in environmental chemistry and is a member of the Royal Society of Chemistry (MRSC).

- Frank Wellenreuther

Frank Wellenreuther is a senior scientist at the Institute for Energy and Environmental Research. Frank is a specialist consultant with more than 15 years of experience in Life Cycle Assessment and related environmental footprinting. He is a senior scientist and theme leader at ifeu, the Institute for Energy and Environmental Research based in Germany. He specialises in the field of food and beverage packaging with a broad technical knowledge about paper and plastic based products. He has led numerous ISO-compliant LCA projects and has also performed many critical reviews. Ifeu is an independent and not-for-profit scientific research and consultancy institute.

- Joris Simaitis

Joris Simaitis is a PhD researcher at the University of Bath, developing advanced LCA methods of transport technologies. He is an accredited LCA practitioner (PIEMA, REnvP) with over 5 years' experience in delivering and reviewing LCA in consumers goods, construction, and energy technologies.

1.5 Public disclosure

The results of this study are intended to support comparative assertions to be disclosed to the public.

2 Scope definition

2.1 System descriptions

The packaging formats that will be modelled in this LCA study are described in Table 2.

Table 2 The studied products and their variables.

Packaging Name	Function in System	Representative image of the packaging format
1L D-PAK™ Carton	Refill packaging to contain detergent and be used to refill PP bottle	
1.8L LDPE Pouch	Refill packaging to contain detergent and be used to refill PP bottle	
1L LDPE Pouch	Refill packaging to contain detergent and be used to refill PP bottle	
1L PP Bottle	Original packaging to be refilled by either an LDPE pouch or a D-PAK™ carton. Assumed to be refilled 10 times.	

The different refill systems that are modelled and compared in this study are detailed Table 3 alongside the refill system name that is used throughout this report.

Table 3: The refill system options that are compared in this report.

Refill System Name	Descriptor
System 1	1L PP detergent bottle refilled with 10 1L D-PAK™ cartons
System 2	1L PP detergent bottle refilled with 5.56 1.8L LDPE pouch
System 3	1L PP detergent bottle refilled with 10 1L LDPE pouch

In addition to the above refill systems compared in this report, in the sensitivity the use of these packaging formats as part of a single use system is also explored.

The data for the D-PAK™ carton consists of primary data provided by Elopak. The data for the PP bottle and the LDPE pouches were also provided by Elopak.

Elopak gathered the data for the PP bottle and LDPE pouches using German based market research. A selection of bottles and pouches packaging formats available on the market were surveyed. This market research was conducted by Elopak in 2020. The packaging formats were analysed using microscopy, FTIR and DSC analysis to determine the plastic type and amount used in each packaging format. After this research was conducted the most likely pouch and bottle formats that were selected and proposed for the LCA study. The selected packaging formats were assumed to be options that would perform the same function as the 1L D-PAK™ carton in a refill system. It was also assumed that this German market research was representative of a general European market. The limitations of this are discussed in section 4.5.

This data was supplemented with secondary data and assumptions.

A full list of assumptions and exclusions from the study is detailed in 2.7 and 2.8. Data tables are available in Appendix A.

2.2 System Function

The function of the packaging systems included in this study is to:

- Contain 11L of detergent product and protect it from damage, tampering or contamination.
- Communicate information to consumers (e.g. use instructions) via printed labels.
- Allow the customer to effectively use the detergent product that the packaging contains.

In addition to the above functions, the function of the packaging when it forms part of a refill system is:

- To allow a consumer to refill the original packaging 10 times.

2.3 Functional unit

The chosen functional unit (FU) of the study is defined as:

"The packaging required to provide 11 litres of detergent to a customer"

This functional unit was selected to be consistent with the function of the system being modelled as described in sections 2.1 and 2.2. This functional unit was selected to enable the main comparisons of this study are focused on the use of the packaging in a refill system while also encompassing a scenario that is explored later in the report to understand the function of all packaging formats in a single use system.

2.4 Product System Boundaries

To ensure consistent, comparable results the system boundaries of for all the product systems are the same.

The life cycle stages included in this study for all packaging formats can be defined as **'cradle-to-gate plus end of life'** and include:

1. Raw material extraction, processing, and production of individual packaging components (caps, labels, bottles etc)
2. Transport to manufacturing sites.
3. Manufacturing of the finished packaging format
4. Transport of empty packaging to the detergent filling site
5. Transport of filled packaging to retail/distribution centre
6. Transport to end-of-life
7. End-of-life treatment of all packaging

The following life cycle stages are excluded from the study:

- All life cycle stages associated with the detergent product that the packaging formats are intended to contain. This includes the production of the detergent, the filling process to fill the packaging with detergent and transport impacts associated with the detergent.
- All impacts associated with retail and use of the products, including retail impacts and transport to the final customer location.
- The impacts of tertiary packaging for all packaging formats

Note: The Systems considered are assumed to function in a traditional retailer route rather than through online retailing, hence the inclusion of the transport to retail/distribution centre.

2.5 Product System Descriptions

2.5.1 Raw material extraction and production of packaging components

The raw material extraction and packaging component production phase includes the extraction and production of the raw materials and the production of the packaging components (e.g. caps, carton board).

Table 4 outlines the mass of each component, plus the overall mass of each packaging format included in this study.

Table 5 details the format and weight of the secondary packaging included in this study. The secondary packaging included is the primary packaging associated with the packaging formats after filling with detergent.

An outline of the packaging components for each packaging format are given below the tables. More detail detailed on the assumptions and exclusions associated with the packaging formats are detailed in sections 2.7 and 2.8.

Table 4: The component mass and overall mass of the primary packaging formats included in this study. See Appendix A for more details.

Packaging Format	Components	Mass (g)	Overall Packaging Mass (g)
1L D-PAK™ carton	Cartonboard	23.02	30.8
	Barrier materials (incl. PE, Metallocene PE, EVOH, and tie)	5.07	
	Ink	0.07	
	PE Cap & Closure	2.7	
1L PP bottle	PP Bottle	62.8	76.8
	PP Cap & Closure	11.3	
	LDPE Label	2.6	
	Ink	0.07	
1.8L LDPE pouch	LDPE Pouch	25.7	29.4
	HDPE Cap	3.6	
	Ink	0.07	
1L LDPE pouch	LDPE Pouch	16.4	20.1
	HDPE Cap	3.6	
	Ink	0.07	

Table 5: The mass and format of the secondary packaging included in this study.

Primary Pack Format	Secondary Packaging Name	Mass (g/pack)
1L D-PAK™ carton	Wraparound Cardboard Box	8.24
1L PP bottle		9.10
1.8L LDPE pouch		10.00
1L LDPE pouch		10.00

1L D-PAK™ carton

The raw materials and packaging components for the for the D-PAK™ carton are the liquid carton board, the resins that are used for coating and barrier layer which include a polyethylene layer, an EVOH layer, and a tie layer. There is also a PE cap which contains a blend of LDPE and HDPE. Information on the mass and composition of each component are primary data provided by Elopak.

1L PP bottle

The raw materials and packaging components for the PP bottle are the PP granulates required to produce bottle, the PP granulates for the cap and the LDPE granulates for the label. The information on the material composition of the PP bottle components is based on primary data obtained from Elopak via an analysis of common detergent bottle formats placed on the market. No primary data was available on the production locations for the PP bottle, cap or label. Therefore, it was assumed that all components for the PP bottle are produced in Europe to align with the D-PAK™ component production locations.

1.8L and 1L LDPE pouches

The raw materials and packaging components for the LDPE pouches are the LDPE granulates required to produce pouch itself and the HDPE granulates for the cap. The information on the material composition of the LDPE pouches was obtained from Elopak. As with the PP bottle, no primary data was available on the production locations for the LDPE pouch or cap. Therefore, it was assumed that all components for the LDPE pouches are produced in Europe to align with the D-PAK™ component production locations.

Secondary Wraparound Cardboard Box

The raw materials associated with the secondary packaging for the filled packaging formats are corrugated cardboard that is formed into boxes. The details of the primary packaging for all packaging formats are based on primary data provided by Elopak. Elopak provided several different secondary packaging orientations, these are explored in the sensitivity section. Due to the differences in the shape and size of the D-PAK™ carton, the pouches and the bottles, different numbers of products sit within the secondary packaging. This changes the mass of secondary packaging allocated per product.

2.5.2 Transport to the manufacturing site

The transport to manufacturing site phase includes the impacts associated with transporting the packaging components and raw materials from the suppliers to the packaging production site.

1L D-PAK™ carton

The final D-PAK™ carton is produced at the Terneuzen Elopak site in the Netherlands. The transport distances and locations for each of the carton components from supplier to Terneuzen are given in Table 6 and were based on primary data provided by Elopak.

Table 6:Transport distances and modes of D-PAK™ components from supplier to Elopak factory.

Component/material	Supplier Location	Distance to Terneuzen (km)	Mode of Transport
Liquid carton board	Sweden	1650	Truck >32T EURO4
Resins & barrier layers used for coating	Netherlands	6	Truck >32T EURO4
PE Cap	Germany	494	Truck >32T EURO4

1L PP bottle and 1.8L LDPE pouch

As no primary data was available on the production locations for the PP bottle or the LDPE pouch, the PEF guidance (European Commission, 2021) was used to estimate transport distances. The supplier to factor recommendations were selected to model transport from an EU based production location to the final manufacturing site. The assumed distances are detailed in Table 7.

Table 7: Assumed transport distances of components for PP bottle and LPDE pouches, taken from PEF guidance (European Commission, 2021).

Transport Scenario	Distance (km)	Mode
Supplier to factory	130	Truck >32T EURO4
	240	Freight Train
	270	Ship (Barge)

2.5.3 Product manufacturing

This phase includes the impacts associated with any manufacturing impacts that occur at the manufacturing site for the empty packaging.

1L D-PAK™ carton

The coating and converting process of the carton are carried out in the Netherlands. The coating process involves the addition of resins and barrier layers - these include the PE layer, the EVOH layer and the tie layer. The converting process involves the printing and cutting activity. The main energy sources for coating and converting are grid electricity natural gas, and propane. The data for the D-PAK™ production process use primary production data supplied by Elopak.

1L PP bottle & 1.8L LDPE pouch

As with the raw material and component production stage no information was available on the product manufacturing stage for the PP bottle or the LDPE pouch. For this reason, assumptions were made on the production processes for the final packaging. To maintain consistency with other assumptions it was assumed final product manufacture happens in Europe. Ecoinvent 3.10 was used to select appropriate manufacturing locations and process efficiencies. Table 8 details the assumed manufacturing processes for each of the final packaging components. Further detail on these assumptions is found in section 2.7.

Table 8: Assumed production processes per component for the LPDE pouch and PP bottle.

Packaging Format	Component	Assumed Process
LDPE Pouch	HPDE Cap	Injection moulding| injection moulding | Cut-off, U, Ecoinvent 3.10
	LDPE Pouch	Extrusion of plastic sheets and thermoforming, inline | extrusion of plastic sheets and thermoforming, inline | Cut-off, U, Ecoinvent 3.10
PP Bottle	PP Bottle	Blow moulding| blow moulding | Cut-off, U, Ecoinvent 3.10
	PP Cap	Injection moulding| injection moulding | Cut-off, U, Ecoinvent 3.10
	LDPE Label	Extrusion of plastic sheets and thermoforming, inline | extrusion of plastic sheets and thermoforming, inline | Cut-off, U, Ecoinvent 3.10

2.5.4 Distribution and storage

The distribution and storage stage includes the transportation of the empty packaging to the detergent filling site, the transportation of the filled packaging to retail/distribution centre and the storage of the packaging at retail/distribution centre.

No primary data was available on the transportation distance or destinations of the empty packaging from the packaging manufacturing site to the filling site for any of the packaging formats. Therefore, the PEF guidance (European Commission, 2021) was used to estimate distances and modes. For empty packaging transportation to the filling site the 'from supplier to factory' scenario was selected.

Primary data was also unavailable for the transportation distance and destination of the packaging from the filling site to retail/distribution centre. Therefore, the PEF guidance was again used to estimate distances and modes. For filled packaging transportation to retail/distribution centre the ‘factory to retail/distribution centre’ scenario was selected, assumed 100% intracontinental travel. This PEF assumption is tested in the sensitivity section in section 4.4.2.

Note that all impacts associated with the detergent itself including the production of the detergent, the filling process, plus the weight of the detergent during distribution was not included in this study. In addition, it was assumed that there are no impacts from storage as detergent is stored at room temperature.

2.5.5 Waste Collection

This phase includes impacts associated with the collection and transport of the packaging at the end-of-life to the waste treatment locations. Transport distances of the packaging to end-of-life were estimated using an assumption provided by Eurostat (Eurostat, 2018) which was also used in the dataset ‘market for waste plastic, mixture [NL]’. The assumptions are shown in in Table 9.

Table 9: Estimated transport distances to waste treatment processes as specified by Eurostat (Eurostat, 2018)

Waste Treatment Process	Distance (km)	Mode
Incineration	68.789	Truck >32T EURO4
Landfill	68.789	
Recycling	68.789	

2.5.6 End-of-life

This phase includes all the impact associated with the treatment of the primary and secondary packaging.

It was assumed that each packaging format is treated using a combination of recycling, landfill, and incineration. The percentage of each packaging format vary and are detailed in Table 10. It is assumed that the remainder of all packaging not recycled is treated using landfill and incineration in a 24:76 split as detailed in EU statistics (European Commission, 2018).

Table 10: Assumed recycling rates for all packaging formats included in this study.

Packaging format	Percentage Recycled	Reference
D-PAK™ Carton	51%	Taken from Alliance for Beverage Cartons and the Environment (ACE, 2021)
PP Bottle	63%	Collection rate for household plastic bottles taken from Recoup (Recoup, 2022)
LDPE Pouch	6%	Flexible packaging recycling rate taken from Wrap (Wrap, 2020)

Wraparound Flute (secondary packaging)	64%	Packaging waste recycling taken from Eurostat (Eurostat, 2021)

2.6 Process maps

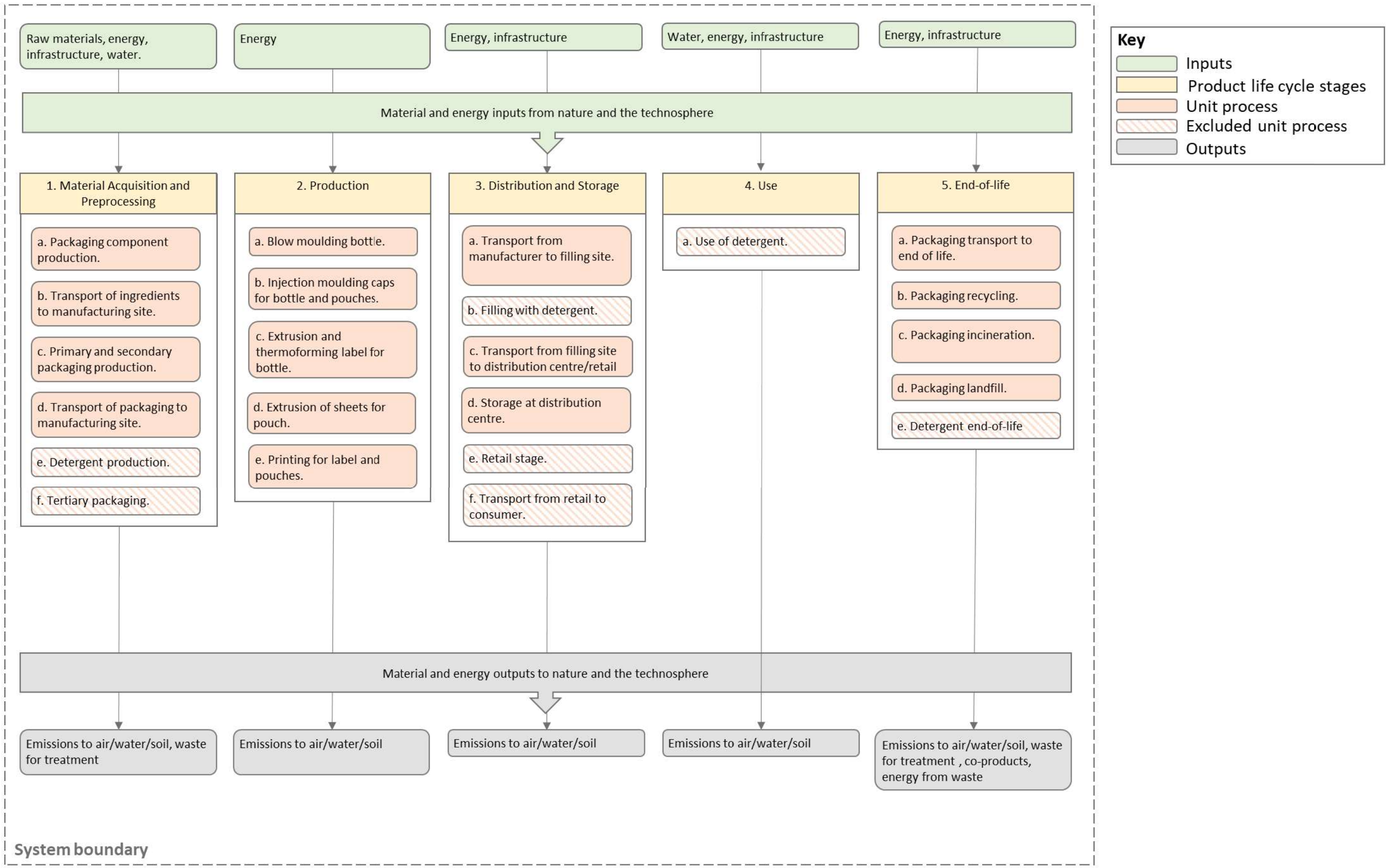

Figure 5: Process map for the PP bottle and LDPE Pouch refill systems (Systems 2 and 3)

