Kaunas University of Technology
Institute of Environmental Engineering
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Longevity Extension of Textile Apparel Based on Strategies of Ecodesign, Circular Economy and Value Chain Traceability

Master's Final Degree Project

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Sustainable Management and Production (6213EX001)

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Summary

The textile industry is one of the most impactful worldwide and there are numerous impacts during the value chain of clothing. One of the most significant ones is textile waste, which is mainly incinerated or landfilled. To tackle these and other challenges, the EU has developed the Ecodesign for Sustainable Products Regulation, introducing specific design requirements for various products put in the European market and the concept of the Digital Product Passport as a tool to enhance traceability and sustainability. The extension of longevity in clothing is a critical approach to slow down material flows and decrease environmental impacts.

This work focuses on analyzing Ecodesign, Circular Economy and Traceability strategies for longevity extension of garments through the value chain and tackling the found gap in the downstream traceability. To do so, first, a literature review is prepared about these topics; then, semi-structured interviews with KTU experts are done during March and April of 2025.

After classifying the longevity main strategies according to the stakeholder and life cycle phase, an LCA is performed, using SimaPro 9.5 and the ReCiPe 2016 method, for one polyester dress (0.478 kg), showing the differences between the baseline, which includes raw materials extractions, manufacturing, distribution, first use, collection, sorting and incineration as EoL, and different scenarios with variations across the whole life cycle stages. Results show that one polyester dress made with fiber-to-fiber recycled PET, in a sustainable manufacturing process and with extended use by re-purchase in a C2C platform, can decrease the environmental impact by 68%.

DPP is proposed to be an integral tool that can help track garments after purchase and gather more accurate data about the use phase, allowing more precise LCAs to identify unknown hotspots. Further research needs to be done around this topic to find the best strategies to ensure long-lasting garments without compromission quality and their environmental performance.

Santofimio Varón, Luisa María. Drabužių ilgaamžiškumo didinimas taikant ekologinio projektavimo, žiedinės ekonomikos ir atsekamumo vertės grandinėje strategijas. Magistro baigiamasis projektas / vadovė doc. dr. Inga Gurauskienė; Mechanikos inžinerijos ir dizaino fakultetas, Kauno technologijos universitetas.

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Santrauka

Tekstilės pramonė ir visa tekstilės vertės grandinė daro reikšmingą poveikį aplinkai. Vienas svarbiausių poveikių kyla dėl tekstilės atliekų deginamų arba šalinamų sąvartynuose. Siekiant spręsti šias ir kitas aplinkos, žaliavų ir gaminių problemas, ES parengė Tvarių gaminių ekologinio projektavimo reglamentą (ESPR), kuriuo nustatomi specialūs dizaino reikalavimai įvairiems Europos rinkai tiekiamiems gaminiams ir skaitmeninio gaminio paso (DPP) koncepcija, kaip atsekamumo ir tvarumo didinimo priemonė. Drabužių naudojimo laiko pratęsimas įvardijamas, kaip svarbi strategija, siekiant sulėtinti medžiagų srautus ir sumažinti poveikį aplinkai.

Šiame darbe pagrindinis dėmesys skiriamas ekologinio projektavimo, žiedinės ekonomikos ir atsekamumo strategijoms, prailginant drabužių ilgaamžiškumą ir vertinant bei siekiant valdyti atsekamumo spragas vertės grandinėje. Šiam tikslui pirmiausia atlikta literatūros analizė, vėliau 2025 m. kovo ir balandžio mėn. atlikti pusiau struktūruoti interviu su KTU tekstilės ir mados ekspertais, tada tyrimas papildytas poveikio aplinkai vertinimu.

Būvio ciklo analizė (LCA) atlikta vienai poliesterio suknelei (0,478 kg), naudojant SimaPro 9.5 ir ReCiPe 2016 metodą, skirtingiems ilgaamžiškumo scenarijams, sudarytiems pagal suklasifikuotas pagrindines strategijas, suinteresuotąsias šalis ir gyvavimo ciklo etapus. Ši analizė leido įvertinti skirtumus tarp kelių darbe apibrėžtų scenarijų: bazinio scenarijaus, kuris apima žaliavų gavybą, gamybą, platinimą, pirmąjį naudojimą, surinkimą, rūšiavimą ir deginimą (kaip gyvavimo ciklo pabaigą); ir kitų scenarijų, kurie skiriasi specifiniais požymiais skirtinguose gyvavimo ciklo etapuose. Rezultatai rodo, kad viena poliesterio suknelė, pagaminta iš perdirbto PET pluošto, taikant tvarų gamybos procesą ir ilgesnį naudojimą – parduodant antrinio naudojimo C2C (vartotojas vartotojui) platformoje – gali sumažinti poveikį aplinkai iki 68 %.

Skaitmeninį produkto pasą (DPP) siūloma laikyti neatsiejama priemone, galinčia padėti stebėti drabužius po įsigijimo ir surinkti tikslesnius duomenis apie naudojimo etapą, leidžiančią tiksliau atlikti LCA ir nustatyti nežinomus „karštuosius taškus“. Atlikus tyrimus nustatytas poreikis šia tema vykdyti tolesnius mokslinius tyrimus, kad būtų galima rasti geriausias strategijas, kaip užtikrinti drabužių ilgaamžiškumą, nepakenkiant jų kokybei ir aplinkosauginiam veiksmingumui.

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Abbreviations:

B2C – Business to Customer

C2C – Costumer to Customer

CBMs – Circular Business Models

CP – Cleaner Production

DPP – Digital Product Passport

EF – Environmental Footprint

EoL– End of Life

EPR – Extended Producer Responsibility

ESPR – Ecodesign for Sustainable Products Regulation

GWP – Global Warming Potential

LCA – Life Cycle Assessment

NGO – Non–governmental organization

PET – Polyethylene terephthalate

RoW – Rest of the World

rPET – Recycled Polyethylene terephthalate

WFD – Waste Framework Directive

Introduction

The textile industry is one of the most impactful in the contemporary world, not only ecologically, but also socially. Fast fashion and consumer culture has led to a considerable number of garments being produced and discarded annually. Not only the high amount of waste generated is of concern, but also the different impacts occurring along the entire value chain of textiles: use of hazardous substances, water use and pollution, air emissions, not to mention the precarious conditions in which workers may find themselves.

Trying to tackle all the problems above, the EU has developed the Strategy for sustainable and circular textiles, which includes the updated Ecodesign for Sustainable Products Regulation, which focuses on energy–related products and most physical products, including textiles. Even though the concept of Ecodesign is not new, the implementation of this as a legal requirement might be a game changer for manufacturers and retailers.

The Ecodesign methodology has multiple approaches, depending on the type of product, but it can differ from the selections of raw materials to the final disposal. Considering that it is widely known that waste generation is a major problem in the textile industry, extending the lifespan of garments can prevent unnecessary purchases and disposals. Thus, there are different strategies to increase longevity of clothing, starting with circularity principles, design decisions and alternative business models.

Circular Economy seeks to shift the linear economy model, where waste is generated from manufacturing processes, losing value, and generating significant environmental impacts. On the other hand, Ecodesign focuses on the efforts that designers and manufacturers can make to reduce the environmental footprint of products. Among all Ecodesign approaches, this study focuses specifically on design for longevity. Additionally, alternative business models aim to enhance cooperation between different stakeholders and to preserve the value of goods as long as possible.

This work has two main subjects: strategies for clothing longevity extension and downstream traceability. Starting from a literature review, this work lists the most important strategies implemented in the life cycle of garments. Within the use phase, a traceability gap is found from reviewed studies, showing the difficulty to track and apply the mentioned strategies. This is why an LCA is chosen as a tool to measure the environmental impacts of a garment based on different strategies, and to proof the need to trace clothing with the DPP and gather more data about the use stage. For purposes of this work, the words apparel, clothing, clothes and garment are used with the same meaning.

Research questions

How strategies for clothing longevity extension based on Circular Economy, Ecodesign and Traceability can influence the environmental impact of a garment through the value chain?

Aim

Analyze the potential of different strategies within the value chain for longevity extension of clothing to increase circularity and decrease environmental impacts.

Objectives

1. To determine the most relevant longevity extension strategies used in the EU, based on literature review and interviews.
2. To evaluate the environmental impact of a garment's life cycle in Lithuania, based on different strategies for longevity extension.
3. To identify areas of opportunity to increase the lifespan of textiles apparel and their traceability after purchase.

1. Relevance of longevity extension in clothing

Focusing on extending the lifespan of clothing is important, not only to comply with the legal requirements in the EU, but to shift the way consumers and producers behave regarding manufacturing processes and sustainable products. It is becoming increasingly evident that society has an obligation to transition to a circular economy and to prevent more potential environmental impacts from textile products and related services.

1.1. EU regulations

The EU has developed the Strategy for Sustainable and Circular Textiles [1], which includes the updated Ecodesign for Sustainable Products Regulation [2], as a response for the European Green Deal [3] and the Circular Economy action plan [4] that started in 2020. This strategy includes the Ecodesign for Sustainable Products Regulation (ESPR), that replaces its last version of 2009. This is highly important because of two reasons: the 2009 Directive was aimed at energy–related products, while the 2024 version covers virtually all physical products; and it expands the Ecodesign requirements to enhance durability, circularity and the environmental performance of products that are put in the European market [2].

The Digital Product Passport (DPP) is a tool proposed by the recent ESPR. Its main objective is to contain all relevant information about a product and its environmental impact throughout the supply chain, it needs to disclose data about its material and origin, technical performance, and repair activities. The DPP pretends to help manufacturers, consumers, and authorities to make more informed decisions about sustainability, circularity, and regulatory compliance [2].

The Waste Framework Directive (WFD) sets up basic principles for waste management in EU countries. It introduces the “polluter pays principle” and “extended producer responsibility.” After the 2023 amendment, and in accordance with the Strategy for Sustainable and Circular Textiles, it establishes that, by 1 January 2025, Member States need to implement separate textile containers for its collections. It also reinforces the need to have a stronger capacity for sorting, re-use, and recycling, by doing investments for infrastructure and new technological solutions [5].

EPR is considered to be soon mandatory for the textile industry as well, as it has been successful in managing waste from multiple products, such as batteries, electric and electronic equipment and packaging. This is expected to reduce waste and increase circularity within the value chain, by implementing Ecodesign into the products. The European Commission’s proposal encourages funding by producers on research, and the development of innovative technologies aimed at enhancing circularity in the textile sector [6]. EPR also favors traceability on global material flows and CMBs, by attracting investments in the infrastructure needed for collection, sorting, reuse and recycling [7].

Other relevant policies are REACH Regulation [8] dedicated to managing chemicals within industries and promotes the reduction of these or the use of non-hazardous alternatives. The Directive on repair of goods [9] which makes manufacturers responsible for the repair, extending the lifetime of products. With this, producers need to consider Ecodesign requirements and the availability of spare parts. Even though the Directive is aimed mainly at electric devices, The Commission is working on updating the list of products subjects of reparability. Additionally, the Directive regards Empowering Consumers in the Green Transition [10], aimed to inform users to make informed purchases and avoid greenwashing.

1.2. Industrial challenges and needs

The textile industry has multiple impacts throughout its whole life cycle and value chain. Below in table 1, are listed some of the main aspects to consider when thinking about the textile industry and its sustainability. That is why it is important to have a holistic perspective and life cycle while addressing all these situations.

Table 1**.** Challenges and responses in the textile industry

Challenge	**Current responses**	**Future opportunities**
Specifically talking about **cotton production**, the global average GWP of conventionally grown cotton is 1,808 kg of CO_2 equivalent per 1,000 kg of fiber produced, while organic cotton result is 978 kg of CO_2 equivalent per 1,000 kg of fiber grown, meaning a reduction of 46% [11].	Use of alternatives of natural fibers, to replace cotton, such as **cellulose** or **fiber-to-fiber recycled cotton**.	Considering new sustainability requirements from regulations and from user wishes, clothing manufacturers need to find alternatives for the traditional fibers. Research is particularly important for technological innovation.
Excessive water demand during natural fiber growing (up to 15,000 m^3 per ton grown cotton [11]), but also during manufacturing processes of fabrics [12].	Efficient wastewater treatment plants and recirculation in manufacturing [13].	Creating novel strategies to dye and process textiles with a less amount of water. Alternative dying techniques can reduce the demand for chemical dyes since they use up to 90% less water and 85% less energy than traditional dying methods [14].
Water pollution, not only with toxic chemicals but microplastics from washing synthetic fibers [12].	Eliminate or replace hazardous substances from textile industry [13].	Green chemistry principles aim to reduce the load of effluent while increasing resource efficiency. Using safer substances [15].
Pre-consumer waste, the fashion industry is responsible for around 40 million tons of post-consumer textile waste a year, most of which is either sent to landfills or incineration [16].	Reduce waste by different strategies such as **increasing life use of the products, reuse, remanufacture, recycling** [13].	It is imperative to develop innovative solutions for textile waste management.
Fast fashion not only causes great impacts to the ecological means, but also to the population where these factories are located. Seasonal collections are released each year, promoting an accelerating consumption behavior of cheap low-quality products.	DPP is the tool designed to disclose all the social and environmental impacts of manufacturing processes [2].	Companies need to be equally environmentally and socially responsible. Moreover, consumers' education is needed to slow down materials flows and extend life use of products.
Textiles are hard to recycle due to mixed fibers and lack of technology.	Chemical or mechanical recycling, which can be energy intensive, is usually for non-woven fabrics.	Developing non-mixed fibers, with the least chemical substances possible and innovative technologies to have efficient and affordable recycling processes [17, 18].

All these challenges mentioned above might be addressed through the whole value chain, and that is why different Ecodesign, and circular strategies are important, not only for the textile industry, but also for multiple sectors. Environmental aspects like waste generation can be prevented, which is the first and main aspect for waste management, for instance. Considering how large Ecodesign and Circular Economy subjects are, this work focuses on ***strategies to extend clothing longevity.*** Designing and manufacturing long-lasting products and encouraging extended use of clothing are critical strategies to slow down the material flow by decreasing the purchase of new products [19] and, thus, reducing the industrial pressure on natural resources.

1.1. Current state of textile production, international market and waste generation

Fashion and textile products change through several activities that involve the conversion of fiber to yarn, yarn to fabric and fabric to garment. During these processes, a large amount of waste is generated, which reduces productivity and efficiency [20]. The EU was the first importer of apparel and textiles worldwide in 2022, with 35.5% and 20.7% each [21]. For the year 2020, 8.7 million tons of finished textiles were imported, of which 45% (3.9 million tons) represented clothing. In average, EU citizens consumed 6.0 kg of clothing, 6.1 of household textiles and 2.7 kg of shoes that year for a total of 14.8 kg per capita [22] (Fig. 1). In consequence, according to the European Environment Agency [23], in 2020, 6.95 million tons of textile waste was generated, meaning around 16 kg per person. It is 1.2 kg more than what was consumed. It was reported that 72.9% were recycled, 15.7% incinerated and 10.7% landfilled (Fig. 1).

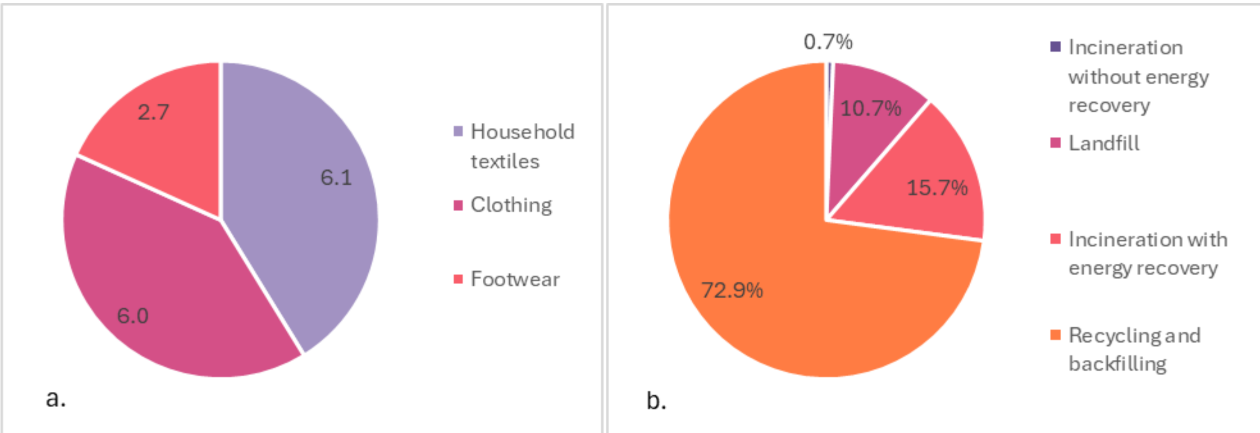


Fig. 1. a. Estimated consumption of clothing, footwear and household textiles (excluding fur and leather clothing) in 2020, kg/capita [22]. b. Treatment of textile waste in the EU in 2020 [23].

Particularly for Lithuania, in 2018, 13.5 tons of clothing were supplied, with an average of 4.8 kg per capita. Out of the municipal waste flow, 8% represents textiles [24]. The report made by the European Environment Agency states that collection rates are low (11%), as is the recycling rate (20%). According to the Post-consumer textile circularity in the Baltic countries' report [25], by the same year, used textiles came from various sources: charities/social enterprises (10%), commercial collectors (50%), brands (7%) and municipal waste centers (33%) (Fig. 2). However, it was not until 2025 that the implementation of textile waste collection containers became mandatory for all municipalities in the EU. Municipalities in the country have successfully started this initiative, following the strategies established in their Municipal Waste Prevention and Management Plans [26].

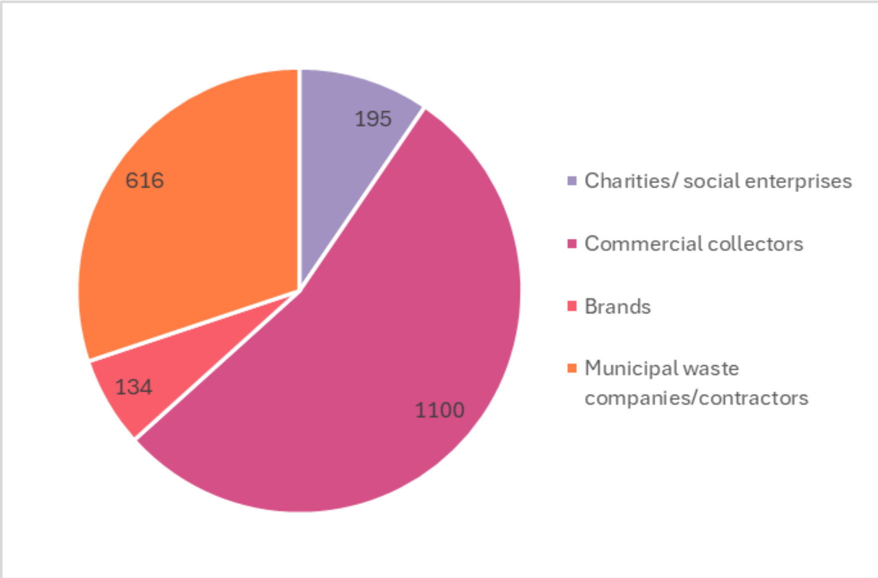


Fig. 2. Separate collection of used textiles in Lithuania in tons (2018) [25]

Lithuania not only has to manage its own waste, but it is also known for being involved in the import, processing (sorting into different categories based on quality and value), and trade of used textiles. The country was the first European importer of used textiles and rags per capita (around 22 kg) in 2018. This practice might be significantly negative for domestic circularity, since certain recycling businesses prioritize imported textiles due to consistency in the supply, over textiles collected locally [25].

2. Literature review

2.1. Circularity and traceability within the fashion industry

Circular economy is a concept that is gaining more importance with time, and it is being slowly adopted by society. This concept refers to a new systematic model of consumption and production and aims to eliminate the "end of life" concept (replacing the "linear economy") by implementing different actions such as reducing, reusing, recycling, and recovering materials throughout the value chain. It encourages the use of renewable energy, and the elimination of hazardous substances and waste [27]. It operates in different scales from micro level (products, companies, and consumers), meso level (industrial parks) and macro level (cities, regions, etc.), with the goal of achieving sustainable development in an environmentally and socially way [28].

Circularity strategies have become well known, moving from the 3Rs to the 9Rs model, shown in Fig. 3, emphasizing the deceleration in the consumption of natural resources and dematerialization. The more circular a material is, the longer it remains in the value chain, preferably retaining its original quality and value, thus less materials are needed to manufacture new products. The priority is always preventing the use of natural resources and new raw materials [29].

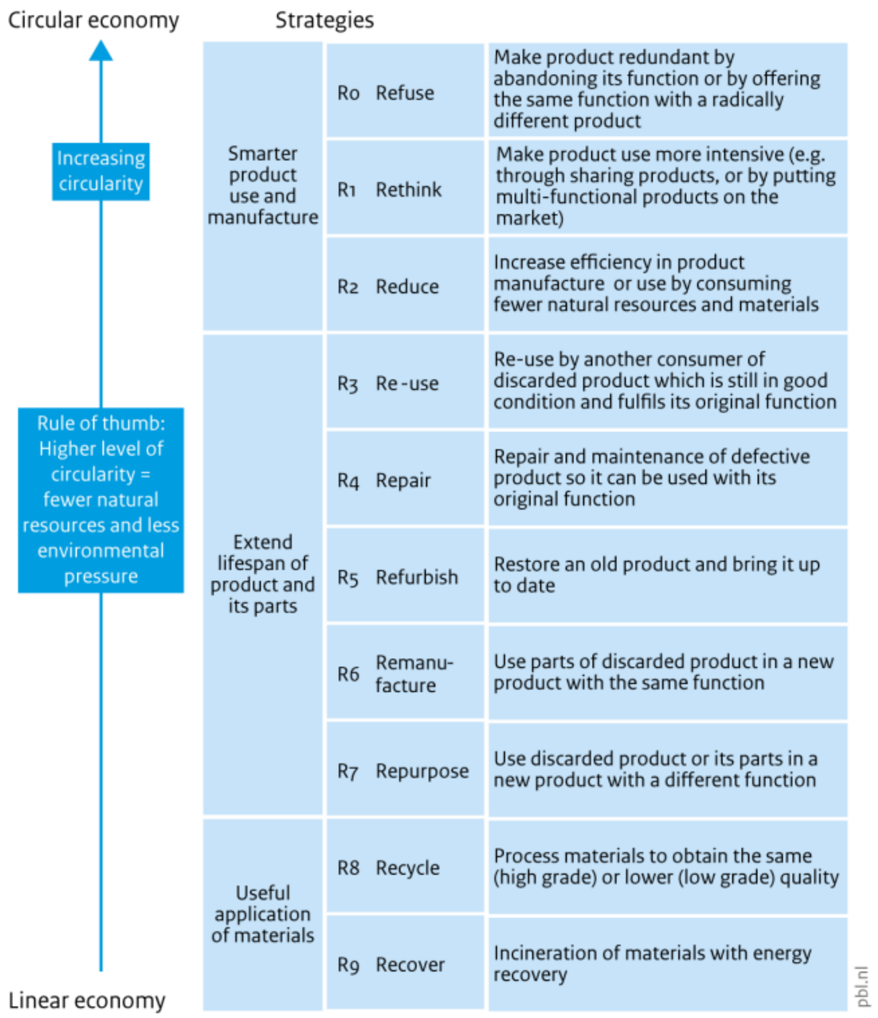


Fig. 3. Circular economy strategies [29]

The concept of "circular fashion" has been mentioned in 2014 in Sweden based on the principles of circular economy and sustainable development. In this way, the fashion industry must design durable non-toxic products that can be biodegradable, reusable and recycled. Brands not only need to focus on environmental sustainability, but also on social responsibility with decent working conditions and preferences in local resources [30].

