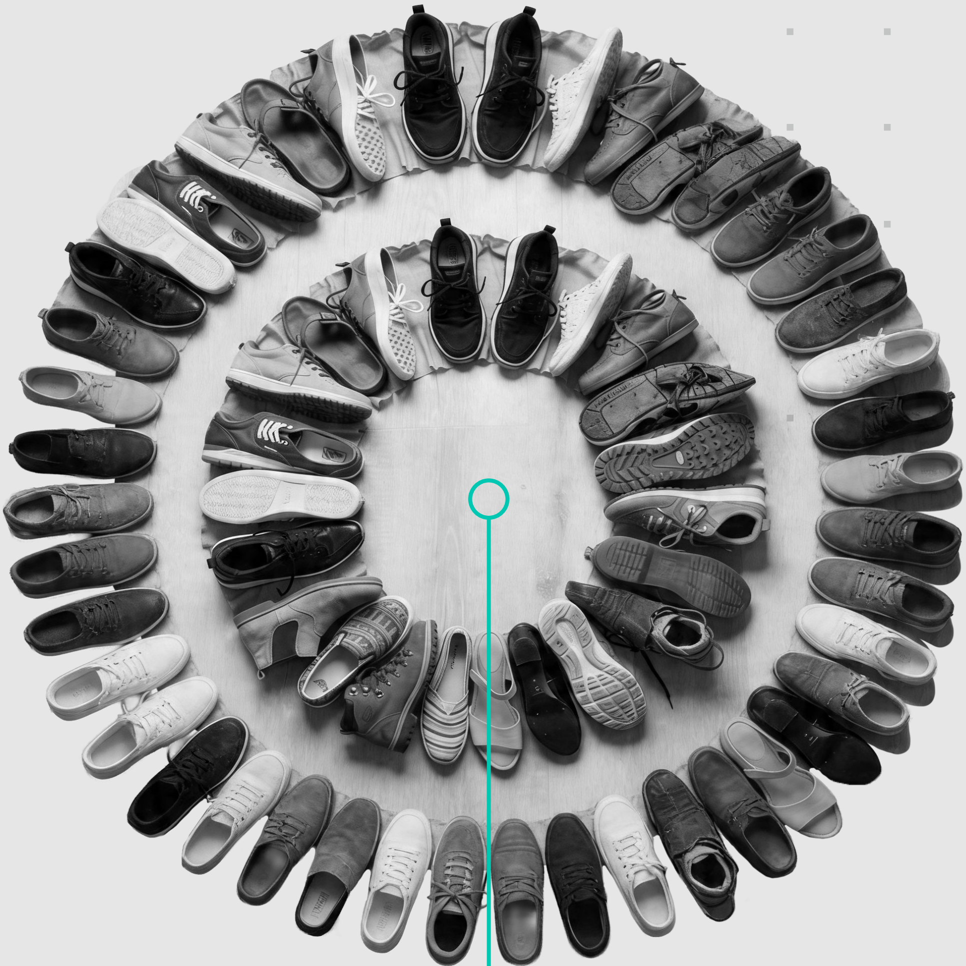
CLOSING THE FOOTWEAR LOOP



Material Flow and Composition Analysis of Non-rewearable Post-consumer Footwear Waste in Europe

CIRCLE ECONOMY

FASHION FOR GOOD

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Circle Economy's Textiles Programme works to build the data, technology, and infrastructure needed to valorise textile waste at end-of-use and help apparel brands scale circular strategies and business models. With deep expertise in textile-to-textile recycling, circular business models, design for cyclability, technology assessment, and circular infrastructure developments, our mission is to connect a fully circular supply chain of producers (manufacturers, retailers, and brands) with solution providers such as collectors, sorters, recyclers, manufacturers, and logistics partners.

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GLOSSARY

Comparability of analysis results amongst sorting facilities is fundamental in order to obtain reliable research outcomes. Therefore, speaking the same language is imperative. Key definitions to be used throughout the project are described below (alphabetically) to ensure sorters, recyclers, and other stakeholders involved in the research, or wishing to conduct further research building on these results, have a clear understanding of the categorisations used.

Archetype
The categorisation of footwear into different types based on function and design. Sub-archetypes further support the characterisation of Archetypes. For this study, Archetypes are defined based on industry standards and with the input of brand partners. The overview of footwear archetypes used can be found in Annexe III.

Assembly techniques are the methods used to attach the upper to the sole or bottom unit of a shoe. Common techniques include:

- **Bonded:** Attaching the shoe's upper to its outsole using adhesives or cementing, and may, in some cases, involve heat and/or pressure, but relies predominantly on glueing.
- **Vulcanised:** Shoe construction that involves a heat-treatment process that bonds the rubber sole to the fabric upper. This method often involves the use of uncured rubber or rubber cement with heat and/or pressure, and thus results in limited material options.
- **Single Moulded Sole:** Entire sole (outsole and midsole) is made in one mould, for example, sandals.
- **Glued or Cemented:** Adhesives attach the sole to the upper.
- **Direct Injected:** The sole is fused to the upper by placing the upper in the mould and directly injecting a liquid material into the mould cavity.
- **Stitched or Welted:** The sole and upper are sewn together with thread.
- **Nailed or Pegged:** Small nails or tacks fix the sole to the upper.
- **Mixed:** A combination of two methods (such as stitched and glued).

Biomechanical Support is the intentional design and integration of structural elements within footwear (such as shanks, sole components, and heel counters) to manage and optimise the body's natural movement. This includes the distribution of plantar pressure, stabilisation of the musculoskeletal system, and the mitigation of impact forces during the gait cycle. In a circularity context, this support is often achieved through multi-material "sandwich" constructions that are currently difficult to disassemble.

Chemical recycling is a generic term that includes several advanced recycling processes (solvent processing, depolymerisation via solvolysis or enzymes, gasification). Depending on the recycling processes, energy consumption, yield, and output vary widely; reaction outputs include syngas, monomers, and polymers. The recycling process produces substances that can be used as raw material to manufacture new materials.

Closed-loop recycling is the process by which the product, in this context, footwear, is recycled and reintegrated back into the footwear value chain. This means the recycled material is used as a raw material to produce a new pair.

Colour refers to the colour of an article that is considered the solid or dominant colour. If it is not possible to define a single dominant colour, the article is to be considered multicoloured. The dominant colour categories for the analysis are predefined. All shades of one colour (such as light green) should be considered within the category of the solid colour (green).

Cream quality or Grade 1 or Grade A footwear refers to the highest-quality grade of the rewearable category. When post-consumer footwear reaches sorting facilities, it is sorted into different quality grades to direct it to different destinations based on its condition, where the highest-quality grade for footwear with no damage and/or from popular brands is segregated and is called 'cream quality'. It should be noted that the parameters across categories are not standardised, and categorisation can vary within sorters based on end-market destination requirements.

Disruptor refers to an element present on Footwear (such as a fastener, button, zipper, or fabric patch) that may disrupt the recycling process and must be removed before the product is suitable as feedstock for recycling. For this study, any additional surfaces added to the main surface of the shoe's upper are considered a disruptor and categorised by material rather than form.

Downcycling entails reprocessing discarded footwear to create new consumer or industrial products, a process that is usually mechanical (cutting, shredding, bonding). It occurs when new products do not re-enter the footwear supply chain, resulting in subsequent use of lower value than the original source of the material, for example, shredded and compressed material into gym floors.

Grade 2 or Grade B quality footwear refers to post-consumer footwear with minimal signs of wear and still in wearable condition, as graded by the sorting facility. It should be noted that the parameters between each category are not standardised, and the categorisation can vary within sorters based on the end-market destination requirements.

Incineration involves the combustion of waste materials at high temperatures to reduce their volume and mass. This process can be used to generate energy (Waste-to-Energy), but it also releases emissions and produces residual ash that must be managed.

Insock is a removable or fixed thin layer, typically textile-based (often non-woven), positioned on top of the insole to line the footbed and provide a clean, comfortable interface between the foot and the shoe structure (Figure 31), and may also be known as sockliner.

Insole is the structural component of a shoe located directly above the outsole and below the foot. It is the part to which the upper is attached (e.g., lasted or stitched) during assembly (Figure 31).

Landfilling refers to the disposal of waste in a designated land area, or landfill. This is typically the final stage of the waste hierarchy for materials that cannot be reused or recycled.

Mechanical recycling refers to the recycling processes that focus on recovering waste by mechanical processes such as melting, grinding, shredding, granulation, spinning, etc. They may include downcycling applications, such as for insulation or fillings for other industries or applications, as well as closed-loop recycling footwear applications.

Midsole is the intermediate layer between the insole and the outsole, primarily responsible for shock absorption, stability, and comfort (Figure 31).

Mono-layer refers to products that are made from one layer or type of material.

Multi-layer refers to footwear products that are made from more than one distinct layer, each of which may be composed of different materials. For this study, multi-layer footwear can be segregated into different categories in the following manner:

- **Upper:** Multilayer refers to an item of footwear that contains a second layer on the inside of the upper (such as a fleece lining in boots). External layers on the outside of the upper are treated as disruptors rather than as additional layers.
- **Sole:** Multilayer refers to a sole composed of a primary plus one or more minority layers that together make up less than one-third of the total surface area. For this study, we recorded up to two additional visible layers on the outsole.

Non-rewearable footwear is footwear that cannot be reused in its original form, such as footwear that does not fall under cream or grade two quality grades on the second-hand market, determined by the sorters and exporters who categorise products based on market requirements. Footwear can be considered non-rewearable for a range of reasons, but primarily due to physical damage and due to archetypes (designs/styles) that are not in demand on the second-hand market at the moment, or due to the lack of the second shoe in a pair.

Outsole refers to the outermost, visible layer of the sole. The outsole can be made up of one or more materials, layers or components.

Post-consumer footwear is footwear that has been disposed of or donated by citizens or end-users at a commercial or industrial institution.

Pre-consumer footwear refers to finished or semi-finished footwear that does not reach the market. This primarily consists of factory rejects (defects), damages, and deadstock that are diverted for recycling or disposal before they can be sold to consumers.

Pre-processing is the process of extracting materials from post-consumer footwear, either through disassembly, followed by shredding, or shredding the entire product, and removing the disruptors to prepare the material for recycling.

- **Disassembly** refers to the process of dismantling and separating disruptive materials and hardware from the main product. Disassembly can also include the process of separating the upper and sole of the shoe.
- **Shredding** is a mechanical process that reduces footwear into smaller particles to enable further material recovery, typically followed by mechanical separation to isolate material streams.

Reuse is the process of an item being used again and sold as second-hand, either as is or after repair and/or cleaning.

Recycling is the process of converting waste materials into new, raw materials and objects. This involves breaking down the original product into its constituent parts, which are then broken down further to create new material. There are different types of recycling based on their processes and output.

- **Recycling after disassembly** is the process of breaking down the upper and sole of the item of footwear before the process of recycling.
- **Recycling after whole shoe shredding** is the process of shredding the whole item of footwear prior to recycling.

Rewearable footwear refers to post-consumer footwear that can be reused in its original form, for its original purpose. Rewearable footwear in this study was further classified into Cream and grade two, and further, as defined in Annexe IV.

Sorting refers to the systematic separation and classification of post-consumer footwear based on condition, archetype, material composition, and intended end-of-use pathway.

At the product level, sorting primarily distinguishes between:

- **Rewearable footwear:** Items in good condition that can be resold without significant intervention. These are typically graded further (e.g., cream, grade 1 or A, Grade 2 or B, tropical mix) depending on quality and market demand.
- **Non-rewearable footwear:** Items that are damaged, heavily soiled, incomplete (e.g., single shoes), or otherwise unsuitable for direct resale. This fraction may be directed toward recycling or disposal pathways.

Beyond product-level grading, sorting can also occur at the material level, particularly when footwear is prepared for recycling. This can include:

- Density-based separation, where materials are sorted using float–sink or similar techniques.
- Near-Infrared (NIR) sorting, which identifies polymer types based on spectral signatures (though it has limitations, particularly with multilayer products, black or carbon-filled materials).
- Manual sorting, which may not be able to determine material compositions, but can be done by archetype.

Strobel board is a thin textile or non-woven sheet used as a base onto which the upper is stitched during Strobel construction. It forms part of the insole structure (Figure 31).

Upper is the part of the shoe that covers and secures the top and sides of the foot. It can be constructed from textiles, leather, or synthetic materials and includes components such as the vamp, tongue, and lining (Figure 31).

ACRONYMS

ABS	Acrylonitrile Butadiene Styrene
ESPR	Ecodesign for Sustainable Products Regulation
EVA	Ethylene Vinyl Acetate
EU	European Union
EPR	Extended Producer Responsibility
PU	Polyurethane
PVC	Polyvinyl Chloride
RUB	Rubber (Natural)
RUB SBR	Natural Rubber + Styrene-Butadiene Rubber
SBR	Styrene-Butadiene Rubber
SBS	Styrene-Butadiene-Styrene
THF	Textile, Household Goods and Footwear
TPU	Thermoplastic Polyurethane
TRL	Technology Readiness Level
RSL	Restricted Substance List

EXECUTIVE SUMMARY

WHY THIS MATTERS

The global footwear industry produces approximately 23.8 billion pairs of shoes every year[1], yet around 90% of discarded footwear is landfilled or incinerated[2]. Recycling for the overall textiles and footwear stream remains below 1% globally[3]. Unlike apparel, post-consumer footwear flows are poorly understood, largely because footwear is exported under the same trade codes as worn clothing, masking volumes, quality, and destinations.

Footwear's inherent complexity with multi-material construction, permanent bonding techniques, limited disassembly infrastructure, and the need for pairing individual shoes has resulted in a system where reuse and recycling are structurally constrained, despite growing regulatory pressure and brand ambition to circularise products.

By building a shared, data-driven understanding of what post-consumer footwear looks like, where it flows, and what limits its circulation, the industry can direct investment toward solutions with actual scale potential.

WHAT THIS REPORT SETS OUT TO DO

Closing the Footwear Loop (CTFL) Phase 1 delivers the most detailed analysis to date of post-consumer footwear waste streams in Europe, with a specific focus on non-rewearable footwear, which represents the largest and least understood fraction of collected shoes.

The report combines literature review, stakeholder interviews with recyclers, sorters and industry experts, and on-the-ground pilots analysing data from 1,200 individual post-consumer shoes, generating a unique dataset that captures material composition, assembly techniques, colour, damage, archetype, and recyclability constraints. This evidence base provides a critical foundation for informed design, infrastructure, and policy decisions.

By leveraging this evidence base, Phase 1 serves as guidance for the upcoming Phase 2 Circular Design Guidelines and Phase 3 Validation of Pre-processing and Recycling Innovations, scheduled for release in Q2 and Q3 of 2026.

Key system insights: Building a robust understanding of the Post-Consumer Footwear waste stream

The post-consumer footwear stream is dominated by non-rewearable products.
The current landscape of the post-consumer footwear flows was mapped (see Figure 1), revealing that from the total collected discarded textiles from separate collection, 9% by weight is footwear, while apparel and household textiles account for 90%. Comparing the collection to production demonstrates that the Footwear collection shows significant potential to be increased.

Out of the **9%** of the collected footwear:

50% is non-rewearable footwear vs **45%** in apparel.

46% is rewearable footwear vs **55%** in apparel, with footwear further divided into:

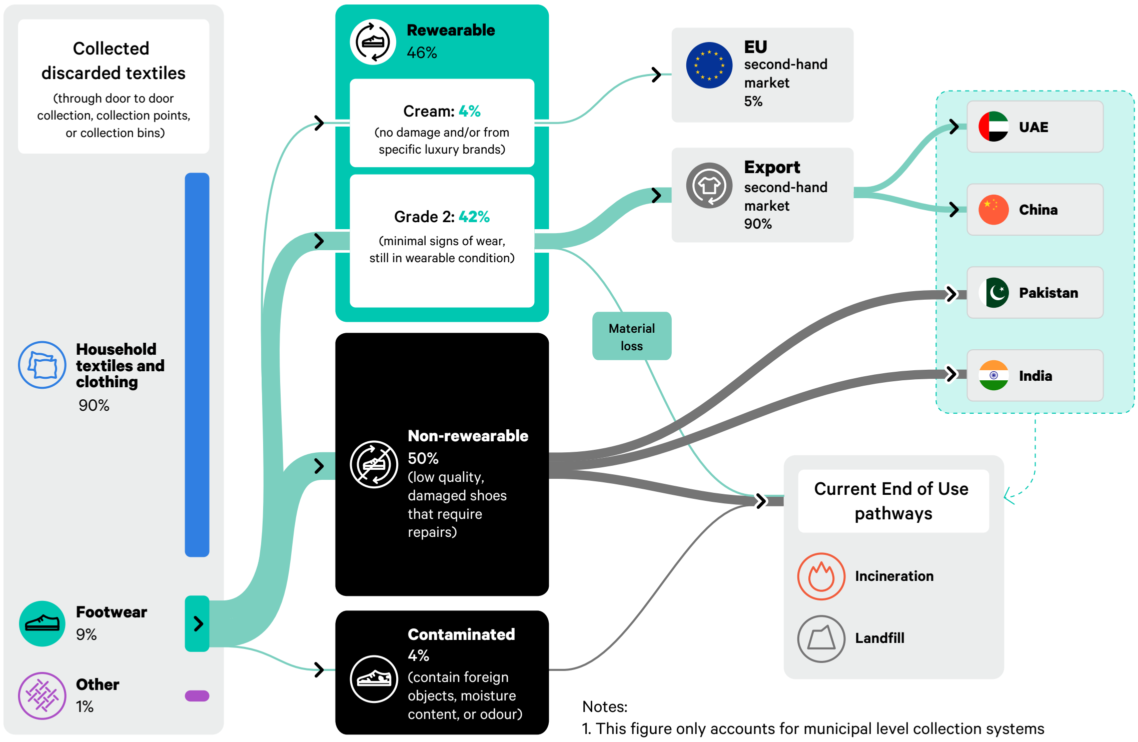
- **42%** is Grade 2; and
- **4%** qualifies as Grade 1 or cream quality.

~4% is contaminated footwear that is non-rewearable, and hindered for recycling due to damage from moisture, paint, heavy dirt, chemicals or other contaminants.

Based on the stakeholder consultations held in this project, non-rewearable and contaminated post-consumer footwear generally is exported to non-EU countries, particularly Pakistan and India, or goes to incineration and landfills, highlighting a structural gap between collection and circular processing.

On the other hand, Grade 2 footwear is generally exported for reuse to non-EU countries, particularly the UAE, China, and Pakistan. Lastly, the Cream quality fraction is resold within the European second-hand markets.

Figure 1: Current Mapping of Post-consumer Footwear Waste Flow



Notes:
1. This figure only accounts for municipal level collection systems
2. Dotted arrows are assumptions and small percentage of these quantities are re-exported to UAE based on archetypes

Source:
Combined desk research and stakeholder consultations

Recycling estimates globally remains below 1%, considering textiles and footwear[3]. In the context of footwear, this is mainly because of the product's complex composition, technology limitations for material identification and disassembly, non-enabling or incentivising policy, and the low market demand.

Design complexity, not material scarcity, is the primary barrier.

An analysis of data from 1,200 single non-rewearable shoes obtained from a sorting facility collecting post-consumer textiles and footwear in Catalunya, Spain (representative of footwear waste in the EU collected during spring/summer months of 2025) was conducted to examine the quality and composition.

The manual sorting process captured different features and characteristics of post-consumer footwear, including the following:

- Damage
- Colour
- Brand
- Assembly technique
- External disruptors
- Archetype.

Additionally, material composition data was collected with 2 different NIR scanners, Matoha's Fabritell and ShoeTell. The analysed shoes also went through CETIA's Sensorhub to identify internal disruptors through its X-ray and through IDShoes to take a 5-angle image of each shoe. By assessing a dataset of 14 data points per shoe ultimately yielded key insights.

Material analysis shows that many shoes contain recyclable thermoplastics, particularly in soles. However, recyclability is currently systematically hindered by the complexity of footwear construction, which relies on a high volume of specialised components and permanent bonding techniques to ensure rigorous performance requirements, such as structural durability, biomechanical support, and long-term wearer safety. In the material analysis of the post-consumer sample, the following complexity was found:

51.9% had permanent adhesives, showing primary assembly methods are glued, while only 19% was stitched and 8.7% had mixed assembly.

52% had blended uppers and various materials in the sole, like SBS (16%), EVA (15%), Rubber and SBR (14%) as primary sole materials.

Only **10.5% shared the same material for both the midsole and outsole.** Even seemingly simple shoes combine multiple polymers, foams, textiles, rubbers, and adhesives. In contrast, in apparel, 93% of the non-rewearable fraction was found to be mono-layered in Sorting for Circularity Europe, demonstrating the difference in complexity.

~90% had external disruptors such as logos, patches, and trims, and 21.8% of the shoes had internal disruptors. While disruptors are common in apparel as well, they are often easily removable, whereas in footwear, we deal with both internal and external disruptors.

Technology detection constraints, from the use of **Carbon Black in majority of 24.6% black soles** or lagging development in sorting technology for footwear with **37% unknown sole material.**

Importantly, **24% of non-rewearable shoes showed no physical damage,** suggesting missed opportunities for refurbishment, cleaning and repair, or component reuse. The absence of proper pairing at the disposal stage is also a challenge with the current infrastructure, contributing to the lost opportunities for reuse.

First-time applications of sorting technology infrastructure to footwear show strong potential and require further development.