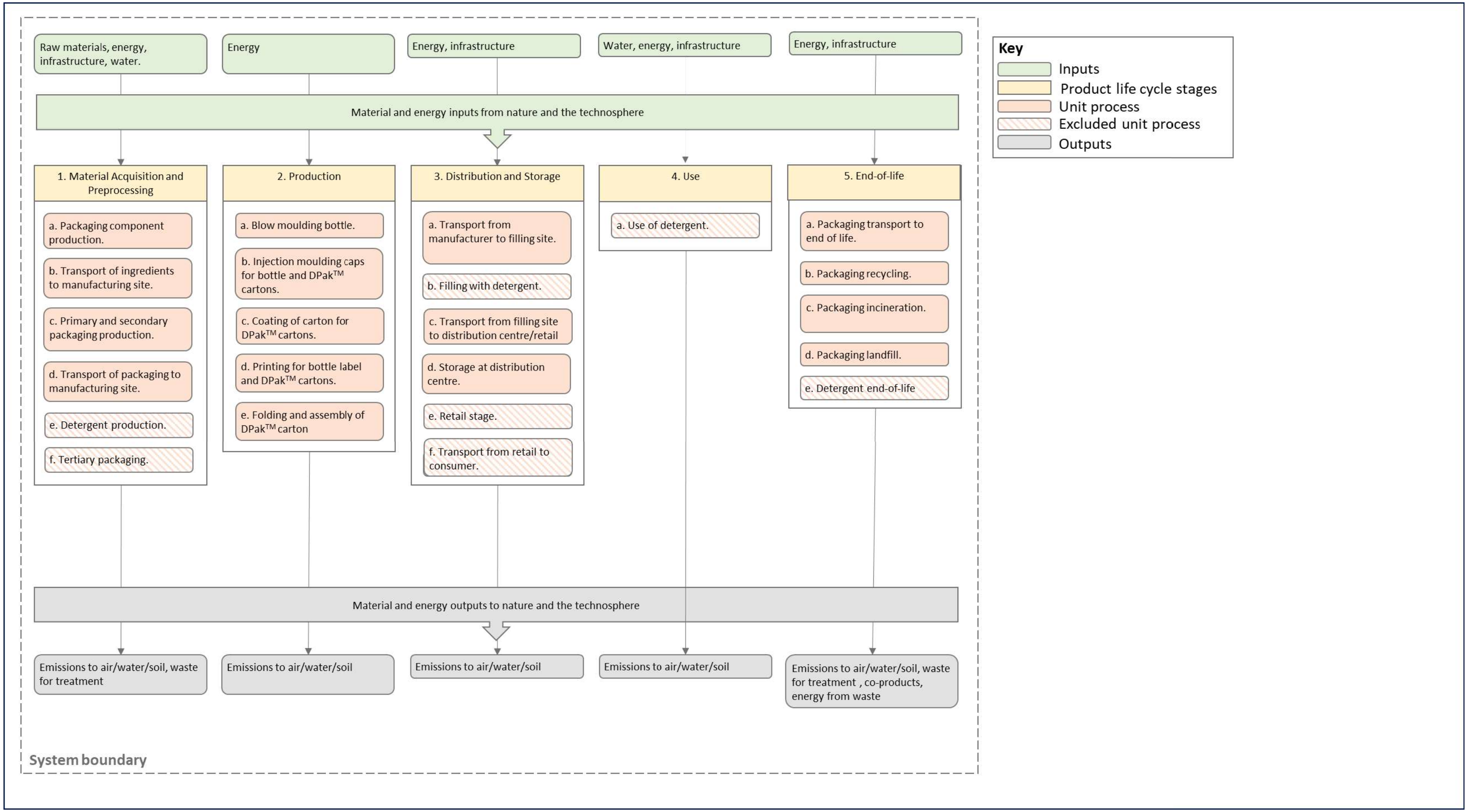

Figure 6: Process map for the PP bottle and D-PAK carton refill system (System 1)

2.7 Assumptions

Table 11: Details of the assumptions made in this project set out per life cycle stage.

Stage	Assumption	Source/Justification
General	In the refill system the PP original packaging will be refilled with detergent 10 times using the D-PAK™ carton or the LDPE pouch before going to end-of-life	This assumption was based on discussion with the Elopak team.
General	Pouches and bottle selected for the refill system were chosen based on German market research data and assumed to represent typical market packaging and do not correspond to actual packaging scenarios where a D-PAK™ carton may be picked over a pouch	The formats for the pouch and the bottle were selected by Elopak based on market research to identify the most likely packaging format that will form part of the refill system/that will be direct competitors to a D-PAK™ carton refill system.
Raw material extraction, processing, and production of packaging components	It was assumed that the resin and barrier layer raw materials are all produced in the Netherlands for transport to the Elopak factory in the Netherlands.	Elopak purchase the resins and barriers from a supplier located in Terneuzen
	All packaging components for the LPDE pouch and PP bottle are produced in Europe.	Matches supply chain scenario of D-PAK™ Elopak.
	Label for the PP bottle is LDPE	Based on common packaging formats knowledge.
	Ink consumption for the pouches and the bottle is assumed to be the same as the ink usage for the D-PAK™ carton (see Section 2.5.2). This was done to simplify the modelling for this component as it contributes 0.3% to the total global warming impact of the D-PAK™ carton. Additionally, the bottle is likely to use less ink than a carton so	To maintain comparability of systems.

	using this approach would likely overestimate the impact contribution of ink on the products' life cycle impacts.	
	Secondary packaging was assumed to be a carboard wraparound flute. This is added to the bottle, pouch, and D-PAK™ carton after the detergent filling stage. The amount of secondary packaging used per pouch model is assumed to be the same due to lack of data.	Primary data and research from Elopak.
Transport to Manufacturing Site	Transport distances and modes of LDPE pouch and bottle components assumed to be: From supplier to factory: 130km by >32T EURO4 truck 240km by freight train 270km by barge	EU PEF guidance (European Commission, 2021)
	Assumed transport mode for D-PAK™ components from supplier to Terneuzen factor is >32T EURO4 Truck	EU PEF guidance (European Commission, 2021)
	Assumed that the transport distance and transport type used for D-PAK™ carton's ink is the same as for the resin PE component's transport to manufacturing site (See section 2.5.2).	
Product Manufacturing	Assumed manufacturing processes for LDPE pouch, label, caps and bottle: Caps: Injection moulding Pouch: Extrusion & Thermoforming Bottle: Blow Moulding	Taken from (Active Plastics, n.d.)

	Label: Extrusion and Thermoforming	
Distribution & Storage	Assumed transport mode and distances for transport of all packaging from the production location to the detergent filling site: From supplier to factory: 130km by >32T EURO4 truck 240km by freight train 270km by barge	EU PEF guidance (European Commission, 2021)
	Assumed transport mode and distances for transport of all packaging from the production location to the detergent filling site: Factory to retail/distribution centre. 100% intracontinental supply chain: 3500km by >32T truck	EU PEF guidance (European Commission, 2021)
	Assumed that the detergent is stored at room temperature	N/A
Waste Collection	Assumed waste collection and transport distances: Incineration: 68.79 km >32T truck Landfill: 68.79 km >32T truck Recycling: 68.79 km >32T truck	Distances taken form Eurostat (Eurostat, 2021)
End-of-life treatment process	D-PAK™ carton recycling rate: 51%	Taken from Alliance for Beverage Cartons and the Environment (ACE, 2021)
	PP Bottle recycling rate: 63%	Collection rate for household plastic bottles taken from Recoup (Recoup, 2022)
	LPDE pouch recycling rate: 6%	Flexible packaging recycling rate taken from Wrap (Wrap, 2020)

	Wraparound Flute (secondary packaging): 64%	Packaging waste recycling taken from Eurostat (Eurostat, 2021)

2.8 Exclusions

Table 12: Details of the exclusions made in this study.

Exclusion	Justification
Adhesive used to stick the label to the PP and HDPE bottles	Weight is less than 1% of the weight of the whole product therefore negligible impact assumed.
Secondary and tertiary packaging for packaging components up to deterrent filling is assumed to have negligible impact and is excluded.	No information available on secondary and tertiary packaging of components but likely to contribute to less than 1% of the mass of the product.
Tertiary packaging for transportation of the filled packaging to distribution of retail is assumed negligible and is excluded	No information available on tertiary packaging of components but likely to contribute to less than 1% of the mass of the product. Tertiary packaging likely to be pallets which are reused and therefore have minimal effect on individual product impact.
Filling of the detergent packaging was excluded in this study	No information available on filling of packaging with detergent. It is likely that the detergent filling process will be immaterial to the overall packaging impacts, This has been discussed in the limitations section.
Storage of packaging	No information available on storage of packaging products, but likely to have negligible impact therefore excluded.
The retail, transport between retail and use and use phases are excluded	No information was available on these life cycle stages. However, it is likely that these stages will have negligible contribute on the overall environmental impacts of the systems. In addition, from a comparative perspective these life cycle stages are likely to be very similar between the different packaging systems.
Waste produced at manufacturing sites during the production of studied products	No information available on waste incurred during the production of the studied products. It is assumed that the products would be part of large production runs, therefore set up manufacturing waste would be negligible when allocated per product produced.

2.9 Time coverage

Unless stated otherwise, activity data were collected from the most recent data source available - representing the calendar year 2023.

2.10 Geographical coverage

The geographical boundary of this study is Europe. For the coating and production of the D-PAK™ carton the factory is located in Terneuzen, Netherlands.

To maintain this geography Netherlands (NL) factors were selected for the electricity required to produce the D-PAK™ carton. For all other processes related to the D-PAK™ carton NL factors were not available, so Europe factors (RER or Europe without Switzerland) were selected. If Europe factors were not available Global (GLO) factors were selected.

For all other packaging formats modelled Europe factors (RER or Europe without Switzerland) were selected where possible. If Europe factors were not available Global (GLO) factors were selected.

2.11 Cut-off criteria and allocation

In the process of building an LCI it is typical to exclude items considered to have a negligible contribution to results. To do this in a consistent and robust manner there must be confidence that the exclusion is fair and reasonable. To this end, cut-off criteria are defined, which allow items to be neglected if they meet the criteria:

- Mass: if a flow is less than 1% of the mass of the product it may be neglected;
- Energy: if a flow is less than 1% of the cumulative energy it may be neglected;
- Environmental significance: if a flow is less than 1% of the key impact categories it may be excluded;
- The sum of excluded processes does not contribute more than 5% to any of the impact categories.

Specific details on known exclusions in this study are outlined in section 2.8.

If an item meets one of the criteria but is significant to one of the other criteria it may not be neglected. For example, if a substance is small in mass but is expected to have a notable contribution to the environmental results then it may not be excluded.

The system model: *Allocation, cut-off by classification,* was chosen for this study.

2.12 Multi-output allocation

Allocation of Elopak site-level impacts during board production was carried out on a physical basis. Data for the production and coating of the D-PAK™ carton was primary data provided by Elopak. The data was provided on a site level basis and consisted of electricity, natural gas and propane use for coating and carton production process.

The site level data was assumed to be equally allocated between the total m^2 of carton board both coated and produced into cartons. Therefore, the site level consumption was divided by the total m^2 to calculate electricity, natural gas and propane used per m^2 of carton board. This value was then multiplied by the m^2 of the D-PAK™ carton to determine the electricity, natural gas and propane consumed by D-PAK™ carton for both the coating process and the carton production process.

This approach was deemed to be an acceptable approach to take as the Terneuzen site only produced cartons and no other products.

The allocation procedure for secondary data from ecoinvent 3.10 (cut-off) is outlined on the ecoinvent website (ecoinvent, 2024) and within the methodology documents for each process used. The processes used in this study are described in Appendix A.

2.13 End-of-life allocation

The methodological choices for allocation for reuse, recycling and recovery have been set according to the polluter pays principle (PPP). This means that the generator of the waste shall carry the full environmental impact until the point in the product's life cycle at which the waste is transported to a scrapyard or the gate of a waste processing plant (collection site). The subsequent user of the waste shall carry the environmental impact from the processing and refinement of the waste but not the environmental impact caused in the "earlier" life cycles.

For recycled materials, the primary producer does not receive any credit for the supply of a recyclable product, and these are available burden-free to recycling processes. This means that recycled materials only bear the impacts of the recycling process.

For incinerated materials, the incineration is allocated completely to the treatment of waste and the burden is assigned to the waste producer. The heat or electricity produced from incineration comes burden-free.

The chosen end-of-life allocation method can have significant impacts on the overall results of an LCA. While the PPP method was applied to the baseline results this is not an argument that the PPP method is the best choice for an LCA study. All end-of-life allocation methods have advantages and disadvantages in the way that impact is allocated.

To explore the potential differences in end-of-life allocation choice within this study and to adhere with the requirements of ISO14040/44 of including an alternative end-of-life allocation method, the Circular Footprint Formula (CFF) has been applied as a sensitivity case. CFF results can be seen in section 4.4.2.3. The CFF, developed by the EU Commission, was chosen as the alternative allocation method for this study as, unlike the PPP, it assigns credits for the use of recycled materials, the production of recyclable materials according to relative supply and demand. It also gives credit for the production any heat or electricity via incineration with energy from waste.

2.14 Impact categories and impact assessment method

In LCA, the life cycle impact assessment (LCIA) stage is where characterisation factors are applied to LCI data to generate environmental impact results. There are several LCIA methods that can be chosen, all with slightly different characterisation factors (both in terms of coverage and values) and different underlying characterisation models used to generate these factors.

The ReCiPe v1.08/ World (2016) (100-year Mid-point Hierarchical) were used unaltered and as provided in this LCA to assess the environmental impacts. As such, the characterization models used for deriving each category indicator were considered appropriate to meet the main goal of this study (i.e., to compare environmental profiles of the carton refill system with the pouch refill system) as they were derived by a consensual LCIA method that is well used and internationally respected.

ReCiPe was developed by PRé Consultants, the University of Leiden (CML), Radboud University Nijmegen (RUN) and the National Institute for Public Health and the Environment in the Netherlands (RIVM). This method was chosen as it is the most common method used by LCA practitioners and covers a broad range of impact categories. It must be noted that this method does not consider the impact of marine litter or other losses to the environment, which is a particular concern for plastic bottles. In addition, this study excludes any impact from the long term storage of biogenic carbon in landfills for the carton.

When applied to inventory data, the ReCiPe impact assessment method generates indicator scores which can be represented at the 'mid-point' or 'end-point' stage. At the 'mid-point' stage a score is given for each impact category in units specific to that category (e.g. kg CO_2e), whereas at the end-point stage, the potential damage to the environment estimated and units (e.g. species lost per year) are common to many impact categories (grouped as damage to ecosystems, damage to resources and damage to human health). For this study, the mid-point method was chosen as it reduces uncertainty in results compared to end-point results. The indicator results are calculated in accordance with the ReCiPe method and in line with the assumptions and exclusions outlined in this report.

Descriptions of the impact categories used in this study can be found in Appendix B.

2.15 Interpretation to be used

The outputs from the LCI and LCIA are interpreted in accordance with the goal and scope as outlined in this section. This results interpretation focuses on:

- Identifying the environmental impact hotspots of the packaging systems included in this study
- Comparing the environmental impacts of the different systems included in this study
- Evaluating the limitations and completeness of the LCA
- Drawing conclusions and recommendations from the results

3 Life cycle inventory assessment

3.1 Data collection procedure

1L D-PAK™ carton

In this study primary data was provided by Elopak and any gaps were supplemented using secondary data and assumptions.

