R3PACK - REDUCE, REUSE, RETHINK PACKAGING TOWARDS NOVEL FIBRE-BASED PACKAGING AND REUSE SCHEMES

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ADDITIONAL AUTHOR(S) CONTRIBUTION	
Name	**Organisation**
Manon Bessone, Mathilde Boutin, Amandine Combet, Estelle Doineau, Olivia Robin, Jade Rolland	(RE)SET

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TABLE OF ABBREVIATIONS

AU: Aarhus University

D: Deliverable

EU: European Union

LCA: Life Cycle Analysis

OPP: Oriented Polypropylene

OPPmet: Oriented Polypropylene metallised

OTR: Oxygen Transmission Rate

PPWR: Packaging and Packaging Waste Regulation

PET: Polyethylene Terephthalate

POS Advertising : Point of Sales Advertising

R&D: Research & Development

RVM: Reverse Vending Machine

T: Task

WP: Work Package

WVTR: Water Vapor Transmission Rate

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EXECUTIVE SUMMARY

Context
R3PACK aims to accelerate the reduction of single-use plastic packaging in the agri-food industry across Europe, through two complementary approaches: reuse and fibre-based substitution. This deliverable (D5.2) is part of Work Package 5 – Cross-sectorial validation, demonstration and upscaling of the solutions in the R3PACK project. Its overall objective is to provide a consolidated assessment of what was achieved in practice, how the initial framework of the demonstrator (defined in D5.1) evolved, and which conditions are required for large-scale deployment. lines.
It analyses the evolution and results of the upscaling and demonstration phase of those pillars, drawing lessons from the operational, technical, and organisational experience of the pilots.

Objectives
The purpose of D5.2 is to evaluate the progress achieved across the pilots, identify the main technical, economic, and operational challenges, and compare the maturity and scalability potential of the reuse and substitution models tested under R3PACK.

Methodology
The analysis builds on results from previous deliverables (WP3 and WP4) and partner feedback collected during implementation.
It covers the three progressive phases defined in the project, with distinct developments for each pillar:

- **Reuse** – preparation, pilot, and demonstration phases: from the definition of protocols and alignment among partners, to small-scale in-store pilots and larger demonstrations assessing consumer behaviour, logistics, and operational feasibility.
- **Substitution** – laboratory and pilot validation: focused on the development and testing of fibre-based packaging materials (machinability, barrier properties, regulatory compliance), without reaching the stage of industrial or commercial demonstration due to limited technological maturity.

Key findings

- **Reuse -** Demonstrations validated the operational feasibility of reuse systems across 20 stores and 26 SKUs, with encouraging levels of consumer engagement and return rates when the system was visible, simple and well-explained.
  The project generated **major technical advances** on packaging robustness, repeated washing cycles, allergen management, sealing integrity and the integration of return logistics into existing industrial and retail workflows.

  These developments represent a **true operational "unlock"** for reuse. For many manufacturers and retailers, R3PACK provided the first full validation of how reusable packaging can be produced, handled, transported, washed and returned at scale — identifying which adjustments are required on production lines, what washing parameters ensure safe reuse, how deposits should be managed in-store, and how return flows can be integrated into current logistics.

  This practical evidence has already enabled several partners to **initiate or expand their own reuse initiatives**, using R3PACK specifications, washing parameters and operational learnings as a foundation.
  At the same time, the experiments confirmed that achieving economic

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competitiveness with single-use plastic will require **massification, process optimisation and harmonised governance systems**, particularly for washing, logistics and deposit management.

Overall, the Reuse pillar demonstrates that reusable packaging is **technically and operationally possible**, but reaching industrial competitiveness will require continued investment, standardisation and efficiency gains across the entire loop.

- **Substitution**: Significant technical progress was achieved on fibre-based packaging materials during the laboratory and industrial-line trials. Across several dry and semi-dry food categories, partners validated the **machinability and sealing performance** of paper-based structures containing more than 80 % fibre and 90 % bio-based content. Trials confirmed that fibre-based multilayers can be processed on existing plastic-oriented equipment, provided that sealing temperature, pressure, jaw configuration and tension control are precisely adjusted.
  Ageing and preservation tests showed **satisfactory performance for selected food categories**, particularly for medium-barrier products such as savoury biscuits or pastry dough. These results provide practical evidence that paper-based packaging can meet shelf-life requirements for certain product families.

  However, current fibre-based structures still face limitations for **high-fat, high-aroma or transparency-critical products**, where barrier performance remains significantly below conventional plastics. Economic constraints also remain a major barrier: paper-based substrates are typically **two to five times more expensive** than plastics and reduce line speeds by 10–20 %, making industrial deployment difficult in low-margin segments.

  Regulatory uncertainties—particularly concerning recyclability criteria and the treatment of composite materials under the PPWR—continue to influence investment decisions. Scaling these solutions will require progress on barrier properties, cost reduction, and equipment specifically designed for high-speed paper conditioning.

  Overall, the Substitution pillar demonstrates strong technical feasibility for selected categories, while highlighting the need for **continued R&D, cost-efficiency improvements and regulatory clarity** before fibre-based packaging can become a competitive alternative to single-use plastics at industrial scale.

- **Cross-cutting insights:** Both pillars show that reducing single-use plastic requires **coordinated experimentation across the entire value chain**, from product design to manufacturing, retail operations, washing, and end-of-life. Reuse and substitution respond to different product needs and constraints, and no single approach can address all packaging situations.
  Common challenges include:
    - the need for **harmonised standards and governance frameworks**,
    - improved **cost-efficiency and operational performance**,
    - clearer **regulatory signals** supporting investment,
    - and sustained **consumer communication** to support behaviour change, particularly for categories where packaging cues influence expectations.

  A transversal lesson emerging from both pillars is that reusable and fibre-based packaging will only become fully competitive alternatives if Europe

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continues to **invest in technical progress**, just as single-use plastics benefited from decades of optimisation.

Next steps
The insights generated in D5.2 have directly fed into:

- **D5.3 (Decision Tool)**, which consolidates the technical and economic learnings into a category-level decision-support framework;
- **D7.3 (What-if Scenarios & Policy Recommendations)**, which uses these findings to identify regulatory, technical and financial levers for scaling reuse and fibre-based packaging at European level.

1. CONTEXT AND EVOLUTION OF THE DEMONSTRATION FRAMEWORK

The D5.2 deliverable builds on the activities of Work Package 5 – Cross-sectorial validation, demonstration and upscaling of the solutions. Its objective is to assess the outcomes achieved in practice across the reuse and substitution pillars, analyse deviations from the initial plan, and identify the conditions required for large-scale deployment.

Since the start of the project, both pillars have progressed significantly, but with adjustments to the original phasing of activities.

- For reuse, the launch of in-store demonstrations required additional time to identify suitable packaging solutions, develop new reusable formats, and adapt industrial lines. These steps were essential to ensure that pilots were representative of real-life conditions.
- For substitution, the focus shifted towards technical development and validation of fibre-based materials, as most industrial partners were not yet able to conduct full-scale demonstrations due to the limited maturity of existing paper-based solutions.

These operational realities led to a six-month extension of the project (until November 2025), approved by the European Research Executive Agency. This extension allowed partners to conduct longer pilot monitoring (up to one year on-shelf for certain product categories), collect more robust data on sales and return rates, and better characterise the environmental and economic impacts of the tested solutions.

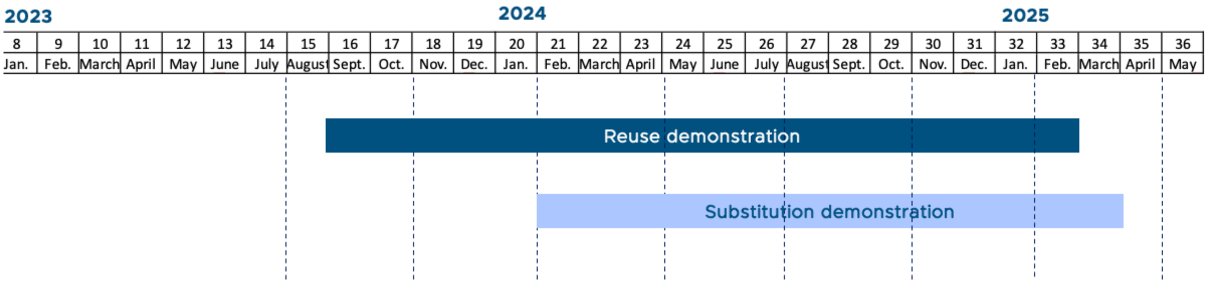

Figure 1 : Initial planning of the reuse and substitution demonstrations (as defined in D5.1).

As illustrated above, both pillars followed distinct trajectories, reflecting their respective levels of maturity. While the reuse stream moved from concept to in-store

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pilots, the substitution stream focused on validating technical feasibility at lab and pilot scale. These adjustments strengthened the relevance of the demonstrations and ensured that the results collected in R3PACK are robust, representative, and transferable to other European contexts.

2. REUSE PILLAR

2.1. Phasing and scope (revised)

The reuse demonstrator was initially structured in three phases, as defined in D5.1. During implementation, the schedule and scope were revised to reflect packaging development delays, supplier mobilisation, and operational challenges encountered by manufacturers and retailers. The initial and final phasing are illustrated below

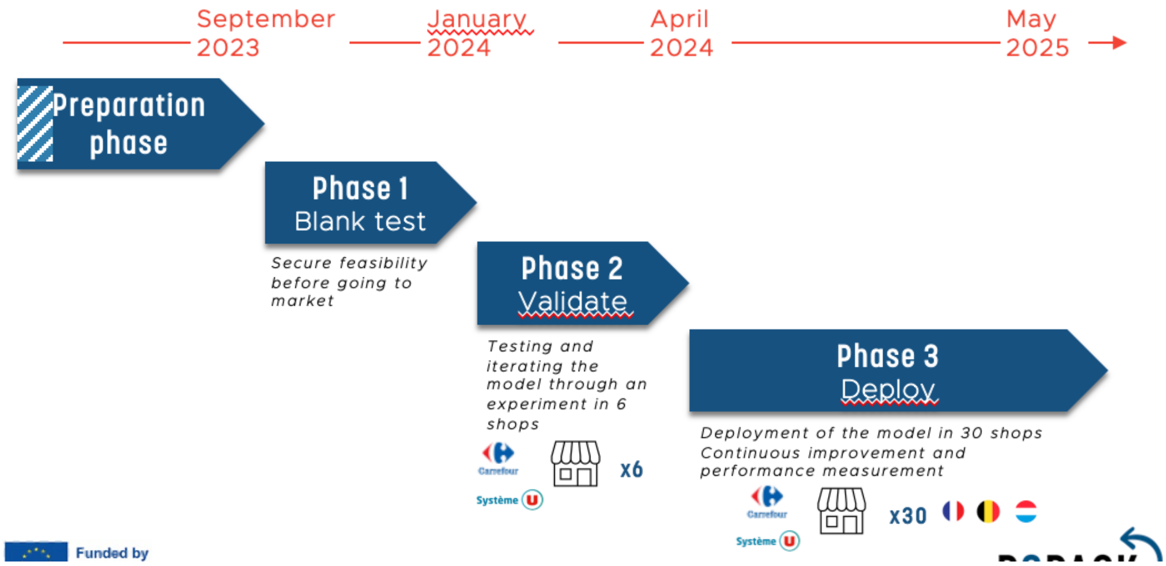

Figure 2 : Initial Reuse demonstrator phasing (D5.1)

