


Durability in fashion: A cross-domain review of definitions, measurements approaches, and environmental implications

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ABSTRACT

Durability in the fashion industry is increasingly recognised as a key lever for the circular economy transition, as it is associated with increased product lifetimes, decreased resource use, prevented waste generation, and reduced environmental impacts. Despite its growing relevance, durability remains a fragmented and partially operationalised concept across the domains that shape product standards, environmental assessment, and policymaking. This paper provides a cross-domain review of how durability is defined, measured, and linked to environmental impacts within the fashion sector, to clarify conceptual inconsistencies and identify pathways toward a more robust integration of durability into environmental assessments. The analysis spans four key domains: (i) Product Category Rules (PCRs), (ii) environmental labels, (iii) European policy frameworks, and (iv) academic literature on apparel and footwear. Results show that durability is predominantly addressed through isolated physical performance tests or minimum quality thresholds, while rarely being translated into explicit lifetime metrics. Environmental labels and PCRs mainly treat durability as a pass-or-fail requirement, without linking it to product lifetime or environmental performance. Within policy frameworks, durability emerges through progressively increasing levels of conceptualization and operationalisation. Academic literature reflects similar fragmentation, with a prevalence of qualitative approaches and limited quantitative integration into life cycle assessment. Overall, the findings highlight a critical gap between the recognised environmental importance of durability and its practical operationalisation. The paper concludes by outlining key challenges and opportunities for harmonising durability concepts to support credible environmental assessment in the fashion sector.

1. Introduction

Durability has progressively emerged as a central priority in the fashion sector concurrently through the convergence of quantitative scientific evidence, outcomes from fast fashion business models, and emerging responses from policymakers and industry associations. Empirical assessments show that the environmental footprint of fashion is driven more by systematically short garment lifetimes than by marginal inefficiencies in production (Ellen MacArthur Foundation, 2017; Niinimäki et al., 2020; Tecchio et al., 2016; WRAP, 2017). In a systemic perspective, a relevant share of the accumulation of waste and environmental pressure in the EU fashion sector is directly attributable to shortened product lifetimes. Empirical analyses in fact show that while global clothing production has doubled over the last two decades, the

average number of wears per garment has declined by 30–40%, leading to a sharp increase in impacts per use and to premature end-of-life flows (Niinimäki et al., 2020). System-level assessments also estimate that underutilization and early disposal account for more than half of total material value losses in the fashion system, a loss structurally linked to accelerated consumption cycles (Ellen MacArthur Foundation, 2017).

From a life-cycle perspective, this translates into waste generation both directly, through increased dismissing rates, and indirectly, through higher resource consumption required to keep the same level of service. In this context, lifetime increase has been proposed to amortize environmental burdens. Tecchio et al. (2016) demonstrated that maintaining the first use phase of a product yields higher environmental benefits than downstream strategies such as recycling, since any substitution or reprocessing necessarily requires additional resource inputs.

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Further quantitative studies confirmed that lifetime extension is one of the most effective waste-prevention strategies. Extending garment use by as little as three months indeed reduces carbon, water, and waste impacts by 5–10%, while longer extensions can reduce impacts per use by up to 30%, even in the absence of technological improvements (Cooper and Claxton, 2022; Niinimäki et al., 2020; WRAP, 2017).

This overall evidence has been incorporated into EU product policy (European Commission, 2022a) through the Ecodesign for Sustainable Products Regulation (ESPR) (European Parliament, 2024), which explicitly recognizes durability as a core sustainability requirement. The ESPR framework acknowledges that environmental pressures are strongly driven by shortened product lifetimes and accelerated replacement cycles and therefore prioritizes lifetime extension as a primary lever for waste prevention and resource efficiency. Indeed, the effective lifetime of garments is not determined only by technical or material-related aspects, but also by social and behavioural dimensions, including user care practices, perceived attractiveness, and patterns of continued use across time.

On this basis, the durability concept is moving from a qualitative design attribute to a progressively formalised concept for credible circular economy strategies in the EU fashion sector and prospectively to a measurable requirement for regulatory compliance.

Despite this compelling evidence on the environmental imperative for enhancing garment durability, translating this priority into effective strategies remains a significant challenge. The concept of durability itself is multifaceted and lacks a consistent operationalisation across the key domains that shape product standards, consumer information, and regulatory frameworks. Consequently, the potential of durability as a lever for environmental impact reduction is hindered by fragmented and often incompatible definitions, measurements, and claims. To bridge this gap between its recognised systemic importance and its practical application, it is essential to systematically examine how durability is conceptualized and assessed across the primary arenas that govern the fashion sector.

A first relevant domain concerns Product Category Rules (PCRs), which provide standardized guidelines for assessing and reporting the potential environmental impacts of a specific group of similar products using Life Cycle Assessment (LCA) to create consistent Environmental Product Declarations (EPDs) (EPD International, 2026). However, despite their long-standing role in standardizing the environmental assessment of products, current PCRs address durability primarily through intrinsic, material-based performance criteria, and only rarely provide connections between product lifetime and environmental impact modelling.

In parallel, environmental labels and certifications have increasingly incorporated notions related to product quality and longevity, yet typically in indirect or marginal ways. Although attempts have been made to map sustainability-related labels in the fashion sector (Plakantonaki et al., 2023; Ranasinghe and Jayasooriya, 2021), a recent analysis of eco-labels in the textile and clothing sector shows that durability-related requirements are rarely central in certification schemes and, when present, tend to be embedded as isolated technical criteria rather than as part of a holistic durability concept. As highlighted by Ziyeh and Cinelli (2023), the proliferation of eco-labels and the lack of harmonization in their assessment methods generate overload, ambiguity, and confusion among consumers.

Similarly, durability has gained growing attention within European policies aimed at fostering the transition from linear to circular production and consumption systems. The forthcoming ESPR identifies product durability as one of the key performance parameters to enhance product circularity, together with (and among) other circular economy principles such as reliability, reusability, repairability, and recyclability (European Parliament, 2024). Within ESPR, the textile sector, and particularly the fashion branch, has been identified as a key priority and is among the first product groups for which specific requirements are expected to be developed (Faraca et al., 2024). Parallel initiatives, such

as the Extended Producer Responsibility (EPR) for textile waste and the drafted Green Claims Directive, also refer to durability as a key pillar for their future development (European Commission, 2023, 2025). In this context, durability has already been integrated into policy-driven LCA frameworks of fashion products, both at the European and Member States level. Indeed, the European Commission recently accepted the Apparel and Footwear Environmental Footprint Category Rules (PEFCR), which explicitly integrate product durability in the evaluation of their environmental performances (Quantis, 2025). In parallel, a national initiative was developed in France, with the Environmental Cost scoring system, introduced under the French Climate and Resilience Law (ADEME, 2025; République Française, 2021). Both approaches proposed an integration of durability parameters, which, although stemming from very different standpoints, act as modulating variables for defining product lifetime, within the assessment of environmental profile. These initiatives illustrate a rapid regulatory shift, though with heterogeneous approaches to defining and operationalizing durability.

A similarly mixed picture emerges from the academic literature. Recent contributions increasingly recognize the relevance of durability in the transition toward sustainable fashion, yet there is still no shared conceptualization. For instance, Vanacker et al. (2022) note that even within the relatively homogeneous domain of luxury fashion, the literature lacks a unified view, oscillating between physical dimensions (e.g., resistance to wear) and emotional or symbolic dimensions (e.g., attachment, timeless design), and rarely considering how these dimensions interact across the product lifecycle. Their framework demonstrates that most studies focus on isolated phases (most often design or material selection), overlooking how durability evolves and is influenced by production, use, and end-of-life.

To provide a general baseline for how durability is conceptualized across sectors, a preliminary screening of international technical standards was conducted (see Supporting Information). This analysis indicates the existence of a broadly shared cross-sector understanding of durability as the ability of a product to maintain its functional performance over time under expected conditions of use, maintenance, and exposure. However, it also highlights the absence of a specific and commonly accepted definition tailored to the fashion sector, reinforcing the need for a more systematic and domain-specific investigation.

Therefore, given the central role that durability is assuming in the transition toward more circular production and consumption systems, and the current lack of consensus regarding its definition and measurement approaches within the fashion sector, this paper aims to systematize the state of the art on how durability is currently conceptualized and assessed, and explore how it relates to products' environmental impacts through its potential influence on product lifetime. This objective is addressed by conducting a comprehensive investigation across four key domains: i) PCRs, ii) environmental labels, iii) European policy frameworks, and iv) academic literature within the fashion sector. Our scope is not to provide a methodological guide for conducting a cross-domain analysis, but rather to carry out such an analysis in practice. The resulting insights are then systematized to guide researchers, LCA practitioners, and policymakers toward a more robust and consistent understanding, and potential integration, of durability considerations in the apparel and footwear sector.