The main sets of primary data collected were:

1. The carton product specifications, carton component suppliers, bill of materials and production utilities required for carton production,
2. The electricity, natural gas and propane used to both coat and produce cartons at the Elopak Terneuzen site,
3. The secondary packaging specifications, after the detergent filling stage, for the carton, LDPE pouch and PP bottle were provided by Elopak.
4. The primary packaging specifications for the PP bottle and LDPE pouch were primary data provided by Elopak calculated through direct measurements of packaging placed on market.

Details on the primary and secondary data used in modelling can be found in Appendix A.

3.1.1 Energy from combustible fuels

No energy data from combustible fuels required conversion in this LCA.

3.2 Sources of published data

3.2.1 ecoinvent v 3.10 (2023)

Studied unit processes were mapped to an activity or activities in the ecoinvent 3.10 Life Cycle Inventory (LCI) database. Where the unit process does not match an activity exactly the closest available proxy is used. Secondary production data from ecoinvent was unit for all unit processes. Appendix A details the LCI data used in this study.

3.3 Data quality requirements and assessment

Here the data used to create the model is qualitatively assessed by its precision, completeness, consistency, and representativeness.

The general data quality requirements and characteristics that needs to be addressed in this study are shown Table 13.

Table 13 - Data quality requirements based on ISO 14044

Aspect	Description	Requirement in this study
Time-related coverage	Desired age of data and the minimum length of time over which data should be collected	General data should represent the current situation of the date of study, or as close as possible. All data should be less than 10 years old.
Geographical coverage	Area from which data for unit processes should be collected	Data should be representative of the European marketplace.
Technology coverage	Type of technology (specific or average mix)	Data should be representative of the technology used in Europe.
Completeness	Assessment of whether all relevant input and output data are included for each data set.	Specific data will be benchmarked with literature data. Simple validation checks (e.g. mass or energy balances) will be performed.
Representativeness	Degree to which the data set reflects the true population of interest	The data should fulfil the defined time-related, geographical, and technological scope.
Precision	Measure of the variability of the data values	Data that is as representative as possible will be used. A sensitivity analysis will be used to determine the influence of variability in key parameters on the study conclusions.
Reproducibility	Assessment of the method and data, and whether an independent practitioner will be able to reproduce the results	Information about the method and data (reference source) should be provided.
Sources of the data	Assessment of the data sources used.	Data will be derived from credible sources, and references will be provided.

Uncertainty of the information	e.g. data, models, assumptions	A sensitivity and qualitative uncertainty analysis will be conducted.

To ensure the quality of data was sufficient, data quality checks were completed on key data parameters. Data quality checks were completed using data quality indicators (DQIs).

Data quality indicators were applied to key data parameters to ensure that the data was fit for purpose. Key data parameters were assessed against a data quality matrix and assigned scores between 1 (best) and 5 (worst). The data quality matrix used in this study was adapted from Weidema et al. (2013). The full data quality assessment can be found in Appendix C.

3.3.1 Precision

The datasets used in this study are based on primary measured data, calculated based on primary information sources, or from reliable secondary data sources. As such the precision of this study is deemed to be good.

3.3.2 Completeness

Each unit process was checked for mass balance and completeness of the life cycle inventory assessment. Only excluded unit processes are knowingly omitted from the study to meet the time and data limitations of this project.

3.3.3 Consistency

To ensure data consistency, all primary data was collected or calculated with the same level of detail, while all background data was sourced from the ecoinvent 3.10 database.

3.3.4 Representativeness

Temporal: All primary activity data was collected between 2021 and 2023. As the study intended the reference year 2023, temporal representativeness is high. Ecoinvent 3.10 published 2023 was used to model secondary production data, this was the latest version at the time of the study. While this provides good temporal representation for processes such as electricity mixes, the technological processes on which the factors are based provide relatively low temporal representativeness. Full details of the ecoinvent factors used is available in Appendix A.

Geographical: Where possible primary and secondary data was collected specific to the countries or regions under study. Proxy data sets are used for the distribution and end-of-life phases due to limited data available for the specific geographies available. Geographical representativeness is acceptable.

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 acceptable.

4 Life cycle impact assessment & interpretation

This section provides the results from the impact assessment comparing the following refill systems:

1. System 1: 10 x 1L D-PAK™cartons and 1x 1L PP Bottle
2. System 2: 5.6 x 1.8L LDPE Pouch and 1x 1L PP Bottle
3. System 3: 10 x 1L LDPE Pouch and 1x 1L PP Bottle

Highlighted in this section is any significant finding relevant to the goal and scope of this study.
The quality of the life cycle inventory data and results have been deemed sufficient to conduct this LCA in accordance with the goal and scope outlined in this study.

The system boundary and cut-off decisions have been reviewed to ensure the availability of LCI results are necessary to calculate the indicator results. The calculation was done by taking the input data described in Section 3.1 and multiplying them with the unit process values taken from the data sources described in Section 3.2.

Note that the reported impact categories represent potentials, therefore they are approximations of environmental impacts that could occur if the emissions would follow the underlying impact pathway and meet certain conditions in the receiving environment while doing so. The robustness of each impact category should also be considered when interpreting the results, see Section 2.14.

The results relating to all impact assessment categories defined in Section 2.14 are presented here. A key focus of this study was the Global Warming, Water Consumption, Fossil Resource Scarcity, and Land use impact assessment categories. These impact categories were selected because they are key priorities for Elopak. Additionally, given the studied products are consumer products, these categories are likely to resonate more with consumers. Although these four impact categories were priorities for Elopak, interesting results across all impact categories were highlighted.

The results of this LCA may be interpreted according to the goal and scope of the study:

- Generate accurate, reliable, and comparable environmental impact profiles for two different refill system options (refilling with plastic detergent bottle using a carton vs refilling with a pouch).
- Compare the environmental impact profiles of the refill systems, highlight the differences between the systems
- Quantify the potential environmental impact savings for customers of swapping to a refill system.
- Identify environmental impact hotspots in the 1L D-PAK™ carton and recommend possible opportunities for environmental impact reduction.

4.1 Absolute results

4.1.1 Comparison of packaging systems

Presented in Table 14 are the absolute environmental impacts for the three refill systems considered in this study:

- System 1 1L PP detergent bottle refilled with 1L D-PAK™ carton,
- System 2: 1L PP detergent bottle refilled with 1.8L LDPE pouch,
- System 3: 1L PP detergent bottle refilled with 1L LDPE pouch.

Table 14: The absolute environmental impacts for the 3 key refill systems considered in this LCA: System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle. Highlighted in green for each impact category is the refill system with the lowest results for that category, highlighted in orange is the second highest result for that category, and in red is the highest result for that category.

Impact assessment category	Unit	System 1	System 2	System 3
Global warming	kg CO2 eq	1.327	1.744	1.840
Stratospheric ozone depletion	kg CFC11 eq	6.84E-07	6.07E-07	6.94E-07
Ionizing radiation	kBq Co-60 eq	0.123	0.116	0.114
Ozone formation, Human health	kg NOx eq	0.0032	0.0031	0.0033
Fine particulate matter formation	kg PM2.5 eq	0.0010	0.0013	0.0012
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.0035	0.0035	0.0036
Terrestrial acidification	kg SO2 eq	0.0025	0.0028	0.0028
Freshwater eutrophication	kg P eq	6.75E-04	9.06E-04	9.80E-04
Marine eutrophication	kg N eq	1.60E-04	2.02E-04	2.33E-04
Terrestrial ecotoxicity	kg 1,4-DCB	13.951	12.222	13.258
Freshwater ecotoxicity	kg 1,4-DCB	0.055	0.086	0.091
Marine ecotoxicity	kg 1,4-DCB	0.084	0.124	0.132
Human carcinogenic toxicity	kg 1,4-DCB	0.181	0.204	0.208

Human non-carcinogenic toxicity	kg 1,4-DCB	1.251	1.914	2.057
Land use	m2a crop eq	0.458	0.068	0.087
Mineral resource scarcity	kg Cu eq	0.0032	0.0036	0.0036
Fossil resource scarcity	kg oil eq	0.039	0.064	0.058
Water consumption	m3	0.0097	0.0094	0.0095

Figure 7 and Figure 8 present the difference in environmental impact when using System 1 compared to Systems 2 and 3. A positive percentage denotes a higher environmental impact for System 1 compared to Systems 2 and 3.

As seen in Figure 9, System 1 has a higher land use impact compared to Systems 2 and 3; it has 575% higher land use impact than System 2, and a 425% higher impact compared to System 3. Higher land use impacts are to be expected for fibre-based packaging products compared to fossil-based plastic products due to the production of raw materials. Given how much higher the land use impact is for System 1, Figure 7 and Figure 8 show the percentage change between scenarios without the land use impact category, to show better granularity of the other impact categories.

In Figure 7 and Figure 8, we can observe that for global warming impacts, there is a 21% lower impact for System 1 compared to System 2, and a 26% lower impact for System 1 compared to System 3.

For fossil resource scarcity impacts, there is a 24% lower impact compared to System 2, and a 28% lower impact compared to System 3. For water consumption, there is a 2-3% higher impact compared to both Systems 2 and 3.

On top of land use and water consumption impacts, the other impact categories where System 1 has a higher impact compared to the other two refill systems are ionising radiation and terrestrial ecotoxicity. Across these impact categories, System 1 has 5-14% higher impact. System 1 also has a higher impact compared to System 2 for stratospheric ozone depletion, ozone formation (human health), and ozone formation (terrestrial ecosystems). Across these impact categories, System 1 has 0.4-13% higher impact compared to System 2.

System 1 has a lower impact than Systems 2 and 3 across 9 impact categories, ranging from 10% to 40% lower environmental impact. System 1 also has a lower impact that System 3 across an additional 3 impact categories, ranging from 1% to 4% lower environmental impact for those impact categories.

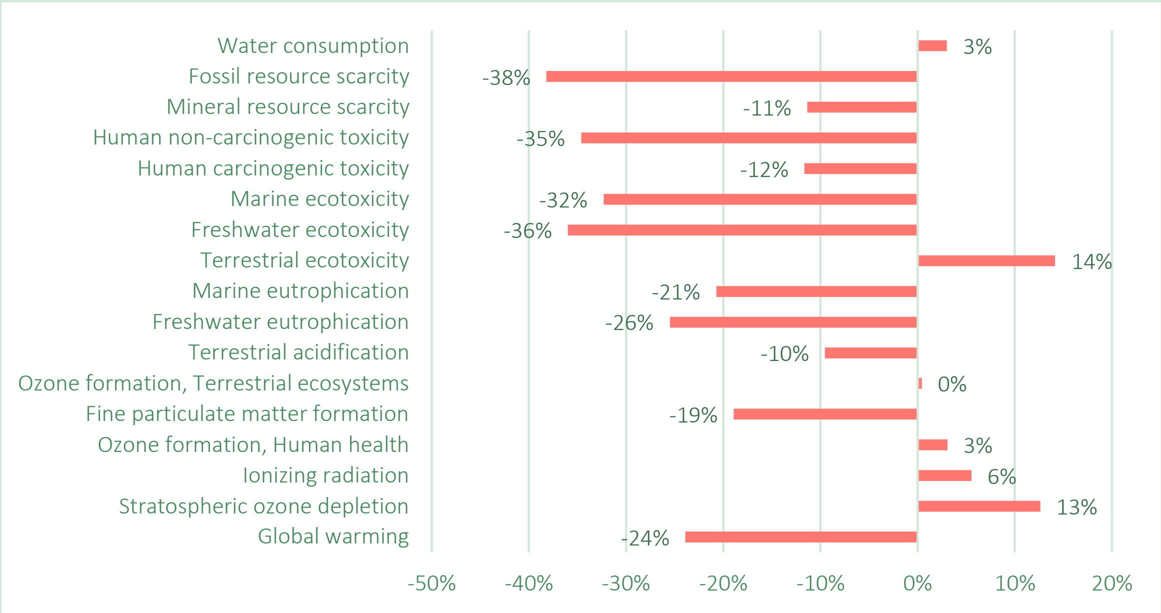

Figure 7:The percentage difference in environmental impact when comparing the System 1 and System 2 (excluding land use). System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle

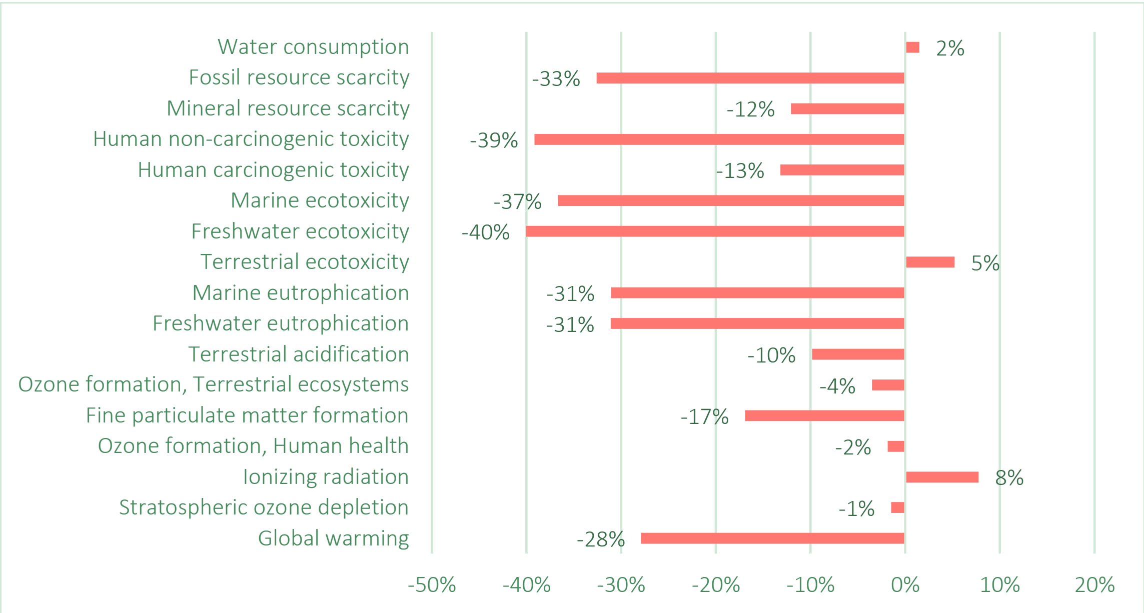

Figure 8: The percentage difference in environmental impact when comparing the System 1 and System 3 (excluding land use). System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle

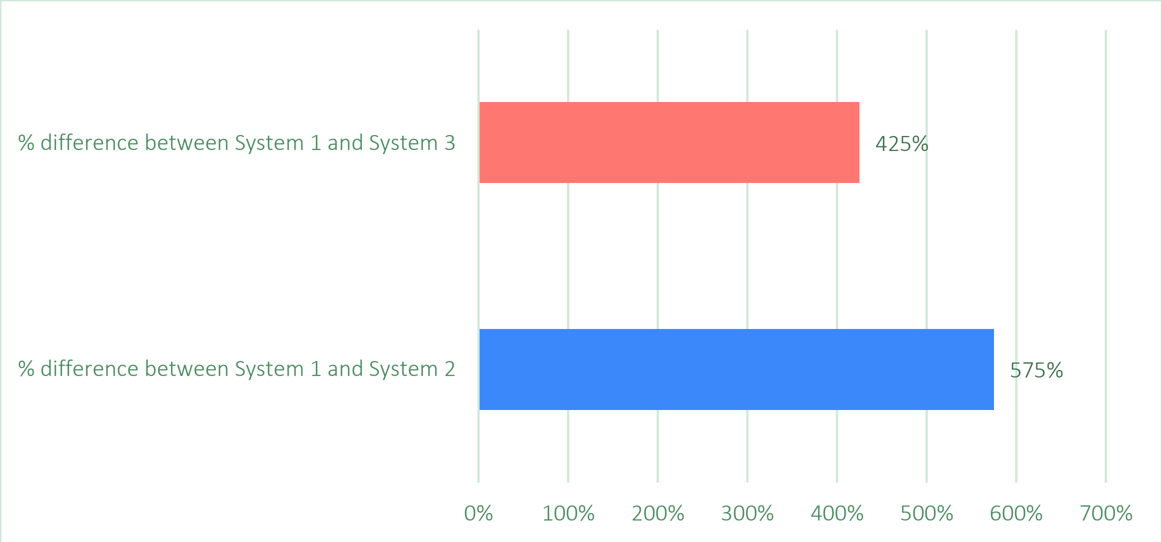

Figure 9: The percentage difference in land use impact when comparing the System 1 with Systems 2 and 3. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

Figure 10 shows the global warming impact per refill system by life cycle stage. Here we can observe that the material acquisition stage accounts for the largest share of the total impact, accounting for between 50% and 56%. The results show that System 1 has a lower global warming impact compared to System 2 and 3. This is driven by lower material acquisition and end-of-life impacts. The lower end-of-life impact of the System 1 is driven by the assumed 51% recycling rate of D-PAK™cartons (ACE, 2021), as opposed to the 6% of the LDPE pouches (Wrap, 2020). A more in-depth analysis of the main contributors to each stage can be found in section 4.2, and a sensitivity analysis of the end-of-life allocation for the studied systems can be found in section 4.4.2.2.