Within the methods to implement and manage circularity, there are Life Cycle Assessment (LCA), Traceability and Ecodesign. LCA is the evaluation and analysis of the potential environmental impacts throughout the life cycle of a product or service. It considers multiple environmental categories that can help to identify hotspots in a value chain. On the other hand, Traceability is the capacity to track and disclose information about all stages of a product, from raw materials extraction, to manufacturing, use and end of life [31]. This means that producers must have detailed knowledge of their suppliers to know the origin and nature of the resources used and useful information for other stakeholders within the value chain: users, repair services, reuse markets and recyclers.

2.2. Ecodesign

According to the Regulation (EU) 2024/1781, Ecodesign is "the integration of environmental sustainability considerations into the characteristics of a product and the processes taking place throughout the product's value chain" [32]. In general terms, Ecodesign is the implementation of one or more sustainable strategies into the product's design in order to reduce its environmental footprint throughout its life cycle. The ISO 14006: 2020 mentions it is a "systematic approach", which is imperative to consider when a product is contemplated as a system where multiple processes are related to each other [33].

Research made by Jochamowitz Yriberry, Jochamowitz and Yriberry [34] and Islam and Perry [13] have valuable information about this topic, but one of the aspects they have in common is the difference between two approaches for Ecodesign implementation: *operational/ hard side*, which refers to the technical part, while the *organizational/ soft side*, refers to the main actors involved and their importance of performing Ecodesign practices. This shows the importance of having a systematic perspective when assessing sustainability within a company or organization.

The literature review made by Harsanto et al. [35] establishes three approaches regarding sustainability in the textile industry: 1) *product innovation*, where includes Ecodesign, Ecolabel, LCA, Materials innovation and Packaging; 2) *process innovation*, which consists of Cleaner Production (CP), Ecoefficiency, Waste management and Supply Chain Management; 3) and *organization innovation,* with Environmental Management System (EMS), Collaboration and Business Models. The first two approaches can be analog to the operational approach cited above.

On the other hand, The Nordic Council of Ministers develops a list of requirements before the EU Regulation was updated in 2024, setting an example of how Ecodesign can be also implemented for non-energy related products [36]. In general, the main aspects they consider when implementing Ecodesign are *recyclability*, *durability*, *reparability,* and *reusability*. The last three concepts are under the idea of *extending the life span* of products.

Ghezzo [37], mentions a different Ecodesign approach, but equally relevant for textile manufacturing: *zero waste* pattern cutting. Discarding the left cut-offs is losing high-quality material, it means that it is an inefficiency of the process, because these may go to incineration or to other downcycling processes. Saccavini and Shafqat [31] comment on *biodegradability* and *composability*, while Vezzoli et al. [38] indicate the concept of *biocompatibility*, which means that outputs should not affect the dynamics of ecosystems. Thus, the selection of biocompatible materials and resources must be evaluated.

Alternatively, textiles are complex products because in many cases fabrics are a mixture of different fibers, which make them hard to manage at the end of their life. With the concept of Ecodesign, these should increase their recyclability, not only to produce other textiles, but for any other product too. Ovam [39] mentions a different requirement: closing the loop through implementation of recycled content, *dismantlability*, *traceability* and recyclability. It also highlighted *responsible production* through environmentally friendly textiles, *labor conditions*, and *chemical use and content*.

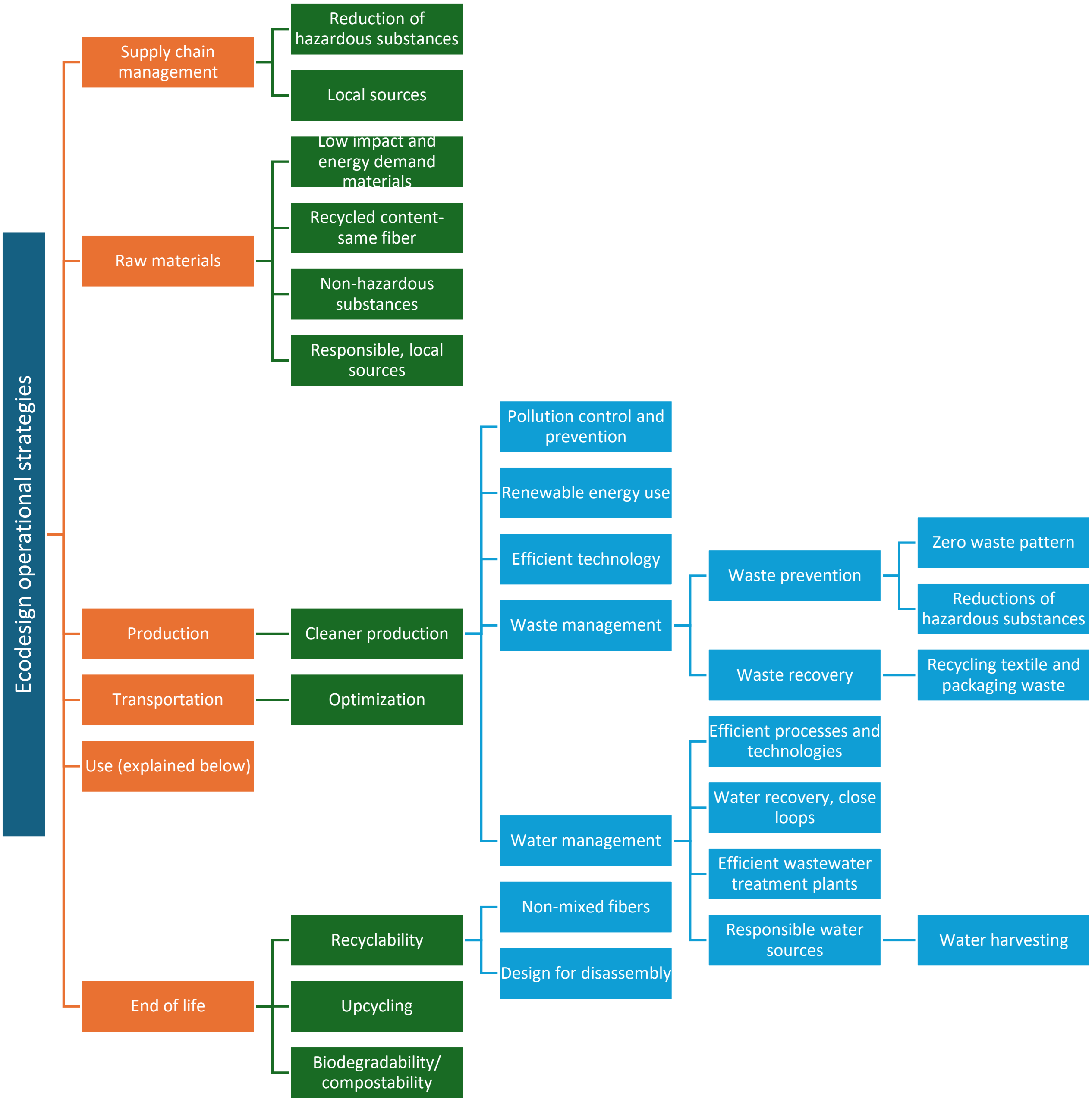


Fig. 4. Mapping of Ecodesign operational strategies [13, 31-39]

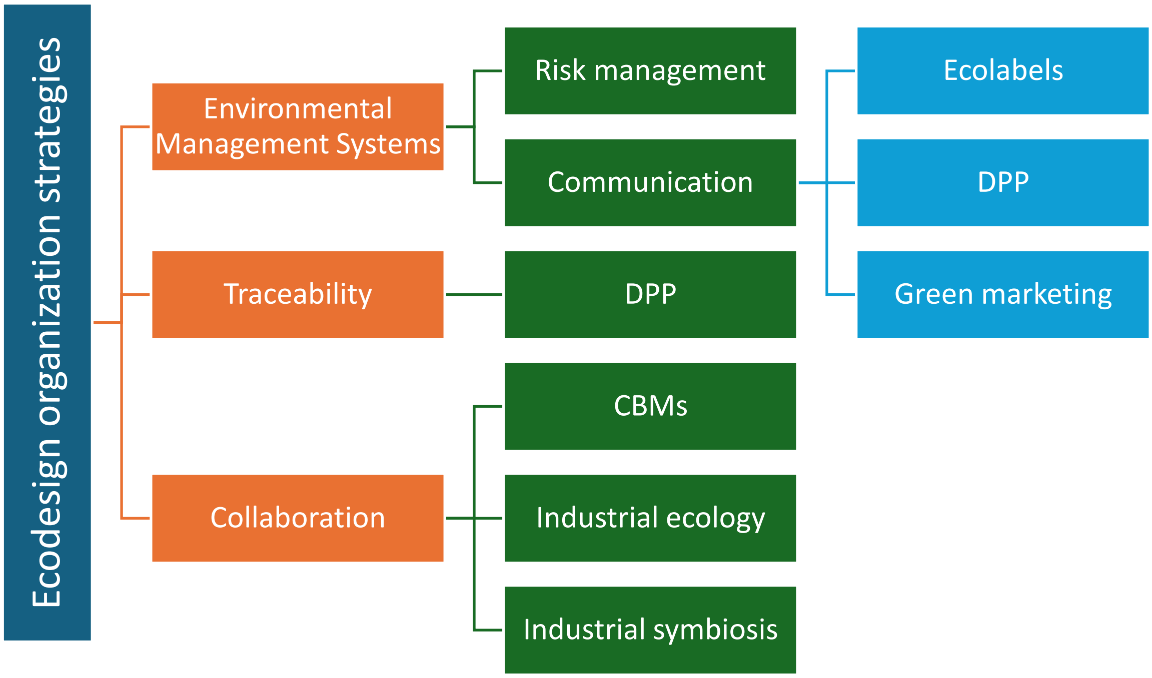


Fig. 5. Mapping of Ecodesign organizational strategies [13, 31-39]

Summarizing the literature review regarding the operational and organizational approach of Ecodesign and a deep emphasis on Life Cycle, the strategies are listed in Fig. 4 and Fig. 5. All strategies are relevant to managing the environmental aspects and decreasing impacts. However, specific strategies for longevity extension are explained in the next section.

2.2.1. Design for longevity

Talking specifically about the design process, the main goal is to ***extend the life span of products***, also known as ***design for longevity***. For this, different principles may be implemented. For example, technical requirements are summarized in the report by Ovam [39] on standard norms. One of them is extending life span through *quality materials, reparability, and maintenance*. In addition, Cooper et al. [40] report more options to extend longevity in garments, also mentioning the relevance of *classic designs*. A different concept is disclosed by the NGO WRAP [18] which is *versatility* to extend the lifespan. Also, Vezzoli et al. mentioned the Design for *reliability*, explaining it is related to "a low number of components and solid assembly solutions" [38, p. 142].

On the other hand, Botta [41] reports general definitions and recommendations on how to implement minimum Ecodesign requirements in textiles products. She highlights the importance of good technical requirements of fabrics (fabric performance, finishing processes, etc.) and yarns. One of the most remarkable is the definition of *testing methods* to evaluate longevity in terms of hours of wear or washing cycles and achieve longer-lasting garments. For example, the EF guidelines for a t-shirt establish an expected lifetime of only 52 washes, meaning it would last only a year if washed once per week. Moreover, Guo et al. [42] highlights the need to have standardized methods to evaluate the absolute durability and to compare different types of garments, regardless of how a particular consumer may use them in real life.

After quantitative research, Laitala, Boks, and Klepp [43] identify the reasons for wardrobe discarding, aiming to find design solutions to extend lifespan. After collecting seventy reasons, they highlight strategies focused on size and fit; clothing care; technical quality, durability, and functionality; emotional attachment; and fashion trends. From their study with the Wardrobe method, researchers are able to confirm that reasons to buy or discard an item go beyond physical durability and highlight the importance of focusing on different approaches like repair services and communication strategies.

In addition, from a survey among 161 young people, McNeill et al. [44] proves that they are willing to maintain or repair their articles if they have a connection to them, whether because the article has a high price or sentimental meaning. Redress [45] also indicated that this emotional attachment can be created by designers and brands when they collaborate with the customer, for example, collecting feedback to better understand their values; or when there are embedded values in the garment since its production.

In summary, the Ecodesign strategies for ***longevity extension*** are classified as follows in Fig. 6:

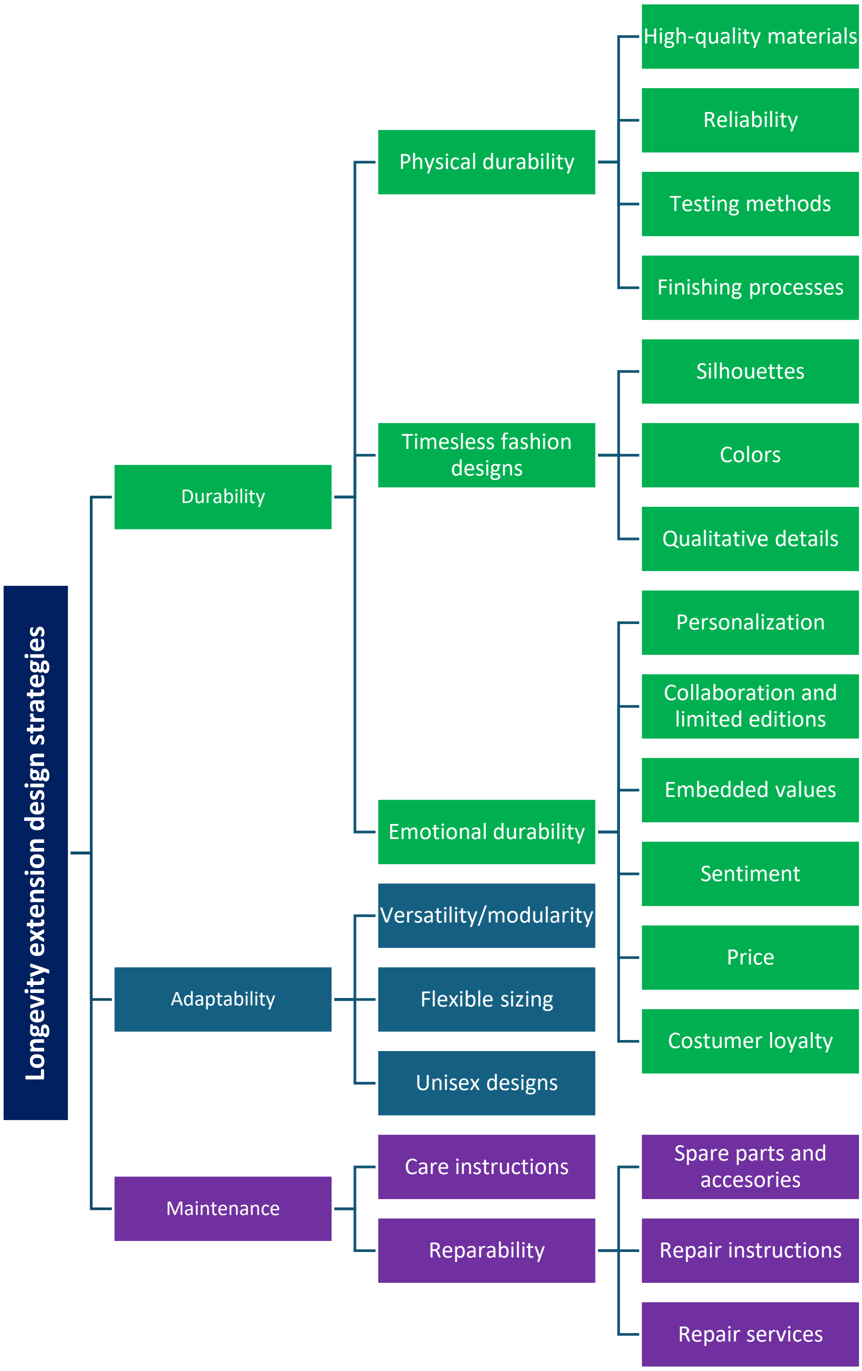


Fig. 6. Mapping of longevity extension design strategies [18, 38-42, 44, 45]

2.3. Alternative business models

Ecodesign and circular economy are not practices that can be implemented individually. It is necessary to create and increase collaboration between companies and sectors [13, 35]. Manufacturers have limitations when guaranteeing products longevity, because it is related to the design itself [46], thus, there are bigger forces that need to act for fashion longevity, circularity, and sustainability. The inevitable implementation of EPR within the fashion industry gives companies the opportunity to rethink their business model.

Circular Business Models (CBMs) seek to ensure that systems and services retain resources for the longest possible duration [47] and reduce the number of products made while maintaining the value of the ones already existing [48]. They show how resources efficiency is increased, and the environmental footprint is reduced [35]. There are distinct types of businesses models: for example, Tura and Laukkanen [46] discuss specifically Sharing Economy Business Models (SEBMs) with practices like gifting, lending, sharing, swapping, renting, leasing, and second-hand. Although environmental impacts for producing added items may be decreased, the impacts of logistic, shipping and take-back may rise [49]. Outside the sharing concept, within the fashion industry also exists repairing and recycling (up and down) business models. Collection and recycling are expected to increase in the EU with the adoption of the Directive 2018/851 EU for separate collection of textile waste to ensure its re-use from 2025.

Next, take-back and warranty programs are designed to increase the length of product life and to reduce landfill waste [50]. Take-back models can be brand-selective or unselective, also, they can be operated by the brand itself or by third parties [49]. For example, the company PVH has a take-back pilot program to repurpose post-consumer clothing with different options like product repair, resale, downcycling, or chemical recycling opportunities [51]. On the other hand, H&M has a program as a service provided by a third party [52], that manages collection and coordination to complete the sorting process in three distinct categories, rewear, reuse and recycle [53]. The company responsible for this is SOEX I:CO, with headquarters in Berlin. They have two sorting facilities that focus on the waste hierarchy: prevention, reuse, preparation for reuse, recycling, recovery, and disposal [54].

Big companies have the capacity to implement programs for post-consumers' garments, like re-commerce, rental, and reuse. It is imperative that these big forces collaborate and create partnerships with small and medium enterprises with different business models. According to the analysis made by Dragomir and Dumitru [51], big companies like VFC, H&M and Inditex have donated millions of EUR and collaborated with multiple NGOs to work around collection and reuse of clothing. Also, they have the economic means to fund research on, for example, textile re(up)cyling, as Inditex did in 2020, investing 3.5 million USD. These initiatives show that large companies can implement EPR in their business models.

Digital platforms are stronger than ever, especially after Covid lockdown, becoming highly relevant for e-commerce and the life extension of used clothing. Two Lithuanian companies have implemented CBMs: Vinted, Giver Tag and Looptex. Founded in 2008, Vinted has expanded all around Europe and even to United States. This is a C2C marketplace, where users can sell and buy not only clothes, but different second-hand items [55]. Used garments are becoming more popular, as demonstrated by the French case, where the platform generates the highest volume of income in the country, surpassing two big actors like Amazon and Kiabi [56]. On the other hand, Giver Tag not only focuses on online exchanges, but on physical events, where people gather to swap their wardrobes [57]. This platform has been released recently but has the potential to promote longer life use for clothing, indicating the savings of environmental impact based on the swapping.

A good example of how different CBMs can work together in Lithuania is Looptex [58]. This is a digital platform with fashion solutions, from the purchase of second-hand items to repair services. Looptex has integrated stakeholders in a collaborative network to maximize the use and value of clothing. As shown in Fig. 7, there are different actors and services working simultaneously to ensure a circular economy within the fashion industry. By providing repair services or a website to buy and sell, this company, which is not related to the design phase, ensures the longevity extension of fashion apparel in the country.

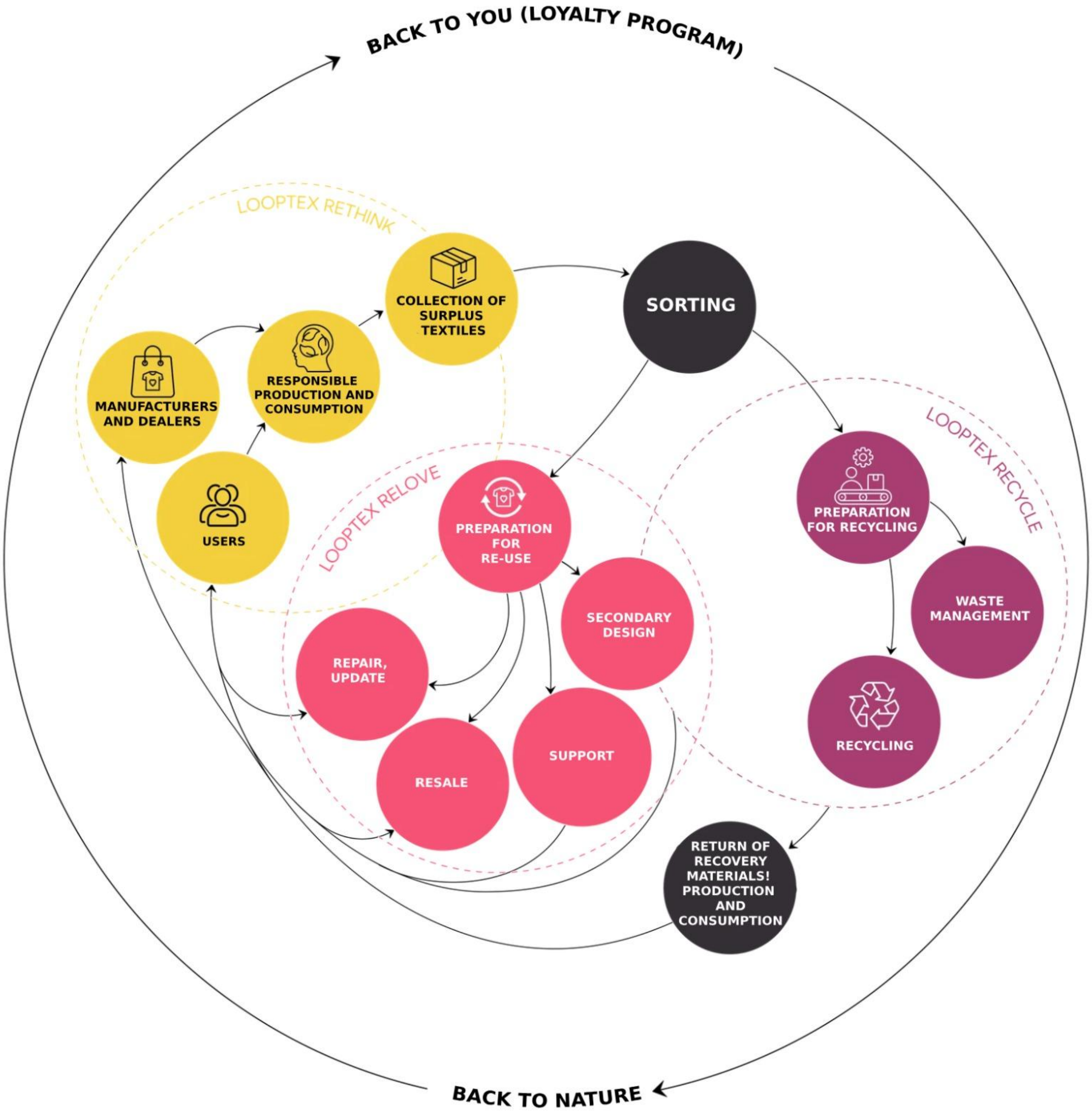


Fig. 7. Looptex business structure [58]

2.4. Research gap

Claxton et al. [59] conducted a practical study to evaluate design for longevity in clothing products and create a protocol to evaluate this aspect related to laundry habits by consumers. On the other hand, Gwilt and Pal [60] performed experimental works to extend garments' longevity through two specific strategies: modularity and incremental aspects (referring to micro-design elements that can be added to the garments; this strategy is very related to the principle of versatility). These two show two different approaches to facing the same object: the extension of clothing longevity.