2. Methodology

Given the study's aim to investigate how durability is conceptualized, measured, and linked to environmental impacts specifically within the fashion sector, the methodological approach is structured around a multi-domain analysis intended to capture the diverse interpretative dimensions through which durability is addressed. The scope of the investigation covers fashion products, meaning apparel and footwear products, excluding accessories and non-wearable textile goods (e.g., home textiles), as these fall outside the focus of emerging regulation and

product footprinting frameworks. The overarching goal is to identify convergences, inconsistencies, and gaps in how durability is defined and operationalised across domains that influence product standards, labelling schemes, policy instruments, and academic research. To achieve this objective, four main domains of analysis were identified: (i) PCRs, (ii) environmental labels, (iii) European policy frameworks, and (iv) academic literature for apparel and footwear. Each domain was selected based on its role in shaping how durability assumptions contribute to product lifetime modelling and environmental impact assessments, either theoretically, methodologically, or operationally. Academic literature contributes to knowledge development, providing conceptual definitions and scientific evidence; European policy frameworks translate scientific findings into regulatory principles and requirements; environmental labels contribute to inform consumers and market actors; PCRs and related methodological documents serve a technical function by standardizing environmental impact assessments for practitioners and industry stakeholders. Despite these differences, the analysed domains are strongly interconnected and mutually influential, justifying the adoption of a multi-domain analysis to capture how durability is defined and operationalised across the fashion sector. Moreover, the literature provides shared definitions and methodologies grounded in science-based evidence that are applied across all domains according to their specific context and audience. The results obtained from these distinct sources were subsequently synthesized to provide a comparative perspective and to identify patterns that may support the development of a harmonized conceptualization of durability. The following sections provide a detailed description of the selection of sources for each domain.

2.1. Product Category Rules (PCRs)

PCRs are technical documents that define category-specific rules for the development of LCA studies and for the preparation of EPDs, ensuring consistency, transparency, and comparability among products belonging to the same category. In this work, 24 established PCRs dealing with textile, footwear, and apparel sectors were identified by consulting the PCR library on the EPD International website (EPD International, 2026). It was then decided to not consider textile-related PCRs since the focus of this work is represented by finished fashion products, leaving a pool represented by 13 PCRs. After further refining, PCRs that had expired and had been replaced by newer and broader PCRs were excluded, while expired PCRs without an updated or superseding reference were retained. As a result, a final pool of 4 PCRs was considered, which are reported in Table 1: i) Apparel, except fur and leather apparel (EPD International, 2024a), ii) Footwear (EPD International, 2019), iii) Jackets, coats and other similar outdoor garments (EPD International, 2024b), and iv) Rubber articles for footwear (EPD International, 2021).

2.2. Environmental labels

To identify relevant fashion-related labels, the search focused on the Ecolabel Index, the largest global database dedicated to cataloguing labelling schemes (Ecolabel Index, 2007). Given the study's objective and geographic scope, the screening was restricted to labels operating within the European market, with a focus on apparel or footwear products, and addressing durability-related terms. Applying these criteria, seven labels were identified and examined to extract information on the presence of durability-related requirements, including minimum performance thresholds, test-based compliance criteria, or references to product lifetime. Labels in the scope of our analysis are reported in Table 2.

2.3. European policy frameworks

Policy instruments addressing durability cannot be systematically

Table 1

Product Category Rules (PCRs) included in the analysis. Each PCR is classified based on the product under its scope and the year until which it is valid.

PCR name	Product	Valid until (year)
Apparel, except fur and leather apparel	UN CPC 282 (Knitted or crocheted fabrics; wearing apparel, except fur apparel)	2028
Footwear	UN CPC 293 (Footwear, with outer soles and uppers of rubber or plastics, or with uppers of leather or textile materials, other than sports footwear, footwear incorporating a protective metal toe cap and miscellaneous special footwear), UN CPC 2942 (Tennis shoes, basketball shoes, gym shoes, training shoes and the like), UN CPC 2949 (Other sports footwear, except skating boots), and UN CPC 295 (Other footwear, except asbestos footwear, orthopaedic footwear and skating boots).	2028
Jackets, coats and other similar outdoor garments	CN codes 6101, 6102, 6201, and 6202, the NACE/CPA codes C14.12 and C14.13. The product category is a sub-category of the UN CPC code 282 Wearing apparel, except fur apparel, corresponding to the two-digit C 14.1 CPA code.	2024
Rubber articles for footwear	UN CPC 3627 vulcanized Rubber: hard rubber, articles of hard rubber	2025

UN= United Nations; CPC= Customs Procedure Code; NACE= Nomenclature statistique des activités économiques dans la Communauté européenne (Statistical classification of economic activities in the European Community); CPA= Classification of Products by Activity.

Table 2

Environmental labels included in the analysis. Each label is classified based on the type of scheme, the region of origin, and the scope of products covered.

Label name	Scheme type	Region	Scope of the label
Blue Angel	Voluntary Type I ecolabel	Germany	Textile products, including
EU Ecolabel (textiles)	Voluntary Type I ecolabel	European Union	Textile clothing and accessories
EU Ecolabel (footwear)	Voluntary Type I ecolabel	European Union	Footwear
Cradle2Cradle	Voluntary Type I ecolabel	Global	Apparel and Textile
Global Organic Textile Standard (GOTS)	Voluntary Type I ecolabel	Global	Organic textile products, including apparel
Nordic Swan Ecolabel	Voluntary Type I ecolabel	Nordic Countries	Textile products, including clothing
OEKO-TEX® STANDARD 100	Certification programme	Global	Textile products, including clothing

identified through bibliographic databases, as they are distributed across heterogeneous institutional sources and vary widely in format (regulations, delegated acts, policy communications, environmental scoring system). Therefore, this study adopts a purposeful sampling strategy (Palinkas et al., 2015) grounded in three inclusion criteria: (i) the policy must be defined within the European context, (ii) direct relevance to apparel and/or footwear products, and (iii) reference to durability, lifetime, or durability-related requirements. Based on these criteria, the selected corpus includes the two main frameworks currently shaping durability requirements at the European level: the ESPR (European Parliament, 2024) and the EU Strategy for Sustainable and Circular Textiles (European Commission, 2022b). We also included within the scope the recently approved Apparel and Footwear PEFCR (Quantis, 2025), as it can be defined as a policy-driven environmental assessment methodology. The analysed frameworks are detailed in

Table 3
European policy frameworks included in the analysis. Each framework is classified based on its legal status, year of publication, main goal, and scope.

Policy framework	Legal status	Year	Goal of the framework	Scope of the framework
EU Strategy for Sustainable and Circular Textiles	Policy strategy (non-binding)	2022	Define EU policy direction toward circular, durable, and low-impact textile value chains.	Textile products in general, including apparel
Ecodesign for Sustainable Product Regulations (ESPR)	Policy Regulation (binding)	2025	Horizontal framework to establish ecodesign requirements for a broad range of products (including textiles), aiming to improve circularity and reduce environmental impacts across product lifecycles.	Physical products, including apparel
Apparel and Footwear Product Environmental Footprint Category Rules (PEFCR)	Policy-driven environmental assessment methodology	2025	Voluntary framework to assess the cradle-to-grave environmental impacts of apparel and footwear products, according to the PEF methodology.	Apparel and footwear

Table 3.

2.4. Academic literature

The analysis of academic literature was conducted through a scoping review approach (Tricco et al., 2018), aimed at mapping how durability is defined and examined within scholarly research related to fashion and its environmental impacts. The search process was conducted on Scopus, considering publications available up to November 2025, using the combination of keywords in the fields of fashion (“apparel” OR “cloth” OR “garment” OR “textile” OR “fashion” OR “footwear” OR “t-shirt” OR “coat” OR “jacket” OR “shirt” OR “dress” OR “shoe” OR “boots” OR “sportswear” OR “knitwear”), durability (“durability” OR “wear resistance” OR “tear resistance” OR “longevity” OR “lifetime extension”), and environmental assessment (“life cycle assessment” OR LCA OR “environmental impact” OR “environmental footprint” OR “environmental analysis” OR “impact assessment” OR “environmental assessment”). The search returned 266 results. No temporal restrictions were applied in the literature search. A first screening based on titles and abstracts led to the exclusion of 205 records, considered outside the scope of the study, primarily due to the presence of durability-related terminology in unrelated fields such as construction materials, composites, and nanotechnology. Of the remaining records, 14 were excluded due to the unavailability of the full text. In addition, for these studies, the screening of the available abstracts indicated that their content was not aligned with the scope of the present review. 1 publication was excluded since not available in English. An additional 27 articles were removed since, although they mentioned durability in the context of fashion products, they did not provide a substantive discussion of durability definition, its determinants, or its connection to product lifetime and environmental

performance. The final dataset consists of 19 scientific publications. The literature screening process, as well as the full list of selected papers, is reported in Supporting Information.