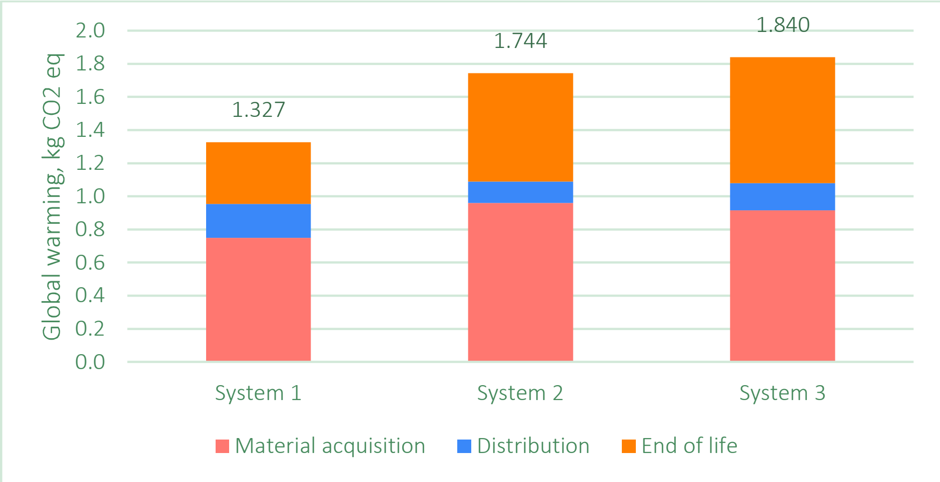

Figure 10: Global warming impacts across refill systems. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

Figure 11 shows the absolute water consumption impacts of the refill systems by life cycle stage. Here we observe that the water consumption impact is dominated by the material acquisition phase, accounting for between 92% and 94% of water consumption. Although System 1 has a higher water consumption impact, the results show that there are similar levels of water consumption across the three systems. Hence, due to the uncertainty of this impact category (see Section 4.5), the higher result for System 1 is not significant. Additionally, as outlined in Section 4.5, an error in

Ecoinvent 3.10 in the wastewater treatment process further compounds this uncertainty in the water consumption results.

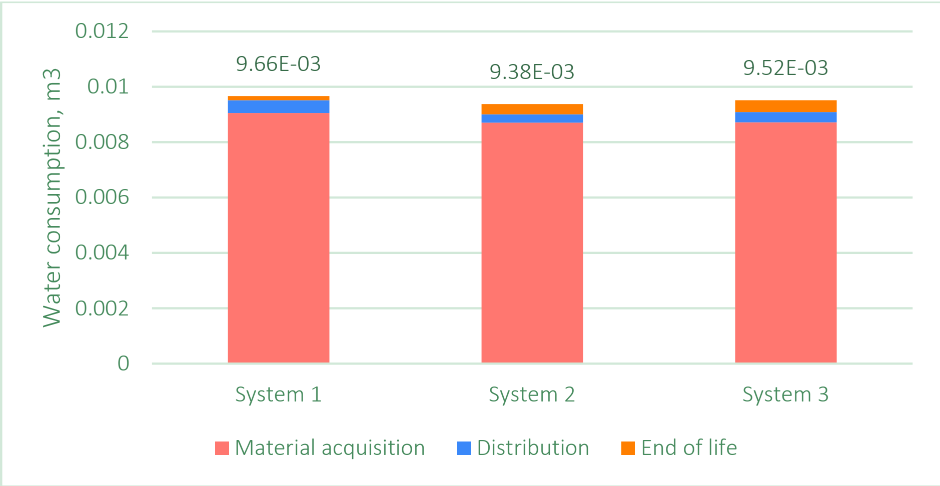

Figure 11: Water consumption impacts across refill scenarios. System 1 refers to 1L PP detergent bottle refilled with 1L D-PAK™ carton, System 2 refers to 1L PP detergent bottle refilled with 1.8L LDPE pouch, and System 3 refers to 1L PP detergent bottle refilled with 1L LDPE pouch.

Figure 12 shows the absolute land use impacts of the refill systems by life cycle stage. Here we observe that the land use impact is dominated by the material acquisition phase as well, accounting for between 87% and 97% of land use impacts. The results show that the D-PAK™ refill system has a 425% to 575% higher land use impact compared to the LDPE refill systems.

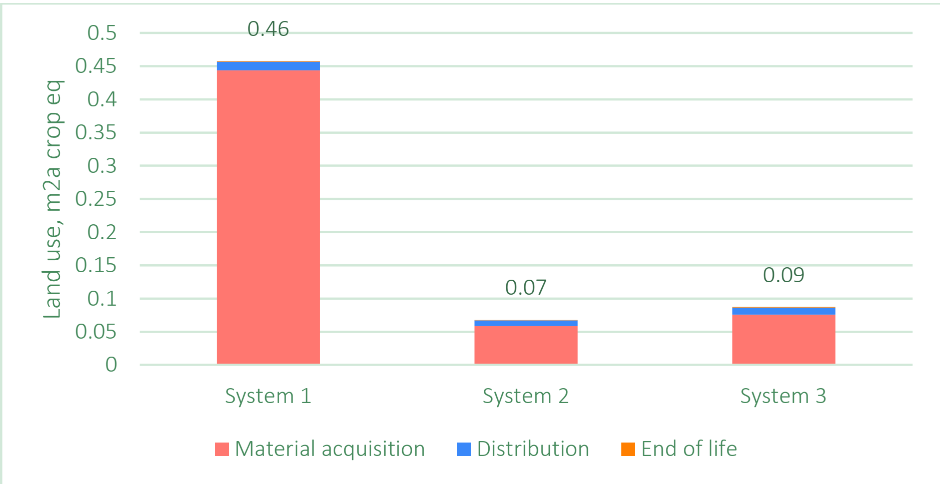

Figure 12: Land use impacts across refill scenarios. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

Figure 13 shows the absolute fossil resource scarcity impacts of the refill systems by life cycle stage. Here we observe that the fossil resource scarcity impact is dominated by the material acquisition phase, accounting for between 87% and 95% of fossil resource scarcity impacts.

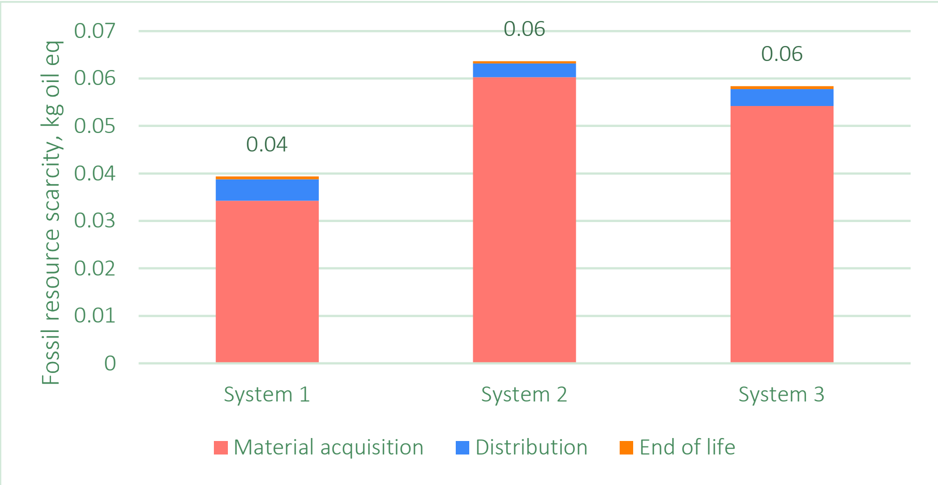

Figure 13: Fossil resource scarcity impacts across refill scenarios. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

As seen in Figure 14, Figure 15, and Figure 16, the contribution of the PP bottle in each of the Systems is limited to between 5-36% of total system impacts. For System 1, the PP Bottle contributes the least to the land use impact category (5% of total), and the most to fossil resource scarcity (36% of total) and freshwater ecotoxicity (36% of total). For System 2, the PP Bottle contributes the least to the marine eutrophication impact category (17% of total) and the most to land use (36% of total). For System 3, the PP Bottle contributes the least to marine eutrophication (15% of total), and the most to ionising radiation (36% of total).

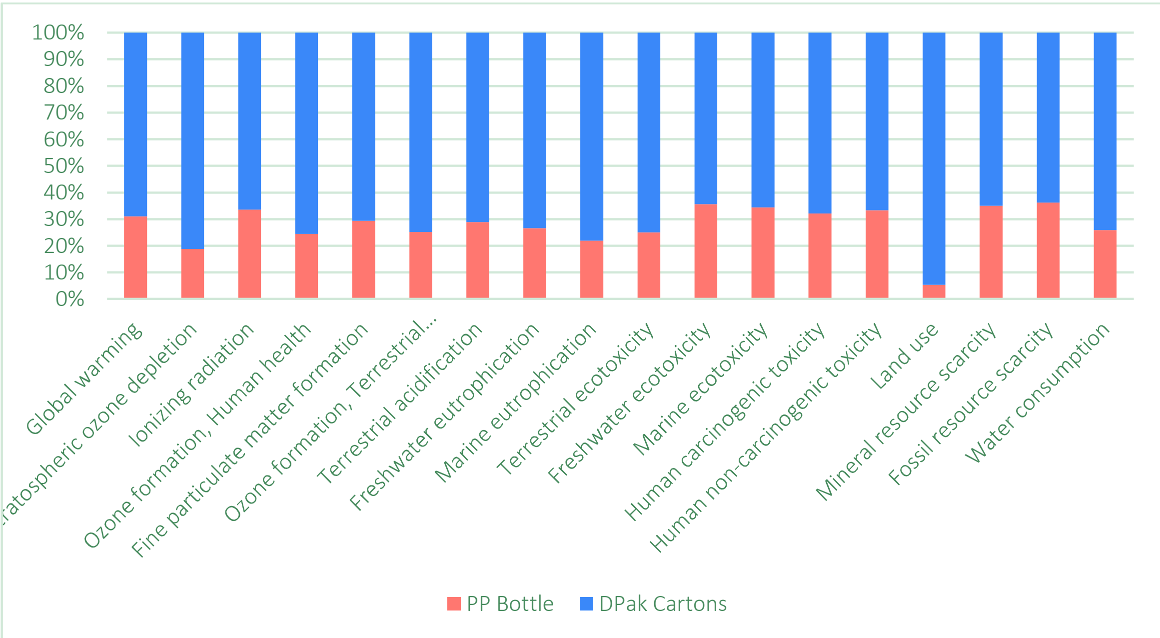

Figure 14: The relative contributions of the packaging formats across the life cycle of System 1 across all impact assessment categories. System 1 refers to: 10 D-PAK™ Cartons and 1 PP Bottle

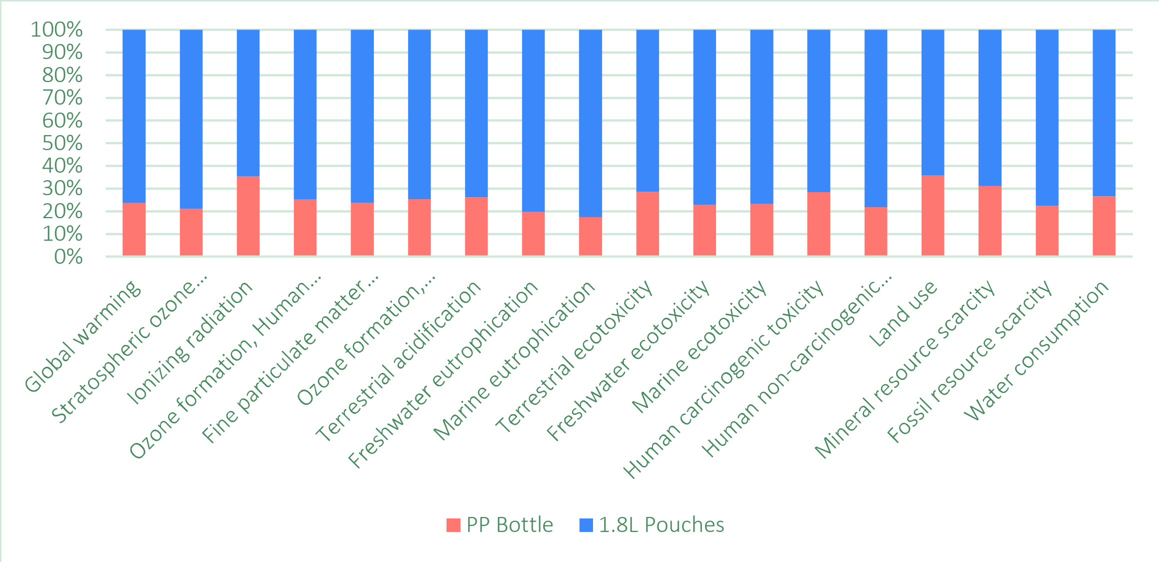

Figure 15: The relative contributions of the packaging formats across the life cycle of System 2 across all impact assessment categories. System 1 refers to: 5.56 1.8L LDPE Pouches and 1 PP Bottle

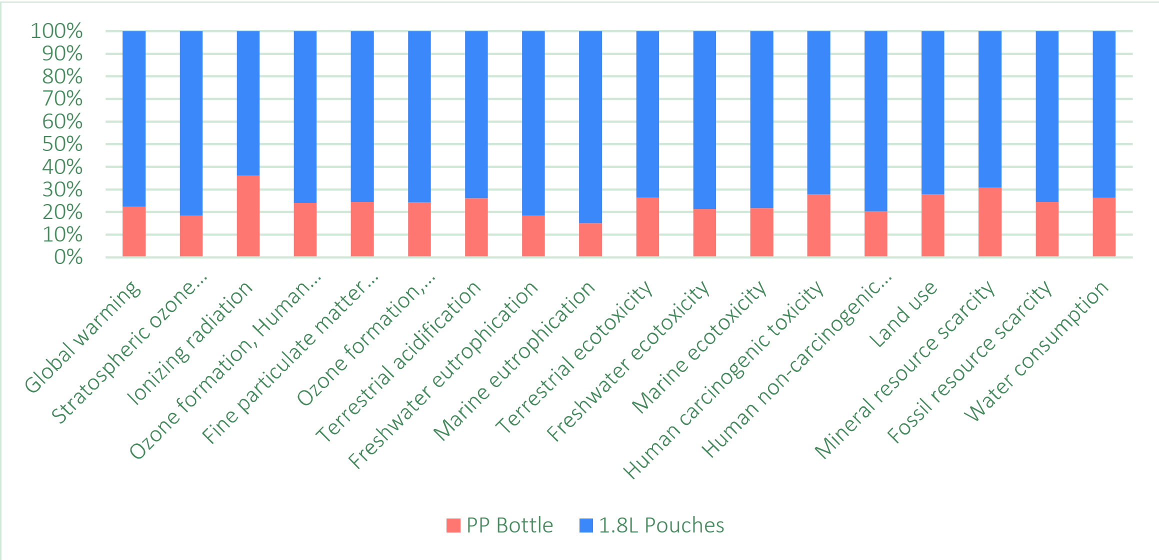

Figure 16: The relative contributions of the packaging formats across the life cycle of System 1 across all impact assessment categories. System 1 refers to: 10 1L LDPE Pouches and 1 PP Bottle

4.2 Hotspot analysis

Environmental hotspots enable understanding of the relative contributions of different processes to the overall environmental impacts. Figure 17 represents the relative contributions of different life cycle stages in the life cycle of System 1, Figure 18 presents the relative contributions System 3, and Figure 19 the relative contributions for System 2. Detailed results on process contributions can be found in Appendix F.

The limitations of different impact categories are also discussed and should be considered when interpreting the results. These can be found in Section 4.5.

For System 1, the largest contributor to all impact categories except for freshwater ecotoxicity and terrestrial ecotoxicity is the material acquisition stage (see Figure 17). For System 3, the material acquisition stage is the largest contributor to 11 out of 16 impact categories (see Figure 17). For System 2, the material acquisition stage is the largest contributor to 12 out of 16 impact categories (see Figure 18).

As seen in Figure 10, Systems 2 and 3 have higher global warming impacts than System 1. Figure 18 and Figure 19 show that the global warming impacts are largely due to the material acquisition phase (50-55% of total) and the end-of-life phase (38-41% of total). The end-of-life impacts are due to the incineration of LDPE at end-of-life, with incineration accounting for 31% of total impact for System 2, and 31% of the total impact for System 3. For System 1, the material acquisition phase contributes to 56% of the total life cycle impact, and the end-of-life phase contributes to 28% of the total life cycle impact. The incineration of waste plastic from both the D-PAK™ PE barrier and the PP Bottle used in this system account for 16% of the total global warming impacts. Impacts relating to the incineration of LDPE and PE in all 3 systems are driven by the incineration of fossil carbon content of the plastic which releases carbon dioxide and other greenhouse gases into the atmosphere.