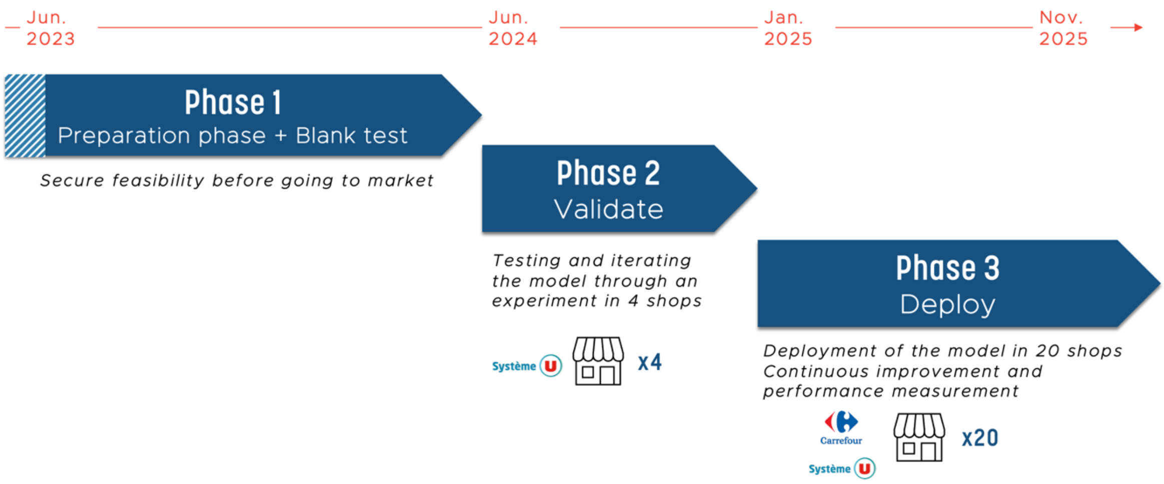

Figure 3 : New Reuse demonstrator planning – definitive version

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Scope of the demonstration
Across phases 2 and 3, the pilot covered a growing assortment of product categories, progressively expanding to the following segments:

- Juices
- Alcoholic beverages
- Syrups
- Prepared salads
- Cut vegetables
- Ambient grocery (salty & sweet)
- Dairy products
- Oils & condiments

Phase 3 finally reached:

- 20 stores (16 Carrefour + 4 U)
- ~30 reusable SKUs, including glass and PP formats across complex product categories.

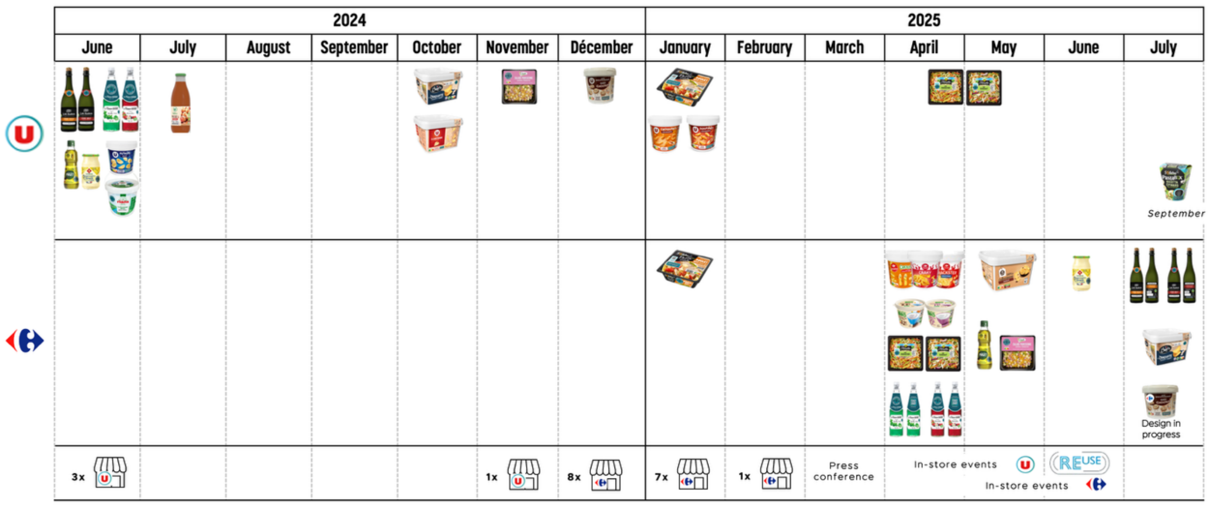

Figure 4 : Reuse Product references planning deployment

2.2. Demonstration phases description

2.2.1. Phase 1 - Preparation and feasibility testing (Jun 2023 → Jun 2024) - Task 5.2

Phase 1 focused on securing the technical, organisational and logistical feasibility of the reuse model before any market deployment. It combined product selection, packaging development, supplier onboarding and full operational validation of the reuse loop.

Product & packaging definition

- Selection of products based on sales potential, rotation, and filling-line compatibility.
- Review of existing packaging or co-development of new reusable formats with packaging suppliers (glass and PP).

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- Definition of expected production volumes, based on an initial return rate assumption of 30%.

Supplier selection and loop configuration

- Competitive tenders to select packaging manufacturers, washing partners (immersion for glass and spray for plastics), the reuse operator and the RVM provider.
- Formalisation of the end-to-end loop: collection, identification, storage, washing, redistribution.
- Selection and parameterisation of The Keepers RVMs (EAN recognition, deposit reimbursement settings, multi-format compatibility).

Technical validation

- Washing tests to assess removal of residues, label wash-off performance, water retention risks and drying behaviour.
- Label testing to identify a non-water-soluble label with water-soluble adhesive suitable for reuse.
- Transport and palletisation tests to secure the integrity and stability of new packaging formats.

Common visual identity and deposit definition

- Design of a shared graphical identity (logo, PLV), in the absence of a national or EU reference for reuse communication.
- Definition of deposit values using common criteria (below €1, incentive to return, coherence across volumes), given the lack of national guidance.

Phase 1 was essential to validate the overall technical robustness of the system and ensure that both manufacturers and retailers were fully operational before entering in-store experimentation.

2.2.2. Phase 2 - Small scale deployment (Jun 2024 → Dec 2024) - Task 5.3

Phase 2 consisted of the first operational deployment of the reuse model in real retail conditions, across four Coopérative U stores located in northern France and supplied from the same warehouse. The objective was to test the end-to-end loop at small scale, validate the operational workflow and progressively introduce reusable products on shelves.

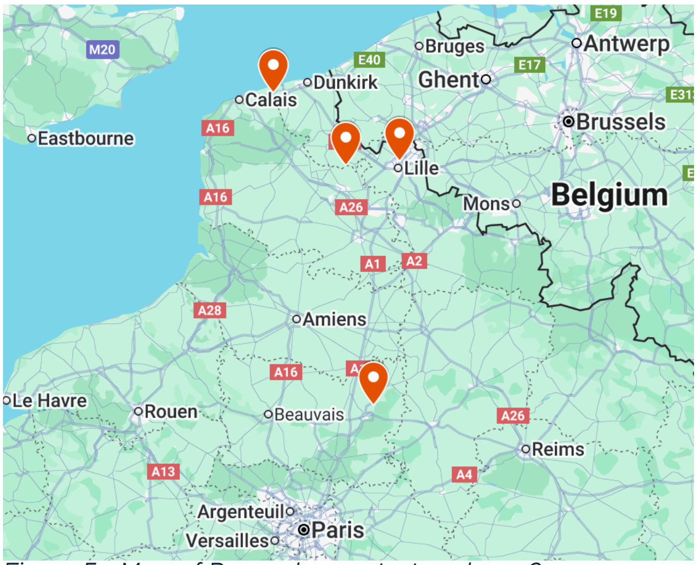

Figure 5 - Map of Reuse demonstrator phase 2

Product deployment and rollout sequence

The in-store rollout occurred in several waves:

- **First wave:** introduction of products requiring only limited packaging modifications, mainly glass bottles (cider, syrup, oil, juice, mayonnaise) and existing plastic formats already compatible with reuse (e.g. pails for snacks or dairy products).
- **Subsequent waves:** onboarding of more complex references, including reusable buckets and prepared salads in sealed PP

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trays. These required additional development work, as no market-ready reusable equivalent existed.

Technical and industrial preparation
Before product introduction, manufacturers finalised a series of technical steps initiated during Phase 1:

- food contact validation and ageing tests,
- sealing and tamper-evidence tests for newly developed reusable formats,
- machinability and filling line adjustments,
- label validation and washing compatibility.

These steps ensured that each new SKU could be safely deployed in operational conditions.

Commercial and organisational alignment
Phase 2 required significant coordination between manufacturers and the retailer, including:

- commercial negotiations and product referencing,
- alignment of ordering, delivery and warehouse processes for new reusable formats,
- adjustments to internal IT flows (product codes, deposit management, stock visibility).

These interactions were essential to prepare a consistent market launch and ensure proper integration into the retailer's existing supply chain.

In-store preparation and activation
Operational deployment in stores involved several activities carried out jointly by Coopérative U and project partners:

- installation and configuration of the **RVM** (Reverse Vending Machine),
- set-up of **in-store communication materials** (PLV, shelf talkers, banners),
- implementation of the shared **reuse logo** on product labels,
- briefing and support to store teams to introduce the new reusable offer (ordering, replenishment, placement, consumer explanation).

Project teams conducted close follow-up with store managers during the first weeks of deployment to ensure smooth execution, visibility of the reusable offer and proper functioning of the return system.

Phase 2 scope
By the end of Phase 2, the pilot covered:

- **13 reusable SKUs**,
- **4 stores**,
- a combination of **glass** and **plastic** reusable formats across several categories.

Phase 2 thus validated the operational deployment of the reuse loop at small scale, paving the way for the multi-retailer scale-up conducted in Phase 3.

2.2.3. Phase 3 - Scale up (Jan 2025 → Dec 2025) - Task 5.4

Phase 3 extended the reuse model to a multi-retailer and multi-region deployment, providing a robust basis to assess scalability under real operational conditions.

Expansion of the pilot

- The number of participating retailers increased from one to **two** (Coopérative U and Carrefour).
- The number of stores expanded from **4 to 20**, including **16 additional Carrefour stores** across new regions.

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- The assortment grew to **nearly 30 reusable SKUs**, covering a wide range of categories: juices, alcoholic beverages, syrups, prepared salads, cut vegetables, sweet and savoury groceries, dairy products, oils and condiments.

Operational integration with Carrefour
Onboarding Carrefour required adapting the reuse loop to a new commercial and IT environment. Each retailer operated different systems for product referencing, invoicing and deposit management, which required manufacturers to reconfigure part of their internal processes.
The presence of another reuse scheme (Loop) in some Carrefour stores also required harmonising in-store communication and ensuring consistency of messaging for consumers.

Strengthening logistics and in-store execution
The scale-up enabled:

- larger and more stable flows of reusable packaging between stores, warehouses and washing partners,
- harmonised deployment of communication materials and RVMs across regions,
- a more diverse consumer base and larger dataset to assess purchasing and return behaviours.