Therefore, the final body of analysis of this study included 4 PCRs, 7 environmental labels, 3 European policies, and 19 academic research articles. The selected sources were then analysed to extract information on (i) how durability is defined or conceptualized, (ii) what indicators or metrics are proposed to assess durability, (iii) whether durability is linked explicitly to product lifetime, and (iv) whether and how durability is integrated into environmental impact assessments.

Based on this structured analysis, the sources were compared iteratively to identify recurring ways in which durability is framed and used across domains. Through this process, three main patterns were inductively identified: “durability as a technical requisite”, “durability as a longevity driver”, and “durability as an operational parameter”. The distinction between these patterns is based on the role attributed to durability in each source, particularly in relation to its level of operationalisation and its connection to lifetime and environmental assessment. These patterns do not correspond to rigid or mutually exclusive categories; rather, they represent dominant interpretative logics through which durability is framed, measured, and eventually used to inform environmental assessment. A detailed description of the patterns is provided in Section 4.1, as they are used to organise and interpret the results.

3. Results

3.1. Product Category Rules (PCRs)

PCRs define the methodological requirements for modelling, calculating, and reporting the life cycle environmental impacts of products within a specific category. Examining these rules allows to identify how product lifetime is addressed in current fashion LCA practice and highlights opportunities to integrate durability-related parameters in future revisions or regulatory frameworks. Although durability is not yet consistently operationalised in PCRs, these documents provide a methodological basis for its systematic integration.

The four PCRs included in our investigation reveal a common insight into how durability is addressed in this domain and thus lead to reflections that tend to be comparable. Primarily, each of them proposes a series of individual pass-or-fail tests, designed to verify the minimum technical requirements for the product concerned. Abrasion resistance (EPD International, 2024b, 2024a, 2021, 2019), tear strength (EPD International, 2024b, 2024a, 2019), tensile strength (EPD International, 2024b, 2024a), flex resistance, adhesion (EPD International, 2019), colour fastness (EPD International, 2024b, 2024a, 2019), pilling resistance, dimensional stability, and surface pH (EPD International, 2024b, 2024a), all describe the capacity of a material or product to resist forms of degradation that would compromise its function or perceived acceptability. Thus, although the aforementioned tests do not measure durability directly, they quantify properties that correspond to potential limiting states in real use. Mechanical failure is captured through indicators such as tearing, tensile rupture, seam slippage, or loss of structural adhesion. Physical wear-out is assessed through abrasion tests or flexing endurance for soles and uppers. Chemical and photolytic ageing is evaluated through colour fastness to artificial light or accelerated ageing procedures for leather components. Changes in material integrity or user safety can be inferred from pH values, perspiration reactions, or dimensional instability during laundering. Each test, therefore, represents a discrete measurement of a degradation pathway, offering quantitative thresholds beyond which functional adequacy declines. Yet, despite their relevance, these tests remain disconnected from one another and are not embedded within a unified durability assessment framework. They describe isolated mechanisms of degradation but do not converge into a model that establishes how these mechanisms interact over time, how they combine to produce a limiting state, or how

they translate into a predictable service life. Moreover, they do not clarify whether maintenance or repair actions, such as conditioning, cleaning, component replacement, or reinforcement, could slow, mitigate, or reverse the measured degradation. Therefore, they cannot determine whether a loss in performance measured in the laboratory is definitive or whether it could be offset through appropriate care. An exception to the prevailing approach is found in the (now expired) PCR for Rubber Articles for Footwear, which introduces a Reference Service Life (RSL) parameter linked to the functional unit. This parameter is defined through a formula that incorporates an abrasion index, an estimate of annual step frequency, a normalisation factor, and a coefficient accounting for average yearly steps under the assumption of continuous daily use of the sole. In this sense, the RSL parameter could offer a procedural cue for lifetime estimation, but it is present only in the expired document, and none of those currently in force offer such a proposal. Another point to be mentioned concerns the PCR for Footwear, which cites two complementary approaches in accordance with the PEFCE for Apparel and Footwear: product durability may be declared on the basis of the number of wears over the defined service duration or may be adjusted through the application of a multiplier methodology. Both offer an alternative to the 'classical' series of individual specific tests, as stated in the PCR. However, as discussed further in section 3.3, the PEFCE for Apparel and Footwear contains some critical points that could undermine the effective reliability of the method. A summary of the analysed PCRs is offered in Table 4. This situation illustrates that the main barrier to achieving a quantitative, standard-based definition of durability in these industries is not the lack of performance data, but the absence of a methodological framework capable of integrating them. Consequently, durability remains a largely conceptual notion, disconnected from its potential operational role, and is neither effectively employed as a parameter for lifetime quantification nor directly incorporated into the environmental impact assessment of fashion products.

3.2. Environmental labels

When examining how environmental labels integrate the concept of product durability, different approaches emerge, ranging from mandatory quantitative performance testing to strategic design methodologies focused on extending longevity. Table 5 provides an overview of the analysed labels. The EU Ecolabel (European Commission, 2019) and the Nordic Swan Ecolabel (Nordic Ecolabelling, 2022) explicitly mandate that products must meet rigorous physical performance standards, integrating durability as a core component of "fitness for use". For textile products, both systems require criteria addressing fabric resistance to pilling and abrasion and durability of function for finishes (e.g., water repellent or flame-retardant treatments must withstand specified washing and drying cycles). For footwear, the EU Ecolabel's Criterion 7 defines precise physical requirements, such as uppers flex resistance, outsole abrasion resistance, and tear strength, with distinct performance minimums based on the footwear category (e.g., General sports versus

Table 4

Analysis of selected Product Category Rules (PCRs), including the definition and possible representation of durability, and whether durability is inferred for lifetime estimations and environmental impact assessment.

PCR name	Definition of durability	Possible representation of durability	Durability inferred for lifetime estimations	Durability inferred for environmental impact assessment
Apparel, except fur and leather apparel	No	Functional characteristics are measured in accordance with reference standard tests.	No	No
Jackets, coats and other similar outdoor garments	No	Functional characteristics are measured in accordance with reference standard tests.	No	No
Footwear	No	Number of wears per product duration service, or 'multipliers methodology', related to scores obtained through specific tests.	No	No
Rubber articles for footwear	No	Reference Service Life is defined as a function of Abrasion Index and Usage Frequency.	No	No

Table 5

Analysis of selected environmental labels, including the definition and possible representation of durability, and whether durability is inferred for lifetime estimations and environmental impact assessment.

Label name	Definition of durability	Possible representation of durability	Durability inferred for lifetime estimations	Durability inferred for environmental impact assessment
Blue Angel	No	"Fitness for use" requirements, based on test reports.	No	No
EU Ecolabel (textiles)	No	"Fitness for use" tests, aimed at ensuring sufficient physical resistance and longevity.	No	No
EU Ecolabel (footwear)	No	Parameters contributing to durability. Category-specific tests.	No	No
Cradle2Cradle	No	Quality tests that address common failure modes.	Durability testing can be used to derive the length of the use phase	No
Global Organic Textile Standard (GOTS)	No	"Technical quality parameters" for final consumer products.	No	No
Nordic Swan Ecolabel	No	"Quality and performance requirements" that ensure the product is suited for a long lifetime.	No	No
OEKO-TEX® STANDARD 100	No	Durability is implicitly measured through Color fastness testing requirements.	No	No

Fashion) (European Commission, 2016). Similarly, the German BLUE ANGEL label (Ral Environment, 2023) includes specific requirements for "Fitness for use," encompassing color fastness to saliva, fabric resistance to pilling and abrasion, and the durability of functions like water repellency. Conversely, product safety certification OEKO-TEX®

STANDARD 100, while including color fastness standards (to water, perspiration, and dry rubbing), does not explicitly associate it with durability within its guidelines (International Association for Research and Testing in the Field of Textile and Leather Ecology, 2025). A different approach is proposed by the Cradle to Cradle Certified® (C2C) standard, which incorporates durability under the "Circular Design Opportunities and Innovation" category, recognizing that prolonging the product use phase is a crucial strategy for maximizing circularity and reducing environmental impact (Cradle to Cradle Product Innovation Institute, 2025). C2C links durability directly to reducing the environmental burden associated with frequent replacements. Achieving higher levels of certification (Gold/Platinum) requires materials to demonstrate they can "substitute for virgin material without loss of essential product function or material durability," measured by indicators such as the decrease in tensile strength, abrasion resistance, or tear strength after reprocessing. Moreover, the C2C certification references the Apparel and Footwear PEFCR as a recognised mechanism for demonstrating durability performance, as a strategy for prolonging the use phase of a product, which is essential for achieving the Gold level certification.