System 1 has a marginally higher water consumption impact (2-3% higher impact) than the two pouch refill systems. For all systems, the material acquisition phase makes up most of the water consumption impacts (92-94% of total). For System 1, this is driven by the D-PAK™ packaging board (26% of total) and the LDPE used (21% of total). For System 2, the water consumption impacts are driven by the LDPE granulate process, accounting for 79% of total impact. For the System 3, the water consumption impacts are driven by the LDPE granulate process, accounting for 50% of total impact. It should be noted, however, that there is an elevated level of uncertainty relating to this impact category. This uncertainty is greater in regions of higher water scarcity and results from variability in actual water availability (due to uncertainty in precipitation).

System 1 has higher land use impacts than the LDPE Pouch refill systems, with a 575% higher land use impact compared to System 1 and a 425% higher land use impact compared to System 3, driven by the material acquisition phase. This is driven by the land use impacts of the liquid packaging board process which makes up for 82% of total land use impacts for that scenario. The land use impacts for Systems 2 and 3 are mostly driven by the material acquisition phase, followed by the distribution phase. Within the material acquisition phase, the land use impacts can be traced back to the use of pulpwood in the making of the corrugate board used to package the LDPE pouches for distribution and retail.

System 1 has a lower fossil resource scarcity impact than Systems 2 and 3. The main driver for impact for the System 1 is the material acquisition phase which contributes to 87% of total impact. This is largely due to the impact of hard coal and lignite used in ethylene production (27% of total) within the D-PAK™ carton's PE barrier and PP Bottle materials. For System 2, fossil resource scarcity impacts are linked to the extrusion of plastic sheets and thermoforming (41% of total) and the production of polyethylene (25% of total). As for System 3, the extrusion of plastic sheets and thermoforming (33% of total) and the production of polyethylene (20% of total).

As seen in Figure 7 and Figure 8, System 1 also has higher impacts than Systems 2 and 3 for ionising radiation and terrestrial ecotoxicity. Within these two impact categories, the main impact contributor to the overall impact of System 1 is the material acquisition phase (54-96% of total). Within these impact categories, the main contributor to the overall impacts for Systems 2 and 3 is material acquisition. Distribution impacts for Systems 2 and 3 in terms of terrestrial ecotoxicity are also significant due to break wear emissions from the lorries used in the distribution phase of the life cycle. Additionally, System 1 has higher impacts than System 2 for stratospheric ozone depletion, ozone formation (human health), and ozone formation (terrestrial ecosystems). Within these impact categories, the main impact driver for Systems 1 and 2 is the material acquisition phase except for System 2's stratospheric ozone depletion impacts which are driven by end-of-life impacts.

As seen in Figure 7 and Figure 8, System 1 has lower impacts than Systems 2 and 3 for fine particulate matter formation, terrestrial acidification, freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, marine ecotoxicity, human carcinogenic toxicity, human non-carcinogenic toxicity, and mineral resource scarcity. Across these impact categories, the material acquisition phase continues to make up most of the total impact for System 1 (44-80% of total impact). For Systems 2 and 3, the material acquisition phase contributes to most of the impact (48-88% of total impact) across these categories except for freshwater eutrophication, marine eutrophication, freshwater ecotoxicity, and marine ecotoxicity. For those impact categories, the end-of-life phase contributes to the majority of total impacts. Additionally, System 1 has lower impacts that System 3 for stratospheric ozone depletion, ozone formation (human health), and ozone formation (terrestrial ecosystems). System 3's impacts for these impact categories are driven by the material acquisition phase (48-70% of total impact).

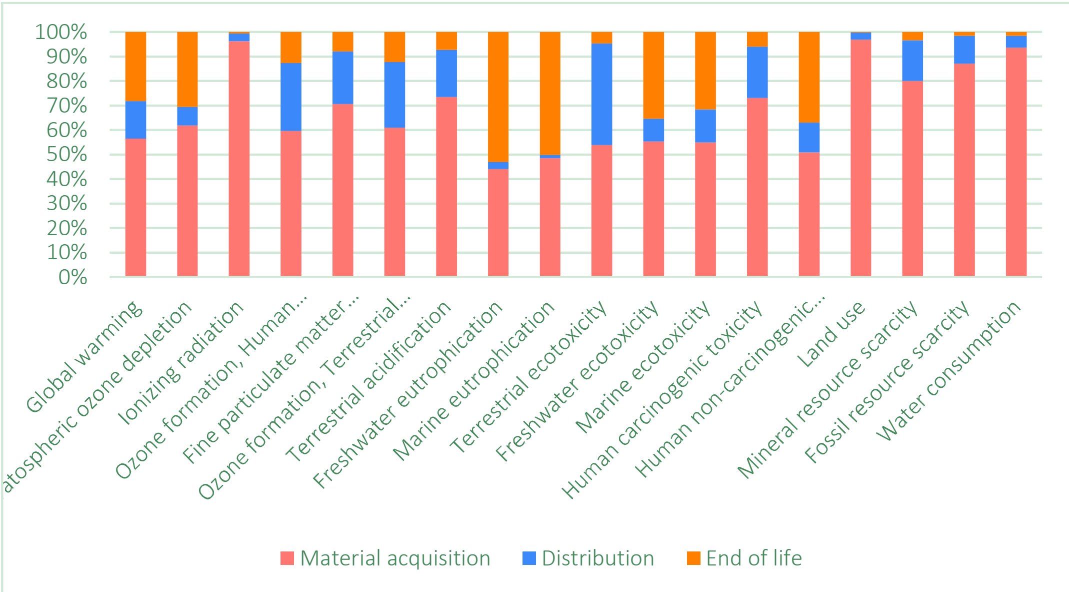

Figure 17: The relative contributions of processes in the life cycle of System 1 across all impact assessment categories. System 1 refers to: 10 D-PAK™ Cartons and 1 PP Bottle.

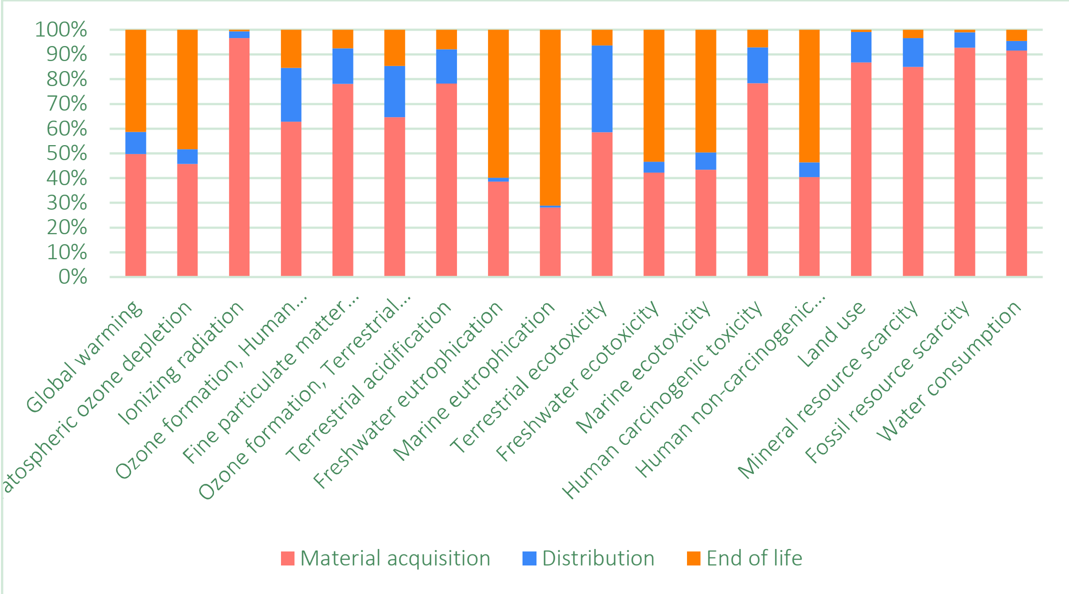

Figure 18: The relative contributions of processes in the life cycle of System 3 across all impact assessment categories. System 3: 10 1L LDPE Pouches and 1 PP Bottle.

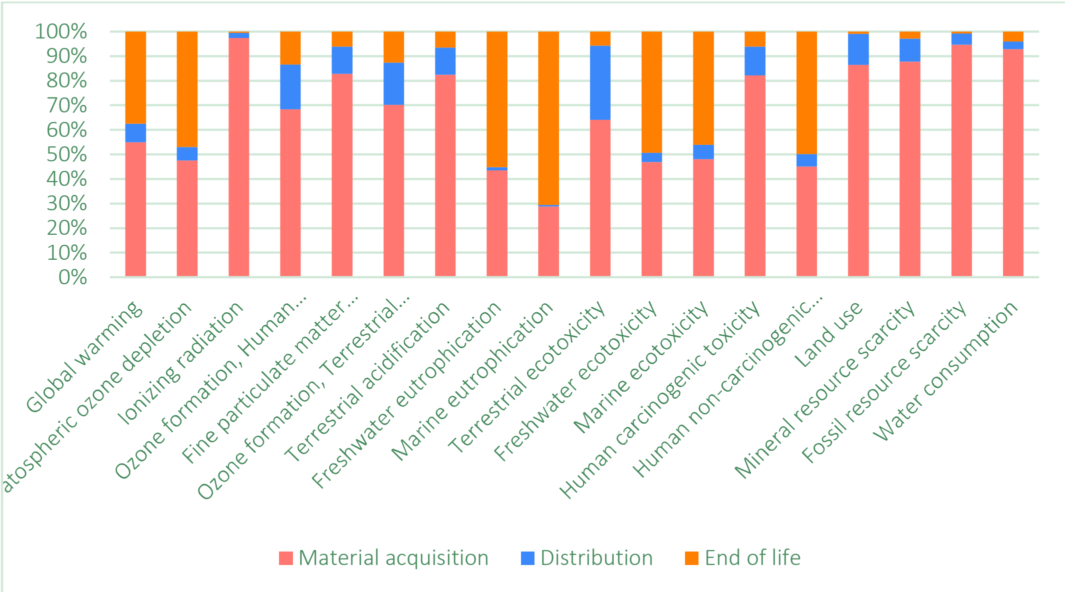

Figure 19: The relative contributions of processes in the life cycle of System 2 across all impact assessment categories. System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle.

Although the focus of this LCA is to compare the System 1 with the LDPE Pouch refill systems available to consumers, given Elopak has more control over the impact of its D-PAK™ carton it is worth investigating the hotspots within this product's life cycle. As such, Elopak could make changes to their product according to the impact hotspots found; recommendations for impact reduction can be found in Section 4.6. Hotspots over the 16 impact categories for this product can be found in Figure 20.

As seen in that figure, for global warming impacts, the largest contributor is the materials acquisition phase, accounting for 53% of the total life cycle impact. This is driven by the impact of the liquid packaging board (10% of total) and the lining of the board (16% of total). The lining of the board has a higher impact compared to the board itself; this is despite the lining weighing approx. 5g and the board weighing approx. 23g. The second largest life cycle stage impact is the end-of-life of the D-PAK™ carton, contributing to over 32% of the total life cycle impact. This is largely due to the proportion of D-PAK™ materials that are not recycled and are sent to landfilling and incineration. It should be noted that it was assumed that 51% of D-PAK™ cartons are recycled. This assumption is explored in the sensitivity section and is subject to limitations, see section 4.5.

Figure 20 also shows that for the water consumption impact category, the largest contributor is the liquid packaging board (44% of total) followed by the lining (22% of total). Overall, the material acquisition phase accounts for 94% of total water consumption impacts. For land use, as expected, the material acquisition phase accounts for the largest share, 97%, of the total impact. This is driven by the land use from the production of liquid packaging board (94% of total). For fossil resource scarcity, the material acquisition phase makes up for 83% of total impact, with the largest impacts driven by the plastic lining of the carton (25% of total), the cap (21% of total), and the downstream distribution transport (17% of total).

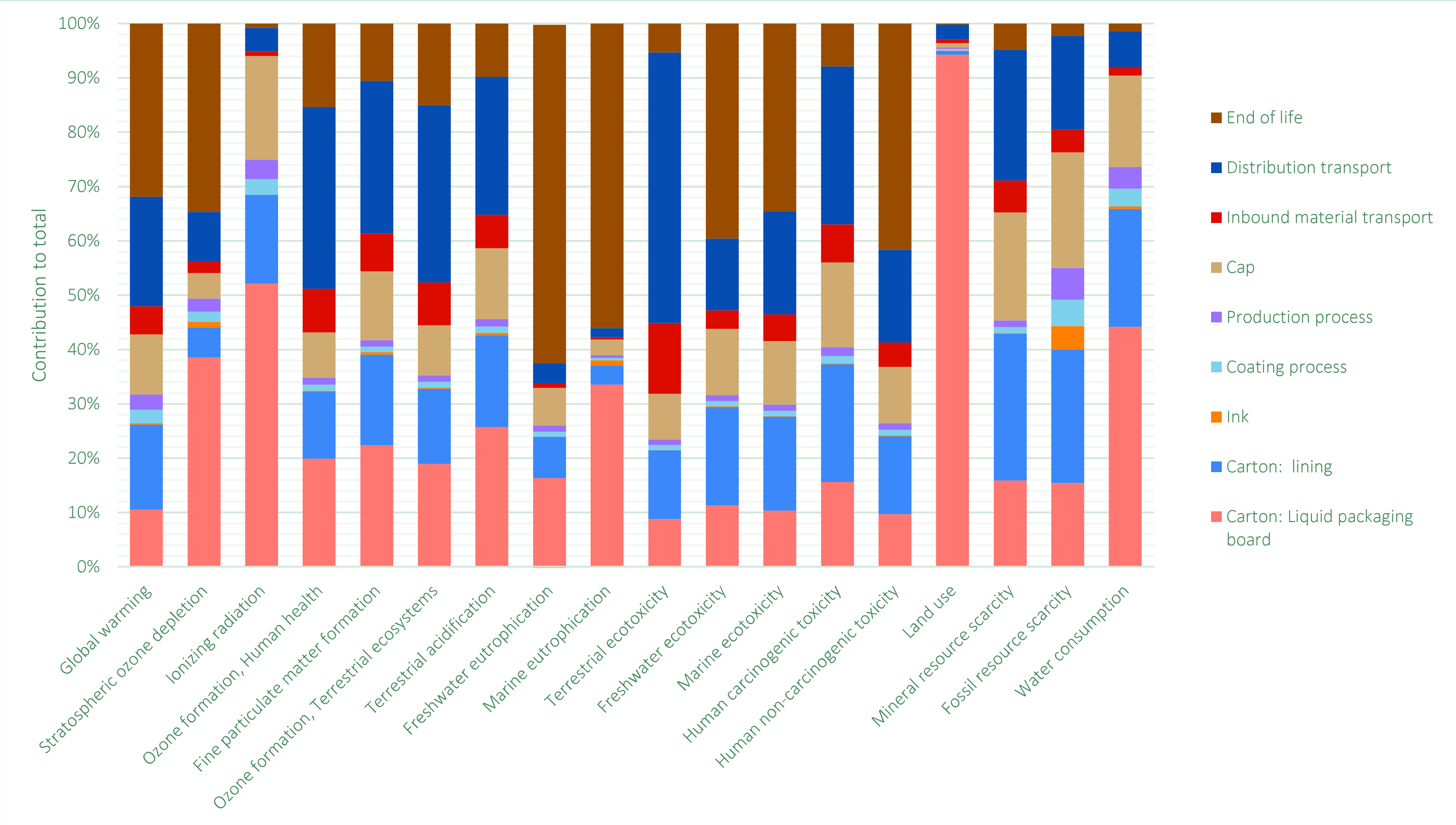

Figure 20: Whole life cycle impact contributions for the D-PAK™ carton only (1 unit) across all 16 impact categories considered in this study.

4.3 Interpretation

Highlighted in this section is any significant finding relevant to the goal and scope of this study.

Accurate and comparable environmental profiles were developed for the three different refill scenarios considered.

It can be concluded that from the environmental profiles of the refill scenarios in this study, that the System 1 has a lower environmental impact than Systems 2 and 3 across 11 impact categories including global warming (24-28% reduction in impact) and fossil resource scarcity (33-38% reduction in impact. System 1 also has a lower impact than system 3 across an additional 3 impact categories.