Initial sorting technologies, which originated in the apparel and plastic sector and have since been adapted for footwear, successfully detected over 60% of materials. Promising early results were seen with Matoha's ShoeTell prototype, which was developed at the start of the project. Nevertheless, there is a strong need for further development of sorting technology specifically dedicated to scanning footwear materials.

At the time of the report compilation, NIR-based sorting systems demonstrate significant technical limitations with:

- Black and dark-coloured materials (nearly all black soles were unreadable, encompassing 24.6% of the sample), as the carbon black pigments used in these components absorb the majority of the near-infrared spectrum rather than reflecting it, ruling out polymer identification by a sensor.
- Complex blends, new materials and layered constructions.

As a result, 37% of sole materials and 17% of upper materials could, at this stage, not be identified, limiting the ability to direct footwear into high-value recycling pathways and reinforcing conservative, low-value end-of-use decisions.

The 8 Impact End-to-End Sneaker Recycling Study

Through a 2,000-pair pilot, The 8 Impact demonstrated that post-consumer footwear recycling is scalable and yields recycled materials functionally competitive with virgin rubber.

WHAT THIS REPORT CONTRIBUTES

Building on the Sorting for Circularity work, this report provides the footwear industry with:

- A quantified breakdown of post-consumer footwear flows, quality grades, and destinations.
- The first large-scale, product-level dataset on non-rewearable footwear composition and construction.
- Evidence-based identification of design features that actively block recycling.
- A realistic assessment of where existing recycling technologies can and cannot work today.

Together, these insights shift the conversation from abstract ambition to practical system constraints and levers for change.

PRIORITY ACTIONS FOR INDUSTRY

To unlock greater circularity, action is required across the **product, service, system & data levels.**

Drawing on the findings, the report identifies **three intervention layers** that must advance in parallel:

Product & design level

- Design footwear for **disassembly and material separation,** without compromising durability or long-term performance, to enable footwear recycling, for example, leveraging mechanical fasteners or reversible adhesives.
- Reduce unnecessary **material blends and decorative disruptors.**
- Improve design choices (e.g. material labelling, use of non-carbon black pigments, and limit multi-material and complex attachment of disruptors) where possible for **detectability and sorting accuracy purposes.**
- Systematic data collection throughout the manufacturing process, supported by traceability tools like Digital Product Passports (DPP), is essential to enhance sorting accuracy and ensure compliance with evolving regulatory requirements.
- Embed circular design principles early, particularly for **high-volume lifestyle and casual footwear archetypes.**

Further actionable guidelines towards circular product design will be provided in Phase 2's Roadmap to Circular Design Guidance, to be released in Q3 of 2026.

Service level - Improve sorting and extend product active lifespans

The findings show the significant opportunities to advance circularity across the value chain. The study indicates that visible wear and contamination, rather than structural failure, are the primary factors determining non-rewearability. This implies that cleaning and refurbishment systems could theoretically extend the life of footwear before recycling, highlighting an immediate opportunity to extend product active lifespans.

Infrastructure development must prioritise the waste hierarchy, specifically by focusing on opportunities to increase the rewearable fraction of footwear. Enhancing the economic viability of post-consumer footwear resale can be achieved by integrating cleaning, repair, and refurbishment services within sorting infrastructures, or by further developing AI-enabled sorting technologies for rewearable items.

Infrastructure & system-level improvements for feedstock accessibility

- Invest in **dedicated preprocessing capacity** to enable component separation, contaminant removal, and refurbishment.
- Strengthen the end-of-use value chain (collection, sorting, reuse, and recycling) to improve material recovery and minimise waste. Support pilots for **manual and hybrid sorting** as near-term solutions.

Investing in a dedicated preprocessing value chain is integral. Facilities need to separate components, remove contaminants, and channel lightly damaged items to refurbishment to bridge collection, reuse, and recycling. Collaboration among brands, recyclers, and innovations is required to scale recovery pathways and validate new materials. A reliable data foundation on post-consumer footwear flows is imperative, as lacking this information limits informed decision-making and long-term planning.

Data, policy & collaboration

This research establishes the missing data foundation for post-consumer footwear flows, such as material composition and footwear condition. This new clarity resolves previous strategic planning gaps, enabling informed decision-making to scale recycling technologies and execute long-term circularity planning.

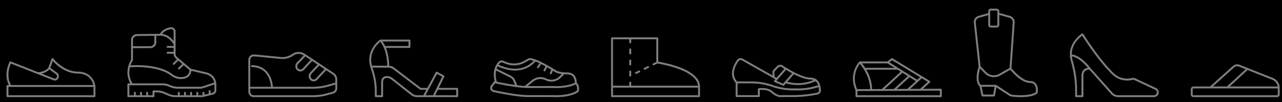
Given the structural complexity of footwear, which differs significantly from apparel in composition and end-of-use processing, it is recommended that footwear legislation be decoupled from apparel frameworks. Tailored policymaking will enable:

- Evidence-Based Policy: Implementing reliable data systems to inform circularity incentives like EPR and ESPR.
- Strategic Investment: Providing the transparency needed to guide infrastructure investment and scale recycling technologies.
- Sector Alignment: Standardising shared definitions, material taxonomies, and reporting to ensure industry-wide compliance and progress.

THE PATH FORWARD

Post-consumer footwear waste shows potential for valorisation, transforming a previously overlooked area into a viable material stream as an alternative to fossil-fuel-based inputs. Achieving circularity for post-consumer footwear waste demands coordinated action at the product-, service-, system, and data level, rather than relying on technological development alone.

The key path forward involves strengthening circular design practices, promoting the rewear potential, improving sorting and preprocessing capacity and technology, and establishing robust data systems. This report establishes that transforming non-rewearable shoes from a complex waste challenge into a valuable material resource is challenging, but possible through collaborative intervention. By grounding future policy and innovation in real-world product evidence, the footwear sector can take decisive steps toward closing the loop.



01.

INTRODUCTION

The global footwear industry produces around 23.8 billion pairs of shoes annually, with approximately 90% of disposed footwear ending up in landfills or being incinerated.[2] These end-of-use outcomes are driven largely by the complexity of footwear construction, which makes material recovery both technically challenging and economically unviable.[4] For example, a single running shoe can contain up to 65 distinct parts made from various material combinations and assembled through more than 360 steps—a level of complexity that is mirrored in the disassembly and recycling process.[5] That being said, with a deeper understanding of the human body and body kinetics, the industry saw an evolution of how footwear is designed, and has significantly contributed to how shoes are constructed today. While a typical shoe has similar components and basic structure, each archetype is designed keeping in mind its function and use over time, and while this may result in more material combinations are more distinct parts, it also results in better performance and use, and it would be accurate to say that the many elements of shoes are not designed in just for aesthetic purposes, but for performance in many cases.[6]

The complexity of the product is compounded by limited reverse logistics and the absence of circular design principles, as well as the small number of solutions that can disassemble and recycle components at scale, reinforcing a linear model of production and disposal. While some brands, sorters and recyclers are piloting solutions, such as innovative materials, designs and take-back programmes, systemic change remains limited.

In response to this urgent need and building on the findings of the Sorting for Circularity (Apparel) Project, Closing the Footwear Loop was initiated.

The Project aims to accelerate circular innovation in the footwear industry by aligning individual and industry efforts with a collaborative, cross-sector approach that maps post-consumer footwear waste in Europe and addresses the roadmap towards circular design (to be released in Phase 2), innovations (to be released in Phase 3), infrastructure, and business model challenges at scale.

The first project phase, encompassed in this report, aims to map post-consumer footwear waste in Europe with the aim of gaining a better understanding of the current state, with special focus on material composition, complexity, and potential recyclability in post-consumer footwear. In this phase, on-ground pilots were conducted to gather new data, identify key learnings, culminating in a detailed analysis of the nuances of the footwear waste stream, its material composition, and the distinction between rewearable and non-rewearable post-consumer footwear. This phase of the study was conducted through desk research and stakeholder interviews, which supported the further development of the pilot and its activities. The phase culminated in an on-ground analysis of data from 1,200 non-rewearable items of shoes (find further details in the Methodology section).

02.

THE CURRENT LANDSCAPE OF THE FOOTWEAR INDUSTRY

The footwear industry covers a wide range of products across different archetypes, brands, and styles, with a diverse range of materials. It operates in a complex, interconnected value chain, with China, Vietnam, and Italy as the leading exporters and the US, Germany, and France as the main importers.[7] The global footwear market is projected to grow from US$495.5 billion in 2025 to US$789.5 billion by 2032.[8]

The supply chain is responsible for approximately between 0.45% and 0.70% of worldwide greenhouse (GHG) emissions.[9] When it comes to production, manufacturing a typical shoe today emits 1.5 kgs of CO2, while the total grave-to-grave carbon footprint is equivalent to 6.7 kgs of CO2 per pair.[10] Alongside this, escalating regulatory scrutiny and EPR mandates have transformed footwear's risk profile, making circularity a strategic necessity for market access and compliance.[10]

2.1 Mapping the Global Footwear Value Chain

The footwear value chain is complex, multi-staged, and materially intensive, spanning design, material production, manufacturing, distribution, use, and end-of-use management. At the production stage, footwear typically consists of multiple components and layered constructions, with impact profiles varying significantly across archetypes. However, material production and manufacturing consistently account for the majority of carbon emissions. Energy-intensive processes such as steam chest moulding, injection moulding, compression moulding, and vulcanisation rely on high temperatures, pressure, and predominantly fossil-fuel-based electricity or steam. The environmental burden is further amplified by the widespread use of high-impact materials in the sole, including EVA, PU, rubber, and in the upper, including leather and polyester, making material selection and processing technologies central drivers of overall footprint.

To add to the process, like apparel, footwear manufacturing accounts for large volumes of untapped post-industrial waste. Waste generated from factories and production facilities is, in most cases, scarcely collected and diverted at scale, and can uncover a big potential for recycling in manufacturing hubs.

Following **manufacturing,** footwear enters global distribution networks. **Retail and production** stages remain largely disconnected from end-of-use systems, with **take-back schemes** still limited. Consumption patterns reinforce the linearity of the system: the average EU citizen purchases multiple pairs of footwear annually, translating to approximately 4 kg of footwear annually, and many common segments, such as sneakers, are used for roughly one year before disposal. While repair services exist, they are unevenly adopted, and are guided based on the construction of the shoe, and may result in being economically uncompetitive compared to purchasing new footwear. In France, for example, the cost of shoe resoling starts at 30 euros.

Post-consumer footwear is primarily **collected** through municipal textile systems, charities, commercial collectors, and limited brand initiatives. In most countries, footwear is collected alongside textiles. For example, France operates a collection for Textile, Household Goods, and Footwear through a dedicated Producer Responsibility Organisation. Proper disposal plays a critical role in preserving reuse value, yet growing collection volumes and saturated second-hand markets are placing pressure on existing infrastructure.

Sorting remains strongly market-driven rather than material-driven. Footwear is graded into cream, rewearable (various subcategories), and non-rewearable fractions. Cream and higher-grade items are resold domestically or exported to African and Asian markets, while non-rewearable footwear is largely destined for incineration or landfill. Recycling remains marginal, diverting less than 1% of footwear waste generated. Current recycling approaches include shredding for downcycling and limited disassembly-based recovery, but technical barriers such as complex bonding and material mixtures constrain scalability.

As a result, **landfill and incineration** remain dominant end-of-use pathways. Although **Waste-to-Energy** ranks above landfill in the EU waste hierarchy, low material value and high domestic treatment costs incentivise export as a primary downstream solution. Overall, the footwear value chain remains structurally linear, with production intensity, short use phases, and limited recycling infrastructure reinforcing systemic inefficiencies at end-of-use.

The Figure 2 below, depicts the key materials, processes, constraints and actors of each value chain step, and you can find the detailed learnings in the Annexe IV.

Figure 2: Value chain mapping of materials, processes, constraints and actors

	MATERIALS & VOLUMES	PROCESSES	CONSTRAINTS	ACTORS
Raw Materials	Sole: EVA, PU, TPU, PVC, SBS, SBR, rubber Upper: polyester, elastane, blends, leather, adhesives	Fossil-based, high carbon intensity, polymer-heavy	Limited traceability and transparency	
Design and development	40+ materials per shoe	Predominantly glued/ vulcanised assembly Performance-driven, multi-layer construction	No circular design framework embedded	Brands Material suppliers Manufacturers
Manufacturing		Cutting, stitching, injection & compression moulding, vulcanisation, gluing The impact is ~29% due to materials and ~68% from manufacturing emissions		
Distribution and retail		Global export networks Increasing consumption volumes	No reverse logistics integration	Retailers and e-commerce platforms Brands, Shops, Markets, Wholesalers and sourcing agents
Use	~4kg footwear per EU citizen/year Average lifespan ~1 year (sneakers)		Repair declining due to cost competitiveness	Consumers
Collection		Municipal bins, charities, limited brand take-back	No footwear specific infrastructure	Consumers Repair shops
Sorting		Market-driven grading systems	NIR limits; adhesives complicate recovery and identification Manual sorting does not currently account for composition sorting	Commercial collectors Charities and non-profit organizations Local authorities Commercial sorters
End of Use		Reuse dominant pathway Recycling <5% (mostly mechanical, open-loop) Incineration & landfill remain prevalent		Commercial sorters

2.2 End-of-Use Pathways

While Europeans generate around 16 kilograms of textile waste per person annually (likely including footwear),[11] reliable data on the disposal of footwear specifically remains scarce. It is estimated that 1.2 million tonnes of footwear are discarded annually within the EU, with 5% recycled, 15% reused, and 80% landfilled.[12] From our stakeholder insights, it was gathered that 46% is rewearable (both within and outside the EU), 50% is non-rewearable, and about 4% is contaminated, and the majority ends up in incineration or landfill (see Figure 3). Additionally, it is important to note that second-hand hubs in Europe are a fluctuating market that is informed by geopolitics: Ukraine, for example, was a key destination for second-hand export, until the conflict with Russia.[13] However, these figures are difficult to verify due to the lack of footwear-specific disposal data, limited traceability of waste flows, and insufficient information from end-destination countries that import used goods from Europe.

It is estimated that 1.2 million tonnes of footwear are discarded annually within the EU, with 5% recycled, 15% reused, and 80% landfilled.

The same data limitations apply to post-consumer footwear exported from Europe. Most datasets group footwear together with clothing and household textiles under HS code HS6309, described as 'worn clothing and other worn articles', providing no footwear-specific breakdown. Nevertheless, in 2023, destinations in Africa and Asia were the most common, with Pakistan (13%), the United Arab Emirates (12%) and India (7%) as the leading importers.[14]

National Efforts to Unpack Footwear Flows: The Netherlands

While no EU-level data exists on footwear waste and recycling, the Dutch Ministry of Infrastructure and Water Management commissioned a study examining the environmental impact, end destinations, and waste flows of footwear in the Netherlands.[15] The study found:

- Approximately **10%** of all newly produced shoes—shoes that are never worn—are destroyed through incineration or recycling.
- About **25%** of Dutch post-consumer footwear is disposed of in textile collection bins, while roughly **75%** ends up in residual waste.
- After sorting, post-consumer shoes are directed to the following destinations:

  10% Reused as 'as-new' shoes, with 2% staying in the Netherlands and 98% exported to other European countries.

  60% Summer shoes, largely exported to Africa and reused there.

  15% Winter shoes, exported evenly between Asia (50%) and Africa (50%) and largely reused.

  15% Leftover or 'third choice' shoes (often dirty or damaged), exported to Pakistan. After repair, roughly 50% enter the second-hand market, while the remainder is landfilled.

- The average lifespan of work shoes, sports shoes, and trainers is around one year, while leather shoes and boots tend to last longer.
- Simple repairs, such as replacing heels or soles, can extend the lifespan of leather and work shoes. However, the number of shoe repairs and shoe repairers in the Netherlands has been declining for years, primarily due to competition from cheap new shoes, which are often difficult to repair.

At the time of publication, this was the only detailed national-level report in the EU analysing footwear end destinations and waste flows.

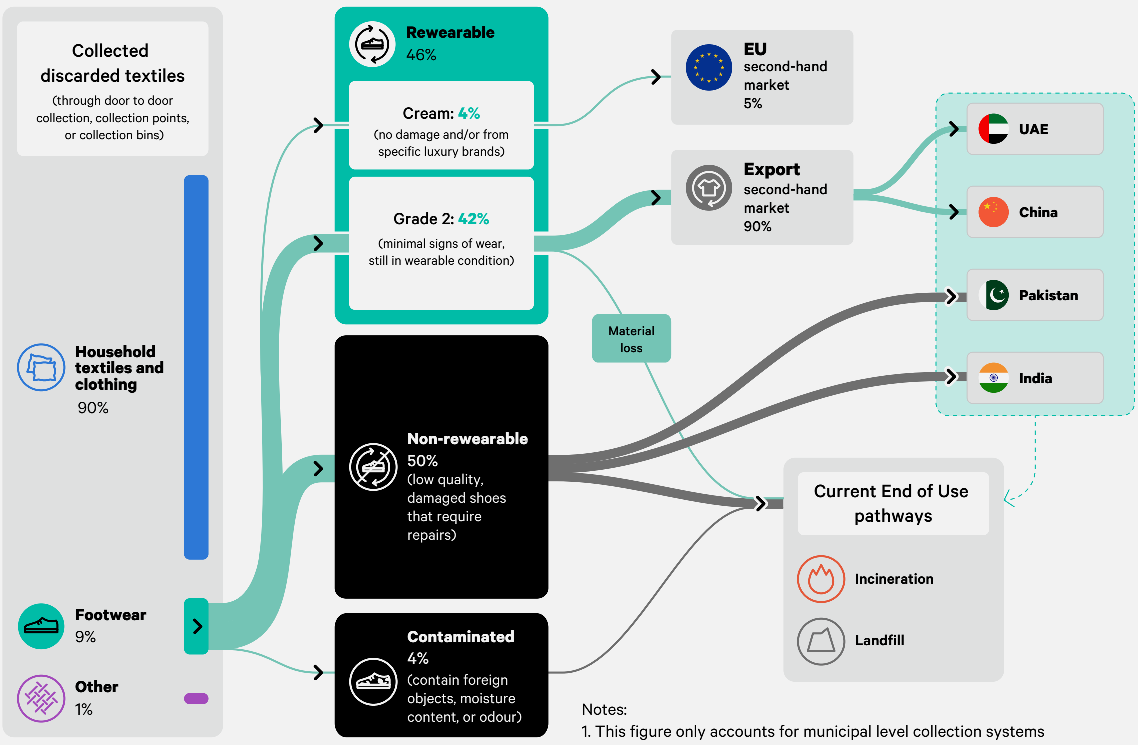
Based on these learnings, we can approximate that each year, within the European Union, for each person, between 3.75 kgs - 7.5 kgs of footwear is collected through the textile waste stream.

Stakeholder consultations with European sorters and innovators, combined with desk research, indicate that the lack of consolidated data on post-consumer footwear flows is compounded by the fact that many available datasets aggregate footwear with used household textiles. Based on the information currently available, footwear accounts for approximately 6–12% of the post-consumer textile waste stream. Within this share, about 4% is identified as cream quality, 42% as Grade 2 quality rewearable, and 50% as non-rewearable. Based on these learnings, we can approximate that each year, within the European Union[16], for each person, between 3.75 kgs - 7.5 kgs of footwear is collected through the textile waste stream.[17]

Of the total volume of collected and sorted footwear, only 5% is resold in local second-hand shops. Approximately 90% is exported after sorting by archetype and quality grade. Consulted stakeholders also reported that some organisations export footwear to countries such as China by classifying it as 'used and rewearable', as the import of waste is prohibited under Chinese law. In regions where such imports are allowed, including several African countries and Pakistan, footwear typically enters under waste codes and undergoes an additional round of sorting, after which a portion is re-exported. Based on volumes, Pakistan continues to be the leading global importer of post-consumer textiles and footwear.

According to the consulted parties, exports are often prioritised as a downstream pathway for discarded shoes, mainly to avoid the high incineration costs in Europe. As a result, sorting practices are largely driven by the product's suitability for local and global second-hand markets rather than by material composition. Figure 3 below illustrates the footwear waste flow derived from the combined desk research and stakeholder consultations.

Figure 3: Post-Consumer Footwear Flows



Notes:
1. This figure only accounts for municipal level collection systems
2. Dotted arrows are assumptions and small percentage of these quantities are re-exported to UAE based on archetypes

Source:
Combined desk research and stakeholder consultations

Footwear flows in Europe lack dedicated infrastructure and are largely undocumented, mostly because of their low value and the absence of end markets for this type of waste. Additionally, there are challenges in the collection of post-consumer footwear that lie mainly in the lack of consumer awareness of proper disposal methods.[18] Altogether, these complexities and volumes make it difficult to find end markets for post-consumer footwear today, both within Europe and across the globe.