On the other hand, Luo, Wu and Ding [61] confirm the difficulties to perform an LCA with a cradle-to-grave scope because it is challenging to estimate the total number of wears, since this variable depends on many factors like the material properties, the use, and care from the consumer. Here it is important to highlight that many studies assume there is only one consumer that has specific laundry habits. There are some authors that consider the reuse or repair within their analysis, but it is imperative to keep exploring the environmental impacts of these actions, because there is a potential reduction in environmental pressures due to the minimization of purchases and resources use. Also, the processes in the use phase, defined by the system boundaries, vary notably according to the purpose of the study and the conditions under which the research is conducted [61]. Thus, doing comparative analysis among studies becomes a more challenging task for researchers and organizations.

At first instance, this work focuses on strategies for longevity extension in clothing and their influence on the environmental impact through its life cycle. To assess that impact, LCA is performed considering all stages, from raw material to EoL. While researchers generally agree that the use phase is the most environmentally impactful, this conclusion is largely based on theoretical data and assumptions. In practice, tracking consumer behavior, such as laundry frequency or garment reuse (and reuse), is extremely challenging. As a result, the actual impact of the use phase remains partially underexplored, highlighting the need to gather more empirical data on this stage.

An outstanding study by Klepp, Laitala, and Wiedemann [47] aims to establish functional units of clothing lifespan for LCAs. They focus on what to measure and how to measure it. First, they establish that lifespans can be measured in four ways: number of uses, years, number of users and number of cleaning cycles. Among the methods for measuring are surveys, qualitative interviews, and wardrobe studies. They prove through a wardrobe survey how different values of units vary depending on the type of garment and whether intensive or extensive wear. This research is a good example of how the gap during the use phase is attempted to be filled.

Nevertheless, there is not a specific study mentioning how to track the lifespan of a product once the user has purchased it. Experts have put their efforts into mapping how many tons are sold and discarded every year, but there is no data about how long a specific product functions after its purchase until its final disposal. Evaluating the number of units of items that are reused or discarded every year is crucial to better know what type of garments are discarded first and why, and in the same way, to work in different strategies to extend life span and prevent premature disposal. Fig. 8 shows the current and ideal scenario for clothing traceability. Now, data availability is regarding how many tons of products are sold and discarded each year, but it does not mean the purchased items are the same discarded. Then, in the ideal scenario, with improved traceability mechanisms, allow to know how many products and which type are bought and discarded each year, and to estimate how long each garment is used.

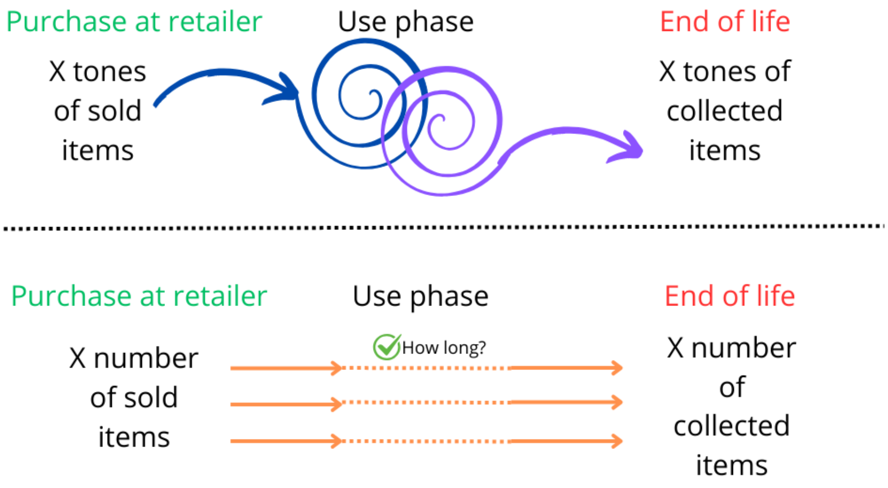


Fig. 8. Comparison of traceability in current and ideal scenarios

Fig. 9 exhibits the traceability differences between upstream and downstream stages. Producers have detailed records of their supply chains and environmental impacts during manufacturing processes. However, when it comes to stages after the purchase, there is uncertainty about the use phase and the EoL path, making assumptions based on theoretical information or surveys that can be biased or not wide enough.

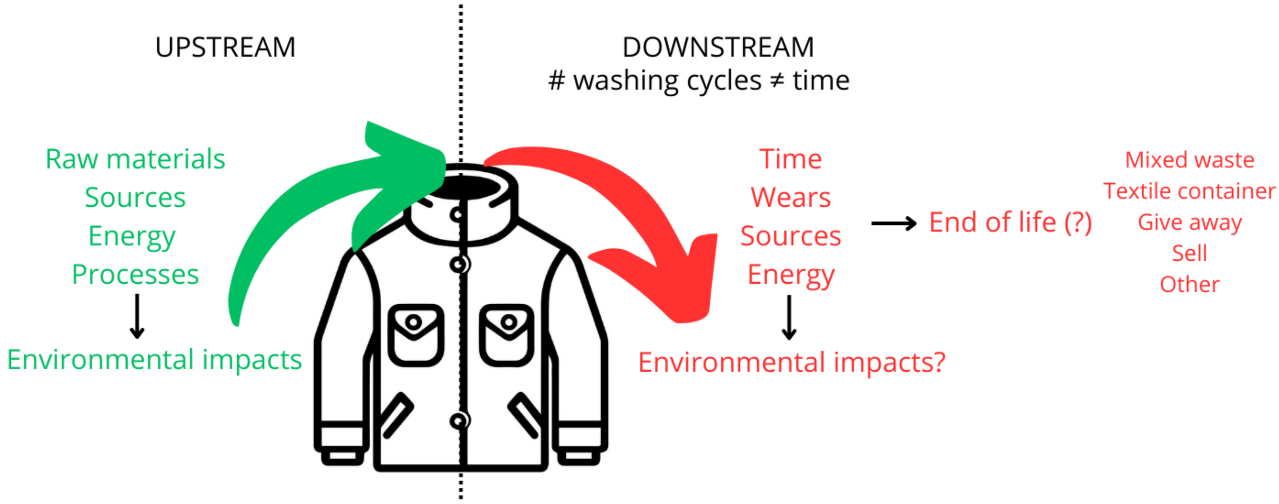


Fig. 9. Gap in the downstream traceability for clothing

Far from longevity extension, Dani, and Shabiimam [62] have a clear example of LCA for viscose fabric, with a gate-to-gate scope, but Bianco et al. [63] have an LCA with cradle-to-gate scope. These two scopes are the most common ones for LCAs, since it is difficult to trace the end of life of specific products and there is no exact data that can be analyzed, even though that is commonly known the main options that textiles go through at the end of life, as incineration. This is the reason **increasing downstream traceability of textiles is key to understanding gaps regarding the circularity of clothing and how they can be fulfilled with potential strategies for longevity extension.**

3. Methodology

3.1. Methodology flow

The necessity of research on the topic of longevity extension comes from the updated EU Regulation about Ecodesign in various products. Considering the large environmental impacts of the textile and clothing industry, this needs to be reviewed carefully regarding upcoming sustainability requirements and how they are implemented in manufacturing. Fig. 10 shows the flow research stages.

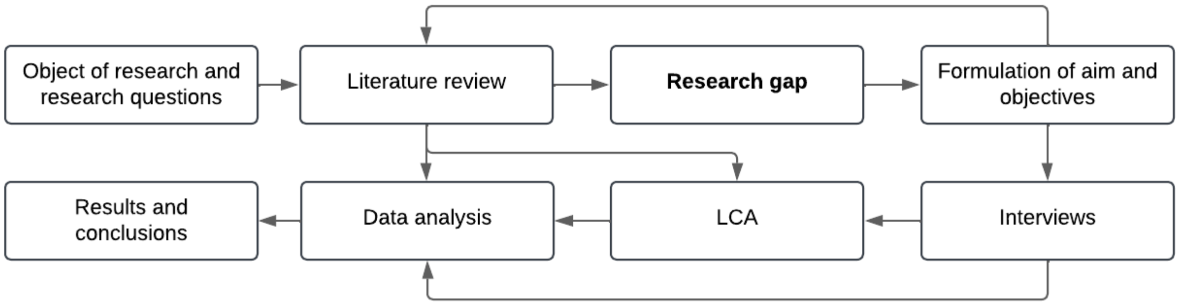


Fig. 10. Research design

The literature review is conducted on Ecodesign, Circular Economy, Traceability, and sustainability practices during manufacturing processes of fashion products. The main Database used is Scopus, using filters for the year (from 2020 until 2025, mainly) and key words such "Ecodesign", "sustainability", "longevity", "durability", "extension", "clothing", "textiles", among others. Other reports made by NGOs and companies are equally important to understand tendencies throughout the years in the fashion industry. Most of the reviewed articles are focused on the EU or European countries.

After the research gap is identified, the specific research question, aim and objectives are established, focusing specially on strategies to extend the use of fashion products. From this, two paths are followed: a qualitative approach, with interviews and a quantitative one, based on an LCA. From the literature review and interviews comes the need to proof how the strategies for longevity extension influence the environmental impacts in the life cycle of garment, and this is the reason the LCA is performed after gathering all the theoretical information. Finally, results are discussed, providing recommendations and future opportunities to fulfill this gap.

3.2. Interviews

After having a theoretical framework, semi-structured interviews are designed to collect data about strategies and challenges for the design of long-lasting fashion products and implementation of sustainable strategies. The target groups for interviews are experts in the textile field, professors from KTU Fashion Engineering program, listed in Table 2. For each expert, general and special questions are formulated, depending on their field of knowledge (see Appendix 1 for specific questions). General questions are about their experience in the textile industry and how they perceive durability through the value chain. Specific questions are related to quality of materials, standards for quality evaluation, mechanical properties of fabrics and confection, and consumers' education.

The interviews are conducted during March and April of 2025 during sessions of 30 minutes each. Every session is recorded and transcribed automatically with the consent of the interviewers. The consent form template can be found in Appendix 2. It is pertinent to notice here that the interviews have been done during the early stages of this study, thus the questions are oriented mainly to Ecodesign strategies for producers.

Table 2. List of interviewers

No.	Code	Name	Description
1	E1	dr. Daiva Mikučionienė	Vice-Dean for Research, Professor and Researcher in the Faculty of Mechanical Engineering and Design, KTU.
2	E2	dr. Erika Adomavičiūtė	Associate Professor and Researcher in the Faculty of Mechanical Engineering and Design, KTU.
3	E3	dr. Jurgita Domskienė	Associate Professor and Head of Study Programs in the Faculty of Mechanical Engineering and Design, KTU.
4	E4	dr. Vaida Jonaitienė	Associate Professor in the Faculty of Mechanical Engineering and Design, KTU.
5	D1	dr. Kęstutis Lekeckas	Professor in the Faculty of Mechanical Engineering and Design, KTU.
6	S1	Rasa Virbickė	Doctoral student at the Institute of Environmental Engineering. Research in the field of non-traditional yarns and fabrics for sustainable textiles, KTU.
7	S2	Agnė Jučienė	Doctoral student at the Institute of Environmental Engineering. Research in the field of sustainable resource management in circular systems, KTU.
8	C1	Reda Siudikienė	Quality manager at Omniteksas.
9	C2	Mantas Naulickas	Purchasing and Warehouse manager at a textile company (title is confidential).

3.3. Life Cycle Assessment

An LCA using SimaPro is the chosen method to evaluate and compare how different strategies of longevity extension alter the environmental impacts of the life cycle of garments. The life cycle refers to the consecutive and interconnected stages of a product system, including raw materials extraction to final disposal [64]. LCA can be comprehended as a method to evaluate and manage environmental impacts associated with goods or services. The first time the ISO incorporated LCA is in 1997 with the Standard ISO 14040 Environmental Management – Life cycle assessment among other norms that have been summarized in the most recent version of 2006.

Although this methodology has been standardized in the 1990s, it began around the 1960s with the name of Resource and Environmental Profile Analysis (REPA) or Ecobalances. These methods are based on the inventory of materials, energy, emissions, and waste. However, data has become more complex, and it has been needed to summarize it in potential environmental impacts. At the same time, databases like EcoInvent and software like SimaPro, GaBi or OpenLCA are born to manage and calculate these impacts [65].

According to ISO 14040, there are four study stages: goal and scope definition, where it is included the system boundaries; the inventory analysis, which is the inputs and outputs data related to the system; the impact assessment, that provides additional information to evaluate results from the inventory and understand the environmental performance of products or services; and interpretation, where results are summarized and analyzed, to come to conclusion or recommendations, according to the goals stipulated (Fig. 11) [64].

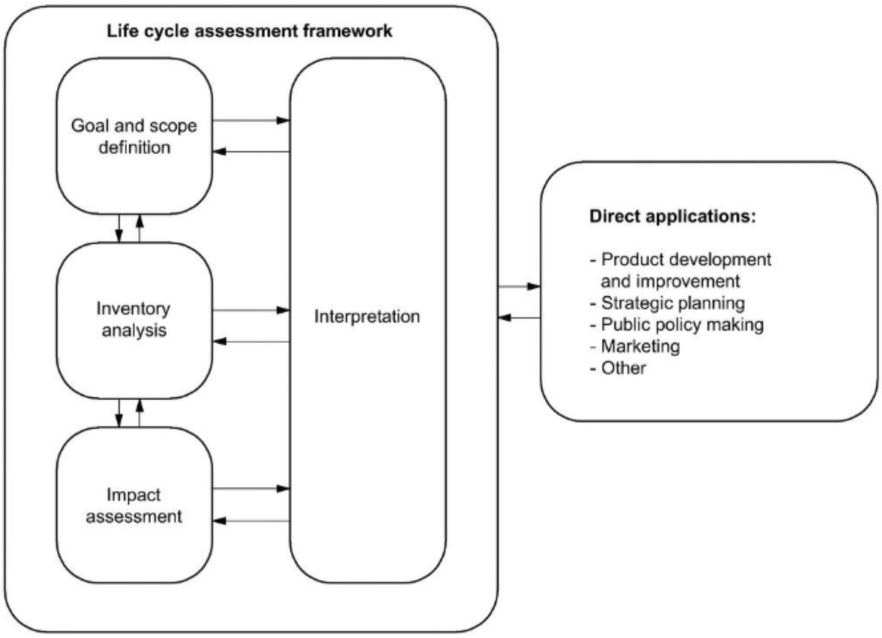


Fig. 11. LCA stages [64]

After the literature review, strategies for longevity extension and the gap in the traceability of clothing' use phase are identified. An LCA is chosen to evaluate the potential environmental impacts that clothes really have during their life use. LCA is a key tool withing the ESPR since Ecodesign is based on the environmental performance through life cycles stages. LCA allows identifying hotspots or key points, promoting designers and producers to improve the product design and reduce those pressures. It is an essential element for decision making when thinking about the materials, processes and the expected product life span [66, 67].

3.3.1. Goal and scope

Goal: to compare the environmental impact of different use scenarios for a polyester dress, based on strategies for longevity extension, in Lithuania.

Polyester has been selected as the material of study because most textile LCAs focus on cotton, and further insights and comparisons involving PET are needed [68, 69]. Also, the estimated data needed for the LCA of a polyester drees has been gathered by Sandin et al. [70] for the environmental assessment of Swedish clothing, which has been used in this study, considering the geographical and socio-economical similarities with Lithuania.

Different scenarios are performed to make the comparisons, considering the main stages of the life cycle for the dress. The purpose is, not only to evaluate different paths of reuse, but also how different raw materials, manufacturing processes and distributions can alter the environmental impacts through the value chain. The data available from literature describes the manufacturing process of a polyester dress based on fast-fashion models and virgin PET. To make a comparison with "sustainable manufacturing" and other types of PETs, an additional literature review has been necessary to estimate how much is the difference between alternatives. The stages of first use, collection sorting and second use are modeled in the software, with collected data. The specification of each scenario is described below.

Functional unit: one new polyester dress (0.478 kg) used twenty-six times, with 8.7 laundry cycles [70].

System boundaries: Cradle-to-grave: raw material extraction, production, distribution and retail, use and EoL.

Data and software: SimaPro 9.5 is used, which has EcoInvent databases included. The data used for the baseline is based on the research made by Jučienė et al. [71]. However, their scope only includes raw material extraction, production, distribution and retail, first use, and EoL, being the first use considered as 19.4 laundry cycles. Hence, data has been modified to correspond to 8.7 laundry cycles. Additionally, in the baseline, collection and sorting stages have been added in this study. Further data for inputs has been collected from scientific literature and/or estimated based on empirical information. Interview with S2 is particularly important in data collection for the LCAs, because more information is considered besides the one disclosed in the published study [71]. Detailed information for inputs can be found in Appendix 3.

Impact categories from the ReCiPe2016 method in midpoints [72]: according to the LCA performed, these are the most significant impacts among the eighteen categories the method use.

- Global warming (kg CO_2 eq): it measures greenhouse gases emission, and it is the main indicator of environmental impact, it is used for the Carbon footprint.
- Freshwater and marine ecotoxicity, and Human toxicity (carcinogenic and non-carcinogenic) (1.4-DCB eq): they consider the environmental persistence, accumulation in the human food chain and toxicity of a chemical. These are selected due to the high number of chemical substances involved in the life cycle, especially considering global datasets are used, like energy sources.
- Fossil resource scarcity (kg oil-eq): it is the relation between the energy content of fossil resource and the energy content of crude oil. It is selected due to the intensive energy-use activities involved in the life cycle of clothing, especially when global datasets are used.
- Water consumption (m^3): it measures the water that has been incorporated into products, transferred to watersheds, evaporated or disposed into the sea. It is selected because of the intensive water-use activities involved in the life cycle of clothing.

Categories have been characterized and normalized in the software and then weighted separately using the weighting scores proposed by Sala et al. [73]. These scores (Table 3) are selected because this approach focuses on the Environmental Footprint method suggested by the European Commission. These factors have been identified after workshops with experts and a literature review about various weighting approaches.

Table 3. Weighting factors used for the single score [73]

Impact category	**Final weighting factors (%)**
Climate change	21.06
Human toxicity, cancer effects	2.13
Human toxicity, non-cancer effects	1.84
Ecotoxicity freshwater	1.92
Water use	8.51
Resource use, fossils	8.32

The system shown in Fig. 12 considers a general picture of all scenarios for the use phase. The main raw material is polyester from PET. The manufacturing process includes melt-spinning of PET fiber, yarn production, fabric production, and confection. The manufacturing process is assumed to be done outside Lithuania, considering the data used by Sandin et al. [70]. Generally, LCAs for clothing consider reuse as one option for EoL. With this approach, reuse is a strategy to extend the life use, thus, it is part of the use phase. The use phase includes washing, machine drying and ironing. EoL is the stage when the product no longer fulfills its original function, for example, it is recycled to other fibers, downcycled or incinerated. For this study EoL can be done in the country or outside.

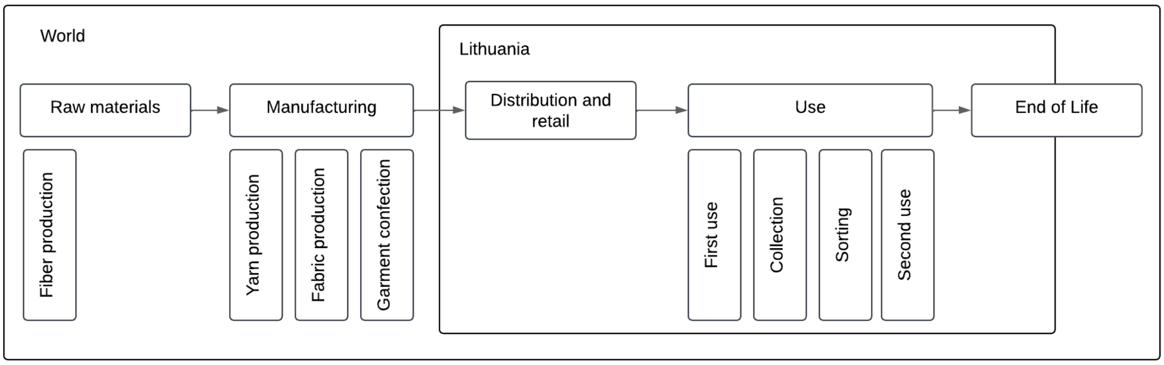


Fig. 12. General system boundaries for LCA

3.3.2. Inventory and scenarios

Base line – Local EoL (BL)

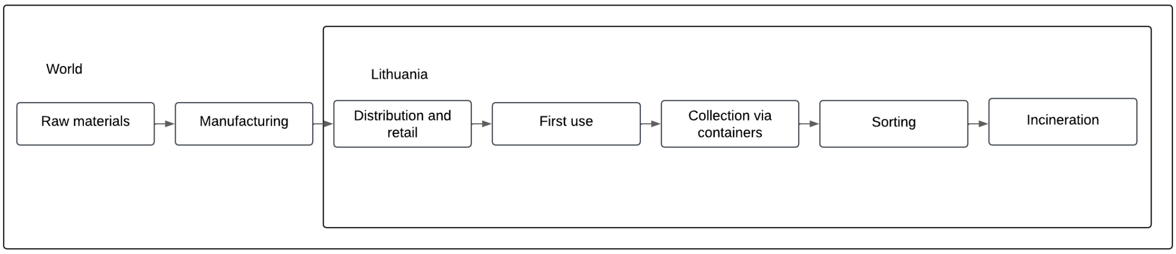


Fig. 13. Flow chart for the baseline scenario

The starting point is an LCA that estimates the environmental impacts of one kilogram of new fabrics (Fig. 13). In this case, only polyester is considered, in this case, from virgin PET. This analysis only includes washing, drying, ironing and partial transportation during the use phase, plus incineration as EoL. Based on Sandin et al [70], it is assumed that a dress is used 26 times by the first user and washed 8.7 times. One laundry cycle considers washing, drying, and ironing. It is important to notice that the information is based on H&M data that the author includes for the study. To this research, H&M is considered a fast-fashion model regarding manufacturing practices. Therefore, Li et al. [74] state that fast-fashion brands are eleven times more impactful than traditional companies.

