Identifying data gaps in the textile industry and assessing current initiatives to address them

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This study identifies data gaps throughout the textile industry supply and value chains, from fibre to the end of product life stage and assesses current initiatives addressing them. It also exposes the following challenges: missing data, data accessibility, data management, reliability and relevance, mandatory or non-mandatory data collection, data sharing, and data cost issues.

Drawing on a literature review, 17 stakeholder interviews and 2 expert workshops, the study gathers essential insights from the field, and evaluates current and forthcoming initiatives for addressing data gaps. It goes on to discuss policy options geared towards using data to help achieve a sustainable transition and circular economy in the textile sector. Views on how to use data to tackle the fast fashion phenomenon are presented at the end of the study.

AUTHORS

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Executive summary

Transparency and traceability are currently challenging issues in today's long, global, and saturated textile supply chains. For example, a fashion brand can acquire information from the factory in which the garment is assembled and sewn together (from tier one), even if this phase is, in most cases, outsourced to lower-cost countries. Moving further along this production chain to access other tiers and other factories and their informational resources is challenging. The further down the supply chain the need for information goes, the harder it is to obtain reliable and accurate data. On the other hand, supply chain processes generate a huge amount of data which, if correctly collected and precisely analysed, helps companies make more sustainable decisions throughout the entire upstream supply chain processes (from fibre to product phase).

Moving towards a circular economy (CE) unfolds the need to acquire new kinds of data from downstream actions such as reuse, reselling, and recycling. This data is still largely missing, and new tools, measurements, and standards need to be developed to be able to obtain and share the data from these actions. Currently, in many cases, data collection and handling still use conventional Excel sheets and email. This makes the data not only hard to obtain, but also hard to share between stakeholders if it is not in a suitable format.

To realise the European Commission's vision of sustainable and circular textiles, several policy regulations are on the way. The goal is that this will lead towards the development of more sustainable practices in the industry and in business. Moreover, informing consumers might also change their behaviour. This development leans on measurements and evaluations based on reliable data on the resources, materials, products, and processes used during a product's lifetime.

To identify these data gaps and inform our approach in this study, we integrated data from different sources. A literature review was performed to identify the current understanding on data gaps in the textile sector, especially regarding the sustainability and circularity of textiles, as well as possible tools to bridge these gaps. The literature review consisted of scientific journal articles, book chapters, and reports. Moreover, ongoing projects were followed (their websites and webinars) to find the latest developments in data issues, especially how they connect to policy regulations and emerging tools. Seventeen stakeholders were interviewed, representing different angles and knowledge areas in the textile and circular economy sector. Two specialist workshops were organised, not only to obtain deeper insights into data use and data gaps, but also to explore future possibilities, such as how data could be used to support the sustainability transition.

The study examined the data gaps throughout the textile supply and value chains, from fibre to the end of product life stages. The study revealed the challenges relating to data: missing data, data accessibility, data management, data reliability and relevance, mandatory or non-mandatory data collection and sharing, and costs. Listing the data gaps linked to product, logistics, use phase, system levels, end-of-life stage, and waste handling revealed that much work still needs to be done to acquire reliable, accurate data so that decision-making can be based on data.

An especially important discussion is the one about Life Cycle Assessment (LCA), which is used as a basis for many environmental impact evaluations, but currently lacks some of the data that need to be measured according to new regulations. Moreover, Social Life Cycle Assessment (S-LCA) is becoming more important as an evaluation tool because it can help decipher the social side of sustainability and links to new regulations. While the pressure is to move towards a circular economy, essential actions linked to textile circularity (lifetime, reuse, reselling, recycling) are currently missing from data collection, measures, standards, and tools. The evaluation of biodiversity loss lacks a data measurement system. These are just some examples of the data gaps discussed in this report.

After exposing the data gaps and data challenges, the study progressed to linking the data needs to different tools and initiatives. The tools that attempt to support the transition towards circularity and CE are especially challenging, and their evaluation should be based on accurate, up-to-date data, which might currently be completely lacking. There is a risk that if accurate, reliable data does not exist, calculations cannot guide us towards the right decisions, and even fraudulent data might be used.

At the end of the report, we discuss policy options. We highlight issues such as **mandatory or non-mandatory data; harmonised and standardised data; and affordable, accessible, and higher-quality data bases**. At the end we also describe the options for tackling the issue with fast fashion. Mandatory regulations offer an opportunity to "level the playing field" and prevent greenwashing and data fraud, and to expose the real environmental or social impacts of each stakeholder. Accordingly, mandatory principles will strengthen sustainability-minded companies' competitive position on the market. The same rules have to apply to everyone in the supply and value chain. Data can bring **transparency and traceability,** and we can connect real, accurate information on environmental impacts or social sustainability issues to specific products, factories, or brands. In this way it is easier not only for producers to select more sustainable solutions or partners who can offer these, but also for consumers to select more sustainable products based on data and reliable (and more transparent) communication. Thus, using several regulations (policy mix), with the help of reliable and accurate data as well as **incentives and fees**, we can begin to move away from fast fashion and towards sustainable and circular textile systems and fashion, which are in better balance with the environment.

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List of acronyms

AI	Artificial Intelligence
API	Application Programming Interface
B-2-B	Business to Business
B-2-C	Business-to-Consumer
CE	Circular Economy
CEAP	Circular Economy Action Plan
CF	Carbon Footprint
CO2	Carbon dioxide
CSRD	Corporate Sustainability Reporting Directive
CTI	Circular Transition Indicators
DPP	Digital Product Passport
EPR	Extended Producer Responsibility
EOL	End-of-life
ESG	Environmental, Social and Governance
ERP	Enterprise Resource Planning
ESPR	Ecodesign for Sustainable Products Regulation
GCD	Green Claims Directive
GDPR	General Data Protection Regulation
GS1	Standard for Data Sharing
HS	Harmonised System
IoT	Internet of Things
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCSA	Life Cycle Sustainability Assessment
ML	Machine Learning
NFC	Nearfield communication technology (uses RFID)
PEF	Product Environmental Footprint
PIM	Product Information Management
PLM	Product Life Cycle Management
PRO	Producer Responsibility Organisation
PSILCA	Product Social Impact Life Cycle Assessment
RDBMS	Relational Database Management Systems
RFID	Radio Frequency Identification
SHDB	Social Hotspot Database
S-LCA	Social Life Cycle Assessment
No-SQL	Non-relational Data Models

1. Introduction

The European Green Deal strategy constructed by the European Union (EU) aims for climate neutrality by 2050. The Green Deal was introduced in December 2019, and since then has set the goals for policy work, which aims to follow a roadmap for a sustainable and inclusive economy. This approach emphasises the need to address climate change, environmental degradation, and social inequality. Key pillars include cutting greenhouse gas (GHG) emissions, enhancing energy efficiency, promoting clean and circular economies, and preserving biodiversity. Thus, the European Commission adopted the New Circular Economy Action Plan (CEAP) in March 2020. The aim of this action plan is to enhance the regenerative model to reduce resource consumption and increase recycled material use. Seven key product value chains have been identified in CEAP as posing the highest sustainability challenges and requiring urgent, comprehensive actions. Textiles have been distinguished as the fifth "highest-pressure" industry on resource consumption and GHG emissions. Therefore, the EU strategy for sustainable and circular textiles has been proposed for coordinating how textiles are produced and consumed throughout the life cycle of the products. CEAP was followed by the EU strategy for sustainable and circular textiles, which proposes many new regulations.

The European Commission's vision for the textile sector in 2030 is as follows:

- *all textile products placed on the EU market are durable, repairable, and recyclable, to a great extent made of recycled fibres, free of hazardous substances, produced in respect of social rights and the environment*
- *"Fast fashion is out of fashion" and consumers benefit longer from high-quality affordable textiles*
- *profitable reuse and repair services are widely available*
- *the textiles sector is competitive, resilient, and innovative with producers taking responsibility for their products along the value chain with sufficient capacities for recycling and minimal incineration and landfilling*

To realise this vision, the European Commission is developing several policy regulations that will lead to the development of this industry towards more sustainable practices. This development leans on measurements and evaluations based on reliable data on the resources, products, and processes throughout products' lifetime. When data is given context by use of digital technologies, it transforms into useful information that can be used for resource and product optimisation. Therefore, data plays a critical role in the transition towards sustainability (Kristofersen et al., 2020).

Fast fashion emerged at the end of 1990s and has shown to be a successful business model, based on low-cost production, low-paid workers, and a very short use time of clothing. Fast fashion relies on constant consumption, especially on impulse buying; that is, on "instilling a sense of urgency when purchasing". The results of this business model have led to the industry producing almost twice the amount of clothing items that it produced before fast fashion. (Niinimäki, 2018; 2020). Ultra-fast fashion has emerged after the COVID-19 period, which means constant fast-changing micro-trends that entice consumers to overconsume, as well as producing in ever-faster cycles of production that are based on weak labour practices, aggressive marketing through social media, and impulse purchasing. Fast fashion and ultra-fast fashion are shortening the use time of clothing and increasing the amount of waste. The material throughput in the fashion system is fast, and products are disposed of after a very short use time. Fast and ultra-fast fashion models are understood to be the bottlenecks of the green transition. Policy regulation is also trying to fight this phenomenon.

1.1. Textile supply and value chain

A textile supply chain is defined as the production process path from raw material to the end product. In this complex supply chain, different suppliers, and factories, often located in several different countries, process their part in the chain to produce the fibre, yarn, textile, colour, or garment. The direction of actions in the supply chain are said to be upstream. It has been stated that the textile sector is among the most globalised value chains in all industrial sectors (Centre for Industrial Studies, 2021), and therefore, controlling all aspects in the supply chain is difficult. A value chain, on the other hand, "create[s] value for and with the customer", which means that the focus is on downstream chain actions and that the company creates value together with the customers (Cura et al., 2022, p.7). Examples of downstream actions are extending the use time of garments, reuse, re-commerce, and recycling.

The increase in global fibre production in the last 25 years shows the huge growth of the textile and fashion sector, and the growth of the fast fashion business in particular has drastically worsened the situation (Niinimäki et al., 2020). It is obvious that this sector has an adverse impact on climate change, and is creating pollution and biodiversity loss. Therefore, a new understanding is needed, as well as further rethinking how products are designed, manufactured, or used, so that we can achieve a better system-level balance and clearly decrease the environmental impacts caused by this industry (e.g., Niinimäki et al., 2020). In this transition process, data is key for better decision-making throughout the supply and value chains.

1.2. Data in the textile supply chain

Most industrial production processes are located in developing countries (mainly in Asia), and the produced textiles and garments are transported to developed countries (Western countries and the USA). After use, some of the textile waste is then transported to developing countries (mainly to Africa). Textile waste streams are increasing in all countries, but especially in Western countries, in which the fashion consumers are located. This aspect increases the complexity of collecting data and documenting information throughout the textile supply or value chains while trying to include all actors and their data throughout the product's lifetime (from raw material to finished products until the products' end of life). This also means that the actors and industrial players are on different levels in terms of their data handling capabilities. Currently, in many cases, data are still collected and handled in the conventional way of using Excel sheets and manually filling in documents. "The digital maturity level in the sector is generally very low and dominated by manual processes. A fashion brand in Germany, for example, has to deal with 37 interfaces on average" (Cirpass, 2024, p.78). This statement indicates the challenge of handling supply chain data when the aim is to increase transparency, traceability, and reliability within the textile industry.

Textile and apparel supply and value chains are currently moving from a linear model to a circular one, which requires new partnerships, knowledge sharing, and data utilisation. (e.g. Niinimäki, 2018; Jain et al., 2024). "To enable this shift from a linear textile value chain to a more circular one, industry practitioners and academics have acknowledged that data availability and traceability is a crucial factor in supporting decision-making" (Papú Carrone, 2020, cited in Jain et al., 2024, p.182). A real transition to sustainability, especially to the circularity of textiles, requires full awareness of system-wide impacts and how, for example, rebound effects may ensue. We are already moving towards a CE, yet we do not know how, for example, "inefficient recycling technologies may overweigh the positive impacts of certain CE solutions" (ibid., p.182).

Consensus is lacking on what data means, where it can be stored or found, and how it can be made available for sustainability calculations or evaluation purposes. Data needs to be processed in a format that is suitable and useful for focused activities. Decision-makers need data that is meaningful in a certain context and is processed into meaningful knowledge (Sivarajah et al., 2017).

Different actors in the supply or value chain need different types of data, and currently they "mainly use; a) data from their direct suppliers in the form of certificates, quality or technical indicators, material contents; b) data from their own operations/manufacturing, e.g. energy, water, chemical efficiency, waste flows, production volumes, health and safety issues; c) data on reclamations and returns; d) sales and marketing data; e) consumer data based on interviews or online behaviour; f) user data, when clothing is provided as a service or rented (e.g. number of washes can be traced using microchips). In some cases, these datasets may be further processed into LCA-type indicators, such as carbon or water footprints" (Jain et al., 2024, p.185).

Because the textile manufacturing chain is complex and the process phases are located in several factories, very often even in several countries, collecting data throughout the supply chain is a huge challenge and requires enormous effort. In many cases, it is very costly. Typically, data is collected through the actions of the factory and from tier 1 suppliers (direct suppliers). Accessing data throughout the supply chain is currently highly challenging, and in many cases, even impossible. The processes of the manufacturing phases, such as fibre cultivation, yarn manufacturing and dyeing, textile weaving, textile printing, textile finishing, and garment sewing, are located in different locations. Therefore, current data collection efforts can be defined as limited. Enhancing data collection and use is desperately needed so that data can support a system-wide sustainability transition, as well as transparency and traceability.

Transparency = Transparency is defined as "relevant information about the supply chain which is made available for all elements of the value chain in a harmonised way, which allows for common understanding, accessibility, clarity and comparison" (Richero and Ferrigno, 2017).