France as a policy frontrunner for circular footwear

France has established a compensation system to incentivise the use of recycled materials and pioneered a mandatory Extended Producer Responsibility (EPR) scheme for textiles, household linen, and footwear (THF). Under this scheme, producers and importers are required to finance and manage the collection, sorting, and treatment of THF products at end-of-use.[19] Refashion oversees the implementation of the EPR scheme and supports companies, downstream stakeholders, and innovation projects aimed at enabling circular and sustainable practices across the THF value chain.[20]

According to Refashion, footwear represented 18% of the total production volumes and products put into the French THF market in 2021 and accounted for 7% of all collected post-consumer THF. Whereas 90% of collected footwear in France is reused, only a small share is recycled due to the limited availability of industrial recycling solutions.[21] In response, Refashion has supported several initiatives to advance footwear circularity. In collaboration with CETIA – a partner on Phase one of this Closing the Footwear Loop study – it helped develop Sensor HUB, an automated system for identifying the characteristics of post-consumer footwear to address the complexities of sorting and preprocessing for recycling.[22] Refashion has also supported the ZAPATEKO II project, which focuses on identifying technological obstacles to footwear recycling,[23] and has produced both a Best Practice Guide on Footwear Design for Recycling and a mapping of footwear recycling solutions.[24]

France is also home to pioneering footwear recycling technologies developed by THE 8 IMPACT, a partner in the Closing the Footwear Loop project (Phase one). Together, the supportive regulatory framework and active innovation ecosystem position France as a clear frontrunner in advancing circularity in the footwear sector.

2.3 Key Systemic Challenges

The circularity potential of footwear is currently constrained by several systemic challenges:

- Complex product composition.
- Technology limitations.
- Labelling of materials used and chemical compliance/safety.
- Market demand and investment needs.
- Geographic disconnect between end-of-use locations and manufacturing hubs.
- Purity of feedstock streams and RSL limitations of putting back into the fashion value chain.

The first four challenges[5] are detailed below.

1. Complex Composition and the Gap in Infrastructure

A primary barrier in advancing the optimisation of footwear at the end-of-use starts at the disposal point and lies in the hands of consumers. When it comes to disposal, consumers tend to hold the most power, and their decisions directly define when, where and most importantly, how they dispose of their items.[25] Furthermore, the limited understanding of consumers' perspectives is a pivotal reason for the failure to actually close the loop and to scale institutional strategies.[26] Added to these issues, it is integral to highlight the importance of disposal procedures, and low-hanging gaps like pairing or tying the shoes together at disposal can increase the rate of rewearability after disposal.

A fundamental barrier to advancing recycling in the footwear industry is the technical and economic difficulty of deconstructing products that are complex by necessity. A single shoe archetype, such as a high-performance runner, can contain over 40 tightly-bonded materials, meaning disassembly remains labour-intensive and recovery unviable at scale. This physical challenge is exacerbated by a systemic information gap: the lack of standardised communication between designers and recyclers reinforces technological and design lock-ins. Consequently, it is important to conclude that the primary bottleneck is not only the product's complexity itself, but also the absence of an infrastructure that can incentivise and streamline the profitable sorting and pre-processing of these products into pure waste streams.

2. Technology Limitations in Sorting and Pre-processing

At the collection and sorting stage, automated identification technologies face significant constraints. Near-infrared (NIR) scanners struggle to recognise black or dark-pigmented materials, which absorb light and do not reflect light that can be read by NIR spectroscopy.[27, 28] Hidden disruptors such as metal or plastic inserts often go undetected without more advanced tools like X-ray systems, complicating preparation for recycling. Understandably, manual sorting at this stage exists today, at different levels, and is highly dependent on its end use. Manual sorting at commercial sorting facilities currently sorts only for rewear as other markets are currently not at scale. On the other hand, sorting can also be done manually at an archetype level, especially where recycling technologies require materials that are found specifically in an archetype, for example, for a high rubber and EVA yield from the performance and lifestyle shoes.

In addition to advancing sorting with NIR spectroscopy, the need for other sorting technologies is also integral to scale sorting with better results, since the main barrier here is not the complexity of the products, but the inability to separate into pure waste streams. Since the inception of the project, technological advancements in this area have been noted, and other methods like fluorescence-based and Hyperspectral Imaging are being tailored to overcome the specific sorting challenges faced by the footwear and textile sectors.

During disassembly, widespread use of glueing and vulcanisation prevents components from being separated without damaging the materials. No industrial-scale technologies currently exist to efficiently dismantle mixed-material shoes. Even when materials are correctly identified, most recycling technologies are designed for pure textile or plastic streams and cannot process complex blends such as polyester–elastane or rubber–EVA combinations. This currently results in recovered outputs of low purity and limited value.[29, 31] Bonding methods exacerbate the challenge. For example, glued or stitched soles can obstruct the identification of underlying materials during sorting.

3. Regulation on the Chemical Use and Labelling of Materials Used in Footwear

The EU's Directive 94/11/EC requires that labels specify the composition of the upper, lining and sock, and outer sole– only for materials accounting for at least 80% of the surface area or volume of the outsole.[30] While intended to reduce fraud and increase transparency for customers, this information does not support the purity requirements for sorting and recycling. Labels are often printed on packaging or paper tags that are removed before disposal, leaving post-consumer footwear without material identification.[34] Additionally, these labels are often not just for consumer awareness, but are used for classification of products by governments to inform trade, data, restrictions and duties. On the other hand, chemical use is another integral concern of the recycling industry. RSLs (Restricted Substances List) are paramount for end-of-use management, and labelling can ensure that data on RSLs can be verified when being considered as feedstock for recycling.

Moreover, footwear is currently not covered by the Ecodesign for Sustainable Products Regulation (ESPR). A study assessing footwear sustainability is planned for completion by 2027 under the Ecodesign for Sustainable Products and Energy Labelling Working Plan 2025-2030.[31, 32] Although the EU Ecolabel criteria for footwear (Commission Decision (EU) 2016/1349) address material origin, resource use, emissions, hazardous substances, durability, corporate responsibility, and packaging, they are not well aligned with the requirements of end-of-use management.[38] Overall, there is no policy framework that enables or incentivises the development of suitable circular end-of-use solutions for footwear. Under the revision of the Waste Framework Directive (2025), there is an inclusion of footwear in the EPR framework being implemented in the EU (by April 2028). This would require each EU PRO to also be sorting footwear, aligning with the EU's five-step waste hierarchy.[33]

4. Market Demand and Investment Needs

Footwear recycling remains an underdeveloped and largely untapped market. Weak demand for closed-loop recycled materials means post-consumer footwear continue to flow primarily into second-hand markets for resale or to landfill and incineration. Limited financial investment in end-of-use infrastructure and innovation further hinders progress, compounded by a lack of political pressure and regulatory incentives.

The technical challenges of footwear recycling are significant: shoes incorporate multiple material types and layers, and fully automated sorting systems do not yet exist. Processes rely heavily on manual labour and specialist knowledge. The quality of recycled materials—particularly from outsoles, often the most worn component—remains inconsistent. Mechanical recycling can lead to material loss, and recovered materials rarely match the quality and performance of virgin materials. As a result, recycling is predominantly open-loop, redirecting materials into other applications such as automotive and flooring products rather than new footwear. The emergence of chemical recycling in footwear is a promising development, yet it is still far from being available commercially.

These combined economic and technical barriers mean that successful large-scale circular footwear systems remain scarce, and many stakeholders are still in the exploratory phase. Under the principle of Producer Responsibility, the manufacturers who 'made' the waste are being tasked with 'managing' the waste, thus making brands accountable to ensure the long-term viability of circular footwear streams.

Innovations for Circular Solutions Beyond Recycling

Circular initiatives need to move beyond theoretical frameworks into measurable, large-scale practice to be effective. Following are examples of repair and refurbishment implementations to extend the 'first life' of a product.

- Woshwosh is a Polish company specialising in footwear renovation, cleaning, and personalisation services, renewing 550,000 pairs of shoes since 2015. Operating through a network of partner shoemaker shops and pick-up points, it has offered convenient B2B and B2C services since then.[34, 35]
- WEAR is a Dutch company focusing on cleaning, repair, and minimal refurbishment. Their second-hand sneakers are thoroughly cleaned and fitted with new insoles.[36]
- Nike introduced the Reuse-a-Shoe (RAS) programme in the US for post-consumer shoe collection, later expanding globally through the Recycling (open loop) and Donation (RAD) service to collect footwear and apparel, has collected and recycled more than 30 million pairs of used shoes since 1990. Their Re-Creation collections use vintage Nike products to reduce footwear waste.[37]
- VEJA launched its cobbler project in 2020, enabling customers to clean, repair, and extend the life of their VEJA and non-VEJA sneakers in partner stores. A mobile repair station, run with Log'ins, repairs over 1,000 sneakers monthly. Since 2020, VEJA has repaired more than 27,000 pairs.[38]
- Dr. Martens have partnered with the Boot Repair Company[39] (BRC) in the UK to offer direct-to-consumer repair services. This service enables customers to repair their boots, shoes and sandals, offering services from resoling to zip replacements. The welted construction of Dr. Martens' footwear enables resoling - outsoles can be removed, welts restitched, and new outsoles heat-sealed without compromising the integrity of the original product. This partnership with BRC also enables Dr. Martens' ReWair program[40] in the UK, reselling more than 13,000 refurbished products via partnerships with eBay and Depop since 2022.
- Vivobarefoot's Revivo is their brand take-back program, which provides consumers with the options of repair, resole and refresh their products to extend their life. Through the 'Revivo' program, they refurbished and resold over 63,000 pairs in 2025. They have partnered with The Boot Repair Company, UK to revive returned Vivobarefoot products back to life and resell them on their platform.

Innovations for Recycling Solutions

- CETIA is a company based in France developing robotics and AI-enabled solutions for identification, dismantling, detection, sorting and preparation. Through the Re_SHOES programme, it has developed tailored machinery for automated separation and sorting of shoe soles. Its IDSHOES technology allows automated recognition of shoe archetypes, brands, and image capture.[41]
- IDELAM is a French company focused on the disassembly of footwear, using a patented process based on a mixture of supercritical CO2 and liquid co-solvents to remove adhesives.
- PICVISA's Ecoflake is an optical sorting machine for flakes using near-infrared spectroscopy (NIR) technology at a flake level at high speed, which can be applied to sort shredded footwear materials.
- THE 8 IMPACT is a French recycler dedicated to recovering materials from footwear and tennis balls. Using advanced recycling processes, it sorts and preprocesses rubber, EVA, TPU, and textiles into high-value recycled materials.[42, 43]
- FastFeetGrinded is a Dutch recycling company that disassembles and separates discarded footwear to recover high-quality, reusable materials for footwear and other various industries.[44]
- Novoloop chemically alters hard-to-recycle post-consumer plastics in footwear, including TPU and cross-linked materials, to create building blocks used for new footwear plastics.

There is a significant opportunity to scale emerging solutions to meet global waste reduction needs. We are now positioned to strengthen the supporting reverse logistics and markets required for a circular ecosystem. By refining data on footwear flows and material composition, we can move beyond resale to unlock the economic and technical feasibility of large-scale recycling. Addressing these remaining infrastructure gaps is the essential next step to fully activating a high-value, circular footwear ecosystem in Europe.

03.

METHODOLOGY AND STUDY LIMITATIONS

After our initial desk research and stakeholder consultations, we were able to gather contextual learnings on footwear, materials and the current landscape of footwear waste in Europe. The research focused on barriers to adopting circular strategies, current infrastructure and technology, end markets and their pricing dynamics, TRL and emergent technologies for processing, sorting, and recycling, volume and quality of post-consumer footwear flows, and footwear material composition. The stakeholder consultations supported the understanding of common practices in end-of-use management of footwear, and helped shape the methodology for the detailed manual sorting analysis of post-consumer footwear.

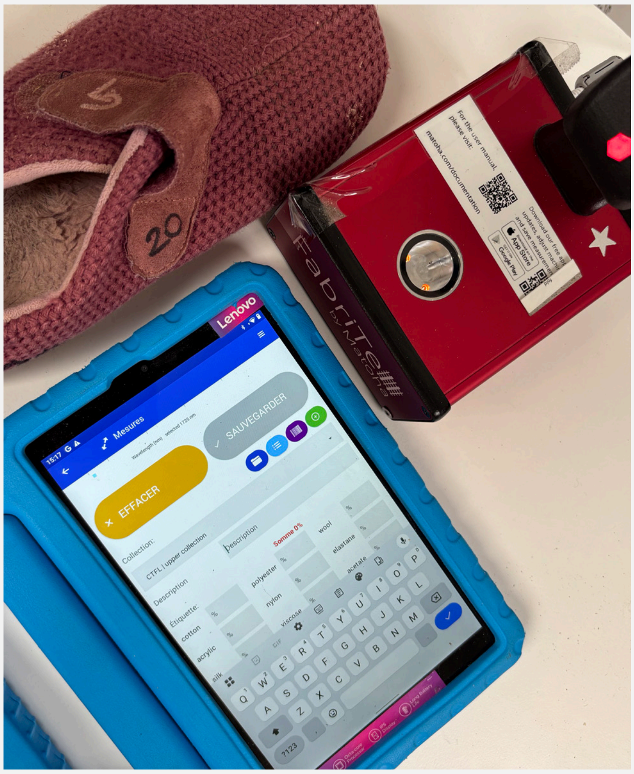
Data collection was targeted at understanding essential characteristics of footwear, and collecting data that can help shape decisions for end-of-use and prioritisation of solutions for optimisation, and the viability of the various types of materials that can be yielded from post-consumer footwear. In order to get the best results, the methodology was designed to test a range of machines and methods.

Data collection on a sample of 1,500 unpaired, single, random shoes was conducted using a tagging system and a material-profiling approach, with visual inspection, basic manual tools, and advanced digital tools, on the whole shoe without disassembly or shredding. The sample was obtained from Spain, thanks to a partnership with Modare Koopera in Barcelona, which sorted 7,200 used footwear items, separating 4,340 (60.2%) rewearable shoes, 2,500 (34.7%) non-rewearable items, and 360 (5.1%) contaminated items that were sent for incineration. From this, 2,500 non-rewearable items were sent to CETIA for detailed analysis encompassing 14 data points per shoe, as illustrated. The selection of shoes was intended to be as random as possible, to avoid favouring any footwear archetype over others and to give a realistic picture. It is important to note that from the 1,500 shoes, due to human and machine errors, a sample size of 1,200 shoes (with 14 data points collected per entry) was considered for analysis after cleaning the data.

NIR scanning was used for both the footwear sole and textile upper, using Matoha's ShoeTell (Figure 4) and Fabritell (Figure 5) devices, respectively. CETIA's IDShoes, as well as Sensorhub with its X-Ray capabilities, were also applied.

Figure 4: Matoha's ShoeTell to Identify Footwear Sole Material, set-up at CETIA

Figure 5: Matoha's FabriTell to Identify Footwear Upper Material, set-up at CETIA



3.1 Study Limitations

Being a first-of-its-kind study, challenges and limitations were inevitable. One of the most significant challenges in this study was establishing a foundation that accurately reflects the complexity of post-consumer footwear. Obtaining a truly representative sample and defining footwear archetypes that capture the full diversity of products on the market, all proved to be intricate tasks. These steps were critical, as they shape the reliability of subsequent material identification and circularity assessments. To add to this, the data collected by sorters on the ground had to be sanitised at a high level as they were collecting this detailed information on complex feedstock for the first time. The following section elaborates on the limitations encountered across these three areas, highlighting how variability in collection methods, the diversity of product designs, and the subjectivity of rewearability criteria influenced the study's outcomes.

Feedstock

Initially, the study aimed to characterise a European sample, but, based on previous experience from the Sorting for Circularity Europe study, which showed low variability across countries in post-consumer materials, only one country (Spain) was selected as a provider of post-consumer materials. The random selection of shoes would likely have been different if obtained at a different time of year, at a different facility, or through different collection methods. These variables were not taken into account when it comes to their correlation with footwear characteristics.

Originally, a list of archetypes was created and validated with the brand working group; however, the diversity of product types encountered in the post-consumer stream was greater than expected a priori. Archetype definitions were first developed through industry consultations and then refined based on insights from brand partners. Circle Economy aimed to maintain the highest diversity and inclusion of footwear types when listing and organising archetypes into a typology, and effectively, a drop-down menu for the manual data collection process.

Finally, the division of rewearable and non-rewearable materials was conducted by professional sorters at a partner facility of Modare in Spain, who have provided the CTFL research team at CETIA only with footwear considered non-rewearable. This approach was taken to obtain a sample that best reflects realistic pathways for post-consumer footwear.

Due to the novelty of footwear recyclability, while NIR spectroscopy existed for apparel, the Matoha ShoeTell prototype was used for the study. Additionally, there was a lack of material libraries available for training NIR machines. During this phase of the project, the NIR machines were trained using a material library by ReFashion, but this study was the first time the machine and the material library were used for a study of this type.

Accuracy

With regard to the accuracy of the Matoha FabriTell, the scanner can detect two main textile materials with typical accuracies of ±5% for pure samples and ±10% for blends.[45] For the Matoha ShoeTell, a scanner developed specifically for footwear and used on such a large sample for the first time, the machine reads mainly mono-materials and only identifies up to four blends with limited accuracy in their breakdown.

Accuracy of material identification can also be affected by decisions made during footwear design and manufacturing, including:

- **Coatings:** Specific coatings, notably polyurethane, influence detection accuracy, whereas perfluorinated waterproofing coatings do not appear to have this effect.
- **Carbon black pigments** inhibit the material identification when scanned by NIR technology.
- **Thick prints:** PU or PVC iron-ons inhibit the identification of the material underneath.
- **Presence of elastane:** Matoha FabriTell devices detect it at 5%+, but secondary material in blends if under 17% are grouped as contaminant rather than named explicitly.
- **Unknown results:** The scanner produced an 'unknown' result when scanning materials such as complex blends of more than three materials, natural leather, synthetic leather, natural and synthetic fur, and, occasionally, silk, wool, or linen. NIR technology struggles to identify leather because the complex, inconsistent chemical composition of modern leathers, especially those with synthetic coatings, can interfere with spectroscopic analysis. Furthermore, the surface properties of leather, such as its reflectivity, are altered by tanning processes and ageing, making it difficult for NIR to obtain consistent readings. In cases where supported materials are used, the unknown result is typically caused by coatings, pigmentation, or operator error.

Productivity

While productivity was not an objective in this study, it is worth reflecting on how time-consuming the collection of 14 data points per shoe was. The study achieved approximately 11 minutes per item, with 4.5 minutes on average spent on the machines and the remaining time spent on manual data collection and other miscellaneous activities, such as moving pellets from one station to another. The data collection performed in the study does not mimic the data requirements for effective recycling and is therefore not to be taken into account for business case evaluations. Productivity is significantly reduced because each batch of shoes is analysed by five different machines across three stations, making it a slow, detail-oriented process.

04.

UNPACKING THE NON-REWEARABLE FRACTION

Currently, there is a significant knowledge gap in footwear end-of-use volumes, composition, characterisation, destinations, processing, and recycling potential. To understand this further, the project needed to conduct a careful analysis of the current landscape and processes. Circle Economy conducted three main methods of data collection: desk research, stakeholder interviews, and a detailed analysis of a random sample of post-consumer footwear as illustrated in Figure 6. Complementary analyses were conducted by PICVISA and THE 8 IMPACT to compare the results of different sorting techniques and technology providers. Please see Annexe I for more information on the methodology.

Figure 6: Steps involved in data collection

1 Desk research
Literature review of various academic papers and reports.

2 Stakeholder consultation
5 experts, 3 sorters, 3 recyclers, and 3 innovators

3 Methodology development and validation
Methodology for a manual sorting of a random sample of 1500 shoes.

4 On the ground data collection
Carried at the CETIA facility for 1 week.

5 Data analysis and report writing
Material Flow and Composition Analysis report (figure 6)

Data collection on a sample of 1,500 unpaired, single shoes was conducted using a tagging system and a material-profiling approach, with visual inspection, basic manual tools, and advanced digital tools. The sample was obtained from Spain, thanks to a partnership with Modare Koopera in Barcelona, which sorted 7,200 post-consumer footwear items. From this, 2,500 non-rewearable items (Figure 7) were sent to CETIA for detailed analysis encompassing 14 data points per shoe, as illustrated in Figure 8.

Figure 7: Portion of non-rewearable post-consumer footwear waste from Moda re Koopera for analysis at CETIA

4.1 The Non-rewearable Value Chain Today

Collection and Sorting

In Europe, footwear is generally collected through used textile collection bins, sometimes supported by EPR fees. Collected footwear is generally sorted manually by quality, trend, gender, condition, damage, and brand. From there, footwear is either reused, incinerated or landfilled, sometimes after being exported to a country where incineration or landfilling are cheaper or less regulated.

> ***"Footwear is not designed for disassembly. Adhesives, mixed materials, and disruptors are major obstacles."***
>
> Recycling expert

In line with these observations, interviewees consistently estimated that only a small share of collected footwear is recovered or reused. While the literature review indicates that in the EU 5% of post-consumer footwear waste is recycled, 15% reused, and 80% landfilled[14], the recycled and reused shares are estimated to be potentially lower than 5% and 15%, reinforcing that current footwear collection systems primarily function as waste management rather than circular recovery mechanisms.

Across different facilities, shoes make up between 6% and 12% of the total collected feedstock (THF goods) annually. Experts noted that around 90% of these shoes have a synthetic upper, with sneakers, both performance and casual, forming the most common second-hand footwear. High-end, branded sneakers rarely appear in these waste streams.

The most common reasons shoes are considered non-rewearable are quality and archetype. If there are any signs of wear or damage, including dirt, small stains or discolouration, footwear is considered largely non-rewearable, unless the brand or style is particularly in demand and would justify a potential refresh or repair likely to be carried out by the potential consumer or second-hand retailer.

Overall, sorting occurs based on the requirements of buyers, international wholesalers, and importers of second-hand goods. Footwear categorised as higher quality is generally sold in Europe, while lower-quality footwear is sold outside Europe. Approximately 90% of sorted footwear is exported to international second-hand markets, while only about 5% is resold in local European second-hand shops. Sorters emphasised that incineration is costly, which indirectly incentivises export.