For global warming, a significant difference between System 1 and Systems 2 and 3 is the end-of-life impact. Indeed, though the material acquisition phase is marginally lower in System 1, the end-of-life phase impacts Systems 2 and 3 lead to the largest difference in the results of the scenarios. In Section 4.4.2.2, the sensitivity of the results to the recycling rates of the studied products is explored. Across the water consumption and land use impact categories, the main impact contributor for all refill scenarios is the material acquisition phase.

It is important to note that the System 1 has higher impacts in 7 impact categories compared to System 2, and higher impacts in 4 impact categories compared to System 3. This includes land use impacts where System 1 has 425-575% higher impacts compared to systems 2 and 3. Impacts for land use are largely driven by the material acquisition phase with System 1 relies on fibre-based materials rather than fossil-based materials, it produces a higher land use impact than its LDPE pouch refill system alternatives.

Please note that as stated in ISO 14044, LCA should not provide the sole basis of comparative assertion intended to be disclosed to the public of overall environmental superiority or equivalence, as additional information will be necessary to overcome some of the inherent limitations of LCA.

4.4 Evaluation

4.4.1 Completeness

In the case where no data is available for a unit process, a comparison between two possible options may be performed. This comparison may show that the impact of the unit process is material or conclude that the difference between the studied products is not significant or not relevant for the given goal and scope. The basis of the completeness check is a checklist including all required inventory parameters, required life cycle stages and processes as well as the required impact category indicators.

Key – X = data available, / = some data available, - = no data available, (P) – Primary data, (S) - Secondary data

Table 15 - Summary of completeness check

Sub process	D-PAK Carton System	LDPE Pouch System	Complete?	Comment
Packaging components	X (P,S)	X (P,S)	Y	Primary data obtained for D-PAK, bottle and pouch relating to weight of material used in packaging components. Secondary data emissions factors used.
Packaging components transport to production site	X (P,S)	X (S)	Y	Primary data obtained for the D-PAK carton. Secondary assumptions used for the LPDE pouch and the PP bottle. Secondary data emissions factors used for both systems. Sensitivity carried out on the secondary data choices.
Packaging production process	X (P,S)	X (S)	Y	Primary data obtained for D-PAK production process. Secondary data assumptions used for LDPE pouch and the PP bottle. Secondary data emissions factors used for both.
Packaging transport to filling site	X (S)	X (S)	Y	Secondary assumptions used from PEF to determine distances for both systems. Secondary data emissions factors

Sub process	D-PAK Carton System	LDPE Pouch System	Complete?	Comment
				used. Sensitivity carried out on the secondary data choices
Packaging transport to retail/distribution	X (S)	X (S)	Y	Secondary assumptions used from PEF to determine distances for both systems. Secondary data emissions factors used. Sensitivity carried out on the secondary data choices
Packaging transport to end-of-life treatment	X(S)	X (S)	Y	Secondary assumptions used from UK government data to determine distances for both systems. Secondary data emissions factors used.
Packaging end-of-life treatment processes	X (S)	X (S)	Y	Secondary assumptions used from various sources to determine treatment routes. Secondary data emissions factors used. Sensitivity carried out on the secondary data choices

4.4.2 Sensitivity Analysis

Eight sensitivity analyses were explored in this study to test the validity of results and observations drawn from the baseline model. Table 16 outlines the sensitivity analyses conducted and the motivation behind the selection of each.

Table 16: Sensitivity analyses undertaken in this LCA.

Sensitivity	Motivation	Analysis
Variation in the percentage of recycled content included in the LDPE pouch	To determine if a change in the recycled content of the pouch affects the comparison to the carton system	50% and 100% recycled content were explored

Sensitivity	Motivation	Analysis
Variation in the recycling rate of the carton, pouch and bottle	To test the assumptions of recycling rate for all packaging formats and understand if this impacts results.	Carton recycling rates: • Best case: 75% • Worst case: 35% LDPE pouch recycling rates: • Best case: 17% (Plastics Recyclers Europe, 2022) • Worst case: 0%, based on the fact flexible films are not widely recyclable across Europe and the UK. PP Bottle recycling rates: • Worst base: 45% (Recoup, 2022)
Variation in the end-of-life allocation method. Utilisation of Circular Footprint Formula (CFF)	To determine how different end of life approaches affect the results	Using default values and method provided by the European Commission (European Commission & Sphera, 2020)
Variation in the estimated distribution distances	To test the impact of the distribution distance assumptions taken from PEF	1200 km downstream transport from filling site to distribution centre/retail using local supply chain assumption from PEF. (European Commission, 2021)
Variation in pouch weight	To test if the specifications of the LPDE pouch impact overall results, considering that there are many formats of refill pouch on the market	See Appendix G for details
Variation in bottle material	Guided by Elopak it was highlighted that PP is not the only material type likely for detergent bottles. To test if the specifications of the PP bottle impact overall results, considering that detergent may also come in other plastic bottles.	HDPE selected as an alternative material, same material was assumed for the cap and label. The weight assumed was 68.02g based on the density of HDPE and the volume of the PP bottle.

Sensitivity	Motivation	Analysis
Variation in secondary packaging choice	Elopak supplied several different secondary packaging options, so these were explored to determine if secondary packaging changes impact results.	See Appendix H for details
Comparing bottle, pouch, and carton performance in single use systems.	To understand how the impact comparison may change if the packaging is used in a single use system, considering that some consumers may continue to stick with single use despite refill options being available	11 of each packaging formats were compared to simulate the function of the packaging operating in a single use system, while maintaining consistency with the functional unit of the study.

4.4.2.1 Pouch recycled content variability.

The results of the sensitivity analysis exploring the variation in the percentage of recycled content included in the LDPE pouch are shown in Figure 21. Here we can see that the variation in the recycled content of the LDPE used in the LDPE pouches result in lower overall impacts compared to their respective refill system baselines. For System 2, 50% recycled content reduces the global warming impact of the system by 34%, and 100% recycled content reduces the global warming impact of the system by 37%. For System 3, 50% recycled content reduces the global warming impact of the scenario by 5%, and 100% recycled content reduces the global warming impact of the scenario by 11%. Compared to the System 1 baseline, the global warming impact of System 3 remains higher by at least 31%. However, compared to System 1's baseline, the impact of System 2 changes the direction of the results. With 50% recycled content, System 2 has a 13% smaller global warming impact than System 1, and with 100% recycled content the impact of System 2 is 17% smaller than System 1. From this sensitivity analysis, it is evident that the direction of the results is sensitive to the amount of recycled content considered in the LDPE pouch alternatives.

Across other impact categories, when System 2 has 50% recycled content in the LDPE pouch its impacts change between -15% (water consumption) and 2% (marine eutrophication). When it has 100% recycled content in the LDPE pouch, its impacts change between -31% (water consumption) and 5% (marine eutrophication). For System 3, the use of 50% recycled content in the LDPE pouch changes its impacts by -11% (water consumption) and 2% (marine eutrophication). The use of 100% recycled LDPE in System 3 changes impacts between -22% (water consumption) and 3% (marine eutrophication.

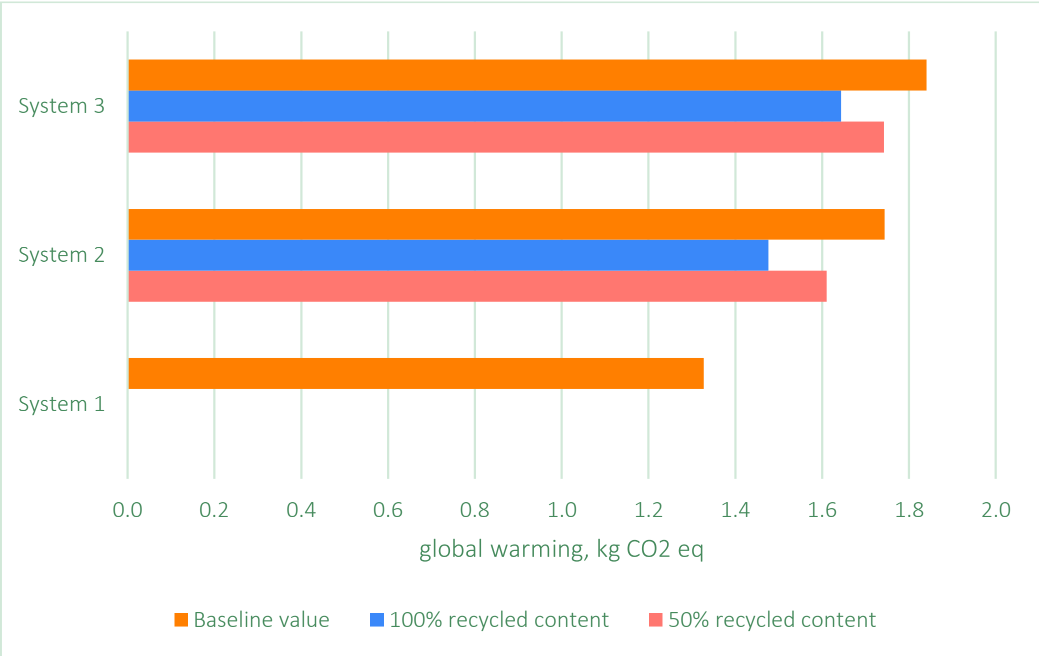

Figure 21: Sensitivity analysis investigating the influence on climate change impacts of the studied refill systems under the sensitivity scenario exploring the variation in recycled content of the LDPE pouches. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

4.4.2.2 Recycling rate variability

The results of the sensitivity analysis exploring the impact of the variation in the recycling rates of the D-PAK™ carton, LDPE pouches, and PP bottle on the refill systems considered in this study can be seen in Figure 22. For System 1, the best-case end of life scenario leads to a decrease in global warming impact of 8%, and an increase of 21% with the worst-case scenario. For System 2, the best-case end-of-life scenario leads to a decrease in global warming impact of 3%, and an increase of 5% with the worst-case scenario. For System 3, the best-case end of life scenario leads to a decrease in global warming impact of 4%, and an increase of 5% with the worst-case scenario.

Even in the best-case end-of-life scenario for System 3, the global warming impact is still 33% higher than the System 1's baseline results, however it is only 13% higher than System 1's worst-case scenario. In the best-case end-of-life scenario for System 2, the global warming impact is still 27% higher than System 1's baseline results, however it is only 8% higher than the System 1's worst-case end-of-life results. Overall, even using worst case end of life allocation assumptions for System 1 (i.e. where 0% of cartons get recycled), System 1 still has a lower impact than Systems 2 and 3. There isn't a directional change in the results for global warming impacts, this is also true for the water consumption, land use, and fossil resource scarcity impact categories (See Appendix D).

Across other impact categories, the best-case end of life scenario for System 1 leads to reductions of <1% (for ionising radiation, land use, fossil resource scarcity, and water consumption) to 17% for freshwater eutrophication. The worst-case end of life scenario for System 1 leads to increased environmental impacts of <1% (for ionising radiation and land use) to 42% for freshwater eutrophication. For System 2, the best-case end of life scenario leads to reductions of <1% (for 9 impact categories) to 7% for marine eutrophication. The worst-case end of life scenario for System 2 leads to increased environmental impacts of <1% (for 9 impact categories) to 9% for marine eutrophication. For System 3, the best-case end of life scenario leads to reductions of <1% (for 9 impact categories) to 7% for marine eutrophication. The worst-case end of life scenario for System 3 leads to increased environmental impacts of <1% (for 9 impact categories) to 9% for marine eutrophication. The impact categories most affected (with the biggest percentage change from the baseline values) by the end-of-life scenarios from the results of this study are freshwater eutrophication and marine eutrophication.

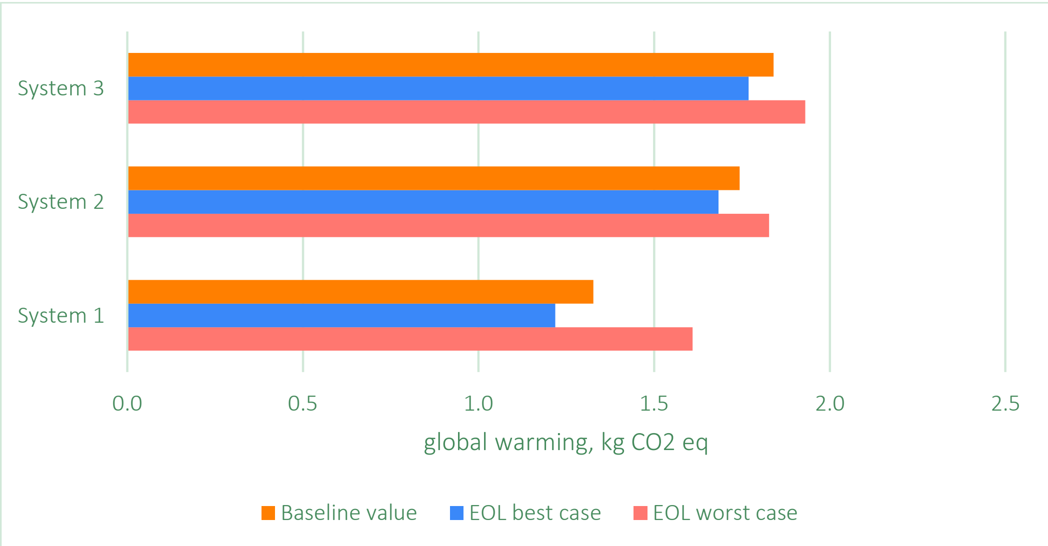

Figure 22: Sensitivity analysis investigating the influence on climate change impacts of the studied refill systems under the sensitivity scenario exploring the best-case and worst-case end of life allocations for the LDPE pouches, the D-PAK™ carton, and the PP bottle. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

4.4.2.3 Circular Footprint Formula (CFF)

The results of the sensitivity analysis exploring the variation in climate change impact using an alternative end-of-life allocation method, the Circular Footprint Formula, are shown in Figure 23.

The results show that across the three systems the climate change impact is lower when utilising the CFF method (47%, 45% and 42% lower across systems 1 to 3)

The impacts across all three systems have a narrower range of results compared to the cut-off method used in the baseline with a range of 0.3 kgCO2e across all the systems when using the CFF compared to 0.5 kgCO2e when using cut-off.

Figure 20 also shows error bars that show the impact of changing the recycling rates to explore the impact of the best and worst recycling rates, the effects on baseline are described in 4.4.2.2.

Figure 20 shows that if the worst-case recycling rates are realise for system 1 and the best rates are realised for systems 2 and 3 then overall impact of the systems falls to within 0.1 kgCO2e of each other.

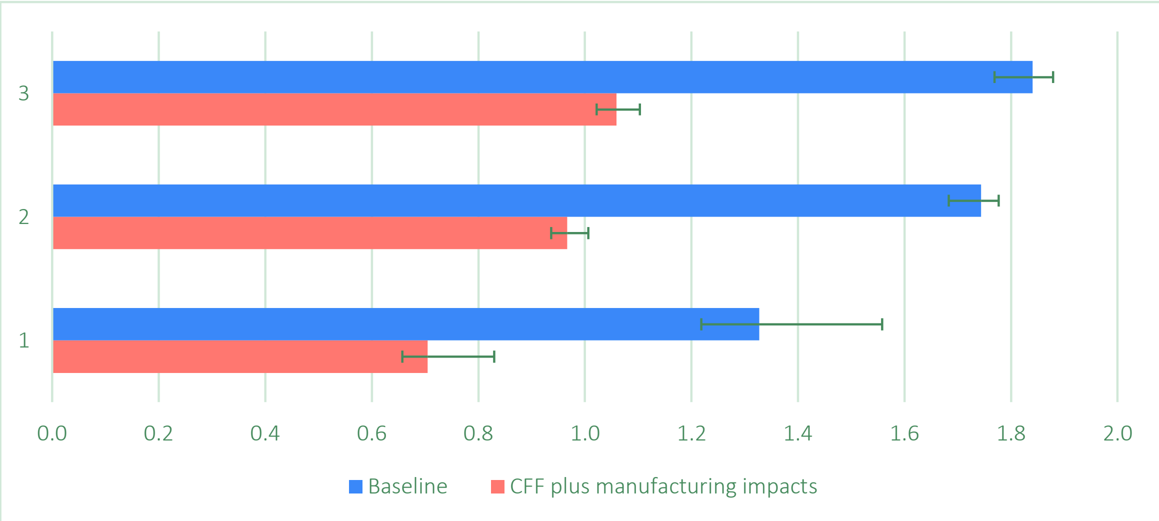

Figure 23: Sensitivity analysis investigating the influence on climate change impacts of undertaking an alternative end-of-life allocation method. System 1 refers to 1L PP detergent bottle refilled with 1L D-PAK™ carton, System 2 refers to 1L PP detergent bottle refilled with 1.8L LDPE pouch, and System 3 refers to 1L PP detergent bottle refilled with 1L LDPE pouch.