Scenario 0 – Export EoL

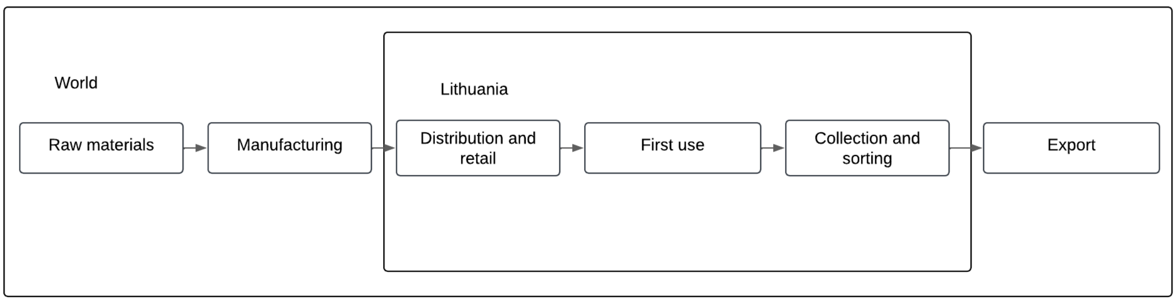


Fig. 14. Material flow for scenario 0

Pakistan is chosen as the destination of export, considering that it is the country that imports the most used clothing from Lithuania [75]. However, for this study, landfilling is the EoL due to the uncertainty of how really textiles are managed in this country [76] (Fig. 14).

Scenario 1 – Container collection (S1-2U)

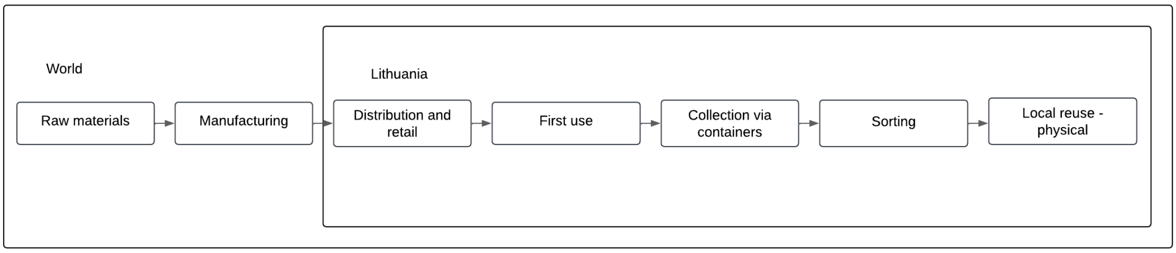


Fig. 15. Material flow for scenario 1

This scenario, shown in Fig. 15, considers a fast-fashion manufacturer with rPET. The inventory is the same for raw materials, manufacturing, distribution and first use as the base line. However, based on Fidan et al. [69], a fabric made with rPET can be 32.45% less impactful than virgin PET. So, this is the environmental impact reduction considered for raw materials in this situation. After the dress is used 26 times, it is discarded through the textile containers available in the cities. After the collection and sorting, 88% of clothing is prepared for reuse and the rest is incinerated [77]. In this study, local reused is selected, which includes 13 uses. In SimaPro, collection includes the transport and the sorting process.

Scenario 2 – Boxes collection (S2-2U and S2-B2C)

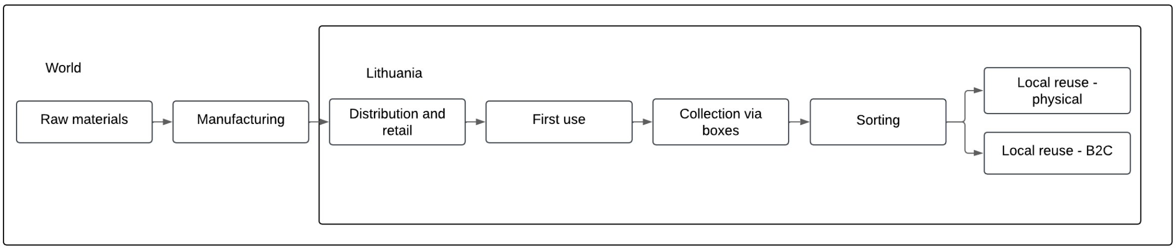


Fig. 16. Material flow for scenario 2

Fig. 16 shows a similar flow to scenario 1. It is also considered a fast fashion model with rPET, and with 26 uses by the first user. However, the discard is through special boxes, following the business model of Looptex (explained in section 4.2). This company prioritizes local reuse and keeping the product value within the country. After clothing is collected, it is washed, and repaired, if needed. In this case, it is assumed that there are two alternatives after maintenance: local repurchase, which can be done via the physical store or the website. In SimaPro, physical reuse includes user transport, while B2C reuse includes delivery with an average distance between Vilnius and four other cities (Kaunas, Klaipeda, Šiauliai and Panevėžys).

Scenario 3 – Digital C2C (S3-C2C)

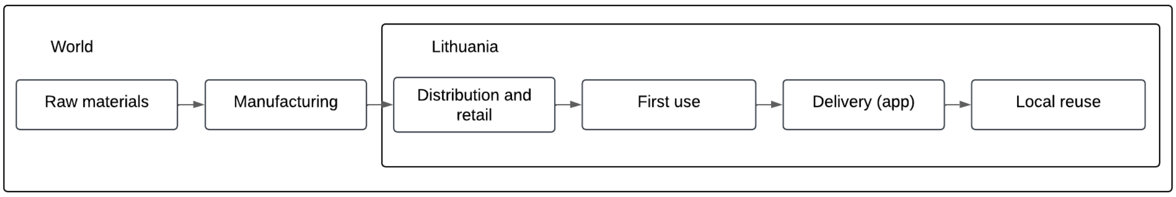


Fig. 17. Material flow for scenario 3

In scenario 3 from Fig. 17, the raw material is fiber-to-fiber recycled polyester, and the manufacturing process is more traditional or sustainable. Thus, the materials represent 73% less impact [78], while the production is eleven times less impactful than fast fashion [74]. The distribution and the first use remain the same as previous scenarios. Here, there is no collection by a third party, since there is direct delivery to the second user, considering it is sold on a digital platform like Vinted.

Scenario 4 – Swapping (S4-swapp)

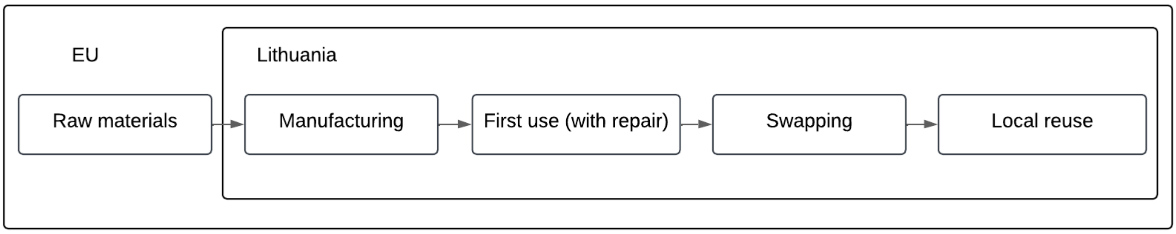


Fig. 18. Material flow for scenario 4

This scenario, in Fig. 18, considers a local customized process to manufacture the dress. Raw materials represent 15% less impact because of shorter supply chains [79]. While the manufacturing process is the same, there is no distribution since the user goes directly to the physical studio. Here it is assumed that the manufacturing process is higher quality than fast fashion, thus it has a higher price. With these conditions, the consumer wants to keep the garment as long as possible, and it is used 52 times and repaired once. This includes the transport and repair process. After, it is swapped directly with another person, who uses it 26 times.

For scenarios from 1 to 4, EoL is not considered because after the second use, because the dress may be reused again through one of the alternatives shown here. This cycle can repeat a certain number of times, but there is no certainty, since there is no data available. In Table 4, there is a summary of scenarios showing the main differences between them.

Table 4. Main differences in the baseline and each scenario

Scenario	Materials	Manufacturing	Distribution and retail	First use	Collection	Sorting	Second use/EoL
Baseline (BS)	Virgin PET	Fast fashion	International haul	26 uses	Container	Regular	Incineration as EoL
Scenario 0 (S0)	Virgin PET	Fast fashion	International haul	26 uses	Container	Regular	Export and landfilling
Scenario 1 (S1-2U)	rPET 32.45% less impactful	Fast fashion	International haul	26 uses	Container	Regular	13 uses, purchased physically
Scenario 2 (S2-2U)	rPET 32.45% less impactful	Fast fashion	International haul	26 uses	Boxes	With industrial washing	13 uses, purchased physically
Scenario 2 (S2-B2C)	rPET 32.45% less impactful	Fast fashion	International haul	26 uses	Boxes	With industrial washing	13 uses, purchased website
Scenario 3 (S3-C2C)	Fiber-to-fiber recycled PET 73% less impactful	Sustainable manufacturing, 11 times less impactful than fast fashion	International haul	26 uses	N.A.	N.A.	13 uses, purchased app
Scenario 4 (S4-swapp)	Local virgin PET 15% less impactful	Sustainable manufacturing, 11 times less impactful than fast fashion	N.A.	52 uses and repair	N.A.	N.A.	26 uses, direct swapping

4. Results and analysis

4.1. Interviews discussion

The following two sections disclose the responses from eight interviewers (without S2) and their analysis supported with the literature review.

4.1.1. Two-way responsibility: producers and consumers

For the question "What is the percentage of responsibility producers and consumers share when ensuring clothing longevity?" fifty-fifty is the general response of interviewers. One of the aims of this work is to understand the role of designers and manufacturers when implementing Ecodesign strategies for product longevity. However, during these interviews and the literature review it has become evident that consumers have a significant role in ensuring a long lifespan of apparels.

In the first instance, the main aspect of textile longevity is the physical durability of materials and confection, which is well known among the field, and it is standardized for its evaluation. However, when it comes to other features, like classic designs or reusability, it is difficult to measure those with numerical means. Considering that at least half of the lifespan of garments depends on consumers, it is relevant to develop methods to measure these characteristics. Thus, more questions are generated: what criteria can be used to compare two designs and determine if one is more long-lasting than the other considering more aspects besides physical durability?

Manufacturing companies ensure physical durability of their products by choosing high-quality materials and technological processes for confectionery. For example, E1 focuses more on the importance of mechanical properties and technologies for manufacturing processes, and as E2 mentions too, designers and manufacturers are familiar with the ISO norms (Table 5) to assess durability and quality properties.

Table 5. Most common standards for durability assessment [80]

Durability characteristics	Standard used
Tensile strength: maximum stress fabrics can manage without breaking, elongation and elastic recovery.	ISO 13934-1,2
Tear strength: The tear strength indicates the force needed to propagate a previously started tear in a fabric.	ISO 13937-1, 2, 3, 4
Bursting strength: measure of the tensile strength and extensibility of knitted and elastic fabric.	ISO 13938-1, 2
Seam strength: maximum force application needed to break sewn seams. ("Fundamental textile testing: Mechanical and physical tests")	ISO 13935
Seam slippage: exposing seams to strong forces and assessing the ease of yarn distortion in the fabric.	ISO 13936 1,2,3
Abrasion resistance: the resistance to wear and holes, caused by rubbing during use.	ISO 12947-2 (2016)
Pilling is the formation of small knots on the surface of fabrics caused by wear and rubbing. Different test methods may be used.	ISO 12945-1,2,3
Dimension stability is a measure of how textiles change in length and width after being washed and dried.	ISO 5077

Color fastness properties: evaluate a material's color resistance against fading or staining under certain conditions or treatments.	List of ISOs 105

The main outcome from the interviews with C1 and C2 is their business models and the approach they have towards clothing. Even though Omniteksas also offers services to produce fashion products, their main market is workwear and sportwear. C2's company also focuses mainly on workwear and official uniforms for governmental institutions. Considering this, both have design specifications from clients they must comply with and follow their quality expectations. When it comes to this precise type of garment, standards and requirements are well established by clients, because they need to fulfill a specific function. This illustrates how "brands" can demand high quality services and materials from their suppliers. However, in the fashion industry, this is not always the case because, sometimes, companies choose to attract consumers' attention with competitive prices over durability or sustainability.

On the other hand, brands have the responsibility to add or to create emotional attachment through their designs: the shape, colors, or logos they decide to implement. As stated by C1 and C2 during the interviews, clients have the final decision on design matters, and they only comply as service providers. Also, it is important to add symbols to build relationships between, for example, the consumer and their heritage.

E3 mentions how Fashion forecasting plays a crucial part in garments longevity: forecasting months before with innovative designs and fabrics may lead to an incorrect approach for the current market, causing many products not to be sold. ZARA´s example, from INDETEX, they have the capability to collect and analyze vast amounts of data to renew their designs every two weeks [81]. Social media and artificial intelligence also have a crucial role in this task currently.

Sustainability and circular strategies are becoming increasingly important in manufacturing processes but implementing these may be harder than expected. E3 states this is a long discussion due to its complexity, but specifically talking from a business perspective, it is not easy since these strategies mean to consider consumers' intentions and to study if they are ready for these new products with new prices. Interviews made to experts in Europe and Australia confirm this statement, who claim that consumers prefer good looking garments over sustainable garments because they are driven by fast fashion tendencies and brands are indecisive about whether to charge more for their products in order to implement design features that increase quality and durability [82-84].

De Aguiar Hugo, De Nadae and Da Silva Lima [85] point out the current circular actions that companies have implemented so far, dividing them into three categories: reduce (raw materials, resources, chemical substances, consumption), reuse (raw material, resources and clothing) and recycling (mechanical and chemical). From this point of view, it is clearer to understand the main challenges found in their research. Challenges are divided into five main categories: market/economic (organizational and lack of importance in the design phase), institutional (lack of support to implement "ecological solutions"), social/cultural (fast fashion and lack of attention in second-hand clothing), technological, and stakeholders (difficulty of having a sustainable supply chain).

From their literature review about the obstacles in the fashion industry, Abdelmeguid, Afy-Shararah and Salonitis [86] divide their study into two main parts: hard and soft aspects. Firstly, the hard aspects are *Business Model Innovation (BMI)*, related to how fast fashion has overridden the market and sets the standards for other elements as resource efficiency, circular design, product life extension and end-of-life circularity; *regulatory pressures*, where it also mentioned the lack of government support and lack of strict regulations to implement circularity principles in the industry; *stakeholders'* *pressures,* as mentioned above, it is the necessity to align all the supply chain actors in the context of circular economy; and *financial pressures*, meaning the difficulty of having support for long-term returns such as circular business, because they are not ”profitable”.

Regarding the soft aspects, Abdelmeguid, Afy-Shararah and Salonitis [86] mention the Green Intellectual Capital, divided also in three sub-categories: *green human capital (GHC)*, referring to the lack of knowledge, skills and resources, like time or money; *green structural capital (GSC)*, as the lack of circular economy principles embedded in the organizational culture and resistance to change; and *green relational capital (GRC),* as the lack of collaboration and trust among brands, retailers and supply chain stakeholders. Finally, the second soft aspect is Customer-related issues, such as the difficulty of communicating to consumers, the importance of circular economy initiatives and managing behaviors outside companies.

Fast fashion is a remarkably successful business that takes years to replace while new business models and economic systems are built. As part of practical research, looking into the sustainability reports of different large apparel companies worldwide, Dragomir and Dumitru [51] find that the emphasis on durability differed from the fast fashion business model but supports the companies’ goal of minimizing their environmental impact across the entire value chain. As a result, companies aim to extend the lifespan of garments by collecting second-hand clothes, cleaning, repairing, reselling, or renting them.

There are studies that compile information about how companies and designers are facing upcoming challenges to adapt to more sustainable products and migrate from a linear to a circular economy. Companies which have sufficient capacity can calculate their carbon emissions and perform LCAs, facilitating their adaptation to circular practices. Some brands focus more on ***durability*** than using natural fibers, mono-materials, or biologically circular materials, because there are no alternative resources for specific products, like winter jackets, which need unique quality requirements. Thus, they expect the recycling of mixed fiber to develop further. Others may implement adaptive design strategies to extend their life use, like an extra seam to the waistbands, arms, or legs; or incorporate permanent collections, meaning, timeless designs that can be worn at any time or season [82-84, 87-89].

Karell and Niinimäki [84] confirmed that participant companies in their study have ***product longevity*** as the most important approach, focusing in two discussions: ***technical longevity*** (select high-quality materials, product structure and reparability) and ***aesthetics*** (timeless designs). However, designers may feel restricted by companies’ values and operations, and it might be difficult for them to implement sustainability into their designs. Designers are advised what material and process to use, and they lack major influence in design strategies or sourcing processes, because most of the time these decisions come from the directives [84, 88].

Despite all the effort large companies put into their brands, small companies have more difficulties implementing circular strategies such as measuring emissions, testing products or implementing recycling programs, because they lack time, resources, or capacities to do so. When it comes to prioritization, small and medium enterprises cannot comply with eco-innovations [82, 84, 90, 91]. Small companies implement durable designs attached to their brand ethos, while larger enterprises can focus on physical and technical durability [88].

In the second instance, it is needed to identify new consumers’ behaviors towards clothing and sustainability, considering that the EU Strategy for Sustainable and Circular Textiles emphasizes user education and awareness. Extending the lifespan of clothing is not only the responsibility of brands during the design phase; it also depends on consumers and how garments are used and cared for. Extending longevity of textiles is crucial to reducing fast fashion and consumer culture. Customers can enhance garments' circularity by boosting their active lifespan by following maintenance and repair guides, for example. Many brands opt to publish care instructions on their websites, focusing on, for instance, water use in cleaning. To disclose this information, brands may employ blogs, social media, labels, and catalogs [51]. The next step is to evaluate how much consumers follow these guidelines.

A Lithuanian example is the brand LeKeckas by Kestutis Lekeckas, characterized to create tailored suits for man with scrap of high-quality fabrics. Even though they work with excellent materials, D1 remarks on the importance of the buyer's care with the products. They are provided with care instructions and repair services, but it is completely up to them if they let the suits "reshape" after each use, as D1 mentions, this is one of the main strategies to guarantee the product's durability.

E1 and E3 highlight the importance of new generations being more aware of climate change and sustainability. Changing consumers' behavior is vital. People are more aware of this situation because information is easier to access than before. However, digitalization and information can be a double-edged sword because sustainability must not be seen as a temporary trend, but an actual and established parameter in our daily lives.

Particularly, a report made by the NGO WRAP reveals essential information about how United Kingdom consumers practices can reduce the ecological footprint of textiles use. For example, extending the active use of clothing by an additional nine months could lead to a reduction in carbon emissions, waste, and water use by 20–30% for each of these environmental impacts [92]. Besides the known practices for producers, the report shares that washing clothes less often (10% less), washing at a lower temperature (from 46°C to 39°C), using larger loads (0.3 kg more) and tumble-drying less in summertime (30%) can cut the carbon footprint by 7% [92]. Also, life extension by reuse and better practices for production and fiber choice can have a significant impact on decreasing ecological footprints, as shown in Fig. 19.

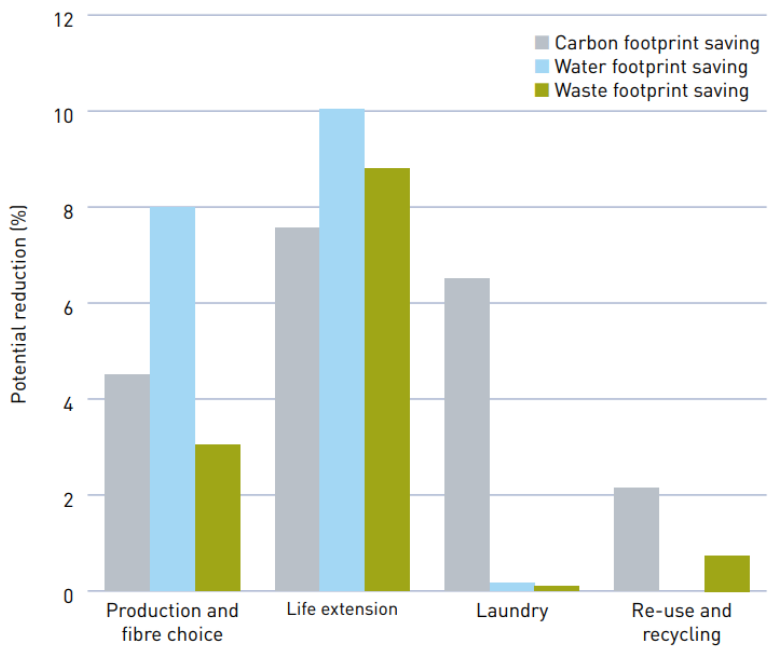


Fig. 19. Projected reductions in carbon, water and waste footprints based on implementing good practice [92]

The report made by Cooper et al. [93] covers exhaustive work with different methods to analyze design for longevity in garments. This study includes interviews with the industry representatives to understand their point of view regarding design for clothing longevity and focus groups with consumers to comprehend their perspective about products lifespan and their behavior. Their general findings are that consumers lack knowledge of how to make clothing last longer: take care of labels, repair or recycle products. Also, consumers are not aware of efficient or sustainable laundry habits, and they may vary depending on habits, traditions or priorities like time, energy, or water. However, consumers are open to having more education and information about clothing care.

An additional important finding is the relation between quality and the brand image that consumers have. This presents an opportunity that product developers must seize to ensure they meet consumers' expectations and enhance their product quality, durability, ease of care and aesthetics [93]. Wakes et al. [94] confirm through a survey that respondents expect higher-priced products to have a better quality than others and they expect to wear them more often than lower-priced garments. Also, they prove a direct relation between the price and the likeliness to read care labels and follow the instructions after purchase. However, there is still a sizable portion of respondents who do not follow these after the first wash.

The survey conducted by McNeill et al. [44] reveals that consumers' high sensitivity to fashion trends is the main motivator for purchasing and disposing of a considerable number of garments. However, emotional connection may increase the time they own products and might encourage them to repair their clothes. Thus, the authors suggest that creating this connection between products and consumers may change disposal behavior even more effectively than fashion itself and emphasize the importance of "providing support for garment maintenance (such as repair or modification upskilling)" [44, p.367].

After reviewing 217 articles, Schiaroli, Fraccascia and Dangelico [95] focus on different topics: the "pre-purchase" phase, meaning the intention to buy and everything involved before using the product; the use phase; and the post-use phase. Specifically talking about continuing wearing, the authors confirm that consumers are pressured by social factors and fashion trends to update their wardrobes very often. Regarding laundry practices in the use phase, it is stated that consumers prefer elevated temperatures and specific washing frequencies, due to habits. However, these practices vary depending on the garment type: for example, underwear and sportswear are washed more frequently due to the detection of strong odor, compared to jeans or sweaters.

Another important aspect for consumers to discard or replace an item is repairing, since most people lack these skills, they cannot do it themselves, and repair services are even more expensive than purchasing a new product. Once again, the emotional connection to a specific garment can be a motivator for the consumer to get it repaired [95]. Additionally, the third aspect of the use phase is the concept of clothing as a shared service, where many barriers and drivers are explained to be part of a collaborative fashion consumption network.

A third actor needs to come in place, and it is Governments / regional authorities. As E3 remarks, even though there are plenty of guidelines and methods created by different organizations, companies are still not sure how to implement Ecodesign requirements, for example the DPP as one of these. Coscieme et al. also mention the importance of policies to target design choices by "defining quality requirements and increasing taxation on less durable products" [49, p. 455].

Directives and Regulations, at least in the EU, need to specify what is a product of high quality and what are the values for those parameters that are expected to be met. In the latest communication from the European Commission [96], the working plan for Ecodesign for sustainable products is established, putting Textiles/Apparel in the first place of priority and recognizing the need to set Ecodesign requirements about product performance and product information (DPP) through delegated acts within the next five years.

