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SUSTAINABLE DESIGN FOR RECYCLING

Deliverable 1.2

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TABLE OF ABBREVIATIONS

Abbreviation	Definition
D4R	Design for Recycling
DPP	Digital Product Passport
EC	European Commission
EPR	Extended Producer Responsibility
ESPR	Ecodesign for Sustainable Products Regulation
MEErP	Methodology for Ecodesign of Energy-related Products
PRO	Producer Responsibility Organisations
SWOT	Strengths, Weaknesses, Opportunities, Threats
WFD	Waste Framework Directive

EXECUTIVE SUMMARY

This document constitutes Deliverable D1.2 "Sustainable design for recycling" of the European project "Fostering circularity in textile: innovative interoperable solutions and best practices for implementation and harmonization of EPR schemes", also known as "Circula-TEX"

The deliverable outlines the scope of Task T1.2, "Collaborative analysis: sustainable design for recycling", which is dedicated to collecting, structuring and analyzing stakeholder-driven insights on how design choices can enhance textile recyclability. It presents the outcomes of the co-creation activities carried out across the **different stakeholder groups**, highlighting best practices, technical challenges, and cross-value-chain requirements that influence the feasibility of recycling processes, while also providing a consolidated overview of innovative design strategies aligned with emerging EPR frameworks and circular economy objectives.

Building on this foundation, the report examines the role of Design for Recycling (D4R) as a key enabler of circularity in the textile sector and a critical lever for the effective implementation of future Extended Producer Responsibility schemes. The analysis integrates perspectives from manufacturers, recyclers, research centers, and circular economy experts, revealing a persistent misalignment between product development processes, still largely driven by cost, performance, and market dynamics, and the technical and economic realities of end-of-life management, with recyclability often remaining a secondary consideration in design decisions.

Material choices emerge as the most decisive factor influencing recyclability, as complex fiber blends, adhesives, coatings, and additives significantly hinder recycling processes even in small quantities, whereas mono-material or reduced-complexity designs improve material recovery but introduce trade-offs with durability, functionality, aesthetics, and cost. The findings further highlight that **recyclability depends on achieving specific material purity thresholds** compatible with existing industrial recycling technologies. Effective D4R solutions are shown to arise primarily from collaborative approaches that involve early engagement between designers, manufacturers, and recyclers, enabling design decisions to be validated against real processing constraints, although such collaborations remain fragmented and difficult to scale. The report also identifies a set of interconnected barriers, including economic constraints, technical limitations, organizational challenges, fragmented regulatory conditions, and market dynamics, which together limit the widespread adoption of D4R.

In this context, emerging EU regulatory frameworks, particularly the Ecodesign for Sustainable Products Regulation, textile EPR schemes, and instruments such as the Digital Product Passport, are recognized as essential enablers to realign incentives, improve traceability, and support investment in circular design and recycling infrastructure.

Overall, the deliverable concludes that **Design for Recycling is not solely a design challenge but a systemic one**, requiring coordinated action across the value chain, strengthened competencies, and stronger alignment between design and end-of-life systems.

The findings of D1.2 provide a foundational input for subsequent project activities, particularly WP3, which will assess technical feasibility and industrial applicability, and WP6, which will translate validated outcomes into comprehensive design guidelines for the textile sector, ultimately supporting the transition toward a circular and resilient European textile system.

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3. INTRODUCTION

The Circula-TEX project, with its multidisciplinary approach, aims to support the EU Strategy for Sustainable and Circular Textiles by facilitating the redesign of textile value chains through the adoption of a circular approach. It ensures compliance with the expectations set by Extended Producer Responsibility (EPR) schemes and European directives.

A key element of this report is its structured analytical approach to Design for Recycling, aimed at providing a comprehensive understanding of current practices, regulatory developments, and emerging needs within the textile sector. The document is designed to guide the reader through the methodological framework, contextual background, and practical outcomes, ensuring a clear link between analysis and actionable results.

Following the Executive Summary, the document is organized in line with the table of contents and guides the reader from the context and methodology to regulatory framing, co-creation outcomes, structured results, and final conclusions.

The deliverable is structured as follows:

- **Chapter 3** introduces the context and scope of the work, framing the relevance of Design for Recycling within the Circula-TEX project and the wider transition toward circular textile value chains.
- **Chapter 4** presents the methodology adopted for the study, including the stakeholder engagement approach, data collection and analysis process, and the main limitations affecting the interpretation of results.
- **Chapter 5** outlines the European regulatory framework and EPR focus, covering the current EU landscape, relevant legislation, ESPR, the EU Strategy for Sustainable and Circular Textiles, Extended Producer Responsibility, and JRC preparatory work on textile products.
- **Chapter 6** describes the co-creation activities carried out within the consortium and with external stakeholders, including the internal workshop, stakeholder mapping and engagement strategy, interviews, and the synthesis of stakeholder feedback.
- **Chapter 7** presents the core results of the report, identifying solutions emerging from co-creation, requirements for designers and manufacturers, needs reported by recyclers, and the alignment of these findings with EPR objectives.
- **Chapter 8** concludes the document by summarizing the main insights and reflecting on the implications of Design for Recycling for circularity in the textile sector.
- **Chapter 9** provides the list of reference documents used throughout the deliverable

4. METHODOLOGY

4.1 STAKEHOLDER ENGAGEMENT METHODOLOGY

The overall strategy to engage the stakeholders was presented in D1.1 – Stakeholder engagement and co-creation. More details were then given about both internal and external cocreation strategies. Overall, the double logic can be summarized as:

- Internal: workshop to elaborate a SWOT analysis
- External: one-to-one interviews with the stakeholders identified on D1.1. Additional stakeholders have been identified since then in collaboration with consortium partners leveraging on existing or previous collaborations.

To ensure the maximum grade of freedom in their answers to the questions and to respect their privacy and confidentiality, the answers collected are not associated with brands, names or any details that could give the possibility to determine who has answered that question.

The contact procedure was defined according to the following logic:

- If one of the partners involved in WP1, or any other consortium partner, already had direct contact with a stakeholder, two options were available. The lead contact could either reach out to the identified stakeholder directly, or alternatively, share the contact details with the partner interested in engaging that specific stakeholder, who would then proceed to arrange the interview.
- Once a stakeholder confirmed their availability and willingness to contribute, WP1 partners responsible for the topics involved collected their questions. In some cases, stakeholders requested to receive the questions in advance; when this occurred the lead contact anticipated the overall questions prior to the interview. If no such request was made, the 1-hour call followed a standard structure: a brief introduction to the project and WP activities, a quick round of introductions of the participants, and then each partner presented and discussed their respective topic areas.

As for the reasons previously mentioned, the company names are not disclosed, but in ANNEX I – List of participating stakeholders, a general description of the stakeholder is given.

4.2 DATA COLLECTION AND ANALYSIS

The predefined list of questions was adjusted according to the stakeholder category, ensuring that each interview could draw effectively on the specific expertise and experience of the respondents. Although the questions had been designed in advance, the conversation followed the natural flow of the discussion, allowing additional insights to emerge whenever relevant.

The following tables will illustrate which top topics were discussed in function of the type of stakeholder

	Manufacturers			
Core topic	**D4R integration**	**Design hindrances**	**Barriers to D4R**	**Mono vs multi-material**
Questions	Mono/duo-material redesign Eco-design guidelines & PLM	Latex & adhesives Multi-layer bonded structures Trims, prints, coatings	Cost & pricing pressure Consumer expectations	Performance trade-offs Dye/aesthetics constraints Dimensional stability

	Manufacturers			
	Tiered circularity criteria		Regulatory uncertainty	

Table 1: Top topics discussed with manufacturers

	Recyclers			
Core topic	**Design hindrances**	**Post-consumer barriers**	**Material thresholds**	**Traceability needs**
Questions	Multi-material blends Coatings & finishes opacity Elastane content thresholds	Feedstock inconsistency Volume & scale needs Sorting technology limits	Min. polyester % for viability Elastane limits Blending low-quality streams	Unknown chemical composition DPP utility at industrial scale AI-based sorting potential

Table 2: Top topics discussed with recyclers

	Research centers			
Core topic	**Technology & AI**	**System-level barriers**	**Education & skills**	**Circular leverage points**
Questions	AI as predictive design tool Computer vision for sorting Digital traceability	Research–industry misalignment Business model inertia Lack of economic maturity	Material literacy gaps Weak university–industry links Eco-design narrowly taught	Production first Overemphasis on recycling Reuse & extended use priority

Table 3: Top topics discussed with research centers

4.3 LIMITATIONS

While the stakeholder engagement activities conducted within this report provide valuable insights and contribute to a comprehensive understanding of Design for Recycling practices, it is important to acknowledge a number of methodological and practical limitations that may have influenced the outcomes. These limitations are inherent to participatory and qualitative approaches involving external actors, particularly within a complex and evolving sector such as textiles.

The following points highlight the main constraints encountered during the engagement process, which should be taken into account when interpreting the results and assessing their applicability:

- **Uneven geographical coverage:** Despite efforts to ensure balanced representation, stakeholder participation was not uniformly distributed across all European regions. Some countries or regions are underrepresented, potentially limiting the generalizability of findings.
- **Limited response rate:** The number of stakeholders engaged, while sufficient for qualitative insights, remains limited compared to the overall size and diversity of the textile value chain.
- **Value chain representation imbalance:** Although different actors were targeted, certain segments of the value chain (e.g., SMEs, recyclers, or downstream actors) may be less represented than others, affecting the completeness of the analysis.

- **Potential response bias:** Responses provided by stakeholders may reflect institutional positions, strategic interests, or socially desirable answers rather than fully objective or critical assessments.
- **Variability in level of expertise:** Stakeholders involved displayed differing levels of knowledge and familiarity with Design for Recycling and ecodesign concepts, which may have influenced the depth and comparability of the feedback collected.
- **Limited comparability of inputs:** Inputs collected through interviews and co-creation sessions are inherently qualitative and context-specific, making it difficult to ensure full comparability across different stakeholders or countries.
- **Time constraints:** The timeframe available for engagement activities limited the possibility of conducting iterative consultations or follow-up rounds that could have been refined and validated initial findings.
- **Dependence on stakeholder availability:** Engagement outcomes were influenced by stakeholders' availability and willingness to participate, which may have limited the diversity and number of contributions.
- **Context-specific insights**: Some findings reflect specific national, organizational, or sectoral contexts and may not be directly transferable to other settings without adaptation.
- **Evolving regulatory and market context:** Given the rapidly developing EU policy framework on textiles and circular economy, some stakeholder views may become outdated as new regulations emerge.

5. REGULATORY FRAMEWORK AND EPR FOCUS

The regulatory framework for design for recycling in clothes centers on EU directives promoting circularity through Extended Producer Responsibility (EPR). These rules incentivize producers to create recyclable garments via eco-modulated fees tied to product sustainability. Below is an overview of the current and upcoming regulations:

5.1 CURRENT EU LANDSCAPE

The textile sector is one of the most pervasive and impactful industries in modern society, present across all dimensions of daily life, from apparel and household items to medical equipment, furniture and protective equipment, and in buildings and vehicles, serving both functional and aesthetic purposes.

Global textile production almost doubled between 2000 and 2015, and the consumption of clothing and footwear is expected to grow by 63% by 2030, rising from 62 million tons today to 102 million tons. This trajectory of growth is coupled with severe environmental consequences. From a global life cycle perspective, textile consumption in the EU accounts on average for the fourth highest negative impact on the environment and climate change, and the third highest for water and land use. In the EU alone, about 5,8 million tons of textiles are discarded every year, of which 88% end up in mixed household waste and are therefore incinerated or landfilled, with no chance of a productive afterlife, corresponding to approximately 11 kg per person. These volumes are the direct consequence of a resource-extractive, linear system that relies mostly on non-renewable resources, including oil to produce synthetic fibers, fertilizers to grow cotton, and chemicals to dye and finish textiles, while large resource externalities such as GHG emissions, biodiversity loss and pollution remain unpriced[1].

A major driver of these impacts is the fast fashion model. The trend of using garments for short periods before disposal has fueled unsustainable patterns of overproduction and overconsumption. Although clothing prices in the EU decreased by over 30% relative to inflation between 1996 and 2018, average household expenditure on clothing increased, a paradox that reveals how the fast fashion model has failed to deliver genuine value to consumers while simultaneously accelerating environmental degradation.

The Ellen MacArthur Foundation[2] has identified three structural drivers behind the generation of textile waste:

- First, clothing is generally delivered through linear, single-sale business models that do not provide for take-back, resale or repair;
- Second, products are not always designed to last and are hard to recycle;
- Third, separate collection infrastructure remains underdeveloped and fails to capture all textiles. A striking indicator of the sector's structural inefficiency is the estimate that 4-9% of all textile products put on the market in Europe are destroyed before use, after having been returned unsold.

Together, these drivers lock the sector into a take-make-waste cycle that is increasingly difficult to justify in the context of escalating planetary pressures

The environmental and social costs of mismanaged textile waste are significant. Textile waste burned in open pits or dumped into rivers and seas releases hazardous chemicals that threaten

[1] EU Strategy for Sustainable and Circular Textiles | European Commission
[2] Pushing the boundaries of EPR policy for textiles | Ellen MacArthur Foundation

species and habitats. Substances of concern, such as dyes and chemical finishes introduced during production, leak into the environment as textiles degrade. Plastic-based fibers will remain in landfills for decades, with the average polyester product likely to survive for over 200 years. The most vulnerable populations are disproportionately exposed to textile-related pollution, as they are more likely to reside near dumpsites and disposal areas[2].

Beyond environmental concerns, the sector also faces significant social challenges. Child labor in the apparel industry remains a grave concern and given that women make up the majority of the low-wage textile workforce, improving supply chain sustainability also carries an important gender equality dimension.

At the same time, the EU textile sector holds considerable economic weight and strategic potential. It comprises more than 160,000 companies, employs 1.5 million people, and generated a turnover of EUR 162 billion in 2019. The 2020 Circular Economy Action Plan and the 2021 update of the EU Industrial Strategy identify textiles as a key product value chain with an urgent need and strong potential for the transition to sustainable and circular production, consumption and business models[1].

It is within this context that the design phase emerges as a critical leverage point. The majority of a textile product's environmental impact is locked in at the design stage, yet historically product design has rarely accounted for end-of-life requirements, resulting in items made from mixed fibers that are difficult to separate, finished with chemicals incompatible with recycling processes, or constructed in ways that prevent disassembly. Addressing this gap through collaborative, multi-stakeholder co-creation represents one of the most effective entry points for driving systemic change across the textile value chain.

5.2 RELEVANT EU LEGISLATION

The regulatory framework governing sustainable textiles in the EU has evolved significantly in recent years, with several legislative instruments now in force or under development that collectively shape the conditions for circular design and producer responsibility.

The foundational instrument is REACH (Regulation EC 1907/2006), which restricts the use of hazardous substances in textile products and remains the primary reference for chemical safety requirements throughout the supply chain. The EU Textile Regulation (EU 1007/2011) establishes mandatory labelling and composition disclosure requirements, ensuring that fiber content is communicated to consumers and to downstream actors in the recycling chain.

The Ecodesign for Sustainable Products Regulation (ESPR), adopted on 18 July 2024, establishes the overarching product policy framework under which binding design requirements for textiles will be set; its provisions are discussed in detail in the following section.

Finally, the Revised Waste Framework Directive, effective from October 2025, has introduced harmonized Extended Producer Responsibility (EPR) for textiles and footwear across all Member States, requiring producers to fund collection, sorting, reuse, and recycling of post-consumer textiles, with fees modulated according to the circularity performance of their products, so that designs prioritizing durability and recyclability benefit from reduced contributions and producers face a direct financial incentive for circular product development.

Figure 1 provides an overview of the circular economy framework applied to textiles, showing how key intervention areas, circular business models, product design, consumer behaviour and policy, interact across two main dimensions: **slowing down the loop** (through durability, repairability and extended use) and **closing the loop** (through recycling and material recovery). The figure emphasizes the need for coordinated action across all levels to achieve effective circularity.

