Comparative Life Cycle Assessment: Postevand water carton and standard recycled PET bottle

500 ml (0.5 l) Pure-Pak® Postevand water carton compared to a Danish-produced 500 ml 100% recycled PET bottle

Disclaimer

Comparative Life Cycle Assessment

Postevand

Prepared for:

Andreas Lemche

Postevand

Website: https://www.postevand.com/

Email: andreas@postevand.com

Report written by:

Abigail Clare

Tom Cacciola

Peter Slorach

Website: www.anthesisgroup.com

Tel: 01865 250818

Company Registration: 08425819

Quality Assurance

Peter Slorach

Principal Analyst

Report approved by:

Peter Slorach

Principal Analyst

8th March 2023

Signature …………………………………………………………………

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Critical Review

Executive summary

Anthesis Consulting Group Ltd has prepared this report for the sole use of Postevand and for the intended purposes as stated in the agreement between Anthesis and Postevand 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.

Postevand commissioned Anthesis to conduct a comparative Life Cycle Assessment of their Pure-Pak® 500 ml Carton, compared to a standard Danish-produced 100% recycled PET 500 ml water bottle. This report is specifically focused on the aluminium-free version of the carton, which uses ethylene-vinyl alcohol copolymer (EVOH) instead of aluminium as an oxygen barrier. Postevand are seeking to understand how the environmental profile of their water carton compares to a traditional recycled PET (rPET) alternative and to communicate the differences between these two products to their customers.

This study has used a cradle-to-grave methodology to assess the environmental profiles associated with all stages in the life cycle of the products, including the production and processing of the raw materials, manufacturing, distribution, waste collection and end-of-life processes.

According to the ISO standard, such a comparison must be based on the function delivered by the product. For the purpose of this study, the chosen FU is defined as: “0.5 L of drinking water derived from Danish groundwater, packaged and delivered to a customer in Denmark and consumed immediately.”

The baseline results show that the 500 ml Postevand water carton has an estimated lower climate impact, freshwater ecotoxicity, fossil depletion, freshwater eutrophication and particulate matter formation impacts than a standard recycled PET bottle. The ozone depletion impact of the Postevand carton is estimated to be higher than the rPET bottle. There were some key limitations when calculating water depletion (discussed below and in sections 5.3 and 5.6), however water depletion was measured as higher for the carton than for the rPET bottle. The estimated environmental impacts of the carton and rPET bottle are within the same order of magnitude, with the exception of categories where the data or method are highlighted as introducing particular uncertainty. The estimated climate impacts of the two products are shown in Figure 1 (with the estimated impact of the carton 17.7% lower than that of the rPET bottle)

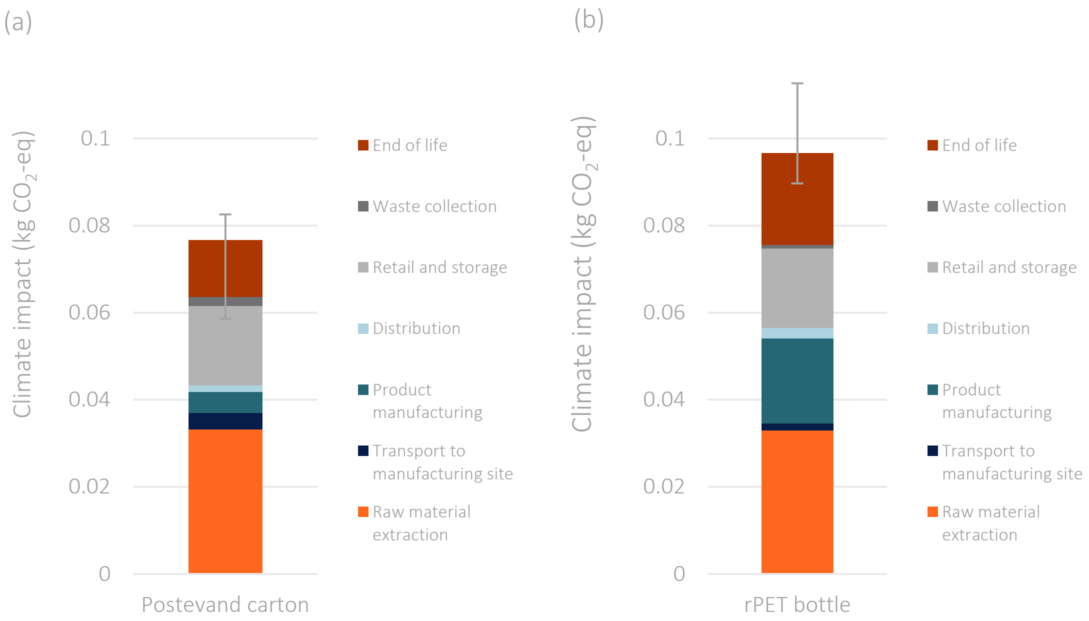


Figure 1 – The absolute climate impacts of the Postevand carton (a) compared to a recycled PET bottle (b)

Based on the assessment and sensitivity analysis in this study, the climate impacts of the Postevand carton are in the following ranges:

- Climate change: 0.059 - 0.083 CO_2-eq

Based on the assessment and sensitivity analysis in this study, the climate impacts of the PET bottle are in the following ranges:

- Climate change: 0.087 - 0.11 CO_2-eq

The main contributors to each impact category for the Postevand carton are the raw material extraction, retail and storage, and end-of-life stages.

The raw material extraction stage is a key hotspot; this may be because the carton has more raw material and packaging components than the rPET bottle. Furthermore, unlike the bottle, these are not made from recycled materials and are, therefore, associated with higher resource consumption. The impacts of the retail and storage stage are likely high due to the high energy consumption.

The results for the carton show high water depletion. This high water depletion is primarily due to the use of an outdated dataset from the board supplier. This dataset does not account for the reuse of nuclear reactor water in the nuclear reactor plant that is used to generate the electricity used. In this study, water depletion is only considered at an inventory level and does not represent an actual environmental impact (i.e., it does not assess water scarcity). The water depletion result should be interpreted with caution and the key limitations around its calculation should be noted.

A sensitivity analysis has been performed which illustrates the lower water depletion that results from substituting this data with the ecoinvent 3.8 dataset for liquid packaging board (see section 5.4.2 for further details).

The climate results are sensitive to the lining material of the carton, the use of renewable energy during raw material and product manufacturing, waste disposal rates, the end-of-life allocation method used in the study, the PET bottle recycled content, the product storage duration and the waste collection transport distance. The water depletion results are also sensitive to the end-of-life allocation method used.

Some geographical and temporal limitations in secondary production data have made it difficult to make specific conclusions about the products.

The results of this study may be improved by the following:

- Using primary data for the raw material extraction stage of both products
- Using an updated primary dataset for the production of the board which considers the reuse of reactor water in the nuclear power plant that is used as the electricity source
- Using primary data for the filling of the rPET bottle
- Using primary data on retail storage duration
- Updated secondary datasets for some processes.

Results from this study LCA can be used to make comparative assertions between the two products included in the scope. 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 product results to general statements about product categories (or vice versa).

This study does not support general statements implying all cartons perform better/worse in these impact categories than all rPET bottles.

1 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.

Postevand is a provider of Danish drinking water, packaged in cartons. Postevand's mission is "to make products with minimal environmental impact that keep you hydrated when you are far away from the tap". The environmental impacts associated with Postevand's packaging are at the forefront of their concerns. For this reason, this LCA study was commissioned by Postevand and was conducted by Anthesis Group an external sustainability consultancy.

Postevand is a provider of Danish drinking water, packaged in cartons. Postevand seeks to compare the environmental impacts of their drinking water packaged in a 500 ml Pure-Pak® carton against the same product packaged in a standard Danish-produced 500 ml recycled polyethylene terephthalate (rPET) bottle.

Postevand has commissioned Anthesis to conduct a comparative LCA of drinking water packaged in a 500 ml Pure-Pak® Postevand carton and drinking water packaged in a Danish-produced 500 ml rPET bottle.

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, 2011) 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 Postevand, 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.

2 Goal definition

2.1 Objectives of the study

This LCA was commissioned by Postevand with the goal to:

- Compare the environmental profiles of drinking water packaged in a 500 ml (0.5 L) Pure-Pak® Postevand carton compared with the same product packaged in a Danish-produced 500 ml rPET bottle within the geographical scope of Denmark using Danish groundwater. Environmental profiles will be characterised from cradle-to-grave;

- Understand the reasons for any differences in environmental impact between product systems (i.e., location of manufacturer, packaging material, starting materials). However, it should be noted that differences in environmental impact may result from features of the secondary data or modelling artefacts;
- Identify significant contributions to the environmental impacts ('hotspots') across the product lifecycle; and
- Identify possible improvement areas of the studied systems that would be of interest for further analyses.

2.2 Intended application

The intended application of the study is to act as scientific support for environmental impact claims made about the Postevand carton. The results of the study will inform future redesign and manufacturing choices.

2.3 Target audience

Consumers and internal stakeholders at Postevand are the target audience of this study. Internal stakeholders include the sustainable transformation team, design managers and procurement specialists as well as any business-to-business contacts. A critical review by the following panel of experts was carried out:

- Frank Wellenreuther, ifeu gGmbH
- Matt Fishwick, Fishwick Environmental Ltd
- Chris Foster, EUGeos SRL

2.4 Public disclosure

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

3 Scope definition

3.1 Function

The studied products in this assessment will be referred to as 'Postevand carton' and 'PET bottle' defined in Table 1.

Table 1: A table defining the studied products and their variables.

Product name	Bulk material of primary packaging	Manufacturing location
Drinking water packaged in a 500 ml Pure-Pak® Postevand carton (alu-free)	Cardboard carton with polyethylene coating and Ethylene-vinyl alcohol copolymer (EVOH) lining layer	The Netherlands & Denmark
Drinking water packaged in a 500 ml rPET water bottle	100% post-customer waste polyethylene terephthalate	Denmark

The function of the Postevand drinking water is to provide hydration, refreshment, and enjoyment. The beverage carton and other packaging described in this study has the following functions from product filling to final consumption:

- Protect the drinking water from damage or contamination
- Contain the product
- Protect the product and enable storage and transport
- Guarantee product safety (through a tamper-evident seal)
- Demonstrate printed information (such as product identification, sell-by date, price etc.)

The functional unit chosen for this study represents the primary functions described above and enables a comparison of the two product systems. Additional functions not described above and, therefore, not captured in the functional unit definition are assumed to be the same for each product system assessed.

3.2 Product system 1 – drinking water packaged in a 500 ml Pure-Pak® Postevand carton

Raw material extraction and production of packaging

All stages relating to the extraction of resources and the production of primary and secondary packaging for the product were included. Packaging production includes extraction of raw materials, processing into packaging materials, processing into packaging formats, and assembly.

The Postevand carton contains groundwater extracted from Denmark. The primary packaging consists of the carton and the cap. The carton board is composed of paper board coated in resin and printed.

The board is supplied by a third-party supplier located and transported roughly 2000km (exact distances from third party suppliers have been omitted to keep details about the supplier confidential). The carton board is manufactured by Elopak in the Netherlands. During manufacturing, resin is added to the board during a coating process. These layers include a polyethylene layer which is coated on both sides. An adhesive tie layer followed by an EVOH lining layer are applied to the inside of the carton. The board then enters a converting process which involves printing and cutting activities to produce the carton board.

The EVOH is provided by a third-party supplier and transported roughly 300km. The tie layer and ink also come from third party suppliers and are transported roughly 50km. The cap is manufactured by Elopak in the Netherlands and is composed of high-density polyethylene (HDPE) and low-density polyethylene (LDPE).

The secondary packaging consists of a cardboard box composed of 100% FSC-certified paper and polyethylene stretch film (LLDPE). The top kraftliner layer of the box is made from virgin paper. The fluting is made of recycled materials. The bottom kraftliner is made from virgin paper. The cardboard box is manufactured by a third-party supplier and transported roughly 150km. The LLDPE is manufactured by a third-party supplier and transported roughly 300km.

The packaging specifications of the Postevand carton are listed in Table 2.

Table 2 - Packaging specifications of the Postevand carton

Type	Component	Mass per unit (kg)
Primary	Board	0.013
	PE total	0.0028
	EVOH lining layer	0.00033
	Tie layer	0.00028
	Ink	4.75E-05
	Cap	0.0026
Secondary	Cardboard box	0.011
	LDPE film	1.17E-09

Transport to the manufacturing site

All external transportation of resources and packaging materials was included.

The board (primary packaging) is transported by sea to the coating plant in the Netherlands. All other raw materials (polymers, EVOH and ink) are transported by diesel truck from the supplier to the coating/converting plant in Netherlands.

Once converted, the carton board and cap are transported by diesel truck and stored in the warehouse in Denmark before transport to the filling plant where the carton is assembled.

The cardboard box (secondary packaging) is transported by lorry from the supplier to the filling plant in Denmark. The polyethylene stretch film (LLDPE) is transported by lorry from the supplier to the filling plant in Denmark.

Product manufacturing

The product manufacturing stage includes coating, converting and filling of the cartons.

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 (Elopak purchases 100% renewable electricity through GO certificates), natural gas, and propane. The data for these stages were sourced from primary data directly from Elopak. The filling process is carried out in Denmark at a third-party site. At this stage, the carton board arrives flat and is assembled into a carton. The carton is then filled with water with the filling machine. The main production utilities for the filling machine include electricity (mainly bioenergy), chilled water, hydrogen peroxide, and compressed air. The filling machine also works with dairy products and, therefore, it is cleaned before every production phase (once per day). The inputs during the cleaning process include electricity, tap water, compressed air, alkaline and sterilant. The data during the filling process is based on primary data from Elopak.

The main source of energy (96% by energy content) for the filling plant is bioenergy which uses onsite biomass (willow) as an energy source. Natural gas is used as an energy backup, approximately

4% (by energy content) of energy is sourced from natural gas. The energy data during the filling process were based on primary data provided by the third-party filling site.

Distribution

The distribution stage includes storage, transport to the distribution centre, and finally, point of sale.

The Postevand water carton is stored in a warehouse at the third-party site. During storage, the warehouse is cooled. Cooling of the warehouse is required for the dairy products and, as the water cartons can be stored at ambient temperature, the impacts of cooling the warehouse are assumed to be allocated entirely to dairy products. These impacts are, therefore, excluded from this analysis.

From the storage warehouse, the carton is sorted for destination and transported by HVO biodiesel truck from the storage warehouse to the distribution centre in Hedensted. From the distribution centre, the carton is sorted together with other general cargo goods and is transported by HVO biodiesel truck to retail in southern Denmark. Data on the downstream transportation of the carton were based on primary data supplied by the dairy where filling takes place.

Storage and Retail

Data on storage and retail were based on the Product Environmental Footprint Category Rules (PEFCR) for packed water. The main energy sources at the distribution centre were assumed to be electricity from the grid and natural gas. The main energy source during the retail stage was assumed to be grid electricity.

The total assumed storage duration of the Postevand carton is representative of the expected shelf-life of EVOH-lined paperboard (2 years at 25 °C) (Maes *et al.,* 2019).

Waste collection

The waste collection phase includes the transport of packaging to end-of-life treatment. Data for transport distances in this stage were based on Bassi *et al.,* 2017.

End-of-life

End-of-life processes of packaging include landfill, material recovery, or waste processing. The proportions going to each destination were taken from The Danish Environmental Protection Agency waste statistics (2017). These data can be found in the table in Appendix A.

3.3 Product system 2 – drinking water packaged in a Danish-produced 500 ml rPET bottle

Basis for creating representative bottle for Danish market

To best compare Postevand's carton against a representative rPET bottle on the Danish market, three rPET bottles of water were obtained in Denmark. These bottles represent three major brands that together covered 43% of the market share of bottled water in Denmark, including carbonated and flavoured water. When carbonated and flavoured water are removed, these brands make up the majority of the market for bottled water in Denmark (Euromonitor, 2022).

The three rPET bottles were weighed, with the cap and label weighed separately. The average mass across the three bottles was used for the bottle, label, and cap.

Raw material extraction and production of packaging

All stages relating to the production of primary, secondary and tertiary packaging for the product were included. This includes extraction of raw materials, processing into packaging materials, processing into packaging formats, and assembly.

The PET bottle is filled with groundwater extracted from Denmark. The primary packaging consists of the rPET bottle, the cap, and the bottle label. The bottle is made from 100% recycled PET and is formed by blow moulding. The cap is made from HDPE and is formed by injection moulding. The bottle label is made from low-density polyethylene and is formed by an extrusion process.

The secondary packaging was assumed to be a polyethylene film (LLDPE) around a 24-bottle pack.

Transport distances for the supply of plastic components were based on a Europe average (Winter, 2014). The transport distance for the secondary packaging film was assumed to be the same as the carton.

The packaging specifications of the rPET bottle are listed in Table 3.

Table 3 - Packaging specifications of the rPET bottle

Type	Component	Mass per unit (kg)
Primary	rPET bottle	0.019
	HDPE cap	0.0018
Secondary	LDPE film	0.002

Product manufacturing and filling

The product manufacturing stage comprises the filling of the rPET bottles.

The main sources of energy for the filling process were assumed to be grid electricity and compressed air. Steam, hydrogen peroxide, and peracetic acid were assumed to be used as disinfectants and sodium hydroxide as a neutralising agent. Deionized water is used in the filling process. The electricity use data during the rPET bottle-filling process is taken from the PEFCR for packed water. Technical data for three of Elopak's chilled filling machines were used to model all other rPET filling data.

Distribution

The distribution stage includes transport to the distribution centre and the point of sale. Transport distances for the distribution of the rPET bottle are based on the recommended distances in the PEFCR for packed water given above.