Traceability = The traceability of a value chain is more than just simply mapping the supply chain. For instance, value stream maps are visual images of materials and information flows in a process. They are commonly used in the production process to eliminate non-value adding activities. Traceability tracks the origin and journey of products and their inputs, from the very start of the supply chain, through the whole supply chain, to end-use. (Cura et al., 2022, p.12)

Data can mean facts, numbers, or factual information that is stored in various locations. Data can be stored for further utilisation and analysis by systems such as "process control systems, monitoring systems, enterprise resource planning (ERP)[1], and emission control systems" (Jain et al., 2024, p.184). By collecting and analysing data, the sector can provide valuable insights that can make decision-making efficient and thus improve the transparency of different actions and remain aligned with the required policy actions. Transparency is needed to increase the accuracy of environmental assessment tools such as the Life Cycle Assessment (LCA), to estimate environmental impacts, to avoid harmful chemicals, and to evaluate the social aspect of sustainability. Data utilisation is required for more advanced knowledge-based decision-making in manufacturing and design processes. Proper data also supports risk management in the industry and business. Jain et al. (2024) has identified the needs for data that can support different stakeholders' decision-making. Table 1 presents the current understanding of this topic.

[1] Enterprise resource planning (ERP) is a tool which supports intelligent automation and processes such as the supply chain and procurements, through digital technologies such as cloud, AI, and machine learning (ML). (https://www.sap.com/products/erp/what-is-erp.html)

Table 1 – Data for stakeholders' decision-making

	Design	Fibre and textile production	Garment production	Retail and logistics	Post-consumer processing
Supplier data	Selecting long-lasting, circular material contents based on supplier data.	Sourcing raw materials from most environmentally sustainable and socially responsible suppliers (including tier X suppliers, not only direct suppliers).	Sourcing fabrics from most environmentally sustainable and socially responsible suppliers (also tier X suppliers, not only direct suppliers).	Sourcing fabrics from most environmentally sustainable and socially responsible suppliers (also tier X suppliers, not only direct suppliers).	
Customer data	Enabling longer lifecycles by providing long-lasting design. Designing a garment or new product types to fulfil a need, not a trend, by better understanding consumer needs. Enabling easier maintenance and repair by understanding consumers (design for maintenance/ design for repair).	Producing only the required amount by understanding demand volumes. Understanding customer (ultimately consumer) requirements, and monitoring, collecting, and providing the data they demand.	Producing only the required amount by understanding demand volumes. Understanding customer (ultimately consumer) requirements, and monitoring, collecting, and providing the data they demand.	Optimising logistics and retail volumes (and thus waste) by understanding demand volumes. Restricting / optimising logistics costs/impacts by studying, e.g. consumer behaviour related to returns.	Building up the required capacity and ensuring steady inflow of post-consumer waste flow by understanding demand volumes and customer behaviour.
Material data	Selecting long-lasting materials and products. Choosing easily recyclable materials and products. Selecting comfortable materials to wear (impacts longevity).				Selecting the most efficient recycling technology by understanding the technical details and recyclability of various materials.
Company-owned process data		Optimising own processes using own process data. Reducing environmental and H&S[2] risks by monitoring own processes.	Optimising own processes using process data. Reducing environmental and H&S risks by monitoring own processes.		Optimising own processes using own process data. Reducing environmental and H&S risks by monitoring own processes.

[2] H&S; health and safety

	Design	Fibre and textile production	Garment production	Retail and logistics	Post-consumer processing
Product data					Steering EOL[3] garments with certain materials or qualities to correct recycling routes. Acknowledging the accumulation or risks of certain harmful substances.
LCA data	Designing products with minimal environmental impacts (e.g. reducing carbon/ water footprint, eutrophication, acidification, resource depletion, respiratory inorganics). Understanding the trade-offs between environmental impacts (e.g. some materials can reduce a carbon footprint but increase their water footprint).	Becoming aware of fibre and textile production impacts in relation to rest of life cycle impacts => and developing a strategy for reducing them if significant.	Becoming aware of garment production impacts in relation to rest of life cycle impacts => developing a strategy for reducing them if significant.	Becoming aware of retail and logistics impacts in relation to rest of life cycle impacts => developing a strategy for reducing them if significant.	Becoming aware of post-consumer processing impacts in relation to rest of life cycle impacts => developing a strategy for reducing them if significant.
Waste data	Designing out waste. Designing new products based on waste flows and side streams.	Minimising losses from fibre and textile in production processes by monitoring sources and volumes of losses.	Minimising losses from garment production by monitoring sources and volumes of losses.	Minimising losses from retail by monitoring sources and volumes of losses.	Ensuring steady inflow of post-consumer waste flow for maintaining operations.

Source: Jain et al., 2024, pp.198–190

Although data utilisation can provide more sustainable opportunities, there are still limitations to its use, such as: "poor data quality, limited analytical expertise, infrastructure that will be needed to store and manage the data, and data security to improve the current business operations (Labrinidis and Jagadish, 2012; Sivarajah et al., 2017), are just some of many challenges that the textile and apparel industry are facing in their digital transformation" (Cura et al. 2022, p.11).

[3] EOL; end of life

2. Methods and research process

A literature review was performed to identify the current understanding on data gaps in the sustainability and circularity of textiles, and to find possible tools to solve them. The literature review (Flick, 2014) examined scientific journal texts, books, book chapters, and reports that included the latest developments in the data field in the context of sustainability and the circular economy. In addition to the many ongoing research projects focusing on data for sustainability, a great number are also emerging. Therefore, not only the latest scientific publications but also information from different ongoing projects was gathered through a desktop study. In addition, qualitative, semi-structured interviews (Kvale, 2007) were conducted, which covered various stakeholders' understandings of data use, data gaps, and data-driven tools. The interviewees represented the whole textile supply chain of actors (designers, manufacturers, retailers, recyclers, policymakers, researchers) so that we were able to gain insight into their experiences and perspectives on data gaps and the initiatives that address them. The list of interviewed stakeholders is presented in Table 2 (anonymised).

In this way, we were able to cover the data requirements across the whole textile supply chain, from fibre production to the end product and end-of-life (EOL). Moreover, we laid open the data requirements in environmental impact assessment (such as LCA, S-LCA, and Carbon footprint (CF)) while closing the loop through textile waste recycling. A CE requires data that enables not only recycling but also ways to extend the use time of garments. This angle requires data on the quality of the fibre, textile, and garment, as well as on the use phase (maintenance, laundry times, use time). These are the areas that need new ways to collect data that we identified through our data collection (literature review, laptop study, interviews). This approach enabled us to obtain a holistic and profound understanding of data gaps in the textile supply and value chains, and to identify the proposed tools to solve these data issues.

Two workshops with stakeholders were held to test the constructed framework (data gaps and solution tools in the textile supply chain) and to co-create an understanding of the future data needs and possibilities, especially in the CE context and given the environmental impacts of the textile sector. The workshops were a way of collecting feedback and constructing a shared understanding of the situation under study. We applied the participatory research approach (Muratovski, 2016). The workshops with business and industry partners were held to especially assess the data initiatives and their application possibilities from an industry and business point of view. These initiatives were evaluated from, for example, the viewpoints of data accessibility, data sharing, data reliability, applying data in different use contexts, data in business decision-making, and the evaluation of environmental impacts in connection with data. We also constantly collected feedback on our study and its development in interviews and workshops by taking into account the experts' feedback (Muratovski, 2016.). In the analysis part, a mixed-method approach was applied and the insights from the interviews and workshops were integrated with the results from the literature review to create a meaningful narrative based on the principles of qualitative research (Flick, 2014).

Lastly, based on the specific study findings, the study assessed the risks, and explored the options for taking advantage of the benefits and tackling the risks associated with the deployment of the current and proposed policies addressing the data gaps within the textile industry, throughout the product life cycle. We collected feedback on the draft version of the report from experts.

The study included the following methods and phases:

A) Literature review
B) Semi-structured interviews
C) Analysis of data to identify the gaps and to build a framework of policy actions

D) Testing the framework in workshops (expert panels) and deepening the understanding based on reflection in the workshops
E) Constructing an understanding of future data possibilities and the lack of current data in connection to proposed policy tools
F) Building a discussion on policy options

2.1. Interviews

The results of the literature review were combined with those of the semi-structured interviews (Kvale, 2007), which covered the different stakeholders' understandings of the data use, data gaps, and data-driven tools in the textile sector. The interviews covered the whole textile supply chain (designers, manufacturers, retailers, recyclers, policymakers, researchers) so that we could gain insights from their experiences and perspectives on the data gaps, as well as their estimation of the initiatives addressing these. Table 2 presents the list of stakeholders interviewed for this study (anonymised) and their field of knowledge/expertise (some experts covered two areas). Altogether 17 interviews were carried out between December 2023 and March 2024. The interviewees were from Finland, the UK, the Netherlands, Denmark, Estonia, Belgium, and Switzerland. Annex A presents the interview questions, which were modified according to each interviewee's area of knowledge and expertise.

Table 2 – Interviewed stakeholders

Interviewee/Field	Designer	Manufacturer	Retailer/brand	Policymaker	Collector/sorter	Waste recycling	Fibre producer	Reuse/resell	Professional association	Researcher	Consultant	Country
Consultant/ Consultancy (textile waste)						(x)[4]					x	NL
Chief Advisor, circular and sustainable textile/Professional Association (industry) Head/ Textile Association (industry)		(x) (x)							x x			FI BE
CEO/Clothing brand with circular activities		(x)	x									FI
Principal Researcher/ Technical Research Institute										x		FI
CEO/ Re-commerce company (fashion)								x				FI
CEO/Fibre recycling company (chemical recycling)						(x)	x					FI

4 (X) represents the secondary field of expertise

Interviewee/Field	Designer	Manufacturer	Retailer/brand	Policymaker	Collector/sorter	Waste recycling	Fibre producer	Reuse/resell	Professional association	Researcher	Consultant	Country
Director of Partnerships/Fibre recycling company (mechanical recycling)						x	(x)					FI
Key Accounts & Sales/ Textile waste circulation company					x							FI
Senior Adviser, circular economy/ Ministry				x								FI
Data expert/Clothing brand			x									FI
Leading research scientist/Research Institute (environment)										X		FI
Director/Research Institute (sustainable design)										x		UK
Principal Sustainability Expert/ Consultancy (LCA)										x	x	CH
Educator and researcher (sustainable fashion design)/Academia (design) Designer/ Clothing brand	(X) x									x		DE FI
Researcher, CE, textile waste systems/Academica (business)										x		EE

2.2. Expert workshops

To test and work on the data gaps in relation to policy instruments, two workshops with experts were held. The aim was to reconstruct process knowledge and context knowledge (Flick, 2014) with experts from the field (also covering several areas of expertise), and to test as well as construct an understanding of policy instruments and their ability to cover data gaps in this industrial context. The first workshop was held online and the second one face-to-face. In both workshops, a Miro board was used to collect all the insights. First, the topic was shortly presented and then the participants wrote their answers on the Miro board (see Annex B, Workshop questions and Table 3). Each topic was followed by sharing ideas in a form of reflective discussion. Fieldnotes were collected during the discussions.

To test and work on the data gaps in relation to policy instruments, two workshops with experts were held. The aim was to reconstruct process knowledge and context knowledge (Flick, 2014) with experts from the field (also covering several areas of expertise), and to test as well as construct an understanding of policy instruments and their ability to cover data gaps in this industrial context. The first workshop was held online and the second one face-to-face. In both workshops, a Miro board was used to collect all the insights. First, the topic was shortly presented and then the participants wrote their answers on the Miro board (see Annex B, Workshop questions and Table 3). Each topic was followed by sharing ideas in a form of reflective discussion. Fieldnotes were collected during the discussions.

Table 3 – Themes and questions of the workshops

Data communication		Formats and methods	Challenges in data collection		Data sharing readiness
What type of data are you receiving/sharing with other supply chain partners?	What data you wish to receive?	In what formats and with which methods do you receive and share the data?	What are the current challenges in data collection?	What are the initiatives or opportunities you are part of or willing to utilise?	Are you ready to clarify and share the following
Data that could be used for environmental impact assessments of the products.	What type of data is missing?	Formats and methods in terms of systems, software, platforms	Do you receive enough data for your environmental impact assessment?	S-LCA	Quality of the product
Data about environmental properties of a product during its lifecycle (i.e. data about raw material, hazardous components, recycled materials content, recyclability, reusability etc.)	What data should be mandatory to collect and expose?	Are these tools for assessing the environmental impacts or only tracking the product?	Is the data relevant /useful?	PEF	Lifetime of the product
	What data should not be mandatory?		Do you know how to utilise the data?	DPP	Repair information
	What are the existing data gaps in your supply chain?		Other challenges?	Other?	Recycling information (linking to a product)
	What should be the content?				

First workshop

The first workshop was held in collaboration with the Telavalue project.[5] The Telavalue project is a co-innovation project funded by Business Finland and aims to demonstrate CE solutions for textile waste. Telavalue held an online workshop afternoon on 12 March 2024, on the topic *Future textile manufacturing*. Our workshop, *Data gaps in the textile industry*, was one of the online workshops and gathered 10 international participants from the Netherlands, Slovenia, Finland, Italy, Singapore, the USA, Portugal, and Israel.

Table 4 – General information on participants of first workshop

Industry segment	Expertise	Position at organisation	Country
- Textiles experts - Academia - Tech - Advisory - Research institute - Board EU textile MMCF - Industry Association/Asia - SaaS platform end-of-life solutions Italy	- LCSA, LCA, S-LCA, EPD, PEF - Sustainable consumption - Sustainable business model - Textile innovation - Ecodesign - Textile technology - Textile sustainability - Sustainable digital printing - Recycling of smart textiles - Digital platforms - Smart textiles and their sustainable development	- Self- employed - Doctoral researcher - Advisory - Senior lecturer - Senior scientific officer - Consultancy - Senior researcher - Marketing - Graduate student in sustainability	NL SI FI x 3 IT PO SG US IL

5 https://telaketju.turkuamk.fi/en/projects/

Second workshop

The second workshop was held with FINIX consortium researchers. FINIX is a multidisciplinary research project funded by the Research Council of Finland, which aims to transition towards sustainable textile systems through researching the following topics: new sustainable materials, digital innovations, new design strategies, CE management, and sustainability impacts.[6] The workshop was a face-to-face event at Aalto University, held on 27 March 2024. Seven researchers and one start-up company representative participated in this workshop.