Phase 3 therefore provided the most comprehensive view of how the reuse system performs at scale, across different retail environments and product categories.

Figure 6 - Map of reuse demonstrator phase 3

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2.3. Reuse comparative analysis and key learnings

This section consolidates the main learnings from the three demonstration phases. To avoid repeating the chronological descriptions presented in Section 2.2, the analysis is structured **by thematic blocks**, each covering:

- **How the topic evolved across Phases 1, 2 and 3**,
- **What technical, operational or organisational barriers emerged**,
- **Which solutions were implemented**,
- **And what remains to be addressed for large-scale deployment**.

This cross-cutting structure reflects the nature of the demonstration: while each phase brought incremental progress, the most relevant insights appear when comparing themes across the entire loop — from packaging development to washing, in-store operations, consumer engagement, and system-wide governance.

2.3.1. Packaging and technical feasibility

Across the three phases of R3PACK, the development of reusable packaging required extensive material, design, and technical adaptations. The work carried out by manufacturers, packaging suppliers and washing partners demonstrated both the feasibility of reuse for a wide range of food categories, and the structural limitations that still constrain the sector today.

Selection and development of reusable formats

In Phase 1, the consortium selected the initial product categories using explicit criteria designed to maximise the operational and economic viability of the reuse model. The selected products met the following conditions:

- High sales volumes, enabling faster circulation of packaging in the loop and better amortisation of washing and logistics costs.
- Regular and frequent purchases, increasing the probability of early returns and generating stable flows for washing partners.
- Compatibility with existing industrial lines, in order to minimise retrofits on filling and sealing equipment.
- Strong consumer familiarity, facilitating acceptance of reusable packaging during early-stage pilots.

From this base, existing formats (mainly glass bottles) were adapted, and several new reusable plastic containers (buckets, trays, bowls) had to be developed, as no market-ready solutions existed for certain food categories. This required extensive testing: machinability, sealing, tamper-evidence, food-contact safety, ageing behaviour, label removal, and transport stability.

Co-development and standardisation efforts

A major achievement of the project was the collaborative development of a standard reusable bucket, involving several competing manufacturers, packaging suppliers and washing partners. This type of cross-industry co-innovation is a first in the sector and was made possible by the neutral and collective framework offered by R3PACK.

The standardisation work included:

- aligning technical specifications among competitors
- consolidating constraints from washing, filling and logistics partners
- designing a format compatible with multiple product categories
- eliminating water-retention areas to meet hygiene and drying requirements

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This effort also raised legal and intellectual-property questions, particularly regarding shared design ownership and competitive sensitivities. These challenges required careful coordination, illustrating the complexity—and necessity—of working collaboratively to build reusable packaging standards.

Label performance and washability

Label removal proved to be a critical design parameter. Tests conducted with washing partners led to the identification of a combination suited for reuse: non-water-soluble labels paired with water-soluble adhesives, which detach effectively during washing without leaving residues.

However, results differed between laboratory conditions and real-world returns:

- early tests on new packaging showed good label detachment
- tests conducted on packaging returned by consumers highlighted variability, potentially linked to longer retention times, label characteristics, or washing conditions

This confirms that label compatibility must be validated in operational conditions, not only on new packaging.

Material limitations and selection

The project explored the reuse potential of both glass and plastics. Glass remains highly suitable due to its smooth surface and compatibility with immersion washing. Plastics, while necessary for certain product categories (safety, industrial feasibility, product protection, environmental performance based on weight), showed limitations regarding odour retention and allergen decontamination.

Polypropylene (PP) was selected as the reference resin due to availability and cost, but field tests revealed residual odours even after multiple washing cycles, prompting further R&D on:

- improving PP surface properties
- testing alternative resins
- adapting industrial washing processes

These findings highlight the need to pursue plastic reuse R&D, as many industrial production lines cannot switch to glass due to safety or equipment constraints.

Key takeaways

- Product choice is a decisive factor for reuse feasibility: high-volume, high-rotation lines with stable consumer demand maximise return rates and cost efficiency.
- Co-development among competitors is possible and effective, but requires strong governance, neutral facilitation, and clarity on intellectual-property rules.
- Washability must be addressed early in the design process, especially for labels and for plastic formats, which react differently than glass.
- Both glass and plastics must remain part of future reusable packaging strategies, given industrial constraints and category-specific requirements.

2.3.2. Washing and reverse-loop operations

Washing performance and the organisation of the reverse loop are among the most decisive factors for making a reuse model operational. While packaging design determines what can theoretically enter a reuse system, washing, hygiene management and logistics determine whether it can operate safely, consistently and at scale.
Throughout R3PACK, the pilots revealed material-specific behaviours (glass vs

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plastic), the strengths and limits of current washing infrastructures, and the operational coordination required between retailers, manufacturers and washing partners to keep the loop running efficiently.

Washing technologies and performance across phases

Phase 1 – Initial validation of washing technologies

During the preparatory phase, R3PACK tested two main washing technologies:

• Immersion washing for glass, a mature and highly effective technology inherited from CHR reuse loops. First tests showed excellent decontamination, no water retention and stable performance.

• Spraying washing for plastic containers, using equipment originally designed for food-service trays rather than FMCG packaging. Early trials identified sensitivities to geometry, residues and surface interactions.

These results highlighted from the outset that washing feasibility and hygiene assurance would differ significantly depending on material and format.

Phase 2 and Phase 3 – Real-world washing on returned packaging

Once packaging began to be collected and returned through the RVMs, the performance gaps between materials became clearer:

• Glass bottles consistently met hygiene and quality requirements. However, existing immersion infrastructures are optimised for bottles only; jars, bowls and wide-mouth formats require dedicated equipment that does not yet exist at scale.

• Plastic containers showed more variability, with occasional persistence of odours (fat, spices, dairy, peanut), micro-residue retention and sensitivity to consumer handling and storage time before washing.

These observations do not indicate that plastic reuse is unviable; rather, they show that plastic reuse requires **targeted R&D and adapted washing processes** to reach the same level of consistency as glass.

Allergen removal: a new requirement for cross-brand reuse

Cross-brand reuse introduced a food-safety challenge that did not exist in traditional reuse loops: ensuring complete removal of the 14 regulated allergens.
This requirement stems from the fact that packaging collected from one product category may be redistributed to another brand with a different recipe.

Phase 2 – First allergen stress tests

• Immersion washing on glass achieved full allergen removal.

• Spraying washing on plastic showed incomplete removal, even after several cycles.

Phase 3 – Realistic contamination scenarios

Tests on real returned packaging confirmed strong performance on glass and improved, but still partial, results on plastic despite the addition of pre-soaking steps.

These results underline that allergen decontamination is a structural R&D frontier for plastic reuse and a prerequisite for safe multi-brand loops.

Material behaviour during washing

Glass

Glass demonstrated excellent behaviour thanks to its smooth surface, compatibility with alkaline baths and predictable washing performance. However, the infrastructure needed to wash jars, bowls and larger formats is not yet widely available.
This limits the categories that can transition to glass and reinforces the need for diversified materials in reuse systems.

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Plastic (PP)
PP was selected for its industrial feasibility, machinability and suitability for categories where glass is not an option (for safety, operational or environmental reasons).
The pilots nevertheless revealed several limitations:
• odour absorption after long dwell time,
• micro-residue retention in corners and edges,
• sensitivity to washing chemistry and temperature.

These findings point to the need for further R&D on plastic resins, surface treatments and washing chemistry—not to exclude plastic from reuse strategies, but to make it more robust in operational conditions.

Reverse-logistics organisation and loop coordination
Phase 1 – Designing the return loop
The consortium mapped end-to-end flows and defined interactions between stores, warehouses, RVMs, transport providers and washing partners. This step included validating palletisation, harmonising identification methods and modelling collection frequencies.

Phase 2 – First operational returns
Early return volumes were low, creating tensions between:
• washing partners that needed regular inflows to maintain process stability;
• retailers that preferred to wait for full RVMs to optimise transport costs.
This required frequent adjustments of collection frequency.

Phase 3 – Multi-retailer complexity
The integration of Carrefour required reworking transport routes, consolidating flows from two different retail systems, and adapting washing schedules.
Volumes increased significantly, but remained below the optimisation thresholds needed for industrial washing infrastructure to operate at full efficiency.

These findings confirm that reverse logistics must reach a critical scale to become economically and environmentally optimised.

Label removal and in-loop traceability
Label removal proved to be a determining factor for washability and loop performance.
Phase 1 tests on new packaging validated the combination of non-water-soluble labels and water-soluble adhesives.
However, Phase 3 tests on real returned packaging showed greater variability, influenced by dwell time, label characteristics and washing parameters.

This highlights the need to validate label performance in real operational conditions, not only in controlled tests.

Key takeaways

- Washing performance is a core determinant of reuse feasibility, directly influencing which materials and formats can be deployed at scale.
- Glass currently performs strongly due to mature immersion technology, but it cannot replace plastic in many food categories due to machinability constraints, breakage risk, safety considerations and weight-related environmental impacts.
- Plastic reuse remains essential for a significant share of FMCG categories, but requires dedicated R&D on resins, surface properties and washing processes—this is a challenge to solve, not a reason to abandon plastic reuse.

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- Reverse-logistics optimisation depends on achieving sufficient scale across products, stores and territories.
- Cross-brand reuse introduces new hygiene requirements, notably allergen removal, that must be integrated into future industrial standards.
- Label design and washability must be validated under real operational conditions, as they have a direct impact on hygiene, washing performance and loop reliability.

2.3.3. Commercial discussions, pricing strategy and retail listing

Commercial discussions played a central role in the deployment of the reuse pilots. While washing and packaging determine the technical feasibility of reuse, its real-world implementation depends on the ability of manufacturers and retailers to align on pricing, listing processes, invoicing systems and operational constraints.
Across the three phases of R3PACK, several structural challenges emerged: the time required to negotiate listings, the complexity of deposit invoicing, the need to maintain price competitiveness for consumers, and the necessity of agile coordination between retail and industrial IT systems.

Negotiation and listing timelines across phases

Phase 1 – Preparing listings and commercial conditions
The preparatory phase revealed that reusable products cannot be listed through standard retailer procedures. Negotiations had to include additional elements:

- the presence of a deposit and its treatment in contracts;
- specific logistics constraints (RVM installation, return flows);
- the introduction of new SKUs with unfamiliar packaging formats;
- new requirements for label design and consumer information.

Several rounds of adjustments were needed between manufacturers, distributors and internal teams (quality, marketing, supply chain, IT) before products could be formally referenced.

Phase 2 – First listings and early deployment
Listing products in four Coopérative U stores required coordinating both commercial and technical elements.
Reusable products, especially new plastic formats (buckets, trays), required more time to reference because commercial approvals could only occur once technical feasibility (machinability, washing, labelling) had been validated.
This created staggered timelines: simple glass bottles entered the market early in Phase 2, while more complex formats such as reusable buckets or salads required longer negotiation cycles.

Phase 3 – Multi-retailer complexity
The integration of Carrefour in early 2025 created a second wave of negotiations. Each retailer uses its own IT, invoicing and stock-management systems, requiring manufacturers to adapt processes twice.
Deposit management differed between the two banners, meaning that manufacturers had to maintain parallel processes for:

- listing SKUs with a deposit value,
- managing refunds and end-of-period reconciliations,
- updating labels and commercial agreements.