The rPET water bottle is assumed to be transported by lorry from the filling plant to the distribution centre. From the distribution centre, the bottle was assumed to be transported by lorry to the retailer.

Storage and Retail

Data on storage and retail were based on the PEFCR for packed water. The main energy sources at the distribution centre were assumed to be electricity from the grid and natural gas. The main energy source during the retail stage was assumed to be grid electricity.

Waste collection

The waste collection phase includes the transport of packaging to end-of-life treatment. Data for transport distances in this stage were based on Bassi *et al.,* 2017.

End-of-life

End-of-life processes of packaging include landfill, material recovery, or waste processing. The proportions going to each destination were taken from The Danish Environmental Protection Agency. This data can be found in the table in Appendix A.

3.4 Functional unit

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

"0.5 L of drinking water derived from Danish groundwater, packaged and delivered to a customer in Denmark and consumed immediately"

Consumed immediately assumes that the water is drank straight away upon purchase. Transport by the consumer and at-home refrigeration is excluded from the system boundaries.

3.5 System Boundaries

This study includes inputs and outputs of materials and energy required in the production of the studied products along the life cycle. The system boundary is cradle-to-grave. The cradle is at raw material extraction or cultivation, whereas the grave is at end-of-life.

3.5.1 Process maps

Figure 2 and 3, define the system boundaries for the 500 ml Postevand carton and the 100% recycled rPET 500 ml bottle

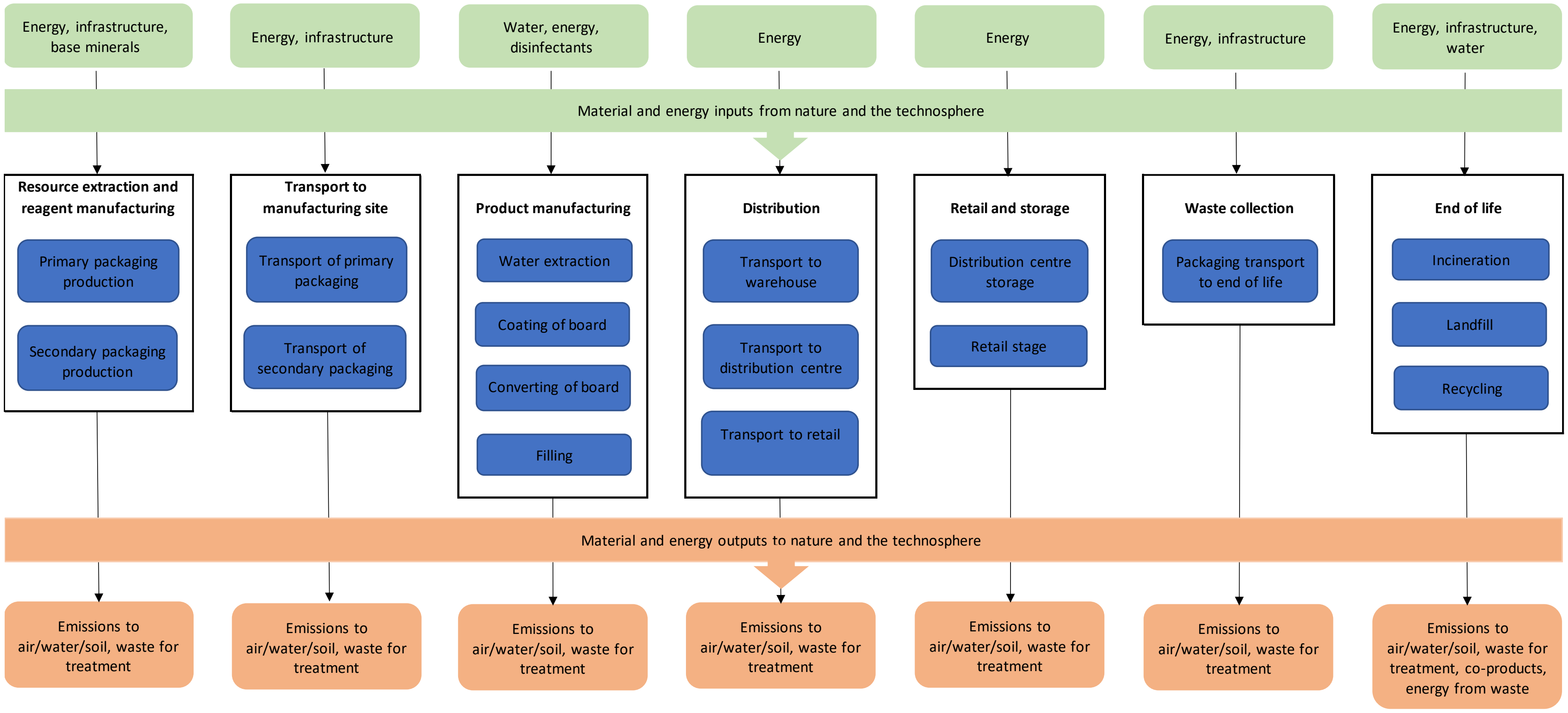


Figure 2: Process map for 500 ml Postevand water carton

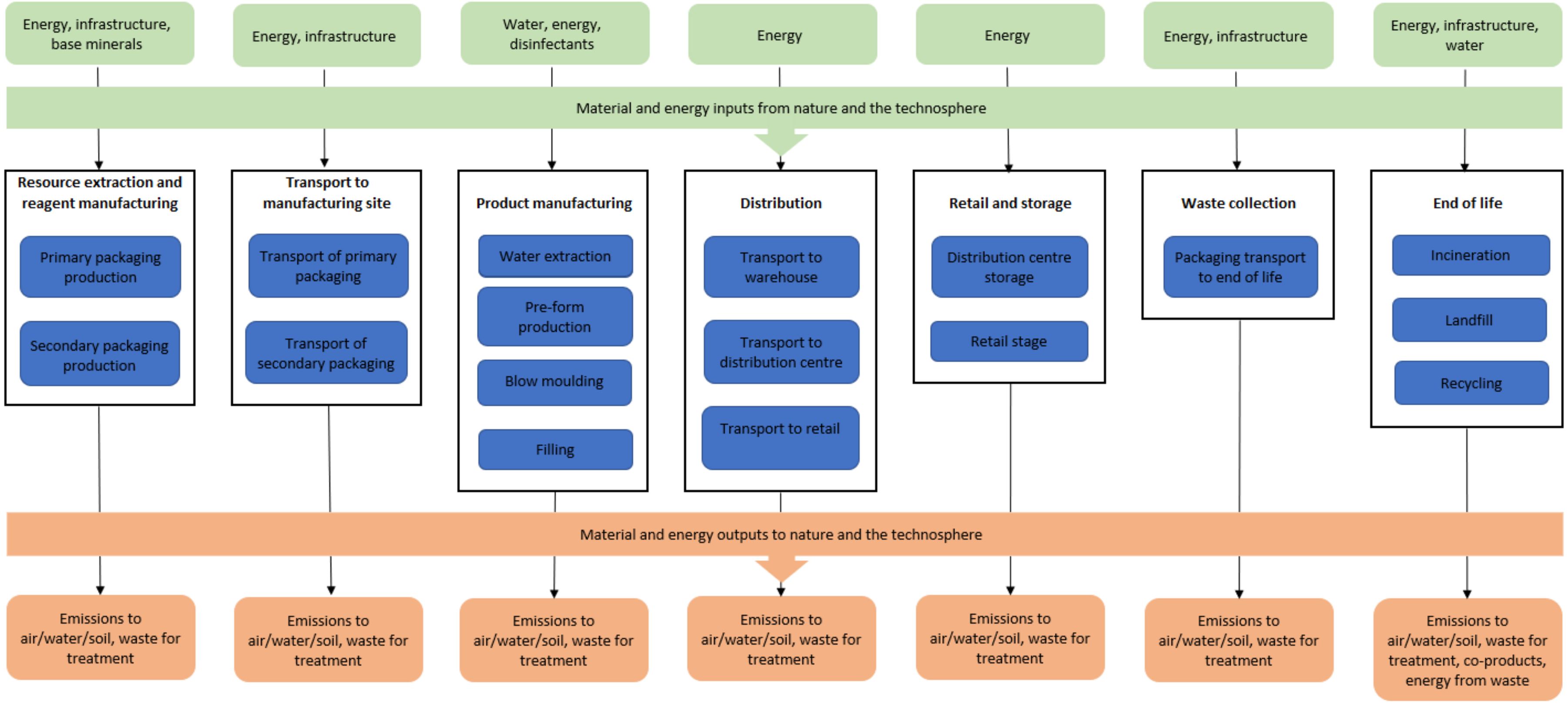


Figure 3: Process map for 100% recycled 500 ml PET water bottle

3.5.2 Quantification of energy and material inputs

In some cases, the exact data for the energy and material inputs required in the production phase was not available. This is the case for the filling of rPET bottles, technical data for three of Elopak's chilled filling machines were used to model material and water data. Electricity use data was sourced from the PEFCR for packed water. Key exclusions from the boundary of the study are listed below with their justifications:

Life cycle stage	Exclusion	Justification
Distribution	Energy use for cooling during storage at the third-party site.	The carton water can be stored at an ambient temperature. Cooling occurs as dairy products are also stored here; therefore, the impacts are allocated to these products.
Storage and retail	Transport to end user	It is assumed the water is consumed immediately and, therefore, no transport would occur.
Use phase	Product use	It is assumed the water is consumed immediately.

3.5.3 Assumptions

Stage	Assumption	Source/Justification
Materials	Secondary packaging for the rPET bottle is assumed to consist of an LDPE film only. This is assumed to be the same weight as the film used for the carton.	The type and source of rPET secondary packaging are not known, however, most PET bottles are packaged in a film only.
	The tie layer of the carton is assumed to be made of polyethylene	Modified polyethylene is often used as a tie layer in beverage cartons - polymerdatabase.com
Transport	Transport distance for the plastic components of the rPET bottle (i.e., cap, bottle, label) is based on a European average and is assumed as 200 km.	Winter, 2014
	Transport distances for the rPET secondary packaging film is assumed to be the same as for the carton.	The suppliers of the rPET secondary packaging are not known. Similar to the carton, the secondary packaging is assumed to be an LDPE film. The transport distance is assumed the same.
	The transport distance of the rPET bottle from the filling plant to the distribution centre is assumed as 500 km.	PEFCR for packed water This distance is greater than that of the carton as the carton is only sold in southern Denmark.
	The transport distance of the rPET bottle from the distribution centre to retail is assumed as 100 km.	PEFCR for packed water

		This distance is greater than that of the carton as the carton is only sold in southern Denmark.
	Carton is assumed to be sent 810 km, for recycling.	Information according to according to Copenhagen Municipality
	All transport distances of secondary packaging materials to end-of-life waste treatment are assumed to be 40 km.	Bassi *et al.*, 2017
Manufacturing	Data for the filling of the 500 ml rPET bottle is assumed as the following: - 5.00E-03 kWh electricity - 2.83E-02 Nm^3 compressed air - 2.42E-02 water - 3.18E-01 steam - 2.68E-04 hydrogen peroxide 50% solution - 5.30E-03 Peracetic acid 98% solution - 2.50E-05 sodium hydroxide 50% solution 1.32E-01 deionized water	PEFCR for packed water Elopak filling machine technical data
	The quantity of water that goes into the filling process for the rPET bottle is assumed to be equal to the quantity of water that leaves the filling process for treatment at end of life.	Primary data provided for the Postevand carton, demonstrates that the water that enters the filling process (excluding that used in the product) is equal to the wastewater leaving for treatment. This has therefore been applied to the rPET bottle.
	Sodium hydroxide and peracetic acid are used to represent chemicals used to clean the filling machine (which are described as "alkaline and surfactant" in data).	The specific chemicals used in this process used are not specified in the primary data provided by the third-party filler. Sodium hydroxide and peracetic acid are used in rPET bottle filling.
Distribution and retail	Distribution centre data is based on a general energy consumption of 30 kWh/m^2 per year and 360 MJ/m^2 per year for the entire building surface and a storage volume ratio calculated as 4 times the product volume. Per 500 ml carton/bottle, this equates to 15 kWh/m3/year of electricity and 180 MJ/m^3/year of natural gas.	PEFCR for packed water
	Retail and storage are included in the system boundary but are assumed to be equal between the compared products.	Energy consumption and storage duration will likely not differ significantly between the two products.

	Retail data is based on a general energy consumption of 300 kWh/m^2 per year for the entire building surface and a storage volume ratio at the retailer calculated as 4 times the product volume. Per 500 ml carton/bottle, this equates to 300 kWh/m^3/year of electricity.	PEFCR for packed water
Waste management	The PET for the rPET bottle is recycled mechanically	Mechanical recycling is the most common method for recycling PET in Europe - https://plasticseurope.org/sustainability/circularity/recycling/recycling-technologies/
	PET bottle is assumed to be sent to the STADLER sorting plant in Taastrup, Denmark	https://www.recyclingproductnews.com/article/33490/stadler-automated-sorting-plant-online-for-danish-recycler
	Denmark incineration waste treatment rates are assumed as the following: • Paper and cardboard incineration rate – 0.3% • Household solid waste incineration rate – 99% • HDPE incineration rate – 57% • LDPE incineration rate – 97% • PET incineration rate – 5% • Carton incineration rate – 100%	Danish Environmental Protection Agency, 2017 Statistica, 2022 PET incineration is assumed as 14% as 84% is recycled and 2% is landfilled in Denmark Alliance for Beverage Cartons and the Environment (ACE) data, 2017
	Denmark landfill waste treatment rates are assumed as the following: • Paper and cardboard landfill rate – 0% • Household solid waste landfill rate – 1% • HDPE landfill rate – 2% • LDPE landfill rate – 3% • PET landfill rate – 2% • Carton landfill rate – 0%	The paper and cardboard landfill rate assumed as 0% as 99.7% is recycled and Incineration is the main disposal route in Denmark (not landfill) Danish Environmental Protection Agency, 2017 McKinsey & Company, 2019
	Denmark's recycling rates are assumed as: • Paper and cardboard recycling rate – 99.7% • HDPE recycling rate – 41% • LDPE recycling rate – 0% • PET recycling rate – 93% Carton recycling rate – 0%	Statistica, 2022 McKinsey & Company, 2019 danskretursystem.dk

3.5.4 Time coverage

Unless stated otherwise, activity data were collected from the most recent data source available - representing the calendar year 2022.

However, projecting the long-term impacts of the current product life cycle may not be accurate in the future. If a circular economy is implemented in Demark, the increased material recirculation would require less input from the biosphere.

3.5.5 Geographical coverage

The geographical boundaries of the material acquisition and pre-processing and production life cycle phases are set to Denmark where possible, otherwise Europe (RER) or global where not possible. Exceptions include incineration and landfill treatment processes, where the geographical boundary was set to Switzerland (CH). Switzerland was chosen for these end-of-life treatment processes as it was deemed to be more representative of the waste sector compared to the other available geographies.

3.6 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. In this study, exclusions could be made if they were expected to be within the below criteria:

- Mass: if a flow is anticipated to be less than 1% of the mass of the product it may be neglected;
- Energy: if a flow is anticipated to be less than 1% of the cumulative energy it may be neglected; and
- Environmental significance: if a flow is anticipated to be less than 1% of the key impact categories it may be excluded.

If an item meets one of the criteria but is expected to be 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.

3.6.1 Multi-output allocation

Allocation of Elopak site-level impacts during board production was carried out on a physical basis (mass-based allocation).

In terms of secondary data, the main database used, ecoinvent v3.8 (cut-off), defaults to an economic allocation for most processes. However, in some cases a mass-based allocation is used, where there is a direct physical relationship. The allocation approach of specific ecoinvent modules is documented on their website and method reports (see www.ecoinvent.org).

3.6.2 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.

3.7 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 2016 v1.13 (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 bottled water with differing packaging) 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. Furthermore, the impact of biogenic carbon in landfills for the carton has not been examined in this study.

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.

The emission factors used for the production of the board are based on primary data and were provided by the board supplier.

The study has analysed impacts relating to the following categories:

- ReCiPe Midpoint Hierarchical v1.13 climate change (GWP100) kg CO_2-Eq.
- ReCiPe Midpoint Hierarchical v1.13 freshwater ecotoxicity (FETPinf) kg 1,4-DC.
- ReCiPe Midpoint Hierarchical v1.13 fossil depletion (FDP) kg oil-Eq.
- ReCiPe Midpoint Hierarchical v1.13 freshwater eutrophication (FEP) kg P-Eq.

- ReCiPe Midpoint Hierarchical v1.13 ozone depletion (OCPinf) kg CFC-11.
- ReCiPe Midpoint Hierarchical v1.13 particulate matter formation (PMFP) kg PM^{10}-Eq.

In addition, the study analyses water depletion using:

- ReCiPe Midpoint Hierarchical v1.13 water depletion (WDP) m^3 water-Eq.

Note that the ReCiPe water depletion indicator remains at the inventory level and does not estimate environmental impact based on factors such as scarcity.

One limitation of this study is that environmental impact categories relating to land use and biodiversity have not been assessed. Land use impacts are relevant for wood-based products in terms of afforestation (e.g., land conversion), changes in forest structure and the impacts of forest management practices. Similarly, wood-based products have the potential to influence biodiversity through increased monoculture (i.e., reduced species richness) and reduced evenness. These impacts have been omitted due to a limitation in the data – the primary data provided for the board did not provide enough information to assess these categories.