Table 5 – General information on participants of second workshop

Industry segment	Expertise	Position at organisation	Country
- Communications - Academia - Information management - Data integration - Research institute	- LCA methodology, environmental impacts, life cycle inventory data - Digital twins, product data - Semantic Web - Sustainability in business - Sustainable consumption practices, circular business models, sustainable communication - Sustainability assessment (esp. social and environmental sustainability)	- Professor - Researcher - CEO - Postdoctoral researcher - Founder/Start-up - Business lead - Associate professor	FI x7

6 https://finix.aalto.fi/

3. Data gaps

In this section we describe the results of our study. The interviews and workshops results are combined with findings from the literature review. Some insights from the desktop study are also included to provide a holistic, broad view of this specific topic.

> *Already now too many types of collecting and asking data exists. This is problematic and challenging for manufacturing factories in Asian countries (Representative/Industry Association, Singapore)*

3.1. Data throughout the textile supply and value chain

After the food industry, the textile industry is estimated to be the second largest sector producing consumer goods. This industry has always looked for the lowest cost points and savings in manufacturing, and therefore, manufacturing locations have moved around the globe throughout the decades. Currently, most of the mass manufacturing of textiles and clothing happens in South-East Asian countries and Sub-Saharan African countries.

> *Without a chain of custody or certificates, it is difficult to obtain data on raw material production. For example, cotton exchanges already include mixed materials from various sources.*

The fast fashion model shortens product lifetime and reduces order volumes, and thus, it is critical that the cost structure in this business remains profitable. Outsourcing production to other countries increases profitability. However, it also creates new challenges such as maintaining control over production quality, and has environmental impacts and social risks. Transparency is also a significant challenge, especially when it comes to collecting accurate information from long supply chains. In addition, the current level of digitalisation and data management is not very sophisticated, which makes exchanging data between different systems and between stakeholders within the value chain difficult. All this means that product data can be lost, inaccurate, incomparable, or not fully shared among all the partners.

> *[T]here's no such thing as sustainability without traceability and there's no traceability without data... (Jain et al., 2024, p.192).*

The interviewees brought up the need to develop harmonised data management systems and described the types of databases these would require. The interview study highlighted how data traceability and transparency is difficult to achieve in the long, complex textile supply chains. Collecting reliable, comparable, timely, and accurate data into manageable systems throughout the entire supply chain is currently very challenging.

> *Supply chain = production chain from fibre to product and where actions go upstream (value increases)*
>
> *Value chain = actions during the use phase or end of product lifetime phase (value decreases)*

3.2. From fibre to textiles and garments

Currently, tracking and monitoring fibre or yarn production processes is hugely challenging, as the traceability is lacking throughout the complex textile supply chain. "Every cotton fabric and piece of apparel that we use today is constructed from millions of small fibers. The fabric may be labelled as 100% cotton, or a cotton-blend, or a manufacturer might claim to have woven fabric from yarn of a specified count, or to have produced a product through a specific process, or in a particular country, or from a certain species or a specific cotton variety. Currently, it is very difficult to objectively verify such claims" (Das et al., 2017, p.5). Even if there is pressure to increase transparency in the textile supply chain, it is hard to do this in practice if "knowledge intensive, trust-worthy system with high levels of accountability and integrity" (ibid.) are lacking.

Cotton is a good example of this complexity of the supply chain. Cotton is cultivated and harvested in many places by local farmers, and the fibres are collected to procurement centres. In most cases, they are co-mingled with cotton material from other sources. Several processes follow: ginning, spinning, dyeing, weaving or knitting, and then cutting and sewing the textile into a garment (Das et al., 2017, p.5). These processes are conducted by different stakeholders, who in most cases, do not know each other. Information gathering throughout these steps is challenging and requires trust. "The farmer may claim, and may even produce a certificate to verify, that the cotton he/she produced is in compliance with strict organic-cotton guidelines. Based on this claim, the entire value chain could continue to label the product as 'organic-cotton'. The current identify programmes are based at least partially on a 'belief-system' that all claims are trust-worthy" (Das et al., 2017, p.6).

> *Global manufacturing has risks. 15–20% of chemicals used in this sector are not accepted in the EU (Leading Researcher, Research Institute).*

In addition to collecting information on the origin and content of the fibre, collecting data on the chemicals used in the fibre cultivation phase and the manufacturing processes is also essential. The chemical load of this industry is huge, and the impacts of chemical use on the environment, farmers' and industry workers' health, and even the end users' safety are difficult to evaluate if we have no accurate information on these chemicals. "During chemical usage in textile manufacturing, the limited data on material safety data sheets are often the only source of information, increasing environmental risks from unsafe usage or disposal" (Niinimäki et al., 2020, p.193). Moreover, the chemical content of the product is important information for when the product ends up in the recycling phase. It would enable textiles containing harmful chemicals to be separated from all other textile waste going through the recycling system and harmful chemicals could be 'cleaned away' from the system (Määttänen et al., 2019). Data on the chemicals used in the finishing and dyeing of textiles, as well as on other chemicals used, is important for both chemical and mechanical recycling (this will be discussed more in Section 3.8.).

In garment production, the greatest concerns, in addition to data gaps, are the effects of the working conditions of factory workers in developing countries (this will be discussed more in Section 4.2.).

> *We know very little from each other in the fibre production. (CEO in a fibre company)*
>
> *From Tier 1, it is possible to obtain data and have a dialogue with companies. However, the reliability and comparability of data are open questions, particularly environmental and social data. (Leading Researcher, Research Institute)*

3.3. Data from different tiers/scopes

The concept of tiers is used in the supply chain when evaluating environmental impacts and CO_2 emissions. Tier 4 means raw material extraction, Tier 3 is raw material processing, Tier 2 is material production, Tier 1 is finished product assembly, and tier 0 is office, retail, and distribution. (Sadowski et al., 2019, p.14). This approach currently excludes the use phase and the end-of-life stage of a product from the evaluation.
While calculating CO_2 emissions, for example, the industry talks about scopes. Scope 1 means the company's own actions and the energy these consume. Scope 2 emissions are "indirect emissions from the generation of purchased energy", and Scope 3 emissions are "all indirect emissions that occur in the value chain of the reporting company, including both upstream and downstream emissions" (Sadowski et al., 2019, p.3).

The further back the need for information goes in the supply chain, the harder it is to obtain reliable, accurate data. For example, a fashion brand can obtain information from the factory in which the garment is sewn together (Tier 1). Even this phase is, in most cases, outsourced to lower-cost countries, such as Bangladesh. The next step would be to ask for information on the materials (textiles, sewing yarns, haberdashery, colours), which might already be challenging. Moving further backwards to the yarn manufacturing or fibre cultivation/production phases, data collection becomes even more difficult. The 'power play' in this industry should also be noted. Bigger companies that purchase larger volumes also have a greater influence on the lower tiers and related data issues. Obtaining and managing data can be more difficult for smaller companies due to lower volumes and less resources, such as manual information management often being the use of Excel only.

3.4. Design phase

Fashion designers are looking for sustainable material choices, including recycled materials, which are suitable and have high enough quality for the intended use. Finding sustainability information on materials is especially challenging, and in most cases, designers have only ecolabels to rely on when selecting their materials (e.g. Karell & Niinimäki, 2020). Designers also hesitate to select recycled materials in their products, as recycled materials still have a 'stigma' of not having high enough or the same level of quality as virgin materials. Sustainability-minded designers are aiming for longer-lasting garments, which means durable, high-quality, reusable garments, but no reliable information exists on how to achieve this in practice (ibid.).

> *There is a need for better data to ensure the quality and durability of materials and products, in order to comply with the ESPR. In particular, this applies to circular materials and their quality/performance data. (Sustainability Expert, Industry Association/Finland)*

The goal of the European Commission is to support the sustainability transition in order to eliminate fast fashion, and thus, information on how to design garments that are easy to repair or recycle is valuable. High quality materials and good assembly work provide an opportunity to extend the use time of garments and supports the second-hand fashion business (as quality garments can have several users throughout their lifetime). The goal to move towards a CE and textile circularity practices brings about new information needs. Designers need information on the aspects that affect the recyclability of products. This is currently a moving target, as sorting and recycling technologies are constantly developing. Therefore, such knowledge needs to be constantly updated and requires dialogue between the actors in the value chain. Expecting changes to take place through the new EU regulations (products need to be recyclable), some designers are already avoiding or limiting the use of blends or elastane in garments, as this prevents chemical textile waste recycling. Instead, they are selecting textile material that includes a maximum of 5% of other material (e.g. in cotton-polyester blends). Elastane content might prevent both mechanical and chemical textile waste recycling. The current understanding is that fabric consisting of blends can be recycled with some technologies, but this information might change when recycling technologies develop further.

3.5. Use phase

Use phase data is significantly lacking, and companies are craving it. Currently, there is no data on how many times clothes are used or how many times they have been laundered. Such data would help us understand the effects of the quality work done in the design and manufacturing phase and its connection to real lifetime expectations. Higher quality would enable longer use time or even several users during a product's lifetime. It would also enable an estimation of when the garment will reach its end-of-life stage and when it should be placed in the textile waste collection bin.

> *Of collected textiles, 50–60% are currently re-used, mostly outside the EU, the rest is down-cycled or incinerated. (Head of European Textile Association)*

Use phase data is very personal for consumers and citizens, and most of the time, very sensitive. This makes collecting it challenging. The European Commission launched the General Data Protection Regulation (GDPR) in 2018 as a guide to protecting personal data. It also prevents companies from collecting users' data without their consent.

Our interviewees claimed that users need an incentive to share their use data (these incentives might be organised through loyal customer programmes, for example). Furthermore, it is important for consumers to understand why sharing their use data would be meaningful. However, collecting very sensitive data or personal information is not necessary; more general data on the products' usage and maintenance would suffice.

There are also data gaps regarding the product information that is available to consumers. Consumers need clearer data on products' environmental and social impacts and textile circularity. At the moment, navigating the jungle of various certificates and labels to understand the impact of their buying decisions is confusing for consumers. According to one interviewee, the EU currently has 230 different environmental ecolabels. The Green Claims Directive (GCD) should help harmonise the numerous ecolabels and certifications being used.

We present an example of use phase data from the workwear sector, in which renting garments is common. In a rental system, using an RFID code (radio frequency identification) enables tracking the garment and checking how many times it has been laundered. In this way it is also possible to define when the garment's usable life will come to an end and when it should be removed from use and placed in a recycling bin. Accurate data on the use phase, such as the exact lifetime of a product, is also helpful when designing durability and aiming towards a longer garment lifetime.

> *Some brands are also developing digital solutions to make product data more easily accessible to customers through, for example, a QR code that reveals product data as well as care information, which would then also be available in the reuse or resale phases.*

3.6. Data in textile (waste) circulation

By 2025, all EU countries will have to organise separate textile waste collection and place textile material into an effective recycling system (Directive (EU) 2018/851). This is part of the European Commission's Waste Framework Directive, and these new regulations are in line with the EU Strategy for Sustainable and Circular Textiles, which aims to support the green transition in the textile sector. To enable effective and economically viable textile waste collection, sorting, and recycling, different kinds of data are needed (this will be discussed in more detail in Sections 3.7. and 3.8.).

There is a significant lack of data on the downstream textile processes (product use and end-of-use phases), and there is little knowledge about how downstream processes work. In particular, detailed information on the number of resources, such as energy or water consumption, or the amount of chemicals used in downstream actions and in textile recycling is lacking. There is also a lack of reliable, accurate, and timely data on post-consumer waste markets (waste coming from households) and more detailed data on the types of waste materials and their content (fibre and chemicals).

The aim that all textile waste will be collected in the EU by 2025 creates a completely new situation, and data collection could help us obtain a realistic understanding of the amounts, content, and recyclability of the waste created, and help establish business measures for waste handling and the use of textile waste in industry. Kaber et al. (2024) propose a data baseline for a more concrete starting point for textile circulation. These guidelines for waste mapping are meant for municipalities, as they are the authority that collects textile waste and follow textile waste streams.[7] This data baseline would enhance collaboration and decision-making on national and international levels and enable effective textile waste recycling. In this sense, the key areas for baseline data are *collection points*, *sorting inflows and outflows, population and geographic information,* and *waste actors* (see Table 6). The baseline should be built for all municipalities, collectors and sorters, and the data should be collected over a period of 12 months and include all the activities within the textile waste chain. The data could be both quantitative and qualitative. Quantitative data could be used to set a baseline for comparing impacts over time, and qualitative data would give the numbers a context. Qualitative data can be collected in feedback form through surveys, thus evaluating the current knowledge or participation of citizens in textile collection and reuse options. (Kaber et al., 2024.)

Table 6 – Minimum list of data to collect for waste baseline

Subject	Data points	Data reporting frequency
Collection points	- Location - Type of collection points - Collector (legal entity)	During baseline, updates as changes occur
Textile quantities collected	kg or tonnes - Preferred: data available per pick up - Alternative: weekly or monthly totals - Worst case: Daily totals for collection route and list of specific containers on the route	Preferred: Monthly Alternative: Quarterly
End points of collected materials	kg, tonnes or % of total	Preferred: Quarterly

[7] See more https://drive.google.com/file/d/1Mu88a0nIR8mMcZkEU0wQNlCL1whdHolV/view?_hsenc=p2ANqtz--RnIgqX-YSs0HpZEZgryEf6NDNd5HYM1KilCWPMNA-oTc22DKoqoiPfyGcSwL0m1nbjcl-tx4-ufHxsBmiGxb6SJFG1A&_hsmi=86905566

Subject	Data points	Data reporting frequency
	- Export out of EU before sorting - Textile reuse – Country of collection - Shoe reuse – Country of collection - Textile reuse – Outside country of collection - Shoe reuse – Outside country of collection - Recycled – All types - Waste	Alternative: 6 months Minimum: Yearly
Entities	- Legal name - Location - Registry name - Registration number - Activities	During baseline, update as changes occur
External data needed	- Estimated total kg of textiles in circulation in the country - Square km in collection area - Population in collection area	Yearly

Source: Kaber et al., 2024, p.5

Although the CE approach is gaining popularity, and the amount of collected textile waste amount, it is also important to understand how to make business out of this waste stream. The most desired type of textile waste is the kind that could easily be put into a fibre-to-fibre recycling system, especially the kind that could go into chemical textile waste recycling or that could be up-cycled (this is discussed more in Section 3.8.4). It is estimated that only 10–20% of textile waste is included in this part, and therefore it is important to obtain data on textile waste streams in different countries.[8] The critical issue to be able to build real business from textile waste is that we need data on not only the amount of this waste, but also on its fibre content.