This duplication reinforced the need for standardisation of commercial rules for reusable packaging across retailers.

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Defining the deposit amount and its commercial implications
In the absence of national or European guidance, deposit amounts had to be defined collectively during Phase 1.
Manufacturers aligned on principles such as:

- keeping the deposit below €1 to avoid discouraging purchase;
- maintaining consistency across volumes and formats;
- setting a level high enough to encourage returns but not high enough to inflate shelf price perception.

Phase 2 and 3 sales showed that deposits of **€0.50 and €0.80** generated the highest return rates.
However, the pilots also demonstrated that deposit value is **not the only driver** of consumer behaviour; brand familiarity, visibility and ease of return often outweighed monetary incentives.

Building a competitive price position for consumers
One of the strongest consumer insights from the pilots is the expectation that reusable packaging should offer **economic value**.
Many shoppers assume that products in reusable packaging should be **cheaper** than single-use equivalents, since the container is used multiple times.

To maintain attractiveness, manufacturers adopted a consistent strategy:

- aligning or reducing the price-per-kilo of reusable products compared with single-use products;
- using the deposit refund as a perceived consumer advantage;
- ensuring that price gaps did not penalise categories with higher packaging costs.

This exercise proved challenging due to the additional costs inherent to reuse (washing, collection, IT upgrades).
The pilots demonstrated that the economic balance of reuse requires both volume and optimisation—pricing alone cannot solve the model's structural cost gaps.

Invoicing, deposit handling and IT constraints
One of the most critical barriers identified across all phases was deposit invoicing.

Current IT systems are not designed to distinguish between the product price and the deposit value.
This led to multiple obstacles:

- certain invoicing IT systems could not add a second invoice line for the deposit;
- VAT handling was inconsistent (deposit not subject to VAT except when not returned);
- discount and "anti-waste" systems could not apply promotions to the product only, excluding the deposit;
- some retailers required deposits to appear on receipts, others accepted foot-of-invoice solutions.

Several manufacturers were unable to implement dual-line invoicing despite attempts during Phase 2 and Phase 3.
This highlights a significant structural issue: **without compatible IT systems, reusable products cannot be deployed at scale**.

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Need for agility and iterative coordination

Across all phases, commercial alignment required an unusually high level of agility:

- continuous adjustments to product listings as technical tests progressed;
- parallel updates of labels, IT systems, store processes and messaging;
- repeated negotiations due to misaligned timelines between development, washing validation, and commercial calendars.

Reusable packaging does not follow a linear product-launch process.
Instead, it requires **iterative, cross-functional alignment** between departments that rarely collaborate in traditional single-use packaging models (quality, IT/invoicing, supply chain, store operations, washing partners).

Key takeaways

- Commercial implementation is as critical as technical feasibility for reusable packaging, and often more time-consuming.
- Listing reusable products requires adapting processes, contracts and IT systems, particularly for deposit management and VAT rules.
- Deposit levels must balance consumer incentives and price acceptability; return rates depend on multiple factors beyond monetary value.
- Consumers expect competitive price-per-kilo positioning, which is difficult to sustain without scale and logistics optimisation.
- Operating with multiple retailers illustrated the importance of system compatibility: differing IT and invoicing processes significantly increased the workload for manufacturers.
- Reuse requires agile, iterative coordination across commercial, technical, and operational teams — traditional linear launch processes are not fit for purpose.
- **Greater interoperability of commercial and IT frameworks — driven by neutral, regulatory or standard-setting bodies — would reduce friction and enable smoother deployment across retailers, without requiring any coordination on commercial strategy.**

2.3.4. In-store operations and merchandising

Across the three phases of R3PACK, in-store operations proved to be one of the most decisive factors for the success of the reuse pilots. Even when packaging and logistics perform well, the visibility, maintenance and daily handling of the offer in stores strongly influence both sales and return rates. The project highlighted how the constraints of large-scale retail — limited staff, fragmented responsibilities, and tightly optimised operations — require a tailored approach for reusable packaging.

Ensuring visibility and maintaining shelf presence

One of the clearest lessons from Phases 2 and 3 is that **reusable products must be highly visible** to be understood and adopted by consumers. Early in Phase 2, the absence of standardised merchandising led to inconsistent placement across stores: some products were spread across aisles, while others were poorly highlighted. This limited visibility and created confusion with single-use equivalents.

Dedicated visibility actions became essential:

- grouping reusable products within the same area of a category to create a clear “reuse block”
- providing impactful shelf communication (labels, shelf stoppers, display materials) to make the offer immediately recognisable
- using distinct colour codes and clear indication of the deposit

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Maintaining shelf presence also required **more stable replenishment practices** than usual. In a retail environment where on-shelf availability is often supported by brand field teams, store staff had to integrate new tasks: monitoring stock levels, installing communication materials, and ensuring the range remained complete.

Store team engagement and operational feasibility

The performance of the pilot strongly depended on the engagement of store teams — particularly department managers responsible for ordering, shelving and implementing communication. Because the concept was new, intensive field support was needed in early phases (store visits, training, animations).

The project showed that:

- **store teams will engage when the process is simple and intuitive**
- additional tasks must be minimised and fit existing workflows
- clear tools help (product lists, ordering references, visuals)

Without this support, visibility drops quickly, leading to lower sales and weaker return rates.

Placement and maintenance of the return machine (RVM)

R3PACK demonstrated that **the position and ease of use of the return machine are crucial drivers of return rates**. Machines placed at store entrances or other high-traffic areas significantly increased usage. Conversely, remote or poorly visible placements reduced returns.

Operational constraints were equally important:

- store staff must empty and maintain the machine easily
- the process must take only a few minutes to avoid operational overload
- the identification system (barcodes, format recognition) must be extremely reliable to prevent consumer frustration

The pilots confirmed an **accumulation effect**: consumers tend to return several items at once, meaning that the broader the assortment and the clearer the in-store signage, the earlier return loops stabilise.

Key takeaways

- Visibility is a core success factor: reusable products need strong and consistent merchandising to exist in consumers' mental model.
- Retail operations must be kept simple: shelf maintenance, ordering and communication must be easy for store teams with limited time.
- Strategic placement of the return machine significantly increases return rates. High-traffic locations and low-effort maintenance are essential.
- Assortment breadth reinforces both sales and returns, as consumers accumulate items before returning them and expect familiar products to adopt the system.
- Embedding reuse into existing retail routines — rather than creating parallel processes — is key to long-term operability.

2.3.5. Consumer behaviour and engagement

Consumer behaviour proved to be one of the most decisive dimensions of the R3PACK demonstration. While the technical and operational components of reuse required extensive preparation, the project showed that consumer acceptance ultimately depends on clarity, visibility, and simplicity. R3PACK generated a significantly larger volume of consumer insights than originally planned, thanks to

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wide-scale in-store engagement activities and continuous monitoring of sales and return patterns across three phases.

Large-scale consumer engagement

To better understand perceptions, barriers, and motivations related to reuse, the consortium conducted an extensive outreach campaign during Phase 3.
Across 10 stores (Coopérative U and Carrefour), a total of:

- 132 days of in-store animations
- 14,859 consumers approached
- 11,202 consumers who engaged in a detailed discussion (75% conversion rate)

This far exceeded initial expectations and provided the most comprehensive dataset on consumer behaviour in a real-life reuse system ever collected under R3PACK.

The in-store conversations revealed that only 3 out of 10 consumers spontaneously understood the difference between reuse and recycling. Yet, once explained, the concept was quickly assimilated, demonstrating that lack of awareness—not rejection—is the main barrier.

Motivations most frequently cited included:

- environmental impact (72%)
- economic benefit linked to the deposit refund (35%)
- desire to consume “better” (34%)
- practical convenience (23%, linked to reducing household recycling volumes)

The main barriers raised were:

- lack of prior knowledge (35%)
- insufficient assortment in relevant categories (21%)
- deposit amount perceived as too high or too low (14%)
- absence of familiar brands (13%)

Visibility and communication in-store

Consumer interviews and animation feedback confirmed that reuse adoption is directly correlated with in-store visibility. Clearer labelling, colour-coded signage, and grouping reusable products together strongly improved recognition.

Both retailers progressively added:

- a dedicated reuse logo
- clearer mention of the deposit amount
- simplified messages explaining the return gesture
- repositioning of RVMs in high-traffic areas

These improvements helped reduce confusion with recycling and made the return process more intuitive.

An important behaviour identified is the “accumulation effect”: most consumers prefer to bring back several packages at once, which explains why return rates stabilise only after three to four months of deployment.

Education on the return gesture

Because the reuse system was new to most shoppers, the packaging itself had to become a communication surface.

Labels progressively integrated:

- a clear mention that the package is reusable

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- the deposit amount
- a unified reuse logo, harmonised across experiments
- instructions to bring the packaging back to participating stores

This harmonisation significantly improved consumer understanding and reduced hesitation at shelf level.

Key takeaways

- Awareness remains the number-one barrier: most consumers initially confuse reuse with recycling, but pedagogy quickly unlocks understanding.
- Clear in-store communication, visible signage, and consistent labelling are essential to drive adoption.
- Consumers expect a broad and familiar assortment; a limited range reduces purchase and slows the development of return habits.
- Price expectations matter: most consumers intuitively expect the reusable option to offer an economic benefit (lower €/kg or the deposit refund), which must be factored into commercial strategies.
- Deposit attractiveness plays a role, but convenience, visibility and education have an equally strong impact on return behaviour.
- The “accumulation effect” means that return rates improve structurally over time, once consumers develop the habit of returning several packages at once.
- Large-scale consumer engagement (animations, interviews, signage tests) strongly accelerates familiarity, trust, and the normalisation of the reuse gesture.

2.3.6. Scale-up and system coherence

As the R3PACK demonstrator expanded, the project revealed that scaling a reuse system is not only a matter of adding more stores or actors. It requires maintaining coherence across operators, logistics loops, financial flows, IT systems and consumer communication. The transition from isolated pilots to a multi-retailer ecosystem brought structural challenges that are critical for any future large-scale deployment.

Convergence with other reuse initiatives: when it works and when it doesn’t

R3PACK encountered two different situations when entering new retail environments:

- **At Carrefour, the R3PACK assortment coexisted with the LOOP initiative.** This convergence worked because both initiatives relied on the *same reuse operator*, shared similar logistics configurations, and used compatible processes for handling returns and deposits. Even if communication codes differed initially, alignment was achievable through coordinated adjustments.
- **At Coopérative U, R3PACK coexisted with the national ReUse scheme.** This time, convergence was *not possible*. Despite using the same RVM hardware, the systems differed on essential pillars:
    - different operators managing returns
    - incompatible financial flows for deposits and reimbursements
    - distinct logistics loops
    - different visual identities and consumer-facing codes

These incompatibilities meant the two systems could not operate side-by-side in a single store without creating operational contradictions and consumer confusion.

Together, these experiences demonstrate that **reuse initiatives are only interoperable when operator, financial and logistical architectures are aligned**—hardware compatibility alone is far from sufficient.