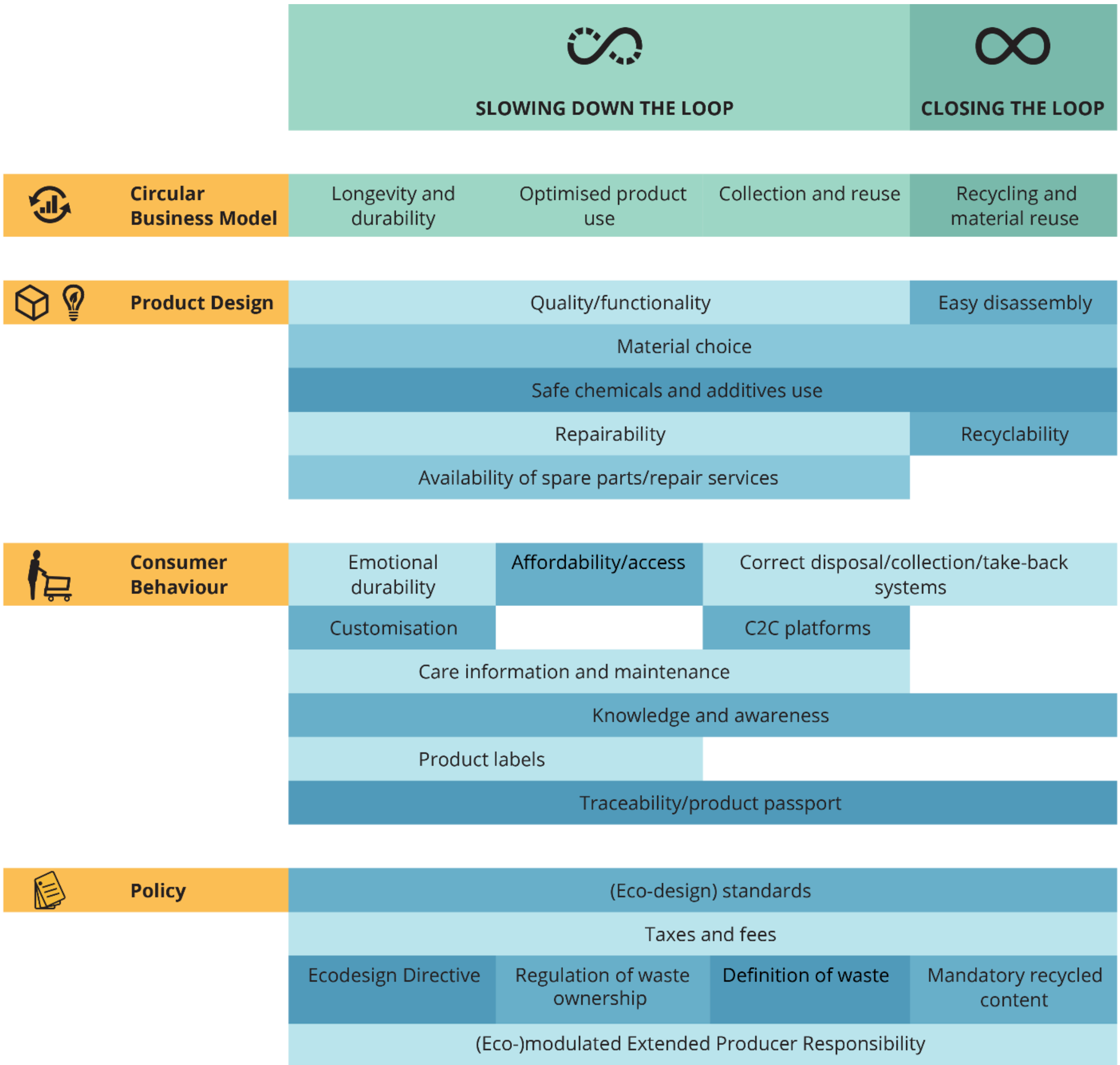

Figure 1: Overview of linkages between circular business model, product design, consumer behavior and policy[3]

5.3 ECODESIGN FOR SUSTAINABLE PRODUCTS REGULATION

With the objective of becoming the **first climate-neutral continent by 2050**, the European Union has accelerated the transition to a circular economy. The **Ecodesign for Sustainable Products Regulation (ESPR),** adopted on **18 July 2024**[4], establishes a comprehensive regulatory framework aimed at improving the environmental sustainability of products placed on the EU market throughout their entire life cycle.

[3] Textiles and the environment: the role of design in Europe's circular economy | European Environment Agency
[4] Regulation (EU) 2024/1781 of the European Parliament | European Commission

The regulation applies to most physical goods, including textiles, and introduces ecodesign requirements that manufacturers must meet to place products on the market. **Ecodesign** is defined as the integration of environmental sustainability considerations into product characteristics and processes across the entire value chain, from raw material extraction to production, use, and end-of-life management.

ESPR sets out two main types of requirements: **performance requirements**, which define qualitative or quantitative targets related to specific product parameters, and **information requirements**, which oblige manufacturers to provide relevant sustainability information accompanying the product. A key instrument in this regard is the Digital Product Passport (DPP), which will provide structured data on product composition, environmental performance, and sustainability characteristics.

The regulation highlights specific measures to address current environmental challenges, including a ban on the destruction of unsold consumer products, including textiles, starting from 19 July 2026, and obligations related to the transparent management of unsold goods.

For the textile sector specifically, the ESPR aims to improve critical product characteristics such as durability, reliability, reusability, repairability, recyclability, and overall resource efficiency. **Durability** is identified as the primary requirement, understood as the ability of a product to maintain its function and performance over time and encompassing related aspects such as reliability, reusability, upgradability, repairability, maintenance, and refurbishment. Recycled content, remanufacturability and recyclability follow as subsequent priorities, reflecting the relatively higher costs and impacts associated with these latter stages of the circular economy hierarchy. Requirements related to substances of concern, carbon footprint, water consumption and waste generation across the life cycle are also addressed.

Overall, the ESPR represents the central policy instrument for the textile sector's transition toward circular and sustainable production and consumption within the EU internal market, combining stricter product design requirements, enhanced information flows, and measures addressing both upstream production and downstream waste management.

5.4 STRATEGY FOR SUSTAINABLE AND CIRCULAR TEXTILES

The EU Strategy for Sustainable and Circular Textiles[1] sets the overarching policy direction for transforming the EU textile sector by 2030. Its core vision is that textile products placed on the EU market should be long-lived, recyclable, largely made of recycled fibers, and free of hazardous substances, with producers taking responsibility for their products along the entire value chain, including at end of life.

The systemic shift will have an impact on how products are designed, produced, used, and managed at their end of life, addressing the sector’s significant environmental and climate impacts.

The Strategy's most relevant actions for design and EPR are:

Mandatory Ecodesign requirements under the Ecodesign for Sustainable Products Regulation (ESPR) will introduce binding product-specific requirements covering durability, reusability, reparability, fiber-to-fiber recyclability, mandatory recycled fiber content, and the minimization of substances of concern. Priority product categories include apparel, household textiles, carpets and mattresses.

Harmonized EU EPR rules for textiles, to be proposed as part of the revision of the Waste Framework Directive (2023), will include eco-modulation of fees, directly linking producer contributions to the circularity performance of their products. A share of EPR contributions is proposed to be dedicated to waste prevention and preparation for reuse.

A Digital Product Passport will introduce mandatory information requirements on circularity and key environmental parameters, including fiber composition, substances of concern, and repair information, improving transparency across the value chain between producers, recyclers and consumers.

The vision the Strategy wants to promote is the creation of a coherent framework through which by 2030 textile products placed on the EU market are long-lived and recyclable, largely composed of recycled fibers and free from hazardous substances (included within the REACH Regulation), and produced in compliance with social and environmental standards.

Furthermore, the novel framework addresses systemic inefficiencies by banning the destruction of unsold or returned textiles as they are a waste of value and resources and tackling microplastic pollution, particularly from synthetic fibers that release the highest quantities during the first 5–10 washing cycles. In this context, producers will have to provide clear guidance on product care, promoting gentle washing practices to reduce fiber shedding and extend garment lifespan. Ultimately, the strategy seeks to transform the textile ecosystem into a competitive, resilient, and innovative sector where producers are responsible for the entire value chain, waste is minimized, and fast fashion is replaced by a model prioritizing quality, longevity, and resource efficiency.

5.5 EXTENDED PRODUCER RESPONSIBILITY

Extended Producer Responsibility (EPR) is a policy principle first defined by Thomas Lindhqvist in 1990 and defined as "*a policy principle to promote total life cycle environmental improvements of product systems by extending the responsibilities of the manufacturer of the product to various parts of the entire life cycle of the product, and especially to the take-back, recycling and final disposal of the product*".

The OECD further defines EPR as "*an environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle*".

The implications of EPR are then double: firstly, there is a shift of responsibility, physically and/or economically, away from the municipalities towards the producer; secondly the introduction of incentives to producers to take into account environmental considerations while designing their products.

In the textile sector[5], EPR schemes are emerging as a significant driver for circularity when complemented by eco-design requirements and fee modulation mechanisms that reward products with superior environmental performance. Recyclability is one of the key parameters through which producers may be incentivized to improve product design, as eco-modulated fees directly penalize products that are difficult to collect, sort or recycle.

The effectiveness of future textile EPR schemes will therefore depend not only on collection and treatment infrastructures but also on the ability of manufacturers and designers to integrate circularity considerations during product development. Design choices related to material composition, product construction, accessory selection and information transparency directly influence the quality and efficiency of subsequent recycling processes.

A fundamental finding emerging from recent EPR discussions is that many current recycling challenges originate upstream, during the design phase. Textile products are often developed

[5] Driving a Circular Economy for Textiles through EPR | Eunomia

without considering end-of-life requirements, resulting in materials and constructions that are difficult to sort, dismantle or recycle.

The Design for Recycling approach seeks to address these barriers by incorporating recyclability considerations from the earliest stages of product development. The table below summarizes the relationship between key Design for Recycling principles and their contribution to recycling performance and EPR objectives.

Design for Recycling principle	Contribution to recycling performance	Alignment with EPR objectives
Use of mono-material structures	Higher material recovery rates	Supports eco-modulation criteria
Reduction of complex fiber blends	Improved recyclate quality	Facilitates circular material flows
Easy removal of accessories and trims	Simplifies dismantling operations	Reduces treatment costs
Material traceability and identification	Enhances sorting efficiency	Supports reporting obligations
Limitation of hazardous substances	Improves secondary material quality and safety aspects	Facilitates compliance with recyclability criteria
Standardized material information	Enables automated sorting technologies	Increases value chain transparency

Table 4: Relationship between Design for Recycling principles and EPR objectives

In the report from the Ellen Mac Arthur foundation[2], EPR can be associated with four structural benefits:

1. Stable and adequate funding: EPR provides dedicated, ongoing, and sufficient funding for the collection, sorting, and treatment of end-of-life textiles;
2. Collective action towards shared targets: It fosters coordination among stakeholders (brands, collectors, recyclers) through binding targets for collection, reuse, and recycling, supporting the circular economy;
3. Attraction of infrastructure investments: It enables investment in collection, sorting, and recycling infrastructure, thanks to improved economic certainty and material supply;
4. Greater transparency and traceability: EPR introduces reporting and monitoring systems, improving visibility over material flows and supporting better decision-making.

5.6 JRC'S "TASK 4 OF THE PREPARATORY STUDY ON TEXTILE PRODUCTS"

Task 4 of the JRC's Preparatory Study on Textile Products[6] analyses the product-level requirements needed to support future Ecodesign, EU Green Public Procurement, and EU Ecolabel criteria for textile apparel. It represents an additional chapter to the 1st milestone of the study, conducted by the Joint Research Centre following the MEErP (Methodology for Ecodesign of Energy-related Products) framework. It defines key product aspects that determine the circularity performance of textile apparel and sets out the characteristics that textile products

[6] Task 4 of the Preparatory Study on textiles for product policy instruments | European Commission

should meet to support durability, circularity, and low environmental impact across their life cycle.

The technical analysis classifies product technologies into three categories: the Base Case (BC), representing the average product on the market; the Best Available Technologies (BAT), which reflect the most ambitious performances already achievable; and the Best Not Yet Available Technologies (BNAT), which are the most advanced solutions not yet implemented at commercial scale. Against this backdrop, Task 4 addresses each major product aspect in turn.

In the context of textile apparel, durability, reliability, and reusability are grouped together because they share common characteristics and overlapping objectives that can be addressed through the same actions, a durable product is generally also reliable and reusable, with physical durability treated as the leading measurable aspect. Concretely, durable and reliable products must demonstrate strong physical performance, including resistance to abrasion, tearing, pilling, colour fastness, soiling, dimensional changes, and seam slippage, while remaining desirable to the user over time. Upgradeable, repairable, refurbishable, and remanufacturable products in turn require modular design with easy physical access to priority parts and simple disassembly using basic tools and fasteners. Maintenance requirements call for clear care instructions covering cleaning, drying, ironing, and storage, while safe chemical profiles demand full disclosure of substances of concern.

High energy, water, and resource efficiency depend on low-impact materials, low-consumption manufacturing processes, and reduced resource needs during the use phase. Recycled content should come from recyclable textiles to support fiber-to-fiber recycling, and recyclable products must be collectable, sortable, preparable for recycling, compatible with existing recycling technologies, and free of disruptive components. Emotional durability, namely the long-term attachment a user develops toward a product, is also recognized as relevant to life-cycle environmental impacts, even though it falls outside the formal ESPR definition of durability. Finally, low-impact products minimize emissions, pollutants, and harmful substances throughout their life cycle, while low expected waste generation requires minimal waste at all stages, emotional durability, and long product lifetimes.

6. CO-CREATIONS ACTIVITIES

6.1 INTERNAL STAKEHOLDERS' WORKSHOP

To kick off the collaboration within the Consortium and collect inputs form internal stakeholders, the first online Workshop was held in April 2025. Four main topics to be discussed in the framework of WP1 were then presented, particularly:

- Sustainable Design for Recycling led by RINA;
- Methods for classification, composition identification, sorting and labelling systems led by COT;
- Reuse, repair, redistribute, refurbish and remanufacture led by NTT; and
- EPR role led by CTB.

Subsequently, participants in the call were divided into four different breakout rooms. In each of them, the task leader encouraged a collaborative and structured discussion about the topic following the **SWOT analysis framework** of each previously presented topic. The answers were collected in a share board, and the raw answers are reported in the following four sub-paragraphs. After reporting the responses exactly as they were provided during the workshop, the main points that emerged for each of them were subsequently summarized.

Table 5: Strengths identified during the internal Workshop

Strengths

- Collaboration with recycling tech experts
- Creating a pull effect
- Design for longevity, repair and re-use are quite clear to implement
- Design for recycling can improve sustainability by mandating that different materials in a product are easily separated
- Developed infrastructure
- Enhanced product recyclability and material recovery
- Established mechanical recycling line
- Experience with pre-sorting for recyclability criteria
- Extensive experience and know-how
- Facilitation of closed-loop textile recycling systems
- Focus on innovation and sustainability
- Growing awareness among brand/SMEs companies for integrating R principles into textile products
- High processing capacity
- If Ecodesign properly implemented, it can increase number of recycled sources in the market, therefore increase demand and number of recyclers
- increase in high quality feedstock for t2t recycling
- Increased availability of mono materials textile
- Innovation
- Knowledge of textile composition and recyclability
- Making products easy dismantlable
- Material compatibility insight, lifecycle thinking from scratch
- Membership in professional networks
- Optimization of resources
- Reduction of waste and landfill dependency
- Regulatory support and incentives more available
- Stakeholder role in EU-level discussions
- Textile manufacturers provide uniform post-industrial waste to use for recycling
- The cultural migration towards more sustainable choices, making consumers to buy according to different choices
- The use of mono materials
- Waste reduction

Table 6: Weaknesses identified during the internal Workshop

Weaknesses
• Challenges with complex blend and multi-materials • Current lack of harmonized recycling • D4R needs harmonization rules • Dependent on technologies to recycle materials, which are constantly evolving, requires constant updating • Design for recycling is not yet standardized and limits the 'freedom of design' for designers and product developers • Difficulty to reach the product quality and durability for many fashion business models actually • Educate manufacturers and define exactly what waste is or ready for reuse. Any alternatives to zippers that could be recycled? • Lack of R&D on the topic • High R&D costs for new recyclable materials • Insufficient effort in designing products using BAT recycled materials. It seems everyone is waiting for the perfect material to substitute 1to1 virgin materials for the same original applications. This is a cultural bias • Issue with companies sitting outside of Europe, how will this be controlled, audited and monitored? -> important to not allow loopholes (Such as the issue we have today with the imports from China which don't have to pay any custom) • Lack of practical knowledge in applying DfR principles • Lack of scalable collaboration models with brands/designers • Limited knowledge and expertise in recyclable textile design • Limited recycling infrastructure and economic barrier since recycled fibers can be more expensive or low quality • limited scalable solutions. SUPPLY CHAIN RESISTANCE. Lack of standardized design for recycling metrics. High cost of innovation. • Limited traceability/data on textile inputs • Market saturation risk -> low quality garments can flood reuse markets • Need integration with other company function to be harmonized • No direct control over product design • The current paradigm in clothing purchase/consumption limits the possibility of application DfR in terms, for example, of materials • This approach clashes with the way the industry currently develops products • Trade-offs between recyclability and product performance • Until now it was more voluntary with the ESPR hopefully this becomes more tangible • Value chain complexity

Table 7: Opportunities identified during the internal Workshop

Opportunities
• Advanced technologies for separation of material blends and disassembly of textile products • AI systems, technologies to facilitate sorting and tracking processes • Clear labelling & traceability • Could be connected to different destinations (thinking about of a category of good designed to be recycled with different technologies for different applications). So it could open for diversification and several niche markets • Design with recycled content, but there is still little recycled content available in the market • Increasing awareness of the environmental impact of textiles (e.g. for fast fashion, ultra-fast fashion, poor quality etc.) • It could be helpful for brand reputation • It could be integrated into sustainability approaches of an organization • It could help maximize the circularity of materials and give a long span life to materials, decreasing environmental impacts and costs • It could lead to job creation (the same material will be processed several times) • It could open to new SBM (for instance a company could implement a take back business model thanks also to D4R) • Legislations ESPR • New materials development (bio-based, mono-material) • New training programs incorporates the new Design for recycling principles • Textile to textile recycling advancements. DPP synergy. Brand circularity commitments. Innovation for detachable components and mono materials. • The demand of consumers for transparency and more attention to production sustainability. • To start offering honest and transparent products made of recycled materials to create cash flow to be reinvested in innovation • Via eco modulations and eco design, there is power to change the whole manufacturing process of a company because it is too costly to be non-compliant and cost-effective to produce durable/recyclable products

Table 8: Threats identified during the internal Workshop

Threats
• Competitive disadvantage if recyclability increases costs significantly • Competitiveness of cheaper recycled feedstock from outside of Europe which helps brands meet the targets but doesn't help the European waste problem and collection, sorting and recycling infrastructure. • Competitiveness of European companies versus cheap clothing from abroad -> we need to start thinking of VAT structures/Gate fees/etc. • Consumer misunderstanding of design for recycling value. • Consumer reluctance if recyclable products are perceived as lower quality • Design for recycling may conflict with requirements for higher durability and functionality/comfort. • Different legislation all over Europe and all over the world • Fragmented industry adoption. • Lack of competitivity if European garments are aligned with D4R principles while garments from Asian region are not • Lack of consumer response if the recycled product is not on par with the virgin quality (look & feel) the consumer is used to or even requiring • Lag in recycling infrastructure capable of handling new D4R products • Lower consumers awareness and low interest in sustainability claims • Market pressure for fast design turnarounds • Misalignment across value chain • No direct economic incentive for brands • Other geographical areas are starting to offer recycled fibers/products that will dominate the EU market if the regulation slows starting of the circular business • Rapidly changing material and recycling technologies create design uncertainty • Regulations to create overly demanding specifications that will practically impede the creation of an offer of recycled products waiting for the 'perfect solutions' • Risk of greenwashing • Risk of higher prices for products which are aligned to DfR principles • Technological immaturity (e.g. high costs for recycling technologies);

The raw inputs collected through the SWOT analysis were subsequently reviewed and overlapping and recurring concepts were clustered to reduce redundancy, while related insights were grouped according to common drivers and impacts. The resulting insights were then structured into coherent thematic areas (Financial, Environmental, Corporate, and Market) as shown in the following tables (Table 9, Table 10,

Table 11 and Table 12). This approach allowed for a clearer, more structured interpretation of the overall results.

