ELLEN MACARTHUR FOUNDATION

Modelling and analysis by SYSTEMIQ eunomia

Unlocking a reuse revolution: **scaling returnable packaging**

Modelling technical appendix

This technical appendix provides detailed information on the calculations and modelling that underpin the conclusions and recommendations of the *Unlocking a reuse revolution: scaling returnable packaging* study.

Section one provides an overview of the analytical model, the system map analysed, and input variables.

Section two gives detailed assumptions, input data, and sources for each of the steps of the system map.

Section three gives an overview of the model calculations, and lists the output variables.

Section four discusses the limitations of this study, and highlights areas where further research is needed.

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SECTION 1 – ANALYTICAL MODEL AND SYSTEM MAP

About the model

Our analysis is based on a comprehensive and granular packaging flow model for four types of single-use packaging and their reusable alternatives. We selected these applications as they vary by material, volume, purchase frequency, and ease of cleaning; and because each is representative of a broader range of products (Figure 1).

The primary goal of this modelling study was to draw out and quantify the impact of the key design choices, for example the role of shared infrastructure and standardisation, and the drivers of impact (including scale and return rates) that are likely suitable for a broader range of products and applications. As such, we focused on like-for-like material substitution to draw out the key drivers of impact beyond the material choice. That being said, we also recognise other options, for instance substituting single-use plastic bottles with glass alternatives, and we have computed high-level results for this substitution in the report.

	1: Beverage bottle			2: Personal care bottle		3: Food cupboard packaging		4: Fresh food packaging	
	Single-use	Reuse	Reuse	Single-use	Reuse	Single-use	Reuse	Single-use	Reuse
Primary packaging	Single-use PET bottle	Reusable PET bottle	Reusable glass bottle	Single-use PE bottle	Reusable PE bottle	Single-use PP flexible	Reusable PP container	Single-use PP pot	Reusable PP container
Lid	Single-use HDPE cap	Single-use HDPE cap	Single-use HDPE cap	Single-use PP snap lid	Single-use PP snap lid	No lid	Single-use PP foil	Single-use PP lid	Single-use PP lid
Example products	Soda, juice			Shampoo, shower gel		Rice, pasta, cereals		Yogurt, cream	
Volume	1L bottle			0.25L format		1.5L format		0.5L format	
Purchase frequency	~ 1 week			~ 2/3 months		~ 2-4 weeks		~ 1 week	
Easiness to clean	Easy			Hard		Easy		Medium	

Each application represents a wider group of products and applications that vary by material, volume, purchase frequency and easiness to clean

Figure 1: Modelled applications

For each application, we sought to understand the impact of key variables as 'drivers' of economic and environmental performance. Specifically, we identified and modelled four 'scenario-builder' variables:

- **Scale** – the share of packaging that switches from single-use to reusable packaging of a particular application type. The analysis modelled scales from 10% to 70%; the former represents a vision of an at-scale return system that could be realistically achieved in the near-term, and the latter a 'system change' scenario, where reusable becomes the most common packaging type for these applications.

- **Return rates** – the share of containers that are returned after each use cycle. High return rates allow for more cycles, reduce the need to replace containers, and lower overall material usage.[1] Our scenarios included return rates ranging between 80% and 95% (equivalent to between approximately four and 15 rotations[2]), as well as a specific sensitivity analysis on this variable.

- **Scale of the shared reuse network** – also referred to as 'effective market share', and the result of two variables:
    - **Scale of the reuse market** – the share of packaging of a particular application type that switches from single-use to reusable packaging. The analysis modelled scales between 10% (Fragmented Effort scenario), 30% (Collaborative Approach scenario) and 70% (System Change scenario); the former represents a vision of an at-scale return system that could be realistically achieved in the near-term, and the latter a 'system change' scenario, where reusable becomes the most common packaging type for these applications.
    - **Sharedness of infrastructure** – the share of packaging managed by a single reuse network,[3] referring to brands and retailers collaborating to use the same reverse logistics, sorting, and cleaning services.[4] A higher concentration of reuse networks can enable a more efficient setup of infrastructure and logistics. The model accounts for 20% (Fragmented Effort scenario), 40% (Collaborative Approach scenario) and 60% (System change scenario) of the reuse market using such shared infrastructure.

- **Standardised packaging** – the number of different pack designs for each application. Fewer designs can enable the pooling of packaging – where individual packs are used by different brands and producers. This decreases complexity relating to sortation, cleaning, and logistics, as well as reducing transport distances, and production and conversion costs. Our analysis modelled two levels of packaging standardisation: a highly standardised and pooled system with few pack designs per application; and a differentiated system where each brand has its own pack design.

To facilitate an informed discussion on the impacts and trade-offs between different system configurations, we developed three possible scenarios, as shown in Figure 2.

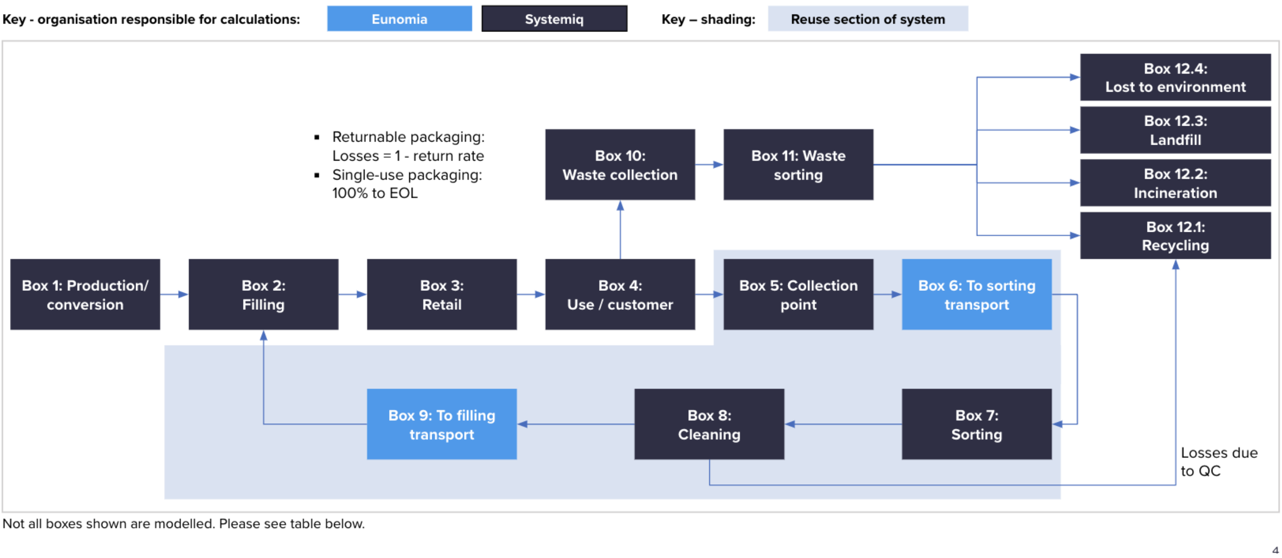
[1] Return rates are directly linked to the average number of loops achieved by a particular packaging type, and are separate to the theoretical maximum number of loops possible with a particular material. The return rate and quality control loss rate (proportion of packaging lost each rotation due to physical defects appearing on the packaging) determine the "effective return rate" of reusable packaging, otherwise described as the proportion of packaging that makes it back to be refilled. The average number of loops, then, is inversely related to the effective return rate.
[2] Accounting for quality control loss rate of 2% (5% for personal care).
[3] A reuse network can be composed of multiple reuse service providers, but they are assumed to work together and operate a collaborative system, sharing e.g. collection, sorting, washing, and reverse logistics.
[4] We assume that collection point infrastructure is always shared between reuse networks to avoid multiple vending machines being required at each retail location, and to improve customer experience.

System variables	**Fragmented Effort** A low scaled and fragmented return system	**Collaborative Approach** An established reuse system with potential to scale beyond	**System Change** A visionary scaled, shared, and standardised return system
Scale and shared infrastructure The volume of packaging switching to reuse, within a common system	Market share: **~2%** Due to low volumes and **fragmented infrastructure**	Market share: **~10%** Possible through big volume shifts to reuse and **some sharing of infrastructure**	Market share: **~40%** Large shift to reuse within a **highly shared infrastructure**
Packaging system Bespoke packaging vs. shared structural design that can return to any filler	Bespoke packaging	Pooled packaging	Pooled packaging
Return rate and average no. of loops How much packaging gets returned, determining how many times it can be reused	**80% return rate** enabling packaging to be reused **~5 times.**	**90% return rate** enabling packaging to be reused **~10 times.**	**95% return rate** enabling packaging to be reused **~15 times.**

Figure 2: Scenario descriptions

System map

To quantify the economic and environmental implications of the return model, we modelled the flows and stocks of packaging through a system map, covering all steps, from production and conversion to end-of-life. The system map and a definition of each box is displayed below. Each box and each arrow were quantified for each scenario, and for different packaging types.



- Box 1: Production/conversion
  New returnable/single-use packaging is produced, converted, and transported to filling line.
- Box 2: Filling
  Returnable packaging (new or reused) or new single-use packaging is filled with product and transported to point of sale.
- Box 3: Retail
  Product is stored and sold by the retailer.
- Box 4: Use/customer
  Product is used by the customer.

- Box 5: Collection point
  Customer returns returnable packaging to a collection point, where it is pre-sorted by application type. The infrastructure for collection points is shared between applications and reuse networks, i.e. all reusable packaging can go to all collection points.
- Box 6: To sorting transport
  Logistics provider collects returnable packaging from distribution centres and transports to sorting and cleaning facility. Reverse logistics from retailer to retailers' distribution centres are not modelled. Different applications and different reuse networks are assumed to have separate logistics networks.
- Box 7: Sorting
  Returnable packaging is sorted into batches of the same pack type, and moved to the washing line, which is collocated. Different applications and different reuse networks are assumed to have separate sorting facilities (or at least separate lines in the same facility).
- Box 8: Cleaning
  Returnable packaging is cleaned, quality-checked, and repalletised. Different applications and different reuse networks are assumed to have separate cleaning facilities (or at least separate lines in the same facility).
- Box 9: To filling transport
  Logistics provider transports returnable packaging back to filling line. Different applications and different reuse networks are assumed to have separate logistics networks.
- Boxes 10 to 12: End-of-life
  Unreturned reusable packaging and single-use packaging is recycled, landfilled, incinerated, or lost to the environment. Returned, sorted, and quality-controlled reusable packaging is fully recycled.

The following table shows which variables were considered in the model for each box in the system map.