There is also a clear lack of knowledge on how to estimate the circularity of a product, and current tools are not suited for this. The existing tools are not product specific and focus more on the process management level than on product level estimation. Evaluating, calculating, and managing product circularity, especially the whole life cycle aspect, is challenging. Life Cycle Sustainability Assessment (LCSA) methodology to support decisions related to the CE and new standards for product circularity assessment are under development.

Life Cycle Sustainability Assessment (LCSA) *is a method used to evaluate the environmental, social, and economic impacts of a product or service throughout its life cycle. By considering sustainability aspects throughout the life cycle, from raw material extraction to production, use, and disposal of the product, it provides a more comprehensive view.*

[8] It is estimated that around 75% of low value textiles can be used in recycling. The best percentage, 10%, goes to reuse, the next best one is 40% and the lowest that is still possible to recycle is 15%. In addition, 15% can be used, for example, as industry wipes, and around 8% can be used in mechanical recycling. (Watson et al., 2016)

3.7. Data in a circular economy

The European Commission wants to create more control over environmental and social issues in the industrial context. Companies are under pressure to construct strategic sustainability objectives. Therefore environmental, social, and governance (ESG) programmes have gained attention in circular supply chains. "The circular economy is based on 'principles of closed loops' in which waste is returned to industry as a valuable raw material" (Niinimäki, 2018, p.18).

There is a concern that the new data requirements will lead to too much complexity and costs for companies. Will this hamper the development of circular solutions by becoming too resource-intensive?

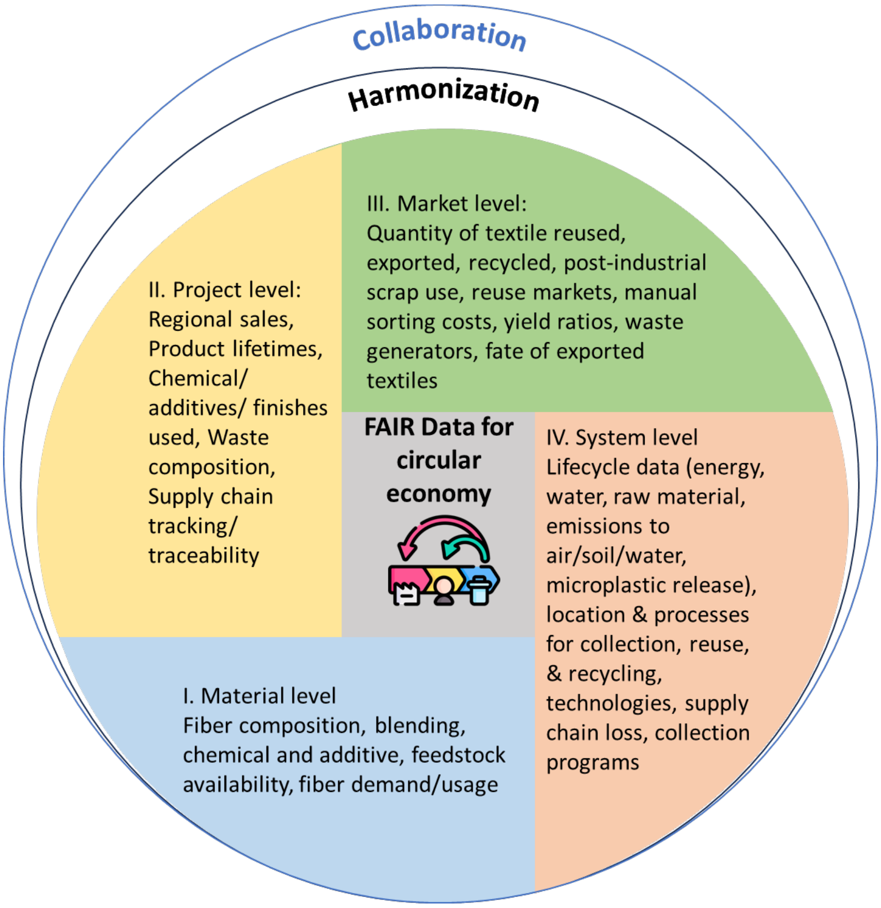
Figure 1 shows how the approach to a CE starts from FAIR (findable, accessible, interoperable, and reusable) data (Schumacher & Forster, 2022). FAIR data can be classified into various levels. At material level, information on fibre composition, fibre blending percentages (e.g., cotton-polyester blend), and chemical and additive content should be included. At project level, regional data on sales and product lifespans could be included. Tracking/traceability of the supply chain could also help data collection. At market level, the quantity of post-consumer textiles reused (thrifted), exported, recycled are required, as is the amount of post-industrial use. At the system level, when evaluating the environmental burden of textile products, life cycle inventory (LCI) the use of energy, water, raw material, as well as outputs into the air, soil, and water (including microplastics) need to be quantified.

*The **Life Cycle Inventory (LCI)** is a crucial component of the **life cycle assessment (LCA).** It involves collecting and quantifying data related to the inputs, outputs, and environmental impacts associated with a product or process throughout its life cycle.*

***Data Collection**: LCI data encompasses information on raw materials, energy consumption, emissions, waste generation, and other relevant factors. Data is gathered from various sources, including industry databases, scientific literature, and company reports.*

The LCA results are sensitive to locations and processes associated with collection, reuse, and recycling, changes in technology options for material recovery, rejects and losses at all points in the supply chain, and options for EOL treatment, including provision for material collection, sorting, and distribution (Schumacher & Forster, 2022).

Figure 1 – For circular transition, FAIR data needs to be collected, harmonised, and shared between all collaborators



Source: Adapted from Schumacher and Forster, 2022, p.26

3.8. End-of-life phase

As there is a huge push to move towards a circular economy (CE), new information on textile circulation is needed. Data on the lifetime expectancy of a product would help us estimate the amount of material returning back to industrial processes (collected as waste). This in turn would help the waste handlers as well as the fibre producers estimate their resources as well as their business opportunities. The areas of circular design lacking data are areas such as product longevity, resource use, waste prevention and diversion, reuse, remanufacturing, recyclability, and the use of safe, renewable, and recycled inputs.

Post-industrial textile waste = Cut-off leftovers from industry. Clean, and content is well-known.

Pre-consumer textile waste = Unsold textiles and garments. Currently rebranded, sold in outlet shops, donated to charity, thrown into landfill, or incinerated.

Post-consumer textile waste = Comes from households. Mixed and unknown content, hard to effectively sort into reuse or recycling. Hard to recycle because of fibre blends, chemicals, and finishing and the need for assembly work to separate nonrecyclable parts (e.g. labels, zippers, buttons).

There is growing interest in using recycled fibres from pre- and post-consumer waste, but no accurate, up-to-date data on the volumes or composition of this waste material are currently available. This makes it very hard to scale up new textile recycling innovations, as it is difficult for investors to estimate the business potential in textile waste recycling, especially in upcycling textile waste to high-quality yarn that can substitute virgin materials (e.g. through chemical regeneration technologies). Data on recycling processes is largely lacking, which makes it difficult to analyse which types of recycling would be most efficient and beneficial for the environment. It is important to receive up-to-date information on recycling technologies, but this information is also highly sensitive from the actors' perspective, as it might be categorised as confidential business information.

There are several challenges and gaps in data collection and verification for the circular transition. One significant issue lies in downstream data, which poses a greater challenge than upstream activities because verifying claims against actual practices is more difficult. There is also a substantial gap In data on the use phase: it is essential to have real 'wearing' data and not just information on how long a product was owned but not necessarily used (most of our garments stay unused or seldom used). Assessments often encounter “wild assumptions” that need to be countered by accurate information to ensure reliability.

The transportation of circular garments presents another gap, where the frequency of use becomes a critical factor. Tracking mechanisms could offer valuable insights, especially if post-purchase information related to user behaviour can be obtained. Specific questions arise regarding the destination of recycled products: Where are they going? How much is sent to developing countries? How much ends up in landfills versus being genuinely reused? These gaps highlight the need for more comprehensive and accurate data collection methods to effectively support the transition to a circular economy.

3.8.1. Reuse and re-commerce

There is a huge impetus on data collection in the textile sector, and data from customers is the most important. For instance, the textile and apparel industry rely on real-time data collection and predictive analytics for insights into customer preferences, market trends, and supply chain efficiency, which ensures that companies can make informed decisions to optimise production. This permits companies to forecast demand on the basis of consumers' style and colour choices and to keep providing a variety to retain consumer interest. Fashion companies have used consumer data to enhance sales, which means the need for data collection for market success is well-understood in the sector (Data Pilot, 2023). Companies collect data from sale figures and customers' feedback.

Most textile and fashion companies, at least the sustainable ones, work hard to control the quality of their product. The price of a product is quickly forgotten after its purchase, but quality is something that stays with the consumers for a long time. Some consumers are looking for quality aspects and repeat their purchases on the basis of their quality experience of a certain brand. Consumers say that they rely on certain brands that have offered quality clothing, and thus, clothing quality can create loyal customer relationships with a brand. This is valuable from the business point of view in uncertain fashion markets. An especially critical phase is the first laundering of the garment and how well the garment keeps its fit, colour, and look during the use and maintenance phases. (e.g. Niinimäki, 2011; Aakko & Niinimäki, 2021) High garment quality also enables longer use time and therefore extends the product's lifetime while also enabling and supporting the second-hand business. High quality is also one asset in the fight against fast fashion, which tends towards short use time garments.

Use phase data (e.g. on duration of use, washing, maintenance, and repairs) is currently lacking, but it is important for estimating the quality of items in the second-hand market. Statistical data on, for example, the lifespan of different garments/products/materials is also relevant. For the second-hand market, data that helps us estimate the quality of garments (or other products) and their resale value is important. Through such data, longitudinal data from second-hand sales in particular, the price of a garment in the second-hand business can be defined more accurately. Certain brands with high second-hand value could include this aspect in their original product prices when garments are bought for the first time. The fact that this garment could be sold again within a certain price range in consumer-to-consumer business could provide a competitive aspect. This would also enable companies to include second-hand business as part of their own activities and calculate its business potential.

Regardless of data, the overall quality of products and materials is ultimately the most important aspect that affects sorting, the potential for reuse or recycling, and the possibility to make business out of re-use or recycling.

For the resale market, digital product passport solutions might be particularly relevant, as they would make the whole chain of custody visible. It is also beneficial for second-hand customers to be able to access original product data on the second-hand items.

The second-hand market is an important part of post-consumer textile circulation because the value of second-hand items is many times higher than materials in fibre-to-fibre recycling (upcycling). For policymaking, it is important to consider that this field, the second-hand business, is operated by various players, including third sector and charity organisations. These actors are important players in textile circulation, and their survival should also be considered in the green transition towards a CE and while building the system for textile circulation.

3.8.2. Waste collection and sorting

There are big gaps in the statistical data on post-consumer textile waste. Firstly, it is very difficult to get up-to-date, reliable, and comparable trade data on, for example, the volumes and quantities of post-consumer waste or products released on the markets. The available trade data is limited, outdated, unreliable, and expensive. According to the interviewees, nearer-to-real-time data is needed for us to understand the flow of textiles. In B-2-B[9] solutions, data on the waste materials is easier to obtain, as it deals with more regulated and limited sources.

The available data also affects the efficiency of sorting and how much textile waste ends up in incineration. More accurate data might help define the intended use for different waste streams. Therefore, it is also important to document and lay open the reliability and transparency of the chain underlying the recycled items for all stakeholders.

The need for data on the available post-consumer waste also goes hand-in-hand with the need for a better infrastructure for textile waste collection and a sorting technology. As the amount of collected waste will increase due to the Waste Framework Directive, the importance of such data will grow. Extended Producer Responsibility (EPR) will also potentially bring further incentives for sorters and collectors to improve data reporting.

For sorters and recyclers, price data would also be important, e.g. how much a certain percentage of recycled content affects the price of the end product. To make sorting profitable, price issues throughout the value chain are crucial.

[9] B-2-B; business to business

Mechanical and chemical recycling (see in more detail below) create different data needs regarding the content of the sorted waste. Yet, even more important than data is the need for technological developments to make recycling and sorting technologies more effective. Furthermore, we need a better understanding of the overall quality of the products put onto the market that end up as waste and have to be handled in recycling processes. Sorting for fibre-to-fibre recycling is currently mainly done manually. Automated sorting and identification technologies are needed, but the big question is who will pay for the investments needed. Currently, only a fraction of post-consumer waste can be used for fibre-to-fibre recycling (resulting in high quality fibres that can be reused in textile industry). Both technological development and data play a role in making recycling solutions more feasible.

Besides data, the interviewees from waste collection and sorting underlined the challenges in making sorting profitable and ensuring the transparent distribution of costs and benefits in textile value chains. Although the regulatory push is seen as the utmost necessity to increase recycling, costs and pricing need to be considered. There is no proper market for textile waste at the moment, waste selling is not profitable, and costs are not spread out in the recycling chain.

> *We are very far from reality. We need to get legal requirements and some sort of incentives into effect so that we get the demand. (Post-Consumer Textiles Expert, Waste management company)*

3.8.3. Mechanical textile waste recycling

Mechanical textile waste recycling has existed for a long time. Already over a hundred years ago, garments made from 100% wool were collected, torn to shreds, and spun into new yarn. Currently, it is mainly post-industrial textiles (cut-offs from garment assembly phase) that undergo mechanical textile recycling, as their fibre content is well known, and their quality is high. Mechanical recycling reduces the quality of the fibre (it becomes shorter in the process), and therefore virgin material needs to be added to reach sufficiently high quality. Thus, post-consumer textile waste can be mechanically recycled, but the end application is seldom the garment industry and the products go to other application areas.

Mechanical recycling is less sensitive than chemical recycling in terms of the fibre (and other) content of the materials. In mechanical recycling, data on any (harmful) chemicals used in textiles is particularly important and often lacking, even in certified textiles. As mechanical recycling processes cannot eliminate chemicals from the textile, the lack of chemical data limits both the ways in which recycled fibres can be used and compliance with the requirements concerning chemicals.