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The hidden complexity of geographic expansion
Increasing the number of stores or regions does not automatically translate into efficiency gains. R3PACK showed that expanding too early or across fragmented routes can lower performance:

- volumes become too diluted to optimise washing and transport
- warehouse configurations differ, forcing manufacturers to adapt processes
- return cycles destabilise due to inconsistent flows
- consumer visibility and communication vary between regions, reducing uptake

Scaling must therefore be approached as a *sequencing challenge*, not a coverage race.

Retailer interoperability requires early standardisation
Carrefour and Coopérative U operate with different:

- IT and invoicing systems (especially for deposit management)
- logistics and warehouse setups
- in-store operational routines
- commercial governance processes

This required manufacturers and wash/logistics partners to readapt processes for each retailer, creating additional complexity.
These findings underline the need for **early alignment on minimum standards** for any future multi-retailer deployment:

- deposit and refund flows
- IT protocols
- RVM setup and recognition logic
- visual identity and consumer instructions
- acceptable logistics configurations

Key takeaways

- Scaling reuse requires system coherence — operator, logistics, supply-chain, IT and communication alignment — not simply more stores.
- Interoperability depends on operator-level convergence: LOOP and R3PACK could merge because they shared an operator; ReUse and R3PACK could not.
- Geographic expansion must be sequenced carefully: fragmented loops with insufficient volume weaken washing cycles, logistics efficiency and consumer returns.
- Early standardisation across retailers is crucial to avoid multiplying incompatible processes.
- For future European deployment, a shared governance or coordination mechanism will be essential to prevent fragmentation of reuse schemes.

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3. SUBSTITUTION PILLAR

3.1. Demonstration framework for the Substitution pillar (as defined in D5.1)

The Substitution pillar was designed to explore the technical and industrial feasibility of replacing single-use plastic packaging with fibre-based alternatives across twelve food categories. Unlike the reuse demonstrator, which relied on a clearly defined operational loop, substitution required the development of new high-performance materials and their integration into existing industrial value chains.

Substituting plastic with fibre-based solutions comes with intrinsic complexity. Food applications require highly diverse barrier properties—oxygen (OTR), water vapour (WVTR), grease resistance, aroma protection—as well as compatibility with industrial packaging processes. Consequently, no single fibre-based solution can address the full range of products considered in R3PACK, and categories progress at different speeds depending on their technical requirements.

To mitigate these challenges and secure progress across the widest possible spectrum of products, the consortium adopted a dual development strategy, as detailed in Deliverable 4.5 *"Process methodology for producing high-performance fibre-based, high-barrier packaging that can be upscaled for commercialisation"*. This strategy combined:

- **a short-term pathway**, focused on more mature paper-based substrates that already meet recyclability, food contact rules and that approach the barrier and sealing requirements of food manufacturers, despite still containing a significant amount of plastic and petro-based materials. These materials were tested on industrial packaging lines to accelerate demonstration and assess immediate deployment potential.

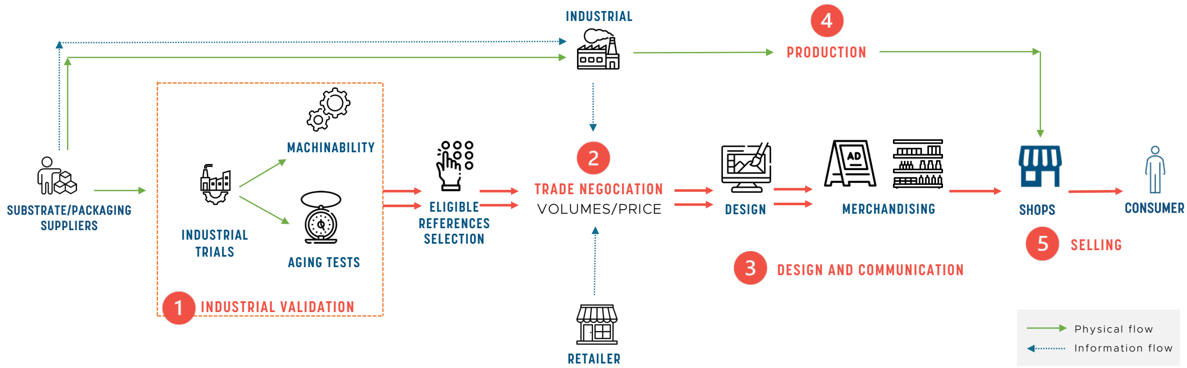

Figure 7: Short-term path development strategy for WP4 substitution in R3PACK project.

- **a long-term pathway**, maintaining long range efforts in substituting plastic by functionalized paper/fibre with innovative solutions (PHA, SiOx, MFC…), while maintaining the objective of a high paper ratio and increased bio-based content (<90%), as well as recyclability in accordance with European standards, compostability or biodegradation.

This dual-pathway approach underpinned the demonstration plan described in D5.1 (see Figure 8).

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According to this plan, the Substitution demonstrator was initially structured into:

1. **A preparation phase** – identification of product requirements, material selection, laboratory and pilot validation;
2. **Phase 1 – Industrial validation** – production on manufacturers' lines, machinability assessment and shelf-life testing;
3. **Phase 2 – Retail deployment** – in-store testing with retailers (Carrefour, Système U) to assess logistics, consumer acceptance and environmental performance;
4. **Phase 3 – Scale-up** – extension to more products and stores.

This initial framework served as the reference structure for the demonstrator, even though several adjustments became necessary during implementation (detailed in Section 3.2).

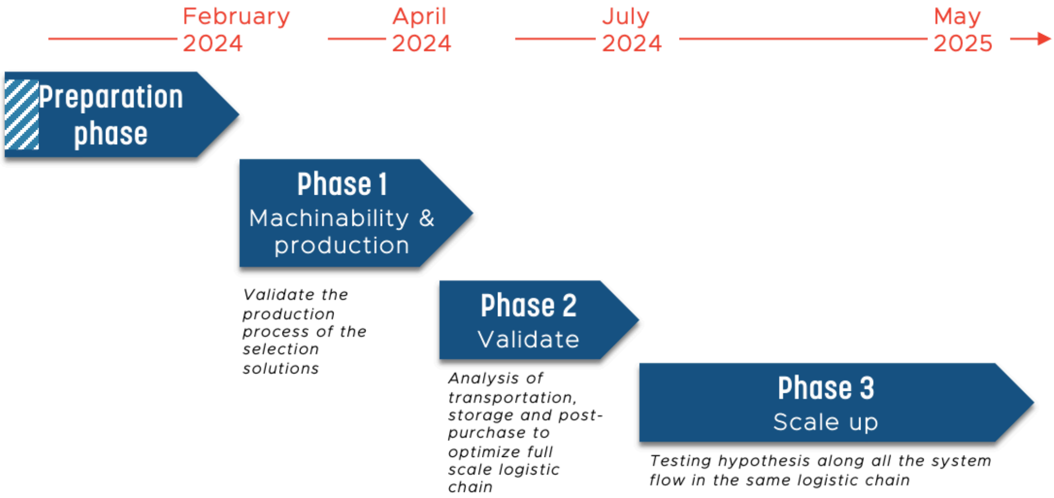

Figure 8: Initial phases described in deliverable 5.1 for the substitution pillar.

3.2. Adjustments to the demonstration plan: operational reality, challenges and deviations

While the overall structure of the Substitution demonstrator was defined in Deliverable 5.1, the actual implementation diverged significantly from the initial plan (see Figure 9). These deviations were primarily driven by (i) the heterogeneous technical maturity of fibre-based packaging solutions across food product categories, (ii) constraints linked to integrating paper substrates on plastic-oriented industrial packaging lines, (iii) economic feasibility concerns, and (iv) regulatory uncertainty following publication of the Packaging and Packaging Waste Regulation (PPWR).

As a result, the demonstration progressed through revised phases, focusing on technical validation and feasibility assessments. The planned in-store deployment could not be reached within the project timeframe.

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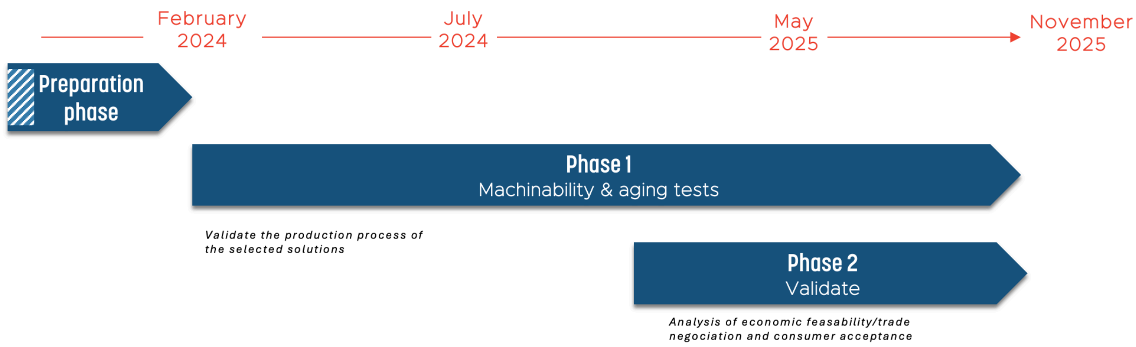

Figure 9: Updated timeline of the substitution pillar by the end of 2025.

3.2.1. Preparation phase - completed as planned

The preparation phase (February 2024) was conducted according to the initial plan and provided the foundation for subsequent industrial trials. It consisted of:

- Mapping product requirements across the twelve targeted food categories and grouping them according to packaging format (flexible vs rigid) and barrier needs.
- Selecting more mature paper-based substrates suitable for each category.
- Conducting pilot tests at Fraunhofer IVV to characterise machinability parameters (friction, stiffness, sealing behaviour) and assess leakage risks.
- Delivering technical guidelines and best-practice recommendations to industrial partners, enabling individual testing on their own packaging lines.

This phase confirmed the feasibility of initiating industrial validation for several food product categories using mature paper-based materials.

3.2.2. Phase 1 - Machinability and ageing tests (July 2024 → May 2025)

Phase 1 focused on validating the machinability of selected paper-based solutions on real industrial packaging lines, as well as assessing shelf-life performance through ageing tests. Progress during this phase varied significantly depending on the food product category.

a) Machinability validation

Several manufacturers successfully produced paper-based packaging on their existing lines with limited adaptations. However, most trials required specific process adjustments such as:

- increased sealing temperature and/or pressure,
- modified sealing jaws to avoid paper tearing,
- adjustments to tension and film guidance systems,
- adaptation of forming tools (e.g. “col de cygne”) to reduce creasing and improve visual appearance,
- recalibration of metal detection systems for metallised paper structures.

These adaptations reflect the structural difference between plastic-oriented industrial equipment and the behaviour of paper films.

b) Ageing and shelf-life performance

Shelf-life tests revealed heterogeneous results:

- **Positive outcomes** for some dry or low-moisture products (margarine pastry dough, savoury biscuits).

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- **Partial performance** for products sensitive to aroma loss, oxidation or humidity (e.g. chips, sweet biscuits), where paper-based materials did not fully match plastic controls.
- **Insufficient performance** for high-fat categories (e.g. chips), where grease migration or seal weakness occurred.

This variability underscores the need for category-specific approaches rather than a single fibre-based solution.

3.2.3. Phase 2 - Validate (May 2025 → November 2025)

In the revised demonstration framework, *Phase 2 – Validate* replaced the larger retail deployment phase foreseen in D5.1. Its purpose was to consolidate the results of Phase 1 and determine whether any product category met the technical, economic and commercial prerequisites to justify preparation for a potential market pilot.