4.4.2.4 Distribution distance variation

The results of the sensitivity analysis exploring the impact of the variation in the downstream transport of the refill scenarios considered in this study can be seen in Figure 24. Here we can see that the variation in the downstream transport of System 1 leads to a decrease in impact of 6%. For System 3, there is a 3% decrease in impact, but its impact compared to System 1's baseline results is 43% higher. For System 2, there is a 2% decrease in impact, but its impact compared to System 1's baseline results is 59% higher.

Across other impact categories, the variation in the downstream transport of System 1 leads to reductions in impact between 1% and 25% (for terrestrial ecotoxicity). For System 2, the change leads to a reduction in impact between <1% and 18% (for terrestrial ecotoxicity). For System 3, the change leads to a reduction between <1% and 21% (for terrestrial ecotoxicity). The impact categories most affected by the variation in downstream transportation are terrestrial ecotoxicity, ozone formation human health, and ozone formation terrestrial ecosystems.

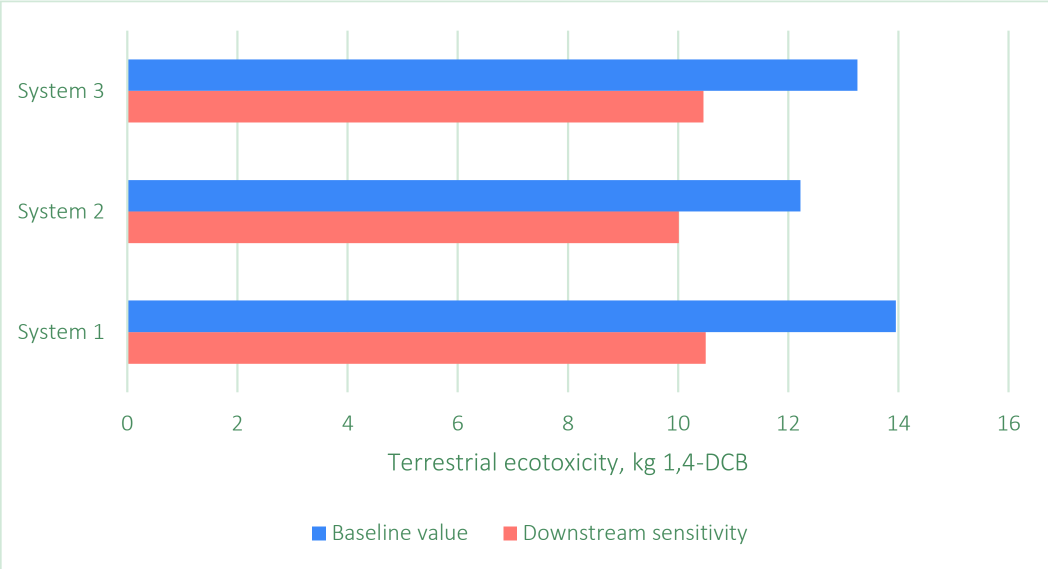

Figure 24: Sensitivity analysis investigating the influence on fossil resource scarcity impacts of the studied refill systems under the sensitivity scenario exploring a decrease in downstream transport distance for the three refill systems considered. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

4.4.2.5 Pouch weight variation

The results of the sensitivity analysis exploring the impact of the variation in pouch weight of the LDPE Pouch refill systems considered in this study can be seen in Figure 25. Here we can see that the impact of System 3 increases by 32% using the weight variance derived from the 0.5L LDPE pouch and decreases by 0.18% using the weight variance derived from the 0.6L LDPE pouch. Compared to the baseline System 1 results, the impact System 3 is 38-82% higher. We also see that the impact of System 2 increases by 57% using the weight variance derived from the 0.5L LDPE pouch and increases by 13% using the weight variance derived from the 0.6L LDPE pouch. Compared to the baseline System 1 results, the impact of System 2 is 49-106% higher. Hence, the variation in weight does not directionally affect the results of the LCA study. This is also true across the water consumption, land use, and fossil resource scarcity impact categories (See Appendix D).

Across other impact categories, the variation in the pouch weight for System 2 increases impacts between 21% (land use) and 61% (marine eutrophication) for the 0.5L pouch scenario and increases impacts between 5% (land use) and 14% (marine eutrophication) for the 0.6L pouch scenario. As for the variation in the pouch weight for System 3, it increases impacts between 8% (land use) and 38% (marine eutrophication) for the 0.5L pouch scenario, and changes impacts between -4% (fossil resource scarcity) and 2% (marine eutrophication) for the 0.6L pouch scenario.

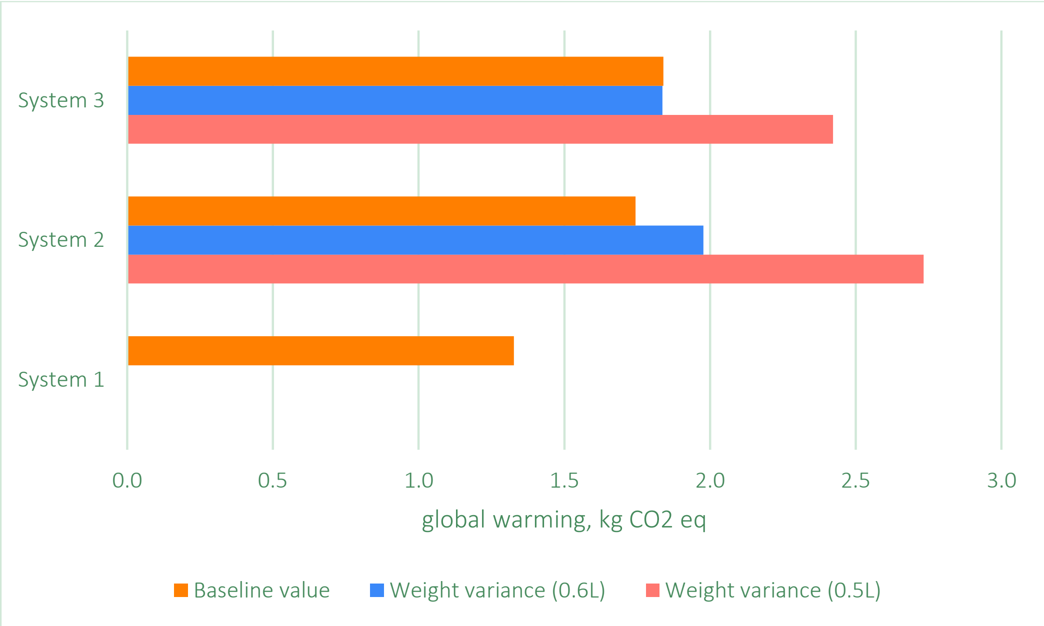

Figure 25: Sensitivity analysis investigating the global warming impacts of the studied refill systems under the sensitivity scenario exploring variation in the pouch weights for the 1L and 1.8L LDPE Pouch refill scenarios. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

4.4.2.6 PP bottle material variation

The results of the sensitivity analysis exploring the impact of the variation in the PP bottle's material on the refill scenarios' global warming impacts in this study can be seen in Figure 26. For this sensitivity analysis, a HDPE bottle was considered, keeping the same assumptions around the amount of material required, and the composition and weight of the other bottle components (e.g. cap, label, and ink). For System 1, the variation in the bottle's material from PP to HDPE leads to a 2.3% increase in global warming impact. For both Systems 2 and 3, the variation in the bottle's material leads to an increase in global warming impact of 1.7-1.8%. Therefore, there isn't a significant directional change in results from a change in bottle material to HDPE; results could differ for a change to a PET bottle. This is also true for the land use, water consumption, and fossil resource scarcity impact categories.

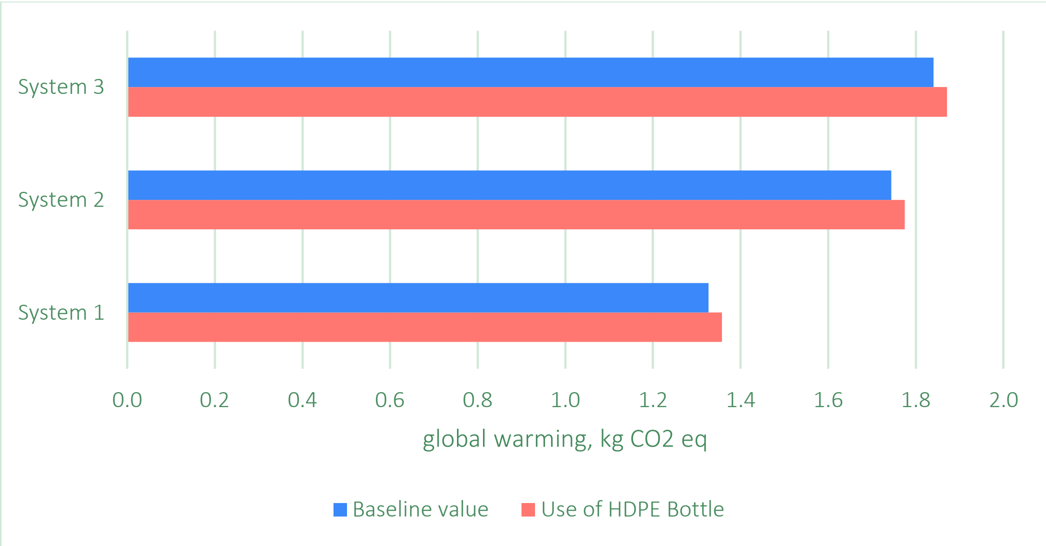

Figure 26: Sensitivity analysis investigating the global warming impacts of the studied refill systems under the sensitivity scenario exploring variation in the material of the bottle being refilled. System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle.

4.4.2.7 Secondary packaging variation

The results of the sensitivity analysis exploring the impact of the variation in System 1's secondary packaging can be seen in Figure 27. Four packaging options are available for the D-PAK™ cartons:

- Option 1: 2x3 Wrap around B-flute, 8.24 g per D-PAK™ carton
- Option 2: 2x3 Wrap around E-flue, 7.92 g per D-PAK™ carton
- Option 3: 2x4 Wrap around B-flute, 12.12 g per D-PAK™ carton
- Option 4: 2x4 Wrap around E-flue, 10.30 g per D-PAK™ carton

The baseline scenario of the D-PAK™ carton uses secondary packaging option 1 (see Appendix H for more details).

As seen in this figure, there is a 0.4% decrease in impact when option 2 is selected instead of the baseline packaging option. There is an increase of 2.4% with option 4 and an increase of 4.5% with option 3. It is worth noting that even with option 4, the baseline impacts of Systems 3 and 2 (respectively 1.74 kg CO2e and 1.69 kg CO2e) are still higher. Therefore, a variation in the secondary packaging options available for System 1 does not directionally affect the results of the comparative LCA.

Across other impact categories, option 2 changes System 1's impacts by between -1% and 0%, option 3 changes System 1's impacts by between 3% and 7%, and option 4 changes System 1's impacts by between 2% and 4%.

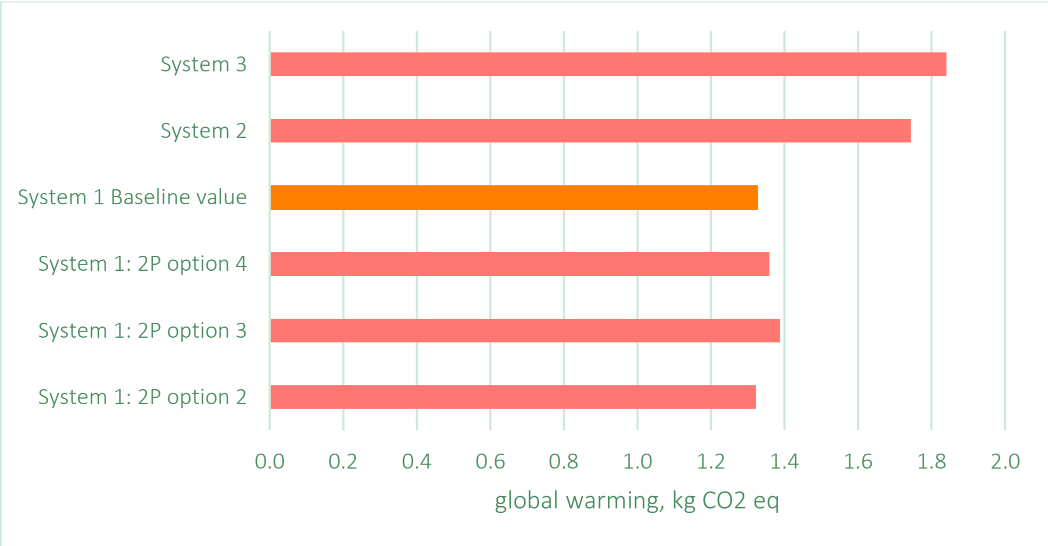

Figure 27: Sensitivity analysis investigating the global warming impacts of D-PAK™ refill system under the sensitivity scenario exploring variation in secondary packaging options.

4.4.2.8 *Packaging function in a single use scenario*

The results of the sensitivity analysis exploring the global warming impacts of a single use system instead of a refill system can be seen in Figure 28. As seen in this figure, overall, a single use system (i.e. a system where consumers continue to stick with single use despite refill options being available), leads to a decrease in overall impact. For System 1, a single use system leads to a 22.5% decrease in impact, for System 2 this is a decrease of 15.6%, and for System 3 this is a decrease of 14.0%. Across these single use scenarios, System 1 using only D-PAK™ cartons has the lowest global warming impact, 16% lower than the System 3's single use system and 7% lower than System 2's single use systems. The single use PP Bottle has the highest impact, 224% higher than the single use System 1 and 318% higher than the baseline System 1 refill system.

Figure 29 shows the impact of the sensitivity analysis exploring the land use impacts of a single use system instead of a refill system. In this figure, the System 1 single use scenario has the highest impact compared to the refill system and the other product systems considered.

Across other impact categories, for System 1, a single use system changes impacts by between -30% (fossil resource scarcity) and 4% (land use). For System 2, a single use system changes impacts by between -24% (land use) and -3% (marine eutrophication). For System 3, a single use system changes impacts by between -30% (ionising radiation) and -7% (marine eutrophication).

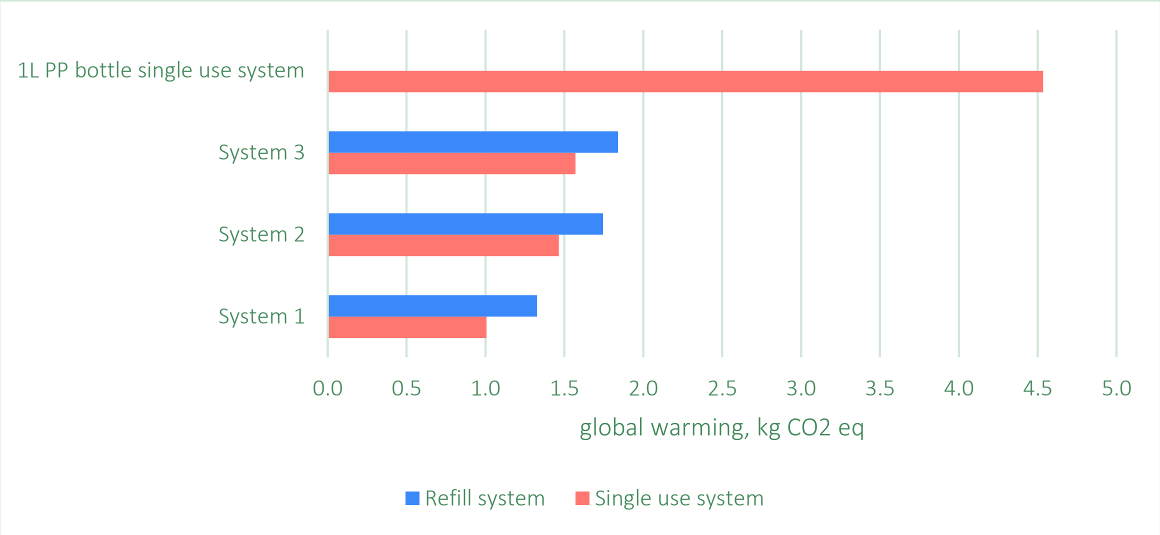

Figure 28: Sensitivity analysis investigating the global warming impacts of a single use system compared to the refill system being considered in this study. For the refill systems: System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle. For the single use systems: System 1 refers to 11 1L D-PAK™ cartons used, System 2 refers to 6.1 1.8L LDPE pouches, and System 3 refers to 11 1L LDPE Pouches.