Mechanical textile waste recycling on the other hand can "digest" fibre blends much easier than chemical recycling. Different blends can be used, and the resulting fibre mix can also be used in different application sectors outside the textile sector, such as in composites or for construction purposes (open-loop-recycling).

3.8.4. Chemical textile waste recycling

Chemical recycling of textile waste is an emerging field, and several technologies are under development, some of which are already scaling up to industrial level processes. Chemical recycling can be used with not only cellulosic fibres[10] (polymer level) but also with synthetic fibres[11] (monomer level). These technologies make it possible to produce fibres with high quality and even use 100%

[10] Cellulosic fibres = e.g., cotton, flax, viscose, lyocell

[11] Synthetic fibres = e.g. ,polyester, nylon, acrylic

textile waste as raw material and still achieve the high-quality yarn suitable for industrial textile manufacturing. Substituting some virgin material with chemically recycled fibres in industrial textile production presents a clear business opportunity.

Chemical recycling technologies can 'remove' some of the harmful chemical content in textiles. This way, they can be 'cleaned' from the textile system.

Chemical recycling requires detailed data/ knowledge on the material content of textiles that affects the chemical recycling processes. Some of the issues on which data (or identification) is needed are:

- Fibre content: percentages of different fibres
- Elastane (not tolerated by many recyclers)
- Colours, dyes, prints
- Chemicals, fire retardants, coatings
- Non-textile parts (e.g. zippers, buttons) that need to be removed before recycling

Regarding both chemical and mechanical recycling, the actors upstream in the supply chain need data on the quality and production efficiency of the recycled fibres. However, as the feedstock comes from different sources, the production efficiency or quality/performance aspects of recycled fibres may vary. Thus, it not easy or currently even possible to provide such data in the same way as with virgin fibres, the content and quality of which is more controlled and homogeneous. This applies particularly to new recycling technologies that can only use one fibre type. In this case, fibre blends are not suitable for chemical recycling of textile waste. It might be possible to place a certain number of blends into the chemical recycling system, but dissolving and removing the other fibres increases costs and decreases the system's business profitability. In chemical recycling, it is important to know the fibre content as well as the chemicals that have been used in textile manufacturing. This situation will probably become easier in the future when the Digital Product Passport (DPP) brings more transparency and information into the system (Legardeur and Ospital, 2024). Moreover, in the future, all textile products will be designed so that they are suitable for recycling. However, for several years we will still be living with garments whose fibre or chemical composition is not well known, which makes recycling them a challenge.

3.9. Environmental impacts and LCA

LCA is the most commonly used tool for evaluating the environmental impacts of production. LCA should be a case-specific calculation to enable tracking of the actual actors within the value chain as well as identifying the raw material resources and how they were produced. Visibility is limited in upstream actions, and in the data on upstream processes, resource use, and yields for LCA. LCA is most often relied on as the average data bank with general assumptions from figures of cotton, polyesters, or other materials. From the perspective of LCA, geographical location data is important for tracking products.

> *LCA is built on a linear model not a circular one (CEO, fibre recycling company)*

Several secondary and generic databases are used for LCA, such as the *Ecoinvent Database*, which was developed by the Swiss Centre for Life Cycle Inventories, and the *GaBi Database* developed by ThinkStep. These are among the most comprehensive and widely used LCA databases; they provide detailed datasets; cover a broad range of materials, processes, and activities; and focus on environmental impacts. Both offer global coverage and are regularly updated to maintain accuracy and relevance. Application-specific databases include the *Agri-footprint Database,* which focuses specifically on agricultural products and processes; the *WEEE database* for the management of electrical and electronic equipment (EEE), created by the French Producer Responsibility Organization; and the *cm.chemicals database* by Carbon Minds, which performs environmental assessments of chemicals and plastics.

Access to these databases has given rise to 'quick and dirty' LCAs, which are based on average data for various processes rather than case-specific information collected from primary data. The result of such an assessment is hotspot mapping, i.e., finding the potentially impactful areas in a life cycle rather than identifying the most problematic areas. The reporting stage should be transparent, and a company should declare whether they are entirely reliant on these databases for their own environmental assessments. Due to limitations in LCA databases, companies working on innovative materials do not see their product specifications in the databases and cannot claim the benefits of their sustainable products on the basis of LCA results.

For EOL (end-of-life) assessments such as recycling, it is more straightforward to quantify the benefits in closed-loop recycling scenarios, such as aluminium recycling. However, challenges arise in open-loop recycling, such as using PET bottles for clothing, due to limitations in the LCA methodology related to consequential modelling issues. Specific data related to the production of clothes, including information on dyes and chemicals, is essential; but it is often hard to obtain. The **PEF (Product Environmental Footprint)** is set to become mandatory, but its reliability hinges on its maintenance and the upkeep of existing databases such as *EcoInvent;* otherwise, there could be significant reliability challenges. While PEF can standardise LCA data to some extent, its scope is limited.

It is difficult to acquire transportation information specific to a location, and even the transportation method affects LCA, although in most cases it is not included in the calculation (estimating the transportation impact according to one product means that the effect remains quite small). There is currently no clear method to cover microplastic/microfibre release, which presents a major threat to aquatic ecosystems. Biodiversity impacts remain unclear, meaning that it is difficult to make claims about the impacts until further studies are conducted. The focus of LCA is primarily on information from the production process (impacts up until the factory gate), particularly consumable energy usage and outputs, including emissions. Companies often struggle to provide this data, as it is not a standard request, and the information may be scattered throughout their organisation.

However, gaps in this information frequently stem from larger companies being hesitant to share data or smaller companies being unable to gather all the necessary information. Some companies purchase the required data, while others rely on electricity consumption measurements, the uncertainty of which was highlighted in the interviews. Over the last 15 years, secrecy has increased, with companies becoming more reluctant to share environmental data due to reputational concerns. Previously accessible data from company reports now often needs to be purchased, or the findings must be concealed. Consequently, access might be limited to LCA results rather than the underlying data needed to ensure correct assessment methodologies. This situation raises concerns about data manipulation. Additionally, data standardisation and quality are significant challenges, as the level of detail and format of data provided by the companies under assessment can vary greatly.

3.10. Social sustainability and S-LCA

The social impacts of the textile and fashion industry are also gaining more importance in the new EU regulations. However, it is not easy to obtain information on them or even know what information to collect. Data gaps are especially evident in relation to marginalised and disenfranchised groups such as informal and migrant workers and women. The data currently available on manufacturers' DEI (diversity, equality, and inclusion) policies is limited. Significant data beyond basic gender breakdowns, on broader DEI indicators, which would be essential to prompt effective measures are often neglected in data collection tools. While S-LCA is particularly influenced by the geographical location of the manufacturing, data on locations is especially hard to come by when tracking products.

One S-LCA database is the *Social Hotspot Database* (SHDB), developed by New Earth to provide social impact data associated with the various stages of product life cycles. It offers information on labour conditions, human rights, community well-being, and other social aspects, facilitating the assessment of social sustainability. PSILCA, or the *Product Social Impact Life Cycle Assessment*, is a methodology for assessing the social impacts of products across their life cycle stages. It relies on existing social data sources and indicators to be able to assess social impacts comprehensively. Benchmarks for social LCA are obtained through the available standards and programmes such as the *ILOSTAT Database,* which is maintained by the International Labour Organization (ILO), and offers a wealth of labour-related statistics on employment rates, wages, working conditions, and social protection coverage, for example. The Human Rights Commission offers guidelines for ensuring that everyone in the supply chain is treated with dignity.

By utilising these databases and methodologies, practitioners can conduct S-LCA studies to evaluate and mitigate the social impacts of products and processes, contributing to more socially responsible and sustainable business practices.

3.11. Data challenges

To achieve **traceability and transparency** (see Sections 5.2. and 5.3.), sensitivity and privacy concerns need to be considered in data collection and sharing. What data are needed and who can see the data are key issues or concerns. Trust and sensitivity issues affect the openness of data systems – these are often the reasons why some data are not openly available. Moreover, data ownership issues can cause problems when sharing data. Data opens up business opportunities and includes business non-disclosure information. "Some value chain actors may be concerned with generating economic value and beating the competition, but others may focus on facilitating a cultural shift, therefore creating value that serves both them and society as a whole" (Jain et al., 2024, p.191).

> *The whole sector (industry) needs to decide the format of data to be collected. (CEO, clothing brand)*

Another concern and challenge is the reliability and validity of data. According to some of the interviewees, in the absence of data requirements, companies mainly try to operate on the basis of trust and codes of conduct.

> *Business sensitive data is one of the core problems in getting really up-to-date information. (Sustainability Leader, Research institute)*

3.11.1. Missing data

Transparency in the textile supply chain is a considerable problem, but in moving towards a CE, data might have an even greater influence; it not only informs but also pushes decision-making in the right direction. Data can "enable this shift from a linear textile value chain to a more circular one…Currently, the understanding of the benefits that can be achieved by data is limited, as is the availability of data across the value chain and pilot cases to showcase the achieved environmental, social and economic gains…In isolation, data are rarely usable in their raw form; they need to be processed into meaningful knowledge or indicators or have a context in order for decision-makers to understand their value and implications" (Jain et al., 2024, p.182). The large amount of data is still missing creates further obstacles for the sustainability transition. Table 7 presents comments from the interviews and workshops on the main concerns regarding missing data.

Table 7 – What type of data is currently missing

What type of data is missing	
PRODUCT-RELATED - technical lifetime of a product - durability (materials and product) - recycling information, EOL - detailed content (fibre, chemicals) - harmful chemicals used in dyeing/ finishing - materials not easy to recycle **LOGISTICS** - data from transportation - freight shipping emissions - social impacts from freight shipping **USE** - use phase data of a product - use phase effluents from washing - real use time **SYSTEM** - input/ output gap concerning energy, water, chemicals, materials **WASTE** - data linked to second-hand use/ landfilling of textiles exported to low-income countries - data linking to waste streams	**TRANSPARENCY** - traceability throughout the supply chain - accurate data from material supply chain **ENVIRONMENTAL** - scientific estimates on the rate of microfibre release based on fibre composition - health and ecosystem impact relations from microfibres/ microplastics - release of dyes and additives and other persistent organic pollutants from microfibres - ecosystem impact from indirect emissions into water during bleaching/ dyeing - real energy data at company level - data from biodiversity loss - risk estimation from the use of chemicals **SOCIAL** - human rights data - working conditions **OTHER** - public data from websites in structured format - data related to design decisions - up-to-date, real-time data, dynamic data - calculations do not fit CE model (they are made for linear model only, e.g. LCA) - granularity of data differs for various databases

Source: from interviews and workshops.

A huge amount of data is still needed on production, logistics and the products themselves. Also, the transparency of the downstream data is limited for the CE transition in terms of the composition of recyclables/ recycled products and waste streams in general. Data on environmental impacts and risks could be improved and information on biodiversity loss is lacking. It is difficult to estimate the microplastic or nano-plastic issue in textile products, or even plastics in general, as well as their environmental impacts.

The EU's new regulations also highlight the social side of sustainability, which should be better calculated and estimated in the future. A primary focus of S-LCA studies is the impact on workers. However, information on who made the clothes and under what conditions is hard to come by (United Nations Environment Programme, 2020). Even in countries with assured workers' rights, informal workers might not be protected. Further, although the CE transition will lead to changes in the materials handled by waste recyclers, transparency in the chemical content of textiles is limited, which might create further risks for textile waste handlers (United Nations Environment Programme, 2020).

3.11.2. Accessibility

One problem in demanding more transparency from the textile sector is the accessibility of all the data needed for certain evaluations. Closed data banks make it more difficult to calculate footprints. For example, LCA impact calculations are very expensive, highly complex, and not accessible to all actors. An easy, simple-to-use tool with high transparency is needed in this case. Our research participants called for more open and accessible data, but business aspects on how to manage the data and who owns the data also need to be taken into account. Although data sharing plays an important role in the circularity of the textile supply chain, not all actors are willing to open up and share their process data. Only limited data is shared with certain actors and selected partners. Sharing data is also opposed for business reasons (confidential information).

> *Access to information may work better in theory than in practice (Jain et al., 2024, p.192).*

There is also the concern that the scientific approach of LCA does not include all the criteria or all the databases of the textile industry, meaning that we can only calculate the issues that are in these LCA databases. If all required data does not exist, this might lead to limited and perhaps even inaccurate calculations.

> *Data is gold, so whoever has the data has its value. You need to put a price on it if you order the actors to release it or at least make it comfortable. (Leading Researcher, Research institute)*

A discussion is underway on whether governments should resource open data banks to help data collection through the supply chain and provide data for footprint calculations. However, keeping such banks up to date, and further updating and resourcing them is difficult. One interviewee suggested that at least a minimum threshold of data/information should be provided in publicly available data systems.

> *Then the data becomes bigger, easier to validate, and more accessible in a shorter period of time. In 2030, we could actually see these sorts of results becoming more commonplace. (Consultant, research consultancy)*

Gathering data from the whole product lifetime is challenging. We still have more data on the supply chain's upstream actions than on the downstream actions (e.g., use phase, end-of-life stage), which limits life cycle estimations. As we know, product-related information from the whole life cycle is not fully accessible, and DPP is planned as one solution to improve and enable better data accessibility throughout a product's lifetime. One researcher also proposed to build the DPP system in such a way that it could be based on real-time data, meaning that the system should be dynamic, and the data should be collected and updated constantly.

3.11.3. Data management

Even though companies realise the importance of data, their data sets are often unstructured (Devillard et al., 2021). They collect information from existing stocks, retailers, and e-commerce platforms, but the "truth is, most fashion and luxury companies have expensive legacy systems built on inflexible, non-scalable, and limited data warehouses that cannot integrate new data sources." Hence, Devillard et al. (2021, p.4) suggest that companies should modernise their data architecture to include "cloud-based data platforms, serverless and containerised data platforms and applications, no-SQL databases[12], flexible data schemas, and solutions that provide real-time data-processing capabilities."

> *Each LCA phase or value chain process generates huge amounts of data, which are owned by the actors themselves and cannot be owned by others unless the collection of certain indicators and specific data sets is required.*

The reality is that today, various data management systems exist. The data required in the systems and the way in which the data should be transferred across different systems and from one actor to another needs to be specified and harmonised. Data should be comparable across different systems, and easily accessible. Currently, different actors have different systems for their own needs and perspectives. Data management is easier for big companies than for small ones.