Although the resale value of footwear fluctuates, it always requires labour-intensive sorting and pairing and, in general, has low economic viability, except for the most valuable quality items. It must be noted that, with the increased accessibility of peer-to-peer resale platforms, many of the most valuable items may be traded there instead of being disposed of, further weakening the business case for sorters.

Post-consumer footwear export destinations

Export destinations are typically determined by product archetype and grade, as different markets demand specific styles or quality levels.

> ***"90% of sorted footwear is exported for second-hand markets, generally to Africa, Asia, and in particular Pakistan"***
>
> Sorter in Europe

Most post-consumer footwear entering Pakistan arrives through a mix of formal and informal channels, primarily via Karachi Port under Special Economic Zone (SEZ) regulations. While some large-scale importers handle these shipments through formal processes, most of the trade flows into long-established informal markets such as Khair Shah and Hajaji Camp. Once in the country, footwear is sorted, paired, graded, and resold based on quality and local demand. A substantial portion finds a second use through resale or repair, supported by strong domestic demand for affordable footwear.

Still, an estimated 5% to 6% of imported shoes remain unsold even after sorting. These are either repaired, repurposed for alternative uses, or sent for incineration. Pakistan also plays an integral role in sorting for re-export to other countries, such as the UAE and India.

> **Although transparency in the trade remains limited, emerging evidence suggests that informal networks often contribute to circularity, with traders and artisans restoring or creatively reusing footwear that would otherwise become wast**e.

Aligning these efforts with a Just Transition means valuing their existing expertise and ensuring that the shift to circularity is socially inclusive. Furthermore, grassroots solutions have already existed in the global south, and while they may not be found at scale, they are a solution to community-based repair and refurbishment. And while these are community-based and community-led solutions for waste generated domestically, the burden of imported waste coming in from the EU and other global north countries continues to grow in these destination countries.

Infrastructure and technology challenges in pre-processing and recycling

In general, although some solutions exist,[46] sorters have little incentive to sort footwear beyond rewearability. The first bottleneck is attributed to the complex design and composition, which makes it difficult to sort footwear at any level. Additionally, even if sorters are able to sort materials, the lack of end markets disincentivises sorters to build these capabilities further. Consequently, without offtake and partners, it is difficult for sorters to invest time and money into scaling appropriate sorting capabilities at their sorting facilities.

Shoes often contain multiple disruptors (adhesives, metals, hardpoints, mixed materials), and performance footwear is especially challenging due to the wide variety of components and the constantly evolving, highly complex designs driven by the need for newness. This complexity makes it difficult to meet performance requirements while maintaining the purity of waste streams necessary for effective recycling.

Today, it is common practice to first shred and later identify and separate materials, meaning that the purification and classification of material is only possible after shredding. Thus, it is generally necessary to grind the footwear into three-millimetre granules to achieve sufficient material separation and avoid granules containing multiple materials. While the requirement for three-millimetre granules is being met by technologies, it is not the best in class, and often the output still contains contaminants such as glues, which hinder the recycling process. This size requirement is directly related to the purity required for the output and may differ by recycling technology and desired output. It's important to note that due to the nascent nature of the technologies available for footwear or footwear materials recycling, closed-loop recycling is still uncommon. To put this into perspective, today most sole materials are thermoset polymers, which so far cannot be chemically recycled (at scale), thus recycling is limited to predominantly mechanical, which produces considerably lower quality materials that need to be downcycled to other industries.

It was revealed that close to 10% of the total sample would potentially be lost due to the presence of disruptors and carbon black pigments that cannot be identified by NIR technology.

On average, it was revealed that close to 10% of the total sample would potentially be lost due to the presence of disruptors and carbon black pigments that cannot be identified by NIR technology.

Consultations with sorters, recyclers, experts, and technology innovators show that footwear recycling technologies are still at a relatively low level of readiness. The most pressing challenge lies in material identification. Near-infrared (NIR) scanners, widely used in the textile sector, face significant limitations when applied to footwear. One sorter reported that 37.7% of their footwear input consists of black-coloured materials, which cannot be detected due to the presence of carbon black pigments. Without precise identification, such material can only be considered suitable for downcycling or lower-value applications. Beyond colour, the structural complexity of shoes creates further barriers. Innovators emphasised that accurate identification would require dismantling shoes piece by piece, yet this process is not only economically infeasible but further complicated by adhesives, which, even after disassembly, remain on the material surface, preventing scanning the material underneath and contaminating it.

Several materials are difficult to classify, such as black synthetic leather, styrene-butadiene rubber (SBR), and thermoplastic rubber (TPR), with SBR in particular lacking sufficiently large, non-black reference samples to enable proper training of the technology. Moreover, NIR sorting struggles to distinguish between visually similar polymers such as polyvinyl chloride (PVC) and polyurethane (PU). Mid-Infrared (MIR) technology can solve the problem of detecting carbon black, but has its own limitations due to the high use of heat, which can damage products, coupled with being more energy intensive and a higher cost[47]. As recyclers noted, these limitations mean NIR technology cannot yet be considered suitable for footwear, and its use in the sector remains limited.

> ***"It's not about recycling the separate components, but about the complexities around disassembly, that's the issue."***
>
> Industry expert

Data from pilot trials conducted with ELDAN Recycling and PICVISA (utilising NIR sorting) indicate that up to 50% of post-consumer input can be lost during the mechanical recycling process. These losses underscore the difficulty of achieving high yields from complex footwear. Furthermore, adhesives act as a significant, persistent contaminant in chemical recycling. In addition, different shredding size requirements across recycling facilities create further inefficiencies. Even when materials can be recovered, the resulting recyclates struggle to compete with virgin materials. This is especially problematic in the case of performance footwear, which has high performance requirements and strict technical specifications that recycled materials rarely meet. Still, rubbers show promise for closed-loop recycling, but PU foams and EVA are more difficult to recycle and reintegrate into footwear material.

Stakeholders agreed that without major innovations, combined with stronger demand-side pressure from brands and regulators, footwear recycling will remain stuck at a low technology readiness level.

Business case for footwear recycling

Stakeholders acknowledged the potential to develop a business case for footwear recycling, but the opportunity remains limited and highly conditional. At present, the sole, particularly the outsole, is considered the only part of the shoe that can be systematically recycled. Even here, the most common pathway is downcycling into lower-value applications, while true closed-loop recycling remains aspirational. While the widespread use of rubber, TPU, PU, and EVA in footwear offers a huge potential for waste reduction, actual recycling is stalled. Unlocking this potential requires overcoming both limited recycling technology and a weak market demand from large-scale buyers.

From an economic perspective, experts highlighted that circular shoes struggle to compete with conventional ones. Producing shoes from recycled materials (especially for TPU) increases material costs by roughly 10–20% or approximately EUR 1.8 per pair. While this margin might be manageable for performance footwear, where consumers are willing to pay higher prices if the performance is improved, it is unviable in the casual footwear market. Recyclers also pointed out that there are still no successful large-scale examples of footwear recycling to learn from. As a result, they are experimenting with cross-industry strategies, exploring sectors with lower performance requirements, such as automotive or bicycle parts, to build economies of scale and achieve price parity.

> ***"Due to high-performance requirements for footwear, it is not the easiest to adopt recycled materials. One potential way to add value to these outputs is to explore different industries with lower performance requirements."***
>
> Recycling innovator and researcher

Experts agreed that open-loop recycling offers more immediate opportunities than closed-loop systems, as it requires fewer technical and quality standards. Some of the recyclers, on the other hand, stated that they are able to carry out closed-loop operations with their technology and are doing so for all materials in different parts of the shoe. But these technologies would need further testing and review to determine whether they perform at scale and meet industry performance and price requirements.

Another recurring barrier lies in design. Stakeholders underlined the absence of frameworks for circular design in footwear, creating a missed opportunity for designers to embed recyclability into their products from the outset. Without such frameworks, disassembly and material recovery remain costly and inefficient. This underscored the objective of Phase 2 of the project, which focuses on on developing a roadmap toward circular design guidelines. Without stronger market signals or policy support, the economics of footwear recycling remain fragile, leaving the sector stuck in an exploratory stage rather than moving toward large-scale implementation.

4.2 On-the-ground data collection of post-consumer footwear

As outlined in the methodology section (Chapter 3), the initial data collection involved a sample of 1,500 unpaired, single shoes, using a tagging system and a material-profiling approach – with visual inspection, basic manual tools, and advanced digital tools, on the whole shoe without disassembly or shredding – which was subsequently refined to a finalised dataset of 1,200 shoes (with 14 data points collected per entry) for analysis.

The sample was obtained from Spain, collected during the spring/summer months of 2025, thanks to a partnership with Modare Koopera in Barcelona. The collection and sorting process involved 7,200 post-consumer footwear items, separating 4,340 (60.2%) rewearable items, 2,500 (34.7%) non-rewearable items, and 360 (5.1%) contaminated items that were sent for incineration.

From this, 2,500 non-rewearable items were sent to CETIA for detailed analysis encompassing 14 data points per shoe, as illustrated in Figure 8 below. The selection of shoes was intended to be as random as possible, to avoid favouring any footwear archetype over others and to give a realistic picture. The team of four CETIA staff, including engineers and sorters, and one Circle Economy staff member managed to collect the data of about 1,500 shoes over five days.

Rewearability in Apparel vs Footwear: comparing the learnings

- Footwear rewearability is lagging behind apparel, despite many shoes showing limited physical damage. In footwear, 42% is grade 2 and only 4% is cream quality, totalling 46% rewearable, while apparel sees 55% being rewearable. Cream quality is defined as the highest quality of the rewearable fraction that can be resold within Europe. In apparel, this cream quality fraction (55%) is generating the majority of the revenue.
- Footwear presents a significant, untapped opportunity for reuse. The primary reasons shoes are discarded are not due to physical damage, but rather system failures in managing pairing, cleaning, and economically viable resale. Notably, 24% of the analysed non-rewearable footwear sample showed no physical damage. In contrast, while apparel also contained a small fraction of undamaged garments, due to factors like fashion cycles, fit, and quality, this percentage was not as high as observed with footwear.

NIR scanning was used for both the textile upper and sole, using Matoha's Fabritell and ShoeTell devices, respectively. CETIA's IDShoes, as well as Sensorhub with its X-Ray capabilities, were also applied.

Figure 8: Overview of data collection points obtained in the study

USER CATEGORY

1. Men's shoes
2. Women's shoes
3. Children's shoes
4. Unisex shoes
5. Other: mention

PRODUCT ARCHETYPE

Performance Shoes
1. Basketball Shoes
2. Football/ Soccer Shoes
3. Running Shoes
4. Cycling Shoes

Sandals
1. Ballerina Flats
2. Heels
3. Dress Sandals
4. Clog

Slides/Slippers
1. Slippers / Flip-flops
2. Slip on shoes

Lifestyle Shoes
1. Trainers
2. Slip on sneakers
3. Collectable sneakers/ Luxury
4. Formal shoes
5. Casual Shoes

Boots
1. Outdoor/Hiking Boots
2. Formal Boots
3. Boots with high heel
4. Snow Boots

Other

COMPOSITION ANALYSIS

Upper
1. Cotton
2. Acrylic
3. Polyester
4. Nylon
5. Viscose
6. Wool
7. Polypropylene
8. Silk
9. Acetate
10. Elastane
11. Unknown

Sole

PET
PA
Rubber
EVA
Neoprene
NBR
Silicone
ABS
PU
PVC
SBR
SBS
TPU
Unknown

COLOUR ANALYSIS

Upper

Primary Colour
1. Red
2. Pink
3. Blue
4. Green
5. Brown
6. Orange
7. Yellow
8. Black
9. White
10. Grey
11. Multi Colour

Accent Colour(s)

Sole

Primary Colour
1. Red
2. Pink
3. Blue
4. Green
5. Brown
6. Orange
7. Yellow
8. Black
9. White
10. Grey
11. Multi Colour

Accent Colour(s)

DISRUPTOR

Internal
1. Metal
2. Plastic
3. Wood
4. Others: mention

External
1. Metal
2. Plastic
3. Leather
4. Textile
5. Electric components
6. Wood
7. Others: mention

ASSEMBLY TECHNIQUE

1. Stitched
2. Bonded
3. Glued
4. Other
5. Unknown

PHYSICAL DAMAGE

Upper

Soiled
Tears/holes
Discoloration
Other: mention

Sole

Detached from upper
Tears/holes
Worn out from use
Other: mention

BRAND

Unbranded

Branded

adidas , Arcteryx, Dr.Martens, ON, Nike, Skechers, Asics, Champion, COACH, Clarks, Colombia, Converse, Crocs, Fila, lotto, New Balance, Puma , Reebok , Salomon, Tamaris, Tommy Hilfiger, Vivobarefoot, Birkenstock, ALDO, Bata , Vans, G-Star, Hush Puppies, Jordan, Kappa, Decathlon, UGG, Hoka, Teva, AHNU, Reformation, Other: mention

4.3 Complimentary material composition study conducted by PICVISA.

PICVISA PILOT: AUTOMATED NIR SORTING OF SHRED FOOTWEAR MATERIAL

The sorting trials conducted using PICVISA technology provide a detailed view into the behaviour of post-consumer footwear waste under automated classification and separation systems. By analysing the distribution of material fractions and the relationship between input and recovered output across different footwear categories, several important insights emerge regarding system efficiency, material characteristics, and the broader implications for circular footwear systems.

To meet the specific input requirements for PICVISA's optical sorting machinery, the footwear sample was first processed through ELDAN's two-stage process of mechanical shredding followed by density separation (Figure 9).

Approach

- Preprocessing: Post-consumer shoes were shredded into smaller fractions to enable sensor-based detection.
- Categorisation: Trials were organised into distinct batches (Performance, Lifestyle, Sandals/Slippers, Boots, and Unmarked) to test the impact of product design on recovery.
- Identification: PICVISA's NIR (Near-Infrared) technology was employed to distinguish between polymers such as TPU, EVA, and Rubber.
- Evaluation: Comparisons were made between the initial input weight and the final recovered output across five distinct footwear batches

Trial Data & Observations

The dataset revealed a clear dominance of light and heavy material fractions across all batches, while metals remained a marginal component.

1. Material loss after shredding and density separation

- Batch 1 (Performance): Highest textile concentration; 73% of materials were identified as light fraction (mostly lost during processing).
- Batch 2 (Lifestyle): 60% material loss.
- Batch 3 (Sandals & Slippers): 53% material loss.
- Batch 4 (Boots): Highest recovery rate, with only 25.5% material loss.

2. Automated NIR sorting efficiency of the 'heavy fraction'

- **Sorting efficiency is dependent on consistency of the input:** Homogeneous categories like Lifestyle (Batch 2) showed near-complete sorting yield, matching outputs closely to inputs. This indicates that homogeneous product categories with consistent material compositions are more compatible with automated sorting. Structured categories like Performance and Boots demonstrated relatively moderate sorting yield.
- **Complexity and inadequate pre-sorting are barriers to material recovery:** Heterogeneous categories characterised by higher material complexity or weaker pre-sorting show noticeably low sorting yield. The Unmarked batch, despite having the highest volume, had the lowest recovery rate due to its heterogeneous nature.
- **Automated recovery yields are dependent on polymer types:** The PICVISA system utilises a sequential detection logic (Black Flakes -> Rubber -> TPU -> EVA). Rubber emerged as the most reliably recoverable polymer (Figure 10), consistently achieving the highest recovery and separation accuracy across nearly all test batches. TPU recovery was lower than manual benchmarks, likely due to TPU being misclassified into the lighter fractions, while EVA recovery proved inconsistent and dependent on the overall batch context.

Key Learnings

1. The study indicates that automated sorting is sensitive to input quality. To maximise recovery rates and output quality, facilities should implement hybrid systems that combine manual or AI-assisted pre-sorting with downstream optical technology. Reducing input variability before it reaches the sensors is essential to minimising rejection rates.
2. Yield efficiency (recovered output vs. total input) is a baseline metric but can be misleading in isolation. Future evaluations must utilise a structured performance framework that balances throughput with material purity and loss rates. This ensures that high-volume batches are not prioritised at the expense of low-quality, contaminated output.
3. To achieve higher efficiency, PICVISA technology is better suited to be deployed where input streams are controlled and pre-classified, such as retail take-back programs, industrial waste, or facilities with established front-end sorting. Conversely, highly mixed municipal waste requires significant preprocessing infrastructure to reach comparable performance levels.
4. Footwear's inherent complexity, specifically multi-material bonding, adhesives, and coatings, acts as a disruptor to optical and mechanical separation. There is a need for stronger alignment between footwear design and the state of recycling infrastructure.
5. Automated sorting cannot solve the circularity gap in isolation. Meaningful progress requires coordinated, systems-level intervention: enhancing collection and pre-sorting systems while also simultaneously improving product design for material circulation and the deployment of integrated sorting technologies.

In conclusion, the PICVISA sorting trials demonstrate both the potential and the limitations of current automated sorting approaches. While high levels of efficiency can be achieved under controlled conditions, significant challenges remain when dealing with heterogeneous and complex waste streams. By adopting a holistic approach that combines technological innovation with system-level improvements, it is possible to unlock greater material recovery and move closer to a truly circular footwear ecosystem.

To enable meaningful comparisons across pilots, geographies, or technology configurations, it is therefore essential to standardise key performance indicators. These should include not only yield/efficiency and loss rates but also the distribution of material fractions and qualitative assessments of input stream characteristics. Such a framework would allow stakeholders to distinguish between performance limitations arising from the technology itself and those resulting from external factors such as material complexity or insufficient pre-sorting.

Figure 9: Shred and separated output at ELDAN Recycling, on the left, light fraction, and on the right, heavy fraction

Figure 10: Rubber sorting, on the left, material sorted as Rubber, and on the right all the other material

4.4 Complimentary material composition study conducted by THE 8 IMPACT

THE 8 IMPACT STUDY: END-TO-END SNEAKER RECYCLING AND KEY LEARNINGS

THE 8 IMPACT conducted a comprehensive study on sneaker recycling (Figure 11), covering the entire material lifecycle– from feedstock characterisation, separation, and regeneration to incorporation into new products and industrial production. Unlike prior sorting-focused studies, this work addresses materials end-to-end, producing recycled compounds that can replace a certain percentage of virgin materials without compromising mechanical, aesthetic, or toxicological properties.

Technical Approach

The study categorised sneakers into three main types: complex, standard running, and vulcanised shoes. Each category was processed separately to maximise material recovery. Pre-sorting was conducted by collectors and French social enterprises, ensuring consistency and low variability. Materials were mechanically separated, followed by micronisation: granulates of ~4 mm were further reduced to ~500 µm, enabling optimal interlocking with virgin materials while minimising energy use. IR spectroscopy was employed to identify materials and enhance separation accuracy. Throughout the process, material quality, mechanical performance, aesthetics, and compliance with REACH and toxicological requirements were rigorously tested at a pre-industrial scale.

Data Verification and Industrial Trials

The study processed over 2,000 pairs of shoes, with statistical verification reducing sorting errors from ~7% to 3%. Mechanical, aesthetic, and toxicological properties were validated for pre-industrial batches containing up to 40% recycled material. Industrial trials, demonstrated that the regenerated materials could meet brand Bills of Properties and integrate seamlessly into production lines. Trials confirmed scalability and industrial feasibility, with extended producer responsibility frameworks helping offset costs for smaller batches.

Key Learnings

1. **Industrial Capability and R&D Approach:** THE 8 IMPACT's process is fully R&D-driven, scientifically validated, and capable of producing recycled materials that meet brand standards and manufacturer acceptance.
2. **Sorting as a Performance Driver:** Category-based sorting ensures minimal variability and consistent material quality. Local social enterprises perform sorting, supporting jobs while maintaining high accuracy (~98%).
3. **Grinding and Separation:** Rubber can be decontaminated and suitable as a virgin substitute. The separation process balances energy use with material quality, stopping at the optimal point to avoid inefficiencies.
4. **Regeneration and Micronisation:** Micronisation produces fine particles (~500 µm) that interlock with virgin materials, ensuring technical and economic value while enabling brand-spec-compliant integration.
5. **Strategic Outcomes:** Recycled materials (rubber and EVA) replace virgin compounds at an industrial scale, achieve price parity through volume and margin control, and require early collaboration with design and supply chain teams. Offtake commitments from brands and manufacturers are critical to realising full production capacity.

This study demonstrates that end-to-end sneaker recycling is technically viable, industrially scalable, and capable of delivering recycled materials that are functionally competitive with virgin materials, paving the way for a circular approach in footwear production.

Figure 11: Masterbatch and sole produced by The 8 Impact

05.

UNPACKING THE RESULTS: A DEEP DIVE INTO NON-REWEARABLE POST-CONSUMER FOOTWEAR

The analysis of a random sample of 1,200 single shoes yielded 14 data points per item. This section presents a detailed analysis of the non-rewearable footwear fraction collected in the study. By examining material composition, colour, assembly techniques, and the presence of disruptors, it provides insights into the technical barriers that limit reuse and recycling potential, while identifying patterns that can inform design for circularity.