Table 9: Synthesis of identified strengths

Financial	Reduced raw material costs through increased recycled feedstock utilization Revenue growth driven by rising demand for circular products Improved margins enabled by efficient recycling operations Cost savings from improved resource efficiency and lower waste management and disposal costs
Environmental	Enhanced material recyclability through mono-materials and design for disassembly Support for closed-loop textile recycling and improved material recovery Reduced waste generation and lower landfill dependency driven by lifecycle-based design
Corporate	Strong technical expertise and collaborations with recycling technology experts Clear strategic focus on innovation and sustainability Active engagement in professional networks and EU-level policy discussions
Market	Growing demand for circular and sustainable products across key industries Increasing willingness of brands and SMEs to adopt circular design solutions Rising consumer preference for sustainable and durable products Expanding market opportunities driven by circular economy trends

Table 10: Synthesis of identified weaknesses

Financial	High costs of R&D and innovation for recyclable materials and components Economic barriers linked to recycled fibers (higher costs, variable quality) High capital investment requirements due to limited scalability of solutions
Environmental	Difficulty recycling complex blends and multi-material products Trade-offs between recyclability, durability, quality, and product performance Dependence on evolving recycling technologies and limited availability of BAT recycled materials and recyclable components
Corporate	Lack of harmonized Design for Recycling rules, standards, and metrics Limited expertise and constrained design freedom in applying non-standardized D4R approaches Weak cross-functional integration and limited control over product design

	Value chain complexity, supply chain resistance, and limited traceability Lack of scalable collaboration models with brands and designers
Market	Persistent preference for virgin materials limiting demand for recyclable alternatives Misalignment between DfR principles and current fashion consumption and development models Limited education and clarity on recyclable vs. reusable waste -> Low market awareness and understanding of recyclable vs. reusable solutions Challenges in enforcement, monitoring, and alignment beyond the EU market Limited demand pull due to unclear value perception of circular products

Table 11: Synthesis of identified opportunities

Financial	New revenue streams and cost savings driven by ecodesign and eco-modulation Investment and job creation linked to circular and recycled products
Environmental	Increased material circularity and extended material lifespan Reduced environmental impacts and lifecycle costs through Design for Recycling and advanced separation and disassembly technologies Advancement of textile-to-textile recycling and mono-material solutions
Corporate	Integration of Design for Recycling into corporate sustainability strategies Development of new sustainable business models (e.g. take-back systems) Innovation driven by new materials, AI-based sorting, traceability, and DPP Upskilling through new training programs aligned with DfR principles Strengthened governance and compliance driven by ESPR requirements
Market	Growing consumer demand for transparency and sustainable textile products Enhanced brand reputation through credible circularity and recyclability claims Market diversification enabled by products designed for multiple recycling destinations Increasing availability and market uptake of recycled-content products

Table 12: Synthesis of identified threats

Financial	Higher production costs and prices may reduce competitiveness of DfR-aligned products Lack of direct economic incentives and competition from cheaper non-EU products

Environmental	Lagging or immature recycling infrastructure and technologies Trade-offs between recyclability, durability, comfort, and functionality
Corporate	Fragmented regulations and uneven adoption across regions and value chains Rapid technological changes and uncertain or overly demanding regulatory requirements Risk of greenwashing and misalignment among value-chain actors
Market	Low consumer awareness or trust in recyclability claims Perception of recycled products as lower quality Strong market pressure for fast fashion and rapid design cycles

6.2 EXTERNAL STAKEHOLDER MAPPING AND ENGAGEMENT STRATEGY

The mapping of the possible external stakeholder began with a questionnaire to which project partners were called to fill out, as detailed in Deliverable D1.1. Partners were asked to complete the questionnaire based on their area of expertise, to identify the fields where they potentially could contribute.

In the questionnaire, the key question asked respondents to provide a list of potential stakeholders who could contribute to one or more of the four topics.

6.3 EXTERNAL STAKEHOLDERS' INTERVIEWS

With the purpose of collecting first-hand experience from textile stakeholders, as mentioned in D1.1, several key players have been interviewed. These players can be clustered as industrial players whose activities are related to manufacturing textiles and carpets, partners of ongoing research projects, Producer Responsibility Organizations (PRO), associations, policy agencies and experts from academia. Support from Circula-Tex consortium and technical partners has been crucial in creating a bridge with the experts.

The main target of the Interview was to define the context in which the interviewee operates, understand the roles they cover within their organizations, identify the main strengths and hindering elements related to design for recycling, and gather their interpretation on what is needed to promote a more sustainable textile business model.

To ensure a degree of objectivity, partners from similar context have been asked the same questions, also to ensure that the outcomes could be comparable.

In ANNEX I – List of participating stakeholders, an anonymous summary of the realities of the stakeholder is reported. This latter choice has been made to ensure full freedom of answering the questions from the stakeholders who answered the call for contributions.

In Figure 2, a schematical summary of the macro-categories of affiliation is depicted. Moreover, Figure 3 shows a graphical representation of the geographical coverage of the interviewees.

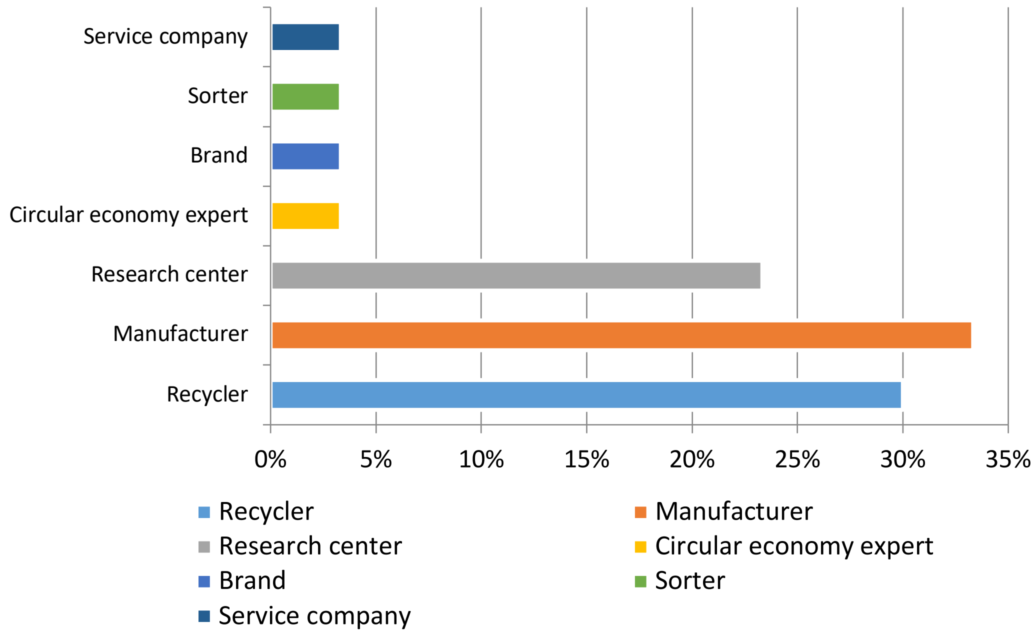

Figure 2: Distribution of interviewed stakeholders by category

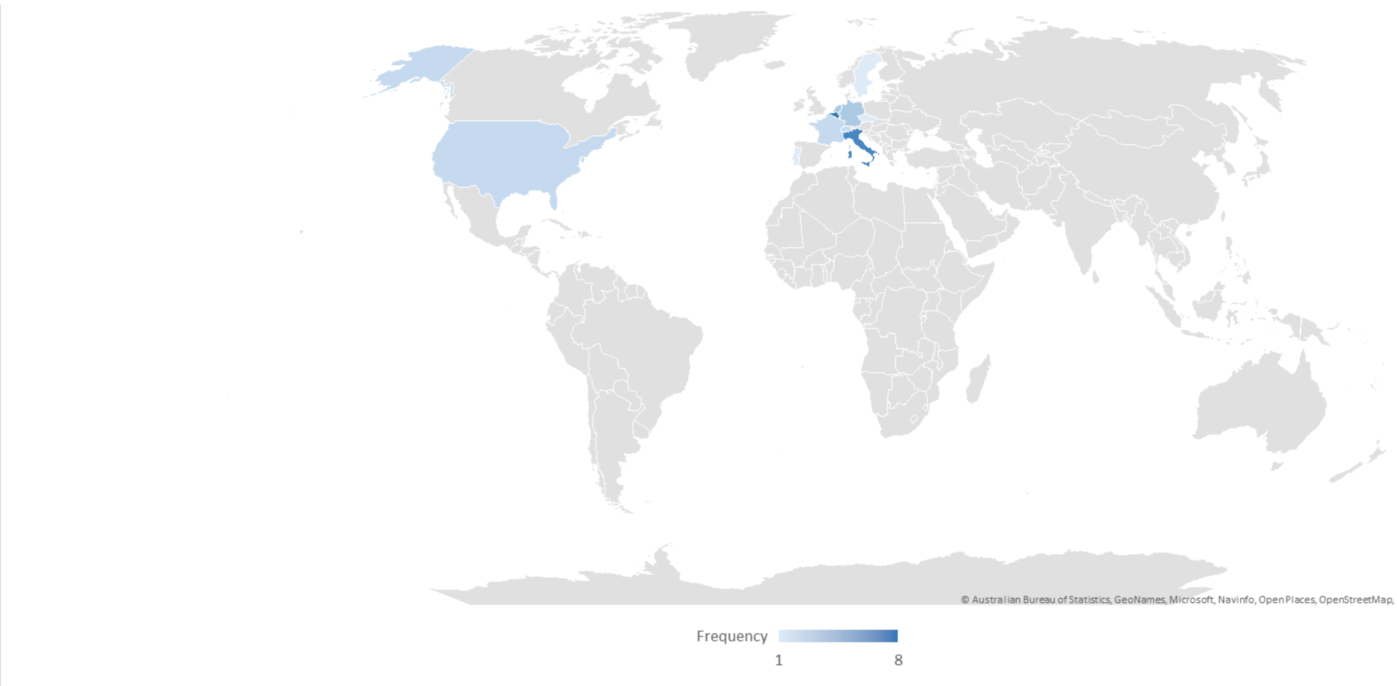

Figure 3: Geographical coverage of the interviewees

6.4 SYNTHESIS OF STAKEHOLDER FEEDBACK

This section provides a structured synthesis of the responses collected through one-to-one stakeholder interviews. In total, over 30 questions were analyzed and systematically grouped into thematic clusters, which were subsequently consolidated into ten overarching macro areas. A detailed overview of the clustering and classification approach is presented in ANNEX II – Overview of clustering and classification .

6.4.1 STATE OF IMPLEMENTATION AND INDUSTRY INTEGRATION OF D4R

How do companies currently integrate design for recycling principles into product development

Across the responses, companies integrate D4R into product development through a combination of product redesign, material selection, process adaptation, and value chain collaboration, although the level of implementation varies depending on product type and market constraints. At the same time, clear differences emerge between the perspectives of manufacturers/brands, who drive design choices, and recyclers, who validate technical feasibility and end-of-life processing.

A central approach consists in **simplifying product architecture**. Many companies are moving away from complex multi-material configurations and instead prioritize mono-material or limited-material solutions, as these significantly improve recyclability. This reflects a fundamental shift from traditional product design, often based on performance and aesthetics, to circularity-driven design. Where full mono-material design is not feasible, efforts focus on reducing the number of components, limiting material blends, and ensuring that the remaining combinations are compatible with existing recycling technologies. Material purity is therefore treated as a key design objective, even if a small share of additives remains unavoidable.

From the recycler perspective, this simplification is essential but must be aligned with real processing capabilities. Recyclers highlight that even small amounts of incompatible materials can negatively impact recycling yields or increase costs. For this reason, they actively analyze product compositions (e.g. bill of materials) and collaborate with manufacturers to replace or minimize problematic substances, ensuring that products placed on the market can actually be recycled within current systems, not just in theory.

Alongside material simplification, companies increasingly embed **material selection criteria directly into the design phase**. This includes screening raw materials and chemicals to avoid substances that could hinder recycling, replacing problematic components with more recyclable alternatives, and aligning product composition with recognized standards and certifications. From the manufacturer/brand side, this process is often formalized through eco-design guidelines, certifications, and internal approval systems. From the recycler side, this is supported through practical validation, such as testing alternative coatings or materials provided by brands to assess their compatibility with recycling processes. In this sense, recyclability is not treated as an end-of-life issue, but as a core design parameter from the outset, supported by continuous feedback loops between design and recycling actors.

Another key element is the adoption of **design-for-disassembly and separability principles**. For manufacturers, this translates into designing products with fewer components or enabling easier separation of layers and materials at end of life. However, for recyclers, the challenge is dual: not only supporting better product design but also developing technologies, such as improved mechanical separation or emerging AI-based sorting systems, to handle both new designs and legacy products that were never designed for recycling. This highlights the need to address both future products and those currently in circulation.

Importantly, D4R integration also extends beyond the product itself to **include production processes**. For manufacturers, redesigning products often requires adapting production technologies, sometimes involving substantial investments in new machinery or production lines (e.g. moving away from traditional multi-material or latex-based systems). This demonstrates that D4R is not only a design exercise but part of a wider industrial transformation. For recyclers, the equivalent challenge lies in improving and scaling recycling infrastructure, increasing plant efficiency, and addressing regional disparities in recycling capabilities.

Collaboration plays a crucial role in this process. Companies frequently work with **suppliers**, **recyclers**, and **technical partners** to test materials, validate recyclability, and co-develop solutions. From the manufacturer and brand perspective, engaging recyclers early in the design phase is essential to ensure alignment with real recycling capabilities and to avoid designing products that cannot be processed at end of life. From the recycler perspective, this collaboration represents an evolution of their role, from end-of-life operators to active contributors in product development. In some cases, this collaboration is complemented by take-back schemes or closed-loop initiatives, further strengthening the connection between design and end-of-life management.

At the same time, companies adopt **pragmatic and differentiated strategies** depending on product categories. While highly simplified designs are achievable for basic or standardized products, more complex items, especially those with strong aesthetic, technical, or performance requirements, remain challenging. Manufacturers and brands must balance recyclability with cost, functionality, and market expectations, which can limit the adoption of mono-material solutions in certain segments. Similarly, recyclers underline that there is no single universal solution, as recycling approaches must adapt to different material streams, technologies, and regional infrastructures.

Finally, more advanced practices include the **formalization of D4R within internal processes**, through design guidelines, training for design teams, integration of sustainability data into product development tools, and the use of lifecycle assessment (LCA) to support decision-making. From the manufacturer side, this often involves structured systems, such as PLM integration or tiered circularity criteria, to guide product development. From the recycler side, key systemic challenges remain, particularly in scaling technologies and improving material traceability. Accurately identifying material composition is essential for effective recycling, and the lack of reliable data continues to hinder large-scale implementation.

Overall, D4R is increasingly embedded by respondents as a **systematic and multidisciplinary approach**, combining design choices, material science, industrial processes, and value chain coordination. Manufacturers and brands primarily drive product simplification and eco-design integration, while recyclers ensure technical feasibility and contribute to innovation in sorting and processing. However, its implementation remains context-dependent, requiring trade-offs, continuous collaboration, and tailored solutions rather than a single universal strategy.

Integration of end-of-life considerations in product development and comparison with performance requirements

The responses indicate that the integration of end-of-life considerations and recyclability in product development remains **limited and inconsistent**, with a clear tension between circularity objectives and **performance-driven design priorities**.

From a theoretical perspective, early integration of recyclability is widely recognized as essential. Embedding circular principles at the design stage, such as selecting compatible materials, reducing material diversity, and enabling disassembly, allows sustainability considerations to be incorporated throughout the product lifecycle rather than addressed retrospectively. However, in practice, this approach is not yet systematically applied.

Across most sectors, end-of-life considerations remain **secondary** to performance requirements. Design processes are still primarily driven by criteria such as durability, functionality, aesthetics, and cost, with recyclability addressed only when it does not compromise these aspects. As a result, circular design is often conditional rather than fundamental, and its implementation varies significantly depending on product category.

Some companies adopt structured approaches to partially integrate end-of-life thinking. These include defining **minimum requirements** to avoid landfill, typically through recyclability or downcycling pathways, and, where feasible, aiming for more advanced solutions such as full material recovery. However, achieving higher levels of circularity depends on the alignment of **technical feasibility**, **economic viability**, and design constraints. Simpler products are generally more suitable for full recyclability, while complex products remain challenging.

From a systemic perspective, the limited integration of D4R is not primarily due to technical constraints but to economic and market factors. Although circular solutions are often technically feasible, they are not yet **cost-competitive** at scale. This limits their adoption in mainstream product development. Moreover, the absence of strong regulatory requirements reduces incentives to prioritize end-of-life considerations in early design stages.

Regulation is therefore identified as a key lever to shift priorities. Strong frameworks can create market demand for circular products, align actors across the value chain, and support the development of necessary infrastructure. Without mandatory requirements, the integration of recyclability is likely to remain uneven and dependent on individual company strategies.