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

4 Life cycle inventory assessment

4.1 Data collection procedure

Where possible primary data was collected by Postevand and the dairy where filling takes place using a standardised data collection sheet. Primary data was also collected by Elopak (and extracted from Elopak's DEEP tool v12). The Elopak DEEP tool contains primary data for Elopak's own operations and the production of some raw materials. Please note that the data used is not inventory data – the board supplier has not made this available. The main sets of primary data collected were:

1. The carton product specifications and bill of materials – Extracted from the DEEP tool v12. Please note that the production of the raw materials used in the manufactured carton has been modelled using data from ecoinvent.
2. The primary packaging specifications for the carton – Primary data from Postevand and data extracted from the DEEP tool v12
3. The secondary packaging specifications for the carton – Primary data from Smurfit Kappa and Postevand
4. The distribution distances and mode of transport for the carton – Extracted from the DEEP tool v12
5. The primary packaging specification for the rPET bottle – Primary data provided by Elopak calculated through direct measurements
6. The energy use for the coating plant – Extracted from the DEEP tool v12
7. The energy use for the converting plant – Extracted from the DEEP tool v12
8. The energy use at the carton filling plant – Primary data provided by the dairy where filling takes place, calculated based on energy use per hour and the number of units produced

Secondary data was collected from the following sources:

1. EPA. (2020) 'Gravure Printing', *Emission Factors,* 4.9.2

2. Product Environmental Footprint Category Rules (PEFCRs) for packed water, April 2018
3. McKinsey & Company. (2019) 'A Research and Business Opportunity for Denmark', New Plastics Economy
4. danskretursystem.dk
5. Danish Environmental Protection Agency (2017). *Waste Statistics*

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

4.2 Sources of published data

4.2.1 ecoinvent v 3.8 (2021)

Studied unit processes were mapped to an activity or activities in the ecoinvent 3.8 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.

4.2.2 Other sources

In this study, the emission factors for the production of the board were supplier-specific emission factors provided by Stora Enso.

Other primary data for the cartons, relating to the bill of materials, supplier-related transport distances and utility and energy use during coating and converting was taken directly from the Elopak DEEP tool v12. Data can be found in Appendix A.

4.3 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 4.

Table 4 - 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 for Denmark.
Technology coverage	Type of technology (specific or average mix)	Data should be representative of the technology used in Europe for Denmark.
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 .

4.3.1 Precision

As most activity datasets in this study are based on primary measured data or calculated based on primary information sources of the owner of the technology, or from reliable secondary data sources, precision has been deemed excellent for the carton and good for the rPET bottle.

4.3.2 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.

4.3.3 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 3.8 database.

4.3.4 Representativeness

Temporal: All primary activity data was collected for the calendar year 2019-2022, As the study intended the reference year 2022, temporal representativeness is relatively high. Temporal representativeness of secondary production data is relatively low (averaging 15 years difference).

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 storage 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.

5 Life cycle impact assessment & interpretation

This section provides the results from the impact assessment when comparing the environmental impacts of the 500 ml Postevand water carton to a 100% recycled PET bottle.

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 environmental relevance of the results have not decreased due to the functional unit used or the system wide averaging, aggregation and allocation.

The system boundary and data 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 (normalised to 500 ml of water) and multiplying them by the impact factor values taken from the data sources described in section 4.2.

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

- To compare the environmental profiles of the two products
- To understand reasons for any differences in environmental impacts between the two product systems
- To identify significant contributions to the environmental impacts (i.e., 'hotspots') across the product lifecycle
- To identify possible areas of improvement in the studied system
- To inform future redesign and manufacturing choices
- To support comparative assertions intended to be disclosed to the public
- To provide conclusions, limitations, and recommendations

5.1 Absolute results

Figure 4 shows the environmental impacts for the Postevand carton compared to the recycled PET bottle. Absolute results can also be found in Appendix E.

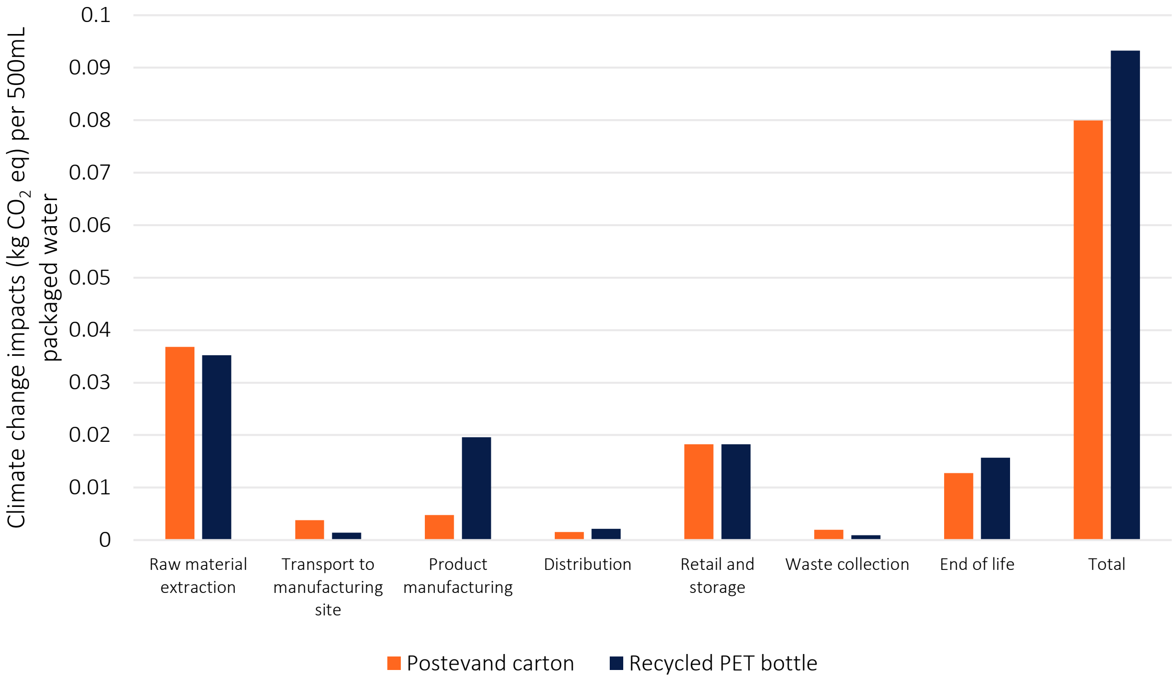


Figure 4a. Absolute climate change impacts of the Postevand water carton compared to a standard Danish rPET bottle

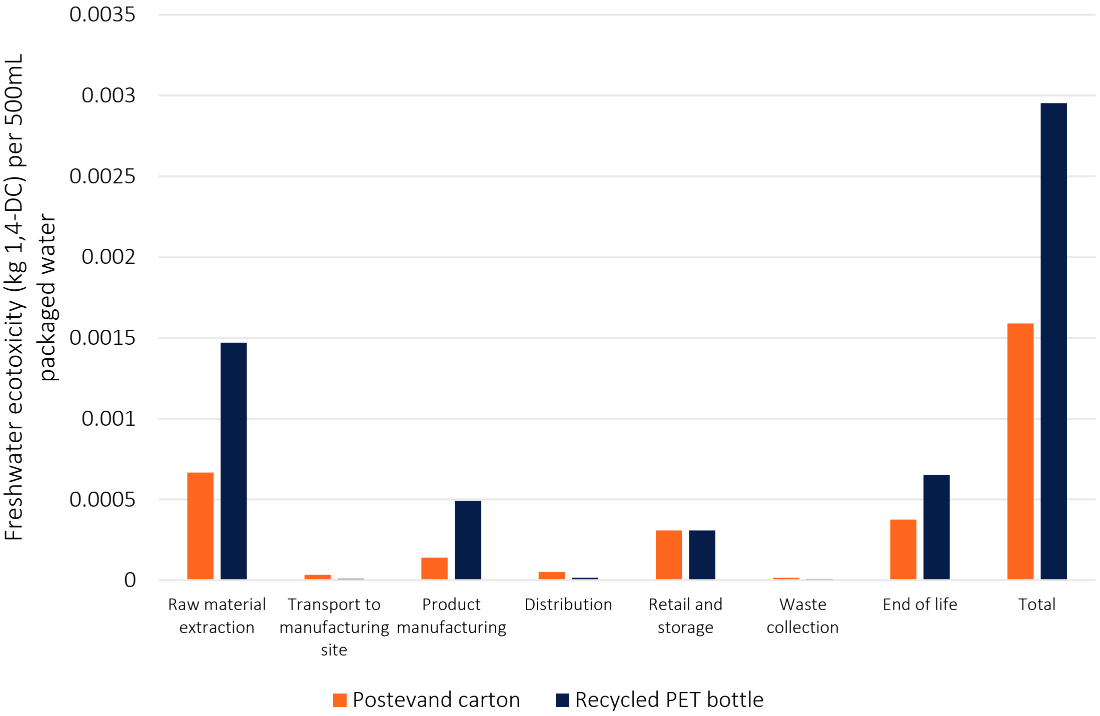


Figure 4b. Absolute freshwater ecotoxicity impacts of the Postevand water carton compared to a standard Danish rPET bottle.

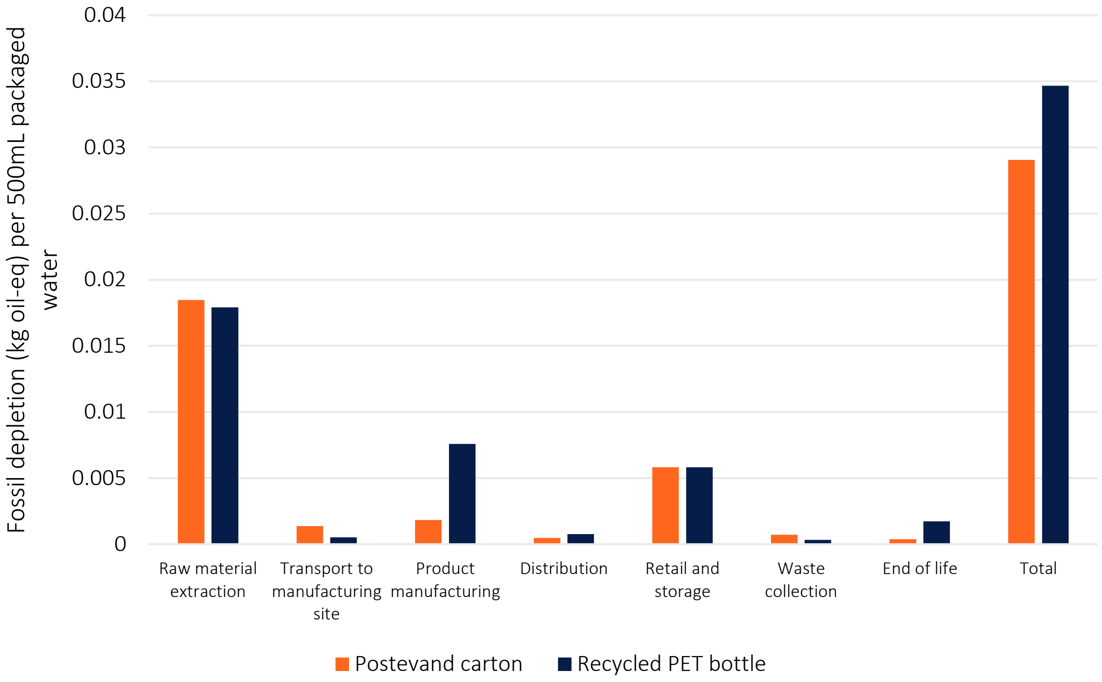


Figure 4c. Absolute fossil depletion impacts of the Postevand water carton compared to a standard Danish rPET bottle.

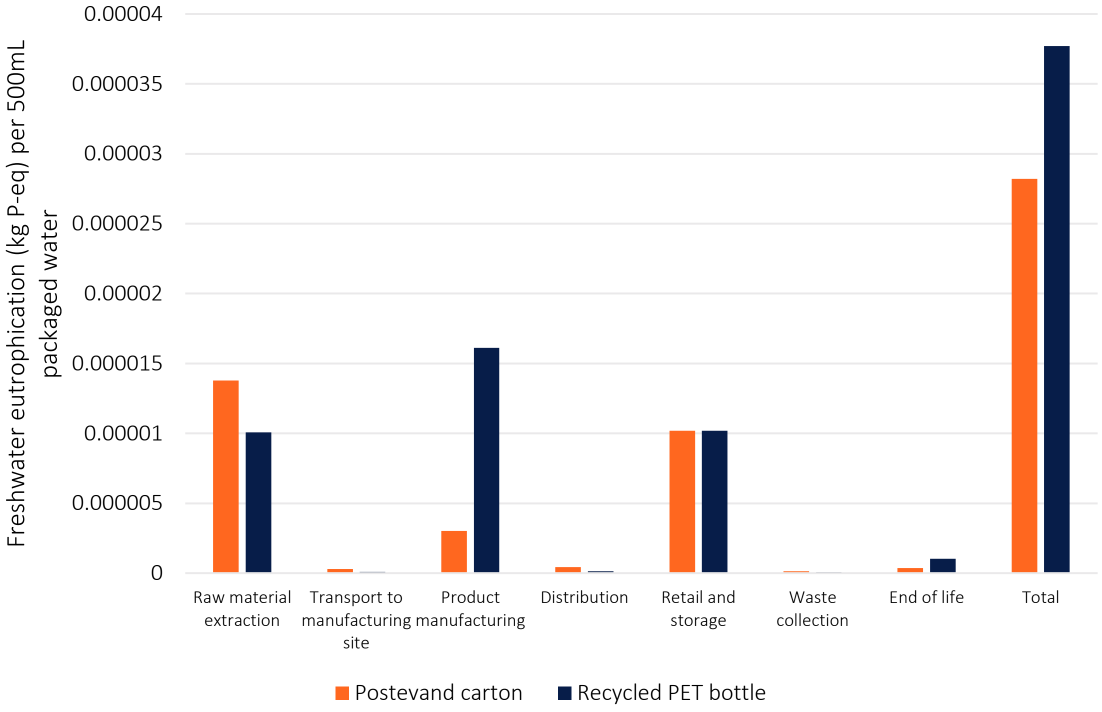


Figure 4d. Absolute freshwater eutrophication impacts of the Postevand water carton compared to a standard Danish rPET bottle.

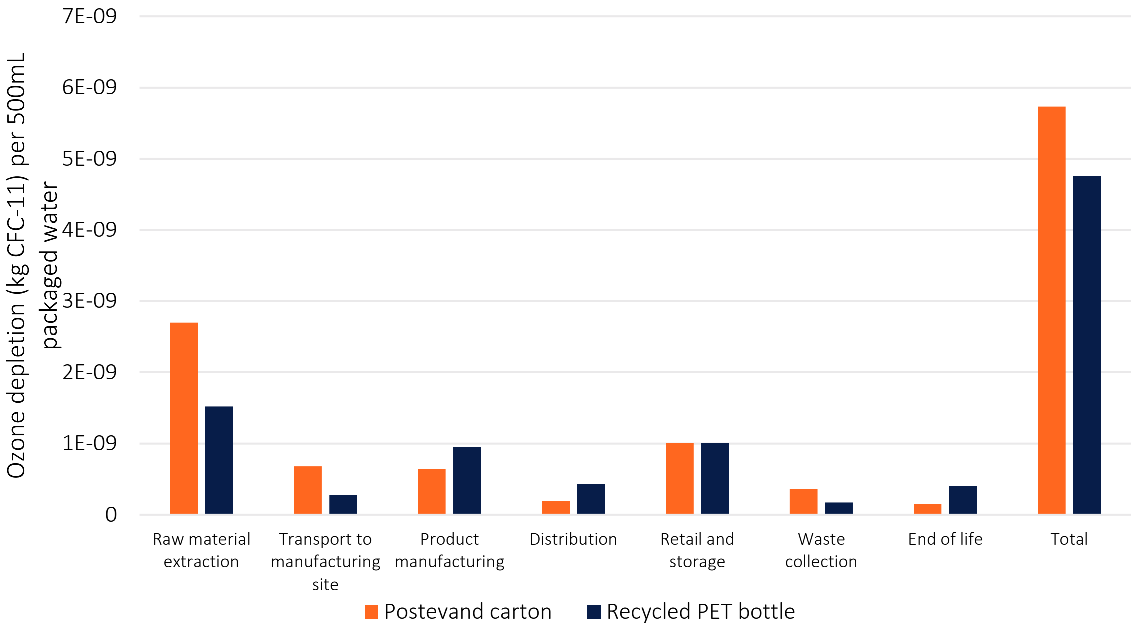


Figure 4e. Absolute ozone depletion impacts of the Postevand water carton compared to a standard Danish rPET bottle.