One interviewee pointed out potentially utilising the data management systems already built for ecolabelling and through this, developing systems that adhere to the upcoming regulations.

> *Relevant data exists in such systems [ecolabes], but this is only the tip of the iceberg. (Senior Ministerial Adviser, government organisation)*

Ecolabels are based on standardised information. Researchers have also proposed using ecolabels to collect and share certain information. An ecolabel could also contain information on the expected lifetime of a product (or a code that discloses the year when the product was manufactured), and this information could be connected to eco-modulation fees.[13] When a product ends up at a waste collection point, the reached lifetime could be checked, and if the real lifetime is shorter than expected, the fee can be increased.

3.11.4. Reliability and relevance

A report by the United Nations Environment Programme (2020) highlighted that impacts such as land and water use are strongly dependent on the type of fibre, textile manufacturing processes, and location. The information on the impacts on human health and ecosystems of the chemicals used

> *Accurate data collection and management is a risk point in all actions and all evaluations.*
>
> *How much can we trust that the actors collect the raw data themselves? What of it is collected by third party platforms? And how can we trust that the data is accurate and reliable?*
>
> *If you put a tax or some kind of financial incentive or legislation on the environmental impacts, you need to be sure that they have been calculated in a comparable way and that the background data is reliable.*

[12] No-SQL database = purpose-built for non-relational data models

[13] Eco-modulation fees penalise the use of materials that have high environmental impacts and reward the use of materials that are better for the environment.

in textile production, especially in the wet processing phase (yarn manufacturing, bleaching, dyeing, finishing) is unreliable. Also, microplastic losses (i.e. <0.5 cm plastics) are being introduced into the ecosystem rapidly, without adequate science-based data on their impact on aquatic life, birds, or even humans. Data reliability can be enhanced using standardised data quality indicators. ISO 14040 and ISO 14044 implicitly require adherence to certain data quality criteria such as reliability; completeness; temporal, geographical, and technological correlation; and precision. Data quality indicators may be assigned scores to ensure comparability with other data bases. These criteria help ensure the integrity and reliability of the data used in LCA studies and should typically be documented in each assessment (ISO, 1997, 2006).

Data reliability is also limited by the lack of harmonisation in the definition of certain terms associated with textiles. For instance, Schumacher and Forster (2022) report that even the term 'textiles' is differently defined by various organisations; for some it includes shoes and fishing nets. Other poorly defined terms include waste vs secondary raw material, biodegradable vs bio-based plastics, contaminant, recycling (including downcycling, upcycling, open loop, and closed loop), EOL, recycled content, pre-consumer or post-industrial, and CE frameworks such as recycling, reuse, repurpose, and remanufacturing.

Globally, better reporting standards and data repositories are required to consolidate the information available for the EOL of textiles (United Nations Environment Programme, 2020). The National Institute of Standards and Technology (NIST) at the U.S. Department of Commerce propose the creation of data repositories based on their expertise regarding material analytics. Schumacher and Forster (2022) suggest that institutes such as NIST could develop tools for all industries for fibre identification in post-use textiles, benchmarking feedstock quality for recyclers, evaluating microplastics characteristics, creating standardisation protocols for product design (including performance metrics for durability), and develop methods for treating/ separating blends.

> *The interview data clearly highlighted that digitalisation is needed to safeguard more reliable and accurate data collection and information sharing. The general level of digitisation (how sophisticated it is) affects how easy it is to get data from companies. For example, many smaller actors in the industry still work mainly with Excel. On the other hand, many companies are already collecting a lot of data without knowing exactly how to use it to prepare for future data needs. They are waiting for a change to come with EU regulations and upcoming required reporting systems.* ***An open question from the stakeholder side is how or whether these new regulations will enhance the transfer of data throughout the supply chain.***

While there is a big interest in collecting data, it is also worthwhile discussing what data it is relevant to collect. What kind of data is relevant for environmental impact assessment and social assessment in particular needs to be defined. Otherwise, there is a risk that too much and perhaps even random data gets collected. Moreover, how detailed the product-specific data needs to be in order to perform precise calculations of impacts should be considered. For this reason, more computational infrastructure for a specific product issue, which in return increases energy consumption for various services, needs to be built. A excessively large data system also has an environmental impact because it uses energy and resources. “However, using a novel technology is not required or even preferable in all cases, as it requires processing capacity and energy, the hardware may also require the use of rare and critical raw materials. Before implementing new technologies, it is important to assess their game-changing qualities as well as the additional resources their implementation may require” (Jain et al., 2024, p.187).

3.11.5. Mandatory or non-mandatory

Manshoven and Opstal (2022) have studied stakeholders' viewpoints on the topic of whether data collection and the regulations in the fashion field should be mandatory or non-mandatory. They have found that in general, there is strong support for mandatory regulations and governmental policies to enable the transition towards a circular fashion system. Everything from design, fibre selection, and manufacturing processes to the use phase and the EOL phase was estimated to benefit from strong regulations and "policy-led transition". "Social justice, transparency, traceability, and value chain collaboration" were also mentioned as more "transversal" aspects that could benefit from mandatory regulations (ibid., p.15). Designers strongly supported mandatory regulations, and so did NGOs and reuse companies. Retail and logistics companies also supported mandatory actions. On the other hand, people working at the company's strategic management level indicated less support. (Manshoven and Opstal, 2022). Table 8, on mandatory or non-mandatory data, is built on the basis of the results and discussion in the interviews and workshops.

Table 8 – What data should be mandatory and what non-mandatory

What data should be mandatory or non-mandatory	
Mandatory	**Non-mandatory**
FIBRE + CHEMICALS - origin of the raw materials - resource consumption of raw material extraction processes - detailed content - production process - hazardous materials - included fossil-based materials **DESIGN** - data for design decisions **USE** - care instructions for maximal durability **REUSE** - previous lifetime, recycle times - quality estimation **END-OF-LIFE** - data linking to product recycling at the end of its lifetime - recycling options - quantity of waste - data on energy, water and chemical consumption in recycling - information from the company level how much goes to reuse or recycling **DECISIONS** - data that you can use in decision-making - sustainability of different stakeholders - data to improve ESGs (environmental, social, governance actions)	- labour costs - sensitive economic/business data - transportation - number of uses

Source: from interviews and workshops.

The World Business Council for Sustainable Development has been developing a Circular Transition Indicators (CTI) tool to be used in the fashion sector while moving towards CE and estimating circularity in fashion. "Due to their importance, some indicators for the sector should be mandatory. However, as data availability can be an issue for some indicators, specifically for the ones where most of the information lies outside of the company, CTI users can consider important indicators with low data availability as recommended. For each step, the sector guidance provides recommendations on which indicators to select for each level of the assessment. The guidance defines which indicator is mandatory, recommended or optional for each level of the assessment. In line with this, 'mandatory' refers to indicators that are mandatory for compliance with the CTI framework but not necessarily mandatory for reporting standards, such as the Corporate Sustainability Reporting Directive (CSRD). Hence, for assessments focusing on other purposes, fashion companies have the liberty to select their relevant indicators." (WBCSD, 2024, p.39). In this report, the mandatory aspects to take into account while aiming to close the resource loops are the material circularity aspects of a product, facilities, and corporate levels (See Table 9). The report also points out that water circularity should be mandatory information at all levels, from facility to corporate. To optimise the loop, mandatory information includes the recovery type for a product or material (EOL information).

Table 9 – Mandatory aspects while closing resource loop

	Product	*Facilities*	*Corporate*
% material circularity	*Mandatory*	*Mandatory*	*Mandatory*
% water circularity	*Recommended*	*Mandatory*	*Mandatory*
% renewable energy	*Optional*	*Recommended*	*Recommended*

Source: WBCSD, 2024, p.39

3.11.6. Data costs

Most of the interviewees raised economic and resource-related aspects related to the upcoming data requirements. Who pays (e.g., for the development of data management systems and infrastructure and for the workforce needed for reporting data) is a big question. They portrayed the potential risk of data requirements becoming too complex and resource-intensive; this might hamper the development of circular and sustainable solutions in a sector populated by many small players. Many interviewees suggested there should be **economic incentives** attached to reporting. In addition, tax incentives should be considered as motivating consumers to, for example, buy circular or more sustainable products.

The upcoming regulations will create cost pressure, and the interviewees raised a concern for the survival of smaller companies and charity organisations, which are important to the textile sector. This should be considered in policy development. Companies are particularly worried about competitivity aspects, and the management and economic impact of the regulations (i.e. costs and resources needed). For example, companies need new IT expertise, and this is expensive. Managing the product information and sourcing data also creates costs, as well as related development investments.

The costs should not only be covered from the companies' pockets. (Digital Programs Director, apparel brand)

Good players are not rewarded. (CEO, garment brand with recycling actions)

I really fear that a lot of third-sector big business at the moment are threatened by this producer responsibility, and they shouldn't be.

We need all the different players, we need charities. We need the resell; we know we need all of these players, and it shouldn't be a competition. (Post-Consumer Textiles Expert, Waste management company)

4. Tools, policy actions, and data

The various regulations that exist or are currently under development will demand much more transparency from the textile sector, which requires all stakeholders to share information and data. Industry-wide standards and harmonised definitions of data are also currently lacking. Identifying critical data points and standardising them will help this sector collect this data, which can then be used in certain evaluations and calculations. Extending the standardisation of terms and definitions to product labelling, digital or otherwise, will also be pivotal in enhancing consumer awareness about care, origins, and material composition (GFA, 2023). This information will also help enhance actions towards a circular economy. In this section we will go through the main tools and policy actions which need further data in order to understand the actual data needs for policy.

4.1. LCA Life Cycle Analysis

LCA is a tool used to evaluate the environmental impacts incurred during the entire life cycle of a product, from raw material extraction to EOL management (ISO, 1997, 2006). It consists of four phases – defining the goal and scope of the study, collecting the data inventory for each life cycle stage, characterising and assessing the impacts, and reporting the interpreted results (ISO, 1997, 2006).

In the circular transition of the textile sector, LCA may help identify opportunities for improvement in environmental performance through reducing resource consumption, energy use, greenhouse gas emissions, and waste generation through material recycling, reuse, and extending products' lifespans (Gonçalves & Silva, 2021). This is essential in order to balance the resource requirements to extend products' life spans and to introduce new products made with higher energy efficiency (Peña et al., 2021). The former is based especially on electronics, but textiles need a broader discussion in regard to LCA. Additionally, although the reuse/ repurpose/ recycle of existing textiles would avoid emissions from raw material extraction/ cultivation, the avoided emissions need to be more than the emissions incurred from the use phase (including transport) of the clothes (Roos et al., 2019). A comparative LCA is useful for benchmarking the environmental performance of different textile products and production methods to guide industry-wide improvements (Hammar et al., 2023). This would promote transparency and give credibility to circular claims by offering a scientifically rigorous methodology for evaluating sustainability performance.

The challenge with LCA is collecting data collection at each stage of the product's life cycle, which requires collaboration among all stakeholders, that is, the raw material producers, textile manufacturers, retailers, consumers, waste management companies, and industry associations or regulatory agencies. At the raw material production (through cultivation or extraction) stage, data on the environmental impacts of fibre production, such as water usage, chemical inputs, energy consumption, land use, and emissions, is obtained from the primary producer. Textile manufacturers provide data on raw material transport, production processes, and product specifications. During manufacturing, which may happen in the same area as raw material production, information on energy consumption, greenhouse gas emissions, water usage, chemical usage, and waste generation is required. Another consideration is the data on transportation-related emissions, packaging materials, distribution distances, and logistics efficiency. For LCA of a circular intervention such as transitioning from virgin to recycled fibres, water and chemical usage in fibre processing needs to be identified during manufacturing (Hammar et al., 2023). Manufacturing processes also include dyeing and finishing processes. Retailers provide data on distribution logistics. In a cradle-to-grave assessment of textiles, the LCA results should account for consumer behaviour that would determine the garment lifespan on the basis of washing frequency and energy use during care and maintenance (Horn et al., 2023). Consumers can provide insights into garment use, care practices, and EOL disposal through surveys, interviews, and behavioural studies. Waste management companies can disclose information on the environmental impacts of disposal methods through waste audits and monitoring. The changes in the methods for designing garments for durability, repairability, and recyclability, incorporating modular or interchangeable components, and using eco-friendly trims and labels means that data collection needs to expand to account for these practices. The industry associations and regulatory agencies facilitate data sharing, standardisation, and verification efforts to ensure consistency and accuracy in LCA. Since LCA is iterative, improved data quality would further optimise environmental performance. Additionally, within a CE, the LCA tool may be used to evaluate the impacts of the EOL stage, for which data on disposal methods, recycling rates, and material recovery efficiencies is required.