Therefore, across analysed labels, durability remains predominantly framed as a minimum technical requirement rather than as a parameter influencing environmental performance. Type I labels are designed as multi-criteria, life-cycle-based certification schemes that reward products with superior environmental performance. However, within these systems, durability functions mainly as a pass-or-fail compliance criterion intended to ensure basic product quality and fitness for use. Although these labels aim to identify products with lower environmental burdens, durability is not operationalised as a variable affecting environmental outcomes, nor is it used to modulate product lifetime within the assessment logic.

3.3. Policy frameworks

The analysed European policy frameworks revealed different conceptualization and integration of durability.

The EU Strategy for Sustainable and Circular Textiles (European Commission, 2022b) positions durability as a central pillar for transforming the current linear and fast-paced textile system. Durability is framed as a core design and policy objective capable of counteracting the prevailing dynamics of fast fashion, which is characterised by decreasing garment use times, rapid turnover, and escalating volumes of production and disposal. The Strategy articulates a clear vision whereby, by 2030, all textile products placed on the EU market will be "long-lived" and designed for extended use. This perspective rests on several assumptions regarding how durability interacts with product lifetime. First, enhanced durability is expected to allow consumers to use garments for significantly longer periods, countering current patterns of premature disposal. Then, the Strategy emphasises that common technical faults, such as inadequate colour fastness, tearing, seam failure, or problems with zippers, are primary reasons consumers discard clothing. Strengthening these technical performance attributes is therefore presented as essential to achieving longer lifetimes. Durability is also positioned as a prerequisite for the viability of repair, reuse, rental, take-back, and second-hand systems. These models rely on garments retaining functionality and aesthetic quality over repeated use cycles, and their potential to extend product lifetimes is explicitly recognised. The Strategy anticipates the introduction of mandatory design requirements that will extend product lifetime and are intended to provide a structural alternative to fast-fashion business models. It also presents durability as a primary route to mitigating the environmental footprint of textile products, repeatedly underscoring that extending product lifetime is the most effective way to reduce climate and environmental impacts, due to its direct effect on reducing the need for new production. However, it is interesting that, as highlighted by Maldini and Klepp (2025), there is an alarming lack of research on the human behavior that

would make the connection between increased durability, product lifetime extension, and smaller production volumes possible. Indeed, the environmental benefits of owning a durable product may be lost if that product is not actually used to its full potential and is purchased in addition to other products that fulfil the same function (Zamani et al., 2017).

The ESPR (European Parliament, 2024) establishes a comprehensive legal framework for setting mandatory ecodesign requirements aimed at increasing the sustainability of products placed on the EU market. Within this framework, durability is positioned as a core performance attribute, essential to achieving the Regulation's broader objectives of environmental sustainability, resource efficiency, and circularity. The ESPR integrates durability into binding design obligations, consumer information provisions, and overarching sustainability goals. It provides an explicit definition of durability as *the ability of a product to maintain its function and performance over time under specified conditions of use, maintenance, and repair*. This definition serves as the foundation for several regulatory mechanisms intended to operationalise durability across product groups, envisioning it as a measurable product characteristic subject to regulatory enforcement. The operationalisation of ecodesign requirements for the various product categories will occur through delegated acts. Although the latter have not yet been published, a recent study by the Joint Research Center identified the clothing sector as a priority product category, which is recommended to be addressed first (Joint Research Centre and AITEX, 2024). This work provides initial methodological direction on how durability may be assessed within delegated acts for textiles. Specifically, it introduces a structured, test-based approach that uses standard methods to simulate ageing, primarily through repeated washing and drying cycles, and to quantify performance loss across key parameters such as dimensional change, pilling, and colour fastness. Product durability is scored by comparing performance before and after the ageing protocol, with the resulting index differentiating among "Bad Case", "Base Case", "Best Available Technologies", and "Best Not Yet Available Technologies", depending on the percentage decrease in physical performance. This approach operationalises durability as the ability of an apparel product to maintain its physical properties over time and represents a more granular and dynamic assessment than the pass-fail performance thresholds typically found in environmental labels and PCRs. However, the preparatory study explicitly cautions that durability should not be equated with actual service lifespan, as the latter is also shaped by consumer behaviour, maintenance practices, and aesthetic or emotional considerations. For this reason, no mathematical linkage between durability scores and lifetime extension is proposed, leaving open the question of whether durability assessments will ultimately inform lifetime modelling and environmental performance within the ESPR framework.

The PEFCR for Apparel and Footwear (Quantis, 2025) constitutes the most operationalised policy-driven framework for integrating durability into environmental impact assessment, embedding durability as a quantifiable parameter that directly influences the product's modelled lifetime and, consequently, its environmental impacts per unit of function. Within this framework, durability is understood as a multidimensional construct encompassing intrinsic product attributes, extrinsic or user-dependent attributes, and reparability. These dimensions collectively shape the product's Duration of Service (DoS), which represents the estimated number of uses over the product's functional life. Product-specific DoS is derived from a Default DoS, which depends on the product sub-category considered, and is adjusted using two multipliers: the Intrinsic Durability Multiplier (IDM) and the Reparability Multiplier (RM), as reported in Equation (1).

$$\text{Specific DoS} = \text{Default DoS} * \text{IDM} * \text{RM} \quad (1)$$

IDM captures the inherent physical performance of the product and is derived from a set of normative laboratory tests addressing common failure mechanisms (e.g., abrasion resistance, tensile strength, dimensional stability). It ranges from 0,67 for low-performing products to 1,45

for high-performing ones. RM accounts for the product's capacity to extend its useable life through accessible and economically viable repair. It evaluates four criteria: repair cost ratio, availability of spare parts, accessibility of repair services, and the presence of repair-related communication. RM ranges from 1 (non-repairable or economically unviable repairs) to 1,15, modestly increasing the lifetime for products. When multiplied by Default DoS, IDM, and RM can extend the default lifetime by up to a factor of $\sim 1,67$, offering a substantial leverage point for lifetime extension within the PEF framework. The integration of durability into the PEFCR has explicit consequences for the environmental impact results. Because the functional unit is defined as one use, the environmental impacts associated with the production, transportation, and end-of-life are amortised across the product's entire lifetime. The PEFCR thus identifies durability as a critical hotspot parameter that substantially influences LCA outcomes. This operationalisation is unique among current policy instruments, as it requires durability testing and scoring to be integrated directly into the environmental footprint calculation rather than remaining a qualitative or conceptual principle.

Therefore, across the three policy instruments, durability emerges through progressively increasing levels of conceptualization and operationalisation. The EU Strategy for Sustainable and Circular Textiles represents the vision level, framing durability as a systemic lever to counter fast-fashion dynamics and reduce environmental impacts through longer product use. Its treatment is strategic and aspirational, assuming, but not quantifying, the link between improved durability, extended lifetimes, reduced production volumes, and environmental benefits. The ESPR advances to an intermediate operational level, defining durability as a measurable performance attribute and outlining test-based approaches to assess ageing effects. However, durability is not yet translated into lifetime modelling, and its environmental implications remain indirect. The Apparel & Footwear PEFCR reaches a fully operationalised level, embedding durability into a formal lifetime equation through intrinsic and reparability multipliers. This framework quantitatively links durability to environmental impact per use, making it the only instrument where durability directly shapes LCA outcomes. However, the PEFCR approach remains largely unprecedented in the academic literature, since no existing studies propose similarly formalised durability multipliers or quantitative lifetime-adjustment mechanisms. The approach relies heavily on laboratory-based thresholds that may not fully capture real-world ageing, user behaviour, or aesthetic obsolescence, which drive garment disposal. Moreover, by translating durability into fixed multipliers, the model risks oversimplifying a multidimensional construct and may produce lifetime estimates that are more normative than empirically grounded, with limited validation against observed product-use patterns. Table 6 summarizes durability integration into the analysed policy frameworks.