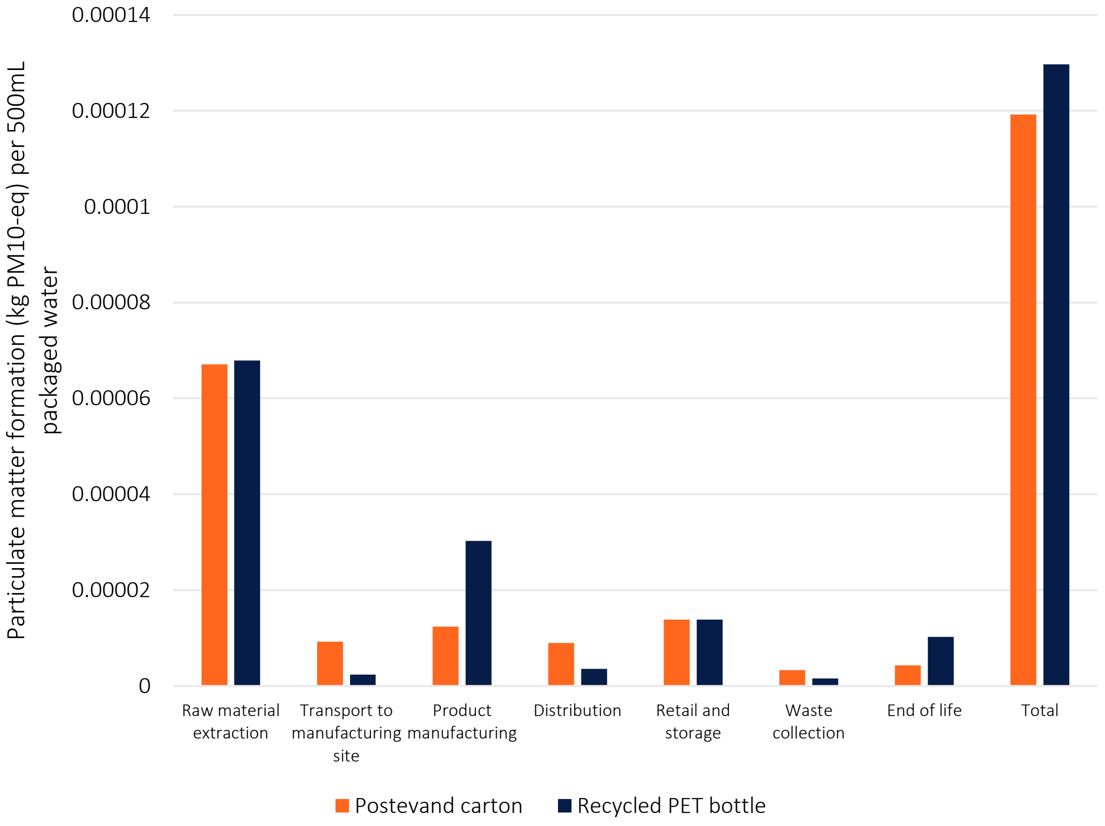


Figure 4f. Absolute particulate matter impacts of the Postevand water carton compared to a standard Danish rPET bottle.

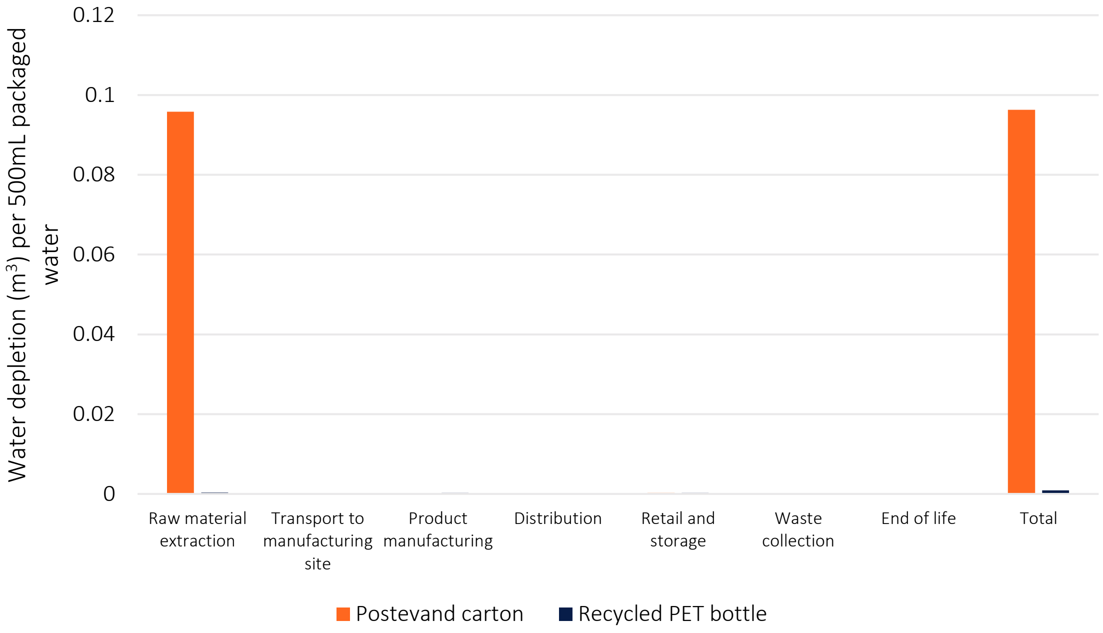


Figure 4g. Absolute water depletion of the Postevand water carton compared to a standard Danish rPET bottle.

The results from Figure 4a-g show that:

- The Postevand water carton has a 17.7% lower climate impact than the rPET bottle.
- The freshwater ecotoxicity impacts of the Postevand carton are 41.8% lower than the rPET bottle. However. please note that there is a high level of uncertainty relating to this impact category.
- Fossil depletion impacts are 18.8% lower for the Postevand carton than the rPET bottle.
- The carton has a 24.9% lower impact on freshwater eutrophication than the rPET bottle.
- Ozone depletion impacts are 15.6% greater for the Postevand carton than the rPET bottle.
- Impacts due to particulate matter formation are 17.3% lower for Postevand carton than the rPET bottle.
- The water depletion of the carton is over 100 times greater than for the rPET bottle. However, the high water depletion is primarily caused by a limitation in the data used to assess it. The reasons for the high water depletion for the carton are discussed in Sections 5.3 and 5.6.

The hotspots behind these differences are explored in the following section.

5.2 Environmental Hotspots

Environmental hotspots help to understand the relative contributions of different processes to the overall environmental impacts. The hotspots for the Postevand carton and recycled rPET bottle are shown in Figure 5 and Figure 6, respectively.

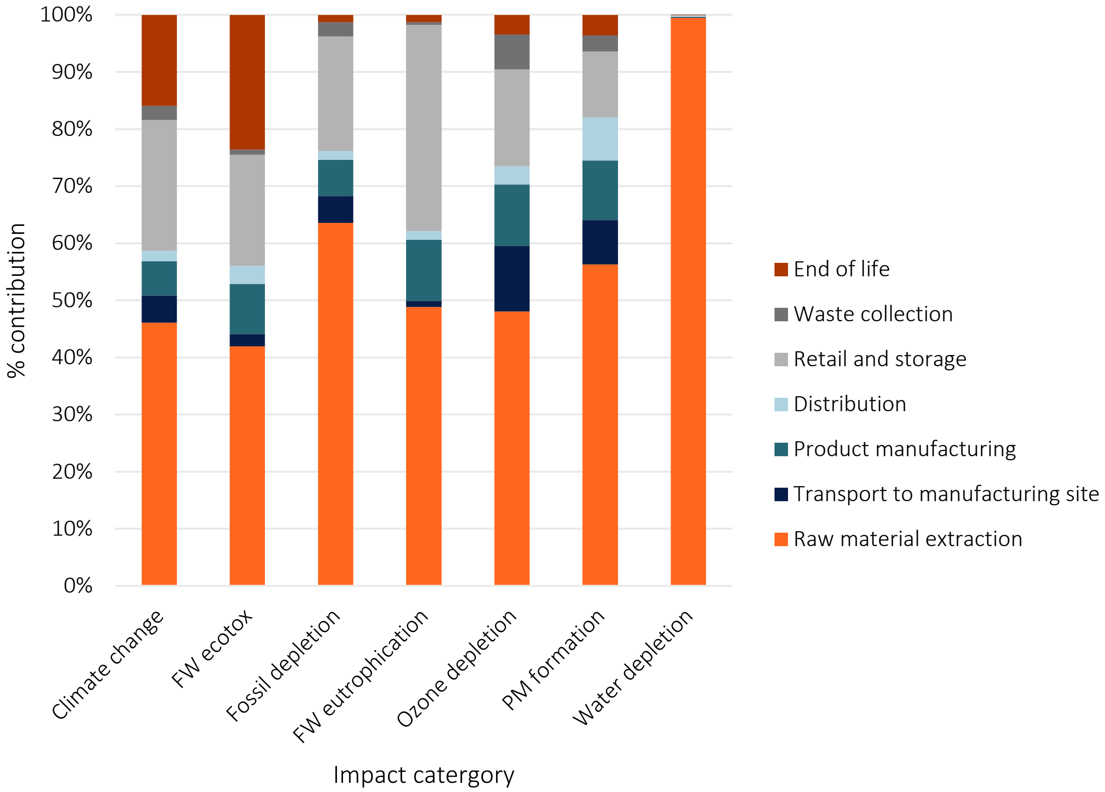


Figure 5. Hotspot – Relative contributions to impact factors for the Postevand carton

Figure 5 demonstrates the largest contributor to all impact categories for the Postevand carton is the Raw material extraction stage. This stage contributes to 43% of the climate change impacts. The stage also contributes 99% of the water depletion, however, please note that this result should be treated with caution due to limitations in the data. The retail and storage and end of life stages also have a high contribution to most of the impact categories. Retail and storage and end of life contribute 24% and 17% to the climate change impacts, respectively.

Figure 5 indicates the raw material extraction stage is a key area where the environmental impact can be reduced for the Postevand carton.

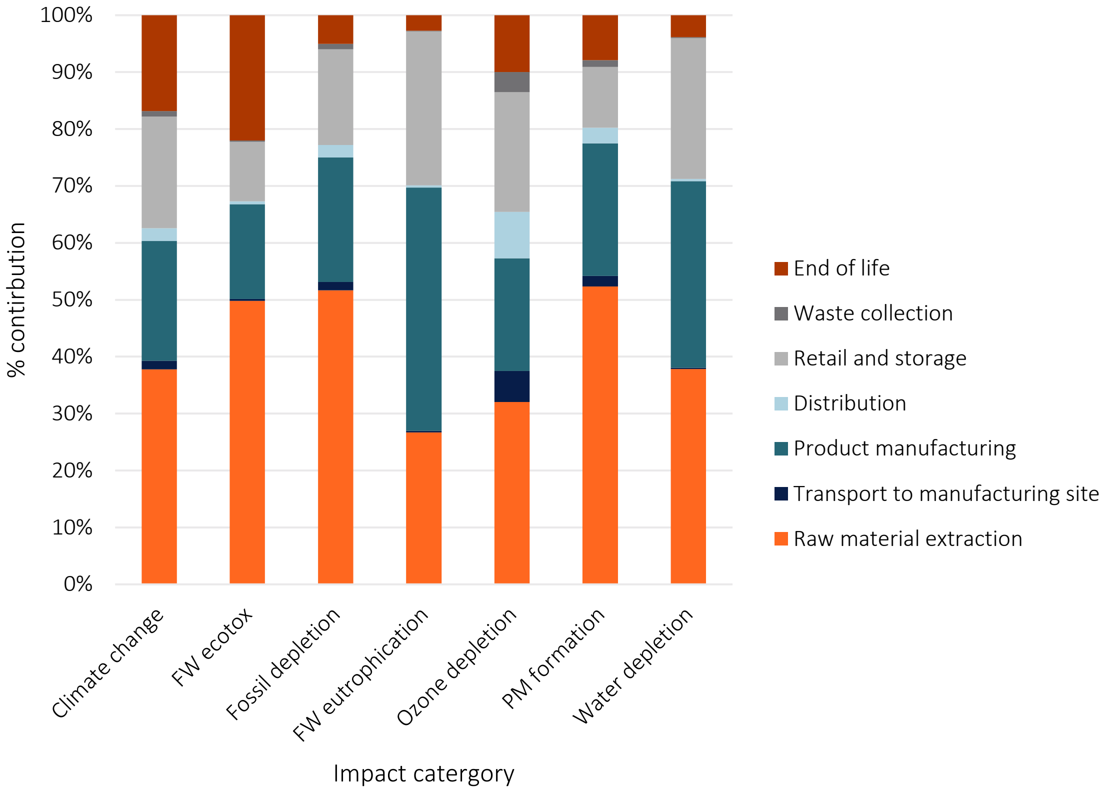


Figure 6. Hotspot - Relative contributions to impact factors for the rPET bottle

Figure 6 demonstrates the largest contributors to all impact categories for the rPET bottle is the raw materials extraction stage. The raw material extraction stage contributes to 35% of the climate change impacts and 37% of water depletion. The product manufacturing, retail and storage, and end of life stages are also significant contributors to climate change impacts. Product manufacturing and retail and storage are significant for water depletion.

Figure 7 describes the environmental impacts of the raw material extraction stage for the Postevand carton and rPET bottle.

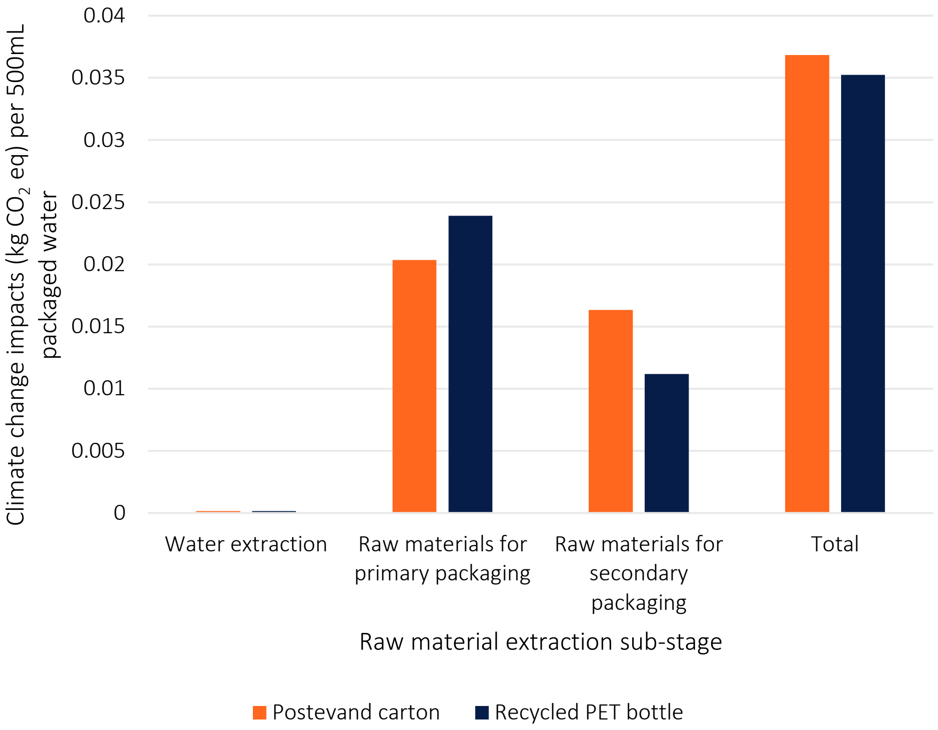


Figure 7a: Hotspot – Climate change impacts from the Raw materials extraction stage.

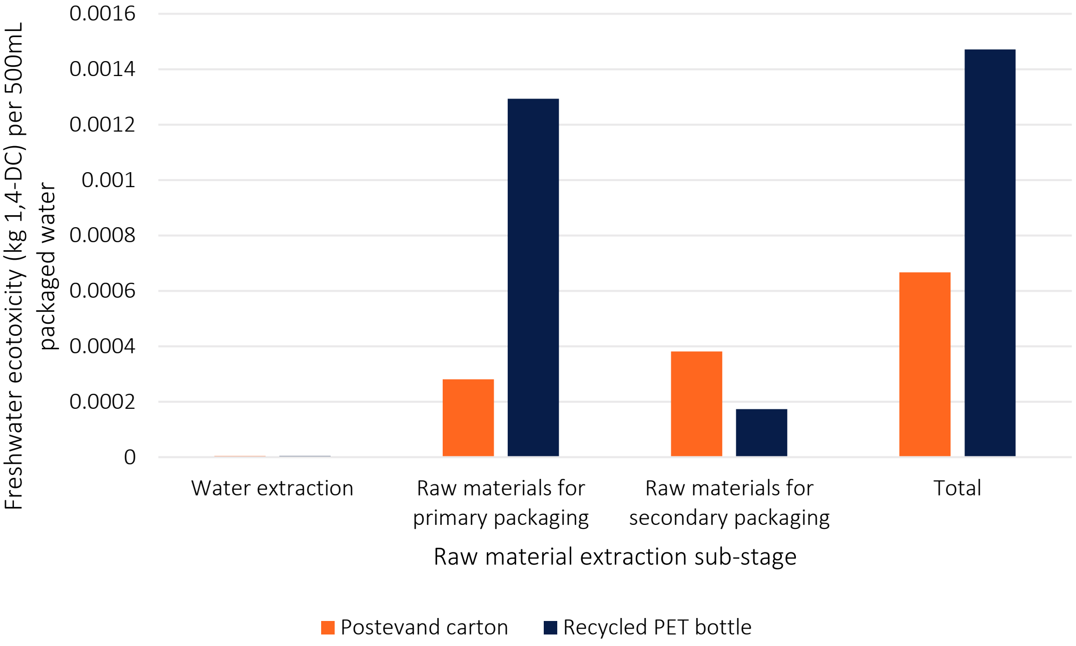


Figure 7b: Hotspot – Freshwater ecotoxicity impacts from the Raw materials extraction stage.