Box	Capex[5]	Opex[6]	FTE[7]	GHG[8]	Water	Comment
Box 1: Production/conversion	✔	✔		✔	✔	No additional FTE assumed for reusable packaging
Box 2: Filling	✔	✔	✔	✔		
Box 3: Retail	No specific modelling, included in the system map for completeness					
Box 4: Use/customer	No specific modelling, included in the system map for completeness					
Box 5: Collection points	✔	✔	✔	✔		
Box 6: To sorting transport (modelling only from distribution centre to sorting and cleaning)	✔	✔	✔	✔		
Box 7: Sorting	✔	✔	✔	✔		

[5] Capex *refers to capital expenditures, a company's (or here a system's) major long-term expenses. Examples in this scenario include physical assets, such as machinery for filling, sorting and cleaning.*
[6] *Opex refers to operating expenses, which are day-to-day expenses incurred by a company (or here system). In this scenario, they include costs such as energy, storage and labour.*
[7] Full-time equivalent
[8] Greenhouse gas

Box 8: Cleaning	✔	✔	✔	✔	✔	
Box 9: To filling transport	✔	✔	✔	✔		
Box 10 to 12: End-of-life	✔	✔		✔	✔	No additional FTE assumed for reusable packaging

List of input variables

The following table provides an overview of all input variables into the model, together with information on whether they are fixed or vary by application and scenario.

Item	Unit	Varied by application	Varied by scenario
System characteristics			
No. of filling facilities	#	yes	yes
Total market volume – products	# billion units	yes	yes
Total market volume – products	m^3	yes	yes
Customer use time	days	yes	no
Reverse logistics time	days	no	no
Slack	%	no	no
Quality loss rate	%	no	no
Maximum no. of loops	#	yes	no
System lifetime	years	no	no
Packaging characteristics			
Primary packaging material	material type	yes	no
Primary packaging volume	litres	yes	no
Primary packaging weight	g	yes	no
Primary packaging recycled content	%	yes	no
Primary packaging – recycling rate	%	yes	no
Primary packaging – incineration rate	%	yes	no
Primary packaging – landfill rate	%	yes	no
Primary packaging – lost to environment rate	%	yes	no
Closure material	material type	yes	no
Closure weight	g	yes	no
Closure recycled content	%	yes	no
Closure return rate	%	yes	no
Closure quality loss rate	%	yes	no
Closure – recycling rate	%	yes	no
Closure – incineration rate	%	yes	no
Closure – landfill rate	%	yes	no
Closure – lost to environment rate	%	yes	no
Capex			
Per unit inputs			

Box 2: Filling	cent / unit	yes	yes
Box 5: Collection point	cent / unit	yes	yes
Box 7: Sorting	cent / unit	yes	yes
Box 8: Cleaning	cent / unit	yes	yes
Per tonne inputs			
Box 1: Production/conversion	EUR / tonne	yes	no
Box 10: Waste collection	EUR / tonne	yes	no
Box 11: Waste sorting	EUR / tonne	yes	no
Box 12.1: Recycling	EUR / tonne	yes	no
Box 12.2: Incineration	EUR / tonne	yes	no
Box 12.3: Landfill	EUR / tonne	yes	no
Opex			
Per unit inputs			
Box 2: Filling	cent / unit	yes	yes
Box 5: Collection point	cent / unit	no	yes
Box 7: Sorting	cent / unit	yes	yes
Box 8: Cleaning	cent / unit	yes	yes
Deposit fee	cent / unit	no	no
EPR fees	cent / unit	yes	no
Per tonne inputs			
Box 1: Production/conversion	EUR / tonne	yes	no
Box 10: Waste collection	EUR / tonne	yes	no
Box 11: Waste sorting	EUR / tonne	yes	no
Box 12.1: Recycling	EUR / tonne	yes	no
Box 12.2: Incineration	EUR / tonne	yes	no
Box 12.3: Landfill	EUR / tonne	yes	no
Recyclate revenue	EUR / tonne	yes	no
Incineration energy revenue	EUR / tonne	yes	no
Per tonne GHG inputs			
Externalities – CO_2 costs	EUR / tonne CO_2	no	no
GHG emissions			
Per unit inputs			
Box 5: Collection point	gCO_2e / unit	no	yes
Box 7: Sorting	gCO_2e / unit	yes	yes
Box 8: Cleaning	gCO_2e / unit	yes	yes
Per tonne inputs			
Box 1: Production/conversion – virgin	gCO_2e / g	yes	no
Box 1: Production/conversion – recycled	gCO_2e / g	yes	no
Box 2: Filling	gCO_2e / g	yes	no
Box 10: Waste collection	gCO_2e / g	no	no
Box 11: Waste sorting	gCO_2e / g	no	no
Box 12.1: Recycling	gCO_2e / g	no	no
Box 12.2: Incineration	gCO_2e / g	no	no
Box 12.3: Landfill	gCO_2e / g	no	no
Box 12.4: Lost to environment	gCO_2e / g	no	no

FTEs			
Per unit inputs			
Box 2: Filling	# FTEs / unit	yes	yes
Box 5: Collection point	# FTEs / unit	no	yes
Box 7: Sorting	# FTEs / unit	yes	yes
Box 8: Cleaning	# FTEs / unit	yes	yes
Water use			
Per unit inputs			
Box 8: Cleaning	l / unit	yes	yes
Per tonne inputs			
Box 1: Production/conversion	l / tonne	yes	no
Box 12.1: Recycling	l / tonne	yes	no

Data was collected through a combination of desk research, literature review, and expert interviews, including companies sharing proprietary data. Data and assumptions were shared and verified with 20+ industry experts, mostly members of the Scaling Return Advisory Group and Contributor organisations listed at the back of the study.

SECTION 2 - DETAILED ASSUMPTIONS, INPUT DATA AND SOURCES

In the following sections the key data assumptions are laid out, together with short descriptions of data sources. The sections are structured along the system map, starting with system-wide assumptions, and ending with end-of-life. In each section, key assumptions are described, followed by assumptions made for the calculation of costs, GHG, water use, and finally FTE where applicable. Proprietary and sensitive data are shown in aggregates, to maintain confidentiality and to protect sources.

General reuse system and packaging characteristics

Variable	Units	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
Customer use time	days	7	7	7	28	28	7	7	84	84
Reverse logistics time	days	28	28	28	28	28	28	28	28	28
Slack	%	-	10%	-	10%	-	10%	-	10%	-
Quality loss rate	%	-	2%	2%	-	2%	-	2%	-	5%
Maximum no. of loops	#	0	25	50	0	25	0	25	0	25
Lifetime of the reusable packaging system	years	0	10	10	0	10	0	10	0	10
Recycled content (body)	%	17%	17%	42%	0%	0%	0%	0%	5%	5%
Recycled content (cap)	%	0%	0%	0%	0%	0%	0%	0%	5%	5%

The customer use time and reverse logistics time are based on assumptions and confirmed during interviews with external stakeholders.

The slack[9] determines the amount of reuse packaging produced and put in the system in order to keep supply steady, and to avoid shortages during times of deviating return rates.

The average quality loss rate[10] of packaging was obtained in expert interviews together with the maximum number of loops of packaging applications before the end of the technical lifetime.

The lifetime of the reusable packaging system describes the amount of time packaging design is in the return system before being updated[11], which means that all packaging needs to be replaced in the system. This in turn means that we have accounted for the production of the 'first batch' of reusable packaging by annualising the costs of that packaging over the given timespans in the model.
The recycled content of packaging was based on European industry[12,13,14] averages, and kept constant over the single-use and reuse applications to make results comparable. Today, there is no industry standard for recycled content in any PE or PP packaging applications that have food contact due to safety concerns and a lack of legislation.[15] While exceptions may apply in individual cases where ambitious sorting and recycling is applied, this was assumed not to play a role in our model, which is based on current trends.

Volumes

The total market volume of packaging units in France was determined by data for household packaging waste.[16,17,18] The total volume of reusable packaging per application was then modelled at various rates of effective market share, as seen in the table below.

- Beverage bottles include the full market volume of non-alcoholic PET beverage bottles (mineral water, soft drinks, juices) in France. This also includes beverages sold in larger or smaller sizes than 1 litre, to enable the model to reflect the full scale of the non-alcoholic beverages market in France.
- Food cupboard includes the full market volume of food products sold in flexible PP packaging in France. This may include food products currently sold in packaging smaller or larger than 1.5 litres.

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[9] Data point gathered from expert interviews and/or correspondence.
[10] Data point gathered from expert interviews and/or correspondence.
[11] Data point validated in expert interviews and/or correspondence.
[12] Eunomia, PET Market in Europe: State of Play 2022 (2022),https://www.eunomia.co.uk/reports-tools/pet-market-in-europe-state-of-play-2022/
[13] Eunomia, HDPE & PP Market in Europe: State of Play 2022 (2022), https://www.eunomia.co.uk/reports-tools/pet-market-in-europe-state-of-play-2022/
[14] Zero Waste Europe & Eunomia, How Circular is Glass? report on the circularity of single-use glass packaging, using Germany, France, the UK, and the USA as case studies (September 2022), https://zerowasteeurope.eu/wp-content/uploads/2022/08/HOW-CIRCULAR-IS-GLASS.pdf
[15] Unilever, We're making the switch to recycled food packaging. Here's how (24th March 2022), https://www.unilever.com/news/news-search/2022/were-making-the-switch-to-recycled-food-packaging-heres-how/
[16] Eurostat, Statistics on packaging waste 2020 (2020), https://ec.europa.eu/eurostat/databrowser/product/view/ENV_WASPAC
[17] EA - Environmental Action - PLASTEAX 2023.03 – France plastic data for 2023
[18] Ademe, Packaging recovery in France - 2020 data (2020), https://librairie.ademe.fr/dechets-economie-circulaire/6027-packaging-recovery-in-france-2020-data.html

- Fresh food includes the full market share of food products sold in rigid PP pots and tubs. This may include food products currently sold in packaging smaller or larger than 0.5 litres.
- Personal care bottles include the full market volume of products sold in non-food PE bottles and was triangulated with consumption data of personal care products in Europe.[19] This may include personal care products currently sold in packaging smaller or larger than 0.25 litres.

Table: Product volumes (in units) of different applications and over varying market shares

Variable	Unit	PET beverage bottle 1L	Glass beverage bottle 1L	Food cupboard 1.5L	Fresh food 0.5L	Personal care bottle 0.25L
Market volume – units	billion units	10	10	8.75	10	2.4
Effective market share: 2%	million units	200	200	200	200	50
Effective market share: 5%	million units	500	500	500	500	100
Effective market share: 10%	million units	1,000	1,000	1,000	1,000	250
Effective market share: 20%	million units	2,000	2,000	1,750	2,000	500

Transport volumes

For transport and storage, packaging units are packed in crates and onto pallets. The dimensions and resulting transport volumes are laid out in the following charts. Food cupboard reusable PP pots are assumed to be nested given they have an open neck and flexible lid that the customer will not return. Fresh food reusable PP pots are assumed not to be nested as they have a single-use PP lid that the customer will return with the pot. This differentiation between dry and wet food was made for hygiene reasons, and because fresh food packaging would need to be returned with a lid to avoid spillage of leftovers.