Overall, the responses highlight a structural imbalance: while early integration of recyclability is recognized as critical, **performance requirements continue to dominate decision-making** in product development. Advancing D4R will require not only technical solutions but also stronger economic incentives and regulatory frameworks that elevate end-of-life considerations to the same level of importance as performance criteria.

Adoption of Design for Recycling and industry readiness to scale circular opportunities

The responses indicate that the adoption of Design for Recycling (D4R) across the industry is **growing but still uneven**, with significant differences depending on the **position within the value chain, company size, and level of regulatory exposure**.

D4R and broader **eco-design principles** are increasingly recognized as core topics, supported by research initiatives, observatories, and pilot projects that generate knowledge and test practical solutions. However, their implementation remains **fragmented and at different maturity levels**. Companies operating at different stages of the value chain face distinct pressures: upstream actors and manufacturers must manage **production-related waste**, while downstream actors are more directly exposed to **post-consumer waste challenges**. This leads to varying degrees of engagement with circular design practices.

The introduction of **regulatory frameworks (e.g. ESPR)** is significantly increasing awareness and urgency around waste management and circularity. As a result, companies are progressively required to organize collectively, for example through **consortia and shared systems**, to address end-of-life challenges. This contributes to a gradual shift from isolated initiatives toward more **coordinated, system-level approaches**, although full alignment has not yet been achieved.

Larger companies tend to be **more advanced and better prepared**, as they have greater resources to invest in innovation, infrastructure, and compliance. They are often already engaged in pilot projects, partnerships, and scaling efforts. However, achieving meaningful change requires **substantial capital investments**, particularly adapting production processes, redesigning products, and developing circular supply chains. This represents a significant barrier, even for large players.

At the same time, the scaling of circular opportunities remains constrained by **uncertainty around economic returns**. While funding instruments and incentives, particularly at the

European level, are available, there is still limited clarity on how these translate into **stable business value and profitability**. Companies therefore face a critical question regarding the long-term viability of circular investments, which slows down large-scale adoption.

More broadly, the transition toward circularity is still in a **development phase**, characterized by experimentation and gradual scaling rather than full industrial maturity. Technologies, business models, and value chains are evolving, but not yet fully stabilized or widely deployed.

Overall, while there is clear progress in the adoption of D4R and a growing recognition of circular opportunities, **industry readiness remains partial**. Advancing toward large-scale implementation will require greater **financial certainty, coordinated action across the value chain, and sustained investment** to move from pilot initiatives to fully scalable circular systems.

6.4.2 MATERIAL CHOICES AND THEIR IMPACT ON RECYCLABILITY

Influence of material choices on recyclability

The responses highlight that **material choices are a primary determinant of product recyclability**, as they directly **influence compatibility with existing recycling technologies**, while being constrained by performance requirements, production systems, and cost considerations.

The most critical materials affecting recyclability are fibers and bonding agents, particularly adhesives. Fiber composition determines whether products can enter specific recycling streams, while adhesives, such as latex (in case of carpets), often represent a major limitation due to strict constraints imposed by recycling facilities on their type and quantity. As a result, even recyclable products may be rejected when incompatible bonding systems are used.

More broadly, **material complexity remains a key barrier**. Blended materials (e.g. synthetic fibre mixes), coatings, and additional components such as trims or padding reduce recyclability by complicating separation and contaminating material streams. Technical finishes (e.g. stretch, water-repellent, easy-care) further increase complexity. In parallel, the quality of incoming feedstock is often insufficient, as materials do not meet mono-material or purity requirements, limiting effective recycling.

An additional constraint is that **material choices** are not always demand-driven but **often depend on material availability within the supply chain**. In some cases, product design starts from available inputs (e.g. yarns), rather than from optimal recyclability criteria, reinforcing dependence on upstream actors and limiting design flexibility.

A key challenge lies in **balancing recyclability and performance**. Materials required to meet durability, comfort, or aesthetic standards may conflict with circularity goals. At the same time, uncertainty related to material composition, especially when using recycled inputs, can further complicate future recyclability and processing.

To address these challenges, companies primarily adopt incremental approaches based on material optimization rather than radical redesign. This includes testing and substituting materials within existing product structures to improve compatibility with recycling processes and enable cleaner separation at end-of-life. Collaboration with suppliers plays a critical role, for example in developing modified adhesives or alternative materials that satisfy both performance and recycling constraints.

In addition, companies implement eco-design practices, including reducing material mixtures, improving material purity, increasing the use of more sustainable inputs, and investing in innovation and R&D. Efforts to improve traceability and transparency of material composition also support downstream sorting and recycling.

However, **progress remains gradual**. Fully recyclable solutions are not always achievable due to technical limitations and cost constraints, combined with limited market acceptance of higher-priced products.

Overall, improving recyclability through material choices requires a continuous balancing of cost, performance, availability, and circularity, with most companies progressing through step-by-step material improvements rather than fundamental changes to product architecture.

Impact of mono-material vs multi-material design on recyclability, performance, and system implications

The responses indicate that the choice between mono-material and multi-material design has significant implications for **recyclability, performance, and system scalability**, but also reveals important practical limitations and trade-offs.

From a recyclability perspective, mono-material solutions are generally considered preferable, as they enable easier sorting and higher-quality material recovery, including compatibility with **chemical recycling processes**, which often require high material purity or specific composition thresholds. Even limiting products to a reduced number of fibers can improve recyclability compared to highly complex blends. However, in practice, achieving true mono-material design is difficult. Even products labelled as single material typically include **additives, coatings, dyes, processing agents, and auxiliary components**, which affect material purity and complicate recycling processes. As a result, complete material homogeneity is rarely achievable in real-world textile applications.

In contrast, **multi-material designs**, including fiber blends, coatings, and functional components, significantly hinder recyclability by increasing separation complexity and contaminating material streams. This reduces both the efficiency of sorting processes and the quality of recycled outputs. From a recycling perspective, variability in material composition also creates uncertainty, as different recycling technologies accept different material ratios and qualities.

However, restricting material diversity introduces important trade-offs in the **use phase**. Performance requirements such as durability, strength, comfort, and aesthetics often rely on fibre blends or specific material combinations. For example, achieving properties such as softness, elasticity, or resistance may require fine fibers or blended materials, which can reduce durability or create compromises in product lifetime. In some cases, **mono-material alternatives may not deliver equivalent performance, particularly for more complex or technical applications**.

The relationship between material composition and **product lifetime** is therefore not linear. While simpler materials may facilitate recycling, they do not necessarily guarantee longer durability, and in some cases may even reduce product lifespan. This creates a tension between optimizing for use-phase performance and end-of-life outcomes.

At the system level, the transition toward mono-material or simplified material design would have broader structural implications. On one hand, it could improve the **efficiency and scalability of recycling systems** by enabling more consistent material streams and reducing processing complexity. On the other hand, it may constrain design flexibility, limit product differentiation strategies, and require significant adaptation across supply chains.

In addition, recyclers highlight that material composition alone is not sufficient; **volume and consistency of material flows** are equally critical. Recycling systems require large, stable quantities of similar materials to operate efficiently and justify investments. Without sufficient scale, even well-designed mono-material products may not translate into viable recycling operations.

Finally, the transition toward reduced material complexity could reshape market dynamics, potentially favoring new or more specialized actors capable of operating within simplified, circular systems, while challenging existing business models based on material diversity and differentiation.

Overall, while mono-material design supports improved recyclability and system efficiency, its implementation is constrained by performance requirements, technical realities, and market conditions. Achieving an effective balance requires not the elimination of material combinations, but a **controlled simplification** aligned with recycling capabilities, combined with sufficient scale and system coordination.

Material combinations to avoid and criteria for ensuring recyclability and viability

The responses indicate that ensuring real recyclability and economic viability requires careful selection of **material combinations**, the definition of **clear thresholds**, and strong alignment with **recycling processes and market conditions**.

A primary issue concerns the avoidance of **incompatible blends and components** that hinder recycling. Materials such as elastane, although beneficial for performance, can significantly limit recyclability, particularly in chemical processes, even when present in small quantities. Similarly, combinations of fibres with very different chemical structures (e.g. certain natural–synthetic blends or high-value fibers mixed with low-value ones) reduce the ability to recover materials efficiently and often lead to downcycling or disposal. In some cases, companies deliberately avoid specific blends, even when they perform well, because they would compromise end-of-life processing.

Another critical aspect is the presence of **problematic additives and bonding systems**, such as certain adhesives, coatings, or backings (for carpets). Even when these components meet technical specifications, they may prevent economic or environmental viability in recycling systems, either by contaminating material streams or exceeding processing limits. This highlights that compliance with technical thresholds alone is not sufficient, materials must also be compatible with **real recycling conditions and outcomes**.

The definition of **quantitative thresholds** is essential for guiding design decisions. Recycling processes often require minimum levels of material purity to be economically viable. For example, synthetic recycling systems may require a high percentage of a single polymer to function efficiently, with lower-purity materials needing to be blended with higher-quality streams to reach acceptable thresholds. This illustrates that recyclability is not binary but depends on achieving **sufficient concentration and consistency** within material flows. At the same time, processing costs must be considered, as low-quality or contaminated inputs increase the economic burden on recyclers.

Beyond composition, the effectiveness of material choices depends on **logistical and systemic factors**. Even well-designed materials cannot be recycled efficiently without sufficient volumes of homogeneous material and well-organized collection and sorting systems. Post-consumer recycling remains particularly challenging due to contamination and variability, requiring extensive pre-processing and coordination across the value chain. In contrast, post-industrial streams are easier to manage due to their higher consistency.

To address these challenges, companies need structured approaches to evaluate material choices, including:

- assessing **compatibility with existing recycling technologies**
- defining acceptable **material thresholds and purity levels**
- considering **economic feasibility**, including processing costs and market value of outputs
- aligning design decisions with **available infrastructure and material flows**

In addition, collaboration across the supply chain and **applied research and pilot projects** are essential to test material combinations under real conditions. These experiments help identify practical constraints, such as quality differences between recycled and virgin materials, and inform more realistic design guidelines.

Overall, the findings highlight that effective material selection requires moving from theoretical recyclability to **practical, system-aligned criteria**, where material combinations are chosen based on their compatibility with industrial processes, their ability to reach required thresholds, and their contribution to economically viable circular systems.

6.4.3 DESIGN STRATEGIES AND PRACTICES FOR RECYCLABILITY

Impact of garment design on recycling efficiency

The responses indicate that garment design can **substantially improve recycling efficiency**, but only when specific material and construction choices are addressed at the design stage.

A primary factor is the reduction of **material complexity**. Limiting the number of materials used in a product, ideally to one or two compatible components, can significantly improve sorting, processing, and material recovery. Even small quantities of incompatible fibres can have a disproportionate impact. For example, the presence of **elastane in otherwise homogeneous materials** can prevent effective recycling, particularly in chemical processes, creating major technological barriers despite high overall material purity.

Another critical aspect is the selection of **compatible components and additives**. Elements such as adhesives, coatings, and prints, commonly used to enhance functionality (e.g. durability or aesthetic performance), can interfere with recycling processes if they are not aligned with the main material stream. Designing with recycling in mind therefore requires choosing substances that do not contaminate or hinder material recovery.

Design decisions also directly influence the **efficiency of industrial processes**. Simplified and more homogeneous material compositions enable higher sorting accuracy, reduce processing costs, and improve the quality of recycled outputs. Conversely, complex blends and non-removable components increase operational complexity and reduce yield.

However, the effectiveness of design interventions is also linked to **system-level conditions**. Policy measures, such as promoting recyclable materials or setting limits on material diversity, can reinforce design choices and accelerate adoption across the industry. Without such frameworks, improvements driven by design alone may remain partial.

Overall, garment design plays a decisive role in enabling efficient recycling systems. Strategic choices related to **material composition, compatibility, and product architecture** can significantly enhance recyclability, but their impact depends on alignment with recycling technologies, industry practices, and regulatory support.

Design elements hindering recycling processes

The responses consistently highlight that several design elements can hinder recycling processes, although their impact varies depending on the specific recycling technology and product category. Overall, the main issue is not the presence of a single problematic component, but rather the combined effect of multiple design choices that increase material complexity and reduce separability. Importantly, both manufacturers/brands and recyclers agree that recyclability challenges emerge from the interaction between product design and the actual capabilities of recycling systems, rather than from isolated technical issues.

A first and fundamental barrier lies in the widespread use of **multi-material and multilayer structures**. When different fibres and materials are combined within the same product, often through tightly bonded or inseparable constructions, they become extremely difficult to process at end of life. While each material may be recyclable on its own, their combination frequently prevents high-quality recycling and results in downcycling or disposal. From the manufacturer perspective, this issue is particularly linked to the extensive use of adhesives and composite constructions, where otherwise valuable materials (e.g. polyester, polyamide, calcium carbonate) lose their recyclability once permanently bonded together. From the recycler perspective, this complexity is further exacerbated by current sorting technologies, which are often unable to detect internal layers or distinguish complex blends beyond the surface level, making effective material recovery extremely challenging.

Closely related to this issue is the use of **adhesives**, **latex**, and **other bonding systems**, which are repeatedly identified as one of the most critical barriers. These elements are widely used to ensure product performance, durability, and cost efficiency, particularly in applications such as carpets. However, they bind materials together in ways that prevent effective separation and contaminate recycling streams. Latex layers, in particular, are frequently cited by manufacturers as highly problematic, while fillers such as calcium carbonate, although functionally beneficial, are difficult to recover once embedded in composite structures. From both perspectives, even when alternative adhesive solutions (e.g. reversible or separable systems) are being explored, these are still at an early stage and not yet widely scalable or economically viable.

Another important challenge concerns **coatings**, **finishes**, and **chemical treatments**. These elements are often applied for functional or aesthetic reasons, but they introduce additional uncertainty into recycling processes. In many cases, their exact composition is not fully known or disclosed, which represents a major barrier from the recycler perspective, as it limits the ability to adapt processes or explain inefficiencies. Certain substances may be incompatible with specific recycling technologies or even rejected entirely by recycling plants due to regulatory constraints (e.g. hazardous substances such as SVHCs or specific adhesives like PVB). While some manufacturers note that certain treatments (e.g. dyes or limited quantities of coatings) may be manageable within specific processes, there is a shared recognition that coatings and laminations will become an increasingly critical challenge, particularly for advanced recycling pathways.

Beyond these structural and chemical aspects, **additional components and accessories**, such as zippers, buttons, labels, prints, and decorative elements, further complicate recycling operations. From a manufacturer standpoint, these elements are often necessary for functionality, aesthetics, or branding, especially in complex product categories such as fashion or technical textiles. From a recycler perspective, while many of these components can be removed through pre-processing steps, their presence increases operational complexity, requiring manual or automated removal, additional sorting, and potentially reducing throughput or fiber quality. For instance, removing trims during mechanical processing may shorten fibers, lowering the quality of recycled outputs. Even small additions such as logos, prints, or labels introduce different materials into the recycling stream, requiring extra separation steps and increasing costs at scale.

A more subtle but equally relevant issue concerns **impurities and minor material fractions**, such as elastane or other blended fibers. Even when present in relatively small quantities, these can disrupt recycling processes and lower the quality of the recovered material. Both manufacturers and recyclers emphasize that maintaining strict composition thresholds is critical: while visible components can often be removed, embedded polymeric impurities within fibers are much harder to manage and represent a key limitation for both mechanical and chemical recycling technologies.

Importantly, the severity of these barriers depends on the **type of recycling process** and the specific operational context. Some technologies are more tolerant of certain components, particularly if they can be removed beforehand, while others require very high levels of material purity. Additionally, recyclers operate with different technical capabilities, acceptance criteria, and process configurations, which creates uncertainty for manufacturers trying to design products that are universally recyclable. This fragmentation makes it difficult to define consistent design guidelines across the industry.

Operational and economic implications further reinforce these challenges. The presence of multiple materials, coatings, and auxiliary components increases the need for pre-processing steps such as sorting, dismantling, and shredding. From the recycler perspective, this directly impacts efficiency, as recycling systems must achieve high throughput to be economically viable. Additional complexity slows down processes, increases costs, and may reduce output quality. From the manufacturer perspective, fully addressing all problematic elements can also be challenging, as it may require redesigning products, changing materials, or adapting production processes, often involving significant trade-offs between recyclability, performance, and cost.

In summary, the main design elements that hinder recycling are those that **increase material heterogeneity**, **prevent effective separation**, or **introduce unknown or incompatible substances**. Rather than a single critical factor, it is the cumulative effect of multi-material structures, bonding systems, chemical treatments, impurities, and auxiliary components that makes recycling complex, costly, and often inefficient. These challenges highlight the need for stronger alignment between product design and recycling capabilities, as well as for collaborative approaches that integrate both manufacturer and recycler perspectives.

Design choices with the greatest impact on recyclability

The responses highlight that the design choices with the greatest impact on recyclability are those that **reduce material complexity, increase transparency, and align products with existing recycling technologies**.

A key factor is the **simplification of material composition**, particularly through limiting the number of fibers used. Mono-material designs are often recommended, but where performance constraints exist, the use of **a maximum of two compatible materials** is seen as a realistic compromise. Beyond this threshold, recycling becomes technically difficult and economically unfeasible.

Another critical choice is the **reduction of multi-layer structures and bonded components**, such as glued parts or complex constructions. These combinations prevent effective separation at end of life and significantly reduce the value of recyclates, even when individual materials would otherwise be recyclable.

The **selection and control of chemicals** is equally important. Limiting the use of complex dyes, finishes, and hazardous substances—and promoting greater harmonization of chemical inputs—can significantly improve recyclability. Even small material fractions, such as elastane, can negatively impact recycling if not carefully managed.

Transparency on material composition is also essential. Many challenges arise because brands and recyclers lack clear information about fibres, trims, and chemical treatments. Improved data and traceability would enable better sorting, processing, and compliance with recycling requirements.