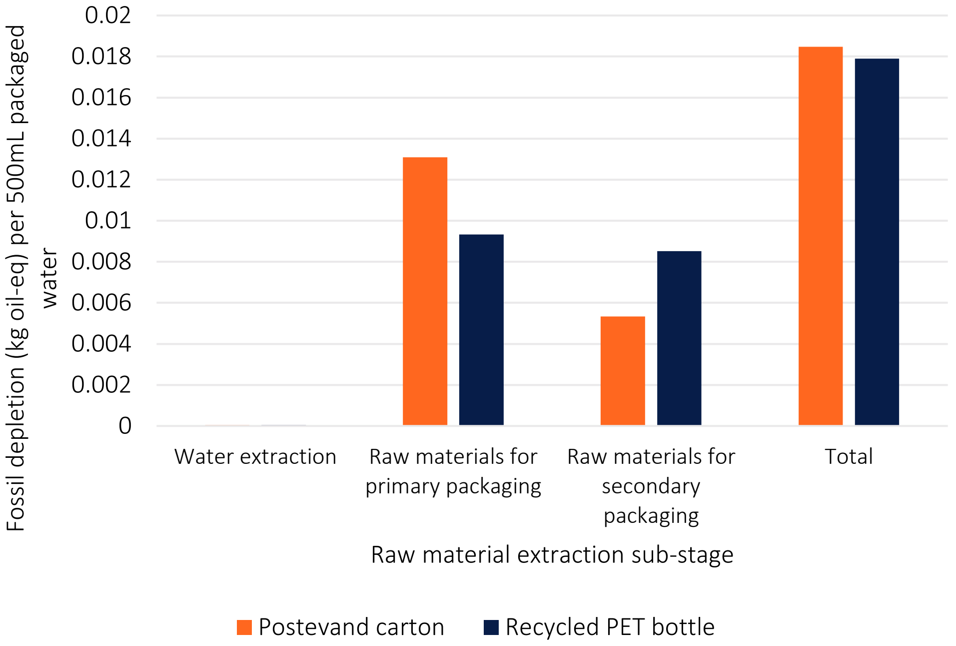


Figure 7c: Hotspot – Fossil depletion impacts from the Raw materials extraction stage.

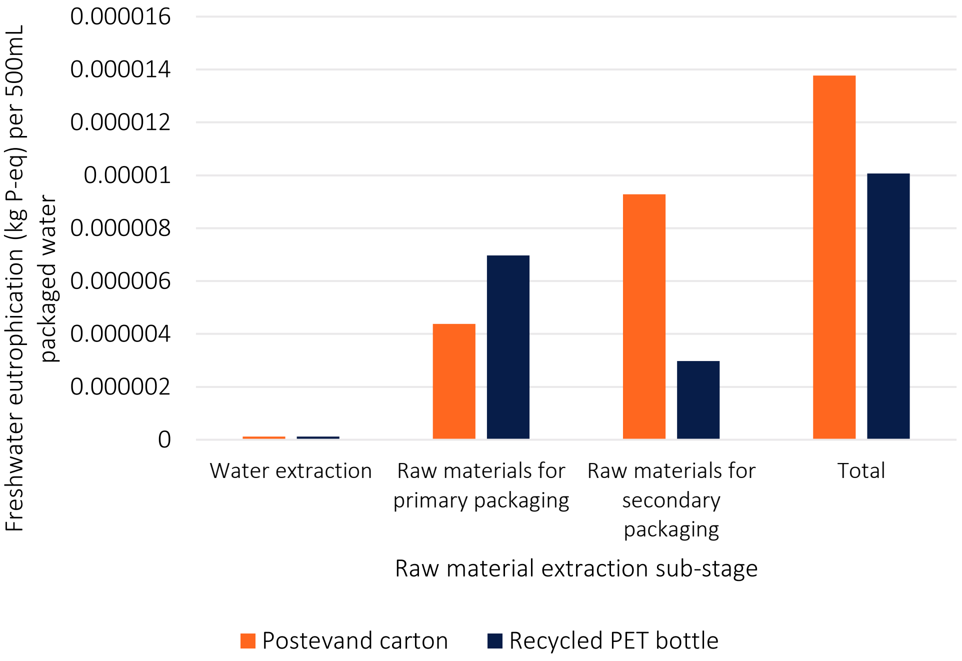


Figure 7d: Hotspot – Freshwater eutrophication impacts from the Raw materials extraction stage.

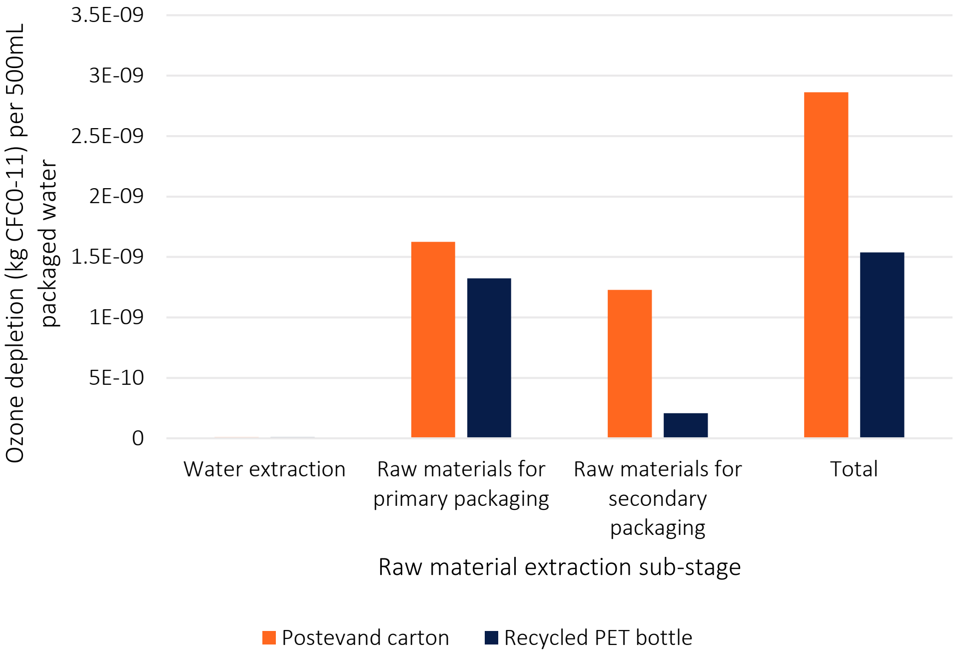


Figure 7e: Hotspot – Ozone depletion impacts from the Raw materials extraction stage.

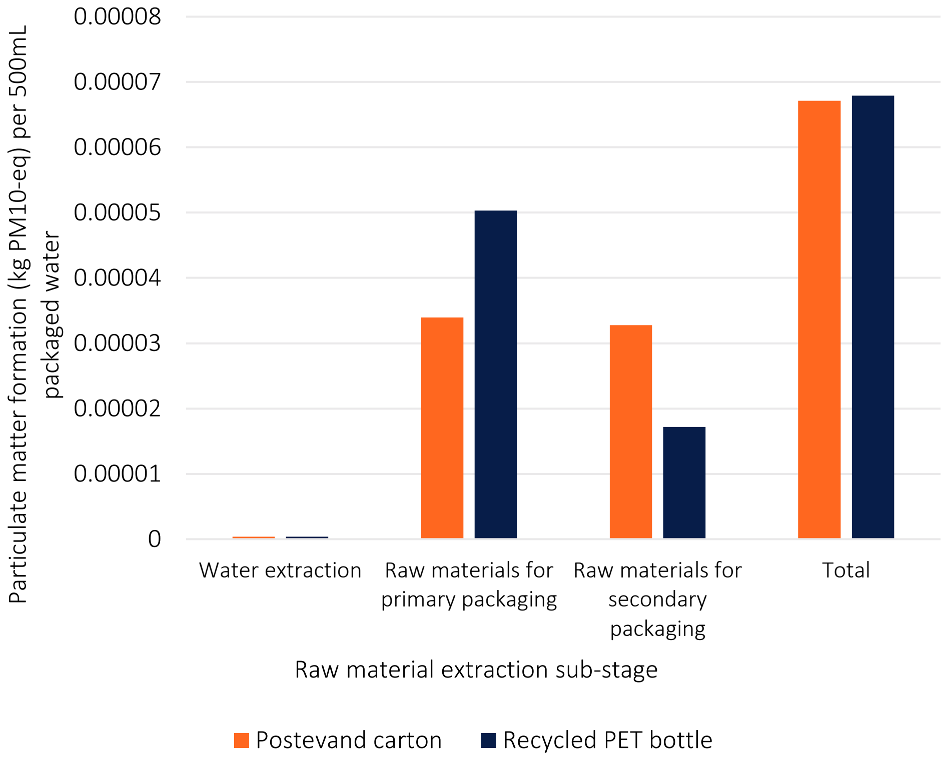


Figure 7f: Hotspot – Particulate matter impacts from the Raw materials extraction stage.

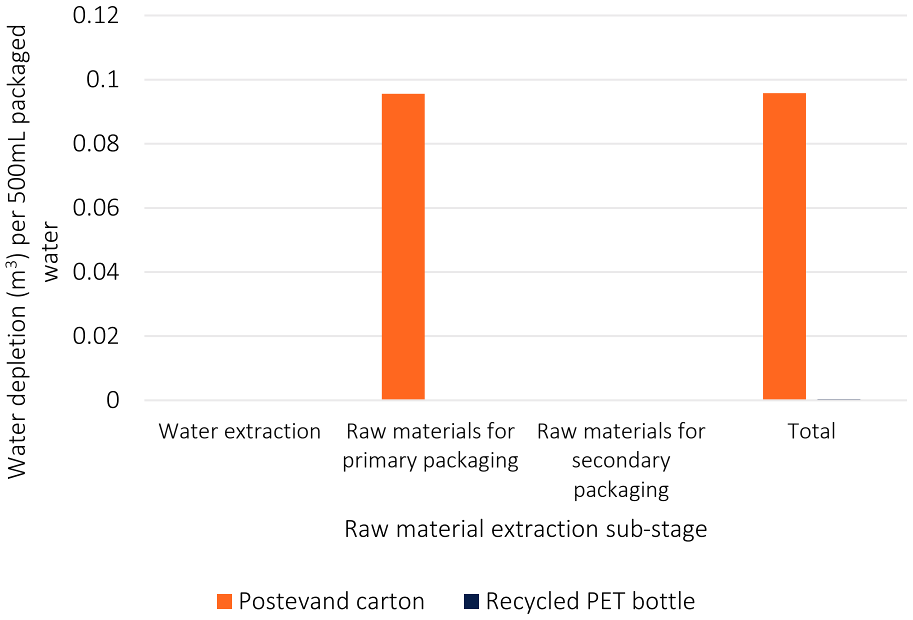


Figure 7g: Hotspot – Water depletion from the Raw materials extraction stage.

Figure 7a demonstrates the raw materials for primary packaging are the largest contributor to climate change for both the Postevand carton and rPET bottle. However, climate impacts from the rPET bottle primary packaging are 31% higher. Extraction of raw materials for secondary packaging is also a significant contributor during this stage.

Figure 7b demonstrates the raw materials for primary packaging are the largest contributor to freshwater ecotoxicity for the rPET bottle and these impacts are 400% greater than for the Postevand carton. For the carton, both raw materials for primary and secondary packaging are responsible for freshwater ecotoxicity impacts. Please note that there is a high level of uncertainty relating to this impact category.

Figure 7c demonstrates the raw materials for primary packaging contribute the greatest to fossil depletion for the Postevand carton and rPET bottle. These impacts are 36% greater for the Postevand carton compared to the rPET bottle. Raw materials for secondary packaging also contribute to fossil depletion for the carton during this stage.

Figure 7d shows the raw materials used in secondary packaging are the greatest contributor to freshwater eutrophication impacts of the Postevand carton. The carton secondary packaging impacts at this stage are greater compared to the rPET bottle. However, when all stages are included, the freshwater eutrophication impacts of the carton are lower than the rPET bottle due to the PET product manufacturing stage.

Ozone depletion impacts for the Postevand carton are due to the raw materials for both primary and secondary packaging (Figure 7e). The Postevand carton primary packaging impacts are 10% greater compared to the rPET bottle.

Impacts from particulate matter formation result mainly from the primary packaging raw materials in the rPET bottle (Figure 7f). For the Postevand carton, these impacts are due to both primary and secondary packaging raw materials.

Primary packaging raw materials for the Postevand carton are the greatest contributor to water depletion (Figure 7g). This is over 500 times greater than the water depletion relating to the rPET bottle primary packaging raw materials, but please note that this result should be treated with caution due to limitations in the data. The reasons behind the higher water depletion for the carton are discussed in Sections 5.3 and 5.6.

Figure 8 demonstrates which primary packaging materials are the largest contributors during the raw materials extraction stage of the Postevand carton and rPET bottle.

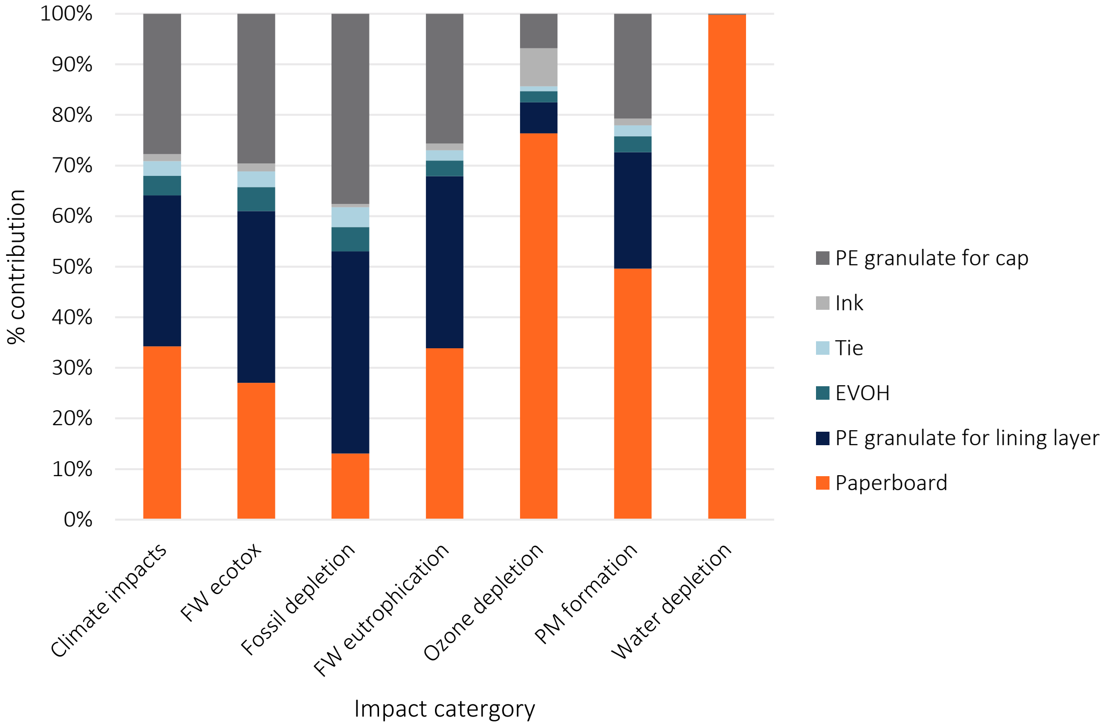


Figure 8a. Hotspot - Relative contributions of each component to impact factors during extraction of Postevand carton primary packaging materials.

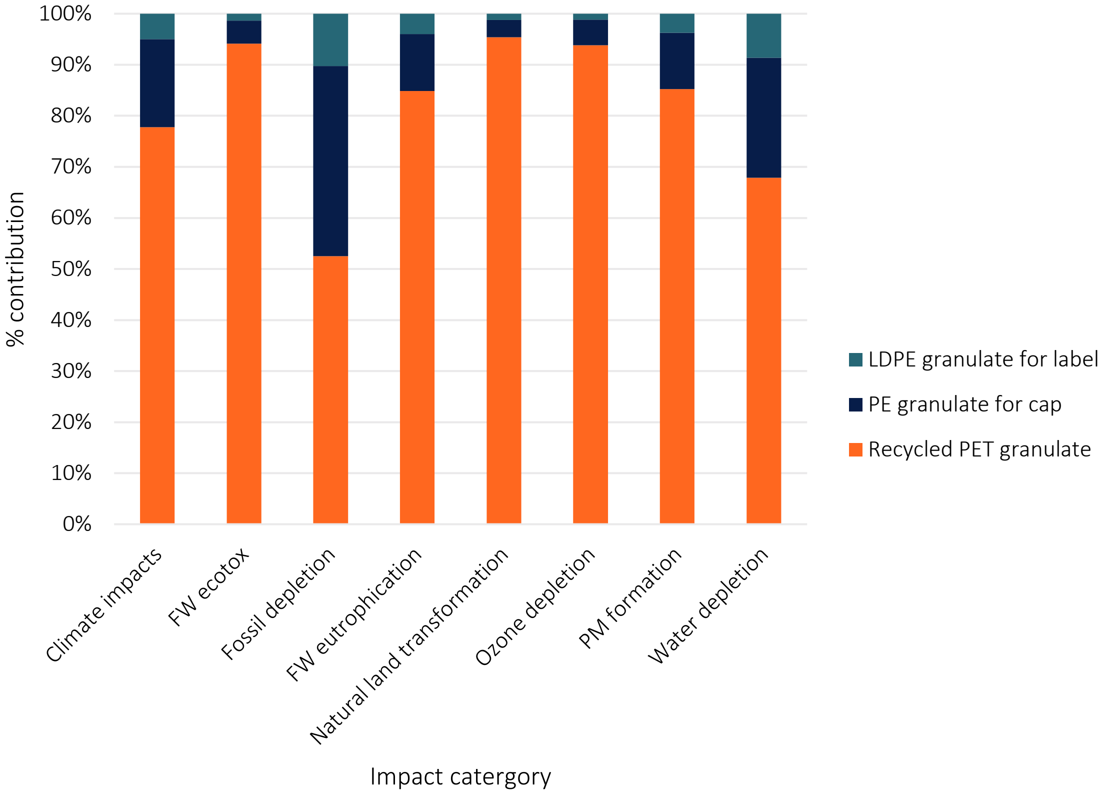


Figure 8b. Hotspot - Relative contributions of each component to impact factors during extraction of rPET bottle primary packaging materials.