[19] *Castellani, V., Sanyé-Mengual, E. & Sala, S, Environmental impacts of household goods in Europe: a process-based life cycle assessment model to assess consumption footprint. Int J Life Cycle Assess 26, 2040–2055 (2021),* https://doi.org/10.1007/s11367-021-01987-x

Figure: Packaging dimensions and transport volumes of beverage and personal care bottles

Beverage bottles – 1l PET and glass - reusable

Dimensions of bottle: 25 cm; 7 cm — H: 25 cm, D: 7 cm

Dimensions of crate: H=35cm; 36 cm; 28 cm — L: 36cm, W: 26 cm, H: 35 cm — 12 units

Crates per pallet

Crates & Pallets		Beverage bottle	
Details	Pallet	Crate	On pallet
Length (m)	1.2	0.275	4
Width (m)	0.8	0.356	2
Height (m)	1.1	0.347	3 or 4
Height of pallet (m)	0.2		
No. crates on pallet			28

Units per pallet → 336

Pallets per truck → 68

Units per truck → 22,848

Personal care bottles – 0.25l PE - reusable

Dimensions of bottle: 15 cm; 5 cm — H: 15 cm, D: 5 cm

Dimensions of crate: H=18cm; 36 cm; 36 cm — L: 36cm, W: 36 cm, H: 18 cm — 36 units

Crates per pallet

Crates & Pallets		Personal care	
Details	Pallet	Crate	On pallet
Length (m)	1.2	0.36	3
Width (m)	0.8	0.36	2
Height (m)	1.1	0.18	6
Height of pallet (m)	0.2		
No. crates on pallet			36

Units per pallet → 1296

Pallets per truck → 68

Units per truck → 88,128

Figure: Packaging dimensions and transport volumes of dry and fresh food containers

Food container – 1.5l PP - reusable

Dimensions of bottle: 20 cm; 10 cm — H: 20 cm, D: 10 cm

Dimensions of crate (nested): H=36; 36 cm; 36 cm — L: 36cm, W: 36 cm, H: 36 cm — 72 units — 2 cm; 20 cm; 36 cm — Nesting: Stacks of 8 containers

Dry food containers are nested for transport from collection to sorting/cleaning and to filling

Crates per pallet

Crates & Pallets		Food flex	
Details	Pallet	Crate	on pallet
Length (m)	1.2	0.36	3
Width (m)	0.8	0.36	2
Height (m)	1.1	0.36	3 or 4
Height of pallet (m)	0.2		
No. crates on pallet			21

Units per pallet → 1,512

Pallets per truck → 68

Units per truck → 102,816

Food container – 0.5l PP – reusable

Dimensions of bottle: 10 cm; 8 cm — H: 10 cm, D: 8 cm

Dimensions of crate (nested): H=36; 36 cm; 36 cm — L: 36cm, W: 36 cm, H: 36 cm — 48 units — 10 cm; 36 cm — Layering: Stacks of 3 closed containers

Wet food containers are not nested

Crates per pallet

Crates & Pallets		Food rigid	
Details	Pallet	Crate	on pallet
Length (m)	1.2	0.36	3
Width (m)	0.8	0.36	2
Height (m)	1.1	0.36	3 or 4
Height of pallet (m)	0.2		
No. crates on pallet			21

Units per pallet → 1,008

Pallets per truck → 68

Units per truck → 68,544

Weight of packaging

Table: Packaging weights for packaging and closures across all applications

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
Weight	grams	26	55	520	8	40	8	16	19	40
Source		Ademe[20]	ALPLA[21]	DLG[22]	Experts	Weight ratio	Experts	Weight ratio	Experts	Weight ratio
Closure		HDPE	HDPE	HDPE	no lid	PE	PP	PP	PP	PP
Weight	grams	2	2	2	-	1	4	4	4	4
Source		Experts	Experts	Experts	-	Weight ratio	Own testing	Own testing	Experts	Experts

The weight of the different packaging applications incl. lids was determined from literature research and expert interviews. Where no information on the weight of the packaging was available, a single use-to-reuse weight factor of 212% was applied to account for the required longevity of reusable packaging. This factor is based on the weight difference between a single-use and reusable PET bottle for which sufficient data exists. For the weight of the reusable 1.5-litre PP rigid alternative to the flexible single-use alternative, a size factor[23] of 250% was used to scale up the 0.5-litre reusable pot to a 1.5-litre reusable pot.

The 26 grams for a single-use PET bottle reflects an average value for 1-litre bottles used by the French environmental agency Ademe.[20] The 55 grams for the reusable PET bottle are a best-practice example from the bottle manufacturer ALPA.[24]

EPR fees

EPR (Extended Producer Responsibility) fees were calculated based on French standards published by Citeo.[25] EPR fees in France consist of a tariff per kilogram of material used, and a fixed price per packaging unit. Recycled content premiums apply where the recycled content exceeds 10% of the total packaging material used.

Table: EPR fees for packaging and closures across all applications

[20] *Ademe (2022). Collecte des bouteilles plastiques de boisson. Rapport annuel d'évaluation des performances pour 2020 et 2021.* https://librairie.ademe.fr/dechets-economie-circulaire/5897-collecte-des-bouteilles-plastiques-de-boisson.html
[21] *ALPA (2023). Reusable PET bottles.* https://www.alpla.com/en/products-innovations/case-studies/reusable-pet-bottles
[22] *DLG (2016). Packaging material made from polyethylene terephthalate (PET).* https://www.dlg.org/fileadmin/downloads/lebensmittel/themen/publikationen/expertenwissen/lebensmitteltechnologie/e_2016_4_Expertenwissen_PET.pdf *(Giving a reference weight for reusable glass bottles.)*
[23] *Size factor includes the assumption that packaging requires a thicker design the smaller it gets. The ratio was determined from a previous Systemiq project where the weight and sizes of different packaging containers were compared.*
[24] *ALPA (2023). Reusable PET bottles.* https://www.alpla.com/en/products-innovations/case-studies/reusable-pet-bottles
[25] *PRO Europe (February 2022). Participation cost overview 2022. p. 29 following.* https://www.pro-e.org/files/PRO-Europe-Participation-Costs-Overview-2022.pdf

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
Reference packaging application		Bottle and vial in clear PET	Bottle and vial in clear PET	Bottle in glass	Flexible PP packaging	Rigid packaging in PP	Rigid packaging in PP	Rigid packaging in PP	Bottle and vial in coloured PET, PE or PP	Bottle and vial in coloured PET, PE or PP
2023 tariff	cent / kg	33.04	33.04	1.31	48.74	35.95	35.95	35.95	35.95	35.95
>10% recycled content premium	cent / kg	5.00	5.00	n.a.	40.00	40.00	40.00	40.00	40.00	40.00
Included		Yes	No		No	No	No	No	No	No
Fixed price per packaging unit	cent / unit	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079	0.079
EPR	cent / unit	0.92	1.85	0.76	0.47	1.51	0.35	0.65	0.75	1.51
Closure		HDPE	HDPE	HDPE	no lid	PE	PP	PP	PP	PP
EPR (lid)	cent / unit	0.17	0.17	0.17	0	0.12	0.22	0.22	0.22	0.22

Box 1: Production/conversion

	Key assumptions	Reasoning
1	Material costs for reusable and single-use packaging are the same per unit of weight within same material category.	As long as reusable packaging is made from the same material, i.e. has similar recycled content, as in single-use plastics, the cost per kg is the same.
2	Weight per packaging unit is higher for reusable than for single-use packaging.	Reusable packaging needs to be more durable and therefore may require a higher thickness than single-use packaging.
3	All recycled content is assumed to be mechanically recycled content and the percentage of recycled content is based on industry standards (for glass and plastic).	Chemical recycling of plastic is currently not scaled. Mechanical recycling currently is the industry standard for plastic and glass.
4	No additional capex is required to create production capacity for reusable packaging.	Production capacity of single-use packaging can be utilised to produce reusable plastic packaging; this has been tested and confirmed with experts. Existing production capacity for glass bottles is sufficient to satisfy additional packaging demand.
5	Water used in production/conversion is proportional to material use.	As long as reusable packaging is made from the same material as single-use packaging, the water use per kg is the same, e.g. for PET bottles.

Cost per unit of packaging

The cost per unit of packaging was determined by the weight of the packaging, and the costs to produce one tonne of material (PET, PP, HDPE, glass) and to convert the material into the respective shape of the packaging. Data for production and conversion was based on the ReShaping Plastics[26] model for PET, PP and PE, and from the Plastic IQ[27] technical documentation for glass.

[26] *Systemiq (2022). ReShaping Plastics. https://www.systemiq.earth/systems/circular-materials/reshaping-plastics/ (underlying data is proprietary to Systemiq)*
[27] *Systemiq (2023). Plastic IQ. https://www.systemiq.earth/portfolio/plastic-iq/*

Table: Cost per unit of packaging and closures across all applications

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
Weight - packaging	grams	26	55	520	8	40	8	16	19	40
Cost per unit -packaging	**ct/unit**	**3.4**	**7.2**	**39.8**	**2.0**	**9.8**	**1.9**	**3.9**	**4.5**	**9.6**
Material lids	unit	HDPE	HDPE	HDPE	no lid	PE	PP	PP	PP	PP
Weight - lids	grams	2	2	2		1	4	4	4	4
Cost per unit - lids	**ct/unit**	**0.6**	**0.56**	**0.6**		**0.2**	**1.0**	**1.0**	**1.0**	**1.0**

Water use per tonne of material and per unit

To determine the water use in production and conversion, the LCA database from Ecoinvent[28] was used. The following table gives an overview of which processes were considered for which materials, and summarises the water usage of different materials per tonne and per unit of packaging.

Table: Water use factors considered for materials of the different applications, and aggregated values per tonne and per unit

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single -use PE	Reusable PE
Production of granulate	litres	x	x	x	x	x	x	x	x	x
Conversion	litres									
Injection moulding	litres	x	x			x	x	x	x	x
Blow moulding	litres	x	x						x	x
Extrusion (film)	litres			x						
Total production/ conversion per tonne	litres	20671	20671	1980	63587	30953	30953	30953	37836	37836
Total production/ conversion per unit	litres	0.5	1.1	1.0	0.5	1.2	0.2	0.5	0.9	1.8

GHG emission per tonne of material

The GHG emissions from packaging and conversion were calculated using data from the EEA.[29] GHG emissions differ, depending on whether packaging was produced from virgin or recycled materials.

[28] Ecoinvent (2023). Ecoinvent Database. https://ecoinvent.org/the-ecoinvent-database/
[29] European Environment Agency (March 2021). Greenhouse gas emissions and natural capital implications of plastics. https://www.eionet.europa.eu/etcs/etc-wmge/products/etc-wmge-reports/greenhouse-gas-emissions-and-natural-capital-implications-of-plastics-including-biobased-plastics/@@download/file/ETC_2.1.2.1._GHGEmissionsOfPlastics_FinalReport_v7.0_ED.pdf

Table: GHG emission factors (virgin and recycled) used for materials of the different applications

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
GHG virgin material	gCO_2e / g packaging material	3.88	3.88	1.16	2.85	2.85	2.85	2.85	3.06	3.06
GHG recycled material	gCO_2e / g packaging material	1.52	1.52	0.86	1.35	1.35	1.35	1.35	1.54	1.54

Box 2: Filling

	Key assumptions	Reasoning
1	Filling includes (re-)labelling of packaging. This applies to reusable packaging and single-use packaging.	Based on desk research and expert interviews.
2	We assume no stock except 'safety stock' is held for both single-use and reuse. The potential extra storing cost for reuse 'safety stock' is assumed to be negligible vs other costs.	Stocks and logistics are optimised in modern manufacturing facilities for cost optimisation. 'Safety stock' of packaging is assumed to be equal for reusable and single-use packaging.
3	The degree of packaging standardisation affects the capacity of filling lines	The more differentiated packaging is, the higher the downtime of filling lines (i.e. machines are stopped to change settings), which in turn affects capacities. This was tested and confirmed during research interviews and site visits.
4	Additional filling capex is required to switch from single-use to reuse packaging.	Filling lines need to be modified, e.g. to include other elements such as de-craters. See below how transition costs for filling have been accounted for.
5	Additional cleaning through air is required for reusable packaging.	Reusable beverage bottles are cleaned before filling and packed in such a way that they arrive clean at the filling sites. Some air is used to remove any dust potentially in the packaging.
6	No loss rates are assumed at filling.	Based on desk research and expert interviews.