Another key element in the EU strategy for sustainable and circular textiles is banning the destruction of unsold or returned textiles and restricting the export of textile waste. The destruction itself is already highly impactful, not only for the environment, but also for communities where products become waste and are incinerated in open air, releasing toxic substances without filtering [97]. Moreover, this practice just keeps encouraging producers to maintain the fast fashion model and consumerism culture. Fig. 20 shows the product flows for returned items, and even when there is an attempt to slow down, at the end, clothing is destroyed by incineration, recycling, or landfilling. For this reason, prohibiting the destruction of unsold or returned products can encourage brands to change the way they design and manufacture their goods [98].

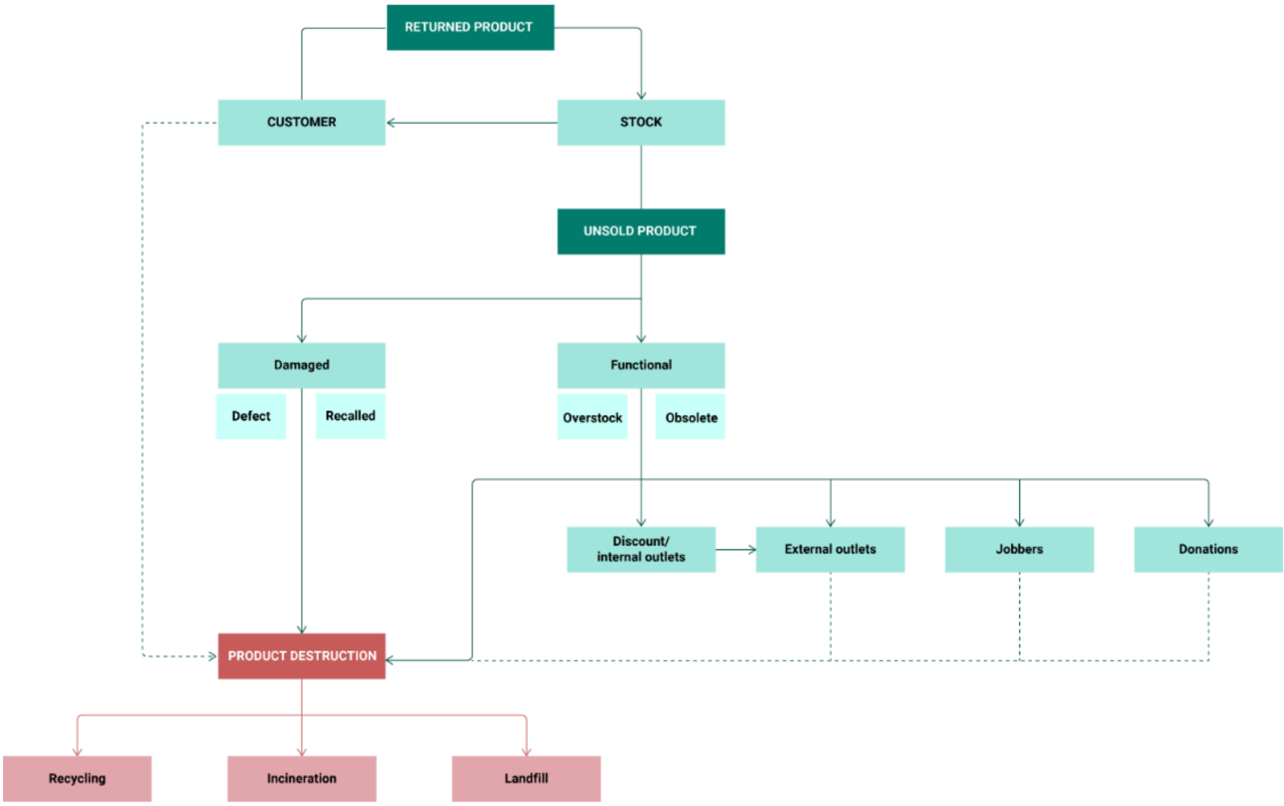


Fig. 20. Product flows for returned and unsold textiles [97]

4.1.2. The importance of Hubs and Databases in innovative supply chains

Alternatively, E3 focused on the supply chain and the responsibility each actor has within the production line. It is relevant to have an aligned understanding of sustainability in the fashion industry, to share common goals and an agenda to be able to walk in the same direction and ensure high quality and long-lasting products.

Dragomir and Dumitru [51] state that large fashion companies control and monitor their suppliers by imposing circularity policies in manufacturing processes. For example, auditing quality standards, implementing Codes of Conducts or demanding compliance with The Higg Index, which is a framework based on five tools to measure sustainability performance (social and environmental) in the apparel industry [99]. Once again, here it is visible how big enterprises have the capacity to choose and demand from their suppliers align to their sustainability goals and implement managerial tools to enhance their environmental performance in their supply chain.

Now, the previous might be particularly difficult for start-ups, small and medium enterprises, so they need wider options regarding their suppliers. **Digital hubs** are modern directories that have the potential to enhance, not only collaboration that is needed as mentioned above, but the access alternative raw materials, supplies, designers, or collaborators. This is particularly important since some brands might lack the knowledge to compare sustainability within varied materials because available sources are not open for everyone or they want to access local suppliers with competitive prices [84, 89].

An example of this is the Circular & Biobased Textiles Innovation Hub, by Textile ETP, that has multiple options for learning, networking, collaborating, and sharing information about a great variety of topics regarding circularity and alternative options in the textile industry [100]. Their high expertise in the topic requires annual subscription, making it unavailable for many people. Other instances are from NGO WRAP, which has an open-source database of over 200 textiles sorters, pre-processors, recyclers, and yarn spinners in the UK and Europe; and The Solutions Directory by Sustain20, also an open directory to find alternatives throughout the lifecycle of fashion products.

The study made by Cicconi [101] sets an example of how interactive platforms can boost collaboration and the integration of sustainability practices during the design phase, considering the whole supply chain, and closing the gap between different stakeholders like material developers, researchers, designers, manufacturers and consumers. This is done in the context of creative industries, but it can be easily replicated in other fields like the fashion industry. Hubs and databases are not new ideas, but they are not spread enough, considering that every year there are more researchers working on novelty materials and substances to replace traditional and polluting ones in the fashion industry. Hubs can spread innovation for sustainable fashion and facilitate the expansion and adoption of effective upcycling strategies [49].

An example of alternative material is the one provided by S1, a PhD candidate working on the research of natural fibers for apparel products, which is chiengora or "dog wool". S1 states this object of study comes from the need to find more sustainable natural fibers for the fashion industry and the opportunity to use "waste" from dogs´ coat. In general terms, S1 confirms this alternative shows good or even better performance compared to other fibers, and it is promising to be useful in the future as a durable material for clothing.

When asked about the perception of producers and consumers about this type of fiber, S1 confirms producers are more concerned about the quality itself, while consumers have mixed feelings: some are positive about undercoat being used instead of thrown away, while others might find it "disgusting". Again, here is present the need to educate consumers regarding fashion trends and alternative materials, as mentioned before.

4.2. Life Cycle Assessment of longevity extension scenarios

4.2.1. LCA of baseline scenario (BL)

The LCA for the baseline, in Fig. 21, shows the most significant stages for the life cycle of one polyester dress of 0.478 kg.

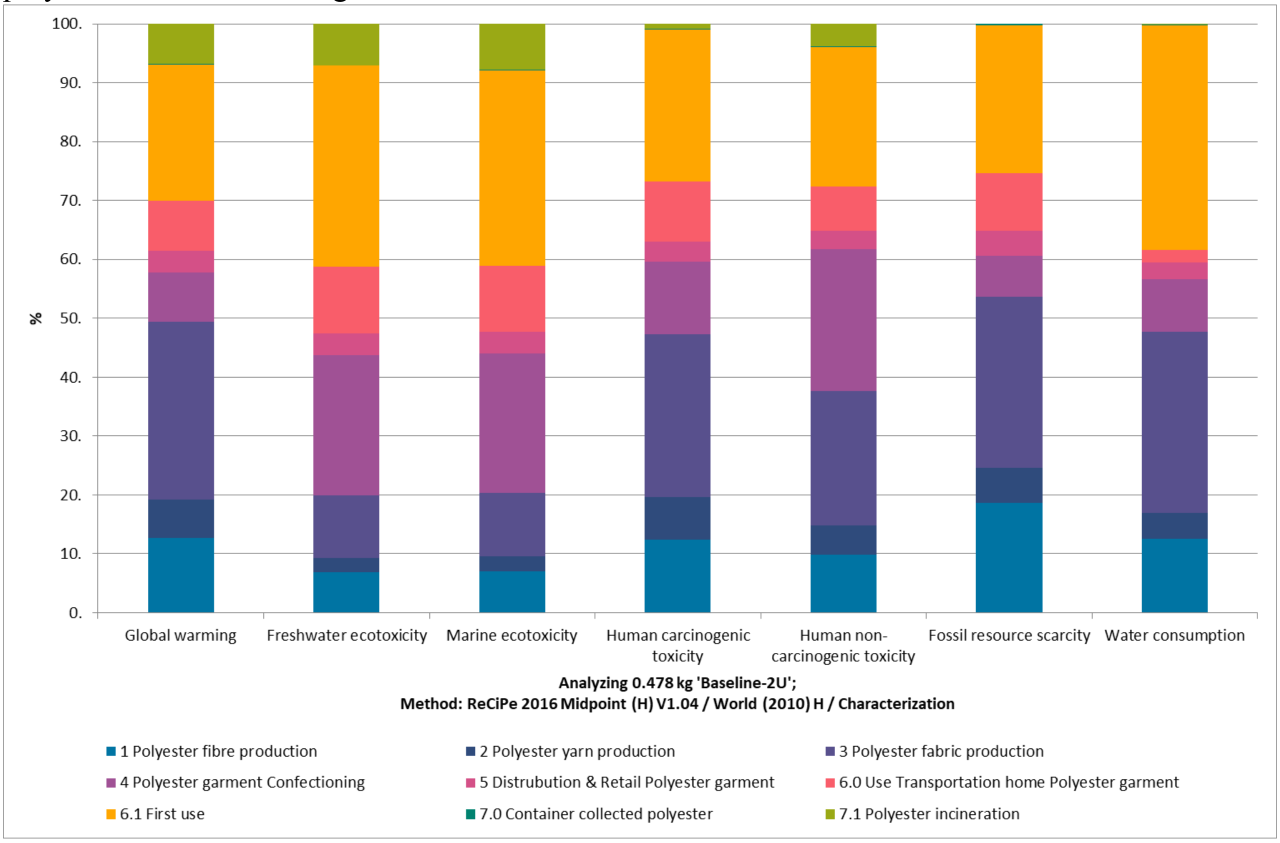


Fig. 21. Characterized LCA results for the baseline scenario

Fabric production and garment confection have a significant weight in all categories because of these are energy intensive activities and the electricity dataset selected: medium voltage, global, since it is assumed all the manufacturing process is outside the country. This aligns with the results by Sandin et al. [70], showing fiber production and confectioning as great contributors to the GWP and energy use. The other important stage is the use phase, where the washing never weights more than 50% of each impact, thus, drying and ironing are more intensive due to the Lithuanian energy mix. Even though 42% of electricity generation comes from wind, followed by hydro with 17% and solar photovoltaics with 11.5%, in 2023, 67.8% was imported [102]. The container collection is almost insignificant, while the incineration is more visible in global warming, freshwater ecotoxicity and marine ecotoxicity.

4.2.2. Scenario 0 – export

Since the baseline and scenario 0 are quite similar, the overall difference is not much. The biggest reduction is less than 7% for marine ecotoxicity, as shown in Fig. 22. Incineration is slightly more impactful than export and landfilling.

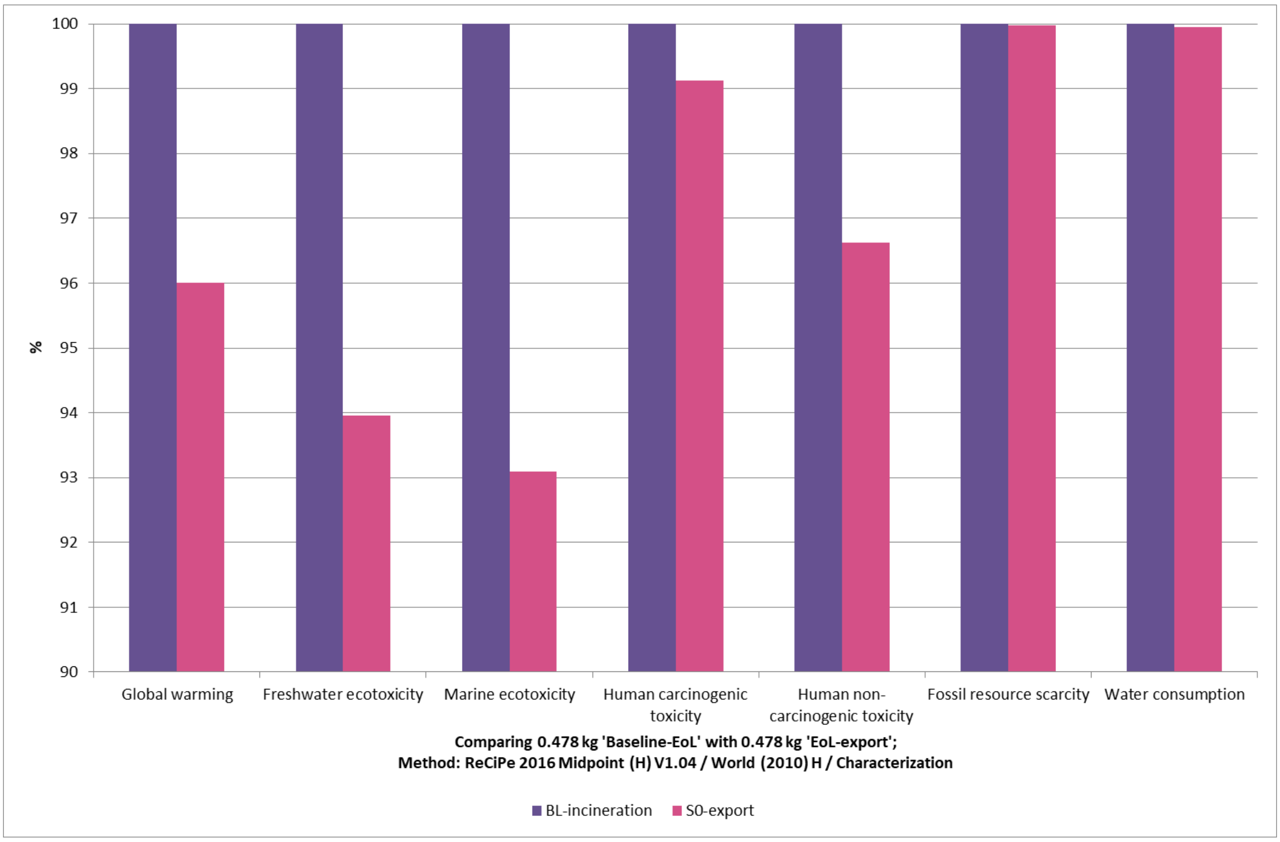


Fig. 22. Characterized comparison per category between the BL and S0

Because the only difference between the BL and S0 is EoL, Fig. 23 shows how local incineration and export for landfilling behave. Export includes transport from Vilnius to Klaipeda (port) and from Klaipeda to Pakistan by ship, and incineration itself. Even with the long-haul distance, export is still less impactful than incineration because it only considers landfilling. Other alternatives like reuse and incineration can be calculated as well for a more precise result. The EoL of clothing is outside the scope of other scenarios, but it is important to notice this is the current tendency in the European market, where a considerable percentage of used textiles is exported to countries in Africa and Asia, making its fate highly uncertain [103].

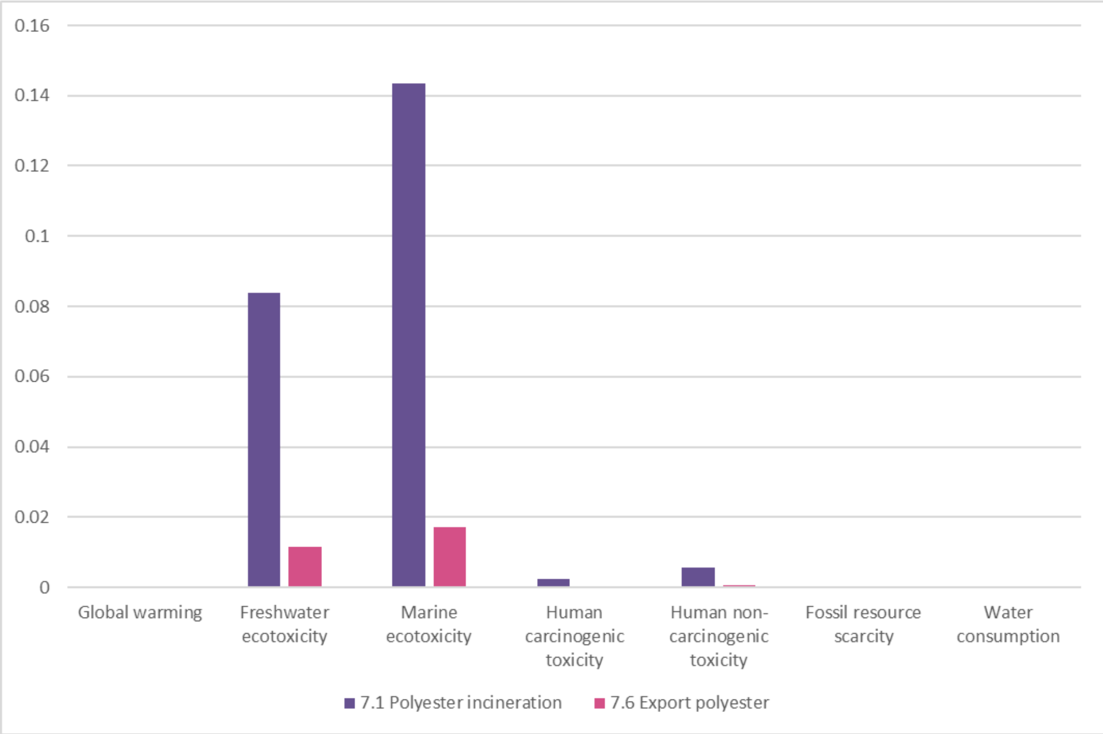


Fig. 23. Normalized comparison between local incineration and export for landfill

4.2.3. Comparison of scenarios 1 – 4

In these scenarios, different strategies for longevity extension are considered and the results vary depending on them. It is important to notice that literature review and information gathered from interviews function as a background and justification of why different variables are selected for each scenario. Fig. 24 shows the comparison between the baseline and the five scenarios exposed here.

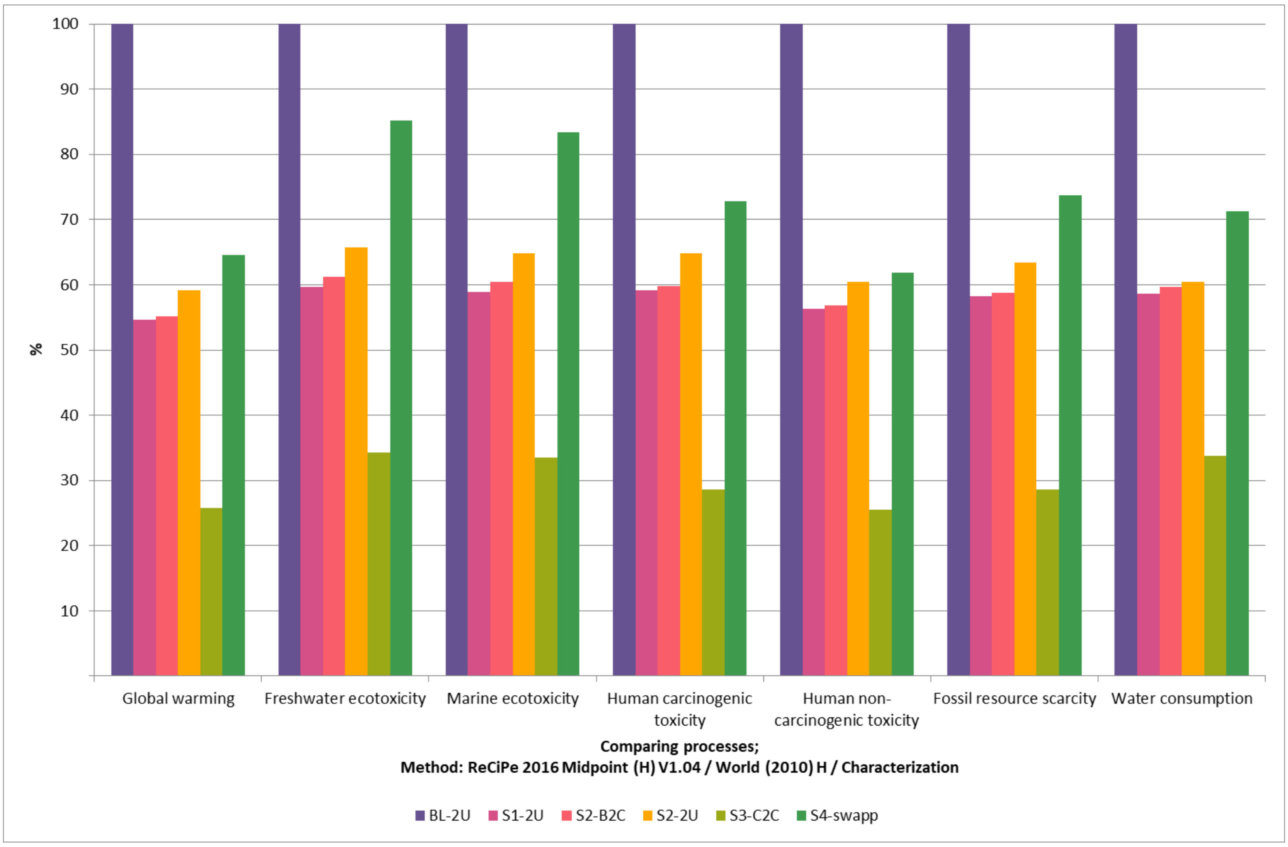


Fig. 24. Characterized LCA results by impact category and scenario

At first sight, all scenarios are lower than the BL, proving that any type of reuse is less impactful than purchasing a new garment. S1-2U, S2-2U, and S2-B2C have a similar behavior since raw materials and manufacturing are the same. Minor differences arise due to specific processes like transport (lorry 7 tons vs lorry 32 tons) and the washing in both S2. This does not increase impacts much, because it is assumed this is an industrial process that is more efficient than domestic washing.

The scenario with the least impactful performance is S3 with repurchase by a digital C2C platform, with a reduction in every category of more than 50%. The impacts decrease significantly because of the raw materials and the manufacturing process. As mentioned before, it is assumed that the fiber production stage is 73% less damaging, while the manufacturing is eleven times less than in S1 and S2, where the fast-fashion model persists. The biggest difference is in global warming, with a reduction of 74.3%.

S2-B2C is slightly higher than S1-2U because of the additional process of industrial washing, but less impactful than S2-2U, because physical purchase means consumers need to move by car or public transportation, while online purchase is counted as the delivery transport and this magnitude is lower than private vehicles.