Figure 8 demonstrates the PE granulate for the carton lining layer and cap, along with the board, contribute the greatest to the primary packaging climate impacts of the carton. Alternatively, the recycled PET granulate is the largest contributor to the rPET bottle climate impacts.

For the carton, freshwater ecotoxicity impacts during the extraction of primary packaging materials are mainly due to the PE granulate for the cap, PE lining layer and the board (Figure 8a). However, for the rPET bottle, these impacts are due to the recycled PET granulate (Figure 8b).

Fossil depletion impacts during extraction of primary packaging for the Postevand carton are primarily due to the PE granulates for the lining layer and cap. For the rPET bottle, these impacts result from the recycled PET granulate (Figure 8).

The Postevand carton primary packaging impacts result from the production of the board (Figure 8a).

The production of the board and PE granulate for the lining are the largest contributors to the extraction of carton primary packaging PM impacts, whereas the production of recycled PET granulate is responsible for the rPET PM impacts (Figure 8).

Figure 8a demonstrates the production of the board contributes greatest to the water depletion for the extraction of carton primary packaging, but please note that this result should be treated with caution due to limitations in the data.

5.3 Interpretation

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

The Postevand carton has an estimated 17.7% lower climate impact than a typical Danish rPET bottle. This is primarily due to the lower product manufacturing and slightly lower end-of-life impacts compared to the rPET bottle. The product manufacturing stage for the carton and rPET bottle contribute to 6% and 21% of the overall climate impacts, respectively.

The Postevand carton has a significantly lower freshwater ecotoxicity impact than the rPET bottle (please note that there is a high level of uncertainty relating to this category). This is due to the emissions that arise from the extraction of fossil fuels and activities involved in the conversion to petrochemicals of the rPET raw materials and production process.

The Postevand carton has a lower fossil depletion impact compared to the rPET bottle. While the rPET raw materials are slightly lower in fossil depletion impact than the carton, the product manufacturing process (due to the processing of plastic components) of the rPET bottles is more energy intensive than the product manufacturing stage of the cartons. The fossil depletion impacts of the carton may be reduced by using a 100% recycled HDPE cap and ensuring suppliers are using renewable energy.

The Postevand carton has a lower freshwater eutrophication impact than the rPET bottle. High eutrophication impacts of the rPET bottle are due to the product manufacturing stage and likely result from the blow moulding process. During the blow moulding process, nitrogen-containing compounds are often used as blow moulding agents to impart a cellular structure to the plastic polymer. These compounds can pollute the air and can be deposited into water sources. Furthermore, during fossil fuel combustion, nitrogen oxides are also released into the atmosphere and can contaminate water sources.

The Postevand carton has a higher ozone depletion impact than the rPET bottle and is due to the raw materials used in both the primary and secondary packaging of the carton.

The Postevand carton has slightly lower particulate matter formation impact than the rPET bottle. For both products the impacts are due to the raw materials. Cardboard production may produce particulates during the pulping process and small quantities in the form of dust during general paper handling. Similarly, the production of the board for primary packaging may also contribute in the same way. Alternatively, fossil fuels used during cardboard corrugating and PE granulate production for the carton lining layer may further contribute to this impact.

The production of the board for the Postevand carton is based on an outdated dataset from the board supplier. During board production, nuclear energy is used and the nuclear reactor water is used back in a circular process. However, the old dataset does not account for this, and the water depletion is presented as depletion/consumption and not water use. This is likely the reason for the high-water depletion results for the Postevand carton relative to that of the rPET bottle. A sensitivity analysis has been performed where this supplier specific board data has been replaced by more generic data, which results in lower water depletion (see section 5.4.2 for further details).

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.

5.4 Evaluation

5.4.1 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.

Table 5 - Summary of completeness check

Life Cycle Stage	Postevand carton	rPET bottle	Complete	Comment/Action
Raw materials	X	X	Yes	Primary data for specifications of carton and data from ecoinvent relating to the production of raw materials for carton and bottle.
Transport to manufacturing site	X	X	Yes	Primary data used for Postevand carton. Secondary data used for rPET bottle. Sensitivity carried out on secondary factors.
Product manufacturing	X	X	Yes	Primary data used for Postevand carton. Secondary data used for rPET bottle.
Distribution	X	X	Yes	Primary data used for Postevand carton. Secondary data used for rPET bottle.
Retail and storage	X	X	Yes	Secondary data only. Sensitivity carried out on storage duration.
Waste collection	X	X	Yes	Secondary data only. Sensitivity carried out on secondary factors.
End of life	X	X	Yes	Secondary data only. Sensitivity carried out on secondary factors.

Key – X = data available, / = some data available, - = no data available

Primary data was available for the Postevand cartons. The PEFCR for packed water was used, when possible, to fill gaps in primary data. Although secondary data and assumptions have been used to fill gaps in primary data, there is consistent use and availability of primary data between the two compared products.

5.4.2 Sensitivity

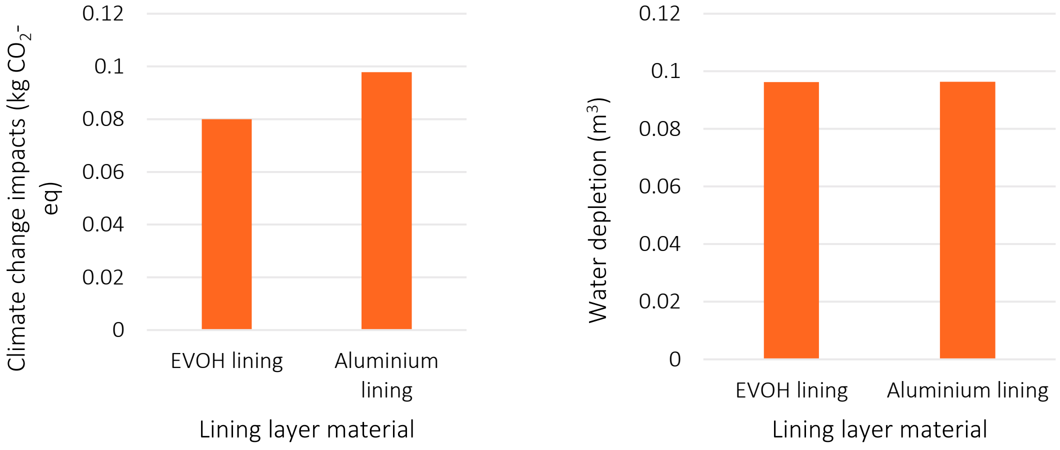
Ten sensitivity analyses were undertaken to test the validity of conclusions drawn by the baseline results. Table 6 demonstrates the reasoning behind each scenario.

Table 6 - Sensitivity analyses undertaken in the comparative LCA

Scenario	Motivation	Analysis
Comparison to an Aluminium-lined carton	To enable comparison to a typical carton on the market as these are usually lined with an Aluminium layer	Use data available in the DEEP tool for a carton lined with Aluminium
Use of renewable electricity during coating, converting and filling	To determine how the impact could be reduced if 100% renewable electricity was used	Characterisation of carton and rPET bottle manufacturing impacts using electricity from renewable sources (high voltage)
rPET bottle filling using 96% bioenergy	To determine how also using bioenergy during rPET bottle filling may reduce the overall impacts	Energy for rPET bottle filling was set equal to carton filling: • 96% bioenergy • 4% natural gas
2030 projected waste disposal rates	To determine how end-of-life impacts may differ in 2030	Impacts were calculated using waste disposal rates and reduction targets taken from the Denmark Action Plan for Circular Economy (2021)
The Circular Footprint formula (CFF) end-of-life allocation method	To determine how different end of life approaches affect the results	The Circular Footprint formula, using company-specific and PEFCR-default values, was used to calculate end-of-life impacts for the carton and rPET bottle. The values used are defined in Appendix D
PET bottle primary packaging using virgin PET	To determine how the impacts of the Postevand carton differ from a virgin PET bottle	Impacts characterised using bottle-grade virgin PET production
Different retail storage duration	To determine how time kept in retail affects the overall impact	Retail storage duration was adjusted to: • 2 weeks (25% shorter duration) • 6 weeks (25% longer duration)

Different distribution distances for the rPET bottle	To determine how distribution distance may affect results. Distribution distance for the rPET bottle was assumed using PEFCR guidance.	Distribution distances for the rPET bottle adjusted to: • 364 km (same as the carton) • 450 km (25% shorter distance) • 750 km (25% longer distance)
Different waste collection distances	To determine how waste collection distance affects the overall impact	Waste collection distances were adjusted to: • 20 km (25% shorter distance) • 60 km (25% longer distance)
Using ecoinvent liquid packaging board factors	To determine to what extent the water depletion is driven by the supplier specific data used for the board.	The ecoinvent factor for liquid packaging board was used in place of the supplier specific data for the board

Analysis on the impacts of the Postevand carton compared to a typical carton on the market that uses an Aluminium lining layer is shown in Figure 9.



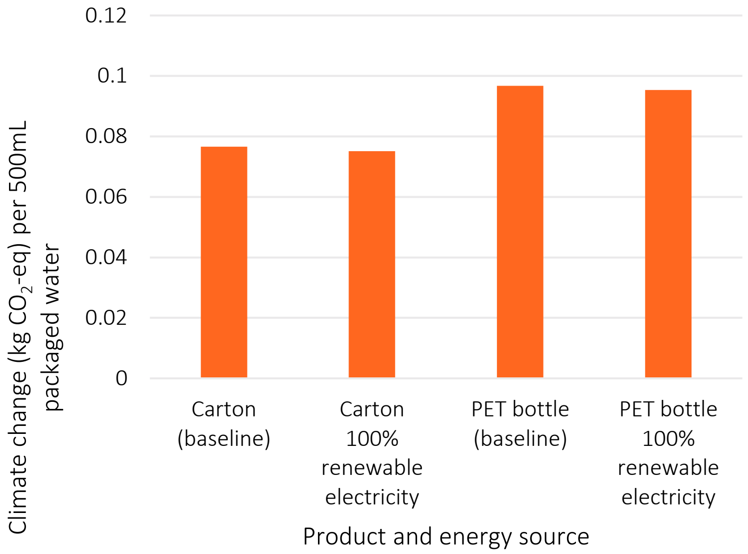
(A) (B)

Figure 9 Overall climate change impacts (a) and water depletion (b) of the Postevand carton compared to a typical carton on the market (Aluminium lining)

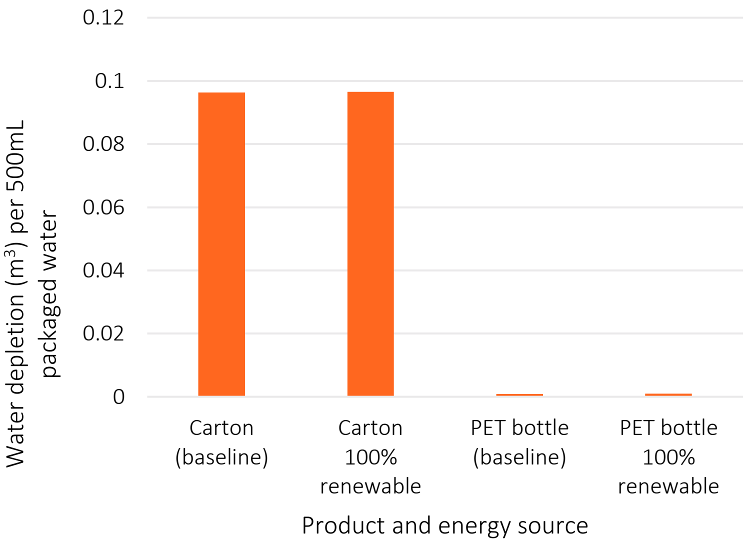
The results from Figure 9 demonstrate that using an EVOH lining layer instead of an aluminium lining in the Postevand carton reduces both the climate and water depletion. The climate impacts are reduced by 19%, whereas the water depletion is not significantly reduced (0.1% reduction).

Analysis on the overall climate change and water depletion of the two products under a 100% renewable energy source scenario is shown in Figure 10. Note – the baseline scenario for the carton represents:

- A mix of renewable grid electricity, natural gas and propane during coating and converting
- Natural gas and bioenergy during filling



(A)



(B)

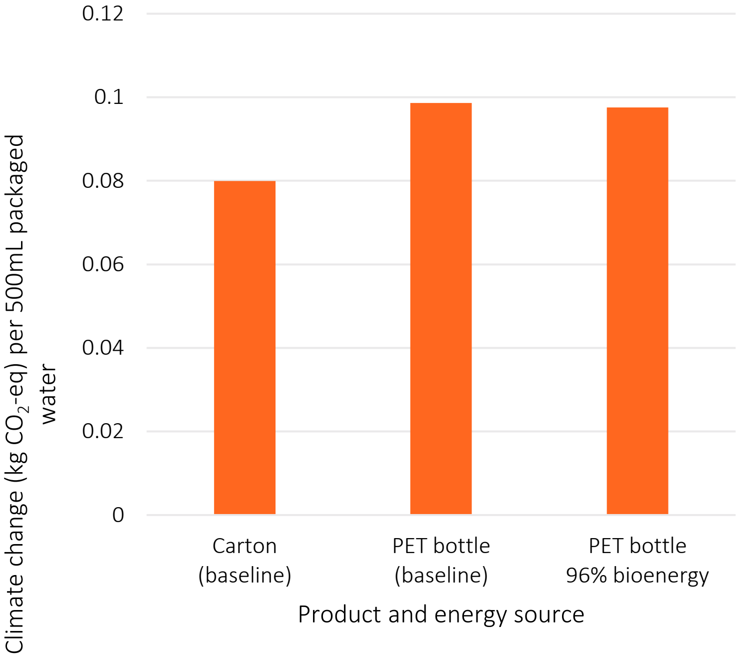
Figure 10. Overall climate change impacts (a) and water depletion (b) of the Postevand carton and rPET bottle under different energy source scenarios

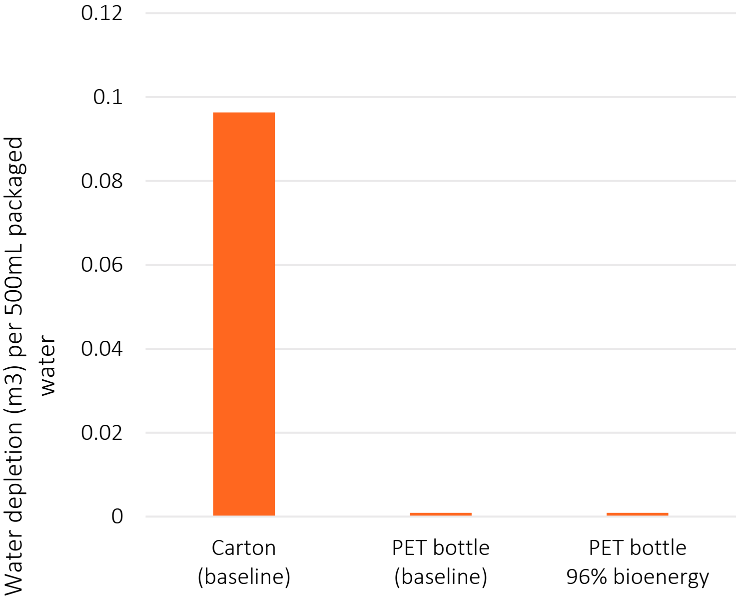
The results from Figure 10 demonstrate that by using 100% renewable energy during carton and rPET bottle manufacturing, climate change impacts can be reduced for both products. For the carton, impacts can be reduced by 2%, whereas for the PET bottle, impacts can be reduced by 1%.

Alternatively, by using renewable energy, the overall water depletion is increased by 0.2% and 5% for the carton and rPET bottle, respectively.

Analysis on the overall climate impact and water depletion of the Postevand carton compared to a rPET bottle when using 96% bioenergy during the filling process is shown in Figure 11.

(A)



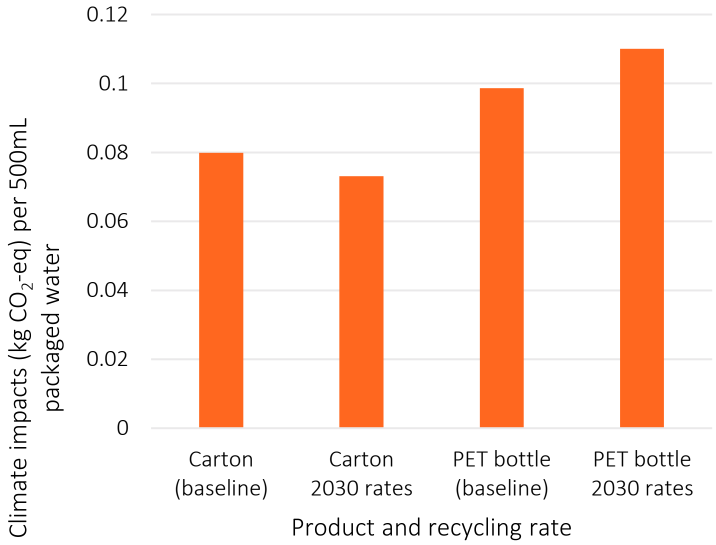


(B)

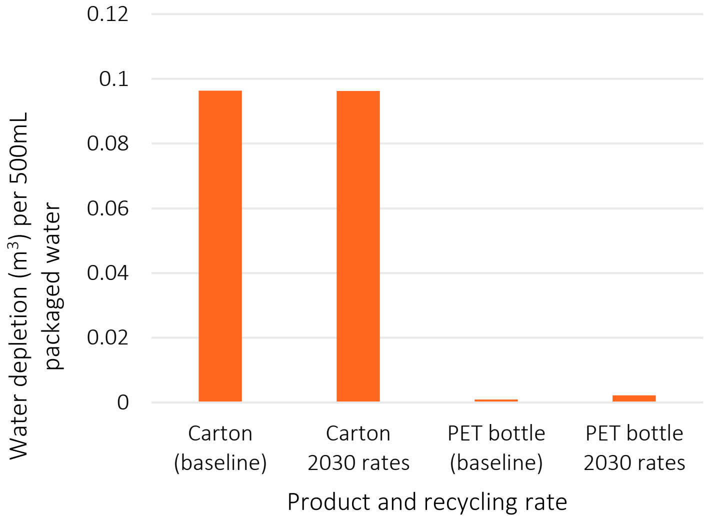
Figure 11. Overall climate change impacts (a) and water depletion (b) of the Postevand carton and recycled PET bottle when using bioenergy during product filling

Figure 11 demonstrates that using 96% bioenergy during the filling process does not significantly reduce the overall climate impacts or water depletion of the rPET bottle.