Per unit costs filling

Capex

Annualised capex per unit is calculated for both single-use and reusable packaging. This is based on the full cost of a new single-use/reusable line, and the lifetime of that line. In other words, we include in the total cost of single-use packaging the cost of keeping this system going by having to re-invest in single-use filling lines at the end of their useful life.

Data for the capex of a single-use and a reusable bottle filling line was gathered through expert consultations, and was cross-checked with multiple industry experts. To obtain data for other filling lines (flexible food, fresh food, personal care), filling lines were adjusted by removing or adding the required elements. Because washing is done before reusable packaging arrives at the sorting line, the washing element was excluded from the reusable filling line. The data received for beverage bottle filling lines concerned lines with the speed of 500 BPM (bottles per minute) and 250 BPM. To get to a representative size of filling lines across applications this data was triangulated and extrapolated to a smaller filling line. The capacity of the 250 BPM line was halved to 125 BPM, and a capex decrease factor of 36% per halving was derived from the two available data points.

In addition, a data point for a personal care filling line of 80-120 BPM was obtained through expert correspondence, which was triangulated with the data retrieved through the method described previously, and yielded very similar results for the capex.

The impact of standardisation on the filling line is assumed to be seen through reduced downtime; there is less need to switch the packaging type being filled. This is seen in reduced downtime by one hour when we switch from a low-standardisation to a high-standardisation model. When running, the capacity per minute of the filling lines is assumed to be the same for low- and high-standardised packaging.

Opex

To calculate the opex, the following costs are included:

1. Energy:
    a. Of the filling line: A sorting line of the given capacity consumes 25 kW electrical energy costing 11.04 ct / kWh[30].
    b. Of the building: An average energy consumption value of 152 kWh / sq.m. / year[31] was applied, to include heating, electrical appliances, etc. Buildings for filling lines including storage are assumed to have a size of 1000 sq.m.[32] on average.
2. Labour: To operate one filling line, per shift 1 FTE is required, and 1 FTE is needed to support logistics in the facility. This labour is assumed to be compensated with minimum wage, i.e. 17.28 EUR / hour incl. employer costs.[33] For the facility, 1 FTE for a supervisory or managerial role is assumed, compensated with the average salary for France of 40.5 EUR / hour incl. employer costs[34].

Note: Costs for storage during the filling process are integrated in the opex calculation by accounting for storage space and labour.

[30] *Eurostat (2023). Electricity prices for non-household customers - bi-annual data (from 2007 onwards).* *https://ec.europa.eu/eurostat/databrowser/product/view/NRG_PC_204*

[31] *IEA (September 2022). Buildings. https://www.iea.org/reports/buildings*

[32] *The building size was estimated based on calculations considering storage, space for machinery and office space. While the resulting space in the calculation varies between applications and may be below 1000 sq.m. this was taken as an average for ease of modelling and to allow for leeway.*

[33] *INSEE (2023). Interprofessional minimum wage. https://www.insee.fr/en/statistiques/2417640*

[34] *Eurostat (2023). Hourly labour costs.* *https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Hourly_labour_costs#Hourly_labour_costs_ranged_between_.E2.82.AC8.2_and_.E2.82.AC50.7_in_2022*

Table: Filling costs ranges across applications (capex, opex, and total costs) per unit

Variable	Unit	Range across applications
CapEx per unit – low standardisation	cent / unit	0.3-0.5
CapEx per unit - high standardisation	cent / unit	0.4-0.5
OpEx per unit – low standardisation	cent / unit	1.3-1.5
OpEx per unit - high standardisation	cent / unit	1.3-1.4
Total cost per unit – low standardisation	cent / unit	1.7-2.0
Total cost per unit - high standardisation	cent / unit	1.7-1.9

GHG emissions filling

GHG emissions at filling lines are based on the energy consumption of the machinery and the building, applying an emissions factor of 67 gr CO_2e / kWh[35] for electrical energy.

Table: GHG emissions of filling across applications per unit

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single-use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
GHG of facility per year	tonnes CO_2e	49.6	49.6	49.6	49.6	49.6	49.6	49.6	49.6	49.6
GHG per unit for low standardisation	grCO_2e / unit	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
GHG per unit for high standardisation	grCO_2e /		0.4	0.5		0.4		0.4		0.4

Additional FTE for reusable filling lines

It is assumed that the operation of filling lines for reusable packaging entails additional labour of 0.25 FTE for logistics, in order to handle the larger volume of packaging applications compared to single-use. It was assumed that one FTE comprises 1,607 annual working hours (35 hours per week excl. 25 vacation days and eight public holidays), in line with the French annual legal working time (for a full-time contract).[36]

[35] *European Environmental Agency (October 2022). Greenhouse gas emission intensity of electricity generation in Europe. https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1*

[36] *https://www.service-public.fr/particuliers/vosdroits/F32428*

Table: FTE of filling across applications per unit

Variable	Unit	Beverage bottle 1L			Food cupboard 1.5L		Fresh food 0.5L		Personal care bottle 0.25L	
Application		Single -use PET	Reusable PET	Reusable glass	Single-use PP (flex)	Reusable PP	Single-use PP	Reusable PP	Single-use PE	Reusable PE
Total FTE per year	FTE		1	1		1		1		1
FTE per unit	FTE / unit		10 e-9	10 e-9		10 e-9		10 e-9		10 e-9
FTE per unit for high-standardisation	FTE /		9 e-9	9 e-9		9 e-9		9 e-9		9 e-9

Box 3: Retail

	Key assumptions	Reasoning
1	Deliveries are received on pallets and in boxes, and are taken care of manually by retail staff – there are no differences between reusable and single-use packaging.	This is the status quo and, although automation may be technologically possible, it is unlikely for the vast majority of retailers.
2	Distribution of reusable and single-use packaging is the same – i.e. how retailers distribute products from distribution centre to individual stores.	Returnable packaging is treated the same as single-use packaging in the upstream value chain. The GHG emissions factors will include an average distribution leg.
3	No additional capex or opex is required to display and stock reusable packaging compared to single-use packaging.	Stocking and shelving products in reusable packaging does not require additional space or labour compared to single-use packaging products, because we are assuming that the additional size of reusable packaging makes no considerable difference to size and weight.
4	Retailers charge an additional amount on top of the product price as deposit in the case of reusable packaging – this process requires no additional capex or opex.	This is common practice where packaging return systems exist, e.g. the Pfandsystem in Germany. The deposit is automatically added when scanning product barcodes, hence no additional systems or FTEs are needed.

5	Packaging from unsold products in retail is negligible.	France enacted a law in February 2016 that forbids supermarkets to destroy any unsold food products, and obligates them to donate products instead. These products that are donated find their way back into the system (i.e. are collected at the relevant return rate).
6	Crates that reusable packaging is delivered in are held at the store, and filled with collected reusable packaging to send to sorting.	This is the most efficient way to manage the B2B reusable packaging system – i.e. assuming no extra legs required to distribute B2B packaging. The additional storage space required for crates is taken into account at the collection stage.
7	Changes in scale or packaging differentiation do not impact retail costs, FTEs or GHG.	Reusable packaging and single-use packaging is treated the same in store, so there are no economies of scale or reduced complexity arising from different pack types.

Retailers operate as point of sale of products in both single-use and reusable packaging. The assumption was made that no additional cost and no additional environmental impacts (GHG, water) occur at the point of sale when reuse packaging applications are added to the portfolio. This is because single-use and reusable packaging are similar and, even though reusable might take a little bit more space (especially for the food cupboard application), we have assumed it to be negligible in terms of both overall cost and environmental impact.

When using a deposit system for reusable packaging, this deposit is collected at the point of sale as well. It is assumed that this happens during checkout via barcode scanning, and does not entail any additional capex or opex requirements; current checkout systems are already equipped for this.

Finally, retailers also operate as collection points. Any costs and environmental impacts occurring at the collection point are described in Box 5: Collection point.

Box 4: Use/customer

	Key assumptions	Reasoning
1	Customers do not change purchasing habits based on single-use / reusable packaging type – i.e. we assume all packaging that is switched to reusable packaging is bought, and customers don't switch to another brand in single-use packaging.	We are not focusing our modelling on customer behaviour.
2	The deposit paid by customers is set in a way that it does not hinder customers from purchasing reusable packaging but at the same time incentivises customers to return the packaging.	Amount paid as deposit needs to maximise return rates. Deposit resulting in 100% return rate is unlikely, due to difference in price sensitivity of customers. For example, reusable pack deposits in Germany range from EUR 0.08 to EUR 0.25.
3	The time that a product with reusable packaging is in use will differ between applications.	Example: A bottle containing shampoo will be in use for weeks while a bottle containing a drink will be in use for a matter of hours.
4	The time that a reusable packaging is stored by customers before bringing to a collection point will not differ between applications.	It is likely that customers store all packaging in one place regardless of the previous application, and that customers will bring empty packaging to the collection point in bulk one or two times a week.
5	The return rate for reusable packaging will not differ between packaging applications.	Customers will likely store all empty reusable packaging in one place, regardless of application, and return in bulk. While in the short term, during transition periods, some applications might achieve higher return rates than others, our model focuses on a scaled system in which return of various applications will be standard.
6	Single-use packaging and unreturned reusable packaging will be discarded with household waste. They will be subsequently handled by waste systems already in place (i.e. recycled, incinerated, landfilled) with corresponding national rates (France).	Only a very small proportion of customers will keep returnable packaging for further use at home. We are modelling an at-scale system where, in the long run, users will not keep many different returnable packaging types for their own use at home. We expect customers to treat packaging in the same way they are used to, e.g. households in France are asked to separate recyclable plastics and glass into separate bins.
7	No GHG impact is assumed from customers using the packaging.	This is likely very minimal versus GHG impacts in other parts of the value chain.