Planned objectives
Phase 2 was expected to include:

- **Economic feasibility assessments**, examining packaging cost, margin structure and potential operational implications.
- **Initial trade discussions** with retailers to explore possible listing conditions for selected references.
- **Review of consumer acceptance considerations**, especially for categories where packaging characteristics (e.g. transparency, perceived quality) strongly influence purchase decisions.
- **Preliminary assessment of readiness for a future deployment phase**, depending on the outcomes of the above analyses.

Activities conducted
During implementation, Phase 2 remained limited to **feasibility assessments**, as no product category fulfilled all the technical and economic requirements needed to progress toward retail preparation.
Phase 2 therefore consisted of:

- Reviewing economic scenarios associated with selected paper-based packaging options,
- Examining commercial constraints related to cost structure, supply-chain implications and expected retail requirements,
- Identifying consumer-related parameters relevant for future substitution pathways.

No market-introduction or listing activities were undertaken within the project timeframe.

3.2.4. Implications for this deliverable

Given the revised phasing and the nature of activities conducted, the Substitution pillar did not follow three fully distinct demonstration phases. Instead, the project progressed through:

- a completed preparation phase,
- a partially achieved technical validation phase (machinability and ageing tests),
- and a feasibility-oriented validation stage without transition to market deployment.

Accordingly, the comparative analysis presented in Section 3.3 is organised **by thematic areas rather than by phase**, reflecting the operational reality of the demonstrator and ensuring consistency with the analytical approach used for the reuse pillar.

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3.3. Substitution comparative analysis and key learnings

The Substitution pillar aimed to evaluate the feasibility of shifting from plastic packaging to paper-based alternatives (>80 % paper ratio) across a range of food product categories. While the initial Description of Action envisaged several demonstration phases, the actual implementation followed a different trajectory: only technical validation (machinability and shelf-life performance) and feasibility assessments could be completed, with no in-store deployment. For this reason, the comparative analysis presented in this section is organised **by thematic blocks**, rather than by phases, following the same analytical approach used for the Reuse pillar.

Use of non-beneficiary products in industrial trials:
Some of the technical tests carried out in the Substitution pillar involved products provided voluntarily by manufacturers that were not beneficiaries of the R3PACK consortium. These manufacturers joined the experimentation through the two beneficiary retailers, Carrefour and Système U, to expand the range of categories assessed—particularly for sweet biscuits, savoury snacks and pastry dough.
Their participation did not involve any financial contribution from the project, and all packaging development work on their side was carried out independently.

3.3.1. Validation of machinability

Machinability tests were the first critical step of the Substitution pathway, since efficient shelf-life validation could only be conducted on packaging successfully produced on industrial equipment with food products. All tests were performed on existing packaging lines designed for plastic films (OPP, OPPmet, PET, PE), requiring adaptations to accommodate paper-based substrates.

Machine adjustments and processing behaviour
Across food manufacturers, similar types of adaptations were required:

- **Higher sealing temperatures and longer dwell times**, due to the lower thermal conductivity of paper.
- **Modified jaw geometry** to distribute pressure and prevent tearing or fibre displacement in the sealing area.
- **Adjusted film tension and guidance**, as paper presents higher friction coefficients and higher stiffness than conventional plastic films.
- **Adaptation of forming shoulders ("col de cygne")** to reduce creasing during pack formation.
- **Recalibration of metal detection systems** in the case of metallised paper structures.
- **Reduced line speeds** (typically −10 % to −20 %) to ensure stable seal formation and avoid defects linked to humidity or reel tension.

These observations confirm that fibre-based substrates are **feasible to process**, but **not drop-in compatible** with existing equipment.

Variability across product categories
Machinability success was strongly category-dependent:

- **Dry and low-moisture products** (e.g. pastry dough; sweet and savoury biscuit categories) showed good machinability despite reduced speed.
- **High-fat or fragile products** required stricter control of reel tension and sealing conditions.

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- **Rigid formats** would require new tooling (moulds, sealing heads), beyond the scope of this demonstrator.

Key takeaways

- Fibre-based substrates can be processed on industrial lines with systematic equipment and parameter adjustments.
- Reduced processing speeds and sensitivity to humidity must be integrated in future economic models.
- Machinability feasibility varies significantly by category and equipment configuration.
- Fibre-based packaging is **not a drop-in replacement** for plastic films and requires dedicated process optimisation.

3.3.2. Validation of product shelf-life

Shelf-life performance was assessed on product categories where machinability had been validated (see Figure 10). Ageing tests measured the ability of fibre-based packaging to maintain product quality (crispness, aroma, moisture level, visual condition) over expected shelf-life durations.

Figure 10 : Results of paper-based flexible packaging production for different product categories within the R3PACK project. a) sweet biscuits, b) savoury biscuits, c) margarine pastry dough, d) chips.

Pastry dough category
Target shelf-life: **30–35 days**
Result: **fully met**
Mass-loss measurements showed preservation equivalent to plastic references. Low greasiness and controlled moisture helped ensure pack stability.

Sweet biscuits category
Target shelf-life: **approximately 12 months**
Result: **reduction of shelf-life by around one third**
Ageing tests showed gradual loss of crispness and aroma, linked to the poorer oxygen and water vapor barriers of the paper-based packaging produced and

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tested. Metallised paper improved performance but did not reach the level of plastic references.

Savoury biscuits and snacks category
Target shelf-life: **approximately 8 months**
Result: **acceptable preservation at target date**
Sensory assessments revealed moderate aroma and crispness degradation. Moisture-barrier limitations remained the primary technical constraint.

Chips category
Target shelf-life: **6–10 months**
Result: **not approved for high-fat food products tested**
Grease staining appeared after several days or weeks in the 3-ply sealing area, regardless of sealing parameters. This indicates insufficient grease resistance and/or sealing robustness. A variant of puffed cereal snacks “pops soufflé” that contains less fat did not show grease staining and remains under continued evaluation. Tests with a partner on a machine adapted to paper material are planned to overcome this problem in the 3-ply area.

Cross-cutting insights
Across all categories:
- Barrier performance (OTR/WVTR, grease, aroma) remains the main limitation.
- Paper stiffness amplifies crease formation, increasing risk of micro-leakage and accelerated degradation.
- Humidity sensitivity affects seal strength and dimensional stability.

Key takeaways
- Fibre-based packaging is suitable for **short- to medium-shelf-life dry products**.
- **High-fat categories** remain incompatible with current paper-based substrates for some packaging configuration (ex: tubular flowpack with 3-ply sealing area).
- Shelf-life performance is category-dependent and cannot yet match plastics for high-barrier applications.
- Improvements in barrier layers and sealing robustness are required for future deployment.

3.3.3. Economic and trade negotiation challenge

Economic feasibility emerged as one of the most constraining factors in the Substitution pathway. Even when machinability and shelf-life validation were encouraging, the financial viability of fibre-based packaging often prevented manufacturers from progressing beyond the preliminary assessment stage (Phase 1.1) or initiating commercial discussions with retailers (Phase 2.2)

High packaging costs limiting early-stage trials
Across the categories assessed, several manufacturers faced packaging costs that were too high to justify testing paper-based solutions on their industrial lines. This challenge was particularly evident in categories where:
- the packaging material was 2 to 5 times more expensive than existing plastic packaging;
- rigid formats (pots, trays) required significant investment in moulds or dedicated tooling;
- suppliers requested minimum order quantities (MOQs) incompatible with small pilot runs.

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For these products, the economic barrier appeared before technical testing could meaningfully begin, preventing manufacturers from planning or carrying out industrial-scale machinability trials.
A consolidated view of how these economic constraints influenced category readiness is presented later in this section.

Structural cost gap between fibre-based and plastic packaging

From an economic standpoint, cost competitiveness remains essential for food manufacturers operating with narrow profit margins. Several structural factors contribute to the cost gap observed:

- **Higher raw material costs** for fibre-based substrates;
- **Lower line efficiency** (typically −10% to −20%) observed during industrial tests;
- **Additional operational adjustments** required during production changeovers.

This increased cost base directly affects the selling price (see Figure 11), manufacturer margin and retailer margin—ultimately limiting the possibility of listing fibre-based packaging in store.

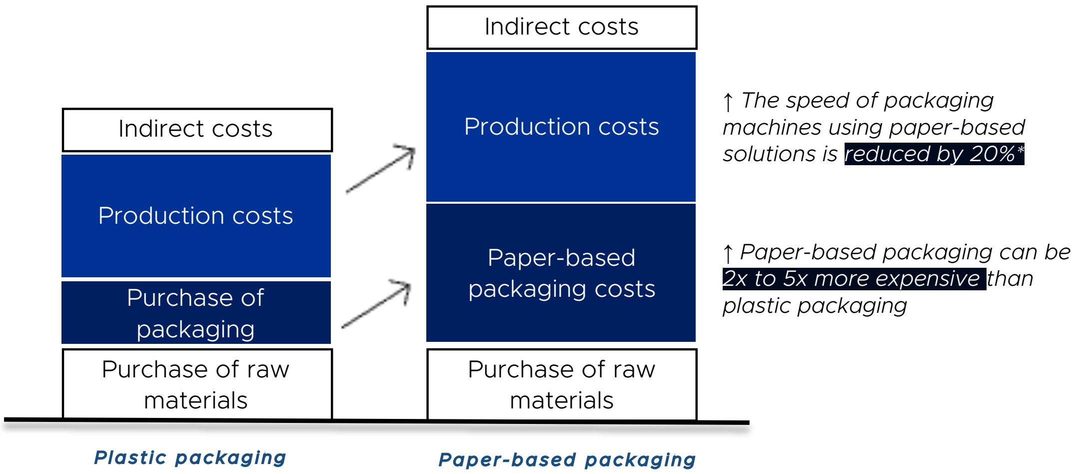

Figure 11: Current costs breakdown for food products in plastic vs paper-based packaging

Detailed economic assessment: Savory biscuits sachets

To quantify these effects, a financial comparison was conducted for a high-volume, low-margin category: savory biscuits sachets. The analysis considers both material and operational costs, including a 20% reduction in line speed.
Key assumptions:

- Unit packaging cost for OPPmet plastic sachet: **0.04 €**
- Unit packaging cost for paper-based sachet: **0.12 €**
- Raw material cost for paper ≈ **5×** that of plastic
- Industrial line slowdown: **20%**

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These assumptions lead to the following margin structure in Table 1:

Table 1: Key Business Impact (rounded)

Metric	Plastic	Paper	Difference
Total Unit Packaging Cost	0.04 €	0.12 €	+0.08 €
Distributor Margin per 1,000*	180 €	103 €	-77 €
Total Annual Volume	2.9 million units	-	-
Estimated Annual Distributor Margin	779,000 €	557,000 €	**-222,000 €**

**Illustrative average, not a factual figure*

The transition to fibre-based packaging results in a **~45% reduction** in retailer margin per 1,000 units, and an annual margin decline of **~222,000 €** for a typical retailer at current sales volumes. Industrial margins are also affected unless manufacturers absorb a portion of this cost differential, further constraining their ability to invest or scale.