Analysis on the overall climate impact and water depletion of the Postevand carton and rPET bottle using projected waste disposal rates for the year 2030 is shown in Figure 12. The waste rates used can be found in Appendix A.



(A)



(B)

Figure 12. Overall climate change impacts (a) and water depletion (b) of the Postevand carton and rPET bottle under projected 2030 waste disposal rates

The results in Figure 12 demonstrate that if the projected waste disposal rates are met in 2030, overall climate impacts may be reduced for the Postevand carton by 10%. However, for the rPET bottle, these impacts may be increased by 15%. Water depletion of the carton under the projected waste disposal rates is likely to remain similar to the current rates (-0.03%), however; water depletion of the rPET bottle may increase by 141%.

Analysis of the overall climate impact and water depletion using different end-of-life allocation methods are shown in Figure 13.

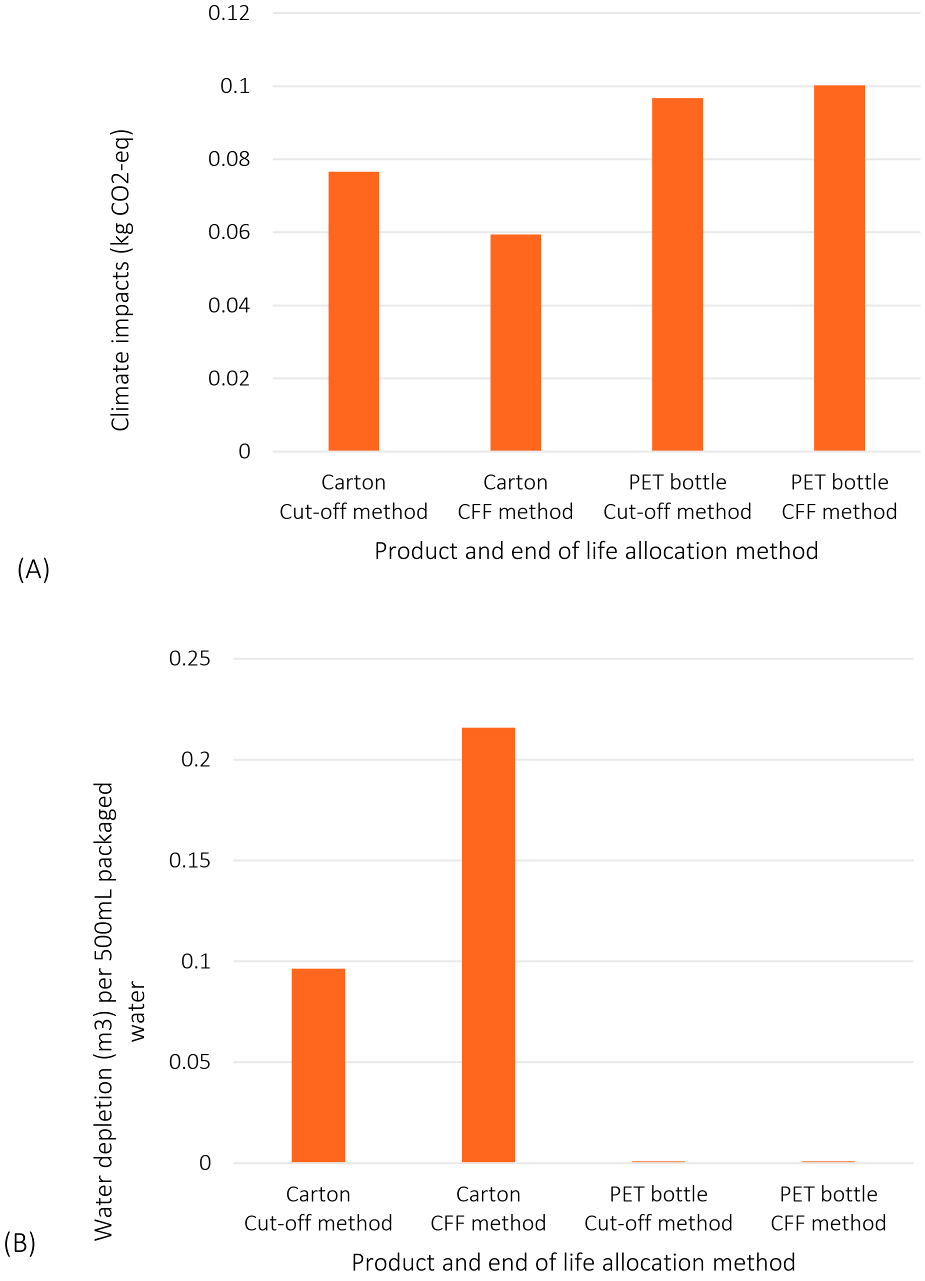
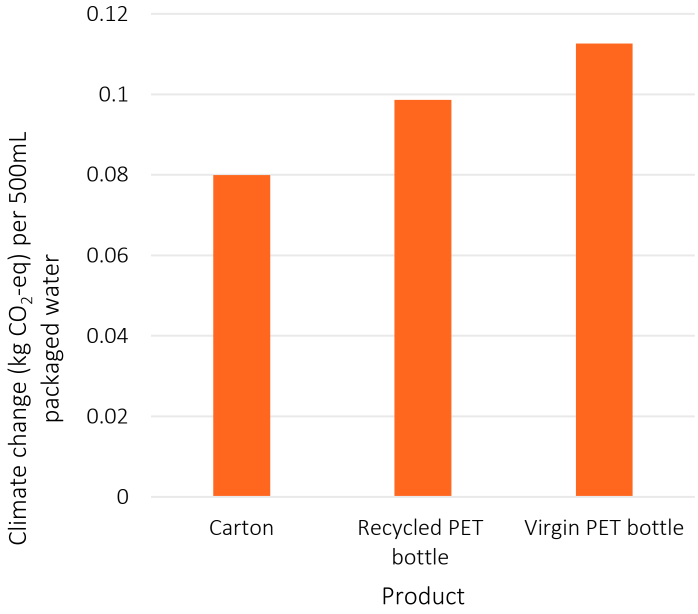


Figure 13. Overall climate change impacts (a) and water depletion (b) of the Postevand carton and recycled PET bottle under different end-of-life allocation methods

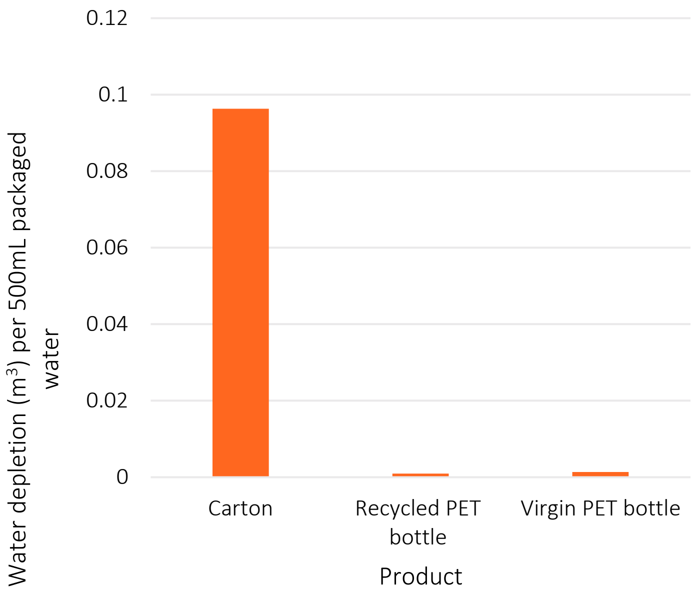
The results in Figure 13 demonstrate that there is a significant difference in the climate change impacts of the two products under the different end-of-life allocation methods. The overall climate impact of the Postevand carton is 23% lower under the CFF method, whereas the overall water depletion is 124% higher.

When using the CFF method, the overall climate impact or the rPET bottle increases by 3%. Alternatively, the overall water depletion reduces by 2%. Using this method results in an overall climate impact of the rPET bottle that is 0.037 kg CO_2-eq greater than the Postevand carton.

Analysis on the overall climate and water depletion of the Postevand carton compared to a recycled and virgin PET bottle are shown in Figure 14.



(A)



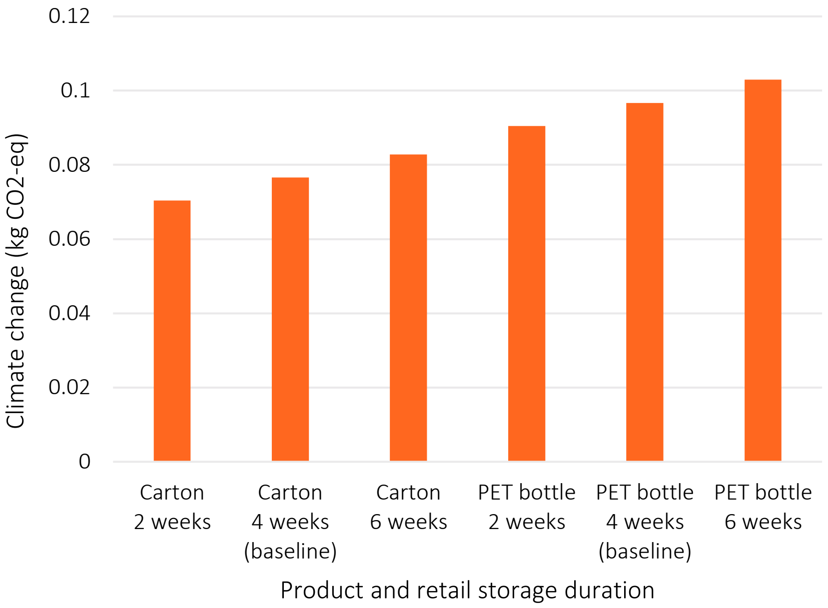
(B)

Figure 14. Overall climate change impacts (a) and water depletion (b) of the Postevand carton compared to a recycled and virgin PET bottle

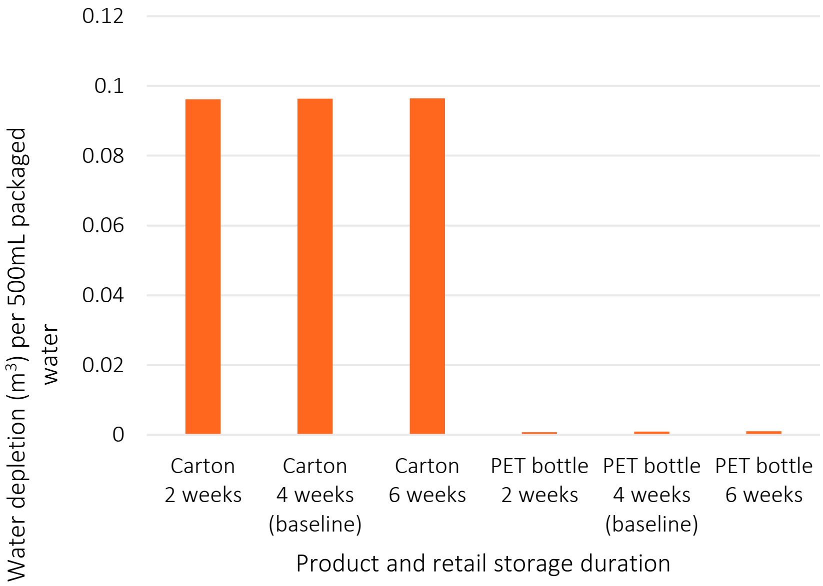
Figure 14 demonstrates that the overall climate change impact of the virgin PET bottle is greater than the rPET bottle and Postevand carton. Alternatively, the Postevand carton has a higher water depletion compared to both PET products.

Compared to a virgin PET bottle, the Postevand carton has a 30% lower overall climate impact, but 68 times greater overall water depletion.

Analysis on the overall climate impact and water depletion of the Postevand carton and rPET bottle under different retail storage duration scenarios are shown in Figure 15.



(A)

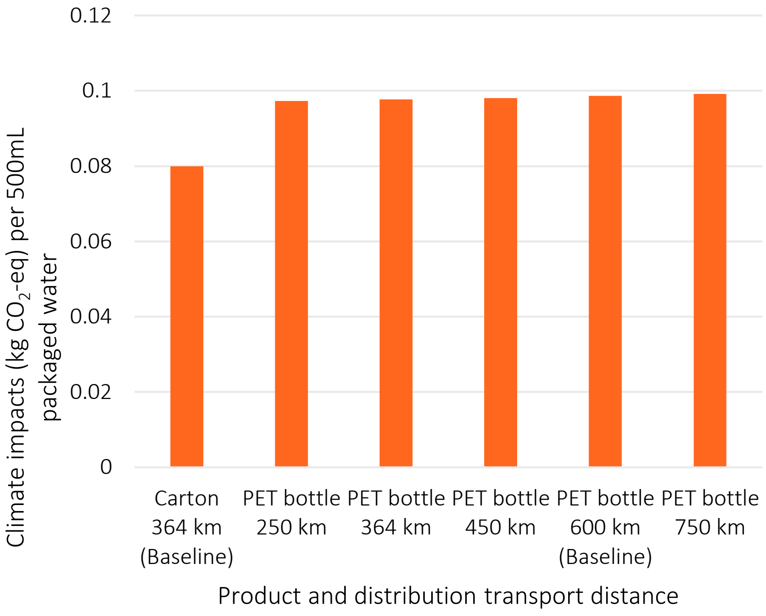


(B)

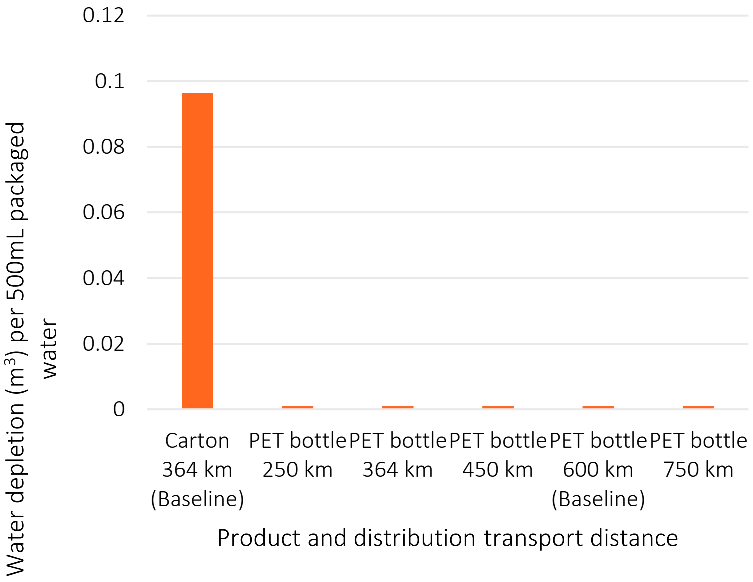
Figure 15. Overall climate change impacts (a) and water depletion (b) of the Postevand carton and rPET bottle under different storage durations.

Figure 15 demonstrates that retail storage duration may impact the overall climate change impacts of the Postevand carton and rPET bottle. Increasing the storage duration by ± 25% (± 2 weeks) may increase the overall climate impacts of the carton and rPET bottle by ± 8% and ± 7%, respectively. A ± 25% increase in storage duration may also increase the overall water depletion for the two products. This increase is insignificant for the Postevand carton (± 0.2%) but more significant for the rPET bottle (± 12%).

Analysis on the overall climate impact and water depletion under different rPET bottle distribution distances are shown in Figure 16.



(A)



(B)

Figure 16. Overall climate change impacts (a) and water depletion (b) of the Postevand carton compared to the rPET bottle under different distribution distances.

Figure 16 demonstrates that the difference in the overall climate change impacts of the two products are still of a similar magnitude under equal transport distances (364 km). Under equal distances, the overall climate change impact of the rPET bottle is 20% greater than the Postevand carton.

However, with equal transport distances, the overall water depletion of the rPET bottle remains lower compared to the Postevand carton (-99%).

Analysis of the overall climate impact and water depletion of the Postevand carton and rPET bottle under equal waste collection transport distances are shown in Figure 17.