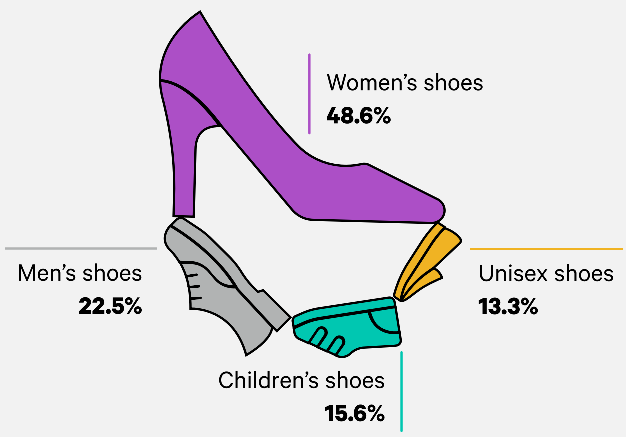
5.1 Non-rewearable Footwear Characteristics

To address existing data gaps, the team systematically recorded data on user category, archetype, type, damage, materials, colour and brand. This allowed for a clearer understanding of why shoes are classified as non-rewearable and provided an evidence-based overview of what is currently being discarded, while also revealing patterns across different product features and qualities.

User category

In our sample, women's shoes were the most represented, accounting for 48.6% of the intended users (Figure 12). This was followed by men's shoes at 22.5%, then children's shoes at 15.6%, and unisex shoes at 13.3%.

Figure 12: User category distribution of the sample of non-rewearable footwear



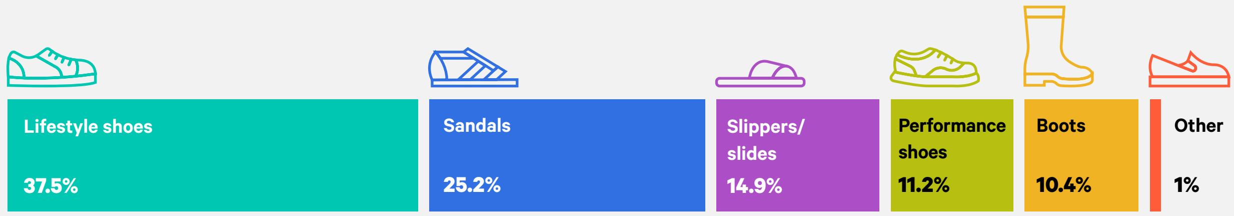
Archetypes and sub-archetypes

Footwear archetypes are subject to different performance requirements and material compositions. For instance, a sandal features a minimal upper and is built from fewer parts and materials compared to a running shoe, which incorporates multiple sole layers and specialised materials to provide the cushioning and support needed for sports activities. Collecting information on archetypes enables a more detailed understanding of the composition and characteristics of non-rewearable footwear. Considering there was no existing system to classify footwear archetypes, the team developed broad archetype categories based on each shoe's main function and design features. Details on how these archetypes and sub-archetypes were classified and illustrated are provided in Annexe III.

In the sample, the most common archetype was lifestyle shoes (37.5%), followed by sandals (25.2%), slippers/ slides (14.9%), and performance shoes (11.2%), as illustrated by Figure 13. Lifestyle shoes represented nearly one-third of the total sample, highlighting their dominance in the non-rewearable stream. The high share of sandals likely reflects the geographic origin of the sample and the time of the year.

Because this variable was collected through visual inspection, sub-archetypes were introduced to reduce human error and capture more precise distinctions within each category. Sub-archetypes were defined by visible functionality or distinctive design elements. Within lifestyle shoes, the largest sub-archetypes were trainers (81%) and slip-on sneakers (11%). For sandals, the breakdown included dress sandals (38%), heels (27%), and ballerina flats (20%). Among performance shoes, running shoes accounted for 69%, followed by other types, such as trail, tennis, golf, and padel shoes (21%).

Figure 13: Archetype distribution



Some existing recycling companies (such as THE 8 IMPACT) look to archetypes as a basis to sort feedstock due to the materials used for specific archetypes, like lifestyle sneakers and performance shoes. This ensures a high yield of recyclable materials for the existing infrastructure. Within our study, we also found that patterns in materiality in the two archetypes were consistent, where EVA was the most common in midsoles and RUB SBR in the outsoles.

Damage

Damage was recorded separately for the upper and the sole and defined as any visible physical deterioration that justified a shoe being classified as non-rewearable. Overall, 76% of the sample showed some form of damage, either in the upper, the sole, or both, while 24% had no visible damage. It is important to note here that one reason for them to be classified as non-rewearable is that they were often single, unpaired shoes, which strongly indicates the need for proper disposal of paired shoes in order to maximise their value on the second-hand market.

A clear difference emerges between the two parts of the shoe: 72% of shoes displayed damage on the upper (for both leather and textile uppers), compared to only 26% with damage on the sole (see Figure 14 below to see the top damage types). In many cases, more than one damage type was present, meaning the percentages shown below are not cumulative. Figure 15 illustrates the distribution of upper damage types. The most common forms were soiling (50%) and discolouration (27%), followed by tears or holes (16%), and other minor issues (1%). Additionally, 3.34% of shoes that showed damage on both the upper and sole were found to have overused outsole and tears/holes.

Figure 14: Top damage types in soles and uppers

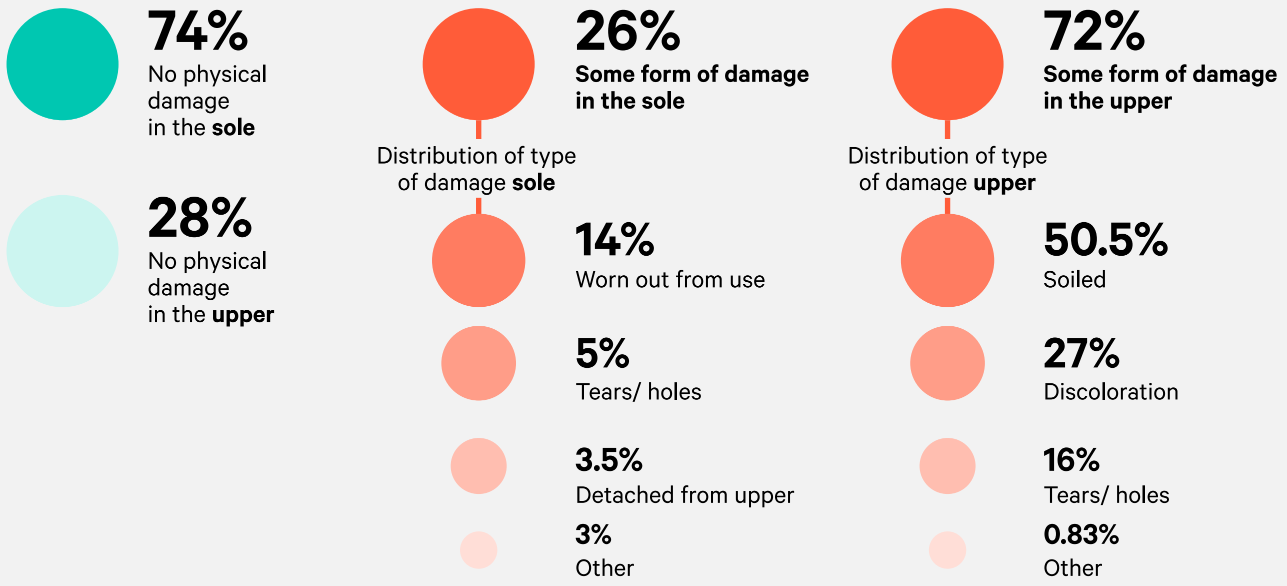


Figure 15: Distribution of the type of damage in the upper across the sample

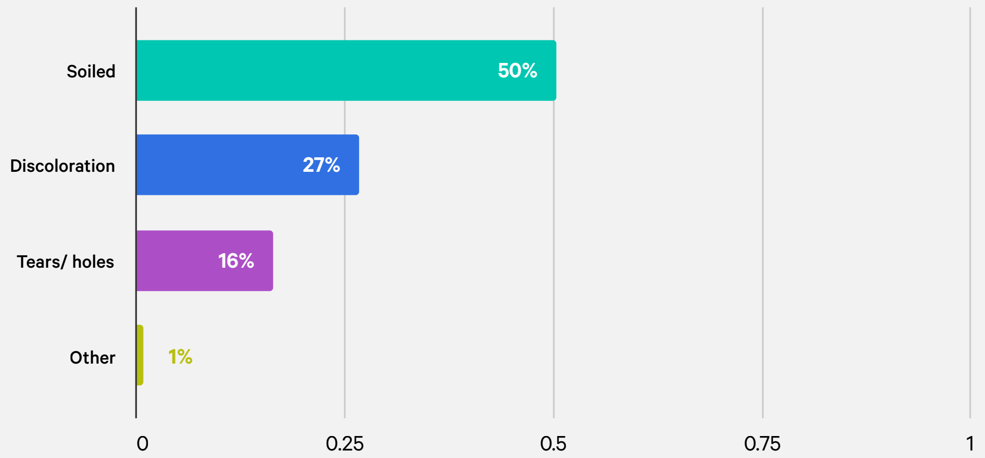
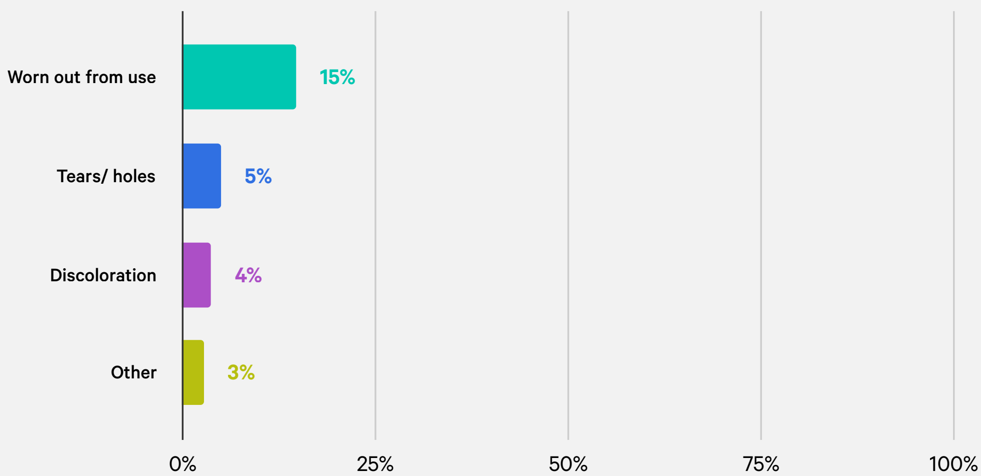


Figure 16 presents the damage distribution for soles, where wear from use (15%) was most frequent, followed by tears/holes (5%), detachment from the upper (4%), and other types (3%).

Figure 16: Distribution of the type of damage in the sole across the sample



As mentioned, a predominant reason for footwear to be categorised as non-rewearable is the absence of a matching pair. However, our findings show that shoes are also deemed non-rewearable due to upper deterioration, more often for aesthetic reasons than structural damage. This pattern highlights an opportunity for repair or refurbishment strategies, as many shoes could theoretically be restored to a wearable condition, and furthermore, a signal to brands to improve the durability of the upper.

As shown in Figure 17, the majority of shoes within each archetype category are damaged. The only exception is slippers/slides, where the share of damaged and undamaged pairs is roughly equal, reflecting simpler construction and shorter use cycles. Figure 18 shows the top damages per archetype.

Figure 17: Damage precedence across footwear archetypes

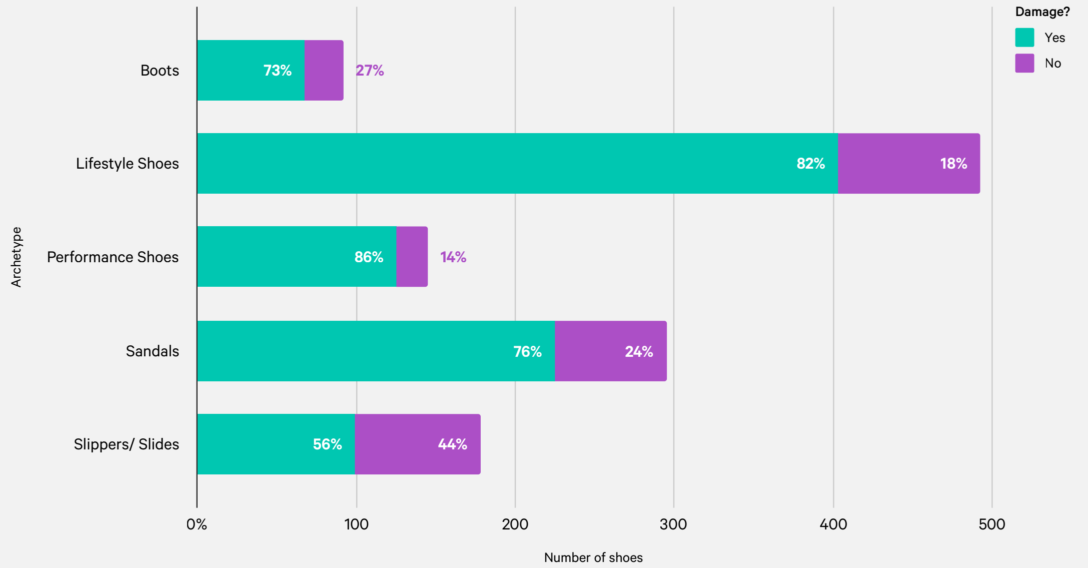
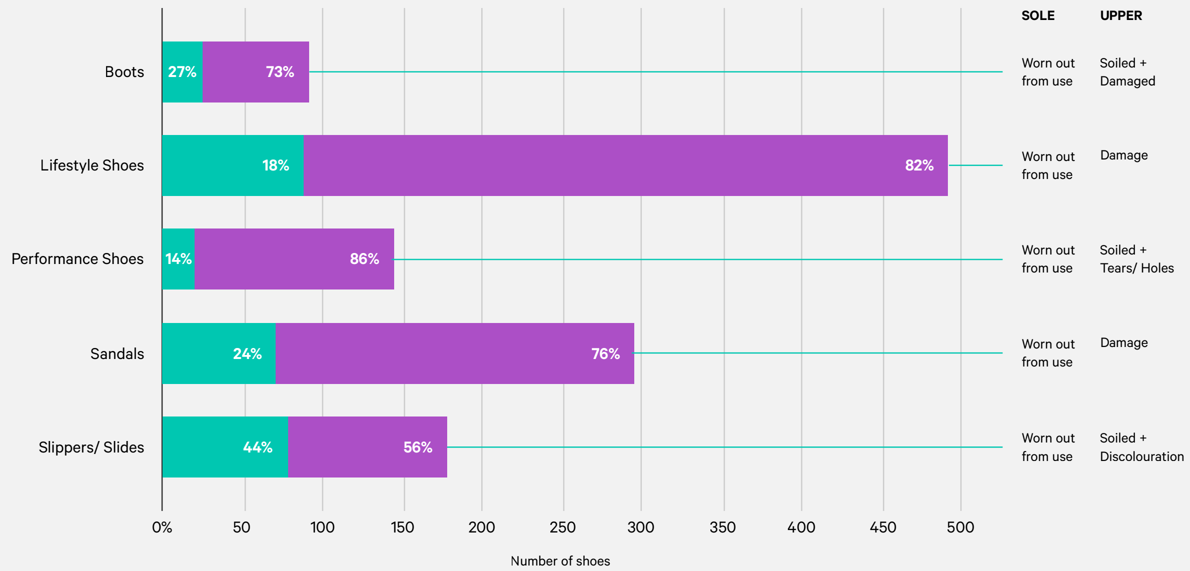


Figure 18: Top damages per archetype



The analysis of sole materials reveals distinct failure patterns linked to specific polymer types. Notably, Styrene-Butadiene-Styrene (SBS), a common thermoplastic elastomer used for its rubber-like flexibility and high grip in casual and athleisure shoes, dominates several damage categories:

- Worn out from use: Predominantly SBS
- Tears or holes: Predominantly SBS
- Detached from upper: Primarily Rubber - SBR
- No visible damage: Mostly SBS

This indicates that SBS, while common, tends to show higher rates of abrasion and surface wear, whereas SBR is more prone to detachment issues. These patterns highlight the trade-offs between flexibility, adhesion, and durability that influence both product lifespan and recyclability. When we see the damage patterns in the textile uppers, mixed compositions showed the most consistent damage across all damage types.

Overall, while the findings indicate visible wear and contamination, the implications of the data show that models for cleaning and refurbishment systems could extend the life of footwear before recycling, particularly if discarded shoes are collected in pairs. Because SBS is the most prevalent material regardless of condition, understanding beyond broad categories to understand how specific SBS formulations influence both product durability and the quality of recycled feedstock.

Brand

Within the sample, 59.5% of shoes were unbranded, while 40.5% belonged to recognisable brands.

To further understand the characteristics of this non-rewearable fraction, the average number of physical damage on the upper was analysed by brand.

The differences found may reflect variations in material quality, upper construction, or usage patterns, providing insight into how certain design or production choices influence durability. However, no definitive conclusions can be drawn without information on each item's production year, usage duration, and wear pattern. Even so, identifying these brand-level patterns can help guide efforts to develop more resilient, longer-lasting footwear that better withstands wear and delays entry into the non-rewearable stream.

5.2 Material composition

Sole

The material composition analysis was conducted separately for the upper and sole.

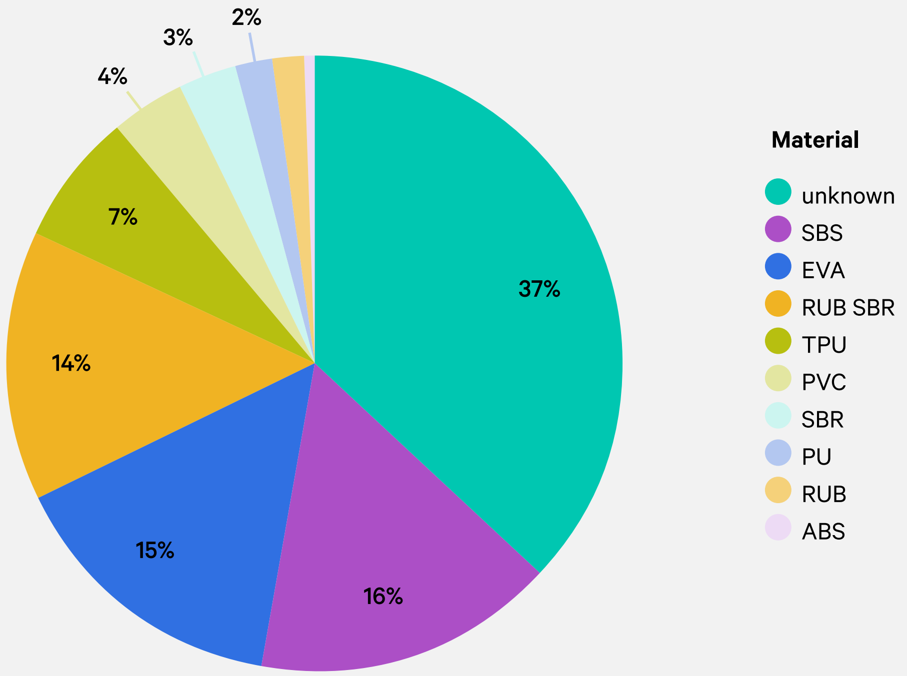
Nearly 37% of soles could not be identified due to technological limitations in detecting materials containing black pigments and/or blended compounds.

For the sole, the results show that the sample size was characterised by a high volume of unclassified or unknown entries; among the categorised samples, SBS, EVA, Rubber, and TPU were the most frequent (Figure 19). Nearly 37% of soles could not be identified due to technological limitations in detecting materials containing black pigments and/or blended compounds.

97% of scanned black soles were classified as 'unknown'

In fact, 97% of scanned black soles were classified as 'unknown', demonstrating how the presence of carbon black pigments makes the material unidentifiable, given the current state of NIR technologies. This unknown category is not only attributed to the sole colour but also to the blended polymers present in the soles, which Matoha ShoeTell cannot currently identify.

Figure 19: Sole material composition



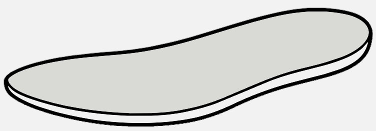
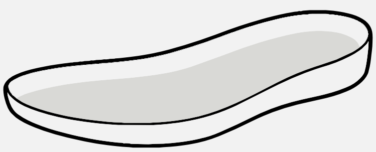
When it comes to materials by archetype, we saw patterns in material type and archetype. For performance shoes, EVA is the most common material. In contrast, SBS is most frequent in sandals and boots, SBR in lifestyle shoes, and EVA in slippers/slides.

A detailed material analysis, including cutting the sole and scanning both the inlay and in-sole (Figure 20), was conducted on 105 shoes – comprising 52 lifestyle and 53 performance shoes to better understand the complexity of footwear composition. These two archetypes were chosen because their soles typically consist of at least two to four distinct components: insock, insole, midsole, and outsole, each often made of different materials.

Figure 20: Set up of cutting footwear for detailed analysis

This detailed data was collected only for the sole, as prior research and expert consultation indicated that the sole represents both the greatest recycling potential and one of the main challenges due to its complex structure and material diversity. The in-depth analysis further revealed that only 10.5% of shoes shared the same material for both the midsole and outsole (among shoes that included both parts). This finding highlights the importance of pre-processing and material separation. From this analysis, it was found that 55% of shoes contained all four sole components, while 45% had three or fewer layers (insock, insole, midsole, and outsole). The detailed results for both archetypes are presented in Table 1.