In addition, **designing products for disassembly**, for example by simplifying trims and making components easier to remove, can facilitate pre-processing and improve recycling efficiency.

However, the responses also stress that the impact of these design choices depends on **available recycling technologies**, which vary significantly. The lack of standardization and insufficient large-scale implementation means that even well-designed products are not always effectively recycled.

Finally, broader **systemic factors** play a major role. Weak regulations, limited economic incentives, and inconsistent policies slow down adoption of design-for-recycling practices. A phased approach, combining better design, increased transparency, and stronger regulatory frameworks, is seen as necessary to enable meaningful progress.

Overall, the most impactful D4R choices are those that **simplify materials, reduce chemical and structural complexity, and ensure compatibility with real-world recycling systems**, while recognizing that technological and systemic constraints still limit their full effectiveness.

Circular design leverage points and role of different lifecycle phases

The responses indicate that the most critical leverage points in circular design lie in reducing production volumes, extending product use, and integrating circular strategies at the design stage, while current efforts tend to overemphasize downstream solutions such as recycling. This perspective is also supported by current circular design frameworks, which stress the central role of design decisions and lifecycle thinking in achieving effective circularity[7]

The most impactful leverage point identified is avoiding or reducing the production of new products. From a systemic perspective, this represents the highest potential for reducing environmental impact, as it directly addresses resource consumption and waste generation. However, this approach conflicts with the dominant industry model based on continuous growth, high turnover, and frequent product renewal, making it difficult to implement in practice.

A second key leverage point is the extension of product lifetime and use cycles, including reuse, repair, and second-hand models. These "upper-cascade" strategies retain more value than recycling, as they preserve the function and embedded resources of products. Despite their potential, these strategies remain underdeveloped compared to recycling, due to limited business models and weaker economic incentives.

At the same time, the integration of circular thinking in the early design phase is highlighted as essential. Effective circular design requires considering material choices, disassembly, and end-of-life pathways from the outset. However, in practice, design processes rarely adopt a fully integrated approach, and circularity is often addressed in a fragmented or reactive manner rather than as a core design principle.

[7] A DESIGN GUIDE FOR CIRCULAR DESIGN STRATEGIES FOR TEXTILE PRODUCTS | HSLU

Currently, the system appears over-optimized around recycling. Recycling has become the dominant focus of circularity strategies, largely because it fits more easily within existing production and consumption models. However, this focus risks reinforcing unsustainable dynamics, such as high production volumes combined with nominal material recovery, sometimes referred to as "fast recycled" systems, which do not significantly reduce overall environmental impact.

If recycling were minimized or removed, the system would face significant disruption, as many current circular strategies depend on it. In the short term, this would create challenges in managing waste flows and maintaining material cycles. However, it would also force a structural shift toward more effective strategies, particularly reuse, repair, and product longevity, accelerating the transition toward a more genuinely circular system based on reduced throughput.

Finally, the responses emphasize the importance of collaborative and experimental approaches between research and industry, such as prototyping and pilot projects. These practices help move beyond theoretical frameworks and enable practical understanding of how circular design strategies can be implemented and scaled.

Overall, the findings suggest that the greatest leverage points lie upstream, at the level of production reduction, design decisions, and use-phase extension, while the current system remains disproportionately focused on downstream solutions. A more balanced approach, prioritizing value retention over material recovery, is required to achieve meaningful circularity.

Key strategic principles for improving recyclability and circular design

The responses indicate that companies should adopt a set of **pragmatic and system-oriented principles** to improve recyclability and effectively implement circular design, centred on simplification, process alignment, and demand-driven production.

A fundamental principle is **material and product simplification ("less is more")**. Reducing complexity in garment design, by limiting the number of materials, avoiding unnecessary features, and prioritizing simpler constructions, significantly facilitates recycling and reuse processes. While strict mono-material design is not always required or feasible, higher levels of **material homogeneity** make processing more efficient and reduce operational challenges across recycling systems.

Closely linked to this is the need to define and respect **material thresholds**. Small quantities of certain fibres may still be manageable within recycling processes, but exceeding specific limits (e.g. high elastane content) can make materials difficult or impossible to process. Companies therefore need to adopt clear internal guidelines on acceptable **composition ranges**, based on the requirements of downstream technologies.

Another key principle is **design alignment with real processing capabilities**. Circular design should not be based on theoretical recyclability but on actual compatibility with existing technologies. Complex garments with multiple materials or intricate construction, even if technically recyclable in theory, often remain impractical in industrial contexts. Ensuring that products can be efficiently opened, separated, and processed is therefore essential.

A further strategic element is the adoption of **demand-driven production models**. Processing and material use should be closely aligned with market demand, avoiding overproduction and unnecessary accumulation of stock. This approach improves resource efficiency and ensures that materials reintroduced into the value chain are directly linked to actual needs, reducing waste across the system.

In parallel, companies should aim for **full value retention**, ensuring that materials are consistently reintegrated into the value chain rather than discarded. This requires designing products that can be effectively recovered and reused, as well as aligning production and recycling flows to minimize losses.

Overall, the responses highlight that effective circular design relies on a combination of **simplification, material control, process compatibility, and system efficiency**. Rather than pursuing idealized solutions, companies should adopt **operationally feasible strategies** that reflect the realities of recycling technologies and market dynamics, enabling scalable and economically viable circular systems.

6.4.4 DESIGN TRADE-OFFS AND PERFORMANCE CONSTRAINTS

Balancing recyclability with performance, durability, and lifespan: key trade-offs

The responses indicate that balancing recyclability with performance, durability, and product lifespan is a complex and context-dependent challenge, shaped by **economic constraints, market dynamics, and systemic industry structures**.

A central trade-off exists between **cost, durability, and circularity**. Designing products with higher durability, through increased material quality or density, often raises production costs, making such solutions less competitive in price-sensitive markets. Consumer behavior further reinforces this constraint, as demand is frequently oriented toward **low-cost, trend-driven products** with shorter lifespans rather than long-lasting, more expensive alternatives. This reduces incentives for companies to prioritize durability or advanced circular design.

At the same time, a structural tension exists between **product longevity and recyclability**. Products designed for extended use may reduce the urgency of recycling in the short term, while shorter-lived products require stronger emphasis on recyclability, disassembly, and material recovery. However, these objectives are not always fully compatible, particularly when achieving high performance requires material complexity that limits end-of-life processing.

More broadly, the industry operates within a predominantly **linear economic model**, where companies are not fully responsible for end-of-life impacts. This limits incentives to invest in circular design and shifts decision-making toward cost efficiency and production speed. Additionally, designers often have limited influence over key variables such as material selection, which are driven by strategic or procurement decisions, further constraining the implementation of D4R.

From a design perspective, companies adopt different approaches. Some integrate sustainability as a core element of their **brand identity**, aligning aesthetics, materials, and product development with circularity principles. Others prioritize commercial factors, implementing only **incremental or superficial changes** that do not fundamentally alter product design. This divergence reflects broader differences in strategic positioning and target markets.

A further challenge lies in balancing **performance requirements**, such as durability, functionality, and aesthetics, with recyclability. In some cases, recycled or simplified materials may compromise performance, while stricter durability requirements (e.g. increased resistance standards) may make recyclability harder to achieve. The appropriate balance therefore depends on how performance thresholds are defined, including through emerging regulatory frameworks.

At the same time, some perspectives emphasize that this trade-off should not be considered absolute. A more **holistic design approach**, which integrates recyclability, durability, and repairability from the outset, can help reconcile these objectives. This requires considering multiple life cycles, integrating design for disassembly, and ensuring that end-of-life is treated as a minimum requirement rather than an optional feature.

Finally, effective implementation depends on broader **organizational and knowledge factors**. Circular design decisions involve multiple functions beyond design, including sourcing, production, and strategy. Limited expertise in materials, recycling technologies, and circular systems, combined with weak cross-functional alignment, reduces the effectiveness of D4R initiatives.

> *Overall, balancing recyclability with performance and lifespan involves navigating interdependent trade-offs between* ***cost, durability, material choices, and market expectations****. Addressing these challenges requires a shift from incremental adjustments toward* ***systemic integration of circular principles****, supported by stronger internal alignment, improved competencies, and enabling economic and regulatory conditions.*

Technical trade-offs in shifting from multi-material to mono-material design

The responses indicate that transitioning from multi-material to mono-material design involves **significant technical and economic trade-offs**, particularly related to **performance, durability, aesthetics, and cost**, while also revealing that outcomes can vary depending on product type and application.

A primary trade-off concerns **performance and durability**. Different materials provide distinct functional advantages and combining them often enhances product properties. For example, certain fibers offer greater **resilience, strength, or wear resistance**, while others enable flexibility or specific tactile qualities. Replacing these combinations with a single material can reduce performance, making it difficult to meet required standards, particularly in demanding or high-performance applications. This is especially relevant in sectors such as sportswear or technical textiles, where material blending is often necessary to achieve required functionality.

At the same time, mono-material designs may create challenges related to **aesthetic quality and design flexibility**. Some materials are easier to dye or manipulate, enabling a wider range of colors, textures, and finishes. Restricting material options can therefore limit design possibilities or require additional development effort to achieve comparable visual results. In practice, companies often retain **hybrid solutions** to preserve aesthetic differentiation and meet market expectations.

However, the shift is not exclusively associated with negative trade-offs. In some cases, removing certain components or substances can lead to **performance benefits**, such as improved safety or reduced complexity. At the same time, efforts to simplify products may reduce material use, contributing to resource efficiency. Nevertheless, these advantages must be balanced against the need to maintain core product functions, such as **structural stability and dimensional performance**, which may be affected when materials are reduced or substituted.

A key challenge lies in achieving **technical equivalence** between mono-material and multi-material solutions. Developing alternatives that match the performance of existing products often requires extensive **R&D, testing, and process adjustments**, particularly when suppliers do not offer suitable materials. This can involve redesigning components internally and iterating through multiple trials to reach acceptable performance levels.

In some cases, mono-material solutions can achieve **comparable performance**, especially in simpler product categories, suggesting that trade-offs are not universal but context-dependent.

However, for more complex applications, testing has shown that mono-material designs may fail to meet required standards, particularly in terms of durability and long-term performance, limiting their commercial viability.

Another important trade-off is **economic**. Mono-material solutions often rely on more specific or higher-quality materials, increasing production costs. While some market segments may accept this premium, cost sensitivity remains a major barrier in broader markets, influencing companies to maintain multi-material designs.

In response to these challenges, some companies are exploring **alternative strategies**, such as designing products for easier **layer separation** rather than complete mono-materiality, allowing for improved recyclability while maintaining performance. This reflects a more pragmatic approach that balances circularity with technical feasibility.

> *Overall, the transition to mono-material design reveals a complex balance between **performance requirements, aesthetic expectations, technical feasibility, and cost constraints**. While mono-materiality can support recyclability, it is not universally achievable or optimal, and in many cases requires compromises or complementary design strategies to maintain product quality and market viability.*

6.4.5 SYSTEM-LEVEL ENABLERS AND VALUE CHAIN DYNAMICS

Collaboration across the extended value chain for Design for Recycling

Companies collaborate across the value chain to support Design for Recycling (D4R) primarily through a combination of **close technical partnerships**, **continuous communication**, and **emerging forms of facilitation between actors**, although these efforts remain fragmented and often limited in scale.

Upstream, collaboration is typically strong and highly operational. Companies work closely with material and component suppliers to co-develop inputs that meet recyclability and performance requirements. This often involves defining precise specifications, testing materials against application standards, and ensuring traceability, certification, and environmental impact measurement. In some cases, **brands actively incentivize suppliers to innovate and align with circularity goals**, while also relying on suppliers' own recycling initiatives or take-back systems within the supply chain. This upstream engagement is essential to ensure that each product component is compatible with both manufacturing processes and end-of-life recycling systems.

At the same time, **collaboration extends to recyclers and processing facilities during the design phase**. For example, companies developing recyclable products (such as carpet collections) work directly with recycling plants to ensure that materials are compatible with existing technological constraints while also aiming to improve the economic viability of recycling processes. This reflects a shift toward designing products not only for performance and durability, but also for recyclability and recovery value.

Downstream collaboration is generally less structured and more uneven. Some companies engage directly with customers, particularly in business-to-business contexts, to facilitate the return of materials, although this is often limited to production waste or small-scale pilot initiatives. In the commercial sector, companies may act as intermediaries, connecting customers with take-back partners and recyclers, and prioritizing reuse wherever possible. However, in consumer-facing markets, downstream collaboration is much weaker due to fragmented distribution channels, private labels, and limited product traceability. As a result, **recovering materials from end users remains a major challenge**.

To address this, companies are exploring tools such as Digital Product Passports, product ID cards, QR codes, and RFID technologies to improve transparency and guide sorting, reuse, and recycling. However, uncertainty about standards, costs, and regulatory requirements often delays large-scale implementation. Regulatory drivers - particularly the anticipated introduction of Extended Producer Responsibility (EPR) schemes for textiles in Europe, are expected to play a key role in accelerating alignment and encouraging more systematic collaboration across the value chain.

Despite these efforts, **most collaboration today is still based on bilateral relationships and informal knowledge exchange rather than structured, industry-wide systems**. Many actors, including brands, suppliers, sorters, and recyclers, tend to operate in silos, developing individual solutions that are not easily scalable. This fragmentation reduces both the economic viability and the overall impact of circular initiatives. For example, take-back or recycling systems are often designed for specific brand partnerships rather than shared infrastructure, limiting efficiency and scale.

There is therefore a **clear need for stronger coordination mechanisms and broader stakeholder involvement**. Interviewees highlight the importance of creating shared platforms, common standards, and joint business models that bring together all actors in the value chain, from material producers to recyclers and waste managers. In particular, closer collaboration between sorters and recyclers, as well as more active engagement from brands with their (often non-European) suppliers, is seen as critical. Sharing financial and operational risks across the value chain is also essential to move beyond traditional buyer–supplier relationships and enable meaningful progress.

In addition, **systemic solutions,** such as EPR schemes, improved waste collection infrastructure, and increased consumer awareness, **are needed to complement company-level initiatives**. Without these enabling conditions, it remains difficult to scale circular solutions, especially in consumer markets.

> *In conclusion, while companies are actively collaborating across the value chain to support Design for Recycling, especially upstream, current efforts are still fragmented and insufficient to achieve scale. More coordinated, system-level approaches involving additional stakeholders, shared infrastructure, and regulatory support are necessary to align actors and unlock the full potential of circular solutions.*

Effectiveness of traceability tools in enabling circular systems and product return

The responses indicate that traceability tools, such as **Digital Product Passports (DPPs)**, QR codes, and tags, have strong potential to support circular systems, but their current effectiveness is constrained by **cost, lack of standardization, and limited industry adoption**.

From a functional perspective, traceability tools can significantly improve **transparency across the value chain**. By providing information on material composition, recycling instructions, and return options, they enable better decision-making for all stakeholders, including producers, recyclers, policymakers, and consumers. In this sense, they are widely perceived as **useful and necessary enablers** of circularity, particularly for improving sorting, recovery, and product return flows.

However, practical implementation remains challenging. One of the main barriers is **cost**, especially when traceability solutions need to be applied at product level. Attaching identifiers (e.g. QR-code-based labels) to every item can be economically unfeasible, particularly in high-volume sectors. Even when technically possible, these solutions may introduce additional material and production costs that are difficult to justify without clear economic returns or regulatory requirements.

Another critical limitation is the lack of **harmonization across the industry**. Current efforts are largely fragmented, with companies running isolated pilots and developing proprietary systems. This fragmentation reduces effectiveness, as traceability only delivers full value when it is **interoperable and standardized** across actors. Without a common framework, recyclers and other downstream operators cannot efficiently use the information provided, and scaling remains limited.

As a result, traceability tools are still mostly in a **pilot and experimental phase**. While their importance is widely acknowledged, there is not yet a fully developed, widely adopted system capable of supporting circularity at scale. The sector is described as reactive, with ongoing testing but limited coordinated implementation.

> *Overall, the effectiveness of traceability tools depends less on their technical feasibility, which is already largely demonstrated, and more on the development of* ***industry-wide standards, cost-effective solutions, and coordinated adoption****. If these conditions are met, traceability systems could play a decisive role in enabling circular systems and improving product return, but at present their impact remains* ***promising but not yet fully realized****.*

Role of business models and market expectations in enabling Design for Recycling

The responses indicate that **Design for Recycling (D4R)** cannot be fully effective without changes in **business models**, as current market dynamics and value creation logic often work against the adoption of circular products.

A key limitation lies in the fact that sustainability is still not a **primary value driver** in most markets. While awareness is increasing, evidenced by the growth of **second-hand markets**, this has not fundamentally shifted consumer willingness to pay. In most cases, customers are **not willing to pay a premium** for sustainable or circular products, especially in price-sensitive segments. As a result, companies are required to deliver more sustainable products at **the same price point**, which constrains the implementation of D4R due to higher associated costs.

This highlights the need for **business model transformation**. Circular design cannot rely solely on technical solutions at product level but requires changes in how value is created and captured, particularly through models based on **reuse, resale, and extended product life**. However, current systems remain largely anchored in high-volume, linear production, making it difficult to prioritise reduction or long-term value retention.

Market expectations play a decisive role in shaping design decisions. **Clients and retailers** often drive demand for innovation in materials, but this is frequently oriented toward **performance, novelty, or cost efficiency**, rather than recyclability alone. Requests may include increasing recycled content, improve material quality, or exploring alternative fibers (e.g. from agricultural waste), but these initiatives must still meet strict requirements in terms of functionality, aesthetics, and price competitiveness.

At the same time, the diversity of client demands reflects a fragmented landscape, where circularity is one of several competing priorities rather than a dominant one. This results in **incremental improvements**, such as increasing recycled content, rather than systemic redesign aligned with D4R principles.