According to Zamani, Sanding and Peters [104], environmental impacts are lower when the product life use is longer (reused as many times as possible), when it is resold online and collected from pick-up points (assuming that consumers go walking or biking). This is a similar scenario to S3, but it also considers other sustainability strategies like lower-impact materials and cleaner manufacturing processes. It explains why it is much more minor than S4.

For S3-B2C and S3-C2C, it has been used the dataset for lorry 3.5-7 metric tons because there is no data for electric delivery vehicles. If the electric passenger car dataset is used, this scenario is the most impactful due to transportation.

Both S3 and S4 consider sustainable manufacturing but S4 with swapping is significantly higher because of a more "intensive" use. However, the tailored dress with 52 laundry cycles has the same impact and two dress with 26 cycles each. If it is assumed to be the same fraction of time for both cases, only the first option generates more waste. Also, if all scenarios have the same raw materials, manufacturing process and distribution, the main difference is in the use phase and EoL and, thus, direct swapping is the best option to reduce the environmental impact of the garment. Sandin et al. [70] prove how wearing twice any of the studied garments can reduce almost by half climate change, energy use and water scarcity. In this study, only S4 contemplated doubling the number of wears, so more comparisons can be made with other scenarios consider this variable as well. Also, they confirm how a combination of different strategies through the whole life cycle can reduce the environmental impact up to 78%, considering double use, solar-power production and walking to the store.

Fig. 25 below shows the single scores for each scenario, based on the weighting factors of Sala et al. [73]. The most significant impact in all cases is Freshwater ecotoxicity, followed by the other assessed toxicities. According to the data and the analysis of the program, this is due to the highly intensive energy processes during the manufacturing, specifically, the fabric production and the garment confectioning. Weighting highlights the large amount of chemicals used and released during the life cycle and the need to rethink processes and the substances used in these. Since this aspect weighs more than 50% in each scenario it is necessary to make a new revision in the inputs of the data and the weighting scores used for this study, because the marine ecotoxicity is not included in those. This approach has scores with and without toxicity categories (human toxicity and freshwater ecotoxicity) because the Environmental Footprint (EF) method proposed by the EU do not consider those categories robust enough to be communicated externally or aggregated in a single score. This can be the reason why other ecotoxicity impacts from the ReCiPe method (marine and terrestrial) are not included in the EF.

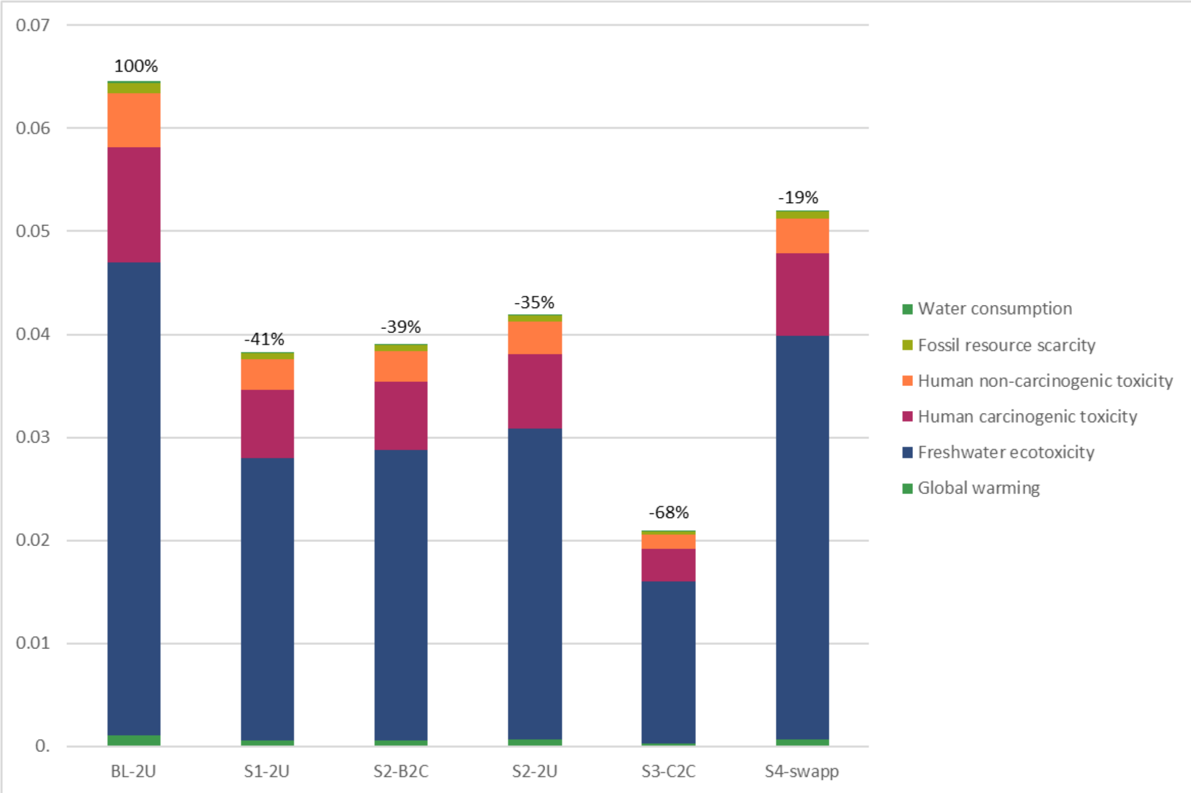


Fig. 25. Weighted categories according to Sala et al. approach [73]

The study made by Trzepacz et al. [105], also selects collection, sorting and transportation to evaluate the environmental impact of a reused polyester t-shirt (52 wears = 52 washing cycles) sold in Pakistan compared to a new product made in Asia and sold in Pakistan. The sorting process includes allocation for incineration and landfilling of "discarded" products, while EoL is divided between landfilling and incineration equally. The environmental impacts only include Global Warming Potential (IPCC) and User deprivation potential (deprivation-weighted water consumption) (AWARE). From the three activities analyzed, international transport is the most impactful (0.0594 kg CO_2 eq), followed by the transport to sorting (0.023 kg CO_2 eq) and finally the sorting itself (0.0033 kg CO_2 eq). Results from this study also show higher environmental impact from the export process (0.595 kg CO_2 eq) than collection and sorting (0.0347 kg CO_2 eq).

On the other hand, Schmidt et al.[106] model 1 kg of polyester reused locally and internationally. The first scenario considers incineration as EoL, while the second one considers landfilling. The finals scores are presented in Person equivalent per ton. Regarding a qualitative comparison, both reuse in the Nordic region and RoW are remarkably close, RoW being slightly more impactful. The difference with this study relies on the fact there is no reuse in the BL and S0, while scenarios 1-4 do not have EoL at all.

Horn et al. [68] demonstrate the environmental impact of a polyester t-shirt, considering two hundred uses (150 washing cycles) and incineration as EoL for the base line. For the comparative scenarios, the first one considers recycled PET as raw material, and the second one considers local reuse (four hundred uses) with EoL. Local reuse decreases environmental impact by 18%, while using recycled PET only 9%; logically, the reuse of an rPET polyester t-shirt is 27% less impactful than the baseline. The most significant impacts are global warming and resource depletion, due to the fabric production and the use phase, which is intensive because of the number of uses and the resources needed for washing and drying. In this study, the reuse of the rPET polyester dress decreased the impact between 35 and 39%.

Previous studies show how experts have been studying the life cycle of textiles and clothing in the EU and abroad. Both Trzepacz et al. and Schmidt et al. consider varied materials and other EoL paths such as recycling. However, it is difficult to find integral research that studies multiple variables throughout the life cycle specifically regarding longevity extension. Even though Horn et al. [68], contemplate different circular strategies, such as using rPET, reuse and recycling as EoL, and Zamani et al. [104] consider various reuse scenarios, there is still missing research focusing on design approaches and consumers' behavior (different than the laundry habits). Usually, consumers' transportation is not included in studies, because laundry is given more importance, when, in reality, transport can have a bigger GWP [104].

For example, repair services may not be particularly impactful themselves but encouraging consumers to learn how to repair their own garments can decrease the necessity of transportation for this activity and extend the use life of garments, preventing purchasing new ones. Thus, the avoided impacts might be quantified. Also, it is worth mentioning that studies vary significantly due to geographical contexts; in Sweden, for instance, laundry may have relative low contribution to GWP, because their energy mix is composed by nuclear power, hydroelectricity and wind, and drying machines are not used as often as elsewhere [104].

4.3. DPP as an integral solution tool

Educating consumers is necessary to ensure longevity extension of fashion products, as most interviewers agreed, consumers have a critical role in the lifespan of clothing, depending on the care given to it. Providing accurate and pertinent information is one of the objectives of the upcoming DPP. This tool is expected to improve sustainability throughout the whole life cycle of textile products, by showing the environmental impacts of each stage, including the use phase. Specifically for clothing, DPP shall disclose information about sustainable laundry practices and repair instructions when needed.

Implementing the DPP can be difficult for companies for several reasons. E3 highlights there is still no specific way to do this and there is not much information about potential costs. It is needed to have more guidance and instructions about this. Companies are willing to implement the DPP, if there is the necessary support to follow the required steps [107]. Even though large retailers already use different instruments like social media to increase the transparency of their value chain, DPP should **standardize** the way all pertinent agents disclose the required information. The report made by TrusTrace [108] confirms the need for standardized processes of different subjects like data, collection, management, and disclosure. Having basic guidelines allows data transferability through all stakeholders and assures better traceability in the value chain.

The same report [108] gives a prototype of how the DPP can be developed, taking as examples the companies Kappahl and Marimekko. It suggests a Data protocol for companies to implement, due to the lack of guidelines provided by the EU and reassures the need for collaboration within actors of the value chain. From an overview of the DPP, it looks easy to read with simple information for the consumer to understand (Fig. 26). This is only a prototype, but it is a good point to start. Materials and Care data are similar to what is already disclosed to consumers, so it is necessary to have more specific data about the materials and components, like their origin.

Also, to mention social sustainability and responsible sources can go under the Compliance title. In this example, it gives instructions about the take-back service provided by the company and URL to follow repair instructions. However, it can also be mentioned whether the company provides repair services and where they are located. For instance, H&M is a large fashion company that only offers repair services in four of the dozens of countries where it operates. The Supply chain headline provides information about upstream traceability, so in the same way, there can be a different headline for the downstream traceability: where it is purchased and where it goes after the first user discards it.

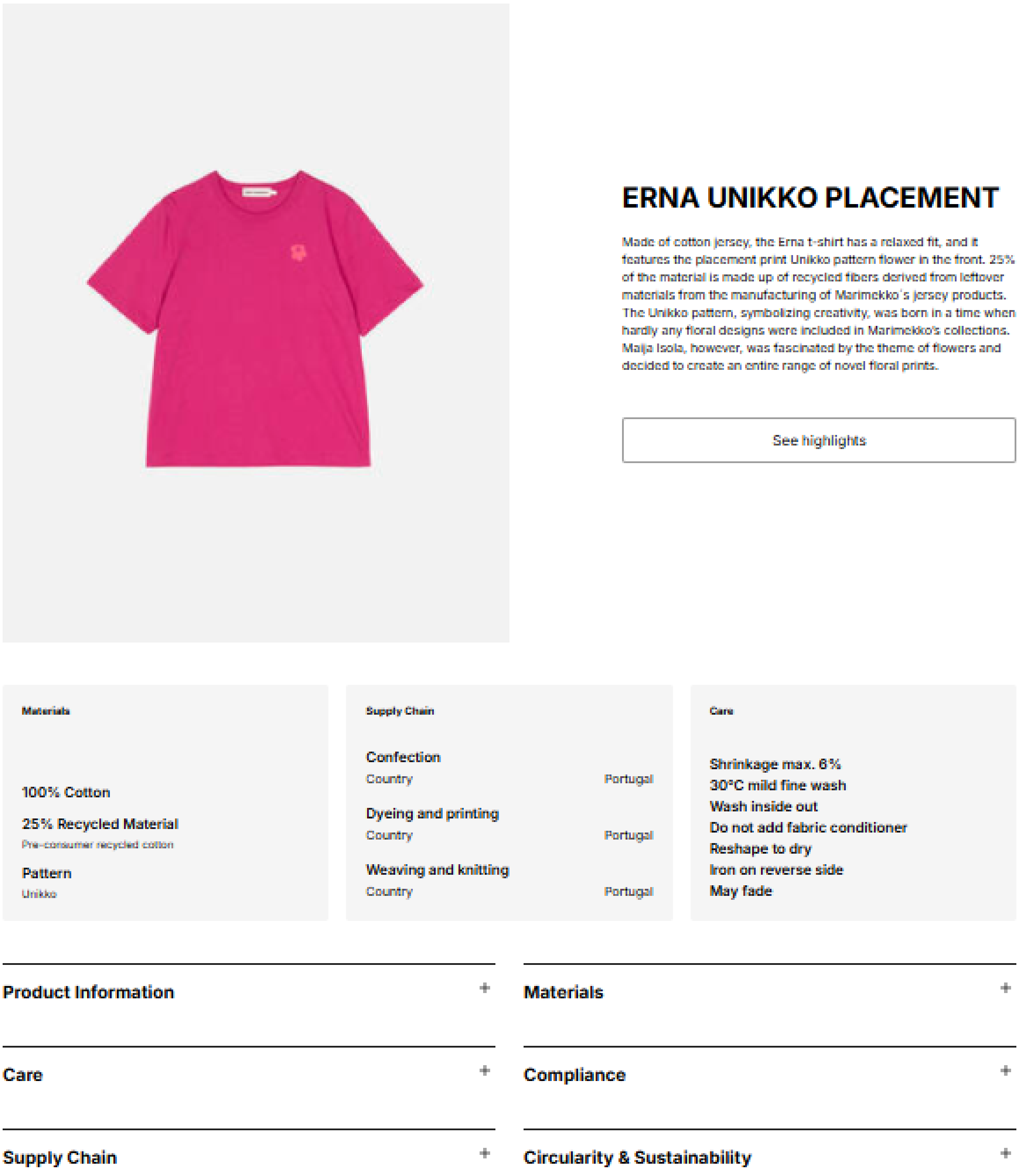
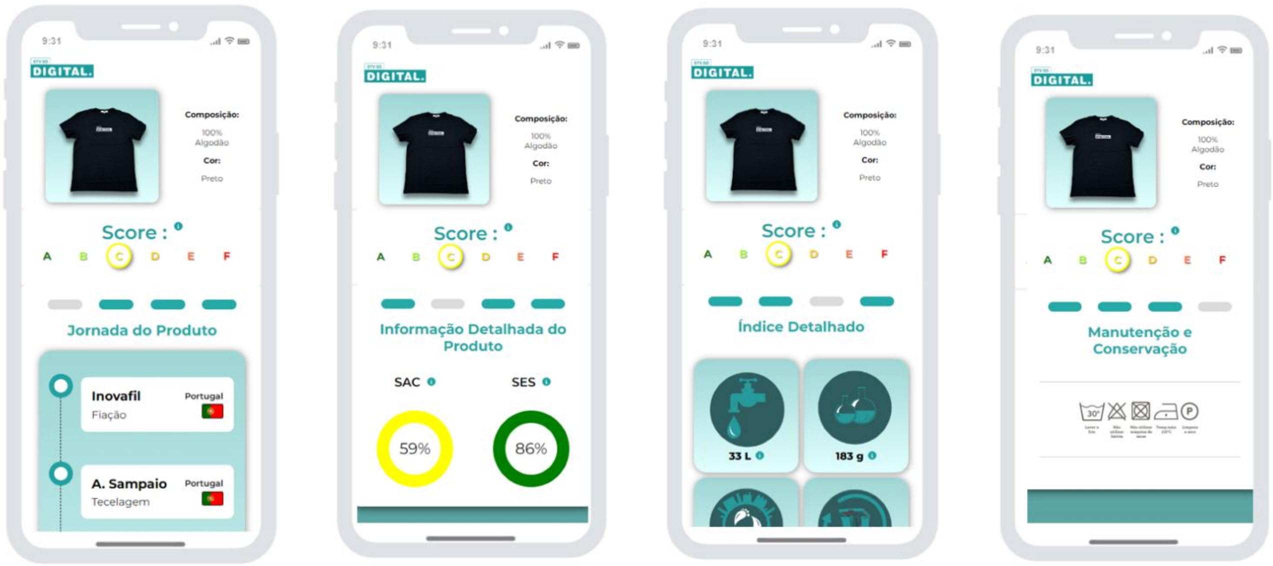


Fig. 26. Information available for the DPP prototype [108]

Alves et al. [109] deliver a more integral proposal for a traceability platform, based on blockchains. They consider multiple environmental, circular, social, and economic indicators through the value chain to estimate the impact of textiles and clothing. The prototype shows easiness to add the information by the stakeholders and to access via a QR code. The user interface shows the journey of the product, meaning the countries it has been to be manufactured and delivered, the detailed information, the detailed index (performance indicators) and maintenance instructions (Fig. 27). E1, E2 and E4 mentioned the importance of mechanical properties and the quality material and in this example, quality control standards are used as environmental indicators, showing how they can be pondered in a single score, giving more detailed information to consumers.



(a) (b) (c) (d)

Fig. 27. Traceability app interface for users, including product journey, product specifications, detailed index and maintenance [109]

Legardeur and Ospital [110] list eleven potential categories for the DPP and one of them is Tracking and tracing after sales, which focuses on sales, modifications and services after products are put in the market. Only here is suggested that customers record data about the conditions and alterations of the item, like if it has been shortened or personalized, for resale, repair, or maintenance purposes. Since the DPP can be a large cloud-based platform, it allows it to be updated automatically by stakeholders. This also opens the possibility for users to submit information, for example, laundry habits, frequency, and other specifications. Another potential feature is not only mentioning the nature of used materials, but explaining the importance of alternative materials, for example, fiber-to-fiber recycled fabrics or natural fibers substitutes, like chiengora, researched by S1.

Both examples disclosed here prove the need to implement traceability after purchase, to better understand textiles flows and their environmental impacts, considering the first purchaser not as the final consumer and that CBMs aim to prolong the intrinsic value of clothing.

DPP has the potential to trace flows and dates when products are sent to retailers, then sold to consumers and sold to second-hand stores, or sent to final disposal, for instance. Fig. 28 exposes a Material flow of how products behave through their life use, considering more aspects besides washing and drying processes. There is a first cycle when a garment leaves the retailer store to be used by the first user. After some time, the user discards it and it is collected in separate ways: textile containers, mixed waste, third parties, others. There is a sorting process after the product leaves the first user, so it can be sent to its second destination. The Distribution options are reuse in local market, export for reuse, recycling and downcycling [25]. If the product does not meet the requirements for any of the possibilities mentioned, it is incinerated in its final stage. These cycles might repeat N times until the item is discarded for incineration.

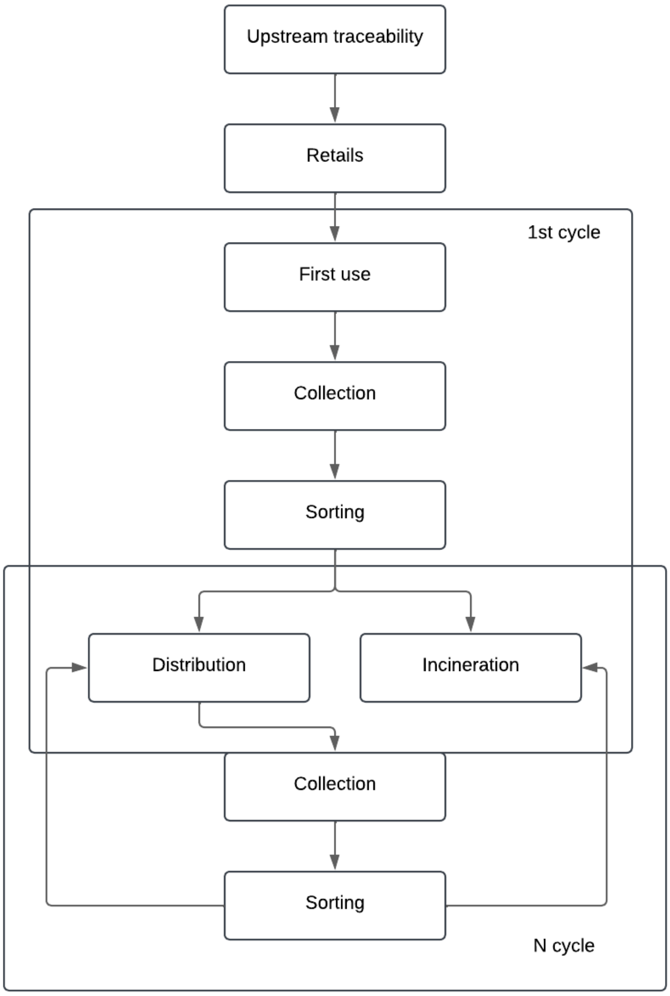


Fig. 28. Clothing flow model for traceability with the DPP

According to the ERSP, each product will have a "unique product identifier" that can facilitate traceability after its purchase. Gathering life use data throughout the clothing flows of Fig. 28 can help map the actual routes garments take after their purchase and have a better view of the real scenario. Moreover, understanding how many months or years are worn each type of garment can help better identify consumers' practices and propose solutions to tackle this problem from a distinct perspective. For example, having an exact number of months for life use is decisive to perform more accurate environmental assessments, such as LCAs. Also, the resulting mapping may lead to discovering other impacts during the use phase, besides water and energy use, such as the underestimated effect of transportation because, as mentioned above, there are exporters and importers countries of second-hand clothing, meaning there are different carbon footprints depending on the region and their energy mix.

DPP can quantify and help to calculate the complexity of the use phase and, hypothetically, allow the extrapolation of data regarding the number of wears or washing cycles. Currently, data collection is challenging, and it is done through questionnaire surveys, diary studies, wardrobe audits, interviews, focus groups, among others [61]. This implies direct contact with consumers and bias, which makes it unviable on a larger scale, where information is generalized or assumed. Data can be collected automatically and directly from users, as Legardeur and Ospital suggest in their report [110], DPP may have an option for users to provide, not only feedback, but information about their laundry habits. This can give better insights into their behavior towards several types of garments, fabrics or even colors.

It is important to notice in this section that DPP is outside the scope of the interviews made, so their contributions are limited. However, this topic can be developed further with additional insights from experts.

4.4. Summary of results

The research question "How strategies for clothing longevity extension based on Circular Economy, Ecodesign and Traceability can influence the environmental impact of a garment through the value chain?" has been address in two main parts. The first one has been identifying said strategies. Table 6 lists those strategies based on the most relevant life cycle stages. Regulators are the rule-setters, so their influence is noticeable in all phases.

Table 6. Matrix of strategies for longevity extension, based on the interaction between stakeholders and life cycle stages

	Designers	**Producers and retailers**	**Consumers**	**Regulators**
Raw materials	Physical durability: 1.High quality materials. 2.Alternative materials.	9.Transparent and sustainable supply chains. 10.Investment in research for alternative materials.	Education through: 19.DPP. 20.Awareness of responsible consumption.	28.Providing detailed standards for Ecodesign and 29.DPP requirements. 30.Provide economic aids/incentives for circularity implementation.
Manufacturing	3.Construction standards.	11.Testing methods. 12.Investment in efficient technologies.	Education through: -DPP. -Awareness of responsible consumption.	
Use	4.Timeless fashion designs. 5.Emotional attachment. 6.Adaptability. 7.Repairability. 8.Care/repair instructions.	13.Forecasting. 14.EPR. CMBs: 15.Take-back programs. 16.Repair services. 17.Product warranty. 18.Availability of spare parts.	21.Emotional attachment. Education through: -DPP. -Awareness raising on responsible consumption. 22.Care/repair instructions. 23.Laundry habits. CBM: 24.Sharing. 25.Swapping. 26.Re-selling. 27.C2C platforms.	