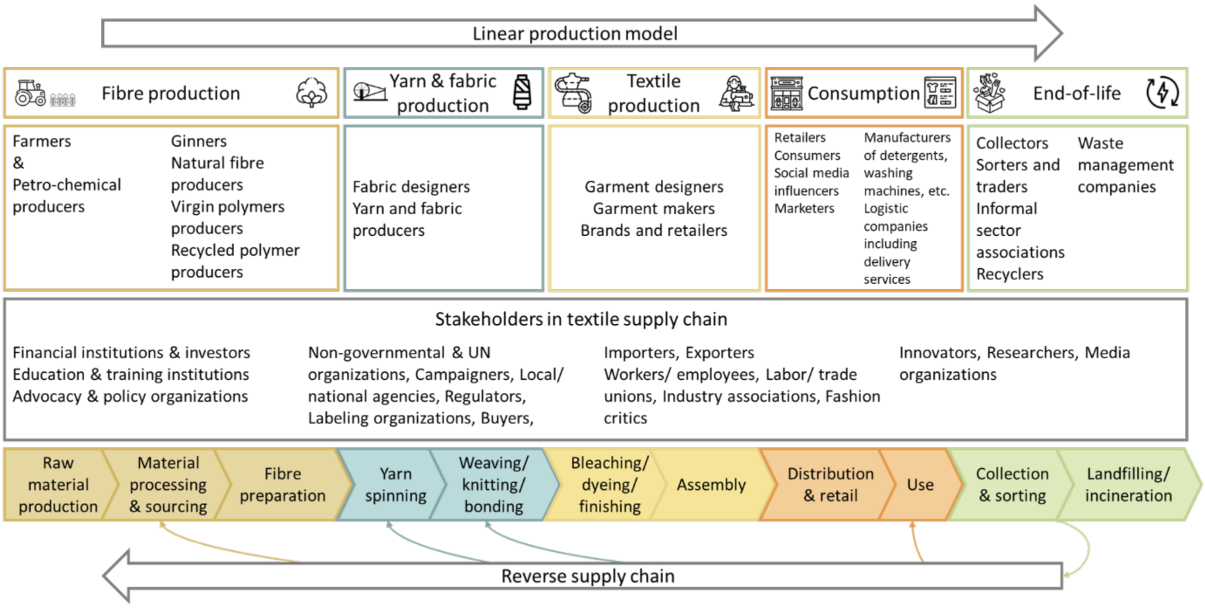
The data inventory is used for impact assessment, and the results of the environmental performance of textile production are measured in terms of multiple impact categories such as global warming potential through greenhouse gas emissions, water use, ozone depletion potential, ecotoxicity through emissions causing eutrophication or acidification, and the impact on human health impact of carcinogens. For clothes, natural fibre production (esp. cotton), wet processing, that is, the bleaching/dyeing/finishing stage of textile production, and consumers' washing frequency stand out as water intensive activities. Wool production impacts land use due to animal rearing requirements, whereas synthetic fibre production will have a higher global warming potential due to increased fossil fuel use. Microfibres, which have emerged as an issue of the use phase, are not yet understood or quantifiable. The environmental impact of textile production is also dependent on the manufacturer's use of energy mix for their equipment. For instance, Asian countries, which that account for the highest manufacturing activities globally, are reliant largely on thermal power plants for electricity production. The use phase in these locations will also have a higher impact because consumers use coal-based electricity for washing purposes (United Nations Environment Programme, 2020). However, a source of uncertainty arises from the inability to determine consumer behaviour based on income levels and to access resources such as electricity and water. These regional assumptions may attribute higher impacts to individual members in the supply chain, even if they use 'cleaner' sources of energy for their operations (Roos et al., 2019). Many studies have not covered use phase transport data, which might also be considered for circular transition, in which the consumer is expected to bring back reusable or recyclable materials as found by Roos et al. (2019).

4.2. S-LCA Social Life Cycle Analysis

Providing insights into the social dimensions of sustainability to complement environmental assessments and ensure holistic decision-making has led to the development of the S-LCA tool (Benoît et al., 2010). S-LCA is based on the same framework that is used to for environmental LCA but focuses on the social impacts occurring throughout the life cycle of garments. Specifically, S-LCA is used to assess the social impacts of the production, use, and disposal of garments on the people involved in the supply chain. These people are referred to as stakeholders and categorised into workers, consumers, local communities, value chain actors (suppliers, retailers, etc), children, and society (UNEP, 2020).

In the textile supply chain, with the introduction of circular activities, workers will also include collectors and sorters working in waste management companies as well as charity and thrift sector. Workers also include providers of technology, such as sorting and identification technologies, recyclers, designers working with recycled content, manufacturers, retailers, and repairers. The data for working conditions for these smaller players in the textile supply chain is hard to collect (Schumacher & Forster, 2022). There is also increased uncertainty in the informal recycling sector involved in collection and sorting waste in low-income countries. Figure 2 shows the stakeholders involved in the textile supply chain, both linear and circular.

Figure 2 – Stakeholders involved in linear and circular supply chain of textile sector



Source: from United Nations Environment Programme, 2020.

To identify the social impacts on workers across the textile life cycle, data on working conditions, wages, health and safety, and labour rights compliance in textile factories and production facilities is needed. Information on supply chain transparency, fair trade practices, and community engagement initiatives related to garment distribution and retail is needed to evaluate impact of value chain actors. Insights into consumer behaviour, product satisfaction, and social impacts of garment use, care, and disposal is needed to determine the impact on consumers. Data related to displacement, exposure to toxins, and protection of cultural heritage is required for to identify the impact on local communities. For children, the impacts are evaluated as a separate category by collecting data on the health issues of children as consumers and on their education. Data on the social impacts of waste management practices, such as technology and economic development, is needed for evaluating the impacts on society. The Guidelines on S-LCA Assessment contain 40 impact categories for each stakeholder (UNEP, 2020).

S-LCA -related data may be both qualitative and quantitative and is collected from primary and secondary sources or a combination of both. To gain more insight into the process or product under evaluation, site-specific data is preferable to generic data, as social impacts vary depending on the location and behavioural differences of the companies and stakeholders involved. Primary data is data on the use of structured or semi-structured interviews with the stakeholders identified in the supply chain. Interviews with open-ended questions could be used to encourage interviewees to reflect upon the social impacts relevant to them. Questionnaires requiring either detailed answers or 'yes'/ 'no' type options are also used to gather information from stakeholders. An advantage of primary data is that through interviews and surveys, the S-LCA practitioner may gather multiple perspectives at all expertise levels and from multiple stakeholders in the supply chain. Secondary data collection covers the use of technical reports, scientific publications, statistical sources, and generic databases to evaluate social hotspots. Commonly used databases are the PSILCA and the SHDB. A combination of primary and secondary data is typically used in cases in which the potential social impacts must be evaluated for changes in conventional supply chains, such as through change in the materials used or the recycling of materials. Hence, experts/ stakeholders were interviewed to identify the social risks of using recycled fibres in the textile supply chain.

Obtaining comprehensive and reliable information across the entire life cycle of products is currently a challenge, especially during primary data collection, due to the limits to which data may be reported honestly. For example, informal waste collectors could be unwilling to share information on their waste collection practices due to fear of losing their jobs, and value chain actors may be reluctant to share information due to fear of receiving poor social responsibility ratings. Additionally, reliance on a secondary database alone may negate site-specific improvements, as several of the social risks are governed by company behaviour. Hence, the collected data needs to be corroborated with information or feedback obtained from NGOs and consumer advocacy groups to assess the effectiveness of social compliance programmes, supply chain transparency initiatives, and stakeholder engagement efforts in promoting social sustainability. NGOs and advocacy groups also provide independent assessments, research, and advocacy on social issues in the textile industry, contributing to data collection and validation efforts. Government agencies typically help create and enforce the labour standards, workplace conditions, and social welfare policies that inform the benchmarks used to monitor industry compliance, although industry participation is necessary to ensure that the standards created are enforceable.

The S-LCA methodology is currently unclear about measuring impacts for circular transitions (UNEP, 2020). It also lacks methodological guidance for investigating the role of digitalisation in the autonomy of labourers or workers, and the likelihood of creating or hindering job growth (Larsson & Lindfred, 2019). In the absence of a harmonised protocol for social assessment, several industries use self-assessment strategies based on data they have collected to create a scoring mechanism for 'acceptable social impact.' Several frameworks have been used to evaluate the social sustainability, such as the *Sustainability Reporting Standards* by Global Reporting Initiative (GRI), the *International Guidance Standards* on Social Responsibility (ISO 26000), SA8000 by Social Accountability International, and AA1000 by the Institute of Social and Ethical Accountability (Messmann et al., 2020). Living wage, jobs created, and working hours are single indicators used for measuring social impacts (Solarte-Toro et al., 2023). *Human Development Index*, *Social Progress Index*, or *Gross National Happiness* are used as indicators for national and regional level social sustainability (Stabler et al., 2023).

4.3. PEF Product Environmental Footprint

The Product Environment Footprint or PEF has been created to harmonise information on environmental assessments. For the textile sector, the PEF database will include information specific to, for example, footwear and apparel. It accounts for many environmental issues to allow companies to present a standardised assessment for water or energy use or other environmental considerations.

As an LCA tool, PEF focuses on quantifying the environmental impacts of products based on standardised methodologies and indicators. While both PEF and traditional LCA tools assess the life cycle environmental performance of products, PEF follows a standardised framework developed by the European Commission, which includes specific impact categories, assessment methods, and reporting requirements tailored to various product categories. PEF focuses on carbon, water, and ecological footprint only to provide a simplified and standardised measure of environmental performance. Hence, it is designed to facilitate comparisons between products and to inform policy decisions, but traditional LCA tools may be more suitable for detailed environmental assessments tailored to specific applications or sectors.

Integrating PEF findings into sustainability reporting and ecolabelling schemes, as well as product certification programmes may allow communication about measurable changes in the impacts of circular transitions, thus ensuring higher transparency.

The data needed for PEF assessment in the textile sector includes information on the environmental impacts of fibre production, including energy use, water consumption, chemical inputs, land use, and emissions. Similar information is needed for the manufacturing stage. The distribution is influenced by the information on transportation-related emissions, packaging materials, distribution distances, and logistics efficiency. The use stage data includes insights into consumer behaviour, garment lifespan, washing frequency, energy use during care, and maintenance practices (e.g. repair, alteration). The EOL stage data requirements include information on waste management practices, such as recycling rates, material recovery efficiencies, and the environmental impacts of disposal methods.

PEF may assist environmental policy makers to develop evidence-based policies, regulations, and incentives to promote CE while establishing sector-wide sustainability standards, guidelines, and best practices to improve environmental performance and competitiveness. PEF also allows consumers to access transparent information on the environmental impacts of products and to make informed purchasing decisions, which is a requirement in several of the upcoming regulations.

4.4. CF Carbon Footprint

Carbon footprint assessment in the textile industry plays a crucial role in evaluating circular transition by focusing on the greenhouse gas emissions associated with the production, use, and disposal of garments. Specifically, it can be used to quantify the carbon emissions generated throughout the life cycle of garments. This tool provides a narrow picture of environmental impacts, but it can guide industry-wide transition to low-carbon and carbon-neutral strategies, such as renewable energy adoption, and mitigate the impacts of climate change associated with textile production and consumption.

By focusing solely on CF, without considering broader environmental impacts or conducting a full LCA or calculating PEF, we can prioritise actions and investments that have the greatest potential to reduce greenhouse gas emissions and mitigate climate change impacts. Thus, communicating achievements/ risks to stakeholders in a clear and straightforward manner fosters transparency and accountability. CF is also useful in aligning the sector with global climate goals and commitments, such as the Paris Agreement targets, across the textile supply chain.

Ideally, CF should be used alongside broader environmental footprint assessments and LCA methodologies since it may not capture other environmental or social aspects of sustainability, such as resource depletion, water usage, or labour rights.

The data needed for CF is limited by its scope, making assessment potentially faster. CF depends on the emissions from agricultural activities or other raw material production activities; textile production facility activities, which include spinning, weaving, dyeing, and finishing processes; transportation-related activities; garment care, which includes washing, drying, and ironing practices; and from waste management practices, which include landfilling, incineration, and recycling processes. It also depends on potential emission reductions from garment reuse, remanufacturing, or recycling initiatives.

CF results may inform climate mitigation strategies, carbon pricing mechanisms, and emissions reduction targets to achieve climate goals and reduce greenhouse gas emissions.

4.5. ESPR Ecodesign for Sustainable Product Regulation

The Regulation on Ecodesign for Sustainable Products (ESPR) aims to extend the Ecodesign directive, which has previously set mandatory requirements for the environmental performance of energy-related products, and will also include other product categories in the future. The aim of the Ecodesign directive has been to reduce energy consumption and minimise the negative environmental impacts of products. The ESPR implements the commitments made in the European Green Deal and the CEAP. It aims to implement the EU's regulatory framework to 'fit for a sustainable future' and 'to tackle fast fashion and textile waste and to make textiles more durable, reparable, reusable and recyclable'. The goal is to decrease the environmental impacts of products throughout their lifetime in order to target environmental impact reduction through promoting CE principles. The aim is also to extend the Ecodesign directive towards other product categories, so that it will cover a broad range of products, including textiles. The idea is to encourage the industry to make products that are more durable, reparable, reusable, recyclable, and even include a certain amount of recycled material content, which will boost material circulation. The PEFCR (Product Environmental Footprint Category Rules) is a tool for the industry to report product-level environmental impacts. The ESPR also introduced DPP to reach more transparency in the textile sector, and the idea is to be able to tag, identify, and link the relevant data to product circularity and sustainability (Legardeur and Ospital, 2024). Also, the EU Ecolabel criteria will be updated to better support the EU Textile Strategy. The ESPR includes several considerations of product design: products should be repairable (e.g. through modular structure, availability of spare parts, maintenance instructions), they should also include recycled content, and should be recyclable at the end of their life (suitable fibre content for recycling and ease of disassembly) (Lüttin, 2024).

ESPR includes the following considerations:

- Durability of a product including technical lifetime information
- Reusability, upgrading, and repairability information
- Minimising energy and water use
- Avoiding substances of concern (harmful chemicals)
- Possibility of remanufacturing and recycling
- Environmental impacts (CF, environmental footprint, microplastic release)

Another implication of ESPR is the banning of destruction or disposal of unsold consumer products, also through recycling. An exceptions to the ban on destruction is if the product carries a health or hygiene concern, cannot be recycled, reused, donated, remanufactured, has a higher negative impact on EOL treatment, reselling it conflicts with the IPR, or if it is unfit for any further application.

Note that in textiles, repairability and durability are somewhat difficult aspects to measure and validate. This is different in textiles than in the energy-related products to which the previous Ecodesign directive applied.

Data needs:

- Energy consumption data for textile manufacturing processes
- Environmental impact data for textile production and usage
- Environmental impact data for product's end-of-life processes
- Information on alternative materials and processes for reducing environmental impact; recycled content of a product
- Data to support design for recyclability
- Data to support the repairability and durability of products

As part of the ESPR, Green public procurement is one avenue for developing the collection and monitoring of data on environmental impact. Public authorities will monitor how well procurers are adhering to the requirements; however, procurement agreements will not be public.