The responses also suggest that stronger **external pressure** is required to accelerate change. Market forces alone are unlikely to drive large-scale adoption of circular design, given current consumer behaviour and competitive dynamics. Instead, **regulatory intervention, industry collaboration, and strategic repositioning** are seen as necessary to create sufficient incentives. In some cases, the urgency of transition is linked to long-term business viability, with companies engaging in **collaborative initiatives** to maintain competitiveness and adapt to emerging circular requirements.

> *Overall, D4R cannot be effectively implemented in isolation from broader system changes. Its success depends on the alignment of* ***business models, market structures, and consumer expectations****, which currently favour cost, speed, and differentiation over circularity. Without this systemic shift, circular design risks remain limited to niche applications or incremental improvements rather than becoming a mainstream practice.*

Economic and logistical challenges of take-back programmes

The responses indicate that **take-back programmes face significant logistical and economic constraints**, particularly related to space requirements, operational complexity, and cost-efficiency.

A primary logistical barrier is the **lack of physical space for collection and storage**. Retailers, especially small or urban stores, often do not have sufficient warehouse or in-store capacity to manage returned products. This constraint becomes more critical when take-back systems require separate collection streams for different materials, which would necessitate multiple containers. In dense urban environments, such as large metropolitan areas, allocating space for several waste categories is often impractical, limiting the feasibility of decentralized collection models.

From a system perspective, this creates a **mismatch between the ideal design of circular systems (which requires sorting and separation at source) and real-world retail conditions**, where operational constraints prevent effective implementation. As a result, take-back schemes risk remaining limited in scale or restricted to specific contexts where space is available.

In addition to **logistical issues, there are important economic challenges**. Managing return flows involves **costs related to collection, handling, storage, and transportation**, which may not be offset by the value of recovered materials—particularly when volumes are low or materials are heterogeneous. For retailers, take-back activities do not generate direct revenue, making them difficult to justify without external incentives or regulatory requirements.

These constraints highlight the **need for more centralized or coordinated collection systems**, which could reduce the burden on individual retailers and improve efficiency through aggregation of volumes. They also underline the importance of designing take-back programmes that are operationally simple, cost-effective, and adapted to real market conditions.

Overall, while **take-back schemes are essential for enabling circular systems**, their implementation is currently limited by space constraints, operational complexity, and insufficient economic incentives, requiring systemic solutions beyond individual actors.

6.4.6 BARRIERS AND CHALLENGES IN IMPLEMENTING D4R

Barriers to the implementation of Design for Recycling

The responses indicate that the main barriers to implementing Design for Recycling (D4R) are economic, technical, regulatory, organizational, and market-driven, and stem from a systemic misalignment between product design, market expectations, and recycling capabilities across the value chain.

The most critical barrier is **economic**. Recyclable solutions typically involve higher costs due to more expensive inputs, lack of economies of scale, and the need for investments in new technologies and supply chain adaptation. At the same time, willingness to pay remains limited, particularly in mass markets, constraining the commercial viability of circular products. Market demand, driven by price, speed, and trends, directly shapes design choices upstream, discouraging the adoption of D4R. From the recycling perspective, this dynamic translates into insufficient volumes of suitable materials and weak business cases for investment. In the absence of strong financial incentives or mechanisms such as Extended Producer Responsibility (EPR), circular solutions remain economically unattractive.

From a **technical perspective**, a central challenge lies in material complexity and performance trade-offs. Manufacturers highlight the difficulty of replacing multi-material constructions, coatings, and functional elements without compromising durability, aesthetics, or technical performance. At the same time, recyclers emphasize that these design choices result in heterogeneous material streams that reduce sorting efficiency and recycling output quality. Specific issues include contamination from certain components, the presence of complex blends, and uncertainty linked to the chemical composition of recycled inputs. In addition, the quality of incoming feedstock is often inadequate, as materials do not meet mono-material or recyclability criteria, further limiting effective processing. A persistent gap also exists between theoretical eco-design principles and actual industrial recycling capabilities, making some design solutions impractical at scale.

A further barrier lies in the **lack of standardization** and alignment **across the value chain**. Manufacturers adopt different design approaches, while recyclers operate with varying technologies and acceptance criteria, leading to fragmentation and uncertainty. The absence of shared design rules prevents consistency in material flows and limits scalability. At the same time, product differentiation strategies, often based on unique materials, finishes, or chemical formulations, reinforce material diversity and further complicate recycling processes. This creates a structural tension between the need for standardization to enable recycling and the market-driven need for differentiation.

Regulatory factors play a dual role. On one hand, evolving frameworks, fragmented requirements, and sector-specific standards create uncertainty and increase complexity, particularly where products must comply with multiple regulatory regimes that may conflict with circular design principles. On the other hand, well-designed regulation has the potential to act as a key enabler by creating demand for recycled materials, setting clear design requirements, and supporting investment in infrastructure. However, current policy signals are often weak, inconsistent, or insufficiently harmonized, limiting their effectiveness in driving systemic change.

From an **organizational perspective**, implementing D4R requires substantial internal transformation. This includes redesigning products and processes, developing new technical and design capabilities, aligning different functions within the company, and coordinating with external partners across the supply chain. These changes are resource-intensive, time-consuming, and particularly challenging in large organizations or complex supply networks. Limited internal expertise and the need for long transition periods further slow progress.

Finally, **market dynamics and consumer behaviour** constitute a structural barrier. The prevailing emphasis on low cost, rapid production cycles, and continuous product differentiation incentivizes complex designs that are inherently difficult to recycle. At the same time, a persistent gap between sustainability awareness and actual purchasing behaviour limits demand for circular products. This reinforces a system in which recyclability is deprioritized in favour of speed, cost efficiency, and aesthetic variation.

Overall, **the barriers to D4R are systemic and interdependent**. Manufacturers tend to emphasize constraints related to cost, performance, and feasibility, while recyclers highlight the downstream consequences in terms of processing efficiency, feedstock quality, and scalability. These challenges are further exacerbated by the lack of coordinated standards, insufficient infrastructure, and weak economic incentives. Overcoming them requires stronger alignment across the value chain, the development of shared design rules, more effective and harmonized regulatory frameworks, investment in collection and recycling systems, and a structural shift in both production models and consumption patterns.

Alignment between research and industry priorities and barriers to scaling recycling innovations

The responses indicate a persistent **misalignment between research and industry priorities**, driven by differences in **economic incentives, business models, and time horizons**, which limits the translation of innovation into scalable recycling solutions.

A key issue is that research and development activities are often **driven by market and commercial priorities** rather than by circularity needs. In many cases, R&D investments focus on new materials, branding, or trend-driven innovations, while less attention is given to improving **recycling systems, material compatibility, and end-of-life performance**. As circularity is not yet a core economic driver, it remains secondary in strategic decision-making, resulting in a fragmented innovation landscape.

At the same time, industry practices, particularly the emphasis on **cost efficiency, performance optimisation, and product differentiation**, often move in the opposite direction of circular design. The widespread use of **complex material blends** to enhance product performance creates significant challenges at end-of-life, reinforcing the gap between sustainability principles and industrial practices. Although some progress is being made (e.g. encouraging the use of materials within the same chemical family), these efforts remain limited.

From a systemic perspective, the transition is constrained by a lack of **economic maturity of circular models**. Environmental sustainability is often treated as a value-added feature rather than a core driver equivalent to economic sustainability. As a result, innovations in recycling struggle to compete with established linear systems, particularly when recycled materials cannot yet match the **cost consistency and performance reliability** of virgin inputs.

A major barrier to scaling recycling solutions lies in **material variability and feedstock quality**. Post-consumer inputs are highly heterogeneous, leading to inconsistent material properties that require continuous testing and adaptation. This contrasts with virgin materials, which offer predictable quality and stable supply. While improved sorting technologies could mitigate this issue, they often involve high costs, and in some applications volume considerations may outweigh the benefits of perfect sorting.

Another critical constraint is the need for **sufficient volumes and economies of scale**. Recycling technologies require large and consistent material flows to justify investment and operate efficiently. Without reliable supply, even well-funded initiatives may fail, as demonstrated by cases where recycling infrastructure could not be sustained due to insufficient input materials. Established operators with existing volumes are better positioned to integrate recycling, while new entrants face significant barriers.

The translation of research into industrial practice is further limited by **technological gaps and uneven development**. While some recycling technologies are mature, others, particularly those aimed at achieving high-quality, fibre-to-fibre recycling, still require further **fundamental research** to reach performance levels comparable to virgin materials. This highlights the importance of continued investment in **basic and applied research**.

Regulatory absence or weakness also contributes to the misalignment. Without strong policy drivers, such as mandatory recycled content requirements, there is insufficient market demand to support large-scale recycling systems. This limits the ability of innovative solutions to move beyond pilot stages and become economically viable.

Overall, the responses highlight that the gap between research and industry is not only technological but also **structural and economic**. Addressing it requires stronger alignment of incentives, including regulatory support, improved sorting and material standardization, greater investment in foundational research, and the development of stable markets for recycled materials. Only through this systemic approach can innovations be effectively translated into scalable industrial solutions.

Managing existing non-recyclable garments in the transition to circular design

The responses indicate that dealing with the large volume of existing garments not designed for recycling requires a pragmatic and transitional approach, combining current technological limitations with long-term system improvements.

A primary consideration is that **only a limited share of current products is recyclable under existing technological and industrial conditions**. Many garments on the market contain complex material blends, additives, and construction features that prevent efficient processing. As a result, not all products can be recovered through high-quality recycling pathways.

In the short term, **management strategies must therefore rely on a hierarchy of end-of-life options**. Where possible, products should be directed toward reuse or second-hand markets. When reuse is not viable, recycling and downcycling can be applied depending on material quality and compatibility. However, a residual share of products will remain non-processable, requiring disposal through incineration or other waste management routes. While suboptimal, this reflects current systemic constraints rather than a lack of intent to improve circularity.

At the same time, **the effectiveness of these strategies depends on the gradual evolution of recycling technologies**. Over time, new processes are expected to handle increasingly complex materials and expand the range of recoverable products. However, this transition will require continued investment, infrastructure development, and improved organization of material flows.

A **critical parallel priority is improving future product design**. Since the existing stock cannot be fully adapted retroactively, the focus must shift toward ensuring that new products are designed for recyclability from the outset. This includes simplifying material composition, enabling disassembly, and aligning design choices with available recycling pathways.

Overall, the **transition requires accepting that part of the current material stock cannot be fully recovered**, while simultaneously **building a system in which future products are progressively more compatible with circular processes**. This dual approach, managing existing waste pragmatically while improving forward-looking design, is essential to enable a realistic and gradual shift toward circularity.

Barriers to processing post-consumer textile waste

The responses indicate that companies face significant challenges in processing post-consumer textile waste, primarily related to **material quality, economic viability, and supply chain readiness**.

A key barrier is the **inconsistency of feedstock**. Post-consumer textiles typically contain a wide range of materials, qualities, and non-textile elements, making it difficult to ensure a **stable and predictable input stream**. This heterogeneity contrasts with post-industrial waste, which is more uniform and easier to process. As a result, companies are required to implement additional **pre-processing steps** (e.g. sorting, cleaning, separation), which increases operational complexity and cost.

Closely linked to this is the challenge of balancing **quality and price**. Higher-quality, well-sorted materials improve processing efficiency and output quality but require more intensive sorting and handling, raising costs. At the same time, the market often does not compensate for these additional costs, making it difficult to establish a stable and economically viable model. While public subsidies are sometimes suggested as a solution, they are not considered a **sustainable long-term strategy**.

Another major constraint is the current lack of **economic incentives** to integrate post-consumer materials into production. In many cases, using such inputs does not significantly improve product performance or competitive positioning, reducing the motivation for companies to adopt them. This is further compounded by the absence of strong regulatory requirements enforcing the use of recycled content.

Finally, the broader **supply chain is not yet ready** to support large-scale use of post-consumer materials. Systems for collection, sorting, and quality control are still underdeveloped, limiting the availability of consistent and reliable material flows. This lack of infrastructure reinforces the risks and uncertainties associated with processing post-consumer waste.

Overall, the barriers to processing post-consumer textiles are systemic and interconnected. Addressing them requires improvements in **material quality and sorting systems**, stronger **market and regulatory incentives**, and the development of more **robust and coordinated supply chains** capable of delivering consistent, high-quality feedstock.

6.4.7 TECHNOLOGICAL AND REGULATORY DRIVERS OF DESIGN FOR RECYCLING

Impact of new technologies and innovations on recyclability

New technologies and artificial intelligence have the potential to fundamentally transform Design for Recycling, **shifting it from a static, rule-based approach to a more intelligent, predictive, and adaptive system**.

With the support of AI, designers can make more informed decisions from the earliest stages, evaluating materials, production processes, and environmental and economic impacts throughout the entire lifecycle of a product. This enables the selection of solutions that achieve a better balance between performance and sustainability, moving the industry toward truly circular design. From both manufacturer and recycler perspectives, this transition also implies a shift from designing in isolation to designing in alignment with real end-of-life processes.

However, while innovation is essential, **one of the biggest challenges today is not the lack of technologies, but the difficulty of scaling them**. Many promising recycling solutions already exist, yet they remain unevenly distributed, often region-specific, and highly dependent on individual recyclers' capabilities. This fragmentation prevents the adoption of standardized solutions at a global or even European level. As a result, stronger coordination, particularly at the European scale, is needed, alongside infrastructure that supports centralized collection and processing systems rather than relying on fragmented, client-based take-back schemes. From the recycler perspective, this lack of standardization and uneven technological distribution directly limits investments and the ability to process materials consistently at scale.

A key area where **innovation can have immediate impact** is **in end-of-life treatment technologies, especially in the separation of materials before recycling**. This is particularly relevant for products designed decades ago, which were not conceived with recyclability in mind. While we are now improving product design for the future, we must also address the large volume of legacy products currently in use. From the recycler standpoint, this is one of the most urgent priorities: incoming waste streams are still dominated by complex, multi-material products produced 10–30 years ago. **Technologies such as AI-driven sorting, computer vision, and advanced pre-treatment processes can significantly improve the identification and separation of complex material streams**, making recycling processes more efficient and economically viable, while bridging the gap between past product design and future circularity.

Material innovation will also play a crucial role. The shift toward mono-material products, standardized components, and modular design will greatly simplify recycling. Products designed for easy disassembly allow different components to be reused or processed separately, increasing overall recovery rates. From a recycler perspective, these design choices are essential to improve yield and output quality, although their benefits will materialize gradually as new products replace legacy ones. At the same time, the development of bio-based materials, such as those derived from agricultural waste, offers promising alternatives, especially when combined with innovations that enable integration with existing recycling systems and avoid introducing new incompatibilities.

Another critical factor is **traceability.** Tools like **Digital Product Passports can provide shared access to data about material composition, facilitating better sorting, recycling, and reuse**. While these tools are not innovations in themselves but rather policy-driven instruments, they can create a foundation for transparency across the value chain. However, their effectiveness will depend on the quality and reliability of the data, which initially may rely on self-declaration rather than verification. From the recycler perspective, traceability is particularly crucial, as the lack of accurate information on materials and chemicals remains a major barrier to efficient processing and to ensuring that recycled outputs meet quality and regulatory standards. In this context, **AI can enhance traceability systems by improving data processing, prediction, and optimization**, as well as supporting **material identification in high-throughput industrial environments.**

Beyond technologies, **systemic improvements are equally important**. Increasing the availability and efficiency of recycling plants and improving collection systems are essential to ensure that recyclable products actually get recycled. For example, in some sectors like carpets, the absence of dedicated collection points often leads to landfill or incineration despite technical recyclability. Establishing centralized collection infrastructures, such as municipal recycling hubs capable of handling multiple waste streams, can significantly improve outcomes, especially in urban areas where space constraints limit decentralized approaches. From both perspectives, better alignment between product design, logistics, and waste management systems is necessary to enable effective circular flows.

Start-ups can also play a key role in accelerating the transition by developing innovative solutions in areas such as **material traceability, advanced sorting technologies, and AI-based tools that translate eco-design principles into practical decision-making**

frameworks. From the recycler side, particular interest lies in technologies that improve sorting accuracy and processing efficiency at scale, while from the manufacturer side, these tools can support design optimization, waste reduction, and supply chain transparency.

Ultimately, **the transition to circularity requires a broader shift in mindset**. Circular economy is not simply about using recycled materials; it requires **designing entire product systems and collections with circularity in mind**. However, current consumption patterns, such as overproduction, remain a major barrier. Even the most advanced technologies and AI systems cannot fully address these challenges without corresponding changes in business models, value chain coordination, and consumption dynamics. From both perspectives, aligning incentives across the ecosystem remains a fundamental requirement.

> *In conclusion, the **future of recyclability will be shaped by a combination of technological innovation, digitalization, improved infrastructure, and systemic change**. The most impactful developments are likely to include AI-driven design and sorting, mono-material and modular products, enhanced traceability systems, advanced separation technologies for legacy products, and scalable recycling infrastructures. Together, these innovations can enable a shift from managing waste at the end of life to designing for circularity from the very beginning, while also ensuring that existing waste streams can be effectively processed within real industrial conditions.*

Influence of regulatory frameworks on design and implications for innovation and competitiveness

The responses indicate that emerging regulatory frameworks are increasingly shaping product design choices, but their effectiveness depends on achieving a balance between **mandatory requirements** and **practical flexibility**.

A key influence of regulation lies in the introduction of requirements related to **recycled content**, which are expected to stimulate market demand for secondary raw materials and support investment in recycling infrastructure. In the absence of such regulatory drivers, markets for recycled materials remain unstable, limiting the economic viability of circular solutions and slowing down technological development. In this sense, regulation is seen as a necessary condition to create the demand signals required to enable circular systems.

Regulatory frameworks are also expanding the scope of design considerations beyond recyclability to include **durability, repairability, and extended product use**. These requirements have the potential to shift design practices toward longer product lifetimes and to encourage the development of supporting ecosystems for repair and maintenance. However, such approaches often remain peripheral to current business models, where activities related to reuse or refurbishment are not yet fully integrated into core operations.