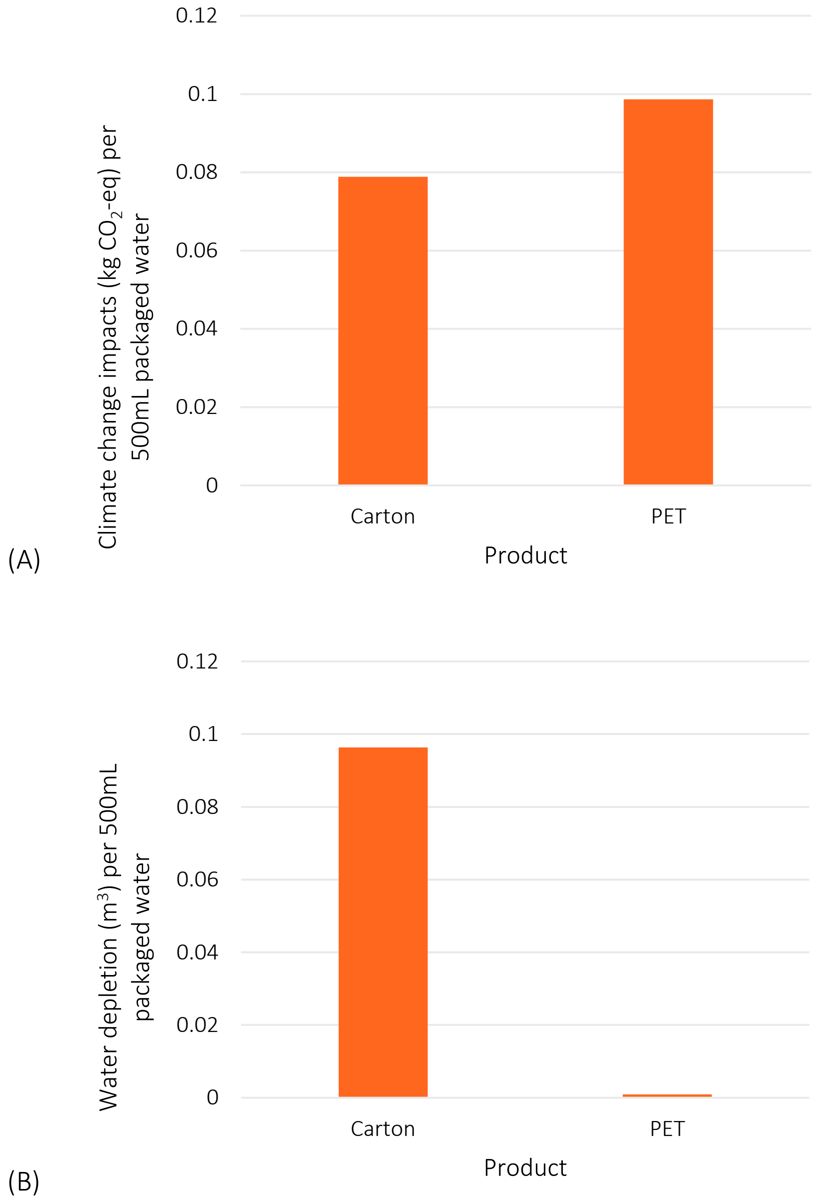


Figure 17. Overall climate change impacts (a) and water depletion (b) under equal (300 km) waste collection transport distances. The results represent the impacts for the Postevand carton and rPET bottle.

Figure 17 shows that under equal waste collection transport distances, climate impacts of the carton are lower (20%) than the rPET bottle. Furthermore, water depletion of the carton remains higher – over 100 times greater.

Analysis of the overall climate impact and water depletion of the Postevand carton using the supplier specific board factor and ecoinvent liquid packaging board emission factor (liquid packaging board production GLO liquid packaging board) is shown in Figure 18.

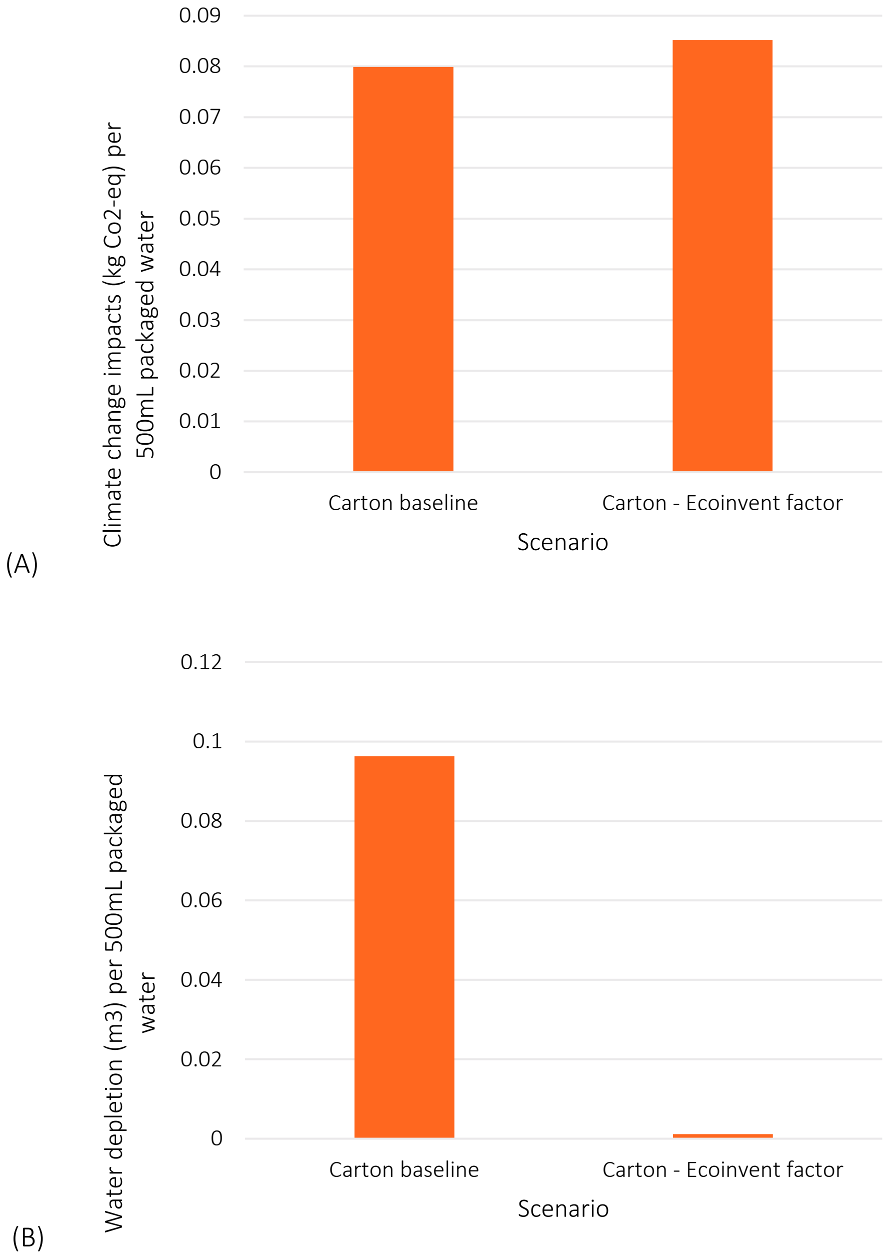


Figure 18. Overall climate change impacts (a) and water depletion (b) of the Postevand carton using the Stora Enso (baseline) and ecoinvent board emission factors.

Figure 18 shows that under the ecoinvent liquid packaging board emission factor, the water depletion of the Postevand carton is reduced by 99%. However, the climate impacts are 7% higher when using the ecoinvent factor.

5.4.3 Uncertainty analysis

The life cycle assessment of the Postevand carton and rPET bottle has been generated using primary data, secondary literature data, and the use of the ecoinvent database (i.e., for production data). A data quality assessment has been applied (see Appendix C) to reflect the quality and reliability of the LCI data, these findings and the assumptions made in this study are reflected in the limitations listed in Section 5.5.

The raw material extraction phase has been modelled using primary data. The transport stage has been modelled using primary data with the support of some secondary data from the literature (i.e., for raw material transport distances). The carton board suppliers only supplied emission factors for the finished board and not inventory data, given the uncertainty over their methodology, a sensitivity analysis was applied using an ecoinvent 3.9 unit process for liquid packaging board.

The product manufacturing and distribution stages have been modelled using primary data for the Postevand carton and secondary data from the PEFCR for the rPET bottle. A sensitivity analysis has been applied to explore the consequence of using alternative energy sources (i.e., renewable grid energy, bioenergy) during the rPET bottle product manufacturing process. The purpose of this was to capture the potential variation in manufacturing practices that may be used during the production of an average Danish rPET bottle given no primary data was available for their manufacture. Similarly, the exact production location of an average rPET bottle is not known and therefore a sensitivity analysis of the distribution distance has been applied.

The retail and storage stage are modelled based on data available in the PEFCR guidance. These generic assumptions have been explored in a sensitivity analysis to demonstrate the effect that retail storage duration may have on the overall results. This has been done to demonstrate how variability in storage duration between the two products may affect the overall environmental impact of the product.

End of life stage is modelled on data available in the literature. A sensitivity analysis has been applied to explore alternative waste disposal rates, different waste collection distances, and the circular footprint formula (CFF) end-of-life allocation method.

5.5 Limitations, representativeness, consistency, and reproducibility

A consistent approach has been applied to both products with primary data available for the bill of materials and energy and utility use during coating, converting and filling. Where data was not available for the rPET bottle, assumptions have been made based on the carton. Where data for both products was not available, the PEFCR has been used. A consistent system boundary and allocation rules has been applied for both products.

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

- Aligning with the goal and scope, the key limitations of this study have been identified: The carton board supplier provided emission factors for the production of the product; they were not able to provide raw inventory data. Therefore, the accuracy of this report is limited by the supplier’s own assessment.
- The production of the board for the Postevand carton is based on an outdated dataset from the board supplier. During board production, nuclear energy is used, and the nuclear reactor water is used back in a circular process. However, the old dataset does not account for this, and the water depletion is presented as depletion/consumption and not water use. This is likely the reason for the high-water depletion figures for the Postevand carton relative to the rPET bottle.

- Primary data for the production of raw materials for the Postevand carton could have improved the accuracy of the results. The high environmental impacts for several impact categories (climate change, fossil depletion, particulate matter formation) may result from the burning of fossil fuels as an energy source. If renewable energy was used during these processes, these impacts may be significantly reduced. Similarly, primary data on cardboard production, including the application of a chlorine-free pulping process, may influence ozone depletion results.
- Primary data for the rPET bottle production could also have improved the accuracy of the results during the raw materials extraction stage. The PET recycling process is energy-intensive, therefore; if renewable energy was used during rPET production, it may further reduce the impact of the product.
- Primary data for filling of the rPET bottle may have improved the accuracy of results during the product manufacturing stage. rPET filling data was taken from the PEFCR for boxed water and the from technical data of Elopak filling machines. The Elopak technical data uses fresh juice as a proxy which may not be an accurate representation of the bottle-filling process.
- The carton recycling rate is based on an old dataset (2017), the sensitivity analysis shows that a higher recycling rate may reduce the climate impact and water depletion for the Postevand carton. Furthermore, under projected recycling rates for the year 2030, the climate impact of the Postevand carton may decrease, whereas the impact of the bottle may increase. As recycling rates improve, the climate impacts of the Postevand carton have potential to further be reduced.
- Depending on end-of-life method used there are significant differences in overall impacts for the two products. Use of the CFF method results in a significantly lower overall climate footprint for the carton and a significantly higher climate footprint for the rPET bottle. Alternatively, the CFF method significantly increases the overall water depletion of the carton. Using this end-of-life allocation method would suggest end-of-life should be focused on for improving for the Postevand carton water depletion.
- Retail storage duration of the products can significantly impact the results. For example, if the carton was only stored in retail for 2 weeks, however, the rPET bottle was stored for 6 weeks, the overall climate impacts of the carton would be significantly lower. Primary data on retail storage duration would improve the accuracy of results.
- The waste streams are assumed to follow the known Denmark end of life waste disposal routes for the specific materials. However, the exact fate of the materials at end of life is not known. Furthermore, as both products are consumed immediately upon purchase, they are likely to enter municipal waste at end of life. However, waste disposal rates representing the disposal route and specific material are not publicly available in the literature. Therefore, the disposal rate used in the study represents the average disposal rate in Denmark relating to the material type only.
- European market averages are used for most of the secondary data. In some cases (e.g., for natural gas used during filling and distribution), Switzerland is used as this is likely to be the most representative for the Denmark production mix. These processes have a large contribution to the overall climate impact for both products which may make it challenging to make specific conclusions about the products.

- This LCA was conducted using calculated results for system processes from the ecoinvent 3.8 database, which limited the practitioner's ability to explore the detailed drivers of ODP results (and perhaps others where the background data is significant).
- Some secondary production data sources which are +10 years old have a large contribution to the overall climate impact. Noting in all cases this refers to the original source process on which the ecoinvent 3.8 unit process is based upon, the background processes will have been updated with each new ecoinvent version. This could limit the accuracy of specific conclusions about the product.
    - Data for the production of the secondary packaging film contributes to 11% of the overall rPET bottle climate impacts.
    - Data for the blow moulding process for the rPET bottle contributes to 16% of the PET bottle overall climate impacts.
    - Data for the natural gas used during carton filling and at the distribution centre contributes to 10% and 9% of the carton and PET bottle climate impacts, respectively.
    - Data for the incineration of waste polyethylene contributes to 15% and 13% of the carton and PET bottle climate impacts, respectively.
    - Data for the incineration of waste paperboard contributes to 16% of the carton climate impacts.
    - Data for the incineration of waste PET contributes to 2% of the PET bottle climate impacts.
    - Data for transport using a 16-32 metric tonne lorry contributes to 39% and 46% of the carton and PET bottle climate impacts, respectively.

The results within this report are limited by:

- The scope, boundaries and reference period defined within this assessment (e.g. cradle-to-grave system boundary)
- The secondary data used for the product systems
- The data quality defined within this assessment (see Section 4.3)
- The assumptions defined within this assessment (see Section 3.5.3)
- The exclusions defined within this assessment (see Section 3.5.2)

The data quality assessment scores each data source for reliability, representativeness and temporal, geographical and technological correlations. Some notable observations from the scoring:

- Some geographical and temporal limitations in secondary production data have made it difficult to make specific conclusions about the products.
- The waste streams are assumed to follow the typical Danish mix of treatment routes for either manufacturing or consumers, the exact fate of processing waste is not known.

5.6 Conclusions and recommendations

The LCA study presented in this report generated environmental profiles of the full life cycle of a 500 ml Postevand carton compared to an average Danish 100% recycled PET bottle and estimates the impact difference between these two products. 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:

- The climate impact of the Postevand carton is estimated at 0.077 kg CO2-eq, approximately 17.7% lower than a typical Danish recycled PET bottle.
    - The estimated climate change impacts of the Postevand carton may range between 0.059 – 0.083 kg CO2-eq under different scenarios. These include different carton lining scenarios, the use of 100% renewable energy during the product manufacturing stage, under different waste disposal rates, under different end of life allocation methods, with differing retail storage durations, under different distribution and waste collection transport distances and when using a different type of board.
    - The estimated climate change impacts of the rPET bottle may range between 0.087 – 0.11 kg CO2-eq under different scenarios. These include the use of 100% renewable energy during the product manufacturing stage, using bioenergy during bottle filling, under different waste disposal rates, under different end of life allocation methods, under retail storage durations and under different distribution and waste collection transport distances.
- Some important impacts (e.g., land use, biodiversity, water scarcity) were unable to be assessed due to limitations in the data. These impact categories may have significant affects for wood-based products. The results should be taken with caution as these trends may differ when other major environmental impacts are considered which have not been assessed in this study.
    - It would be sensible to consider (at least qualitatively), in any decision making, metrics such as Land Occupation and Water Use/Consumption.
    - Although water depletion was examined in the study, this metric is only at the inventory level and does not represent an environmental impact (i.e., it does not assess water scarcity). This is only a representation of water use and does not demonstrate the reusing of water in the nuclear reactor or the amount of consumed water used by the product. This has been demonstrated in the sensitivity analysis, where the ecoinvent factor demonstrates a lower water depletion. Therefore, these results should be viewed for information only and should be interpreted with caution.
- There were some areas where further primary data would have improved the accuracy and specificity of the study. This limitation makes it more challenging to make specific conclusions about these products vs. generic assumptions about water and carton bottled water.
    - The raw material extraction stage is the greatest contributor to all impact categories for the Postevand carton. This may be due to the large amount of virgin components used in the product. This stage is also a significant contributor to the rPET bottle. However, the lack of primary data for both products makes it difficult to draw conclusions.
    - The retail and storage stage is also a large contributor to the carton impacts. This may be due to the high energy consumption at this stage; however, lack of primary data limits these conclusions.
- Decreasing retail storage duration by 25% may reduce the estimated climate impact of the carton by up to 8%.

- Although the ecotoxicity impacts of the Postevand carton are estimated to be lower than the rPET bottle, ecotoxicity results are generally considered to have higher uncertainty compared to some other categories.

Some geographical and temporal limitations in secondary production data have made it difficult to make specific conclusions about the products.

The following recommendations have been made:

- The largest contributor to all impact categories is the raw material extraction stage. Anthesis recommends Postevand focuses on this area for improvement.
- Anthesis recommends investigating the impacts of substituting the secondary packaging cardboard box with a reusable crate to determine whether this could reduce environmental impacts.
- Sourcing recycled materials and ensuring all raw materials are sourced from suppliers that use renewable energy may also reduce the impact in this energy intensive stage, but these changes have not been examined in this study. The water depletion of the carton is likely to be significantly reduced if a primary dataset that represents the recycling on water in the nuclear reactor is available for the board production process. Anthesis recommends seeking data that is more representative of the anticipated technological situation.

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