Readiness across product category

The combined impact of material costs, production slowdowns and tooling investment requirements is reflected in the comparative readiness of the food categories assessed. Categories with technical potential (such as pastry dough or biscuits) remain limited by lack of economic competitiveness, while others (such as high-fat snacks) are constrained by both performance and cost.

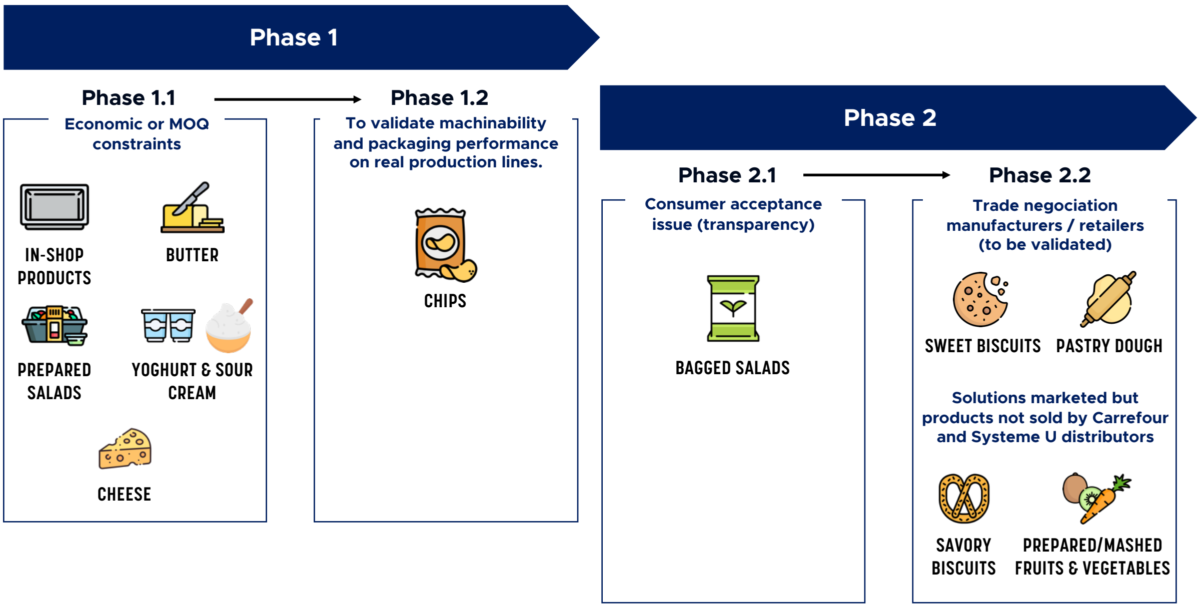

Figure 12: Food product's categories of the programme ranked according to their progress towards deployment in retailer's stores.

This overview illustrates why, despite some promising technical results, most categories could not progress to Phase 2.2 retailer negotiations.

Future cost dynamics and regulatory considerations

Although increasing environmental fees and upcoming PPWR obligations may gradually raise the cost of plastic packaging, stakeholders emphasised that:

- investment decisions require predictable short- and medium-term economics,
- fibre-based packaging must still be viable today,
- and retailers cannot list products whose packaging results in excessive price increases or margin compression.

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The future regulatory context may improve the relative attractiveness of fibre-based solutions, but current economic constraints remain the primary barrier preventing commercialisation.

Key takeaways

- Fibre-based packaging remains **significantly more expensive** than plastic alternatives, with 2–5× higher material costs.
- Industrial-scale production is impacted by **line speed reductions** (−10% to −20%).
- Retailer margins can decrease by up to **45%**, limiting the possibility of listing products.
- Tooling investments for rigid formats create additional barriers to early-stage testing.
- Economic constraints prevented most categories from reaching Phase 2.2 negotiation with retailers.
- Regulatory shifts may improve feasibility in the long term, but **short-term economics remain the dominant bottleneck**.

3.3.4. Regulatory constraints and consumer acceptance

Consumer expectations and regulatory requirements emerged as additional constraints limiting the feasibility of deploying fibre-based packaging for several food product categories evaluated in R3PACK. While machinability and shelf-life performance drive technical viability, the success of any substitution pathway also depends on its alignment with consumer expectations and with the evolving European regulatory framework.

Regulatory constraints (PPWR)

The revision of the Packaging and Packaging Waste Regulation (PPWR) introduced uncertainties that directly affect the feasibility of fibre-based packaging:

- **Minimum fibre content thresholds** (>80%) required for recyclability claims.
- **Restrictions on composite structures**, which limit the use of plastic windows or certain functional coatings.
- **Lack of clarity** on the acceptability of bio-based or mineral coatings (e.g. PHA, SiOx) and their compatibility with recycling streams.
- **Upcoming obligations for recycled content in plastics**, which may alter future cost dynamics but do not change the current economic gap.

These elements created a regulatory environment that made manufacturers cautious about investing in solutions that might not fully comply with future requirements. For several categories, the need for hybrid structures (paper + plastic) to achieve barrier or transparency performance was incompatible with PPWR recyclability thresholds, reducing their deployment potential.

Consumer acceptance constraints

Consumer expectations play a decisive role, especially for products where packaging contributes to reassurance, transparency or perceived product quality.
Grated carrots or fresh-cut salad, for example, require **full transparency** for freshness verification by the customer. Current fully paper-based structures do not offer adequate optical properties (see Figure 13), and hybrid formats reduce the fibre content below regulatory thresholds. As a result, this category faces structural incompatibility with existing fibre-based options.

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Figure 13: Fully paper-based fresh salad bag developed by Les Crudettes

Other categories face acceptance challenges linked to the visual and tactile properties of fibre-based packaging:

- For **snacks and premium products**, crispness cues, gloss, surface texture and perceived "freshness" are strongly associated with plastic packaging.
- Paper-based packs may show **creasing, loss of shape or staining**, which affect consumer perception even if performance remains acceptable.

These consumer considerations reduce the feasibility of listing fibre-based packaging for specific categories, even when technical feasibility is partially met.

Key takeaways

- The evolving PPWR framework constrains the use of hybrid or composite fibre-based structures, especially for transparency-critical products.
- Consumer expectations (visual quality, transparency, tactile cues) pose strong limitations for fibre-based substitution in certain categories.
- Technical performance alone is not sufficient: deployment requires **simultaneous alignment** between performance, regulatory compliance and consumer perception.
- Several categories, such as fresh-cut salads or premium snacks, face **structural incompatibilities** with current fibre-based materials.

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4. GENERAL CONCLUSIONS AND PERSPECTIVES

4.1. Conclusion on the Reuse Pillar

The Reuse pillar delivered one of the first multi-category, multi-retailer demonstrations of reusable packaging systems in real retail conditions at European level. Across 20 stores and 26 SKUs, the project successfully showed that reusable packaging can be integrated within existing industrial and retail value chains.

Technically, the project validated packaging robustness, washing performance for glass, and the operational feasibility of logistics, deposit management and return flows. The co-development of standards reusable packaging (Bucket, salad tray), jointly designed by competing manufacturers and suppliers, constitutes a strong basis for future industrial standardisation.

Economically, the experiments highlighted a structural barrier: **the current cost of reuse systems is not yet competitive with single-use plastics**, which remain extremely cheap. The cost of the reuse loop (collection, transport, washing, redistribution) can only become competitive through **scale effects, optimisation, and massification of flows**. Other challenges identified—IT configuration, deposit invoicing, VAT treatment—are important but relate to operational and regulatory integration rather than to the core economic model.

Socially, consumer response was positive. Visibility, clarity of instructions, and convenience of return emerged as strong adoption drivers. More than 14,000 consumers were engaged across surveys, interviews and on-site activations, with engagement rates above 70 % when the system was clearly explained.

Overall, the Reuse pillar demonstrates that reusable packaging systems are technically viable and operationally implementable, with encouraging consumer interest when the offer is visible, simple and well-explained. However, consolidating consumer habits at scale will require continued communication efforts, price neutrality, and harmonised governance frameworks across retailers and regions.

4.2. Conclusion on the Substitution pillar

The Substitution pillar aimed to replace single-use plastics with highly fibre-based packaging (>80 % paper; >90 % bio-based content) while remaining compatible with existing industrial equipment. Twelve food categories were assessed through both short-term trials with commercially available solutions and long-term development of innovative cellulose-based structures.

Industrial trials demonstrated that machinability is achievable but requires fine adjustments, as fibre-based materials are not drop-in replacements. Feasibility was confirmed for several dry or medium-barrier categories such as margarine pastry dough and savoury biscuits. Ageing tests demonstrated satisfactory preservation for these categories, while confirming the limitations of current paper multilayers for high-fat or high-crispness foods such as chips and sweet biscuits.

Economic constraints remain the primary barrier to deployment. Fibre-based substrates are currently two to five times more expensive than plastics, and their processing typically reduces line speed by 10–20 %, compressing both industrial and retail margins and limiting the willingness to initiate commercial discussions.

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From a societal perspective, consumer acceptance is strongly category-dependent. For some product types, particularly those requiring transparency or strong visual cues, fibre-based packaging requires **significant consumer communication, harmonised messages and shared education efforts** to support a transition in habits and expectations.

Regulatory constraints, notably under the upcoming PPWR, also influence investment decisions. Requirements on recyclability, fibre content and composite structures create uncertainty for certain paper-based innovations, especially when transparency or high-performance coatings are needed.

Overall, the Substitution pillar shows clear technical progress and a realistic deployment pathway for selected categories, but further R&D, economic optimisation and regulatory clarity are necessary before large-scale adoption can be achieved.

4.3. Cross-cutting conclusions and perspectives

The comparative analysis confirms that **Reuse and Substitution are complementary strategies**, each suited to different product families, value chains and consumer expectations. Their maturity levels and deployment pathways differ significantly:

Dimension	Reuse	Substitution
Technical readiness	Operational validation achieved on small industrial scale	Technical feasibility confirmed, but limited to selected dry/medium-barrier categories
Economic model	Competitiveness with single-use plastic remains a major challenge; requires massification, pooled logistics and process optimisation	Significant cost gap vs plastics due to materials and slower line speeds
Regulatory alignment	Strong national incentives in some Member States (e.g. France); no harmonised EU framework	Dependent on PPWR clarification (recyclability criteria, composite structures)
Consumer acceptance	Encouraging consumer interest when systems are visible, simple and well-explained; large-scale adoption requires communication and price neutrality	Category-dependent; more challenging for transparency-critical products or those relying strongly on visual cues
Scalability	Realistic for national expansion once washing standards and governance are consolidated	Requires sustained R&D, improved barrier performance & paper-dedicated equipment

Across both pillars, the project highlights the need for coordinated governance, shared data infrastructures and continuous feedback loops between industrial, technical and retail partners. It also confirms that there is no one-size-fits-all solution for the packaging of tomorrow: the most relevant pathway depends on product characteristics, shelf-life requirements, economic context and consumer expectations.

A transversal insight from both pillars is that reusable and fibre-based packaging will only become fully desirable, competitive and scalable alternatives if Europe

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continues to invest in technical progress. Just as single-use plastics have benefited from decades of optimisation in materials, processes and equipment, both reuse conditioning and fibre-based packaging require sustained innovation to improve performance, reduce costs and deliver a consumer experience comparable to that of current plastic packaging.