3.4. Academic literature

The 19 studies included in the final sample illustrate the diversity of

approaches through which durability is conceptualized and examined within the fashion sector. The corpus spans more than two decades and encompasses a broad spectrum of methodologies, ranging from laboratory-based investigations of material performance and wear mechanisms to qualitative analyses of user behaviour, emotional attachment, and design strategies for longevity. Table 7 provides a resume of the analysed studies. To enhance readability and support comparative interpretation, colour coding is applied to the table to reflect how each source addresses durability across the analysed dimensions. A detailed description of colour coding is provided in the table caption.

A first step in the analysis was to assess whether the publications provided an explicit definition of durability. Results show that most studies did not articulate a clear or formal definition, and only six papers offered one. Laitala and Boks (2012) defined design for durability as practices aimed at enhancing both the physical and technical robustness of garments and the emotional and expressive qualities that support long-term use, thereby capturing both physical and emotional dimensions from a user-centred perspective. Klepp et al. (2016) associated durability and technical quality with the physical ability of garments to withstand a certain amount of use. Similarly, Guo et al. (2025), specifically addressing physical durability, defined it as a measure of the reasonable wear life of a product and how its functionality degrades during use by repeated abrasion, stretching, and laundering. A similar definition was proposed by Caraceni et al. (2024), who framed durability as the ability of a physical product to remain functional without requiring excessive maintenance or repair when operating in its use phase. It identifies how long a product can be used before it needs to be replaced or repaired. Gonçalves et al. (2025) defined textile functional durability as fabrics' ability to maintain their essential physical and performance characteristics under diverse environmental and usage conditions. A more structured definition was provided by Vanacker et al. (2022), who framed durability as a product's ability to withstand changes arising from the environment, distinguishing between intrinsic factors (such as wear, tear, and material degradation) and extrinsic factors (including evolving user needs and shifting fashion preferences).

Then, it was investigated how durability was integrated within each study, considering its connection with product lifetime and environmental performance. Two contributions assessed durability strictly as a technical property through laboratory testing, specifically, shoe-heel wear and slip resistance (Kim and Smith, 2002) and the laundering durability of functionalised antimicrobial cotton fabrics (Xu et al., 2018). In both cases, durability is treated solely as a physical performance parameter relevant to product testing and development, with no explicit consideration of how enhanced durability might extend product lifetime or influence environmental impacts. The majority of the reviewed papers adopt qualitative approaches to describe durability, generally establishing an implicit link with product lifetime and eventually environmental benefits. Laitala and Boks (2012), in their exploration of sustainable clothing design, examined consumer motivations for garment disposal and found that respondents would retain items

Table 6
Analysis of selected European policy frameworks.

Reference	Definition of durability	Possible representation of durability	Durability inferred for lifetime estimations	Durability inferred for environmental impact assessment
EU Strategy for Sustainable and Circular Textiles	No	Durability is not measured	No	No
Ecodesign for Sustainable Product Regulations (ESPR)	The ability of a product to maintain, over time, its function and performance under specified conditions of use, maintenance, and repair.	Physical tests	No	No
Apparel and Footwear Product Environmental Footprint Category Rules (PEFCR)	Intrinsic durability attributes: product-specific characteristics contributing to its potential lifetime; Extrinsic durability attributes: external factors that influence the likelihood of a product reaching its potential lifetime.	Physical tests	Yes, the higher the test results, the higher the potential lifetime	Yes, durability-based lifetime is used for environmental impact assessment

longer if they exhibited higher quality and durability, with fewer issues related to pilling, deformation, or colour loss. They argue that design for durability must address both the technical robustness of garments and the emotional and expressive qualities that foster long-term use. Similarly, Klepp et al. (2016), while exploring natural fibers, framed durability as a combination of technical limits and social conditions enabling extended use. They suggest that the number of repeated uses provides a

more meaningful indicator of durability than lifespan measured in years, as the latter tells little about actual utilisation. Still in the field of design for longevity, Goworek et al. (2020), while identifying tensions between commercial incentives and sustainability goals, defined that durability is implicitly associated with prolonged lifetime (longevity), through both its physical and emotional components. Similarly, Earley (2017) intended durability as a determinant of the lifetime of a garment, emphasising

Table 7

Analysis of academic literature. Colours are used to facilitate the interpretation of the table. Grey cells indicate studies that explicitly define durability. With respect to how durability is represented, yellow denotes a purely quantitative approach, red a qualitative approach, and orange a combined quantitative-qualitative approach. For the integration of durability into lifetime estimation and environmental impact assessment, dark blue indicates no integration, light blue a theoretical (non-quantitative) integration, and green a quantitative integration.

Reference	Definition of durability	Possible representation of durability	Durability inferred for lifetime estimations	Durability inferred for environmental impact assessment
Kim and Smith (2002)	No	Quantitative (mechanical tests)	No	No
De Saxce et al. (2012)	No	Quantitative (mechanical tests)	Yes. Durability indicators are used to calculate the Lifetime Indicator for each bed sheet	Yes. Durability-dependent lifetime is integrated into the LCA
Laitala and Boks (2012)	"Design for durability": improving the physical and technical robustness of garments and addressing emotional and expressive qualities	Quantitative and qualitative (consumer survey on disposal habits and physical examination of wear)	Theoretically. The paper highlights a link between durability and lifetime increase	Theoretically. Durability affects lifetime, affecting environmental impacts
Klepp et al. (2016)	The physical ability of garments to withstand a certain amount of use	Quantitative and qualitative (mechanical limits and the social conditions that allow products to last)	Theoretically. The paper highlights a link between durability and lifetime increase	Theoretically. Durability affects lifetime, affecting environmental impacts
Earley (2017)	No	Qualitative (durability pre-determines lifecycle speed or timeframe)	Theoretically. Durability is expected to improve the functional lifetime	Theoretically. Durability affects lifetime, affecting environmental impacts
Xu et al. (2018)	No	Quantitative (laundering tests)	No	No
Goworek et al. (2020)	No	Qualitative (durability, as longevity)	Theoretically. The paper highlights a link between durability and lifetime increase	Theoretically. Durability affects lifetime, affecting environmental impacts
Vedantam (2021)	No	Qualitative (durability is conceptualized as a product attribute affecting willingness to pay)	Yes. Durability determines the residual value of the product in its "used" period	Yes. Durability influences customer demand and production volumes, and it mediates the total environmental footprint
Hildebrandt et al. (2021)	No	Qualitative (durability is defined as a material property influencing the product replacement factor)	Yes. Durability as a determinant for replacement rate	Yes. Durability is identified as one of the strategic levers that determines the magnitude of environmental impact reduction
Vanacker et al. (2022)	Ability to withstand changes caused by the environment in both the intrinsic and extrinsic dimensions. Intrinsic refers to wear, tear, and material decay. Extrinsic refers to external changes influencing user preferences	Quantitative and qualitative (intrinsic and extrinsic)	Theoretically. Durability is defined as the measurement of the time a product will continue to function as intended and withstand 'wear and tear' before developing a defect	Theoretically. Extending the product's lifespan through durability is necessary to reduce the high environmental costs associated with production and disposal
Benkirane et al. (2022)	No	Quantitative and qualitative (durability as longevity is quantified using a single, aggregated index, which combines physical testing with consumer perception of damage importance)	Theoretically. Development of a consumer-oriented quality score to quantify clothing longevity, based on objective aging factors and consumer disposal decisions	Theoretically. Designing for longevity is described as an eco-design opportunity that could help to reduce the environmental footprint of energy-free items
Kumar et al. (2023)	No	Quantitative (visual degradation)	Yes. The system is designed explicitly to predict the visual degradation over time/use	Theoretically. Extending the product's lifespan through durability is necessary to reduce the high environmental costs associated with production and disposal