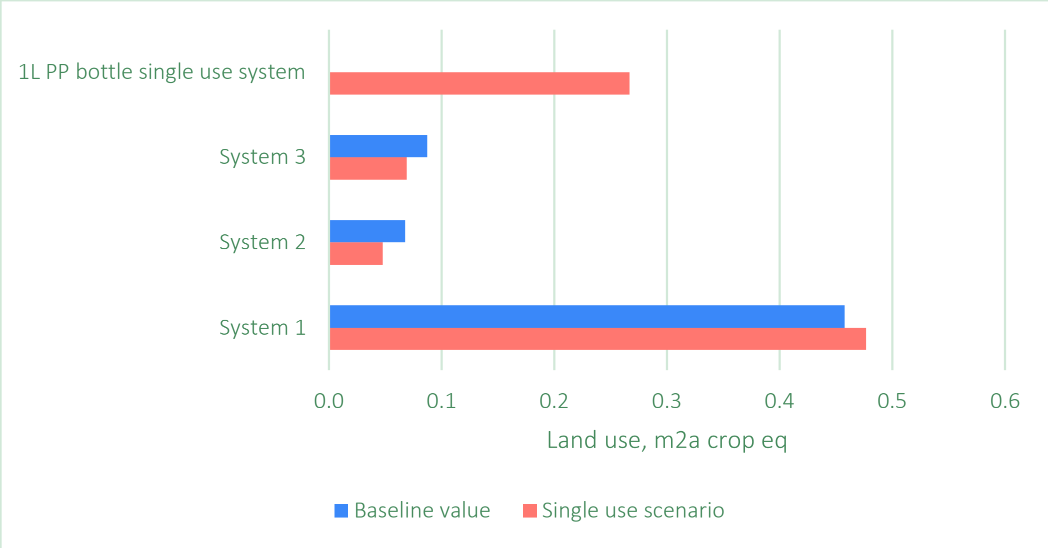

Figure 29: Sensitivity analysis investigating the land use impacts of a single use system compared to the refill system being considered in this study. For the refill systems: System 1: 10 D-PAK™ Cartons and 1 PP Bottle, System 2: 5.56 1.8L LDPE Pouches and 1 PP Bottle, System 3: 10 1L LDPE Pouches and 1 PP Bottle. For the single use systems: System 1 refers to 11 1L D-PAK™ cartons used, System 2 refers to 6.1 1.8L LDPE pouches, and System 3 refers to 11 1L LDPE Pouches.

4.4.3 Uncertainty analysis

The selected data, allocation, assumptions, and impact assessment methodologies all introduce inherent uncertainty into the model results. The completeness and consistency of the data to meet the requirements of the goal and scope have been assessed iteratively whilst undertaking this study and the data quality assessment has been used to document this analysis. A typical way to explore uncertainty of the chosen data could be Monte Carlo analysis, however this requires detailed probability information for the data points in the study, which was not available. Some of the uncertainties discussed in this section have been explored in the sensitivity analyses in section 4.4.2

There is broad uncertainty in this study relating to both the LDPE pouch and the PP bottle, as the packaging formats were selected based on a market analysis of common bottle and pouch formats for detergent refill systems. There are several options on the market for both bottles and pouches that consumers could choose from in selecting detergent packaging. Attempts were made in the sensitivity analysis section of this study to understand if variation in these packaging formats could impact the overall conclusions of the comparison between System 1 and the LDPE pouch refill systems.

Additional uncertainty in this study stems from consumer behaviour surrounding refill systems. It is not certain that consumers buying the D-PAK™ carton, the pouch or the bottle will adhere to the recommended refill structure. Consumers may use all packaging formats as single use options or may refill more or less times than the assumed 10 refills in this study.

Furthermore, some of the results show marginal differences between System 1 and Systems 2 and 3. This is true for the water consumption impact, where System 1 has 2-3% higher impact, and across terrestrial ecotoxicity (5-14% difference), ozone formation human health (2-3%), ozone formation terrestrial ecosystems (-4-0.4%), ionizing radiation (6-8%), and stratospheric ozone depletion (1-13%).

Among the impact categories considered in this study, it is important to note that there is a variation in confidence level of these indicators. High confidence impact categories include global warming, stratospheric ozone depletion, and fine particulate matter formation. Several medium confidence impact categories are included in this study. There is some level of uncertainty associated with ionising radiation; this is mainly related to the fact that many nuclear power stations are situated on the coast and use marine water in their reactors, however all emissions to water (except freshwater) are excluded. Furthermore, "emissions to water, unspecified" is used to map the remaining freshwater emissions. This impact category also excludes emissions to the lower and upper troposphere. The marine eutrophication impact category also presents some limitations. For instance, emissions to water (seawater, freshwater) are unspecified, and several elements such as iron (which affects phytoplankton productivity) and nitrogen emitted to rivers are not considered in this method.

Several impact indicators are low confidence indicators. For human carcinogenic and non-carcinogenic toxicity, there is a high level of uncertainty mainly associated with the limited number of characterised substances. High levels of uncertainty are also present for freshwater ecotoxicity which is currently only represented by toxic effects on aquatic freshwater species in the water column. Impacts on other ecosystems, including sediments, are not reflected in current general practice. Characterised inorganics only comprise of a few metals, and other inorganics are not reflected in this indicator. Human toxicity (carcinogenic and non-carcinogenic) also presents significant uncertainty as the characterised inorganics comprise of a few metals, and other inorganics are not available.

These key uncertainties in this study should be carefully considered when interpreting and reporting the study results.

4.5 Limitations, representativeness, consistency, and reproducibility

A consistent approach has been applied to all packaging formats and systems included in this study. Primary data has been used where possible and available. Where data was not available, in the manufacturing processes of the pouch and bottle formats, assumptions have been made using reliable sources and packaging expertise. Where data was not available for any of the packaging formats, for example in the transportation distances the EU PEF guidance has been used. A consistent system boundary and allocation approach has been applied to all products included in the study.

This report sets out the scope, methodology, inventory data and assumptions used to estimate the environmental footprints of each product in such a way that an LCA practitioner could reproduce the results.

To align with the requirements set out in the ISO14040/44 guidance the following limitations have been identified:

- The end-of-life allocation method selected has a significant impact on the climate change impact of the systems, with all systems showing lower impact when utilising CFF. The range of impact range between the systems is narrowed in range when using CFF. The inclusion of recycling rate variability further reduces this range. This shows that results and conclusions that can be reached from the results are very dependent on LCA allocation choice.
- The manufacturing processes for the LPDE pouch format and the PP bottle format were assumed based on secondary data and matched to ecoinvent factors. Primary recorded data on the production processes for each of these formats could improve result accuracy.
- The LDPE pouch and PP bottle data on the volume, composition, mass and secondary packaging were selected by Elopak based on a market analysis of the most likely packaging format that would be a competitive to the D-PAK™ carton. The conclusions drawn from this assumption were analysed via sensitivity scenarios to understand how results may change the overall. However, these comparisons are theoretical and as such the conclusions may not be representative of all packaging markets. The market research completed to identify the LDPE and PP formats focused on German markets, with the assumption that these formats could be applied to a general European market. These assumptions are limited as packaging formats in terms of volume, mass and composition may differ across markets and from consumer to consumer.
- In this model ecoinvent 3.10 was used. During this project, a few issues relating to water consumption were identified which have not yet been reported by Ecoinvent. The errors in water consumption mainly relate to wastewater treatment processes. In this model some of these wastewater treatment processes are part of background data in the factors selected. As such, there is a degree of uncertainty in the water use results. In addition to this, it is generally acknowledged that there may be a limited level of confidence in water use, fossil resource, and land use indicators compared to other impact categories.
- In place of any other data, it was assumed that the ink consumption for the LDPE, PP and HDPE packaging formats was equivalent to the ink usage on the D-PAK™ carton. Therefore, the ink grammage is considered the same across all packaging formats, this is unlikely to be the case.
- In place of any primary information on downstream distribution (from packaging site to filling and from filling site to distribution to retail) the EU PEF guidance was used. The actual distance each packaging format may travel between sites may differ depending on the location of the detergent filling site and the market. Therefore, the results relating to transport are limited by this assumption. In addition, it is possible transportation impacts of

packaging may be impacted by different loss, failure or wastage rates between the different packaging formats either during transportation to distribution or retail or during the customer use phase.

- The exclusion of the filling and sealing from the boundaries of this LCA are a limitation in the comparison made between the packaging formats. Variations in impact from product waste during filling, manufacturing impact, and sanitising impacts may occur between the studied products due to their shape or filling process. Statistics on both LDPE pouches and the cartons are variable depending on geography and source of the statistic. As such, the conclusions draw on the comparison to end-of-life are limited by inconsistent data availability.
- End-of-life transportation distances used in this study are based on average distances waste travels in the UK as waste distribution information is not available for Europe. This may limit the end-of-life transportation distance results as distances travelled by waste in Europe may differ to that of the UK.
- The assumed number of refills for the refill system selected by Elopak based on internal discussion. In reality refill systems will see variation in the number of refills achieved, this will affect the comparator results. No data was available on the range of refills that could be achieved
- The results show marginal differences between System 1 and Systems 2 and 3 across various impact categories which limits the extent to which one system can be said to have lower environmental impacts than another. As discussed in Section 4.4.3, marginal differences can be found for water consumption (2-3% difference), terrestrial ecotoxicity (5-14% difference), ozone formation human health (2-3% difference), ozone formation terrestrial ecosystems (-4-0.4% difference), ionizing radiation (6-8% difference), and stratospheric ozone depletion (1-13% difference).

More generally, the results within this report are limited by:

- The scope, boundaries and reference period defined within this assessment (e.g. cradle-to-gate plus end of life system boundary);
- The secondary data used for the product systems;
- The data quality defined within this assessment (see Appendix C); and
- The assumptions defined within this assessment (see Section 2.7)

A life cycle assessment should not be used as the sole decision making tool for assessing the sustainability of a product.

4.6 Conclusions and recommendations

The LCA study presented in this report generated environmental profiles of the cradle-to-gate plus end-of-life of the three following refill systems: 1) 10 D-PAK™ cartons and a PP Bottle, 2) 5.56 1.8L LDPE Pouches and a PP Bottle, 3) 10 1L LDPE Pouches and a PP Bottle.

The conclusions of this report are specific to the products examined. The environmental impacts can only be stated within the boundaries and assumptions of this model.

The following conclusions can be drawn from this study:

- System 1 estimated to have a lower environmental impact across 11 impact categories compared System 2, and a lower environmental impact across 14 impact categories compared to System 3.
    - The global warming impact of System 1 is estimated to be 28% lower when compared to System 3, and 24% lower when compared to System 2 based on the

methodology employed in this study. It is important to note that the methodological choices and the recycled content in Systems 2 and 3 play a large role in the directional conclusions of this study as shown in the Sensitivity analyses in section 4.4.2.
    - The water consumption impact of System 1 is estimated to be 2% higher when compared to System 3, and 3% lower when compared to System 2. Limitations to this conclusion can be found in Section 4.5.
    - The fossil resource scarcity impact of System 1 is estimated to be 33% lower when compared to System 3, and 38% lower when compared to System 2.
    - The land use impact of System 1 is estimated to be 425% higher when compared to System 3, and 575% higher when compared to System 2.
- Despite the findings that System 1 has the lowest environmental impacts across 11 impact categories compared to system 2 and 14 impact categories compared to system 3, the sensitivity exploration in this study showed some variation in the results in System 1's results:
    - The estimated global warming impact varies between 1.21 and 1.56 kgCO_2e under different sensitivity scenarios explored in this study.
    - The estimated water consumption varies between 0.009 and 0.010 m3 under different sensitivity scenarios explored in this study.
    - The estimated fossil resource scarcity varies between 0.037 and 0.042 kg oil eq. under different sensitivity scenarios explored in this study.
    - The estimated land use impact varies between 0.450 and 0.474 m2a crop eq. under different sensitivity scenarios explored in this study.
    - In particular, the specifications of the comparative pouch plus the end-of-life treatment assumptions and allocation method have the largest impact on the results. This indicates that, while the carton may have lower environmental impact compared to a pouch system this conclusion is sensitive specific nature of the comparison.
- A sensitivity analysis on end-of-life allocation method showed that climate change impacts of all the systems are very dependent on allocation choice. This uncertainty means that it is likely that any conclusions around the relative performance of the different packaging systems are closely linked to LCA methodology choices.
- Building on the variation that can be seen when exploring the sensitivity of the results there are some aspects of this study that could be improved by including more primary data.
    - The main aspect of this study where primary data would improve the robustness of the conclusions is to include more primary data on the LDPE pouch.
    - In addition, this study could be improved by including a more specific pouch comparison that is a known comparator to System 1. However, a lack of primary data on pouch vs carton refill systems made this difficult to do. To mitigate this lack of primary data efforts were made to include and explore as much variation in the pouch format as possible to understand if and how conclusions may change.
- It should be noted that the entire detergent life cycle is excluded from this study. Regardless of the packaging choice it is possible that the detergent production process, filling process and transportation distance of empty and full packaging between the detergent production site will have a significant impact on the life cycle impacts of all the systems explored here. Results may be impacted by different loss, failure or wastage rates between the different packaging formats either during transportation to distribution or retail or during the customer use phase.

Based on the findings from the study Anthesis have made the following recommendations have been made:

- The largest contributor to System 1 is the impact of raw materials extraction. Anthesis recommend that Elopak explore methods for reducing impact during these stages by exploring options to:
    - Reduce the amount of material used in the cartons; for example, by reducing the weight of the carton board used in the D-PAK™ carton and reducing the thickness of the PE layer on the carton board.
    - It should be noted that any material reductions should carefully consider how the integrity of the packaging is affected. If material reduction leads to increased product loss this is likely to negate any impact reductions made from removing the material.
    - Explore alternatives barriers to LDPE plastic lining such as coatings that maintain barrier properties but have less impact on the packaging's recyclability at end of life.
- Anthesis also recommends that Elopak continue to monitor the end-of-life routes available and recycling process applicable to the D-PAK™ carton. In addition, Elopak should take action in improving collection, sorting and waste processing infrastructure in markets where there are known challenges. This recommendation is driven by uncertainty in both availability of collection and coverage of carton recycling processes across Europe. Additionally, we would recommend that Elopak collaborate with the wider value chain to understand and mitigate any unintended consequences upstream or downstream of the D-PAK™ carton. This could include taking action in improving collection, sorting, and waste processing infrastructure in markets where there are known challenges.

Anthesis

5 References

1) ACE. (2021, Setptember). *Beverage Carton Recycling Facts & Figures.* Retrieved from https://www.beveragecarton.eu/wp-content/uploads/2021/10/ACE-Recycling_BROCHURE_September-2021.pdf

2) Active Plastics. (n.d.). *5 Types of plastic moulding*. Retrieved from https://www.activeplastics.co.nz/types-of-plastic-moulding

3) Commission, E. (2020, November 10). Retrieved from https://wayback.archive-it.org/org-1495/20221006205351mp_/https:/ec.europa.eu/environment/eussd/smgp/pdf/TrainingCFF%20Circular%20Footprint%20Formula10Nov2020_final_corr.pdf

4) ecoinvent. (2024). Retrieved from https://support.ecoinvent.org/system-models#Allocation_classification

5) European Commission & Sphera. (2020, November). Retrieved from https://wayback.archive-it.org/org-1495/20221006205351mp_/https:/ec.europa.eu/environment/eussd/smgp/pdf/TrainingCFF%20Circular%20Footprint%20Formula10Nov2020_final_corr.pdf

6) European Commission. (2018). *Landfill Waste.* Retrieved from https://environment.ec.europa.eu/topics/waste-and-recycling/landfill-waste_en

7) European Commission. (2021, December 15). *Product Environmental Footprint Category Rules Guidance 2021/2279.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021H2279&qid=1696605390097

8) Eurostat. (2018). Retrieved from http://ec.europa.eu/eurostat/web/transport/data/database

9) Eurostat. (2021). *Packaging Waste Statistics*. Retrieved from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Packaging_waste_statistics&oldid=580504

10) JRC. (2010). *General Guide for Life Cycle Assessment - Detailed Guidance.* Retrieved from https://eplca.jrc.ec.europa.eu/uploads/ILCD-Handbook-General-guide-for-LCA-DETAILED-GUIDANCE-12March2010-ISBN-fin-v1.0-EN.pdf

11) Plastics Recyclers Europe. (2022). *Flexible Films Market in Europe: state of play.* Retrieved from https://www.plasticsrecyclers.eu/wp-content/uploads/2022/10/flexible-films-market.pdf

12) Recoup. (2022). *UK Household Plastic Packaging Collection Survey 2022.* Retrieved from https://www.recoup.org/research-and-reports/uk-household-plastic-packaging-collection-survey-2022/#

13) UK Gov. (2023). *2023 Government Greenhouse Gas Conversion Factors for Company Reporting: methodology paper for conversion factors final report.*

14) Wrap. (2020, July). *Creating a circular economy for flexible plastic packaging.* Retrieved from https://wrap.org.uk/resources/guide/creating-circular-economy-flexible-plastic-packaging