It is assumed that no additional costs or environmental implications occur at the use phase of customers. Our modelled duration of use before return to a collection point varies per application as follows:

- Beverage bottles: 7 days
- Food cupboard: 28 days
- Fresh food: 7 days
- Personal care bottles: 84 days

Box 5: Collection point

	Key assumptions	Reasoning
1	The consumption and return rates are constant over the year, across applications and population density.	We assume a % slack of packaging that is available to be filled if the return of reusable packaging isn't smooth over time and geography. Hence, we can assume consumption rates remain constant.
2	The minimum retail store size that will have a collection point is 400 sq.m.	A new French law requiring 20% floor space to be dedicated to refill by 2030 is required for all supermarkets larger than 400 sq.m.
3	Each collection point is made up of one or more Reverse Vending Machines (RVMs). We assume that the capacity of each RVM is the same. The number of RVMs is dependent on their capacity and the total system volume (assuming the same volume at each collection point). Hypermarkets have up to four RVMs and supermarkets up to two RVMs.	The higher the scale or level of shared infrastructure, the more volume in the system, and therefore the more RVMs will be needed at each collection point. The maximum of two and four RVMs at supermarkets and hypermarkets respectively is based on expert interviews, as well as experience in the German market.
4	We will assume a fixed representative RVM size.	Simplification for modelling purposes.
5	The customer does not need to pre-sort the reusable packaging by material. RVMs take all material types (i.e. plastic, glass), but only reusable packaging. The design and operation of the RVM is the same for all packaging applications.	Existing RVMs can take multiple different material types.
6	The RVMs can take multiple containers at once, to speed up the process for the customer.	Existing RVMs can take up to 45 containers per minute.
7	RVMs are not staffed, except for cleaning, emptying, storing, and facilitating reverse logistics.	RVMs do not need permanent attention by staff as they are automatic and store a certain amount of packaging. Depending on the daily return volume, employees only need to spend

		time to empty the RVMs and perform a pre-sorting of materials.
8	A first pre-sorting of the packaging according to application type and reuse network is done by staff. Design and colour sorting happen during a later stage.	It is assumed that packaging is not sorted by design and colour, but only by application type, at this point. Otherwise, storage in the RVM and by the retailer would be very inefficient, requiring lots of different types of crates. However, sorting must be done by application and reuse network, because we assume they go to different logistics channels, and sorting and cleaning centres.
9	Supermarkets require extra storage space to store reusable packaging before pick up, but this does not vary by standardisation level. The amount of extra storage space required will depend on the number of RVMs.	Additional space is required to store empties before they are transported to logistics centres. Storage space doesn't vary by standardisation level, because sorting by design and colour happens in the sorting phase.
10	Low standardisation has no impact on storage space requirements at the retailer and distribution centre.	Because packaging is only pre-sorted by application, and not by design or brand, no additional space for brand- or design-specific crates must be made available. This also reduced time spent on manual pre-sorting.
11	Crates of reusable packaging are put on pallets by supermarket staff ready for transport.	Pallets are the most efficient way of transporting packaging.
12	We assume there are no losses at the collection stage, i.e. all packs returned by customers flow to the sorting stage.	Losses are expected to be insignificant, given that RVMs are automated, and that packaging is then manually put in crates.
13	No additional reverse logistics are required to transport empty packaging back from store to the retailers' distribution centre – i.e. backhaul of store deliveries is used.	Retailers currently use backhaul to take waste from stores to distribution centres, often in cardboard tertiary packaging. If reusable packaging needed to be transported, waste would be much more compact, to allow for reusable packaging to fit in existing channels.

Costs at collection points

Number of reverse vending machines (RVMs)

For each hyper- or supermarket (>400 square metres in size), at least one RVM is installed. We assume a total of 1,825 hypermarkets and 11,219 supermarkets across France.[37] Depending on the market

[37] *INSEE (2021). Dénombrement des équipements en 2021 (commerce, services, santé…).* *https://www.insee.fr/fr/statistiques/3568602?sommaire=3568656*

share of the reuse market (varying from 2% to 70%), the number of RVMs per store is expected to reach a maximum of four in hypermarkets and two in supermarkets, resulting in the following total number of RVMs modelled in France.

Table: Number of RVMs in France (in supermarkets and hypermarkets) based on different market volumes modelled

Scale	Total units (for all applications, in millions)	Market share	# RVMs (for all applications)
Number of RVMs at 2% scale	650	2%	13,044
Number of RVMs at 5% scale	1,600	5%	13,781
Number of RVMs at 10% scale	3,250	10%	15,065
Number of RVMs at 20% scale	6,250	20%	17,847
Number of RVMs at 40% scale	12,500	40%	24,525
Maximum no. RVMs at 70% scale	21,950	70%	29,738

The cost and energy data are based on the specification of a TOMRA T70-Dual RVM.[38] The capacity of this RVM is 45 containers per minute, which, based on operating hours as explained below, results in a maximum throughput of 311 billion units a year. This is more than enough for the 30 billion units assumed in the highest modelled volume.

Capex

A fixed cost of purchasing applies to each RVM, which includes the costs for the RVM, an installation fee and four collection bins. The annual capex per unit is determined by the total annual market volume and the lifetime of the RVM (approximately ten years). This cost data has been collected through expert interviews.

Opex

The opex is calculated based on operating hours and the following four cost components:

1. Operating hours: RVMs operate in parallel with common opening hours of retailers in France, i.e. 8am - 8pm Mon-Sat, 8am - 12pm Sun, and being closed seven days per year. This results in 3,876 operating hours per year.
2. Energy use: during operating hours, RVMs constantly consume idle energy (on standby), and during active use energy consumption increases. For the cost of energy, the 2020-2022 average energy price for non-household customers (11.04 cent / kWh)[39] was applied.
3. Labour: per RVM, one employee spends half an hour per shift to empty RVMs and do a first sorting into crates by application (separating beverage bottles, from food containers, from shampoo

[38] *https://www.tomra.com/en/reverse-vending/our-offering/reverse-vending-machines/tomra-t70-dual*
[39] *Eurostat (2023). Electricity prices for non-household customers - bi-annual data (from 2007 onwards).* *https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_204/default/table?lang=en*

bottles, for example). The cost for labour was calculated applying the hourly minimum wage, including employer costs, at 17.28 EUR / hour.[40]

4. Space at the retailer:
    a) At sales area: per RVM, an area of 1.34 sq.m. is needed for the RVM itself.[41]
    b) In storage: packaging is assumed to be held in-store for one day before being transported to a distribution centre. Depending on the daily volume of reusable packaging, additional space for crates is required in storage. In addition, 10 sq.m.[42] per collection point is required in order to pre-sort packaging into the respective crates.

    The average annual rent price at the retailer is set to 100 EUR / sq.m. / year,[43] but this may vary depending on location and size of the retailer.
5. Storage space at the distribution centre: to account for the space requirements at distribution centres, where collected reusable packaging is assumed to be stored for one day before being transported to the sorting and cleaning centres, the space of palletised units over the varying market volumes is considered. An average price of 50 EUR / sq.m. / year for storage[44] was assumed.

Note: Costs for storage during the collection – both at retailers and distribution centres – are integrated into opex figures by accounting for storage space and labour.

GHG emissions at collection points

The GHG emissions at collection points are determined by the energy consumptions of RVMs. Any other energy consumed at the retailer is assumed not to be attributable solely to the collection of reusable packaging and is therefore not included. An average emission factor of 67 gr / CO_2e[45] for electricity in France was used to obtain GHG emissions from energy use.

FTE at collection points

The additional labour requirements at the collection points are calculated as FTEs (full time equivalents) per year to operate the collection system. It was assumed that one FTE comprises 1,607 annual working hours (35 hours per week excl. 25 vacation days and eight public holidays).

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[40] *INSEE (2023). Interprofessional minimum wage. https://www.insee.fr/en/statistiques/2417640*
[41] *Tomra T70-dual https://www.tomra.com/en/reverse-vending/our-offering/reverse-vending-machines/tomra-t70-dual*
[42] *Assumption tested with expert network.*
[43] *Based on desk research of commercial rental properties in France.*
[44] *Statista (2022). Annual prime headline rent for warehouses over 5,000 square meters in the occupier logistics market in France from 2014 to 2022, by city. https://www.statista.com/statistics/527840/warehouse-primary-rent-cost-logistics-market-france-europe/ *Value for Lille was taken as a proxy to account for warehouse rent differing by region and state of urbanization.*
[45] *European Environmental Agency (October 2022). Greenhouse gas emission intensity of electricity generation in Europe. https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1.*

Table: Total and per-unit FTEs for collections points based on different market volumes modelled

Effective market shares	FTE hours total per year	FTE per year	# million units	FTE per unit
2%	3,159,909	1,787	650	0.0000027
5%	3,338,326	1,888	1,600	0.0000012
10%	3,649,412	2,064	3,250	0.0000006
20%	4,323,433	2,445	6,250	0.0000004
40%	5,941,081	3,360	12,500	0.0000003
70%	7,204,031	4,075	21,950	0.0000002

Boxes 6 and 9: Transport to sorting and transport to filling

As shown in the system map before, transport was modelled from collection to sorting and cleaning (box 6), and from sorting and cleaning back to filling (box 9). A representative sample of distribution centres, filling sites and sorting and cleaning centres was marked using the ArcGIS Network Analyst tool. These were then used to calculate by-road drive times, and associated costs and emissions.

List of input variables for the transport modelling

The table below gives an overview about the input variables for the transport modelling. Assumptions are explained below.

Input variable
Transport volumes per application
Total number of filling locations per application
Number of distribution centres
Annualized capex of sorting and cleaning facilities
Annualized opex of sorting and cleaning facilities
Annual capacity of sorting and cleaning facilities
Population distribution in France
Driver annual salary
Driver on-costs
FTEs per vehicle
Vehicle capital cost
Vehicle operating costs
Fuel consumption per 100 km
Cost per 1L of diesel
GHG emissions per 1L of diesel

List of output variables for the transport modelling

The table below gives an overview of the output variables, and indicates their origin.

Output variable	Origin
Location of distribution centres	GIS model
Number of sorting and cleaning facilities	Additional calculation
Location of sorting and cleaning facilities	GIS model
Number of filling sites for each volume and application	Calculation
Location of filling centres	GIS model
Total number of vehicles travelling per transport leg	GIS model and calculation
Total and per-unit km travelled per transport leg	GIS model and calculation
Total and per-unit number of FTEs required per transport leg	Additional calculation
Total and per-unit vehicle capex per transport leg	Additional calculation
Total and per-unit vehicle opex per transport leg	Additional calculation
Total and per-unit GHG emissions per transport leg	Additional calculation

Transport modelling process and key assumptions

Distribution centres

115 distribution centres were placed using the ArcGIS Network Analyst tool:

- Based on the publication of Seidel et al.,[46] 100 supermarkets are assumed to be serviced by one distribution centre. Assuming approximately 11,500 supermarkets with a minimum floor space of 400 sq.m.[47] in France, this results in a total number of 115 distribution centres.
- The underlying assumption is that the distribution centres are all roughly equally sized, and are located near to where the demand is, based on population distribution.
- Underpinning this assumption is population data for settlements in France with over 1,000 inhabitants – roughly 9,700 settlements, with Paris being split into 20 arrondisements. These are used as the ‘demand points’ in the Network Analyst calculations.
- Only the top 5,000 settlement points with a population over 2,000 are used as the ‘facility points’, meaning that these were the possible locations that Network Analyst could choose for the distribution centres.
- The tool uses actual by-road drive times.
- The distribution centres are then placed so that the overall drive times are optimised across France, and as many demand points as possible are allocated to each centre, up to the maximum capacity of the facility.
- Since the capacity of each distribution centre is assumed to be equal, more populated areas end up having more distribution centres to serve the higher demand.
- The population served by each distribution centre is then used in the logistics modelling in order to calculate the number of units of packaging that are at each distribution centre. The throughput of each distribution centre is based on the assumption that each person produces

[46] *https://edoc.hu-berlin.de/bitstream/handle/18452/24516/dissertation_seidel_saskia.pdf?sequence=15&isAllowed=y*
[47] *https://www.statista.com/statistics/769638/number-food-stores-by-type-france/*

the same number of units, and this is constant through the year. The resulting throughput of each distribution centre is not exactly the same, but very close, as per the first assumption that they are roughly equally sized.