Table 1: Detailed material and sole component analysis of performance and lifestyle footwear

SOLE PART	MATERIAL COMPOSITION PERFORMANCE SHOES		MATERIAL COMPOSITION LIFESTYLE SHOES	
Insock 	**53.9%**	Blends	**34.6%**	Polyester
	34%	Polyester	**25%**	Mixed
	24.5%	Unknown	**23.1%**	Unknown
	3.8%	Did not have an insock	**9.6%**	Cotton
	1.9%	Elastane	**3.9%**	Did not have an insock
			1.9%	Silk
			1.9%	Viscose
Insole 	**39.6%**	EVA	**30.8%**	EVA
	20.8%	TPU	**19.2%**	TPU
	15.1%	Did not have an insole	**13.5%**	Unknown
	13.2%	Unknown	**11.5%**	Did not have an insole
	3.8%	Blends	**9.2%**	SBR
	3.8%	PU	**5.8%**	SBS
	3.8	Elastane	**5.8%**	PU
			1.9%	PVC
			1.9%	Acrylic
			1.9%	Elastane
Midsole 	**64.2%**	EVA	**46.2%**	EVA
	20.8%	Did not have a midsole	**13.5%**	Did not have a midsole
	9.4%	Unknown	**11.5%**	Unknown
	3.8%	SBS	**9.6%**	SBR
	1.9%	EVA/TPU	**5.8%**	TPU
			3.9%	PU
			1.9%	TPU/PU
			1.9	PVC
Outsole 	**37.8%**	SBR	**48.1%**	SBR
	28.3%	EVA	**19.2%**	Unknown
	26.2%	Unknown	**11.5%**	SBS
	3.8%	SBS	**7.7%**	EVA
	3.8%	TPU	**5.8%**	PVC
			3.9%	SBR
			1.9%	TPU
			1.9%	EVA/SBR
			1.9%	EVA/TPU
			1.9%	PU

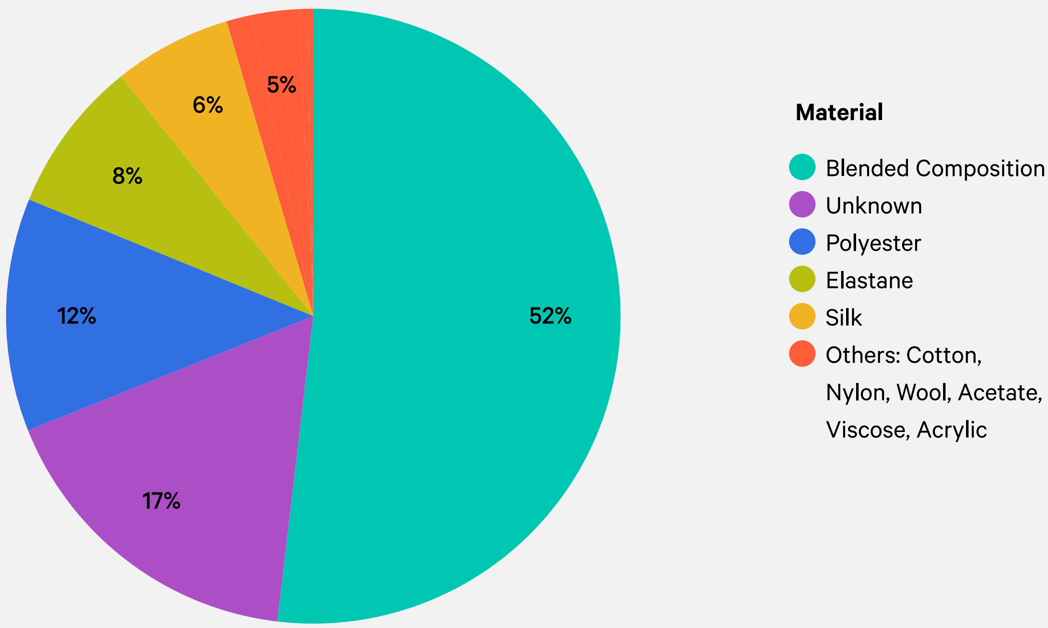
Following the initial on-ground study, the materials were processed through ELDAN shredding and PICVISA automated sorting. The results reveal a recovery gap between manual identification and industrial separation:

- PICVISA identified 41.4% of the material as black flakes, compared to only 24.6% via manual scanning. This suggests that the mechanical shredding process exposes internal black components (reinforcements/linings) previously hidden from surface-level scanning.
- Rubber displayed the most consistent results, with 19.7% recovery against an identified 18.5%, validating its stability in automated systems.
- Both EVA and TPU saw a decrease in yield in the automated trial. EVA dropped from 33% (Matoha) to just 6% (PICVISA), while TPU fell from 14% to 5%. This identifies a critical technical bottleneck where these polymers are likely lost as 'lightweight' or misclassified due to their physical state after shredding.

Upper

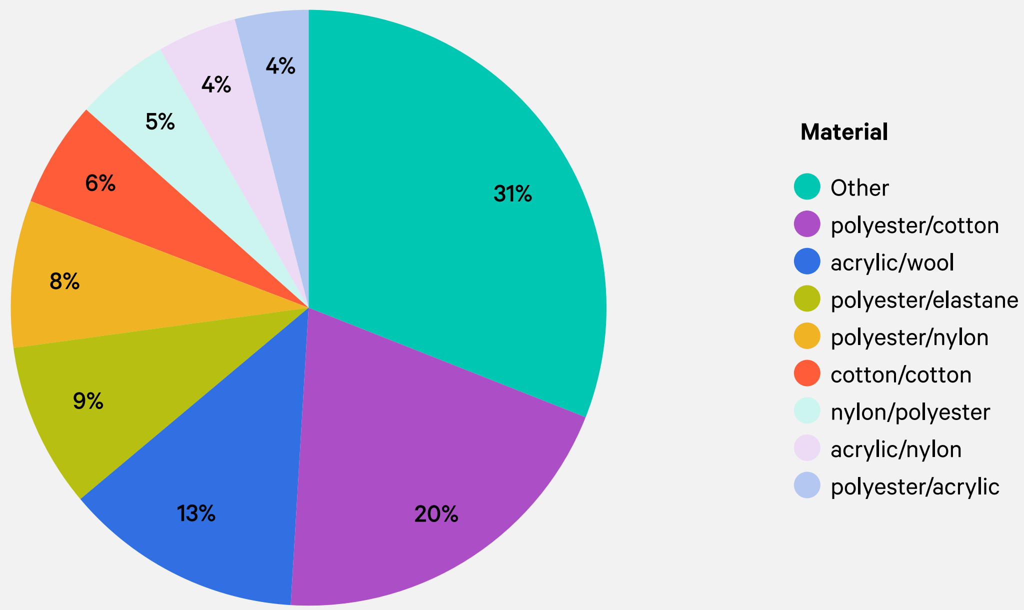
The analysis of the upper material composition shows that nearly half of the sample (52%) consists of mixed material compositions (Figure 21). As noted in the study limitations, leather was excluded from this breakdown as the current technology frequently fails to accurately identify it; the inconsistent chemical coatings and surface reflectivity of tanned leather often interfere with spectroscopic analysis, leading to unreliable readings.

Figure 21: Upper material composition



Among these blends, the most common combinations were polyester/cotton (20%), acrylic/wool (13%), and polyester/elastane (9%). The remaining share (31%) corresponds to other blend types, each representing less than 2% of the total blended fraction (Figure 22).

Figure 22: Share of material composition of blends



When comparing across product archetypes, the majority feature mixed composition as the predominant upper material. Overall, we observe that the most common materials were mixed or unidentifiable, followed by SBS for the sole and material blends for the upper.

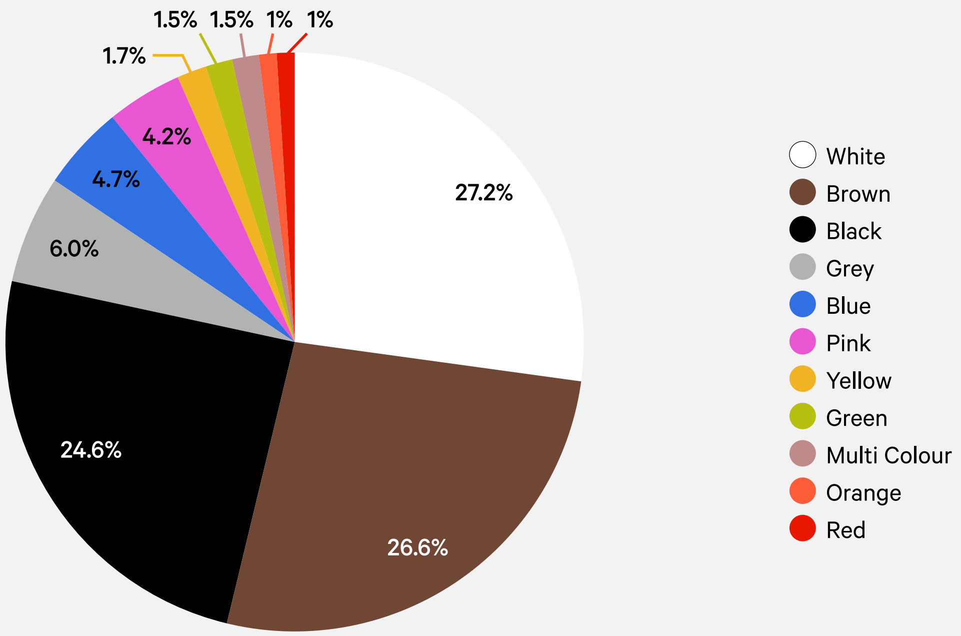
5.3 Colour

Data on colour was collected to understand the complexity of the products. For the upper, understanding colour for recycling was essential to understand the recycling potential. While footwear recyclers today do not specifically need colour segregation, colour analysis also gave us an understanding of the complexity of sorting. For example, if sorters were to sort footwear, they would need to assess each coloured material separately since it would be assumed they are different materials. In the long term, this affects how sorters would need to be trained when sorting at scale.

Sole

The dominant colour of the outsole was white (27.2%), followed by brown (26.6%) and black (24.6%). It is important to note that 97% of black soles had an unknown material composition, due to the limitations of the scanning technology in identifying materials containing carbon black pigments. As shown in Figure 23, 24.6% of soles were black, aligning closely with the 37% of soles categorised as having unknown material composition—indicating a strong overlap between the two.

Figure 23: Share of material composition of blends



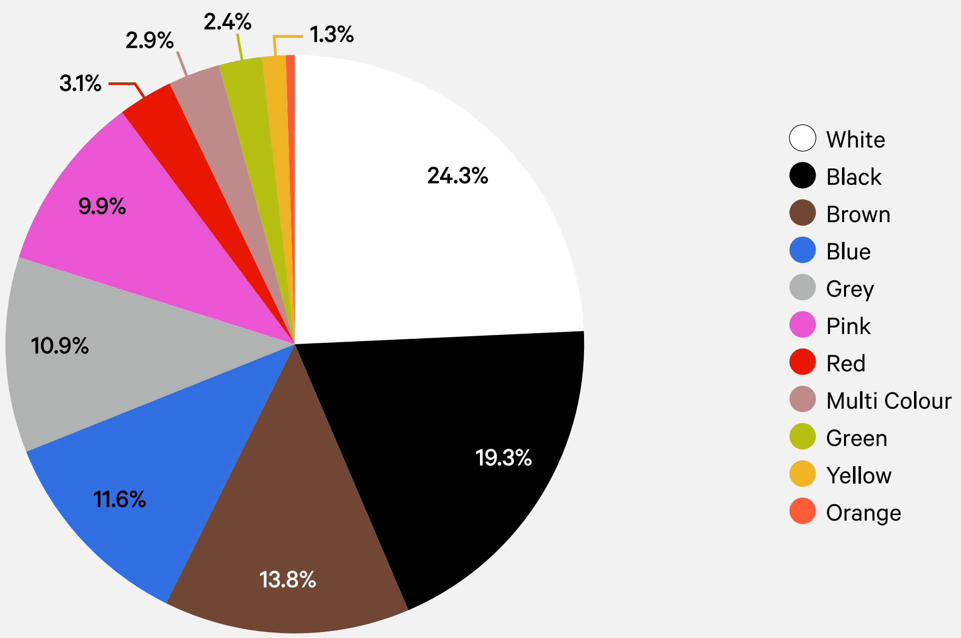
Upper

The colour distribution of uppers varies significantly across shoe archetypes. The most common upper colour for each archetype is as follows:

- Boots: Brown
- Lifestyle shoes: White
- Other: Black
- Performance shoes: Black
- Sandals: Brown
- Slippers/Slides: Blue

Overall, Figure 24 shows that white (24.3%), black (19.3%), and brown (13.8%) are the most prevalent upper colours across the sample, followed by blue (11.6%), grey (10.9%), and pink (9.9%).

Figure 24: Colour found in the upper



5.4 Assembly technique

The assembly technique refers to how the upper and sole are joined together. This characteristic is particularly relevant because it directly influences the ease of disassembly, which is essential for enabling repair, reuse, and recycling processes.

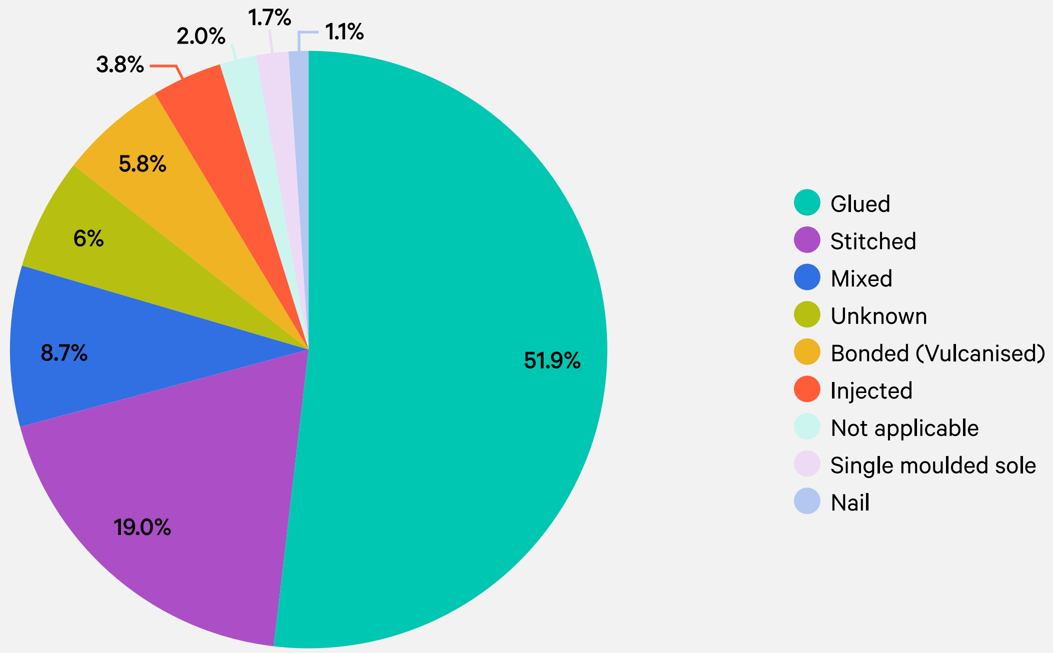
Across the sample, glueing was identified as the most common assembly technique (52%). The presence of glue not only complicates disassembly but also interferes with NIR material identification, since the adhesive layer obstructs the detection of the material beneath it, which could cause shredded material to remain unidentified in solutions like Ecoflake by PICVISA.

The second most frequent assembly method was stitching (19%), followed by mixed techniques (9%). Within the mixed group, the most common combinations were:

- Glued/nail: 5% of the total sample
- Stitched/glued: 2.5%
- Stitched/nailed: 0.5%

The complete distribution of assembly techniques is presented in Figure 25, where 'not applicable' means that there was no bonding technique (such as for shoes that had a detached sole or sandals).

Figure 25: Assembly technique across the sample



When broken down by brand, the majority of shoes were assembled using glue. In contrast, Converse and Vans predominantly used bonded (vulcanised) construction methods, which are typical for their canvas and rubber designs.

Across shoe archetypes, glued is the most common assembly technique, except for slippers/slides, where stitched dominates. The second most common technique varies: glued and nail for boots, stitched for lifestyle shoes and sandals. Nearly all performance shoes were assembled using glue.

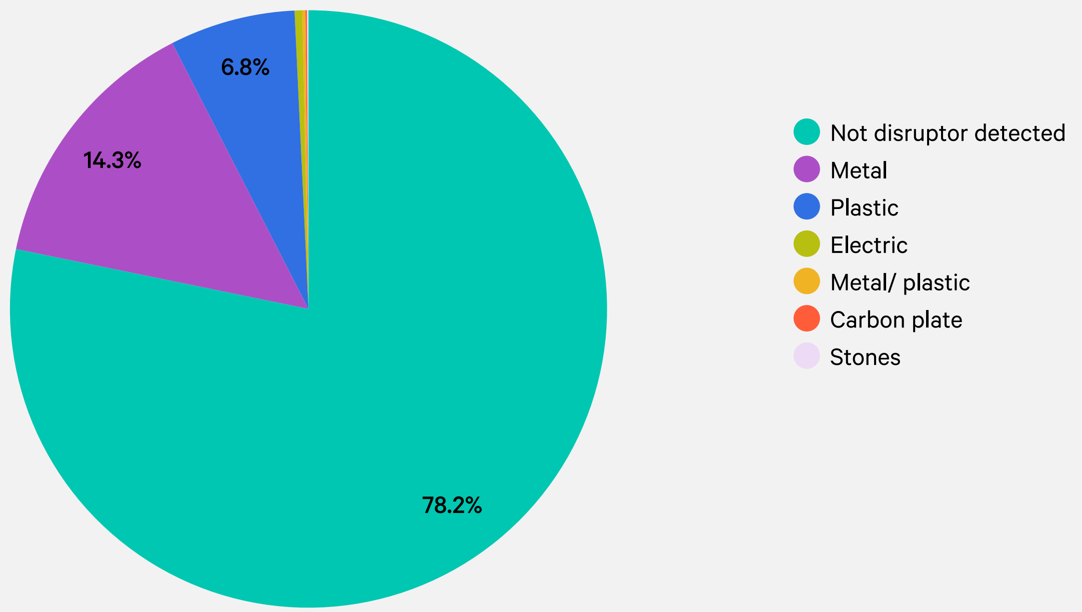
5.5 Disruptors

For this study, disruptors were defined as any additional component in a shoe that is not part of the main upper or sole. These elements were recorded separately as external disruptors (visible features) and internal disruptors (hidden components detected through X-ray analysis). Collecting this information is essential, as disruptors can significantly complicate disassembly, reduce material purity, and pose risks during mechanical or recycling post whole shoe shredding (for example, damage to the recycling machinery).

Overall, the analysis revealed that 89.9% of shoes contained at least one external disruptor, while only 10.1% showed none. In contrast, 21% of the sample contained internal disruptors, whereas 78% had none.

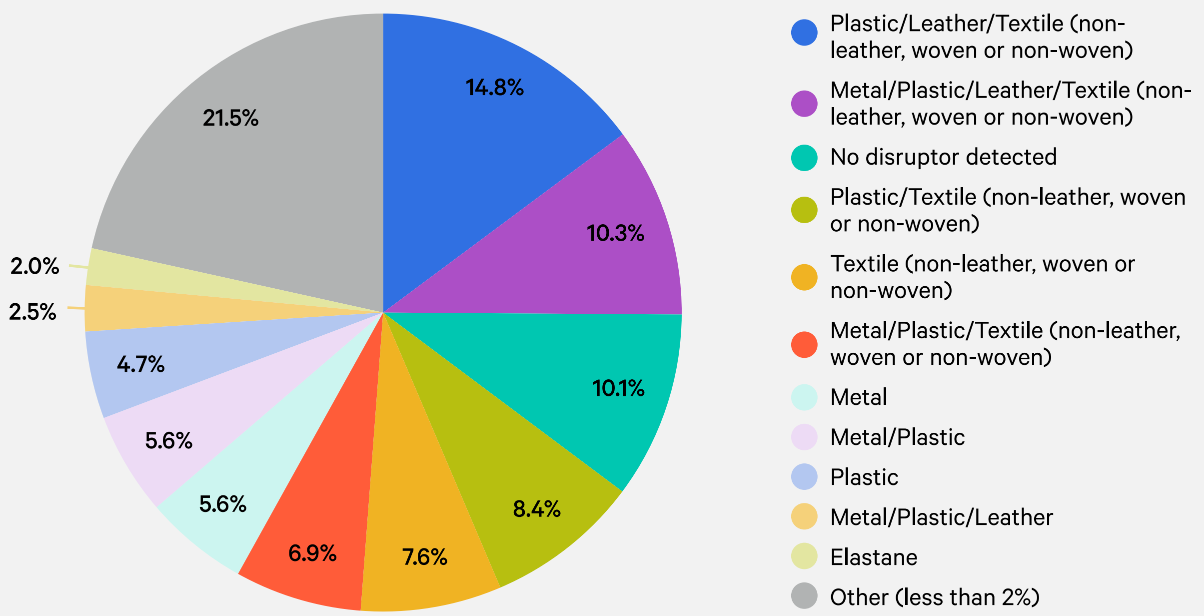
The breakdown of the share of external and internal disruptors can be found in Figures 26 and 27, respectively.