To summarize the strategies that manufacturers and brands may implement to extend life use of their products, a checklist is made based on Fig. 4, considering aspects of Ecodesign, Circularity and Traceability (Table 7). This is intended to be a potential tool that companies consider when designing and producing new long-lasting garments.

Table 7. Checklist for the companies within the textile value chain to ensure longevity extension of apparel

Durability	Physical durability	1.Do these materials comply with durability standards?
		2.Are these certified materials?
		3.Are these solid assembly solutions?
		4.What is the lowest possible number of parts?
		5.Is there access to hubs/data bases to find more durable materials?
		6.Do suppliers have more durable options?

		7.Does the supply chain align with durability goals?
	Timeless designs	8.Classic silhouettes
		9.Neutral colors
	Emotional durability	11.Is personalization a service that can be provided?
		12.Is it possible to collaborate with third parties to have limited edition collections?
		13.What is the purpose of this product?
		14.What is the story the product tells?
		15.What is the origin of this product?
		16.Does the price really reflect the work and quality of this product?
		17.How can customers become loyal to the brand?
Extended use	Adaptation	19.Can this design be modular for separate occasions or weathers?
		20.Can this product be used in varied sizes?
		21.Can this product be used by different genders?
		22.Is this product adjustable?
	Reuse	23.Is there a take-back program?
		24.Is there a second-hand program?
		25.Is there a rental program?
Maintenance	Laundry habits	26.What are the laundry specifications?
		27.Is there something else customers need to know, besides the label?
	Care instructions	28.Are care and maintenance instructions provided?
	Reparability	29.Is there a warranty program?
		30.Is it easy to access the parts in case of repair?
		31.Are repair services accessible for users?
		32.Are repair instructions provided?
		33.Are spare parts and accessories available in case of repair?
		34.Is it possible to collaborate with third parties to provide these services?

Now, the second part of the research question has been addressed through the LCA to quantitatively calculate and compare different life cycle scenarios of a polyester dress, considering various strategies to extend its longevity. The strategies have been identified according to literature review and interviews with textile industry experts. Among the identified, there are Ecodesign, CBMs and traceability strategies, highlighting the importance of different actors such as the producers, consumers, and regulators. LCA is chosen because it is an integral tool of analysis, used worldwide to study the environmental impacts of a specific product or service. In the baseline, fiber production, garment confectioning and the use phase are the most impactful in all assessed impacts, with a weight over 60%. All scenarios show a decrease in the environmental impact compared to the baseline, but scenario 3, with fiber-to-fiber recycled PET, sustainable manufacturing, and reuse through re-selling in a C2C platform, is the least impactful of all scenarios, with a reduction of 68%. Different variables may be altered in the LCAs, like the material, number of uses, or the path of reuse, to create new scenarios and estimate which options are more or less critical.

To make a more accurate analysis, additional data is needed for the sustainable manufacturing, rPET and fiber-to-fiber recycled PET. Several assumptions are made for the collection and sorting in Lithuania since it differs in every region. The results shown here are a general picture of textile sustainability, and it is important to notice that there is no allocation, sensitivity analysis or avoided processes included in these LCAs, making these future considerations for a deeper study. Also, other impact categories can be used, like the remaining ones from the ReCiPe method, water scarcity or Cumulative Exergy Demand. Considering other impact categories might also change the single score, depending on the weighting approach selected. According to Sala et al. [73], there are other categories more meaningful than the toxicity ones, such as ozone depletion and particulate matter, but these have not been used in this study.

Additionally, there are some Ecodesign aspects like the emotional attachment or aesthetics that cannot be evaluated in a LCA easily. Hence, further brand and product oriented environmental analysis is needed, since it has been proved how these qualitative factors might affect significantly clothing life use.

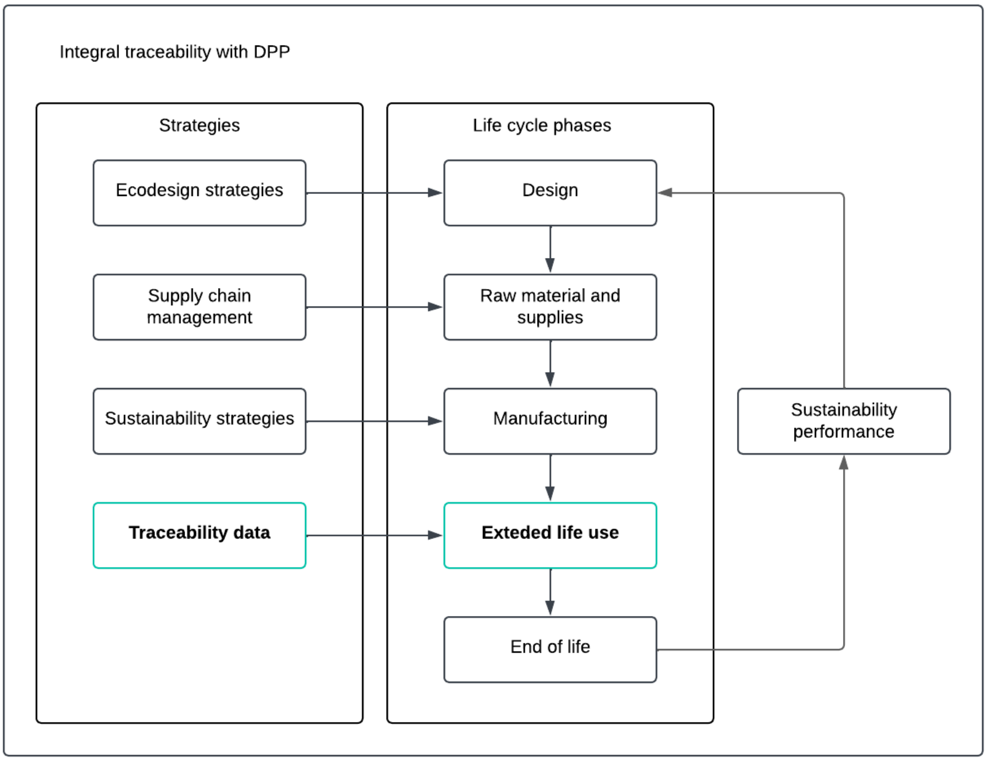


Fig. 29. Developed model for management and environmental assessment of clothing

Finally, Fig. 29 exposes how environmental management and assessment of clothing can be enhanced with traceability data provided by the DPP. This figure contemplates all stakeholders explicitly or implicitly and a continuous improvement in the sustainability performance. Different strategies influence each life cycle phase and alter the environmental impacts of a product. Implementing Ecodesign, Circular Economy and Traceability strategies can extend garments' durability, slowing down their discard and, thus, decreasing their environmental impact.

Conclusions

1. This work focuses on two main topics: identifying strategies for longevity extension in fashion garments throughout the value chain and discussing the gap in the downstream traceability.
2. Based on literature review and interviews with experts, longevity extension can be ensured with thirty strategies identified among the value chain, starting from the design phase, the manufacturing process and the use phase, where this is conceived as all possible uses by different consumers. In the same way, garments' lifespan is beyond producers' scope, and it goes to the consumers' behavior and other factors like policies and education.
3. This work evaluates the environmental impacts of different life cycles scenarios for a polyester dress in Lithuania by performing an LCA, considering different strategies for longevity extension that may vary significantly the environmental performance. However, LCAs prove themselves to not be completely accurate due to lack of data in the use phase and it is proposed to use the DPP as a tool to fill this gap.
4. From the LCA, in the base line, fiber production, garment confectioning and the use phase are the most impactful stages in all assessed impacts, with a weight over 60%. Even though all scenarios show a decrease in the environmental impact, S3 with fiber-to-fiber recycled PET, sustainable manufacturing, and reuse through re-selling in a C2C platform shows the lowest reduction in 68%. After weighting, freshwater ecotoxicity is the most significant one, with over 50% in each scenario, highlighting the large amount of chemicals used and released during the life cycle of garments.
5. Digital Product Passport is an upcoming tool useful for all stakeholders in the value chain of textile products, and it can be the key to filling the gap in the downstream traceability to gather precise data and perform more accurate sustainable evaluations for clothing in the future.
6. Thirty-four guiding questions for companies are mentioned in a checklist, oriented to longevity extension by the strategies identified during this work. Also, here is remarked the importance of consumers' education to ensure longer lifespans from their behavior.
7. Further research is necessary to have a deeper and more integral analysis of clothing longevity extension.

List of references

1. European Commission. EU Strategy for Sustainable and Circular Textiles. 2025 [Accessed 11 February 2025]. Available from: https://environment.ec.europa.eu/strategy/textiles-strategy_en
2. European Commission. Ecodesign for Sustainable Products Regulation. [Accessed 9 April 2025]. Available from: https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en
3. European Commission. The European Green Deal. 2021 [Accessed 11 February 2025]. Available from: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
4. European Commission. Circular Economy Action Plan. [Accessed 11 February 2025]. Available from: https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en
5. European Commission. Waste Framework Directive. [Accessed 11 April 2025]. Available from: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en
6. Press European Commission. Circular Economy for Textiles. 2023 [Accessed 24 May 2025]. Available from: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_3635
7. Ellen MacArthur Foundation. Pushing the Boundaries of EPR Policy for Textiles. 2024 [Accessed 24 May 2025]. Available from: https://www.ellenmacarthurfoundation.org/epr-policy-for-textiles
8. European Commission. REACH Regulation. 2025 [Accessed 24 May 2025]. Available from: https://environment.ec.europa.eu/topics/chemicals/reach-regulation_en
9. European Commission. Directive on Repair of Goods. 2023 [Accessed 24 May 2025]. Available from: https://commission.europa.eu/law/law-topic/consumer-protection-law/directive-repair-goods_en
10. EU. Directive EU 2024/825 of the European Parliament and of the Council. Official Journal of the European Union, 2024 28 February [Accessed 24 May 2025]. Available from: https://eur-lex.europa.eu/eli/dir/2024/825/oj/eng.
11. Textile Exchange. The Life Cycle Assessment of Organic Cotton Fiber. 2014 [Accessed 5 May 2025]. Available from: https://www.ajsosteniblebcn.cat/the-life-cycle-assessment-of-organic-cotton-fiber_38172.pdf
12. EDIRISINGHE, L. G. L. M.; DE ALWIS, A. A. P. and WIJAYASUNDARA, M. Sustainable circular practices in the textile product life cycle: A comprehensive approach to environmental impact mitigation. Environmental Challenges, vol. 16 (2024), pp. 100985 [Accessed 22 December 2024]. Available from: https://doi.org/10.1016/j.envc.2024.100985
13. ISLAM, M. M.; PERRY, P. and GILL, S. Mapping environmentally sustainable practices in textiles, apparel and fashion industries: a systematic literature review. Journal of Fashion Marketing and Management: An International Journal, vol. 25 (2021), no. 2, pp. 331–353. Available from: https://doi.org/10.1108/JFMM-07-2020-0130
14. PAPAMICHAEL, I.; CHATZIPARASKEVA, G.; VOUKKALI, I.; JOSE, N. P.; JEGUIRIM, M., et al. The perception of circular economy in the framework of fashion industry. Waste Manag Res, vol. 41 (2023), no. 2, pp. 251–263. Available from: https://doi.org/10.1177/0734242X221126435
15. RAJ, A.; CHOWDHURY, A. and ALI, S. W. Green chemistry: its opportunities and challenges in colouration and chemical finishing of textiles. Sustainable Chemistry and Pharmacy, vol. 27 (2022), pp. 100689 [Accessed 25 May 2025]. Available from: https://doi.org/10.1016/j.scp.2022.100689

16. McKinsey & Company. The State of Fashion. 2022 [Accessed 17 September 2024]. Available from: https://www.mckinsey.com/~/media/mckinsey/industries/retail/our%20insights/state%20of%20fashion/2022/the-state-of-fashion-2022.pdf
17. MAZZITELLI, M.; PAPILE, F. and DEL CURTO, B. Materials selection and fashion design: strengthening reflections on fibre's nature in fibres and textiles selection. Discover Sustainability, vol. 5 (2024), no. 1, pp. 180. Available from: https://doi.org/10.1007/s43621-024-00294-3
18. WRAP. Circular Design Toolkit for Fashion and Textiles. 2023 [Accessed 8 January 2025]. Available from: https://www.wrap.ngo/sites/default/files/2023-10/WRAP_Design_for_Circularity_Toolkit.pdf
19. COBBING, M. and VICAIRE, Y. Fashion at the Crossroads. 2017 [Accessed 8 January 2025]. Available from: https://www.greenpeace.org/static/planet4-international-stateless/2017/09/de596c1d-fashion-at-the-crossroads-overview.pdf
20. NAYAK, R.; GEORGE, M. and ULHAQ, I. Traditional Fashion and Textile Supply Chain: Concept to Consumer. In: Lean Supply Chain Management in Fashion and Textile Industry, pp. 1–30. NAYAK, Rajkishore ed., Singapore: Springer Nature Singapore, 2022
21. World Trade Organization. World Trade Statistical Review 2023. 2023 [Accessed 10 March 2025]. Available from: https://www.wto.org/english/res_e/booksp_e/wtsr_2023_e.pdf
22. European Environment Agency. Textiles and the Environment: The Role of Design in Europe's Circular Economy. 2022 [Accessed 10 March 2025]. Available from: https://www.eea.europa.eu/publications/textiles-and-the-environment-the/textiles-and-the-environment-the
23. European Environment Agency. Management of used and Waste Textiles in Europe's Circular Economy. 2024 [Accessed 10 March 2025]. Available from: https://www.eea.europa.eu/publications/management-of-used-and-waste-textiles
24. European Environment Agency. Waste Prevention Country Profile Lithuania. 2023 [Accessed 10 March 2025]. Available from: https://www.eea.europa.eu/themes/waste/waste-prevention/countries/2023-waste-prevention-country-fact-sheets/lithuania_waste_prevention_2023
25. WATSON, D.; HVASS, K. K.; MOORA, H. and MARTIN, K. Post-Consumer Textile Circularity in the Baltic Countries: Current Status and Recommendations for the Future. Nordic Council of Ministers. 2020 [Accessed 10 March 2025]. Available from: https://www.norden.org/en/publication/post-consumer-textile-circularity-baltic-countries
26. Kauno miesto savivaldybės tarybos. Kauno Miesto Savivaldybės Atliekų Prevencijos Ir Tvarkymo 2021-2027 M. Planas. Kaunas: 2023. Available from: https://www.kaunas.lt/wp-content/uploads/sites/13/2023/10/KAUNO-MIESTO-SAVIVALDYBES-ATLIEKU-PREVENCIJOS-IR-TVARKYMO-2021-2027-M.-PLANAS.pdf
27. MACARTHUR, F. E. Towards the Circular Economy Vol. 1: An Economic and Business Rationale for an Accelerated Transition. 2013. 1 January2013 [Accessed 30 April 2025]. Available from: https://www.ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an
28. KIRCHHERR, J.; REIKE, D. and HEKKERT, M. Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, vol. 127 (2017), pp. 221–232. Available from: https://doi.org/10.1016/j.resconrec.2017.09.005
29. POTTING, J.; HEKKERT, M. P.; WORRELL, E. and HANEMAAIJER, A. Circular Economy: Measuring Innovation in the Product Chain. PBL publishers. 2017 [Accessed 30 April 2025].

Available from: https://www.pbl.nl/uploads/default/downloads/pbl-2016-circular-economy-measuring-innovation-in-product-chains-2544.pdf
30. RATHINAMOORTHY, R. 2 - Circular fashion. In: Circular Economy in Textiles and Apparel, pp. 13–48. MUTHU, Subramanian Senthilkannan ed., Woodhead Publishing, 2019
31. SHAFQAT, Ali R. and SACCAVINI, A. Eco-design of Textiles. In: Circularity in Textiles, pp. 39–58BATOOL, Syeda Rubab; AHMAD, Sheraz; NAWAB, Yasir and HUSSAIN, Muzzamal. Cham: Springer Nature Switzerland, 2023 Available from: https://doi.org/10.1007/978-3-031-49479-6_3.
32. EU. Regulation 2024/1781 of the European Parliament and of the Council. Official Journal of the European Union, 2024 [Accessed 22 January 2025]. Available from: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32024R1781.
33. International Organization for Standardization. ISO 14006:2020 Environmental Management Systems — Guidelines for Incorporating Ecodesign. , 2020
34. JOCHAMOWITZ YRIBERRY, M. and JOCHAMOWITZ YRIBERRY, S. The role of ecodesign in circular economy to improve the performance of enterprises in the fashion industry: a systematic review of literature. International Journal of Environmental Sustainability, vol. 2 (2023), no. 19, pp. 43–74. Available from: https://doi.org/10.18848/2325-1077/CGP/v19i02/43-74
35. HARSANTO, B.; PRIMIANA, I.; SARASI, V. and SATYAKTI, Y. Sustainability Innovation in the Textile Industry: A Systematic Review. Sustainability, vol. 15 (2023), no. 2. Available from: https://doi.org/10.3390/su15021549
36. Nordic Council of Ministers. Ecodesign Requirements for Textiles and Furniture. 2018 [Accessed 12 December 2024]. Available from: https://norden.diva-portal.org/smash/get/diva2:1221509/FULLTEXT01.pdf
37. GHEZZO, Paolo. Ecodesign approaches in textile products. In: Ecodesign in the Textile Sector. EcoSign ed., 2018
38. VEZZOLI, C.; CONTI, Giovanni M.; MACRÌ, Luca and MOTTA, Martina. Designing sustainable clothing systems: the design for environmentally sustainable textile clothes and its product-service systems. FrancoAngeli, 2022
39. OVAM. Ecodesign Criteria for Consumer Textiles. 2021 [Accessed 8 January 2025]. Available from: https://circulareconomy.europa.eu/platform/sites/default/files/ecodesign_criteria_for_consumer_textiles.pdf
40. COOPER, T.; HILL, H.; KININMONTH, J.; TOWNSEND, K. and HUGHES, M. Design for Longevity. Guidance on Increasing the Active Life of Clothing. WRAP. 2013 [Accessed 8 January 2025]. Available from: https://www.wrap.ngo/sites/default/files/2020-10/WRAP-Design%20for%20Longevity%20Report_0.pdf
41. BOTTA, V. Durable, Repairable and Mainstream. how Ecodesign can make our Textiles Circular. 2021 [Accessed 22 January 2025]. Available from: https://ecostandard.org/wp-content/uploads/2021/04/ECOS-REPORT-HOW-ECODESIGN-CAN-MAKE-OUR-TEXTILES-CIRCULAR.pdf
42. GUO, Y.; MORRIS, K. E.; SUMNER, M. and TAYLOR, M. A framework for measuring physical garment durability. Cleaner and Responsible Consumption, vol. 16 (2025), pp. 100245 [Accessed 24 May 2025]. Available from: https://doi.org/10.1016/j.clrc.2024.100245
43. LAITALA, K. M.; BOKS, C. and KLEPP, I. G. Making clothing last: A design approach for reducing the environmental impacts. International Journal of Design, vol. 9 (2015), no. 2, pp. 93–107. Available from: https://ijdesign.org/index.php/IJDesign/article/view/1613/696

44. MCNEILL, L. S.; HAMLIN, R. P.; MCQUEEN, R. H.; DEGENSTEIN, L.; GARRETT, T. C., et al. Fashion sensitive young consumers and fashion garment repair: Emotional connections to garments as a sustainability strategy. International Journal of Consumer Studies, vol. 44 (2020), no. 4, pp. 361–368. Available from: https://doi.org/10.1111/ijcs.12572
45. Redress. Design for Longevity. Sustainable Fashion Educator Pack Created by Redress. 2019 [Accessed 22 January 2025]. Available from: https://static1.squarespace.com/static/582d0d16440243165eb756db/t/60bf21e45924656df060e49a/1623138798478/1.Redress_SustainableFashionEducatorPack_Topic6_IntroOverview.pdf
46. TURA, N. and LAUKKANEN, M. Toward a sustainable sharing economy with business model innovations in the clothing industry. R&D Management, vol. 54 (2024), no. 5, pp. 1190–1212. Available from: https://doi.org/10.1111/radm.12659
47. KLEPP, I. G.; LAITALA, K. and WIEDEMANN, S. Clothing Lifespans: What Should Be Measured and How. Sustainability, vol. 12 (2020), no. 15. Available from: https://doi.org/10.3390/su12156219
48. WRAP. Circular Business Models Guide for Fashion. 2023 [Accessed 11 March 2025]. Available from: https://www.wrap.ngo/sites/default/files/2023-07/WRAP_CBM_Guide.pdf
49. COSCIEME, L.; MANSHOVEN, S.; GILLABEL, J.; GROSSI, F. and MORTENSEN, L. F. A framework of circular business models for fashion and textiles: the role of business-model, technical, and social innovation. Sustainability: Science, Practice and Policy, vol. 18 (2022), no. 1, pp. 451–462. Available from: https://doi.org/10.1080/15487733.2022.2083792
50. KANT HVASS, K. and PEDERSEN, E. R. G. Toward circular economy of fashion. Journal of Fashion Marketing and Management: An International Journal, vol. 23 (2019), no. 3, pp. 345–365. Available from: https://doi.org/10.1108/JFMM-04-2018-0059
51. DRAGOMIR, V. D. and DUMITRU, M. Practical solutions for circular business models in the fashion industry. Cleaner Logistics and Supply Chain, vol. 4 (2022), pp. 100040. Available from: https://doi.org/10.1016/j.clscn.2022.100040
52. WRAP. Retailer Clothing Take-Back Guide. 2021 [Accessed 3 May 2025]. Available from: https://www.wrap.ngo/sites/default/files/2021-02/Retailer-clothing-take-back-guide-Feb21.pdf
53. H&M. Let's Close the Loop. [Accessed 3 May 2025]. Available from: https://www2.hm.com/en_gb/sustainability-at-hm/our-work/close-the-loop.html
54. SOEX I:CO. Sorting. [Accessed 3 May 2025]. Available from: https://www.soex.de/en/services/sorting/
55. Vinted. Making Second-Hand First Choice our Impact Report 2023. 2023 [Accessed 15 May 2025]. Available from: https://press-center-static.vinted.com/Impact_Report_EN_2023_d4e3d4399e.pdf
56. HENKEL, Regina. Le Marché Français De La Mode Est Désormais Dominé Par Vinted. 2025 [Accessed 15 May 2025]. Available from: https://fashionunited.fr/actualite/retail/vinted-est-le-plus-grand-detaillant-de-mode-en-france/2025051538119
57. Giver Tag. Apie Mus. [Accessed 15 May 2025]. Available from: https://givertag.lt/
58. Looptex. Business Model. [Accessed 12 April 2025]. Available from: https://looptexgroup.eu/veiklos-modelis/
59. CLAXTON, S.; COOPER, T.; HILL, C. and HOLBROOK, K. Opportunities and challenges of new product development and testing for longevity in clothing. In: Product Lifetimes and the Environment (PLATE) Conference proceedings, pp. 62–68Nottingham: Nottingham Trent University: CADBE, 2015 [Accessed 22 January 2025]. Available from: https://irep.ntu.ac.uk/id/eprint/27454/1/PubSub4899_Cooper_NTUimprint.pdf.