In reality, the precise location of these centres will depend on a number of considerations, including price and availability of land. Thus, the distribution centre locations in the results here are considered approximate; they are indicative of where this existing infrastructure could be located to serve the retail network in France.

Sorting and cleaning centres

The number of sorting and cleaning centres is a function of the volume and the capacity (175 million units per year; see section on boxes 7 and 8 for more detail).

Using a similar methodology to that outlined above, the locations of the distribution centres are used as the demand points to find the optimal locations for the sorting and cleaning facilities:

- The output of this calculation is the list of which distribution centre feeds which sorting and cleaning centre.
- Because the locations of the sorting and cleaning centres are based on where the distribution centres were placed, which in turn was based on the population distribution, the sorting and cleaning centres end up also being sited near highly populated areas.
- The throughput is calculated based on the distribution centres (and thus population) served, up to the maximum capacity (175 million units). So, where there are more people and more units, it follows that there will be more sorting and cleaning centres.
- The throughput is assumed to be constant over the year and is based on the throughput from the distribution centres.
- The vehicle calculation (below) models how often a full truckload is ready to be collected.
- This is tested against the optimum location based on the filling location; however, these cannot be optimised together.

Filling sites

The following assumptions and steps were taken to model the filling sites.

- The number of filling sites is a function of the volume and the application. This was estimated based on desktop research and expert interviews:
    - Beverage bottle applications are assumed to need a maximum of 157 filling sites.
    - Food cupboard applications are assumed to need a maximum of 66 filling sites.
    - Fresh food applications are assumed to need a maximum of 83 filling sites.
    - Personal care applications are assumed to need a maximum of eight filling sites.
- In the low-volume scenarios, we assume not all fillers are participating in the scheme, and those that are participating are only required to fill a small volume. For Volume 1, we assume that 50% of the filling sites are participating. At higher volumes, we assume all fillers are involved, but perhaps still not at 100% of their maximum output, in order to reach the volumes being modelled. For Volume 6, we assume 100% of filling sites are participating.

- The locations of the filling sites are again calculated using the ArcGIS Network Analyst tool, using the population distribution as a basis, under the assumption that producers have built their facilities close to the population where the products will be sold, in order to minimise transport distances for their packaged products.
- The GIS tool then calculates which filling site is served by which sorting and cleaning centre. There are cases where there are multiple filling sites close to a single sorting and cleaning centre, as well as some which have no filling site in close proximity. In this case, the modelling was manually calibrated to ensure that the number of units of packaging flowing from one site to another was balanced within the supply chain, even if some drive times were not the lowest possible to the nearest facility.
- Again, as per the modelling for the distribution centres and sorting and cleaning centres, the throughput is assumed to be constant over the year, and based on the underlying population distribution, with a maximum capacity such that the facilities are roughly equally sized.

Vehicle calculations

Using the outputs of the GIS modelling, the numbers of vehicles and km driven are calculated in Excel using a Eunomia logistics model. Key logistics modelling assumptions are as follows:

- The working day lasts nine hours (based on EU driver rules).
- There is a turnaround time of 15 minutes at a collection point – the time it takes to drop off a trailer and pick up a new one (drop-and-hook loading).
- For each logistics journey (i.e. from distribution centre to sorting and cleaning centre, and from sorting and cleaning centre to filling site), the distances and times calculated in the GIS modelling are used to calculate the number of vehicles required to transport the empty packaging.
- The total number of pallets for each application and volume determine the collection frequency and number of stops the vehicle can make per day.
- We only model the journeys where the vehicle has a load to carry. In other words, we assume that vehicles do not travel back empty, and that they go on another job. For example, the vehicle may take empty packaging from the distribution centre to the sorting & cleaning centre, then take the clean packaging to the filling site, then take the filled products to the distribution centre, and so on. This is a common way for this type of distribution to operate, and logistics companies benefit from minimising the number of empty journeys.

Packaging standardisation

High packaging standardisation

For a high-standardisation scenario, we have assumed that each sorting and cleaning centre would deliver clean bottles to its nearest filling site. In other words, the assumption is that the packaging is standardised and pooled well enough that there will be an appropriate filler nearby to receive them. Trucks are assumed to go at full capacity.

Low packaging standardisation

In a low-standardisation scenario, instead we assume that each sorting and cleaning centre has to serve more filling sites, including those further away. This results in increased drive times for box 9 (transport to filling). Furthermore, we assume that the average vehicle is only 75% full. This is because the packaging has to be sorted into more categories, requiring more space at the sorting and cleaning centre. In order to accommodate all these streams of packaging, and to maintain a consistent stream of empty containers to the fillers, vehicles need to transport them more often, even when they are not fully loaded.

Drive times for food cupboard and personal care applications

Based on the relatively low assumed number of fillers in France (see the section on filling sites above for more detail), we assume that each sorting and cleaning centre has to send empty packaging back to all the fillers across France. This results in drive times between two and ten times longer than those for the System Change scenario, depending on the number of facilities. The scale factors are displayed in the table below.

Drive times for beverage bottles and fresh food applications

Based on the higher number of assumed fillers in France, we assume it would not be necessary to send empty packaging from each sorting and cleaning centre to each filling site. In other words, there ends up being a regional effect, where packaging rotates from the customer, to a sorting and cleaning centre, to a filling site, and back to a customer within a region, rather than across the whole country.

Based on the number of filling sites per producer for these applications, we model three or four regions within France, where packaging from a given sorting and cleaning centre only has to be taken to the filling site within that region. This results in drive times two to four times longer than those for the highly standardised scenario. Again, this depends on the volume and application. The scale factors are displayed in the table below.

Table: Scale factors for drive times for low packaging standardisation

Effective market share	PET and glass bottles	Food cupboard	Fresh food	Personal care
2%	1.0	1.6	1.0	1.0
5%	1.0	2.1	1.0	1.0
10%	1.6	3.2	1.6	2.1
20%	2.0	4.3	2.0	2.2
40%	2.8	5.9	3.1	5.8
70%	3.4	9.6	3.7	4.0

Further cost and emissions assumptions

Variable	Unit	Value	Assumption
Staff costs			
Driver costs	EUR / year	57,167	Salary[48] 38,174 Bonus 947 On costs 18,046 (47.3%[49])
FTEs per vehicle	no.	1.4	Vehicles out 7 days per week, but FTE is over 5 days
Vehicle costs			
Interest rate	%	5	Eunomia standard assumptions
Depreciation period	years	9	Eunomia standard assumptions
On costs	%	12	Eunomia standard assumptions
Fuel cost	EUR / litre	1.72	Fuel prices in France[50]
Unit cost large framed curtainsider	EUR	140,000	Eunomia standard assumptions
Annualised cost large framed curtainsider	EUR	19,697	Eunomia standard assumptions, considering interest, depreciation, and unit costs
Maintenance and insurance cost large framed curtainsider	EUR	16,800	Eunomia standard assumptions
Fuel consumption			
Slope	MPG / tonne	-0.139	EUN assumptions[51]
Intercept	MPG	10.8	EUN assumptions[52]
Miles per Gallon	litres / km	282	Unit conversion
Pallets per vehicle	no.	68	Eunomia standard assumptions
Pallet weight	kg	24	Eunomia standard assumptions
Crates per pallet	no.	21-36	See section on 'transport volume' for further details
Crate weight	kg	2.4	Eunomia standard assumptions
Units per crate - PET & glass bottles	no.	12	No nesting, see section on 'transport volume' for further details
Units per crate - food cupboard	no.	72	Nesting, see section on 'transport volume' for further details
Units per crate - fresh food	no.	48	No nesting, see section on 'transport volume' for further details

[48] *https://www.erieri.com/salary/job/heavy-truck-driver/france*
[49] *https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Estimated_hourly_labour_costs,_2022_(EUR).png*
[50] *https://www.fuel-prices.eu/403.shtml/*
[51] *https://imise.co.uk/wp-content/uploads/2017/09/RR5-Effects-of-Payload-on-the-Fuel-Consumption-of-Trucks.pdf*
[52] *https://imise.co.uk/wp-content/uploads/2017/09/RR5-Effects-of-Payload-on-the-Fuel-Consumption-of-Trucks.pdf*

Units per crate - personal care	no.	36	No nesting, see section on 'transport volume' for further details
Unit weight	kg	0.016-0.520	See section 'weight of packaging' for more
GHG emissions			
Emissions diesel	kg CO_2 / litre	2.68	Derived from Michelin[53]

Average transport distances

The tables below show the average transport distances (in km) for each transport leg, based on effective market share and according to application. These are based on the modelling explained above.

Table: Average transport distances for transport box 6 (to sorting and cleaning) per effective market share and application

Effective market share	PET and glass bottles	Food cupboard	Fresh food	Personal care
2%	262	262	262	372
5%	215	215	215	372
10%	150	150	150	262
20%	95	103	95	215
40%	71	73	71	150
70%	92	56	92	103

Table: Average transport distances for transport box 9 (to filling) per effective market share and application, based on high packaging standardisation

Effective market share	PET and glass bottles	Food cupboard	Fresh food	Personal care
2%	258	255	253	332
5%	201	199	201	353
10%	139	142	140	165
20%	88	99	86	173
40%	62	64	55	89
70%	50	40	46	105

Table: Average transport distances for transport box 9 (to filling) per effective market share and application, based on low packaging standardisation

Effective market share	PET and glass bottles	Food cupboard	Fresh food	Personal care
2%	258	410	253	332
5%	201	419	201	353
10%	216	448	219	352
20%	173	421	175	379
40%	176	381	169	521
70%	168	387	169	415

[53] *https://connectedfleet.michelin.com/blog/calculate-co2-emissions*

Boxes 7 and 8: Sorting and cleaning

Sorting and cleaning facilities are collocated, meaning they share a building and do not require any logistics, aside from transport from storage, to the sorting line, to the washing line, and back to storage.

	Key assumptions	Reasoning
1	Packaging is unloaded on pallets from trucks manually.	Can be done automatically but we assume this will be done manually given high infrastructure investment for semi-automatic unloaders.
2	Packaging is taken out of crates and put into sorting machine semi-automatically (e.g. loading turntable or bottle unscrambling machine).	There are various options for putting packaging into automatic sorter – both manual and automatic (static bottle hoppers, loading turntables, conveyers, bottle unscrambling machines). Manual or automatic loading depends on the speed of sorting machine – it is assumed some form of semi-automatic loading is sufficient.
3	Single-use lids are removed during the sorting stage and sent to end-of-life, where they are 100% recycled, except for flexible PP lids (closures to 1.5L PP pot) which are assumed to be put in customers' waste bin. They cannot be recycled due to their small format.	Sorting and cleaning of reusable lids is very complicated operationally, and in the vast majority of today's reuse systems lids are single-use. Thus, our assumption is in line with market practices.
4	Sorting packaging by design is done automatically.	Existing optical sorting machines for bottles can sort different bottle designs (i.e. by colour and shape). Sorting could be done by identifier (e.g. barcode), but it is likely slower, and there is a greater risk of losses due to unreadable identifiers.
5	Packaging is moved from sorting to washing in transport boxes.	There is no need to crate and palletise packaging before washing.
6	Cleaning machine able to both clean and de-label the packaging.	There are existing machines that do this for bottles.
7	The cleaning process for some packaging types (e.g. home/personal care) is more difficult than for others	The packaging shape, the product previously inside the packaging, and the level of safety standards will all impact the cost of cleaning.