Kambanou et al. (2024)	No	Qualitative (durability as longevity)	Yes, durability affects lifetime extension, reducing the number of trousers consumed annually	Yes. Circular business models based on improved durability reduce environmental impacts per functional unit. However, there is no integration of durability as a function of product characteristics, but it is assumed ex-ante
Wiener (2024)	No	Qualitative (durability as longevity)	Theoretically. Improper maintenance and the resulting damage shorten the garment's durability and therefore its lifetime	Theoretically. Extending the product's lifespan through durability is necessary to reduce the high environmental costs associated with production and disposal
Caraceni et al. (2024)	The ability of a physical product to remain functional without requiring excessive maintenance or repair when operating in its use phase. It identifies how long a product can be used before it needs to be replaced or repaired	Quantitative (durability is measured through four physical parameters crucial for urban soles)	Yes. Durability is directly linked to the product's Life Span. By calculating the number of items required to reach a maximum durability value, the study estimates how many sole types are needed to match the theoretical maximum lifetime	Yes. The core purpose of the study is to show how incorporating durability into the Functional Unit definition changes the results of the Life Cycle Assessment (LCA) analysis
Gonçalves et al. (2025)	"Textile functional durability" is a complex, multifaceted assessment of a fabric's ability to maintain its essential physical and performance characteristics under diverse environmental and usage conditions	Quantitative (mechanical tests)	Theoretically. Extending the lifetime is how environmental benefits of the circular models are realized. Still, the LCA is cradle to gate, so even if durability is integrated into the sustainability score, it is not used to define lifetime, as the use phase is out of system boundaries	Theoretically. Durability is explicitly integrated into the multicriteria model to calculate the Product Sustainability Index, but not within the Environmental Impact Assessment
Guo et al. (2025)	The ability of a garment to remain functional during use by resisting repeated abrasion, stretching, and laundering	Quantitative (durability is measured through physical tests from the Product Environmental Footprint Category Rules for apparel and footwear)	Theoretically. Durability as a longevity driver. Improving physical durability is directly linked to extended utilization and the extension of garment lifespans	Theoretically. Extending the product's lifespan through durability is necessary to reduce the high environmental costs associated with production and disposal
Maldini and Klepp (2025)	No	Qualitative (identify how durability is conceptually defined and prioritized within the EU Textile Strategy and its supporting documents)	Theoretically. Increasing product durability is the means to extend product lifetime. Still, there is little empirical research supporting the connection between increased durability, extended life, and reduced production volumes	Theoretically. Extending the product's lifespan through durability reduces environmental costs associated with production and disposal. However, focusing solely on durability risks policy failure if it does not address overproduction and consumption directly
Rodriguez-Macua et al. (2025)	No	Quantitative (durability is measured through a physical score based on laboratory tests. This score is used to build a Product Sustainability Index)	Yes. Durability is linked to Duration of Service, which serves as the precise estimate of the product's lifespan in the LCA model	Yes. LCA is performed, and impacts are normalized by the number of uses, which is derived from physical durability

technical strategies such as designing materials to resist pilling, snagging, and staining. These features are also connected to "slow" design principles that foster emotional attachment, thereby supporting longer use. An interesting approach is proposed by [Benkirane et al. \(2022\)](#), who developed a methodology for designing products for optimal longevity using a consumer-oriented approach. Physical durability is here measured through laboratory tests, while emotional quality is integrated by using consumer perception of product damage types (e.g., holes, loss of shape) in the decision to dispose of the item. The resulting score offers an understanding of perceived quality by weighing product strengths and weaknesses based on consumer awareness, which modifies the product ranking compared to a score without consumer input. The developed index aims to provide a better estimation of clothing longevity, still without an explicit link to lifetime or potential

environmental gains. Other studies framed durability in the context of washing habits and material degradation over use and time. Here, durability is assessed through visual inspection after repeated care cycles, linking durability to the aesthetic appeal, assuming a consumer-oriented perspective ([Kumar et al., 2023](#); [Wiener, 2024](#)). Moving towards a more technical and performance-based definition, [Guo et al. \(2025\)](#) developed a framework for measuring garment durability grounded in a suite of mechanical tests, each weighted according to its influence on the likelihood of garment failure. While the method offers a robust analytical approach to assessing physical durability, the connection to longevity and environmental impact remains implicit. The most comprehensive analysis on durability definition was performed by [Vanacker et al. \(2022\)](#), who aimed to clarify the meaning of durability and resilience within the luxury fashion sector. They distinguish

between intrinsic durability, referring to material performance and the ability to withstand physical changes, and extrinsic durability, encompassing emotional, social, and symbolic aspects influenced by user preferences and shifting fashion dynamics. Emotional durability relates to consumers' attachment to products, whereas social durability concerns external factors, such as changes in trends, that may render garments undesirable. The authors highlight that a holistic assessment of durability is still largely absent, as most studies consider only one dimension or fail to apply both consistently. Across these contributions, durability is thus predominantly described through qualitative accounts, conceptual frameworks, or case-based insights, with limited development of replicable, standardised measurement procedures.

A smaller fraction of studies provides a more operational exploration of the relationship between durability, product lifetime, and environmental impacts. Vedantam (2021), in their analysis of competing apparel resale business models, conceptualized durability as a product parameter capturing deterioration in quality over use. This parameter influences consumers' willingness to pay for second-hand garments and determines residual value in resale scenarios, which in turn affects equilibrium production volumes and the associated environmental impacts modelled through LCA. Hildebrandt et al. (2021), while exploring circular design strategies in the production of bio-based fashion materials, likewise treated durability as a determinant of product life expectancy, incorporating product replacement rates when comparing bio-based leather substitutes with conventional materials. In the context of business models and product designs that prolong the lifetime of construction workwear, Kambanou et al. (2024) defined durability essentially as longevity, operationalised through lifetime extension in the LCA model. Even if there is no integration of durability as a function of product characteristics, it is assumed that if trousers are designed for durability, they will last longer, thus reducing environmental impacts. In these examples, even if durability is explicitly related to lifetime and associated with environmental impacts, it is assumed as an ex-ante value and not derived from the product. A different approach was followed by De Saxce et al. (2012), who linked manufacturing conditions of bed sheets to lifetime predictions for environmental impact assessment, through a durability parameter, derived from physical testing (e.g., abrasion resistance, colour fastness). These indicators were integrated into the functional unit of the LCA, showing that longer lifetimes generally reduced impacts, while also highlighting cases in which improved durability required more resource-intensive processing. Caraceni et al. (2024) adopted a similar strategy for footwear outsoles by combining physical test results into a composite durability parameter, used to estimate the number of items required to deliver a maximum expected lifetime and to normalise the LCA results. Still in the footwear sector, Rodriguez-Macua et al. (2025) explored the environmental implications of the addition of graphene to footwear soles to enhance durability, following the above-described Apparel and Footwear PEFCR. This approach translates specific mechanical test results into a multiplier of product default lifetime, explicitly connecting durability, lifetime, and environmental impacts, based on product-specific performances. A step towards the systematic integration of durability into a comprehensive sustainability index is proposed by Gonçalves et al. (2025). They developed a multicriteria methodology for scoring the sustainability of apparel products (A-E rating), integrating environmental, social, and economic assessment with product-specific durability scores derived from laboratory tests. Although this index explicitly recognizes the role of durability in reducing environmental burdens, the proposed scope for LCA remains cradle-to-gate; hence, durability does not directly influence lifetime modelling, as the use phase lies outside system boundaries.

These studies illustrate that durability can be operationalised as a product-specific parameter within environmental assessment frameworks, but such approaches remain rare. Despite the widespread recognition of the intuitive link between durability and lifetime extension, only a minority of studies model the connection quantitatively. Most contributions refer to durability conceptually, linking technical

robustness or emotional attachment to longer use, but without specifying lifetime functions or empirically grounded time-based effects.

The above-presented analysis shows that the treatment of durability within fashion-related research is conceptually heterogeneous and methodologically fragmented. Overall, three main insights emerge: (i) the absence of a shared definition of durability, (ii) the predominance of qualitative and narrative approaches over measurable indicators, with an implicit connection between durability and product lifetime, and (iii) the limited operational integration of durability within environmental impact assessment models.

4. Discussion

4.1. Comparative discussion across domains: convergences, divergences, and recurring patterns

Building on this cross-domain analysis and on the inductive approach described in Section 2, three recurring patterns were identified, reflecting how durability is conceptualized and operationalised within the fashion sector: “durability as a technical requisite”, “durability as a longevity driver”, and “durability as an operational parameter”. These patterns can be visualized along a spectrum. At one end, durability functions as a basic technical prerequisite that products must satisfy to be considered acceptable, without any explicit connection to product lifetime or environmental outcomes. At the opposite end, durability is treated as a measurable property that directly affects lifetime modelling and environmental impact results. Between these extremes, durability is widely recognised as a driver of longevity and sustainability, but remains only loosely connected to quantitative lifetime estimates. Fig. 1 schematically represents these three durability representation patterns and their conceptual relationships, providing a synthetic overview of the approach adopted in the discussion.