The insights generated in WP5 provide evidence-based guidance for choosing the appropriate packaging strategy, building on the decision-support logic developed in Deliverable 5.3. **The findings of D5.2 have directly informed the work conducted in WP6 (impact assessments) and WP7 (communication & advocacy), providing operational data, technical evidence and category-level insights that were integrated into their final outputs.**

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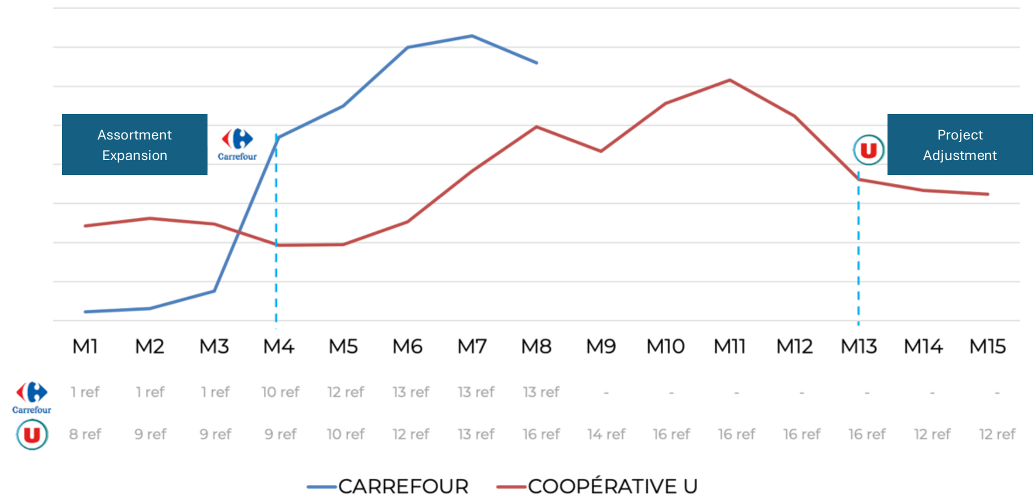
5. APPENDIX

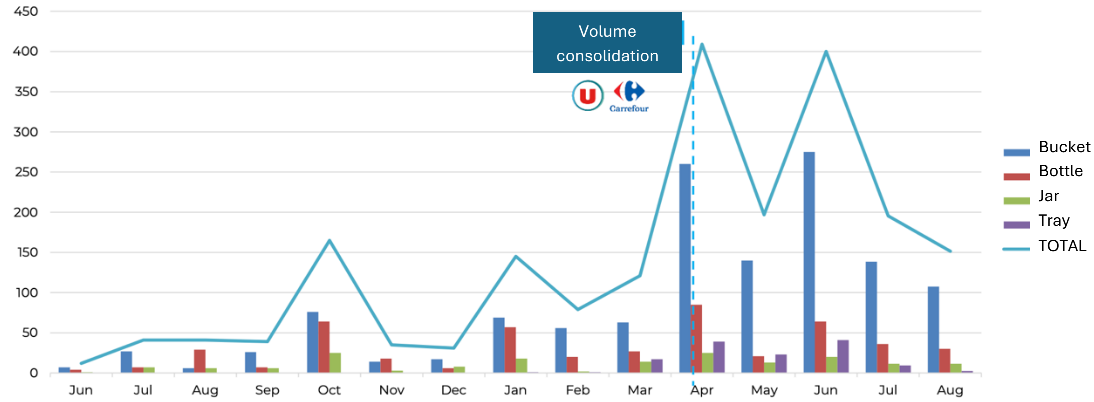
1. EVOLUTION OF SALES BY RETAILER - JUNE 2024 / AUGUST 2025 - Sales trend in units - Launch period



2. TOTAL RETURNS × RETURNS BY PACKAGING TYPE

Bucket (12 SKUs) = 62% of returns
Bottle (6 SKUs) = 23% of returns
Jar (1 SKU) = 8% of returns
Tray (4 SKUs) = 6% of returns

Returns per packaging type (units)



3. TOTAL RETURNS × RETURNS BY DEPOSIT VALUE

€0.50 deposit (14 SKUs) = 67% of returns (overrepresentation of this amount)

€0.80 deposit (3 SKUs) = 12% of returns

€0.30 deposit (3 SKUs) = 11% of returns

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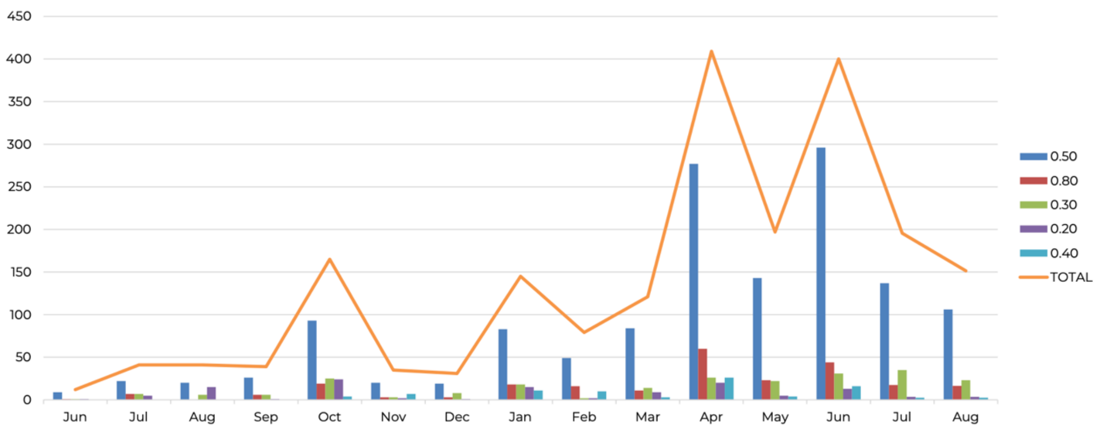
Returns per deposit value (units)

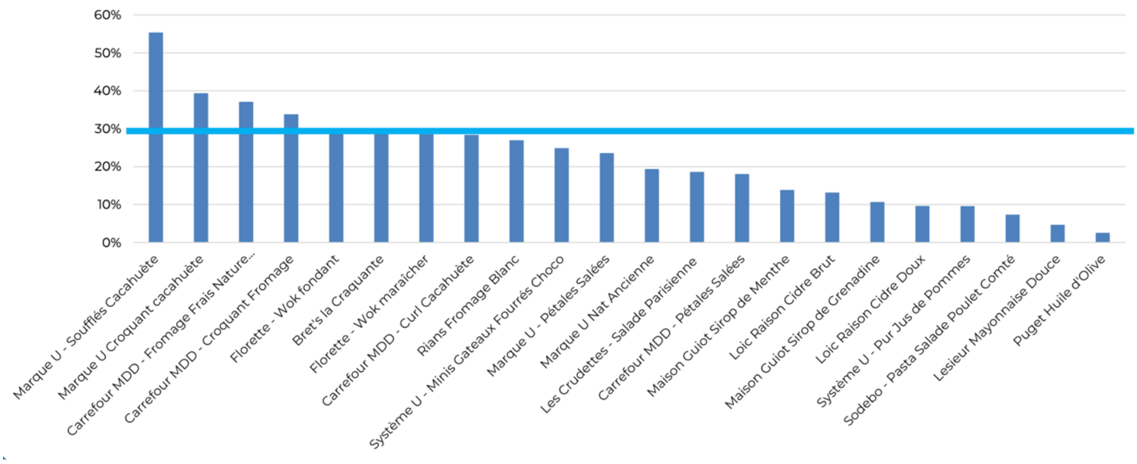


4. TOTAL RETURNS × RETURN RATE AFTER 4 MONTHS

Return rates up to 55%

Most products show a return rate close to 30%

Return rate after 4 months



5. TOTAL RETURNS × RETURN RATE BY PRODUCT - NATIONAL BRANDS

Return rates increase across all SKUs

First visible peaks after 3–4 months for certain products

Return rate per product (%) - National Brands

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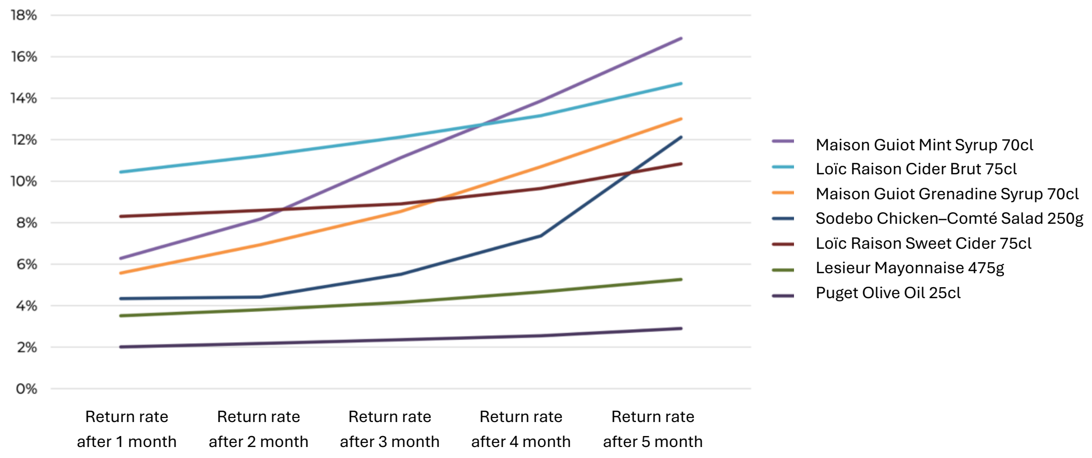
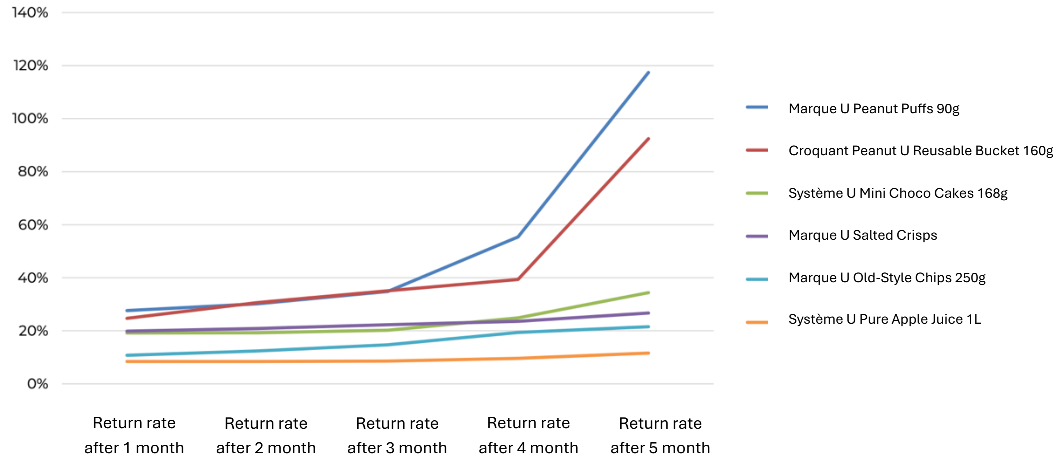


6. COOPÉRATIVE U × RETURN RATE BY PRODUCT - PRIVATE LABEL

Return rates increase for all SKUs

First peaks visible at 3–4 months for some references

Return rate per product (%) - U Private Label



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