	(e.g. bottles). Difference in cleaning costs will be governed by an “easiness to clean” variable.	
8	Each piece of packaging is automatically checked for damage and hygiene.	Cameras can be used to detect damage and high-frequency infrared measuring techniques are used to detect residual product.
9	Packaging lost due to quality control is all recycled.	Given packaging is in a closed-loop system, we can assume the packaging is recycled and not incinerated or sent to landfill.
10	Packaging is put into transport crates automatically, and only the food cupboard application is nested.	Automatic crating of bottles already exists and will be required to keep up with the speed of the sorting machine. Nesting is assumed only for food cupboard for modelling simplicity. Technically, fresh food after sorting could be nested (because lids have been removed).
11	Low standardisation is assumed, to reduce the capacity of sorting and cleaning lines, and increase the opex in our model.	Decrease in capacity is assumed because more designs will slow down the speed of the sorting lines, and for cleaning it will reduce the number of units you can fit into the machine. Opex will increase because more labour will be needed to handle multiple pack designs.

Costs for sorting and cleaning

Annual capacity of sorting and cleaning

In accordance with data gathered through expert interviews, the hourly capacity of a sorting line is estimated to be 30,000 units / hour.[54] Given that an industrial washing line usually operates at roughly half this speed (15,000 units / hour[55]), the assumption was made that two washing lines are installed in each sorting and cleaning facility to enable a steady throughput of units. With 5,824 operating hours a year (16 hours per day, every day, to allow for one cleaning shift), the total annual capacity of a facility is 175 million units.

Capex of the sorting and cleaning facility

Purchasing costs of sorting and cleaning lines were gathered in expert interviews. The lifetime of machinery is assumed to be 20 years.

[54] *Data point gathered from expert interviews and/or correspondence.*
[55] *Data point gathered from expert interviews and/or correspondence.*

The building in which sorting and cleaning lines are housed, to include sufficient storage and office space, is estimated to be 2,000 sq.m.[56] This led to the addition of 800,000 EUR[57] to the capex over a 30-year[58] lifetime, to account for building construction.

Opex of the sorting and cleaning facility

The opex of sorting and cleaning facilities comprises the following costs:

1. Energy:
    a. Of the sorting line: electrical energy is assumed to cost 11.04 ct / kWh[59].
    b. Of the cleaning line: electrical energy is assumed to cost the same as sorting. The thermal energy consumption is assumed to be supplied using natural gas, costing 4.1 ct / kWh[60].
    c. Of the building: An average energy consumption value of 152 kWh / sq.m. / year[61] was applied to account for the building's wider energy consumption, including heating, electrical appliances.
2. Labour[62]: to operate one sorting or cleaning line, two FTEs are required. This equates to six FTEs for the entire facility (one sorting line and two cleaning lines are assumed, as outlined above). Additionally, four FTEs are needed to support logistics in the facility. This labour is assumed to be compensated at the minimum wage, i.e. 17.28 EUR / hour incl. employer costs[63]. For the facility, two FTEs are assumed to allow for supervisory or managerial roles, compensated with the average salary for France (40.5 EUR / hour incl. employer costs[64]).
3. Water: in the case of cleaning, water is required (see 'water use of cleaning'). Water costs were accounted for at 0.4 cents / litre.[65]

Note: Costs for storage during the sorting and cleaning process are integrated in the opex by accounting for both storage space and labour.

Variation factors

It was assumed that lower packaging standardisation has an adverse impact on both sorting and cleaning. To account for this, it is assumed that sorting and cleaning lines operate only at 90% of their total capacity in comparison to the scenario with high packaging standardisation. This capacity

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[56] The building size was estimated based on calculations considering storage, space for machinery and office space. While the resulting space in the calculation varies between applications and may be below 2,000 sq.m., this was taken as an average for ease of modelling and to allow for leeway.
[57] APX Construction Group (June 2021). https://apxconstructiongroup.com/warehouse-construction-cost/
[58] Assumption tested with experts.
[59] Eurostat (2023). Electricity prices for non-household customers - bi-annual data (from 2007 onwards). https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_204/default/table?lang=en
[60] Eurostat (2023). Gas prices for non-household customers - bi-annual data (from 2007 onwards). https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_204/default/table?lang=enEurostat%20(2023).%20Gas%20prices%20for%20non-household%20customers%20-%20bi-annual%20data%20(from%202007%20onwards)
[61] IEA (September 2022). Buildings. https://www.iea.org/reports/buildings
[62] Data point gathered from expert interviews and/or correspondence.
[63] INSEE (2023). Interprofessional minimum wage. https://www.insee.fr/en/statistiques/2417640
[64] Eurostat (2023). Hourly labour costs. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Hourly_labour_costs#Hourly_labour_costs_ranged_between_.E2.82.AC8.2_and_.E2.82.AC50.7_in_2022
[65] Eau de Paris (2023). Water price. https://www.eaudeparis.fr/en/water-price#:~:text=The%20most%20economical%20water,excluding%20subscription

reduction results in additional capex (i.e. assuming slightly bigger machines, or more of them) to ensure the same annual throughput of units as in a high-standardisation scenario, as well as in additional energy and water use. Furthermore, it is assumed that low standardisation requires 25% additional opex, because extra labour is required to handle a larger variety of packaging styles. Because glass bottles are assumed to have a higher breakability than plastic packaging types, a capacity reduction factor of 80% was applied to the sorting line.

At the cleaning line, the packaging types differ in their ease of cleaning. This is impacted by the product's properties (i.e. liquid or dry) and the packaging shape. The following capacity factors were applied to account for the ease of cleaning, using bottles as the baseline:

- Beverage bottles: 100%
- Food cupboard containers: 110% - food cupboard will not set so is easy to clean; given the open neck, this will be easier and quicker to wash and dry than bottles
- Fresh food containers: 85% - fresh food will likely set on packaging, requiring more time and potentially energy to clean
- Personal care bottles: 70% - can have a foaming effect so requires different chemicals and settings to effectively clean

GHG emissions of sorting and cleaning

The GHG emissions of sorting and cleaning were calculated based of the energy consumption of the machinery and the building, applying an emissions factor of 67 gr CO_2e / kWh[66] for electrical energy and 199.8 CO_2e / kWh[67] for natural gas used for thermal energy in the cleaning process. Again, the variation factors mentioned above were applied to account for low standardisation and the easiness-to-clean of different packaging applications.

Table: Sorting GHG emissions across applications and high vs. low standardisation.

GHG emissions: Sorting	Unit	High standardisation	Low standardisation
Plastic application	gr CO_2e / unit	0.11	0.12
Glass bottle	gr CO_2e / unit	0.14	0.12

Table: Cleaning GHG emissions across applications and high vs. low standardisation.

GHG emissions: Cleaning	Unit	High standardisation	Low standardisation
PET bottle	gr CO_2e / unit	3.5	3.9
Glass bottle	gr CO_2e / unit	3.5	3.9
Food cupboard	gr CO_2e / unit	3.2	3.6
Fresh food	gr CO_2e / unit	4.2	4.6
Personal care	gr CO_2e / unit	5.0	5.6

[66] *European Environmental Agency (October 2022). Greenhouse gas emission intensity of electricity generation in Europe.* https://www.eea.europa.eu/ims/greenhouse-gas-emission-intensity-of-1
[67] *Umweltbundesamt (2016). CO_2 Emission Factors for Fossil Fuels.* https://www.umweltbundesamt.de/publikationen/co2-emission-factors-for-fossil-fuels

Water use of cleaning

To calculate the water usage in the cleaning process, a data point for the average water use to clean one glass bottle (120ml / unit) and one PET bottle (80ml / unit) were obtained through expert consultations. Again, the variation factors described above were used to extract a value for the water use of other applications based on the standardisation level and the easiness-to-clean of the relevant packaging.

Table: Cleaning water use with variation factors across applications and high vs. low standardisation.

Water use: Cleaning	Unit	High standardisation	Low standardisation
PET bottle	litre / unit	0.08	0.09
Glass bottle	litre / unit	0.12	0.13
Food cupboard	litre / unit	0.07	0.08
Fresh food	litre / unit	0.09	0.11
Personal care	litre / unit	0.11	0.13

FTE for sorting and cleaning

Five FTEs are assumed to be required for sorting, including two FTEs for the sorting line, two FTEs for logistics and one FTE for management. Seven FTEs are assumed to be required for cleaning, including two FTEs for each of the two cleaning lines, two FTEs for logistics and one FTE for management. These added roles in the sorting and cleaning facilities were calculated based on the total FTE requirements, under the assumption that one employee works 1,607 hours per year. Again, the variation factors described previously were used to calculate a value for the FTEs of other applications based on the level of standardisation and their easiness-to-clean.

Table: FTEs across applications and high vs. low standardisation

FTE: Sorting	Unit	High standardisation	Low standardisation
Plastic application	FTE	0.00000009	0.00000010
Glass bottle	FTE	0.00000012	0.00000012

Table: FTEs across applications and high vs. low standardisation

FTE: Cleaning	Unit	High standardisation	Low standardisation
PET bottle	FTE	0.00000013	0.000000147
Glass bottle	FTE	0.00000013	0.00000015
Food cupboard	FTE	0.00000012	0.00000013
Fresh food	FTE	0.00000016	0.00000017
Personal care	FTE	0.00000019	0.00000021

Boxes 10, 11, and 12: End-of-life

	Key Assumptions	Reasoning
1	Any reusable packaging that is not returned at collection points by customers will be assumed to be discarded in household waste.	Based on local/national waste streams.
2	Single-use packaging is assumed to be discarded with household waste, to include littering.	Based on local/national waste streams.
3	Rates for recycling, landfilling, incineration and losses to environment per material are based on local/national rates. Losses to environment are assumed only to come from littering.	Packaging is managed together with other household waste.
4	100% of the reusable packaging losses that occur in reverse logistics are recycled.	Sorting facilities can manage waste independently and directly work with recyclers.
5	No additional capex is required for recycling, incineration, and landfill of reusable packaging.	Recycling capacity is sufficient to recycle reusable packaging, which is used in more cycles and ends up in recycling later than single-use packaging.
6	Opex, FTE, and GHG per unit of packaging waste do not change with scale or level of packaging differentiation.	Assume waste management facilities work at capacity.
7	EPR fees are paid by the manufacturer and are fixed per kg of packaging material. We will assume the packaging is designed for recycling, and therefore doesn't receive any penalties, but may receive some bonuses.	In France, EPR fees set by CITEO are paid by manufacturers (and retailers for own-brand products). CITEO EPR fees take into account the packaging weight, no. of customer sales units (which, for our modelling, will be one), and any associated premiums or penalties.