Within the first pattern “durability as a technical requisite”, durability is addressed implicitly as a technical precondition for product acceptability, verified through standardised laboratory tests and expressed through compliance with predefined performance thresholds. Rather than being defined as an explicit property, durability is embedded in a set of discrete test requirements that products must satisfy to be considered fit for use. This pattern is dominant within PCRs and environmental labels, and a smaller fraction of academic literature. Across the four PCRs analysed, durability is never defined as such, nor is it measured as an aggregated or time-dependent property. Instead, it is indirectly addressed through a series of individual tests targeting specific degradation mechanisms. Each test captures a potential limiting state, but the results remain disconnected and are not integrated into a unified durability or lifetime model. A similar logic prevails in environmental labelling schemes such as the EU Ecolabel (for textiles and footwear), Nordic Swan Ecolabel, and Blue Angel. In these systems, durability-related criteria are framed under notions such as “fitness for use” or “quality and performance requirements” and are verified through compliance with predefined technical tests. While these criteria ensure a baseline level of product quality, durability remains a gate-keeping condition rather than a differentiating sustainability parameter. Even in more design-oriented schemes such as Cradle to Cradle Certified®, durability-related testing is primarily used to verify material performance, without being systematically translated into quantified lifetime extension or environmental impact reduction. As for the academic literature, Kim and Smith (2002) and Xu et al. (2018) assessed durability strictly as a technical performance parameter relevant to product testing and development, with no explicit consideration of how enhanced durability might extend product lifetime or influence environmental impacts. Within this pattern, durability functions as a necessary attribute, which may prevent products from being considered acceptable or obtaining certification, but it does not inform how long products are expected to last, nor does it influence environmental impact calculations.

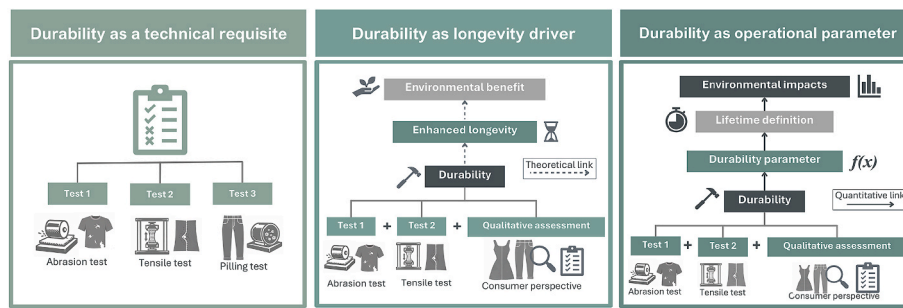


Fig. 1. Schematic representation of three recurring durability representation patterns identified across the domain of investigation.

The second pattern, “durability as longevity driver”, shifts the focus from technical compliance to the relationship between durability and product longevity. Here, durability is explicitly associated with extended use and assumed reduced environmental impacts, but this association remains largely conceptual and is not formalised through quantitative lifetime modelling. This pattern is particularly prominent in the academic literature and in policy frameworks. Numerous studies associate durability with prolonged use by referring to physical robustness, resistance to wear, or aesthetic persistence, often complemented by emotional, symbolic, or social dimensions. For instance, [Goworek et al. \(2020\)](#), [Klepp et al. \(2016\)](#), and [Laitala and Boks \(2012\)](#) emphasise that garments are retained longer when they exhibit higher technical quality and fewer visible defects, but also when they foster emotional attachment or align with users’ identities. [Vanacker et al. \(2022\)](#) formalise this perspective by distinguishing between intrinsic and extrinsic durability, highlighting the multidimensional nature of the concept. Methodologically, this pattern relies on qualitative analyses, surveys, interviews, consumer perception studies, or visual inspections of garment degradation ([Kumar et al., 2023](#); [Wiener, 2024](#)). Even when physical tests are performed, as in [Guo et al. \(2025\)](#) or [Benkirane et al. \(2022\)](#), the resulting indicators are generally used to rank products or inform design decisions, rather than to derive explicit service life estimates. A similar abstract linkage between durability, longevity, and environmental benefits is embedded in the EU Strategy for Sustainable and Circular Textiles ([European Commission, 2022b](#)), which repeatedly positions durability as a key lever for extending product lifetimes and reducing environmental impacts by slowing production and consumption cycles. The ESPR ([European Parliament, 2024](#)) also follows the same line, elevating durability as one of the pillars of the transition to a circular economy model. However, although [Faraca et al. \(2024\)](#) propose a clear framework for assessing durability in the fashion sector, specific to the various product categories, these policy narratives largely assume that increased durability will translate into longer use and lower production volumes, without empirical validation or quantitative modelling of this relationship. Within this pattern, durability operates as a theoretical bridge between product quality and sustainability outcomes. While the longevity rationale is intuitive and widely shared, durability is not translated into measurable lifetime parameters, and its environmental benefits remain asserted rather than calculated.

The third and least common pattern, “durability as operational parameter,” treats durability as a quantifiable parameter, explicitly used to model product lifetime and to influence environmental impact assessment results. This pattern emerges most clearly in the Apparel and Footwear PEFCE (Quantis, 2025), where durability is conceptualized through the IDM, which modifies the product’s Duration of Service, and determines how production-related impacts are amortised over the number of uses. As for the academic literature, only a limited number of studies adopt a comparable operational logic. [De Saxce et al. \(2012\)](#) integrated durability indicators derived from physical tests into lifetime-based functional units for bed sheets. [Caraceni et al. \(2024\)](#) developed a composite durability parameter to estimate the number of products required to deliver a target lifetime, affecting LCA

normalisation. [Rodriguez-Macua et al. \(2025\)](#) explicitly followed the PEFCE methodology to translate mechanical test results into lifetime multipliers, demonstrating how enhanced durability through material innovation (graphene addition) reduces environmental impacts per use. Despite their methodological relevance, these studies remain exceptions within the broader literature. Moreover, even within this operational pattern, significant limitations remain. Lifetime estimates, even when informed by durability-related parameters, are primarily defined as ex-ante averaged data, rather than being empirically validated through case-specific evidence. Behavioural factors continue to be weakly represented, frequently relying on assumed standardised user behaviours that overlook variability in actual use practices. In addition, complex degradation mechanisms and use dynamics are commonly reduced to simplified laboratory tests, which may not adequately represent real use conditions, particularly with respect to aging and long-term performance simulation. Nonetheless, this pattern represents the only approach in which durability systematically influences environmental assessment outcomes.

To better envision the contributions of all analysed sources to the development of the three durability representation patterns, a Sankey diagram is proposed in [Fig. 2](#) to provide a synthetic overview of their relative distribution and alignment. The flows are proportional to the contribution of each source to the identified patterns. When a source reflects more than one pattern, its contribution is evenly split (e.g., 0.5 assigned to each pattern), which explains why the resulting counts are not integers.

Taken together, these three patterns reveal a clear gradient in the treatment of durability, from compliance-oriented quality control, through conceptual associations with longevity, to fully operationalised lifetime and LCA modelling. While all domains acknowledge durability as a desirable attribute, only a narrow subset of frameworks and studies succeed in translating it into a parameter that quantitatively affects environmental results. This fragmentation helps explain why durability, despite its central role in policy discourse, remains inconsistently measured and unevenly integrated into environmental sustainability assessments. Bridging these patterns requires methodological approaches capable of connecting technical performance data, user behaviour, and empirical lifetime evidence within coherent lifetime models, an area that remains largely underdeveloped across both regulatory and academic domains. Among the sources analysed, the most advanced and operationalised framework is currently the Apparel and Footwear PEFCE (Quantis, 2025). This approach represents the most explicit attempt to integrate durability into environmental assessment by linking it to product lifetime within LCA modelling. However, it still relies predominantly on technically defined lifetime parameters and does not actively integrate user behaviour as a determinant of effective product lifespan. At the same time, it remains unclear how durability will be concretely specified within the forthcoming Ecodesign requirements for fashion products under the ESPR ([European Parliament, 2024](#)), particularly with respect to measurement methods, thresholds, and the treatment of non-technical drivers of obsolescence. At present, an interesting approach for defining durability is proposed in the