Figure 26: Share of internal disruptors



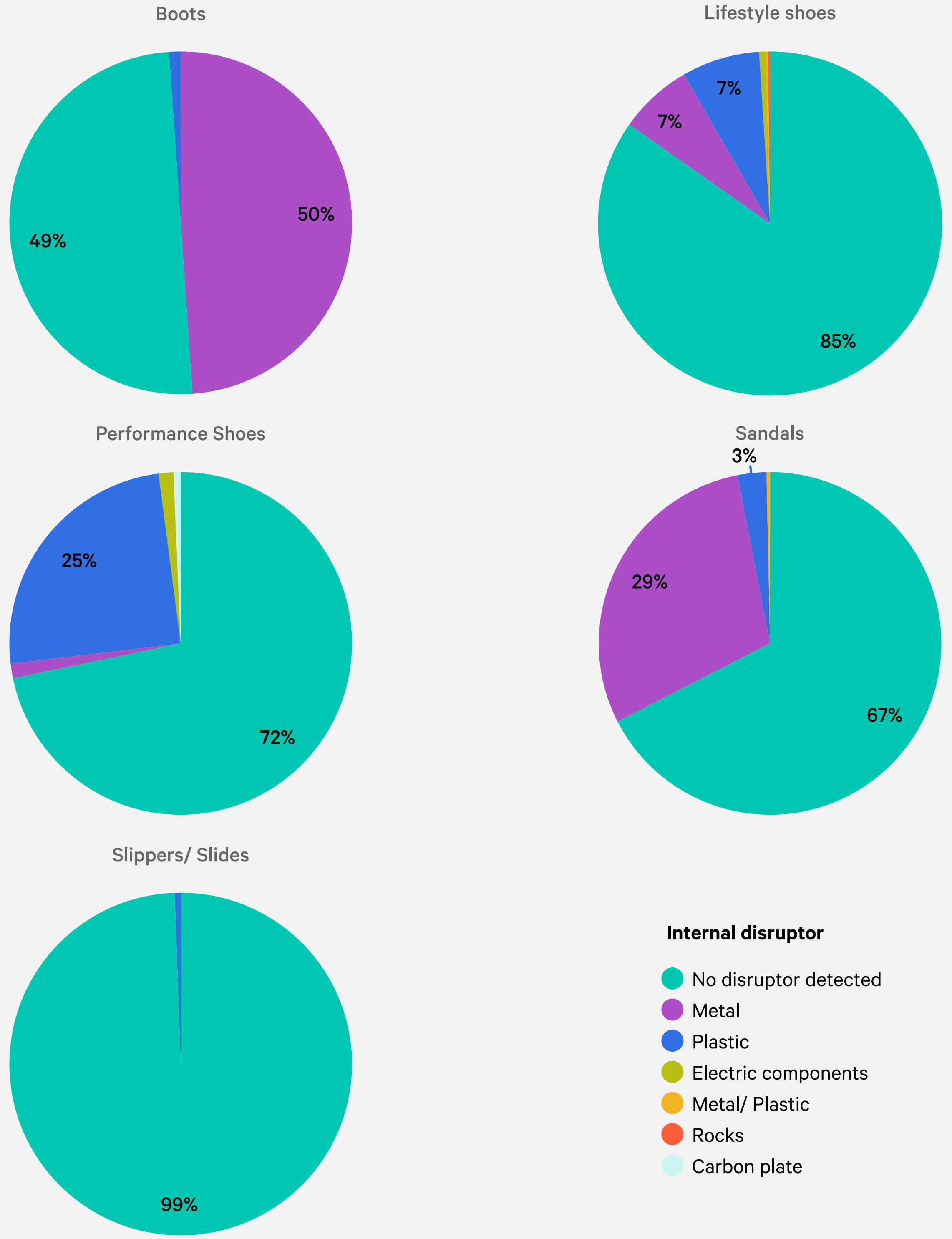
Among external disruptors, a total of 37 unique combinations were identified, including various mixes of textiles, plastics, leather, metals, and elastane. To improve clarity, all categories representing less than 2% of the total were grouped under 'Other', which collectively accounts for 21.5% of external disruptors (Figure 27).

Figure 27: Share of external disruptors



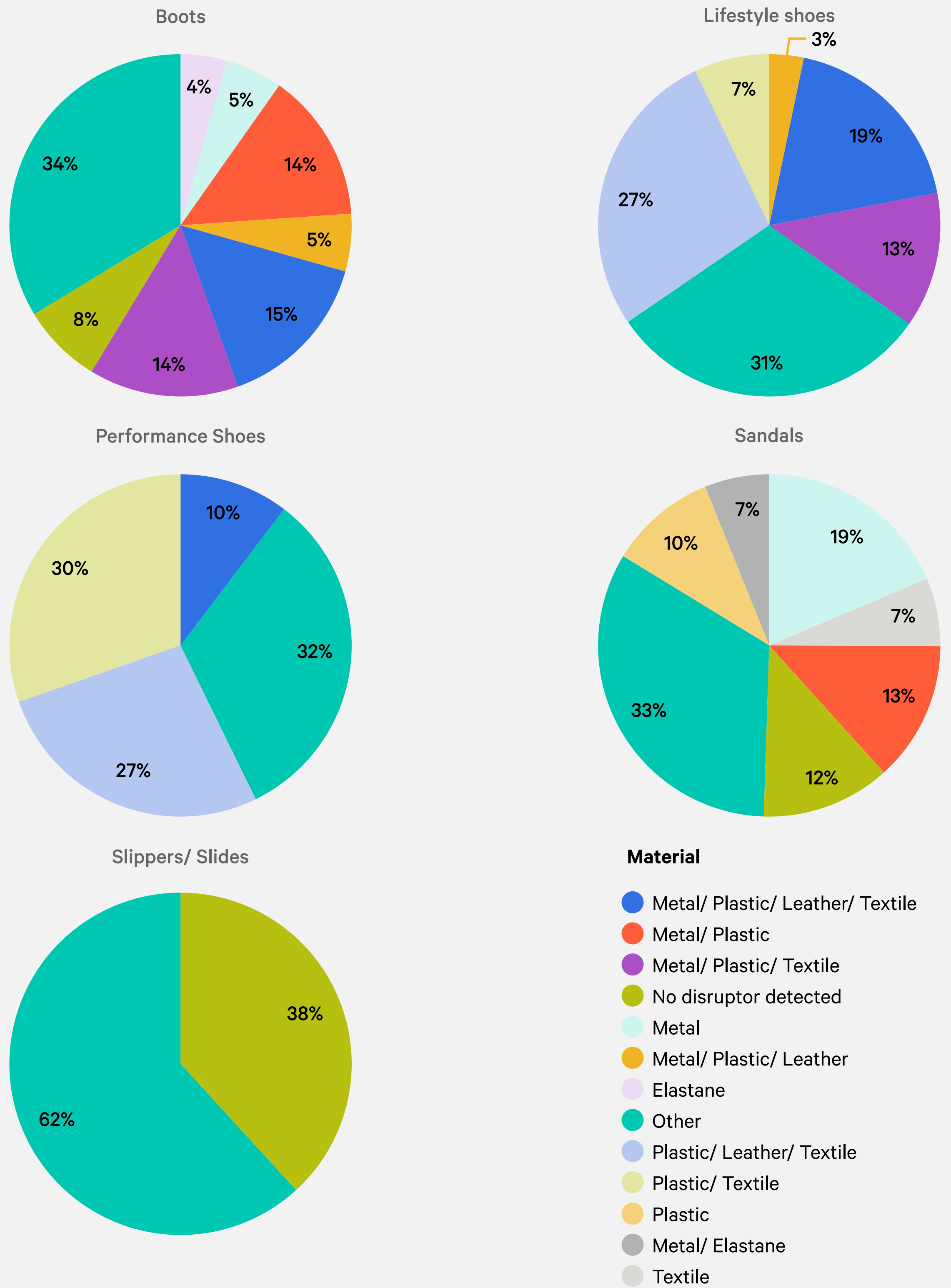
At the archetype level, internal disruptors were most commonly found in boots (50% metal) and performance shoes (25% plastic), as shown in Figure 28. These findings suggest that technical footwear and winter footwear often integrate structural reinforcements or performance-enhancing components—elements that complicate disassembly and material recovery.

Figure 28: Internal disruptors per archetype



For external disruptors, most archetypes included a mix of multi-material combinations, such as metal, plastic and leather or plastic and textile. Boots and performance shoes showed the greatest variety of disruptor materials, while slippers/slides were the simplest, typically containing only a few components such as textile or plastic and leather blends (Figure 29).

Figure 29: External disruptors per archetype



Together, these results highlight that disruptors are nearly ubiquitous in non-rewearable footwear, further complicating material recovery processes. Addressing their design and material integration represents a key opportunity to improve end-of-use management and enable higher-quality recycling outcomes in future footwear production.

06.

RECYCLABILITY POTENTIAL OF NON-REWEARABLE FOOTWEAR

Building on the findings from Chapter 5, this chapter evaluates the recyclability potential of non-rewearable post-consumer footwear within the current technological and market context. The feasibility of recycling post-consumer footwear here is based on the definition of 'recyclability' from apparel standards, defined as the technical ability to recover a material without significant loss of mechanical properties or damage to machinery. While a portion of discarded shoes could be diverted from landfill through targeted interventions, the technical feasibility of recycling remains constrained by material and product complexity, quality and performance requirements for new shoes, and, last but most importantly, the business case.

Across the sample, most shoes exhibit characteristics that make them poorly suited for mechanical or chemical recycling in their current form, without prior extensive pre-processing or preparation for recycling. At the same time, post-consumer materials are suitable for reincorporation into lifestyle footwear applications, such as shoe soles at approximately 30%, without prior material sorting, as practised by THE 8 IMPACT.

The recycling of uppers is primarily hindered by material blends and assembly. Over half of uppers (52%) consist of mixed textile compositions, which makes them poorly suited to both chemical and mechanical recycling, which requires high levels of purity. The high share (about 46%) of polyester-based blends in uppers, and 12% of pure polyester uppers, while challenging to separate, suggests that developing polyester recovery systems could have a significant impact, as these blends dominate across archetypes. Additionally, the high level of external disruptors (close to 90%) regularly found in the upper layer indicates that labour-intensive preprocessing would be required before recycling. This draws on the outcomes of the consultations, where it was highlighted that, due to the loss of material, disruptors, and low material feasibility for recycling, the upper is currently considered to offer little to no recycling opportunities.

In the preliminary research, the sole presented the highest recycling opportunities. Thus, the analysis also focused largely on understanding the composition and characteristics of post-consumer shoe soles. The "Unknown" fraction in soles (37%) remains a major barrier to high-value recovery. This highlights the challenge posed by black carbon pigments in impeding material identification. However, this unknown category is not only attributed to the sole colour but also to the blended polymers present in the soles, which Matoha ShoeTell cannot currently identify, but could potentially identify based on calibration and training with the relevant footwear materials.

As members of the thermoplastic elastomer family, SBS and TPU are technically capable of mechanical recycling. EVA is processed mechanically via shredding and reintegration, with its recyclability potential further supported by emerging de-crosslinking technologies. To ensure successful recovery, these materials need to be isolated from adhesives and thermoset contaminants. Thermosets are a particular risk in the mechanical recycling of TPU, a thermoplastic, because they do not melt; they can clog nozzles and cause significant machinery damage.

As SBR and vulcanised rubber are thermoset materials, they undergo irreversible crosslinking during production and degrade under mechanical stress. When soles made from these materials are worn, abraded, or cracked, the polymer chains partially break down and oxidise, resulting in contaminated fragments and low-quality output. Unlike thermoplastics such as EVA and TPU, these thermosets cannot be remelted after shredding. Therefore, current recycling technologies produce a material that necessitates a maximum threshold for reintegration into new products to ensure performance standards are met.

Approximately 52% of footwear relies on glue-based assembly, a feature that prevents the clean material separation and identification required for high-value closed-loop recycling. While these shoes contain individual components that are technically recyclable, their multi-material complexity and permanent bonding currently limit their practical and scaled recyclability in the current infrastructure. Footwear with these characteristics is often sent for mechanical shredding and open-loop recycling, such as insulation, playground surfaces, or fillers or for diversion into waste-to-energy pathways to recover caloric value and avoid landfilling.

However, the recyclability potential of even the most complex footwear can be unlocked through the strategic interventions outlined in this report. By scaling advancements in sorting infrastructure, investing in pre-processing technologies, R&D in recycling technologies, and adopting design interventions for material circulation, the industry can transition away from downcycling.

Sorting for Circularity Apparel vs Footwear: What we learnt

- Footwear is structurally invisible: Only ~9% of collected THF consists of footwear, while apparel and household textiles account for ~91%. Moreover, as footwear collection is statistically hidden under apparel codes, this delays visibility and therefore investment, policy attention, and infrastructure development for footwear specifically.
- Footwear is fundamentally challenging the apparel-style recycling playbook, as footwear is an order of magnitude more complex than apparel. While apparel sees 93% of the non-rewearable fraction being mono-layered with 42% cotton and 32% blends, footwear sees 52% blended uppers as well as various key materials in the sole, including primarily SBS, EVA, and rubber. Even "simple" shoes combine multiple polymers, foams, textiles, rubbers, and adhesives.
- While disruptors are common in apparel, they are often easily removable, whereas in footwear, we deal with both internal and external disruptors, where the latter is seen on 90% of the sample.
- While the apparel sector has seen progress in sorting and pre-processing technologies for recycling, footwear recycling faces a greater challenge due to complex construction and the necessity for effective disassembly. A significant factor adding complexity to footwear pre-processing is the prevalent use of adhesives (found in 52% of the sample), contrasting with the dominant use of stitching in apparel.

- Footwear presents significant challenges for current automated sorting technology. Unlike apparel, footwear is largely opaque to systems like Near-Infrared (NIR) that the industry has heavily invested in. This is due to several factors, including the presence of black carbon in ~24.6% of the sampled footwear, as well as thick rubber, foams, and complex, often unknown, material formulations. These material characteristics break existing automated sorting logic.
- In order to scale recycling efforts in apparel, the bottlenecks are scale and demand, while 74% of low-value textiles are fit for recycling. In footwear, we have incremental barriers to solve first, namely increasing quality and economics of pre-processing and solving for design challenges (adhesives, disruptors, and material mixes).
- Policy needs to decouple footwear from apparel due to a need for footwear-specific EPR modulation, design guidelines, and data tracking.

CONCLUSIONS AND RECOMMENDATIONS

AT THE SERVICE LEVEL: Encouraging rewearability potential

- A notable finding of this study is that 24% of post-consumer footwear showed no visible damage, yet was still classified as non-rewearable or deemed to have limited resale value. Brands and retailers should consider offering repair, resale and cleaning services to consumers to extend the use of their products.

AT THE DESIGN LEVEL: Optimise processes, materials and design choices

- Prioritise design optimisation, careful material selection, constructions that improve disassembly efficacy, limit multi-material and complex attachment of disruptors and decorative trims to enable material circulation.
- Accelerate investment in technologies capable of handling a broader range of materials while minimising losses.
- Evaluate the balance of design, performance, and end-of-use factors in material choices for footwear, particularly concerning the use of carbon black and other disruptors in footwear materials, specifically soles, to enhance their potential for recyclability.

AT THE SYSTEM LEVEL: Collection, sorting and pre-processing to deliver to the specific needs for footwear recycling

- This highlights an opportunity to extend product lifespans through simple interventions, such as incentivising consumers to dispose of paired shoes. Consumer-facing guidance at the point of disposal, such as encouraging individuals to tie pairs together or place shoes with missing laces in a cloth bag, could meaningfully increase the likelihood that items remain suitable for rewear.
- At present, sorting for recyclability is not widely practised, despite its critical role in preparing the value chain for scaling future recycling solutions. Strengthening this step through dedicated sorting infrastructure, improved operational capacity, and closer collaboration between brands and recyclers will be essential to realising large-scale circularity in footwear.
- Current footwear recycling technologies remain limited in scope, focusing primarily on a small subset of materials and relying largely on recycling after whole shoe shredding.

AT THE DATA AND POLICY LEVEL: Bridge the gap in data

- Finally, the study underscores a major data gap: robust, granular information on post-consumer footwear flows is virtually nonexistent. Understanding these waste streams is a foundational requirement for developing appropriate recycling technologies, sizing infrastructure investments, and making informed strategic decisions across the value chain. Establishing comprehensive data systems should therefore be a priority for industry stakeholders seeking to advance circularity.
- Due to the complex and structural differences of footwear from apparel, we cannot consider the same policies for apparel to be relevant to footwear. Policy makers should consider decoupling the two waste streams for an optimised end of use.
- Introduce recycled-content targets and eco-modulation incentives for footwear, specifically in the designated regulatory framework (i.e. Waste Framework Directive and Ecodesign for Sustainable Products Regulation)

Key barriers

1. **Material opacity and heterogeneity:** The prevalence of 'Unknown' soles and blended uppers limits traceability and prevents high-quality material recovery. Carbon-black pigmentation renders nearly all black soles unscannable by NIR technologies.
2. **Assembly techniques:** The dominance of glued construction prevents separation of materials and introduces adhesive residues that contaminate recycled streams.
3. **Disruptors and trims:** The presence of metals, decorative plastics, or composite trims increases preprocessing costs and reduces recyclate purity.
4. **Damage and contamination:** Although most wear is aesthetic, contamination and surface degradation often preclude reuse, shifting otherwise functional products directly into recycling or disposal streams.

Key enablers for circular pathways

1. **Design and production**
    - Design for recycling: Invest in R&D of products to complement performance requirements and understand the potential end-of-use avenues for products before transitioning into design interventions for disassembly or mono-material single-stream recycling.
    - Transparency: Introducing digital product passports (long-term due to the ESPR timelines) or intermediate solutions such as labelling systems for footwear could support traceability and compliance with upcoming EPR regulations.
    - Carbon black-containing material identification: Sensor technology is evolving toward the detection of carbon-black-pigmented materials; however, developing detectable pigment alternatives serves as a parallel innovation path for current infrastructure, provided these alternatives demonstrate that they can meet existing performance standards.
2. **Refurbishment and cleaning systems**
    - Since much of the non-rewearable footwear is downgraded for aesthetic rather than structural damage, establishing cleaning, repair, and refurbishment lines could reduce waste and extend product life before recycling becomes necessary.
3. **Infrastructure**
    - Establishing dedicated preprocessing facilities for shoes: These processes would include cutting, delamination, and sole separation, which can significantly enhance recyclate quality before shredding or chemical recycling. Preprocessing also enables the redirection of less damaged components toward refurbishment or rewear pathways.
    - Cross-sector collaboration: Partnerships between footwear brands, recyclers, and material innovators can scale pilot programmes for sole-to-sole and textile-to-textile recycling. Integrating footwear waste streams into existing textile or plastic recycling infrastructure would optimise resource use.
    - Accelerate the adoption of sorting technology to improve the purity and efficiency of material separation, including new sensor technologies that can detect carbon black.

ANNEXURES

ANNEXE I

Desk research

Initial desk research was conducted to gather contextual findings on footwear composition, best practices, and the global state of play in end-of-use management. The research focused on barriers to adopting circular strategies, current infrastructure and technology, end markets and their pricing dynamics, TRL and emergent technologies for processing, sorting, and recycling, volume and quality of post-consumer footwear flows, and footwear material composition.

The information available was relatively limited; however, the literature review and analysis still provided valuable insights into the footwear industry, including product design, common materials, and the reuse landscape. The collected sources, such as reports, academic studies, LCAs, and online articles, helped establish a guiding framework for forming an initial understanding of the current landscape and for developing interview guides to address early knowledge gaps.

The literature revealed that footwear has a complex material composition, is built with various layers and structures depending on the product's function, and lacks standard categorisation of footwear product types or archetypes. Additionally, there is a lack of traceability for footwear end destinations in Europe and globally. These challenges were laid out in Chapter 2.

Stakeholder interviews

Stakeholder interviews were carried out to complement the limited literature available and help map the volumes and value of post-consumer footwear. The interviews particularly support the understanding of common practices in end-of-use management of footwear, the business case for footwear pre-processing and recycling, and helped improve the methodology for the detailed manual sorting analysis of post-consumer footwear.

The stakeholder consultation included a total of 17 interviews, and included sorters, recyclers, innovators and other industry experts. The interviews with sorters included more questions about end-market destinations, volumes, and pricing. The recycler consultations focused specifically on the challenges and opportunities for recycling and feedstock requirements. The insights divided across five topics are laid out below.

The interviews were pivotal for the development of the sorting methodology as they highlighted the practical challenges of manual sorting and added complementary observations for the categorisations of archetypes and observation points for data collection. The stakeholders recommended providing clear guidelines for the archetypes recognition and prioritising sole material identification in the analysis. Given the challenges of material detection, it was also recommended to separate the upper from the sole. These recommendations were integrated into the on-the-ground data collection methodology, which is explained in Section 4.3.

ANNEXE II

Overview of data collection stations

Due to the high complexity of footwear as a product, data collection has been divided into three stations with dedicated operators:

STATION 1: MANUAL STATION

This station handled initial tagging, categorisation, and visual assessment.

Setup

- One sorter
- One tablet
- Markers and pens for tagging

Data collected at Station 1

1. **Tagging**
   Each shoe received a unique serial number, recorded at each station for data consistency.
2. **User category**
   Shoes were categorised as:
   - Men's
   - Women's
   - Children's
   - Unisex
   - Other (with explanation)
3. **Product archetype**
   Shoes were categorised into one of six archetypes:
   - Performance
   - Lifestyle
   - Sandals
   - Boots
   - Slides/Slippers
   - Other

Under each archetype, the sorter will be required to further categorise the shoe into subcategories based on visible functionality and/or specific elements of the shoe. Definitions were provided to sorters and defined further through consultations and the input from brand partners (full list can be found in Annexe III.