At the same time, the impact of regulation is constrained by the lack of **alignment and transparency across the value chain**. Designers and companies often lack clear, consistent information regarding recycling pathways, material compatibility, and processing requirements, making it difficult to translate regulatory principles into concrete design decisions. This highlights the need for stronger coordination and data sharing among supply chain actors.

The responses also emphasize that the **stringency and structure of regulation** are critical determinants of its effectiveness. Standards that are too weak or overly flexible may reduce the urgency for companies to adopt circular practices, while overly rigid requirements could limit innovation or create implementation challenges. Effective frameworks should therefore establish clear minimum thresholds while allowing **product-specific or portfolio-level flexibility**, enabling companies to adapt strategies according to different product categories and market conditions.

Regulation is further identified as a key driver of broader policy instruments, including **Extended Producer Responsibility (EPR)** and eco-modulation mechanisms, which can reinforce economic incentives and influence design choices. However, for these mechanisms to be effective, they must be sufficiently robust to alter market dynamics and support investment across the value chain.

Overall, the responses suggest that regulatory frameworks have strong potential to drive the integration of circular design into product development, but their success depends on careful design and implementation. In particular, they must combine **clear and enforceable requirements**, **economic incentives**, and **operational flexibility**, while being supported by improved supply chain alignment and infrastructure. Without this balance, regulation risks being either ineffective in driving change or restrictive in terms of innovation and competitiveness.

6.4.8 ADVANCED AND CONCEPTUAL APPROACHES

Feasibility of closed-loop garment design within brand ecosystems

The responses indicate that designing garments to be reintroduced into new products within the same brand ecosystem is currently **limited in feasibility**, due to a combination of **technical, logistical, economic, and behavioural constraints**, although progress is being made through pilot initiatives and incremental business model innovation.

From a technical and operational perspective, closing the loop at brand level remains challenging. While systems for collection, sorting, and recycling exist, they are not yet sufficiently **efficient or scalable** to enable consistent reintroduction of post-consumer garments into new production cycles. In practice, recovered garments through take-back schemes are often redirected to **resale or recycling pathways**, rather than being reintegrated into new garments of the same brand.

Economic viability represents a major constraint. Initial experiences show that processes such as collection, cleaning, repair, and sorting can generate costs that exceed potential revenues, particularly when handling low-value or highly processed garments. As a result, business models must be carefully adjusted to balance operational costs, return on investment, and market demand. This often leads to prioritising **resale channels** for suitable items, while allocating non-reusable products to recycling streams.

Logistical complexity is another key barrier. Effective closed-loop systems require well-developed **local infrastructure**, including collection networks, sorting capabilities, and recycling partners. These systems are highly context-dependent, and global implementation requires adaptation to different regional conditions. The need for **localized solutions** limits the scalability of closed-loop models across markets.

In addition, **consumer behaviour** plays a critical role. Adoption of circular initiatives such as garment return, resale, or reuse varies significantly across regions and cultures, influencing the availability and quality of returned products. Changing consumer perception and increasing participation are therefore essential to support loop-closing strategies.

Overall, while the concept of reintroducing garments into new production cycles within the same brand ecosystem is technically possible, it is not yet widely viable at scale. Current approaches remain **partial and hybrid**, combining resale, recycling, and selective reuse rather than achieving fully closed material loops. Advancing toward this model will require improvements in cost efficiency, infrastructure, and consumer engagement, alongside more scalable and standardized circular systems.

Design strategies across end-of-life pathways and the role of durability, second-hand, and emotional factors

The responses indicate that effective design strategies must address multiple **end-of-life pathways**, including recycling, upcycling, and downcycling, through a combination of material choices, product architecture, and system-level considerations.

A fundamental principle across all pathways is **design for disassembly**. Both recyclability and upcyclability depend on the ability to easily separate components and identify materials. Without clear product composition and accessible disassembly, neither recycling processes nor value-preserving strategies can be effectively implemented. However, the objectives of these pathways differ. Recycling focuses on recovering raw materials, often with some loss of value, while upcycling aims to preserve or enhance product value through reuse and transformation of components. A combined approach is therefore required, where different product elements are designed for different **value recovery routes**.

Material type significantly influences the appropriate end-of-life strategy. For **synthetic fibres**, closed-loop recycling is generally preferable, as these materials can be regenerated while maintaining core properties. In this context, downcycling is seen as inefficient, given the energy and environmental investments required for recycling processes. In contrast, **natural fibres** are more difficult to recover at high quality, making downcycling a more common, although less optimal, solution for waste management.

A key design challenge lies in addressing **material complexity**, particularly the presence of trims, accessories, and bonded components, which limit both recycling and reuse. The removal of such elements is often technically difficult and cost-intensive. Emerging solutions that facilitate easier disassembly (e.g. removable or dissolvable components) highlight the importance of integrating end-of-life considerations directly into product design.

Beyond material and technical aspects, **durability and product quality** play a crucial role in determining the effectiveness of circular strategies. Low-quality products limit opportunities for second-hand use and often result in premature downcycling or disposal. Designing for durability can therefore help extend product lifetimes and retain value within the system, provided that it is balanced with recyclability considerations.

Second-hand strategies represent a key mechanism for extending product lifetimes and reducing value loss. However, their effectiveness depends heavily on the quality of products entering collection systems. Higher-quality items are more likely to be reused, while lower-quality products tend to be diverted to recycling or downcycling pathways.

The role of **emotional design** is more limited but still relevant. While consumers often have an existing emotional attachment to their garments, this tends to diminish once products enter post-consumer systems. Emotional factors can nevertheless play a role in influencing **collection quality**, as items donated through more direct or personal channels tend to be of higher quality than those discarded anonymously. However, emotional design is not seen as a primary driver of circularity compared to material and structural design principles.

Overall, effective D4R strategies require a **multi-pathway approach**, where products are intentionally designed to enable recycling, reuse, and upcycling depending on component type and material characteristics. This involves combining material transparency, disassembly, and durability considerations to maximize value retention across the lifecycle, while acknowledging that different materials and product categories require different end-of-life strategies.

6.4.9 SKILLS, EDUCATION AND CAPABILITY BUILDING

Integration of Design for Recycling in education, required skills, and industry connections

The responses indicate that the integration of Design for Recycling (D4R) in education is still **limited and insufficiently aligned with industry needs**, reflecting a broader gap between theoretical training and practical application.

A key issue is that eco-design is often **narrowly interpreted**, frequently reduced to the inclusion of recycled materials rather than a systemic approach encompassing **product lifecycle, material compatibility, and end-of-life processes**. Moreover, educational content is rarely tailored to **specific product categories or sectors**, despite the fact that different industries face distinct material constraints and recycling pathways. This limits the ability of designers to translate general principles into actionable, context-specific solutions.

Another critical gap concerns the role of educators. Training systems often lack sufficiently specialised **teacher expertise** in circular design, which directly affects the quality and depth of knowledge transferred to students. As a result, current educational approaches tend to be **too theoretical, fragmented, and disconnected from real industrial constraints**, such as performance requirements, cost pressures, and recycling technologies. This contributes to a broader **misalignment between education and industry reality**, where ideal circular concepts are promoted without fully addressing practical trade-offs.

From a skills perspective, the responses consistently highlight the importance of **material knowledge** as a foundational competence. Designers require a deep, practical understanding of material properties—particularly in textiles—including differences between fibres, behaviour under stress, and performance characteristics. **Hands-on, learning-by-doing approaches** are essential to develop this awareness, as early reliance on digital tools without material understanding can lead to incorrect design assumptions. Alongside this, competencies in **engineering**, **design for disassembly**, and the ability to consider **multiple life cycles** are increasingly important.

At the same time, more advanced skills such as **computational and parametric design** are emerging, but they are seen as complementary and should build upon a strong material foundation. Designers are expected to evaluate trade-offs between **durability, adaptability, and recyclability**, and to integrate circular principles from the earliest design stages.

In terms of industry connection, existing collaborations between academia and industry are still **fragmented and limited in scale**. While some networks and initiatives foster exchange between stakeholders, they often remain niche and do not systematically bridge the gap between education and industrial practice. This limits the transfer of practical knowledge and the alignment of training with real-world requirements.

> *Overall, D4R is not yet fully embedded as a core design competence, but rather remains a secondary consideration. Strengthening its integration requires* ***closer collaboration between education and industry****, the development of* ***sector-specific guidelines****, improved* ***training of educators****, and a shift from theoretical awareness to* ***practical, application-oriented skills****.*

6.4.10 FUTURE DIRECTIONS AND EMERGING TRENDS IN D4R

Most promising eco-design principles in the short and long term

The responses indicate that the most promising eco-design strategies are those that combine **material simplification**, **design validation against real recycling systems**, and **system-level incentives**, rather than relying on single design solutions such as strict mono-materiality.

In the **short term**, the most impactful principle is the **reduction of material complexity**. This does not necessarily imply fully mono-material products, which are often impractical, but rather a controlled simplification of materials and components. Avoiding unnecessary blends, limiting incompatible materials, and preferring combinations within the same chemical family can significantly improve recyclability without compromising performance. Importantly, this approach must be grounded in **evidence-based design**, meaning that materials should only be selected if **proven recycling solutions** exist. Eliminating redundant or non-functional material choices—often driven by habit or supply chain defaults—represents a practical and high-impact intervention.

Another key short-term priority is the integration of **design validation mechanisms**, such as pre-assessment of recyclability before products are placed on the market. This shifts responsibility upstream to the design phase and ensures alignment with existing recycling infrastructures. However, implementing such control mechanisms remains challenging due to the high volume and speed of product development in sectors like fashion.

In the **long term**, the most promising approach is a **system-level transformation**, where eco-design principles are supported by **regulatory frameworks, infrastructure, and economic incentives**. The effectiveness of eco-design depends not only on product-level decisions but also on the broader system in which products circulate. Successful models demonstrate that combining **mandatory requirements**, **convenient collection systems**, and **financial incentives linked to recycled content** can create strong market signals and enable high recycling performance.

Within this long-term perspective, eco-design evolves from a set of guidelines into an integrated system where **design, collection, sorting, and recycling** are fully aligned. This includes greater transparency on material composition, stronger accountability mechanisms, and more consistent feedback loops between designers and recyclers.

At the same time, limiting or eliminating material blends entirely is not considered a fully viable strategy, particularly for performance-driven products. Instead, the future lies in **optimising material choices within realistic constraints**, ensuring compatibility with recycling technologies while maintaining required functionality.

Overall, the responses suggest that the most promising eco-design principle is not a single rule but a **pragmatic and systemic approach**, combining material simplification in the short term with coordinated system-level interventions in the long term.

Impact of circular design on creativity and compatibility with current recycling technologies

The responses indicate that circular design does not inherently limit creativity, but rather requires a **shift in design mindset**, while current recycling technologies remain only **partially aligned** with existing product design practices.

Historically, product design has prioritised **aesthetics, performance, and cost**, with little consideration for end-of-life. As a result, many garments currently on the market are not compatible with recycling processes, reflecting a structural mismatch between **design choices**

and recycling capabilities. Materials are often selected based on convention or short-term criteria rather than recyclability, contributing to the limited effectiveness of current recycling systems.

However, circular design is not viewed as a constraint on creativity. While it introduces certain **design boundaries**, such as limiting material complexity or ensuring compatibility with recycling processes, it also opens opportunities for innovation within these constraints. The responses highlight the existence of a **"middle ground"**, where designers can maintain differentiation and aesthetic value without relying on excessive material variation or non-recyclable components.

Rather than restricting creativity, circular design encourages a more **informed and intentional approach**. Designers are expected to integrate additional criteria, such as material composition, recyclability, and end-of-life impact, alongside traditional considerations of form and function. This expands the design space by introducing new challenges and opportunities for innovation, rather than reducing it.

At the same time, there is a clear need to improve the **compatibility between design and recycling technologies**. Current recycling systems struggle to process many of the products on the market, due to complex material compositions and the absence of standardized design practices. This indicates that technological development alone is insufficient; alignment must also occur at the design level.

To support this transition, the responses suggest the need for **stronger systemic incentives**. For example, introducing mechanisms that reward recyclable products and penalize non-processable ones could encourage companies to integrate circularity into design decisions. This would help shift recyclability from a secondary consideration to a core requirement.

Overall, circular design represents not a limitation of creativity, but a **redefinition of design constraints**, requiring designers to balance aesthetics and performance with material responsibility. At the same time, improving the alignment between **product design and recycling infrastructure** remains essential to ensure that circular design principles can be effectively implemented in practice.

7. RESULTS: OPTIMAL SOLUTIONS, GAPS AND REQUIREMENTS IDENTIFIED

The preceding analysis of Design for Recycling practices, material choices, design strategies, and systemic enablers provides a foundation for identifying the most promising solutions, the persistent gaps that continue to hinder progress, and the concrete requirements that must be met to advance circular design at scale. This chapter synthesizes the key findings emerging from the interviews, moving from descriptive observations toward actionable insights relevant to designers, manufacturers, recyclers, and policymakers alike.

The evidence gathered across value chain actors consistently points to a fundamental tension at the core of circular design: while the principles of Design for Recycling are increasingly recognized and, to varying degrees, embedded in company practices, their implementation remains fragmented, context-dependent, and constrained by structural misalignments between product development logic and end-of-life processing realities. Design decisions continue to be driven primarily by performance, cost, and market expectations, with recyclability treated as a secondary consideration rather than a foundational design parameter. This systemic imbalance, between what is technically desirable and what is economically and organizationally feasible, defines the landscape within which solutions must be sought.

At the same time, the research reveals that progress is neither uniform nor absent. Meaningful innovations are emerging, particularly in contexts where manufacturers, recyclers, and suppliers engage in sustained collaborative processes. Material simplification strategies, design validation mechanisms, and traceability tools are advancing, even if their adoption remains uneven. The challenge is therefore not only to identify what works, but to understand the conditions under which effective solutions can be scaled, replicated, and embedded into mainstream industrial practice.

This chapter is organized around three interconnected dimensions:

- **Section 7.1** examines the solutions that have emerged **from co-creation processes** between value chain actors, highlighting the collaborative dynamics and shared learning that have proven most productive.
- **Section 7.2** identifies the specific technical, organizational, and strategic requirements that designers and manufacturers must address to integrate circular principles effectively into product development.
- **Section 7.3** presents the needs reported by recyclers, whose operational perspective reveals critical gaps in feedstock quality, material transparency, technological capability, and upstream collaboration that must be addressed to enable genuinely functional circular systems.
- **Section 7.4** assesses how the identified Design for Recycling principles align with Extended Producer Responsibility objectives. It highlights EPR as both an economic and governance lever to translate recyclability, traceability, and design simplification into practical eco-modulation criteria.

Together, these three dimensions offer a multi-actor view of where the circular design system currently stands, what is needed to move it forward, and which interventions, at the level of design practice, industry collaboration, and regulatory frameworks, hold the greatest potential for systemic impact.

7.1 SOLUTIONS EMERGING FROM CO-CREATION

The analysis of Design for Recycling practices reveals that the most effective solutions are not the product of isolated design decisions but emerge from structured co-creation processes involving multiple actors across the value chain. Collaboration between manufacturers, brands, suppliers, and recyclers has proven to be a decisive factor in developing products that are both technically performant and compatible with end-of-life processing systems.

A **primary** area where co-creation generates tangible outcomes is **material development and substitution**. Companies working in close partnership with suppliers have been able to co-develop modified adhesives, alternative bonding systems, and substitute materials that simultaneously satisfy performance requirements and recycling constraints. Rather than selecting materials based solely on availability or convention, these collaborative processes enable a more deliberate and evidence-based approach to material choice, grounded in the actual capabilities of downstream recycling technologies. In some cases, recyclers have directly tested alternative coatings or materials provided by brands, validating their compatibility with industrial processes before product launch. This feedback loop between design and recycling represents a structural shift from treating recyclability as an afterthought to integrating it as a core design parameter.

Co-creation has also **driven innovation in product architecture**. The joint identification of problematic design elements, such as multi-layer structures, latex-based bonding systems, and incompatible fiber blends, has enabled manufacturers to pursue simplification strategies that would not have emerged from internal design processes alone. Recyclers contribute essential knowledge about processing thresholds, material purity requirements, and the practical consequences of design choices on an industrial scale. This technical exchange has supported the transition toward mono-material or reduced-material configurations in several product categories, as well as the exploration of designs that facilitate easier separation of layers and components at end of life.

Beyond bilateral relationships, co-creation has begun to take systemic forms. In some cases, companies have developed take-back schemes and closed-loop initiatives in collaboration with recycling partners, creating direct material flows between post-consumer collection and reprocessing. Pilot projects and prototyping activities carried out jointly by research institutions and industry actors have generated practical knowledge on how circular design strategies can be implemented and scaled, moving beyond theoretical frameworks. These experiments have also helped identify real-world constraints, such as quality differences between recycled and virgin materials, and have informed more realistic design guidelines that balance circularity with commercial viability.

However, **the solutions emerging from co-creation remain unevenly distributed and largely limited in scale**. Most collaborative efforts are still based on bilateral relationships and informal knowledge exchange rather than structured, industry-wide systems. Many actors, including brands, suppliers, sorters, and recyclers, continue to operate in silos, developing individual solutions that are not easily transferable or scalable across the broader industry. Take-back and recycling systems are frequently designed for specific brand partnerships rather than shared infrastructure, which limits their overall efficiency and impact. The fragmentation of these initiatives reduces both their economic viability and their systemic effect.