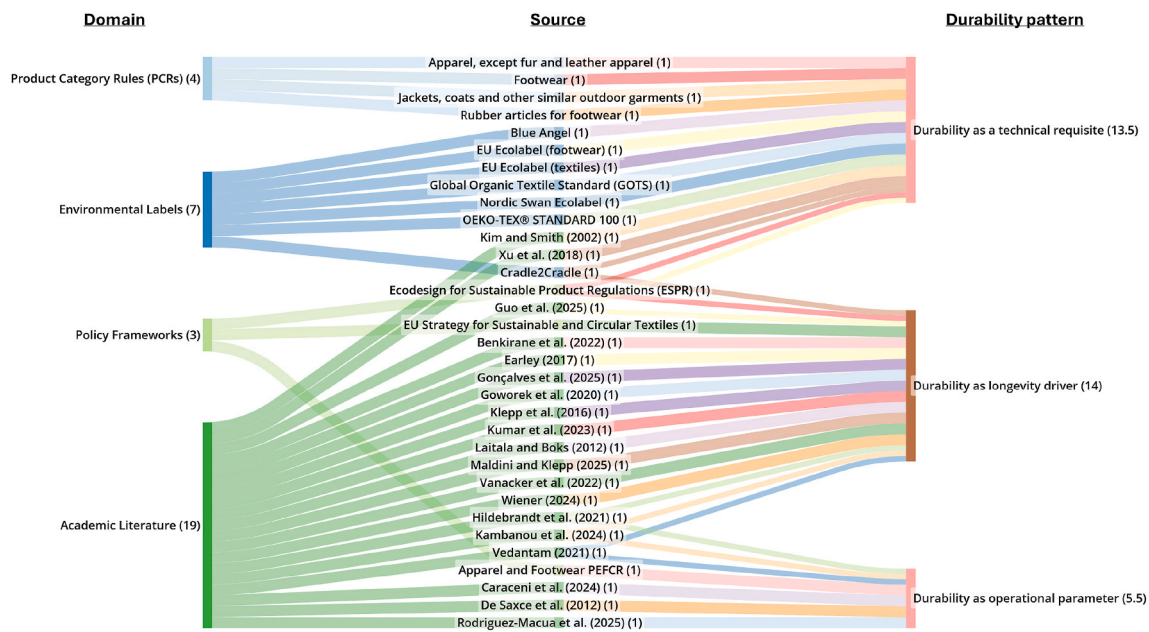


Fig. 2. Sankey diagram illustrating how each source, across the different analytical domains (Product Category Rules (PCRs), Environmental Labels, Policy Frameworks, and Academic Literature), contributes to the conceptualization of durability. The diagram maps the relationships between domains (left), individual sources (centre), and three durability representation patterns (right). Data for the Sankey diagram are reported in **Supporting Information (Table S4)**.

standard EN 45552:2020 (CEN, 2026). Although originally developed for energy-related products, it provides a general and technology-neutral framework that links product lifetime to functional performance, specified conditions of use, maintenance, and the concept of a limiting state and end-of-use phase. EN 45552:2020 methodologically frames durability as a measurable capability to deliver a defined function over time, providing a theoretical basis for future adaptation to fashion products. However, it does not yet include a conceptual adaptation tailored to fashion and textile items. As illustrative examples, it does not explicitly address durability mechanisms driven by time-dependent degradation of physical properties (e.g., the progressive loss of elasticity in elastomeric components), nor does it clarify the relation among different functional parameters, which are central to the functional performance and perceived durability of fashion products. Both EN 45552:2020 and PEFCR primarily address technical durability, while in fashion, the effective limiting state can be determined by user-driven factors, particularly in non-technical products (e.g. luxury items). From a technical standpoint, the quantitative dimension of durability as ex-ante lifetime design remains insufficiently formalised, particularly with respect to the linkage between product-level tests, material-level tests, and consistent units of measurement. Such a technical definition implicitly seems to treat durability as a time-independent feature in case it is expressed in terms of number of uses or cycles, whereas in fashion, both technical ageing (e.g., intrinsic material degradation over time) and aesthetic ageing (e.g., shifting cultural or symbolic value) may occur independently of use intensity. In the present state, these approaches do not appropriately account for the case of heterogeneous consumption patterns and user behaviour, which play a decisive role in determining market product lifetimes. Most notably, future frameworks should specifically integrate aspects of emotional and aesthetic durability, which frequently govern obsolescence in fashion more than functional failure.

5. Conclusion

This paper aims to develop a more comprehensive understanding of durability in the fashion sector by systematizing the state of the art on

how durability is currently conceptualized and assessed, and exploring how it relates to products' environmental impacts through its potential influence on product lifetime. To this end, a cross-domain analysis is conducted, covering PCRs, environmental labels, European policy frameworks, and academic literature on apparel and footwear. By systematically comparing these domains, the analysis identified three recurring durability representation patterns that cut across heterogeneous sources. The results reveal a fragmentation in the treatment of durability; in the most widespread pattern, durability functions as an implicit technical prerequisite, embedded in compliance-based performance testing and expressed through pass-or-fail logic. While this approach effectively prevents premature technical failure and establishes minimum quality thresholds, it does not translate durability into expected product lifetimes or environmental impact reductions. A second, intermediate pattern frames durability as a conceptual driver of longevity and environmental benefit. Here, durability is explicitly linked to prolonged use and reduced impacts, drawing on qualitative and behavioural dimensions. This perspective dominates both academic literature and policy narratives and reflects a broad consensus that longer-lasting products are environmentally preferable. However, the analysis shows that this relationship is rarely formalised through quantitative lifetime models or empirically validated assumptions. As a result, durability operates primarily as a theoretical bridge between product quality and sustainability outcomes, rather than as a measurable or operational parameter. The third and least common pattern integrates durability into environmental assessment by treating it as a quantified variable that directly affects product lifetime and impact calculations. This approach, exemplified by the Apparel and Footwear PEFCR and a limited number of academic studies, demonstrates how durability metrics can be translated into lifetime parameters and used to amortize environmental impacts per use. Despite its methodological relevance, this pattern remains marginal and is characterised by important limitations, including ex-ante lifetime assumptions, simplified representations of degradation, and limited consideration of user behaviour. From a standardization perspective, EN 45552 provides a comprehensive framework for addressing technical durability by linking stress profiles, failure modes, and limiting states through modelling and

testing. However, even if it establishes a general methodological architecture aligned with the PEFCR and ESPR approach, product-specific rules still need to be further defined.

Taken together, these findings highlight a number of critical gaps that currently limit the operationalisation of durability within the fashion sector. First, despite its widespread use, durability still lacks a shared and comprehensive definition capable of capturing both its quantitative and qualitative dimensions in such a context-specific and multifaceted domain. In parallel, there is a lack of case-specific operational definitions that effectively connect product characteristics, usage contexts, and user practices. Existing approaches are predominantly based on ex-ante assumptions, where durability is defined a priori through technical or conceptual proxies. While these approaches enable standardisation and comparability, they are inherently limited in their ability to represent the use phase and can only characterise the product at the point of market entry. Conversely, ex-post approaches based on empirical lifetime data remain scarce. Although they can offer greater reliability in capturing durability-dependent lifetimes as experienced in real-world conditions, they risk being highly context-specific, reducing comparability and remaining largely descriptive of individual product-user trajectories. Finally, the analysis shows that durability is applied across domains as a horizontal concept, yet it remains largely decoupled from its environmental, social, and economic implications, which are rarely integrated in a systematic and quantifiable manner.

From a regulatory and methodological perspective, existing frameworks such as the PEFCR and ESPR provide important starting points by formalising durability as a measurable capability to deliver function over time. However, their current focus remains largely on technical durability and does not adequately capture the heterogeneous use patterns and non-technical limiting states that frequently determine effective product lifetimes in fashion. Future research and policy development should move towards the definition of integrative durability assessment frameworks that bridge ex-ante and ex-post approaches. This would imply establishing a common overarching definition for durability in fashion that incorporates its quantitative and qualitative dimensions, also defining the relation between product durability and product lifetime. In parallel, operational and context-specific definitions should be developed, building on laboratory-based performance testing and empirical use-phase data, such as longitudinal studies or user surveys, to derive more robust and comparable lifetime models for product- and context-specific categories. Furthermore, considering the potential implications that durability may have beyond environmental performance, future research should also explore its social dimension. In particular, the relationship between durability-oriented design strategies and production systems, including their possible effects on working conditions and labour dynamics along the value chain, deserves further investigation. While this represents a significant step beyond the current state of durability assessment, integrating social considerations would contribute to a more comprehensive and systemic understanding of durability within the fashion sector. This way, durability could be effectively embedded into life cycle-based sustainability assessments, driving environmental, social, and economic implications.

CRedit authorship contribution statement

Agata Costanzo: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Pietro Pascolini:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Matteo Cordara:** Conceptualization, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Monia Niero:** Conceptualization, Project administration, Resources, Supervision, Writing – review & editing. **Carlo Brondi:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.cesys.2026.100448>.

Data availability

No data was used for the research described in the article.

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