4. Physical damage

Damage was assessed separately for:

- Upper
- Sole

Multiple damage types could be logged.

Damage categories: Upper

- Soiled: It can be considered dirty, stained, or contaminated with substances such as dirt, grime, grease, or food particles.
- Tear/Holes: The shoe has visible tears, holes and surface damage
- Discolouration: The damage caused by the wearing out of colours due to use, weather or other external factors
- Other: Any other damage on the upper that cannot be categorised

Damage categories: Sole

- Detached from upper: The sole and the upper (or any other element) are detached partially or entirely
- Tears/Holes: The shoe has visible tears, holes and surface damage
- Worn out from use: The shoe has been worn to a certain extent, and the sole visibly wears out.
- Other: Any other damage on the upper that cannot be categorised

5. Brand identification

To distinguish branded versus unbranded shoes:

- Sorters used a predefined brand list from project partners and top shoe retailers in Europe.
- Brands not on the list could be added manually if visible.

Once 100 shoes were processed, they moved on to Station 2.

STATION 2: MACHINERY STATION

This station focused on material identification and colour analysis, supported by manual data capture.

Setup

- One tablet for manual data entry
- One Matoha Fabritell (upper)
- One Matoha ShoeTell (sole)
- ID-shoes with an additional external camera

Data collected at Station 2

1. Composition analysis

Composition analysis was an important data point for us to capture to understand the characteristics of the sample size and to understand the patterns in damage and materiality. This data helped the study further understand feedstock and how materials play a role in different archetypes, and how they may be used as a tool to understand feedstock potential. Material identification used Near Infrared (NIR) Spectroscopy, a non-destructive, rapid analytical technique that detects light absorption (780–2,500 nanometres). Both textiles and plastics can be identified using this technology.

The Matoha Fabritell can identify the following upper materials and blends:

- Cotton
- Acrylic
- Polyester
- Nylon
- Viscose

- Wool
- Polypropylene
- Silk
- Acetate
- Elastane

Note: Matoha's earlier device, Plastell, was originally designed for general plastic identification. However, because footwear contains a wide range of plastics and elastomers, the device's original material-identification scope was not sufficient. To address this gap, Matoha worked to develop a dedicated footwear material library to train a more suitable device. This effort led to the creation of Matoha ShoeTell, a handheld NIR device trained using the Refashion footwear material library, enabling it to identify seven mono-materials found in shoes, as well as four blended rubber compositions.

Matoha ShoeTell: Identifiable sole materials

Mono-materials:

- ABS: Acrylonitrile butadiene styrene
- EVA: Ethylene Vinyl Acetate
- PU: Polyurethane
- PVC: Polyvinyl chloride
- SBR: Styrene-butadiene rubber (synthetic rubber)
- SBS: Styrene-butadiene-styrene
- TPU: Thermoplastic polyurethane

Blends:

- NR/IR: Natural Rubber/Isoprene Rubber
- NR/IR = SBR: Natural rubber and synthetic rubber in equivalent quantities
- NR/IR > SBR: Majority natural rubber
- NR/IR < SBR: Majority synthetic rubber

*May include mineral fillers (calcium carbonate or talc) and additives (plasticisers).

Scanning requirements

- They scanned the most consistent, largest surface of the shoe
- For soles, sorters scanned multiple locations due to colour and wear variability
- If Matoha ShoeTell returned UNKNOWN, the shoe was manually flagged for Batch 5

Limitations of handheld NIR devices are discussed in Chapter 3.

2. Colour analysis

Colour analysis was performed in order to understand the complexity of the products based on colour, as well as to understand technological viability.

Sorters manually recorded:

- Primary colour
- Accent colours (if any)

Colours included: red, pink, orange, yellow, green, blue, brown, black, white, grey, and multicoloured.

Sole colour was often distorted due to:

- Wear
- Dirt accumulation
- Layered soles/outsoles

Sorters used their best judgment; 'Other' could be selected when uncertain.

3. Image capture (ID- Shoes)

CETIA's ID-shoes machine was used for image capture and resulted in a four-angle image (top, side and bottom view) set of each shoe. The additional camera captured the sole. Image capture of the items helped inform the data when it came to damage, and for the verification of data during the analysis phase.

After verifying data and images, the shoes moved to Station 3.

STATION 3: ENGINEER STATION

This station was supervised by a CETIA engineer trained in assembly and disruptor identification.

1. Assembly technique

The assembly technique was identified to understand the level of disassembly required if pre-processing was necessary. The engineer recorded which assembly methods were present (multiple possible):

- Stitched
- Vulcanised
- Glued
- Injected
- No assembly technique (for example, flip-flops)
- Other/Unknown

2. Disruptor presence

Internal disruptors were identified via X-ray using SensorHUB, and external disruptors were identified manually. SensorHUB is an automated sorting machine that identifies textile and footwear materials with high precision. It also features X-ray capability to detect hidden components and internal structures, which was used to check for internal disruptors.

For this study, anything other than the main surface of the upper was considered a disruptor (for example, a logo stitched onto the main body of the upper). In both cases, disruptors were categorised by material rather than form.

Internal disruptor categories:

- Metal
- Plastic
- Electronic
- Other

External or visible disruptors:

- Metal
- Plastic
- Leather
- Textile
- Electronics
- Wood
- Other

3. Batching

The shoes were then grouped into the following batches:

Table 2: Batching of footwear sample

BATCH	DESCRIPTION
1	Performance shoes
2	Lifestyle shoes
3	Sandals, slippers/slides
4	Boots
5	Other/Unidentifiable (including shoes unreadable by NIR or not fitting any archetype)

Each batch was labelled with the Batch Code and Weight, then sent to Eldan for shredding and later to PICVISA for material composition identification.

ANNEXE III

Table 3: This table shows the archetype definitions as used during the training of sorters for the data collection. This classification helped reduce human error in the analysis of archetypes.

Table 3: List of footwear archetypes and definition

ARCHETYPE	SUB ARCHETYPE	DEFINITION & EXAMPLES	
1. Performance Shoes		Footwear designed specifically for athletic or high-intensity activities, optimised for performance, support, and durability.	
	1.1. Basketball Shoes	High-ankle support, thick soles for shock absorption, often heavier and bulkier	
	1.2. Football/ Soccer Shoes	Lightweight with cleated soles for traction; often synthetic upper	
	1.3. Running Shoes	Lightweight, cushioned midsoles, breathable mesh uppers, high flexibility	
	1.4. Cycling Shoes	Stiff soles (often plastic/carbon), clip-in compatibility, minimal tread	
2. Lifestyle Shoes		Footwear made for everyday wear, fashion, or comfort, not necessarily linked to sport or performance.	
	2.1. Trainers	Casual sneakers inspired by athletic shoes, often worn daily	
	2.2. Slip-on Sneakers	Laceless, easy-to-wear shoes with elastic gores or a stretchy upper	
	2.3. Collectable Sneakers / Luxury	High-fashion or limited-edition sneakers are often branded and made with premium materials.	
	2.4. Formal Shoes	Oxfords, Derbies, loafers, made from leather or synthetic leather, designed for formal or business settings	
3. Sandals		Open footwear, generally exposing the toes and/or heel, is intended for warm-weather or casual use.	
	3.1. Ballerina Flats	Closed-toe, flat-soled shoes with minimal structure, often worn for casual or semi-formal occasions.	

ARCHETYPE	SUB ARCHETYPE	DEFINITION & EXAMPLES	
	3.2. Heels	Elevated heels, ranging from stilettos to wedges, with various open/closed toe designs	
	3.3. Dress Sandals	Stylish sandals with decorative elements, often featuring heels or straps.	
	3.4. Clogs	Closed-toe, open-back shoes with thick soles; traditional or medical use is common	
4. Boots		Footwear that covers the ankle and often extends up the leg, used for protection, weather resistance, or fashion	
	4.1. Outdoor/ Hiking Boots	Durable, rugged soles with ankle support, often waterproof	
	4.2. Formal Boots	Sleek boots made from leather, worn in semi-formal or formal contexts	
	4.3. Boots with High Heel	Fashion boots with elevated heels, often made of synthetic or leather uppers.	
	4.4. Snow Boots	Insulated, waterproof boots with rubber soles and traction for snowy or icy conditions	
	4.5. Rain Boots		
5. Slides / Slippers		Easy-on, casual footwear is typically used indoors or for quick errands.	
	5.1. Slippers / Flip-flops	Minimalist sandals or home-use footwear with foam or rubber soles	
	5.2. Slip-on Shoes	Non-laced casual shoes, often soft-soled and flexible	
6. Other		Any shoe types that don't fit clearly into the above categories, such as speciality occupational shoes, fashion hybrids, or extremely damaged shoes	

ANNEXE IV

Footwear manufacturing

KEY ACTORS:
- Designers
- Material Suppliers
- Manufacturers

The footwear supply chain is characterised by numerous steps (see Figure 30). The main stages include design, material production and sourcing, and manufacturing (including cutting, sewing, modelling, and assembly) with most footwear containing multiple components (see Figure x). The array of different archetypes means impact data is often fragmented and variable across archetypes.[48] Still, it is argued that material production and manufacturing are the main sources of carbon emissions. At the manufacturing stage, emissions are largely driven by energy-intensive processes[6, 56]. For instance, manufacturing technologies like steam chest moulding, injection moulding and compression moulding, and vulcanisation processes lead to high carbon emissions as they rely on high temperatures, pressure, and mostly fossil-fuel-based electricity or steam.[49, 50, 51] Additionally, the environmental impact is amplified by the common use of energy-intensive materials for the sole, such as EVA, PU, rubber, leather, and polyester, making material and processing technologies key drivers for the overall impact of footwear production.[52]

Figure 30: Linear and circular footwear value chains

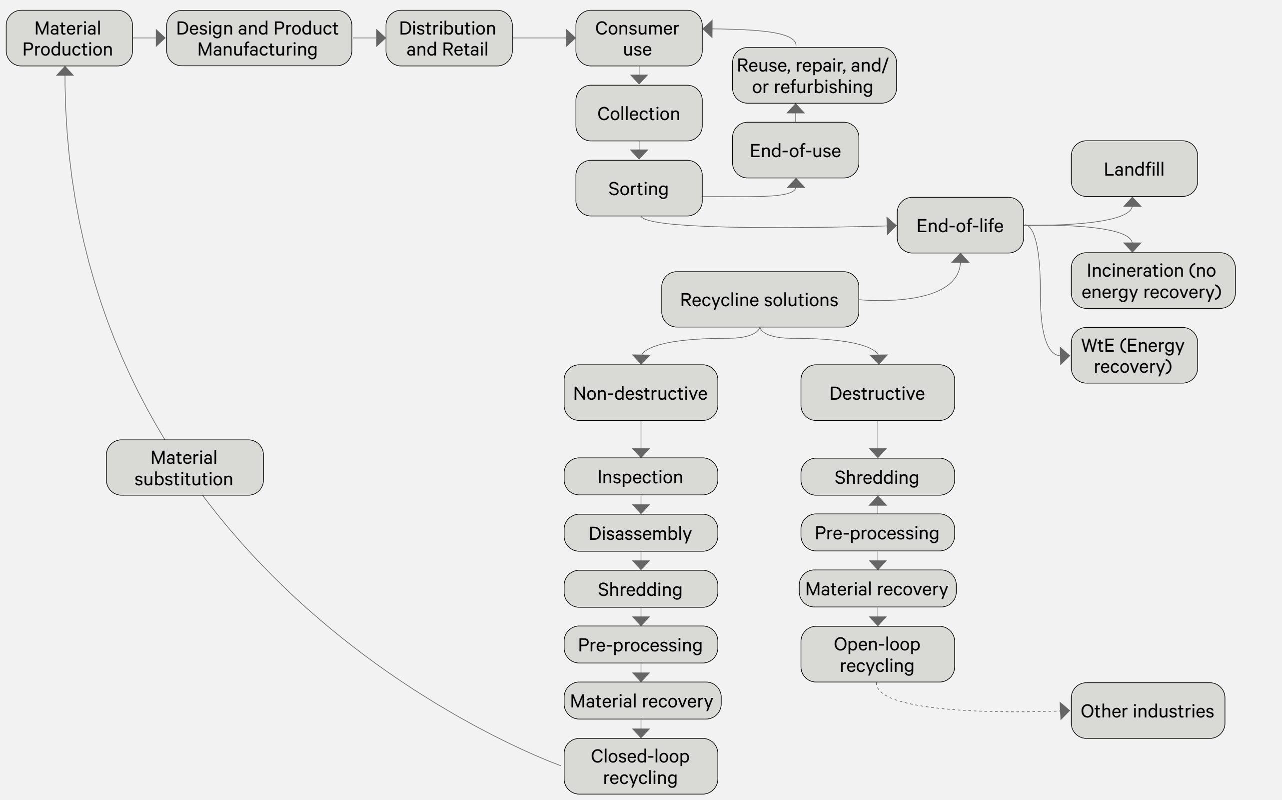
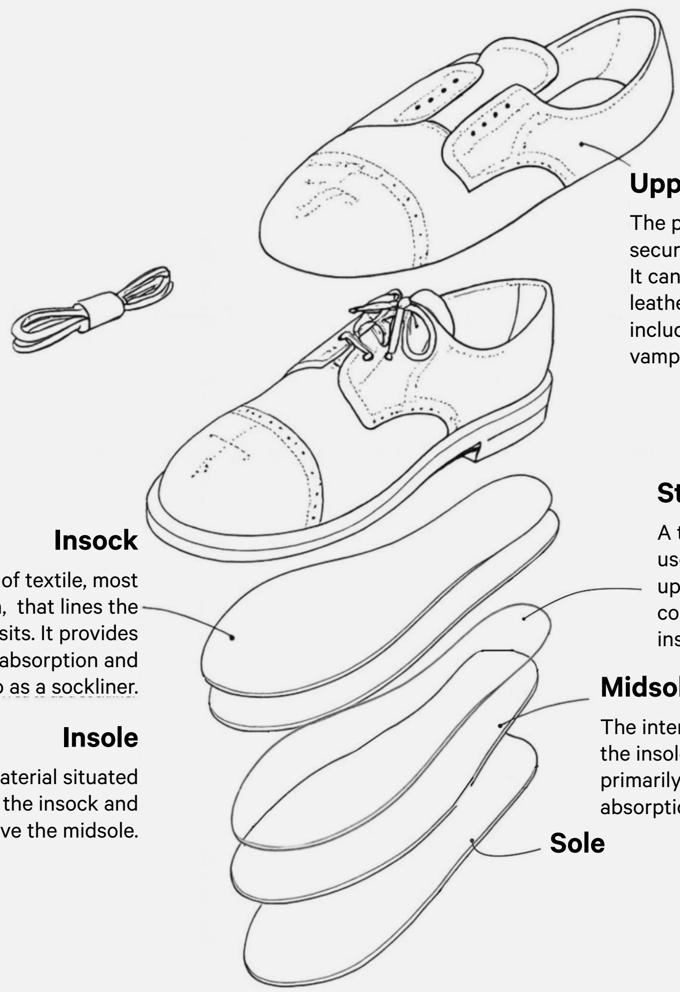


Figure 31: Basic shoe anatomy



Distribution and retail

KEY ACTORS:
- Retailers and e-commerce platforms
- Brands
- Shops
- Marketers

After manufacturing, footwear is distributed and exported to the markets across the globe. Today, both manufacturing and retail stages are disconnected from end-of-use management, with rarely implemented take-back systems.

Use

KEY ACTORS:
- Consumers
- Repair Shops

As noted by the EEA in 2025, the average EU citizen buys 4kg of footwear annually[53] an increase of 48% since 2022[54]. On average, newly purchased footwear is estimated to be used for around one year before disposal, particularly for common consumer segments such as sneakers, casual shoes, and work footwear. [55, 17]

While there are providers for maintenance and repair services that can extend the lifespan of footwear, repair practices remain unevenly distributed across footwear types and consumer segments. Repair services are more commonly used for higher-quality and leather footwear compared to sneakers, particularly because the cost of repair is often not competitive enough against buying a new pair of shoes.[56]

Collection

KEY ACTORS:
- Commercial collectors
- Charities and non-profit organisations
- Local authorities

The collection of post-consumer footwear is generally handled by local authorities, commercial collectors and sorters, charity-owned not-for-profit organisations, and limited but present brand take-back schemes. Only France has a registered Textile, Household goods and Footwear (THF) Producer Responsibility Organisation (PRO) that encompasses both textiles and footwear.

Footwear is generally collected along with clothing through door-to-door collection, commercial collection points, bins, and, in some cases, brand take-back programmes. The collection method can vary across countries and municipalities, depending on urban infrastructure and the strategies set by local authorities. At this stage, consumers play an important role, as proper disposal is crucial to maintaining the highest possible quality of used and paired footwear, thereby increasing their chances of reuse. However, as collection rates grow and second-hand markets are saturated with both clothing and footwear, infrastructure has to be adjusted to ensure proper waste management.

Sorting

KEY ACTORS:
- Commercial sorters

Sorters receive or purchase post-consumer THF from collectors and sort it into quality grades for reuse and/or recycling. Sorting for reuse is currently the main business model for commercial sorters, especially for footwear, given the very limited demand for post-consumer footwear for recycling, the low technology readiness level (TRL) of footwear material sorting, and the difficult disassembly process. Footwear, similarly to textiles, is regularly sorted for reuse into the following categories:

- **Rewearable:** footwear in good condition that has minimal signs of wear and does not require any additional steps (like repair or cleaning) before being reused again. This is further broken down into:
  - **Cream:** Footwear considered rewearable and sold on the domestic second-hand market at the highest price.
  - **Tropical Mix:** Lightly used footwear composed of lightweight, open footwear that can be worn in tropical climates (for example, slippers and sandals).
  - **Grade A+B/1+2:** Footwear considered rewearable and sold at lower prices in European second-hand markets.
  - **Grade C/3:** Lowest value footwear, still considered as rewearable, mainly exported outside of Europe.
- **Non-rewearable**: Footwear that is damaged, significantly stained or soiled, or single shoes that are impossible to pair within the sorting facility.

Sorters might also change or redefine the sorting grades depending on specific requirements set by the buyer. Generally, the cream and rewearable grades are sold for reuse, while the non-rewearable fraction is predominantly incinerated or sent to landfill. See Figure 3 for more details on these waste flows.

End-of-use: Reuse

KEY ACTORS:
- Export brokers
- Second hand

With sorting, footwear that falls into the cream and rewearable grades goes into the resale market, with cream qualities mainly going into European markets and rewearable grades going into African and Asian markets.[13] Export brokers are organisations that facilitate the buying and selling of post-consumer footwear, both within and outside Europe. From here, the footwear is sold at second-hand markets.

End-of-use: Recycling

KEY ACTORS:
- Destructive recyclers
- Non-destructive recyclers
- Recycling solution innovators

Recycling is the process through which materials are recovered to produce new raw materials that can re-enter the production cycle. For footwear, this can translate into different reprocessing of footwear parts or materials to re-enter the footwear industry (closed-loop) or into a different use (open-loop). Current footwear recycling technology categorises recycling by how the item is processed between sorting and recycling. Downcycling involves shredding the footwear as a whole and then separating it for use mainly in primary (footwear) and secondary applications (such as gym floors and sound insulation). Disassembly and recycling involve dismantling shoes to isolate materials for recycling before shredding.

End-of-Use: Incineration and Waste-to-Energy (WtE)

KEY ACTORS:
- Incineration plant owners

Incineration is a waste treatment process in which waste materials are combusted in incineration plants. When shoes do not qualify for reuse and recycling is not common practice, non-rewearable footwear is incinerated or sent to a landfill. In general, incineration is considered a waste management solution for non-recyclable waste that can't go to landfills. However, waste management actors often choose between landfill and incineration based on disposal costs.

Incineration can be done with two different goals: either to reduce the volume of waste (regular incineration) or to recover energy (heat or electricity) from burning of waste (WtE incineration). In general, both incineration practices are receiving pushback, as incineration is currently excluded from the European Emissions Trading System (ETS).[57]

While WtE ranks above normal incineration and landfill in the EU Waste Hierarchy, it is still not considered the first choice for end-of-use management.[58] At the same time, it must be recognised that the extremely low value of post-consumer footwear collected in Europe means that collectors and sorters cannot cover the high costs of domestic WtE incineration. As a result, exporting shoes is often chosen as the most viable waste management pathway.

End-of-Use: Landfilling

KEY ACTORS:
- Land space owners
- Private Waste
- Management companies

Despite being at the bottom of the Waste Hierarchy, landfill and incineration are the dominant treatment options for non-rewearable footwear. Landfilling is the process of disposing of waste in a designated space (a landfill) by layering it on the soil or burying it; municipalities or private companies manage these spaces. While the overall landfill rate has decreased from 23% in 2010 to 17% in 2022, with much waste being exported, it is hard to track the exact waste treatment at the end destination. Additionally, for non-rewearable textiles and footwear, over 85% is generally landfilled or incinerated due to a lack of recycling solutions or pricing dynamics that make it less financially feasible for waste handlers.[13]

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CLOSING THE FOOTWEAR LOOP

CIRCLE ECONOMY

FASHION FOR GOOD