60. GWILT, Alison and PAL, R. Conditional garment design for longevity. In: PLATE: Product Lifetimes And The Environment, pp. 149–153IOS Press, 2017
61. LUO, Y.; WU, X. and DING, X. Environmental impacts of textiles in the use stage: A systematic review. Sustainable Production and Consumption, vol. 36 (2023), pp. 233–245. Available from: https://doi.org/10.1016/j.spc.2023.01.006
62. DANI, H. and SHABIIMAM, M. A. Assessing environmental impacts of a textile company using life cycle assessment approach—a case study. Environmental Science and Pollution Research, vol. 32 (2024), pp. 7335–7343. Available from: https://doi.org/10.1007/s11356-024-33719-7
63. BIANCO, I.; DE BONA, A.; ZANETTI, M. and PANEPINTO, D. Environmental Impacts in the Textile Sector: A Life Cycle Assessment Case Study of a Woolen Undershirt. Sustainability, vol. 15 (2023), no. 15. Available from: https://doi.org/10.3390/su151511666
64. International Organization for Standardization. ISO 14040:2006 Environmental Management - Life Cycle Assessment - Principles and Framework. , 2006
65. BJØRN, Anders; OWSIANIAK, M.; MOLIN, C. and HAUSCHILD, M. Z. LCA History. In: Life Cycle Assessment: Theory and Practice, pp. 17–30HAUSCHILD, Michael Z.; ROSENBAUM, Ralph K. and OLSEN, Stig Irving. Cham: Springer International Publishing, 2018 Available from: https://doi.org/10.1007/978-3-319-56475-3_3.
66. SINGH, Rajesh K. and GOERKE, Julia. Life Cycle Assessments: Essential for EU's Ecodesign Regulation. 2024 [Accessed 24 May 2025]. Available from: https://sphera.com/resources/blog/why-life-cycle-assessments-are-key-to-the-eus-ecodesign-for-sustainable-products-regulation/
67. Environmental Academy. Q&A - the Role of LCA in Eco-Design. 2024 [Accessed 24 May 2025]. Available from: https://www.environmentalacademy.org/lcablog/qa-ecodesign
68. HORN, S.; MÖLSÄ, K. M.; SORVARI, J.; TUOVILA, H. and HEIKKILÄ, P. Environmental sustainability assessment of a polyester T-shirt – Comparison of circularity strategies. Science of The Total Environment, vol. 884 (2023), pp. 163821. Available from: https://doi.org/10.1016/j.scitotenv.2023.163821
69. FIDAN, F. Ş; AYDOĞAN, E. K. and UZAL, N. Sustainability assessment of denim fabric made of PET fiber and recycled fiber from postconsumer PET bottles using LCA and LCC approach with the EDAS method. Integrated environmental assessment and management, vol. 20 (2024), no. 6, pp. 2347–2365
70. SANDIN, G.; ROOS, S.; SPAK, B.; ZAMANI, B. and PETERS, G. Environmental Assessment of Swedish Clothing Consumption—six Garments, Sustainable Futures. 2019 [Accessed 11 May 2025]. Available from: https://core.ac.uk/download/pdf/270109142.pdf
71. JUČIENĖ, A.; GURAUSKIENĖ, I. and KRUOPIENĖ, J. Calculating the Environmental Impact Reduction Due to Extended Lifespan of Clothing Through Clothing Swaps. Sustainability, vol. 17 (2025), no. 10, pp. 4411 [Accessed 13 May 2025]. Available from: https://doi.org/10.3390/su17104411
72. RECIPE, R. In A Harmonized Life Cycle Impact Assessment Method at Midpoint and Endpoint Level Report I: Characterization. 2016 [Accessed 21 May 2025]. Available from: https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf
73. SALA, S.; CERUTTI, A. K. and PANT, R. Development of a Weighting Approach for the Environmental Footprint. 2018 [Accessed 16 May 2025]. Available from: https://publications.jrc.ec.europa.eu/repository/handle/JRC106545
74. LI, Z.; ZHOU, Y.; ZHAO, M.; GUAN, D. and YANG, Z. The carbon footprint of fast fashion consumption and mitigation strategies-a case study of jeans. Science of The Total Environment, vol. 924 (2024), pp. 171508. Available from: https://doi.org/10.1016/j.scitotenv.2024.171508

75. World Integrated Trade Solution. Lithuania Worn Clothing and Other Worn Articles Exports by Country in 2023. [Accessed 7 May 2025]. Available from: https://wits.worldbank.org/trade/comtrade/en/country/LTU/year/2023/tradeflow/Exports/partner/ALL/product/630900
76. SATTAR, S. and AKHTER, N. The European Union's textile waste and used clothing in Pakistan—PIDE—Pakistan's premier economic think tank Advocating reform through socio-economic and public policy research." Accessed: Mar. 27, 2024 (2023), pp. 81–83 [Accessed 7 May 2025]. Available from: https://pide.org.pk/research/the-european-unions-textile-waste-and-used-clothing-in-pakistan/
77. Aplinkos apsaugos agentūra. Tekstilės Gaminių Naudojama Vis Daugiau, Surenkama Ir Perdirbama – Per Mažai. 2025 [Accessed 7 May 2025]. Available from: https://aaa.lrv.lt/lt/naujienos/tekstiles-gaminiu-naudojama-vis-daugiau-surenkama-ir-perdirbama-per-mazai/
78. Patagonia. Patagonia's Common Threads Garment Recycling Program: A Detailed Analysis. 2006 [Accessed 12 May 2025]. Available from: https://www.patagonia.com/on/demandware.static/Sites-patagonia-us-Site/Library-Sites-PatagoniaShared/en_US/PDF-US/common_threads_whitepaper.pdf
79. PARSONS, Laurie. What Your T-Shirt Reveals about 'Carbon Colonialism' and the Global Economy's Vast Hidden Emissions. 2022 [Accessed 7 May 2025]. Available from: https://theconversation.com/what-your-t-shirt-reveals-about-carbon-colonialism-and-the-global-economys-vast-hidden-emissions-177956
80. BOTTA, V.; ECOS and MAGNUSSON, E. Deep Dive: Standards to Measure Textile Durability. Brussels: ECOS: Environmental Coalition on Standards. 2023 [Accessed 12 April 2025]. Available from: https://ecostandard.org/publications/report-deep-dive-standards-to-measure-textile-durability/
81. G, Sandra. Zara's Fashion Revolution through Data Insights. 2024 [Accessed 14 April 2025]. Available from: https://medium.com/thedeephub/zaras-fashion-revolution-through-data-insights-28f8fa728a0f
82. BRYDGES, T. Closing the loop on take, make, waste: Investigating circular economy practices in the Swedish fashion industry. Journal of Cleaner Production, vol. 293 (2021), pp. 126245. Available from: https://doi.org/10.1016/j.jclepro.2021.126245
83. PILLER, L. W. Designing for circularity: sustainable pathways for Australian fashion small to medium enterprises. Journal of Fashion Marketing and Management: An International Journal, vol. 27 (2023), no. 2, pp. 287–310. Available from: https://doi.org/10.1108/JFMM-09-2021-0220
84. KARELL, E. and NIINIMÄKI, K. A Mixed-Method Study of Design Practices and Designers' Roles in Sustainable-Minded Clothing Companies. Sustainability, vol. 12 (2020), no. 11. Available from: https://doi.org/10.3390/su12114680
85. DE AGUIAR HUGO, A.; DE NADAE, J. and DA SILVA LIMA, R. Can Fashion Be Circular? A Literature Review on Circular Economy Barriers, Drivers, and Practices in the Fashion Industry's Productive Chain. Sustainability, vol. 13 (2021), no. 21. Available from: https://doi.org/10.3390/su132112246
86. ABDELMEGUID, A.; AFY-SHARARAH, M. and SALONITIS, K. Investigating the challenges of applying the principles of the circular economy in the fashion industry: A systematic review. Sustainable Production and Consumption, vol. 32 (2022), pp. 505–518. Available from: https://doi.org/10.1016/j.spc.2022.05.009
87. SALO, H. H.; SUIKKANEN, J. and NISSINEN, A. Eco-innovation motivations and ecodesign tool implementation in companies in the Nordic textile and information technology sectors.

Business Strategy and the Environment, vol. 29 (2020), no. 6, pp. 2654–2667. Available from: https://doi.org/10.1002/bse.2527

88. CLAXTON, S. and KENT, A. The management of sustainable fashion design strategies: An analysis of the designer's role. Journal of Cleaner Production, vol. 268 (2020), pp. 122112. Available from: https://doi.org/10.1016/j.jclepro.2020.122112
89. BARTKUTĖ, R.; STREIMIKIENE, D. and KAČERAUSKAS, T. Between Fast and Sustainable Fashion: The Attitude of Young Lithuanian Designers to the Circular Economy. Sustainability, vol. 15 (2023), no. 13, pp. 9986. Available from: https://doi.org/10.3390/su15139986
90. Madalena PEREIRA; Raquel Santos; Teresa Barata; Ana Santiago and Rui Miguel. Sustainability and Circularity in Textile Industry: New Approach for Development of Fashion Products with Textile Pre-Consumer Waste In: Advances in Design, Music and Arts I, pp. 67–82.Cham: Springer Nature Switzerland, 2025
91. LE FEBER, N. and SMIT, M. J. Fashion Companies Pioneering with Eco-Innovations in the Swedish Fashion Industry: Motivations, Resources, and Cooperation. Circular Economy and Sustainability, vol. 3 (2023), no. 4, pp. 1885–1905. Available from: https://doi.org/10.1007/s43615-022-00246-x
92. WRAP. Valuing our Clothes. 2012 [Accessed 12 March 2025]. Available from: https://www.wrap.ngo/sites/default/files/2021-01/WRAP-valuing-our-clothes-2012-07-11.pdf
93. COOPER, T.; OXBORROW, L.; CLAXTON, S.; GOWOREK, H.; HILL, H., et al. Strategies to Improve Design and Testing for Clothing Longevity. Report for Defra. Nottingham: Nottingham Trent University. 2016 [Accessed 21 February 2025]. Available from: https://www.ntu.ac.uk/media/documents/research-documents/strategies-improve-design-testing-clothing-longevity.pdf
94. WAKES, S.; DUNN, L.; PENTY, D.; KITSON, K. and JOWETT, T. Is Price an Indicator of Garment Durability and Longevity?. Sustainability, vol. 12 (2020), no. 21. Available from: https://doi.org/10.3390/su12218906
95. SCHIAROLI, V.; FRACCASCIA, L. and DANGELICO, R. M. How can consumers behave sustainably in the fashion industry? A systematic literature review of determinants, drivers, and barriers across the consumption phases. Journal of Cleaner Production, vol. 483 (2024), pp. 144232. Available from: https://doi.org/10.1016/j.jclepro.2024.144232
96. EU. Ecodesign for Sustainable Products and Energy Labelling Working Plan 2025-2030 2025 [Accessed 21 April 2025]. Available from: https://environment.ec.europa.eu/document/download/5f7ff5e2-ebe9-4bd4-a139-db881bd6398f_en?filename=FAQ-UPDATE-4th-Iteration_clean.pdf.
97. European Environment Agency. The Destruction of Returned and Unsold Textiles in Europe's Circular Economy. 2024 [Accessed 21 April 2025]. Available from: https://www.eea.europa.eu/publications/the-destruction-of-returned-and
98. Press room. Deal on New EU Rules to make Sustainable Products the Norm. 2023 [Accessed 21 April 2025]. Available from: https://www.europarl.europa.eu/news/en/press-room/20231204IPR15634/deal-on-new-eu-rules-to-make-sustainable-products-the-norm
99. Cascale. Cascale Higg Index Brochure. 2021. Available from: https://cascale.org/wp-content/uploads/2021/09/Higg-Index-Brochure-.pdf
100. Textile ETP. Circular & Biobased Textiles Innovation Hub. [Accessed 10 April 2025]. Available from: https://www.textile-platform.eu/innovation-hub-circular-and-biobased-textiles
101. CICCONI, P. Eco-design and Eco-materials: An interactive and collaborative approach. Sustainable Materials and Technologies, vol. 23 (2020), pp. e00135. Available from: https://doi.org/10.1016/j.susmat.2019.e00135

102. IEA – International Energy Agency. Lithuania - Countries & Regions. [Accessed 17 May 2025]. Available from: https://www.iea.org/countries/lithuania
103. European Environment Agency. EU Exports of used Textiles in Europe's Circular Economy. 2023 [Accessed 20 May 2025]. Available from: https://www.eea.europa.eu/publications/eu-exports-of-used-textiles
104. ZAMANI, B.; SANDIN, G. and PETERS, G. M. Life cycle assessment of clothing libraries: can collaborative consumption reduce the environmental impact of fast fashion?. Journal of Cleaner Production, vol. 162 (2017), pp. 1368–1375. Available from: https://doi.org/10.1016/j.jclepro.2017.06.128
105. TRZEPACZ, S.; LINGÅS, D. B.; ASSCHERICKX, L.; PEETERS, K.; DUIJN, H. V., et al. LCA-Based Assessment of the Management of European used Textiles. Belgium: 2023 [Accessed 11 May 2025]. Available from: https://circulareconomy.europa.eu/platform/en/knowledge/lca-based-assessment-management-european-used-textiles
106. SCHMIDT, A.; WATSON, David; ROOS, Sandra; ASKHAM, Cecilia and BRUNN POULSEN, Pia. Gaining benefits from discarded textiles: LCA of different treatment pathways. Denmark: Nordic Council of Ministers, 2016 [Accessed 11 May 2025]. Available from: https://norden.diva-portal.org/smash/record.jsf?pid=diva2%3A957517&dswid=-3448
107. DOMSKIENĖ, J. and GAIDULE, E. An overview of technological challenges in implementing the digital product passport in the textile and clothing industry, vol. 24 (2024), no. 1. Available from: https://doi.org/10.1515/aut-2024-0002
108. TrusTrace. Work Package: Pioneering Digital Product Passports: Transforming Textile Industry Standards. 2025 [Accessed 16 April 2025]. Available from: https://trace4value.se/content/uploads/2025/04/Report-Trace4Value-Pioneering-Digital-Product-Passports.pdf
109. ALVES, L.; SÁ, M.; CRUZ, E. F.; ALVES, T.; ALVES, M., et al. A Traceability Platform for Monitoring Environmental and Social Sustainability in the Textile and Clothing Value Chain: Towards a Digital Passport for Textiles and Clothing. Sustainability, vol. 16 (2024), no. 1, pp. 82. Available from: https://doi.org/10.3390/su16010082
110. LEGARDEUR, J. and OSPITAL, P. Digital Product Passport for the Textile Sector. 2024 [Accessed 24 April 2025]. Available from: https://www.europarl.europa.eu/RegData/etudes/STUD/2024/757808/EPRS_STU(2024)757808_EN.pdf
111. NØRUP, N.; PIHL, K.; DAMGAARD, A. and SCHEUTZ, C. Evaluation of a European textile sorting centre: Material flow analysis and life cycle inventory. Resources, Conservation and Recycling, vol. 143 (2019), pp. 310–319. Available from: https://doi.org/10.1016/j.resconrec.2019.01.010

Appendices

Appendix 1. Questions per interview

Erika Adomavičiūtė
How is the process of New Product Development?
What mechanical properties can ensure durable products?
What features are the most important when designing long lasting garments?
How do you evaluate the quality or the durability of the materials in the lab? What are the parameters to evaluate?

Daiva Mikučionienė
What are the main strategies that can be implemented for textile longevity? How can they be measured?
How can a garment be defined as high quality/long lasting?
What are the main obstacles for entrepreneurs and intrapreneurs when implementing sustainable practices during manufacturing processes? Besides creating skills and knowledge, what else is missing to have more sustainable business models?
What other projects have you worked on regarding sustainability in textiles/clothing?
How do companies feel regarding adopting strategies for longevity?

Jurgita Domskienė
What are the main strategies that can be implemented for textile longevity? How can they be measured?
What are the obstacles companies face to implement ESPR requirements and sustainable practices?

Vaida Jonaitienė
What are the parameters to have a “high quality” garment? How are they measured? What are the most common ones?
How is Ecodesign implemented in clothing? What strategies are the most common ones?
What are the strategies of Design for longevity?
What is the main obstacle when implementing Ecodesign/sustainability in the products?
What is your experience in the textile industry?

Kęstutis Lekeckas
When does the opportunity of leKeckas to come to life arrive?
What Ecodesign strategies do you implement in your designs? What environmental aspects do you implement?
How difficult is it to implement them?
How do you understand durability and how do you implement it?
What parameters do you consider when choosing materials?
What decisions do you consider when designing long lasting products?
What is the behavior of customers towards your designs and materials (sustainability)?
As a designer, what challenges do you consider designers encounter when implementing Ecodesign or sustainable strategies?

Rasa Virbickė
What is your experience in the textile industry and research?
I understand there is a need to find alternative "natural" fibers for textiles? Where does this idea come from?
Can you describe more deeply what your research is? How are you evaluating the quality of these fibers?
What are the results for durability?
What is the perception of producers and consumers about this type of fiber?
What other alternative natural fibers can be produced?
According to your research, what are the most durable fibers?

Reda Siudikienė - Omniteksas
What is your experience in the textile/fashion industry?
How do you ensure durability in your products?
Where does this initiative to have wool for sportswear come from? Did a client request it? Or by your own research?
You offer white label service with a catalog; how do you decide the designs offered by the company?
You stand out for your sustainable practices, is there something you consider that can be improved in this area?
Are brands oriented to longevity? Do they have circular business models for longevity extension? Durability/quality?

Mantas Naulickas
How do you ensure durability in your products?
Could you please tell me more about sustainability in the products the company manufactures?
Do you provide repair services?

Agnė Jučienė
Did you do LCA of different fabrics considering the whole life use?
Where did you get the data for the LCAs?
How much textile waste is discarded every year?
What happens with collected textiles in Lithuania?
On your research, did you assume that clothes were washed 19,4 times by the first user? How do you estimate the washing and drying?
How did you estimate the average distance for transportation to the store?
Did you consider packaging?
Who takes care of the textiles collection and sorting in LT? private companies or the municipal sorting points?

Appendix 2. Consent form sent to interviewers.

Participant Consent Form

Student: Luisa María Santofimio Varón   Email of student: luisa.santofimio@ktu.lt

Study program: MSP Sustainable Management and Production

Supervisor: Inga Gurauskienė   Email of supervisor. inga.gurauskiene@ktu.lt

Thesis topic: Ecodesign techniques and strategies in apparel for longevity extension, Lithuanian context.

Purpose of the research interview: How can longevity be implemented and measured in apparel products?

No.	Items to consent	Yes	No
1.	I am informed that my participation in the interview is voluntary, and I can withdraw from the research at any time without giving any reason and without any adverse consequences or penalties imposed.		
2.	I give permission to be quoted directly in the final master thesis.		
3.	I give permission to use my name and surname in the final master thesis		
4.	I am informed that the data collected during the research can be reviewed by the authorized persons outside the group of researchers (for example, the Research Ethics Commission of Kaunas University of Technology, the Data Protection Officer of Kaunas University of Technology, the Office of the Ombudsperson for Academic Ethics and Procedures of the Republic of Lithuania, the State Data Protection Inspectorate, the court).		
5.	I am informed who will have access to my provided personal data, how the data will be stored and what will happen to the data at the end of the research.		
6.	I am informed that the research results will be publicly available (eLABa).		
7.	I agree to being video recorded (online meeting).		

The research data collected will be stored in password-protected computers and password-protected online cloud at https://ktuedu-my.sharepoint.com/, and only those designated individuals have access to my data.

Address the student, supervisor, and/or the ethics committee of KTU to raise a concern or make a complaint.

Participant

________________________________ __________________ ________________

Name and surname   Date   Signature

Student

Luisa Santofimio   April 04-2025

Name and surname   Date   Signature

Appendix 3. Inventory for the LCA

Inventory for use phase is based on previous LCA performed by Agnė Jučienė [71], following the next logic: 26 uses equal 8.7 laundry cycles. One laundry cycle equals one washing, one drying and one ironing.

Collection

Inputs		Dataset used	Quantity	Unit	Comments
Plastic bag from user		GLO: market for packaging film, low density polyethylene	0.01	kg	Assuming the weight of a plastic grocery bag.
Transport from LT to VNO (Collector)		RER: market for transport, freight, lorry 16-32 metric ton, EURO6	0.006	tkm	Assuming lorry 16-32 metric tons and 191 km.
Sorting (electricity)		LT: SE: market for electricity, low voltage	0.014793	kWh	Based on Nørup et al. [111].
Sorting (heating)		RER: market group for Heat, district or industrial, natural gas	0.0007	m3	Based on Nørup et al. [111].
Bailing		GLO: market for packaging film, low density polyethylene.	0.00267	kg	Based on Nørup et al. [111].
Transport (user)		From baseline		km	
Industrial washing	Garment	from First Use phase	1	kg	Based on Sandin et al [70].
	Water	RER: market group for tap water	12	kg	Based on Sandin et al [70].
	Detergent	from detergent process	0.009	kg	From baseline.
	Electricity	LT: SE: market for electricity, low voltage	0.4	kWh	Based on Sandin et al [70].
	Heating	CH: wood pellets, burned in stirling heat and power cogeneration unit, 3 kW electrical, future	6.84	MJ	Based on Sandin et al [70].
	Wastewater (output)	Europe without Switzerland: market for wastewater, average	11	kg	Based on Sandin et al [70].

Outputs				
Plastic waste	treatment of waste plastic, mixture, municipal incineration	0.01	kg	Assuming the weight of a plastic grocery bag.

Second use and export

Inputs		Dataset used	Quantity	Unit	Comments
Transport from VNO to Klaipeda		RER: market for transport, freight, lorry 16-32 metric ton, EURO6	0.0099	tkm	Assumed.
Transport from LT to Pakistan		transport, freight, sea, container ship, heavy fuel oil	13000	km	Estimated with https://sea-distances.org/
Transport from VNO to LT		RER: market for transport, freight, lorry 3.5-7.5 metric ton, EURO6	0.0255	tkm	Assuming lorry 3.5-7.5 metric ton + 191 km.
Transport (user)		From baseline		km	
Use		From baseline	13	Unit	
Repair	Transport (user) Roundtrip	From baseline		km	
	Electricity	LT: SE: market for electricity, low voltage	0.58	kWh	Assuming that 0.029 kWh per minute and 20 min in the process, based on Sandin et al [70].
Delivery (app)		RER: market for transport, freight, lorry 3.5-7.5 metric ton, EURO6	0.1448	km	Assuming lorry 1.2 metric ton + average distance between five cities in LT
Packaging		GLO: market for packaging film, low density polyethylene	0.02	kg	Assumed.
Outputs					
Bailing waste		treatment of waste plastic, mixture, municipal incineration	0.00267	kg	Based on Nørup et al. [111].
Packaging waste		treatment of waste plastic, mixture, municipal incineration	0.02	kg	Assumed.
Landfilling		Waste yarn and waste textile {IN}| treatment of waste yarn and waste textile, unsanitary landfill	1	Kg	Assumed.
Incineration		Waste polyethylene {RoW}| treatment of waste polyethylene, municipal incineration	1	kg	From baseline.