To **maximize the impact of co-creation, a shift toward more coordinated, multi-stakeholder approaches is required**. This includes the development of shared platforms, common design standards, and joint business models that bring together all relevant actors, from material producers to waste managers, around shared circular objectives. Closer collaboration between sorters and recyclers, as well as more active engagement from brands with their supply chains, is identified as particularly critical. Sharing financial and operational risks across the value chain is equally essential to move beyond transactional buyer-supplier relationships and enable the kind of deep, system-level co-creation that can generate scalable circular solutions.

7.2 REQUIREMENTS FOR DESIGNERS AND MANUFACTURERS

The findings highlight a set of clear and interconnected requirements that designers and manufacturers must meet in order to effectively implement Design for Recycling. These requirements span technical competencies, organizational practices, and strategic orientations, reflecting the multidisciplinary nature of circular design.

At the **technical** level, a foundational requirement is a deep and practical understanding of materials. Designers need to develop:

- detailed knowledge of fiber properties;
- material behavior;
- the performance characteristics of both virgin and recycled inputs.

This includes understanding how specific material choices, such as the inclusion of elastane, the use of latex adhesives, or the application of chemical coatings, affect not only product performance during use but also processability at end of life. Without this **material literacy**, design decisions risk being based on convention or supply chain defaults rather than on informed circularity criteria. Hands-on, learning-by-doing approaches are considered essential to develop this awareness, particularly as early reliance on digital tools without material understanding can lead to incorrect design assumptions.

Equally important is the ability **to define and respect material thresholds**. Designers and manufacturers should adopt clear internal guidelines on acceptable composition ranges, based on the technical requirements of downstream recycling technologies. This means understanding that **recyclability is not binary** but depends on achieving sufficient material purity and consistency within processing flows. Small quantities of incompatible fibers or substances can have disproportionate negative effects on recycling outcomes, and design decisions must account for these sensitivities. Establishing quantitative thresholds, for example, limits on elastane content or restrictions on specific adhesive types, is therefore a practical necessity rather than an optional refinement.

Manufacturers are also required to align product design with real processing capabilities rather than theoretical recyclability. This implies engaging with recyclers at the design stage to validate material choices, test component compatibility, and understand the practical constraints of industrial sorting and recycling systems. Products that are recyclable in principle but incompatible with available technologies do not contribute to functional circular systems. Design validation mechanisms, such as pre-market assessment of recyclability, are identified as high-impact interventions, even if their implementation remains challenging given the volume and speed of product development in sectors like fashion.

From an **organizational** perspective, implementing D4R requires substantial internal transformation. This includes:

- redesigning products and processes;
- developing new technical and design capabilities;

- aligning multiple functions, including design, sourcing, production, and strategy, around circular objectives.

Designers often have limited influence over key variables such as material selection, which are driven by procurement or commercial decisions. Overcoming this requires not only individual competence development but also structural changes in how decisions are made and how sustainability criteria are weighed alongside cost and performance.

Finally, manufacturers should **invest in traceability and transparency**. Accurately documenting material composition, chemical treatments, and component specifications is essential both for enabling effective sorting and recycling downstream and for complying with emerging regulatory requirements such as Digital Product Passports. Many challenges in recycling systems arise from the absence of reliable information about product composition. Manufacturers who proactively build traceability into their product development processes are therefore better positioned to support circular systems and to respond to evolving regulatory and market demands.

7.3 NEEDS REPORTED BY RECYCLERS

Recyclers occupy a critical but often underrecognized position in the circular design system. Their perspective reveals a distinct set of needs that must be addressed to enable effective and scalable recycling of textile and related products, many of which stem directly from design and production choices made upstream in the value chain.

The **most consistently reported need concerns feedstock quality and consistency**. Post-consumer textile waste is characterized by high heterogeneity in material composition, quality, and contamination levels, which creates significant operational challenges for recycling facilities. Unlike post-industrial waste, which is more uniform and predictable, post-consumer streams require extensive pre-processing, including sorting, cleaning, and separation increasing operational complexity and cost. Recyclers emphasize the need for more homogeneous and well-characterized input streams, which in turn depends on improved product design, better collection systems, and more reliable sorting infrastructure. Without consistent feedstock, even technically advanced recycling processes cannot operate efficiently or economically.

Closely linked to this is the **need for greater transparency on material composition**. Recyclers frequently report that the exact composition of incoming products, including fiber types, chemical treatments, coatings, and additives, is not fully known or disclosed. This lack of information limits the ability to adapt processes, explain processing inefficiencies, or ensure that recycled outputs meet quality and regulatory standards. The absence of reliable compositional data is identified as a major barrier to efficient processing, particularly as certain substances may be incompatible with specific recycling technologies or rejected entirely by recycling plants due to regulatory constraints. Recyclers therefore strongly support the development of traceability tools and Digital Product Passports, provided that the data they contain is accurate, standardized, and interoperable across the industry.

Recyclers also express a clear **need for sufficient volumes and economies of scale**. Recycling technologies require large and consistent material flows to justify investment and operate efficiently. Without reliable supply, even well-funded recycling initiatives may fail, as demonstrated by cases where infrastructure could not be sustained due to insufficient input materials. This highlights the importance of designing collection and sorting systems that can aggregate adequate volumes of similar materials, as well as the role of regulatory instruments, such as mandatory recycled content requirements, in creating stable demand for recycled outputs.

From a technological standpoint, recyclers identify the **need for improved separation and sorting capabilities, particularly for legacy products not designed with recyclability in mind**. Incoming waste streams continue to be dominated by complex, multi-material products produced decades ago, which current sorting technologies are often unable to process effectively. Technologies such as AI-driven sorting, computer vision, and advanced pre-treatment processes are seen as high-priority areas for development, as they can significantly improve the identification and separation of complex material streams. At the same time, recyclers highlight the uneven distribution of technological capabilities across regions, which prevents the adoption of standardized solutions and limits the scalability of recycling systems.

Finally, recyclers report the **need for stronger and more structured collaboration with manufacturers and brands during the product development phase**. Rather than being consulted only at the end-of-life stage, recyclers seek to be engaged as active contributors in the design process, providing technical input on material compatibility, processing thresholds, and recycling constraints. This evolution of their role, from end-of-life operators to design partners, is seen as essential to ensure that products placed on the market are genuinely processable within current industrial systems. Without this upstream engagement, the gap between design intentions and recycling realities is likely to persist, limiting the effectiveness of circular design initiatives regardless of their technical ambition.

7.4 EPR ALIGNMENT

The findings presented in Section 6 confirm that **the core principles of Design for Recycling are fully consistent with the rationale of Extended Producer Responsibility (EPR)**. EPR extends producers' responsibility to the post-consumer stage and is intended to create incentives for integrating environmental considerations into product design, notably through fee modulation linked to circularity performance. In this perspective, **the design levers highlighted in the report**, such as mono-material structures, reduction of complex blends, easier removal of accessories, material traceability, limitation of hazardous substances, and standardized product information, should not be considered only as technical design recommendations, but as **product-level characteristics that directly support EPR objectives by improving recovery, sorting, and treatment outcomes**.

More specifically, the evidence collected across the analysis shows that **alignment with EPR is strongest where product architecture is simplified** and **where recyclability is assessed against real industrial conditions** rather than theoretical assumptions. The reduction of material complexity, together with control of additives and coatings, design of products for disassembly, and improvement of traceability all contribute to higher sorting efficiency, better quality of recycled products, lower treatment costs, and greater transparency across the value chain. These outcomes are directly coherent with the design logic of EPR, since eco-modulated schemes are expected to reward products that are easier to collect, sort, and recycle, while discouraging those that generate higher end-of-life costs or lower-value outputs.

At the same time, the results also make clear that this alignment is not yet automatic in current market conditions. Several barriers identified throughout the analysis - including performance trade-offs, the persistence of multi-material and multilayer constructions, the use of problematic adhesives and chemical treatments, limited traceability, lack of standardization, and insufficient collection and recycling infrastructure, continue to weaken the practical implementation of Design for Recycling. In economic terms, recyclable solutions are still often disadvantaged by higher costs, uncertain returns, and weak willingness to pay, while in operational terms even well-designed products may fail to achieve circular outcomes if downstream systems are fragmented or underdeveloped. This confirms **that EPR cannot function effectively as a financing mechanism alone, but must be supported by harmonized design criteria**, reliable information systems, and sufficient investment in collection, sorting, and recycling capacities.

Overall, **the results support an interpretation of EPR as both an economic instrument and a governance framework for product design**. If properly implemented, **EPR has the potential to shift recyclability from a secondary consideration to a core product requirement**, by rewarding simplification, disassembly, transparency, and compatibility with real recycling systems, while also creating the economic conditions needed to scale circular solutions.

At the same time, the evidence suggests that **EPR criteria should preserve a degree of flexibility across product categories**, since strict mono-materiality is not always technically or commercially feasible, and effective circular design often depends on controlled simplification rather than absolute material uniformity. In this sense, the findings of this deliverable provide an **evidence base for translating Design for Recycling principles into practical EPR criteria and future eco-modulation approaches**.

8. CONCLUSION

This report has examined the current state of Design for Recycling across the textile and related industries, exploring how companies integrate circular principles into product development, what material choices and design strategies most significantly influence recyclability, and what systemic conditions enable or constrain the transition toward circular systems. The findings paint a complex but coherent picture: meaningful progress is underway, yet deep structural barriers continue to limit the scale and consistency of circular design implementation.

The central finding is one of systemic misalignment. Product development logic remains predominantly oriented toward performance, cost efficiency, and market differentiation, while recyclability continues to occupy a secondary position in design decision-making. This imbalance is not primarily the result of technical ignorance or individual failure but reflects broader structural conditions, including weak economic incentives, insufficient regulatory pressure, fragmented value chain coordination, and a linear production model that does not hold manufacturers responsible for end-of-life outcomes. As long as these structural conditions remain unchanged, circular design is likely to remain confined to incremental improvements and niche applications rather than becoming a mainstream industrial practice.

Material choices emerge as the most direct lever for improving recyclability. The presence of incompatible fiber blends, latex-based adhesives, complex coatings, and auxiliary components such as trims and finishes represents the primary technical barrier to effective recycling. Mono-material or reduced-material designs significantly improve sorting efficiency and output quality, but their adoption is constrained by performance requirements, cost pressures, and supply chain dependencies. The findings consistently indicate that recyclability is not binary but threshold-dependent: even small quantities of incompatible substances can render otherwise recyclable products unprocessable. This underlines the importance of defining clear and enforceable material composition guidelines, grounded in the actual capabilities of industrial recycling systems rather than theoretical standards.

Collaboration across the value chain is a necessary but insufficient condition for progress. The most effective circular design solutions have emerged from sustained co-creation processes between manufacturers, brands, suppliers, and recyclers, where technical knowledge is exchanged, materials are jointly tested, and design decisions are validated against real processing constraints. However, these collaborations remain largely bilateral, informal, and limited in scale. The industry has not yet developed the shared platforms, common standards, and coordinated infrastructure needed to translate isolated pilot initiatives into systemic change. Advancing circular design requires moving from individual partnerships to industry-wide coordination mechanisms, supported by regulatory frameworks that align incentives across all value chain actors.

Regulation is identified as a critical and currently underutilized enabler. In the absence of strong mandatory requirements, the adoption of circular design practices depends on individual company strategies and voluntary commitments, which produces uneven and unstable outcomes. Emerging frameworks such as the Ecodesign for Sustainable Products Regulation and Extended Producer Responsibility schemes for textiles are expected to significantly accelerate alignment, create demand for recycled materials, and support investment in collection and recycling infrastructure. However, for regulation to be effective, it must combine clear minimum requirements with sufficient operational flexibility, be supported by harmonized standards, and be designed to strengthen rather than replace market-based incentives.

The focus on recycling, while necessary, risks obscuring more impactful circular strategies. The research consistently highlights that the greatest leverage points for reducing environmental impact lie upstream, in production reduction, extended product use, repair, and reuse, rather than downstream in material recovery. Current circular economy strategies in the industry are disproportionately oriented toward recycling, which fits more easily within existing production and consumption models but does not fundamentally challenge the dynamics of overproduction and rapid turnover. A more genuinely circular system requires prioritizing value retention over material recovery, which in turn demands a structural shift in business models, market expectations, and consumption patterns that goes well beyond design choices alone.

Technological innovation holds significant promise but cannot substitute for systemic change. Advances in AI-driven sorting, chemical recycling, digital traceability, and material science are expanding the range of technically recoverable products and improving processing efficiency. However, the most critical barrier to scaling recycling innovations is not technological but economic and organizational: the lack of stable markets for recycled materials, insufficient volumes of consistent feedstock, uneven distribution of recycling capabilities across regions, and the absence of coordinated infrastructure. Technology can support the transition, but only within a broader system in which design, collection, sorting, and recycling are aligned and mutually reinforcing.

Education and capability building represent a structural gap that requires urgent attention. Circular design competencies, including material knowledge, design for disassembly, lifecycle thinking, and familiarity with recycling technologies, are not yet systematically integrated into design education or professional training. The persistent disconnect between academic curricula and industrial realities limits the ability of designers to translate circular principles into actionable, context-specific solutions. Closing this gap requires closer collaboration between educational institutions and industry, the development of sector-specific training tools, and a shift from theoretical awareness toward practical, application-oriented skills.

In conclusion, advancing Design for Recycling requires acknowledging that it is not primarily a design problem, but a systemic one. Technical solutions exist and are improving; what is missing is the structural alignment of incentives, infrastructure, regulation, and industry practices needed to scale them. The transition toward circular design will not be achieved through isolated product improvements or voluntary commitments alone, but through a coordinated transformation involving all actors across the value chain, designers, manufacturers, recyclers, policymakers, and consumers, working within a framework that elevates end-of-life considerations to the same level of importance as performance, cost, and market competitiveness. The evidence from respondents gathered in this report suggests that this transition is not only necessary but achievable, provided that the systemic conditions required to support it are deliberately and consistently built.

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I. ANNEX I – LIST OF PARTICIPATING STAKEHOLDERS

N°	Type	Country	Description
1	Recycler	Italy	Chemical recycling of PA6
2	Manufacturer	Germany	Producer and technology provider recyclable carpets
3	Manufacturer	Belgium	Carpet manufacturer, internal thermos-mechanically recycling post-industrial waste
4	Manufacturer	Italy	Production of polyamide chemicals and polymers
5	Manufacturer	The Netherlands	Carpet manufacturer
6	Manufacturer	Italy	Producer from recycled and recyclable fibres
7	Recycler	Switzerland	Chemical recycling of PET
8	Manufacturer	Belgium	Carpet tile manufacturer
9	Research centre	Italy	Research on textile architecture and advanced materials
10	Research centre	Italy	Research on textile and fashion sector within companies
11	Recycler	Belgium	Mechanical recycling
12	Recycler	France	Chemical recycling of PET
13	Research centre	Czech Republic	Technical textiles cluster fostering collaboration between SMEs, academia and R&D
14	Research centre	France	Research center for textile innovation focused on sustainable and smart materials
15	Research centre	Portugal	Textile and clothing technology center, promoting innovation and circularity
16	Research centre	Switzerland	Focus on sustainable textile systems and circular design
17	Recycler	Belgium	Mechanical recycling
18	Circular economy expert	Netherlands	Focus on molecular recycling, advanced bio-based materials
19	Brand	United States	Global apparel company
20	Recycler	Netherlands	Chemical recycling of cellulosic
21	Sorter	Belgium	Sorting for reuse
22	Manufacturer	Italy	Manufacturer of underwear, lingerie, and swimwear
23	Manufacturer	United States	Global apparel company, jeans manufacturer
24	Manufacturer	Germany	Premium fashion focused on apparel and footwear
25	Research centre	Belgium	Laboratory testing and applied research services
26	Service company	Belgium	Specialist in cleaning and maintenance of carpets
27	Manufacturer	Italy	Manufacturer of underwear, swimwear, and apparel

28	Recycler	Germany	Chemical recycling of cellulosics
29	Recycler	Sweden	Pre- and post-consumer textile waste management

II. ANNEX II – OVERVIEW OF CLUSTERING AND CLASSIFICATION

N°	Macro areas	Thematic clusters
1	State of implementation and industry integration of D4R	How do companies currently integrate design for recycling principles into product development
		Integration of end-of-life considerations in product development and comparison with performance requirements
		Adoption of Design for Recycling and industry readiness to scale circular opportunities
2	Material choices and their impact on recyclability	Influence of material choices on recyclability
		Impact of mono-material vs multi-material design on recyclability, performance, and system implications
		Material combinations to avoid and criteria for ensuring recyclability and viability
3	Design strategies and practices for recyclability	Impact of garment design on recycling efficiency
		Design elements hindering recycling processes
		Design choices with the greatest impact on recyclability
		Circular design leverage points and role of different lifecycle phases
		Key strategic principles for improving recyclability and circular design
4	Design trade-offs and performance constraints	Balancing recyclability with performance, durability, and lifespan: key trade-offs
		Technical trade-offs in shifting from multi-material to mono-material design
5	System-level enablers and value chain dynamics	Collaboration across the extended value chain for Design for Recycling
		Effectiveness of traceability tools in enabling circular systems and product return
		Role of business models and market expectations in enabling Design for Recycling
		Economic and logistical challenges of take-back programmes

6	Barriers and challenges in implementing D4R	Barriers to the implementation of Design for Recycling
		Alignment between research and industry priorities and barriers to scaling recycling innovations
		Managing existing non-recyclable garments in the transition to circular design
		Barriers to processing post-consumer textile waste
7	Technological and regulatory drivers of Design for Recycling	Impact of new technologies and innovations on recyclability
		Influence of regulatory frameworks on design and implications for innovation and competitiveness
8	Advanced and conceptual approaches	Feasibility of closed-loop garment design within brand ecosystems
		Design strategies across end-of-life pathways and the role of durability, second-hand, and emotional factors
9	Skills, education and capability building	Integration of Design for Recycling in education, required skills, and industry connections
10	Future directions and emerging trends in D4R	Most promising eco-design principles in the short and long term
		Impact of circular design on creativity and compatibility with current recycling technologies