End-of-life rates

The end-of-life (EOL) rates of packaging materials were obtained from Plasteax[68] for plastic applications, and from Eurostat for glass.[69] To account for the unknown fate of exported plastic packaging, the share of exported waste was distributed across the other EOL rates. All reusable packaging which is returned is assumed to be 100% recycled, as it is collected and sorted through the reusable packaging system, which facilitates recycling. Any unreturned reusable packaging is treated with household waste. This also applies to all returned single-use lids (closures), apart from the flexible

[68] *EA - Environmental Action - PLASTEAX 2023.03 – France plastic data for 2023*
[69] *Eurostat (2023). Recycling rates of packaging waste for monitoring compliance with policy targets, by type of packaging.*

PP closure of the reusable 1.5-litre food container, which was determined to be unrecyclable due to its thin and lightweight properties.

GHG emissions of end-of-life processes

The GHG emissions of end-of life processes per tonne of material were compiled from Systemiq reports and models.[70] [71] [72]

Water use of end-of-life processes

During the recycling of end-of-life plastic and glass, water is consumed, e.g. for washing the waste. Data for recycling of PET, PE, and glass was extracted from the Ecoinvent[73] database for LCA. As no data is available for the recycling of PP, the value for PE was taken as a proxy.

[70] *Systemiq and Pew Charitable Trust (2020). Breaking the Plastic Wav. https://www.pewtrusts.org/-/media/assets/2020/07/breakingtheplasticwave_report.pdf (underlying data is proprietary to Systemiq)*
[71] *Systemiq (2022). ReShaping Plastics. https://www.systemiq.earth/systems/circular-materials/reshaping-plastics/ (underlying data is proprietary to Systemiq)*
[72] *Systemiq (2023). Plastic IQ. https://www.systemiq.earth/portfolio/plastic-iq/ (underlying data is proprietary to Systemiq)*
[73] *Ecoinvent (2023). Ecoinvent Database. https://ecoinvent.org/the-ecoinvent-database/*

SECTION 3 - MODEL CALCULATIONS AND OUTPUT METRICS

Transition costs

Transition costs are calculated from the total system's annualised capex by first multiplying it by the lifetime of the infrastructure in question and then by the proportion of total capex assumed to be required to transition from single-use to reuse.

The proportion of total capex deemed to be transition capex is calculated based on the following assumptions:

- Production/conversion, retail, customer, and EOL: 0%, i.e. no additional infrastructure is required to produce/convert reusable packaging.
- Filling: Depending on whether the switch is like-for-like (moving to the same type of packaging, e.g. single-use PET bottle to reusable PET bottle) or to a different type of reusable packaging (e.g. single-use PET bottle to reusable glass bottle), the following assumptions were made:
  - Like-for-like packaging switches (PET beverage bottles, fresh food, personal care): we assume that retrofitting a single-use line to take reusable packaging would be 10% of the total capex required to manufacture a new filling line. This is based on insights from experts, who provided us with the cost of a new filling line for reusable packaging, as well as the cost of retrofitting an old line to accommodate reusable packaging. A final transition cost range within the study allows for this percentage to be significantly higher.
  - Different packaging switches: we assume that a completely new filling line is required, so transition capex would be 100% of the capex of a new line.
- Transport, collection points, sorting, and cleaning: 100%, i.e. all collection, sorting and cleaning infrastructure would need to be built new.

List of output variables

Table: List of output variables

Category	Output metric	Units
Economic metrics	**Total cost** (opex and annualised capex) for single-use and equivalent reusable packaging, including EPR and externalities	EUR per unit of utility
	Infrastructure cost of transitioning to reuse system (capex)	EUR
Environmental metrics	**Material use** for reusable packaging vs single-use equivalent	Tonnes per unit of utility
	GHG emissions for reusable packaging vs single-use equivalent	t CO_2e per unit of utility
	Water use for reusable packaging vs single-use equivalent	Litres per unit of utility
	Waste generated (incinerated, landfilled, and lost to environment) from reusable packaging vs. single-use equivalent	Tonnes per unit of utility
Social metrics	Jobs in reuse systems	No. of FTEs

SECTION 4 - LIMITATIONS OF THE CURRENT STUDY

This study undertakes analysis to explore the economic and environmental performance of return-on-the-go and reuse models, to address some of the gaps and enhance the research on the circularity of packaging.

We have taken great care to ensure transparency regarding our data sources, assumptions and methodology, and to provide a rigorous analysis of the implications and trade-offs between different materials and scenarios. However, it is essential to emphasise the limitations of this study, as doing so encourages further research and fosters a healthy discourse within the field. By acknowledging these limitations, we hope to promote an open dialogue and drive progress in understanding the potential and implications of return-on-the-go models. Further calls for research can be found in Part 4 of the study.

- **Reuse model:** This study focused on return-on-the-go reuse models, but recognises that return-from-home models and refill models are promising approaches to enhance the circularity of packaging. Return-from-home models could allow customers to return packaging from the comfort of their homes and thus potentially contribute to higher return rates or leverage existing distribution infrastructure, such as delivery services. Refill models may be better suited for some applications, and may equally warrant a more detailed examination when seeking to understand the potentials of reuse models.
- **Lids:** In our analysis, we assumed all lids to be single-use. However, from a circular economy perspective, reusable lids would be the ideal solution, minimising environmental impact, and promoting further circularity in the packaging system.
- **Geography:** Our analysis modelled the whole of France; however, environmental and economic performance of reuse models vs. traditional single-use models may differ in geographies with a higher or lower population density. Conducting specific analyses, for example in other countries, represents an opportunity for further research.
- **Trade:** Our analysis does not account for cross-border transport and trade of primary packaging, packaged goods or plastic packaging waste. Modelling an international reuse system would require additional assumptions and considerations, for example for applications like personal care and food cupboard, where cross-border transport plays a significant role.
- **Innovation:** Additionally, it is important to note that innovation in the industry is an ongoing process. While our analysis captures the current state of sorting and cleaning facilities, it is worth acknowledging that future innovations and advancements in technology may result in decreased capex and opex for these facilities. These potential cost reductions have not been explicitly considered in this analysis.
- **Data availability:** To ensure a robust assessment, we have explored different sizes and combinations of sorting and cleaning centres. By considering various scenarios and configurations, we aimed to provide a comprehensive understanding of the economic and environmental performance of different system setups. The availability of data, in terms of both

costs and environmental impacts, on filling facilities, collection procedures, and sorting and cleaning facilities, is limited. This is due to the fact that at-scale reuse systems do not exist today. This limitation may introduce uncertainties in the analysis, and it is important to acknowledge these data gaps when interpreting the results. To reduce these uncertainties, we have tested assumptions and the results of our model in 30+ expert interviews.

- **Life cycle assessment:** This analysis does not provide a full life cycle assessment (LCA) of the different system configurations. While we consider various economic and environmental indicators, a comprehensive LCA would involve assessing additional factors such as impacts on biodiversity, human health, and social aspects.
- **Material:** While this study mainly compares plastic-to-plastic applications, it recognises that a broad range of materials is available and suitable for reuse models. It also recognises that further research is needed to assess the safety of reusing materials.
- **Transport logistics modelling:**
    - The main limitation of the transport modelling is that it does not represent any specific supply chain, nor the exact locations of existing facilities; instead, the locations of the distribution centres and filling sites have been estimated based on the population density. This means that the locations may be over-optimised, because they are placed solely based on the optimum drive times to settlement points (as a proxy for the retail locations that they distribute products to), without any regard for the cost of land, or industrial areas where distribution centres are often located; nor does it consider the specific locations of actual commercial areas.
    - In addition, in reality, there may be distribution centres for competing retail chains located in the same area (e.g. on the same industrial estate), while in the modelling we only allow one facility per settlement point. However, the software can place facilities in neighbouring settlements, which it does, for example, by placing a number of facilities around Paris. It could be of interest for a future study to research the actual retail distribution supply chain, and locations of fillers for a specific product. In the absence of such data, the indicative locations modelled here are representative enough to give a range of drive times and distances in France, and to give a realistic representation of the potential logistical considerations of a reuse system.
    - Another modelling limitation is that the size of the facilities is assumed to be standard: all the distribution centres are assumed to be roughly the same size; all the sorting and cleaning centres are assumed to be roughly the same size, etc. As a result, a full logistical optimisation of the sorting and cleaning centre infrastructure was not possible. A future study may want to consider the impact of building more, smaller sorting and cleaning centres, in order to reduce the transport distances further. This may increase the capital and operating costs of the centres, but would reduce the logistics costs, and the optimum balance of these two variables should be investigated.
    - Finally, by necessity, the supply chains themselves were simplified. In reality, you may have several layers of distribution centres between the filling sites and the shops; you may have bottle fillers sending their full products to a beverage distributor, who then supplies the retail chain distribution centres, who then supplies the shops. As above, without a specific supply chain to model, and without the exact locations between

producers, distributors, and retailers, this simplification is necessary to model actual drive times and distances on the French road network.

- Our analysis assumes no additional reverse logistics cost from retailer stores to distribution centres, but rather that the existing logistics infrastructure which distributes goods to the retailers is also used to aggregate collected containers at distribution centres. While this simplifying assumption allows for a focused assessment of specific stages in the value chain, it may not capture the full complexity of the system and the potential logistics involved.

The Ellen MacArthur Foundation is an international charity that develops and promotes the circular economy in order to tackle some of the biggest challenges of our time, such as climate change, biodiversity loss, waste, and pollution. We work with our network of private- and public-sector decision makers, as well as academia, to build capacity, explore collaborative opportunities, and design and develop circular economy initiatives and solutions. Increasingly based on renewable energy, a circular economy is driven by design to eliminate waste, circulate products and materials, and regenerate nature, to create resilience and prosperity for business, the environment, and society.

Further information:
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Systemiq, the system-change company, was founded in 2016 to drive the achievement of the Sustainable Development Goals and the Paris Agreement, by transforming markets and business models in five key systems: nature and food, materials and circularity, energy, urban areas, and sustainable finance. A certified B Corp, Systemiq combines strategic advisory with high-impact, on-the-ground work, and partners with business, finance, policy makers and civil society to deliver system change. In 2020, Systemiq and The Pew Charitable Trusts published "Breaking the Plastic Wave: A Comprehensive Assessment of Pathways Towards Stopping Ocean Plastic Pollution", an evidence-based roadmap that shows how industry and governments can radically reduce ocean plastic pollution by 2040. Systemiq has offices in Brazil, France, Germany, Indonesia, the Netherlands and the UK.

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Eunomia Research & Consulting has been working to address triple planetary crisis of climate change, biodiversity loss and pollution since 2001, through supporting the transition to a circular and regenerative economy. Combining real world practical experience and deep technical knowledge with an active role in policy, Eunomia provides appliable, science-led solutions and insights that drive a positive, regenerative impact on the planet. Eunomia's role in reuse is providing market and technical analysis, sophisticated modelling and advice to policymakers, cities, businesses and civil society

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