> *Market surveillance and customs control in ESPR: monitoring is important for ensuring the reliability of data. However, market surveillance is currently under-resourced. Resources should be considered if control is to be reinforced.*

4.6. DPP Digital Product Passport

The Digital Product Passport (DPP) will provide comprehensive digital documentation for a product throughout its life cycle, including environmental and social information (EPRS-STOA, 2024). The DPP is a direct result of the ESPR guidelines. It includes the key characteristics of a product across its entire life cycle. The DPP would be included in consumer products through a data carrier which acts as a unique identifier for a product. This unique identifier would provide customers/ other value chain actors with the data obtained from prior phases such as manufacture, retail, repair, and recycle. Extensive LCA data needs to be collected for the DPP. Data requirements include holistic information about water, energy, and environmental impacts. Data analytics can be used to identify social or environmental impacts. This measure would likely promote supply chain transparency for tracking data across all channels, such as material sourcing to distribution.

> *The DPP needs to be dynamic to ensure that product changes such as repair are included in the product information. However, it is unclear what happens to products if the initial manufacturer is no longer in business, and who will pay for the maintenance or update of the information. (Leading Researcher, Research Institute)*

The DPP concept is still under development. Some ideas of what it can encompass are described below. DPP data may be collected with several levels of transparency. For instance, first would be public background data, which is essential for all processes. The second would be batch-specific performance data, which is available for anyone who has purchased the product (via secret key shipped with product). The third would be commercially sensitive data that must be specifically requested from the issuer, who will then only provide it to identified and authorised requesters. The DPP needs to store the information that is required at EOL in order to dismantle/ recycle/ remanufacture a product. For complex products like textiles with various dyes and fibres, the level of granularity within the DPP is unclear.

Data needs:

- Product specifications and materials and chemicals used in textile manufacturing
- Environmental performance based on PEF
- Supply chain information to track materials and processes
- Tools and databases for environmental and social impact assessment
- Cradle-to-cradle assessments for multiple life cycles including repair/ remanufacture/ recycle activities
- Verification and compliance standards for all suppliers
- Environmental impact of DPP data storage (scope emissions)

4.7. GCD Green Claims Directive

The GCD regulates environmental claims made by businesses regarding their products or services, ensuring transparency and accuracy in marketing communications. This directive aims to harmonise and verify sustainability claims for a brand in terms of reporting to consumers. The GCD specifically focuses on business-to-consumer disclosures. Companies are obligated to disclose whether a claim applies to the whole product or only part of the supply chain. Additionally, all claims must be based on scientific evidence and look at the entire life cycle of a product. In the reporting of a green claim, the negative impacts (pollution, water, and resource use) should be reported transparently, along with any environmental benefits such as carbon offsets. The DPP is essential for the GCD, as it will be the key data source for verifying green claims.

Data needs:

- Validated environmental performance data supporting green claims for textile products
- Data on compliance with environmental standards and regulations

4.8. Green claims and textile labelling

The GCD should also help harmonise the various ecolabels and certifications being used to help consumers make informed decisions. Currently, the EU has 230 different environmental labels, and some of them are the companies' own, thus not always reliable. Closer scrutiny is likely to reveal gaps in these labels and their criteria.

Green claims and textile labelling provide consumers with information on the environmental attributes of textile products, helping them make informed purchasing decisions. There is a need to update textile labelling to better fit ESPR requirements. EU Ecolabel is the EU's official voluntary label for environmental impacts, and it covers best-in-class products. For example, should include the aspect of a guarantee for the technical lifetime of the product or the recycled content. It is also proposed that the production year be included in the ecolabel, which enables checking the real lifetime of a product at the end-of-life stage.

> *EPR can be based on, for instance, how long the product was on the market based on waste audits and the date of production, and thus we can modulate who will have to pay a higher fee. We need to incentivise the reduction of the volumes placed on the market. (Researcher, EE)*
>
> *It needs to be considered how circular fibres should be labelled. For example, chemically regenerated cellulose fibre should not ideally be labelled as viscose because the circularity/recycling aspect doesn't become visible, and viscose has negative environmental connotations. Furthermore, the current labelling of fibre content is not reliable.*

Data needs:

- Validated environmental performance data for labelling purposes.
- Compliance data with labelling regulations.

4.9. Preventing destruction of unsold products

Preventing the destruction of unsold textile products contributes to waste reduction and supports CE principles. The ESPR includes certain measures to stop the destruction of unsold consumer goods, including textiles. Large companies need to reveal the number of products they discard yearly. Moreover, what is behind these discard figures needs to be explained. Companies need to also provide detailed information on where these products end up. Are they sent for reuse, remanufacturing, recycling, energy recovery, or disposal?

Data needs:

- Inventory data on unsold textile products
- Data analysis of alternative solutions such as resale, recycling, or donation

4.10. EPR Extended Producer Responsibility

Our interviewees considered the EPR very important to incentivise circularity. One interviewee suggested that EPR needs to be harmonised across different industries to include product segments other than textiles. For example, mechanical recycling also serves industries other than textiles.

> *Extended producer responsibility is, I think, crucial. It's very important because it should already turn the companies' eyes to circular solutions and towards more demand-based production. (Director of Partnerships, Mechanical recycling company)*

The EPR mandates manufacturers to take responsibility for the environmental impacts of their products throughout their life cycle, including downstream actions and reverse logistics: product collection at the end-of-life stage, recycling, and disposal. Manufacturers have a responsibility to control not only the product design phase to reduce toxicity but also the product use and end-of-use phases to decrease waste. Reuse, reverse logistics, and recycling actions are part of the EPR.

The EPR requires the producer to identify all the phases of the product life cycle, including all the steps between the reuse and recycling or final disposal. For textiles, this is particularly relevant to clarify the point at which it becomes waste and is no longer usable. This is important to define and identify so that garments that can still be reused are not recycled as waste. Accordingly, we should try to avoid speeding up material throughput in the system. In the waste hierarchy, the extended use of a garment is a more important action than textile waste recycling (e.g. Potting et al., 2017).

The EPR may interrupt current recycling opportunities, including both downcycling and upcycling, which could lead to a loss of social opportunities that support various people in the supply chain. Currently, many people are employed by and earning a livelihood from textile recycling. Additionally, more than half of the textile industry operates with small-scale companies that will be affected by the EPR and need to be included in the data collection associated with the implementation of EPR.

Data needs:

- Cost of collection, sorting, redistribution, and preprocessing for textile-to-textile recycling,
- Reverse logistics infrastructure,
- Quality requirements for products,
- Eco-modulation fee and additional financing requirement,
- Technological possibilities to include recycled content for quality and production efficiency,
- Proof of recycled content,
- Mixture of chemicals and composition across the supply chain,

- Production geographies, weight/ quantities, legal entity, mass balance,
- Harmonisation based on the Waste Framework Directive, National EPR schemes, and Producer Responsibility Organisation (PRO) capability,
- Information on ecodesign practices to facilitate EOL management.

4.11. CSRD Corporate Sustainability Reporting Directive

The CSRD aims to create a standardised reporting format for a company's ESG data.[14] It includes a provision for the yearly disclosure of social and environmental impact. Environmental reporting must be based on LCA tools, that is, it must cover the whole life cycle of a product or process. This directive applies to both EU and non-EU companies. The CSRD applies to the entire supply chain from material sourcing to EOL treatment.

This regulation requires disclosure of non-financial information based on twelve European Sustainability Reporting Standards (ESRS), which includes information on Scope 1, 2, and 3 emissions, climate impacts (e.g., greenhouse gas emissions), resource use (water, energy), air and water pollution, biodiversity impact, circularity initiatives, and social impacts on workers and consumers (Lüttin, 2024). In addition, the CSRD requires companies to develop an action plan on how they will evaluate the climate impacts and report if their climate transition plan accounts for the targets set in the Paris Agreement. An essential aspect of CSRD is the need to perform a 'double materiality assessment', which includes assessing the company's impact on climate change and the financial burden of climate change on the company. This way the CSRD attempts to prevent greenwashing. The CSRD also includes an auditing requirement for the company.

Data needs:

- Quantitative LCA metrics for each product or process
- Emission values in metric tonnes of CO_{2e} for Scope 1, 2, and 3 emissions
- Annual consumption of water and energy in cubic metres or kWh
- Biodiversity impact scores or metrics
- Percentage of recycled or reused materials, waste reduction metrics
- Worker condition ratings, consumer impact scores
- Milestones, timelines, and evaluation criteria for the climate action plan
- Financial implications of climate change risks and opportunities
- Findings from internal and external audits related to ESG performance

Source of data:

- LCA databases, supplier-provided LCA data
- Emission tracking software
- Utility bills and meter readings for Scope 2 emissions
- Climate action strategy documents and emission reduction targets
- Environmental monitoring reports
- Biodiversity impact assessments
- Recycling and waste management records
- Supply chain audit reports
- Worker and consumer surveys
- Financial risk assessments
- Compliance certifications

[14] Environmental, social, and governance risks

4.12. CSDDD Corporate Sustainability Due Diligence Directive

Despite certain similarities, the Corporate Sustainability Due Diligence Directive (CSDDD) and the CSRD are essentially different. Whereas the CSDDD aims for companies to take action to reduce the overall negative environmental and social impacts from their activities, the CSRD aims to ensure that companies report their impact based on standardised reporting tools in order to make ESG performance comparable in a sector.

The CSDDD involves assessing and managing ESG risks throughout the supply chain. It was introduced to address the environmental and social impacts of companies operating within and outside the EU. The aim is to promote due diligence efforts of companies to reduce environmental impacts, improve human rights realisation, provide better living conditions for people in the textile value chain, and increase customer trust in organisations through promoting transparency in the company's operations.

The CSDDD aims to foster sustainable and responsible corporate behaviour in companies' operations and corporate governance. Companies need to observe, evaluate, and resolve the adverse impacts of their actions through the value chain, also including actions outside Europe. For companies, this means, for example, a harmonised legal framework in the EU, creating legal certainty and a level playing field and greater customer trust and employees' commitment. This directive will help promote better risk management, increase the visibility of an organisation for sustainable investors, and promote customer awareness of a company's impacts. For developing countries, the directive will push companies to promote the protection of the rights of workers, increase sustainable investment, and improve living and working conditions. Under the CSDDD, companies are obligated to the due diligence necessary to ensure that value chain actors in their supply chain comply with the requirements for environmental and social impacts.

The costs of establishing any procedures, changing processes due to non-compliance in a value chain, and the costs of improving processes must be borne by the company itself (Botwright & Feingold, 2024). This directive will apply to 'large companies' first, as defined in the framework. However, "the proposal provides supporting measures for SMEs, which could be indirectly affected" (European Commission, 2022).

Data needs:

- Carbon emissions, waste generation, and resource consumption
- Emissions data from suppliers and other supply and value chain actors
- Information on workers' rights, fair labour practices, working conditions, wages and benefits, and worker well-being
- Living standards, healthcare, and education in developing countries that are a part of the value chain
- Information on corporate policies, ethics, and governance structures
- Rate of compliance with local and international laws and regulations
- Costs associated with compliance efforts, process changes, and improvements
- Customer trust, satisfaction, and perception of the company's sustainability efforts
- Employee engagement, satisfaction, and commitment to sustainability goals
- Information on support measures provided to SMEs for compliance

Suitable source:

- Data from direct suppliers (certificates, quality indicators, material contents)
- Data from own operations/ manufacturing (energy, water, chemical efficiency, waste flows)

- Data on reclamation and returns and sales and marketing data (related to sustainability efforts)
- Internal sustainability reports based on environmental impact assessments, energy and water bills, waste management records
- Supplier sustainability reports including emission data from transportation partners
- Supplier audits
- Worker surveys
- Human rights impact assessed by local NGOs or government reports
- Corporate governance reports
- Code of conduct (own and suppliers)
- Legal compliance reports
- Regulatory filings
- Internal legal reviews
- Financial statements, cost accounting records, budget reports

4.13. Data challenges with initiatives

Digital technologies can be best used in terms of data analysis and predictability of operations. It is worthwhile keeping in mind that although these technologies can help in decision-making, a human expert should always supervise them to ensure the quality and reliability of the data. A skilled human is required to have not only the relevant IT expertise but also sector-specific knowledge for diving deep into the information and creating higher efficiency in interpreting useful insights from the data. However, an interviewed data expert highlighted that the raw data should always be available, as the principles of different calculations vary, and the use of raw data is the most reliable way to end up with exact figures.

> *When to collect and use primary data vs when to collect secondary data? Researchers point out that we should always go back to the raw data so that the calculations are correct (calculations have different logics). On the other hand, secondary data might be needed to supplement the primary data.*
>
> *What could different initiatives do in cases of fraud data while waiting for specific solutions?*

The tools do have limitations that should be taken account. For example, in the PEF methodology, the EU's standard for determining a product's Carbon Footprint (CF) does not recognise the uptake of CO_2 by plants. Biodiversity evaluation is emerging as one figure, but data on and tools for measuring it are still missing. The LCA of recycled fibres also includes the impact during primary virgin fibre cultivation or production (e.g. cotton cultivation), and the question arises whether this principle should be changed. This aspect correlates with the worry that current LCA calculation is built for a linear model only and there is no understanding of how to apply it to better suit CE practices and how to best evaluate downstream action (reuse, recycling). In terms of LCA, the material substitution impact is very important. It is important to know what the recycled material could be substituted for if, for example, it substitutes virgin cotton.

Many of the new EU regulations are based on LCA calculations. However, these calculations have limitations, such as missing up-to-date data on, for example, energy use, which is mostly calculated based on country-average figures. LCA excludes transportation data, the exclusion of which still requires further consideration. Online shopping in the fashion sector (especially in the fast and ultra-fast fashion sector) increases the need for logistics, as products are sent and returned several times.

> *The almost non-existent impacts of transportation in the life cycle of textiles: Maritime transport has been thought to have smaller impacts than air cargo, but freight shipping has enormous environmental impacts, negative health impacts on people living near the ports, and massive human rights issues. Next to nothing has been done to solve these issues, because most ships today are registered in convenience flag countries, which have zero environmental and social regulations. (Leading Researcher, Academia)*

Lately the discussion on freight shipping and its environmental and social impacts have also gained attention.

Use phase data is missing, but would it be possible to build that into the EPR for a full life cycle model? New data needs to be collected so that it is possible to define lifetime optimisation (technical lifetime) for different product categories and to define a minimum quality level for different product types. On the other hand, the real length of the use phase should be better linked to regulations, for example, the EPR, ESPR, and PEF.

> *Focusing on the product and assuming this will result in sustainability has serious limitations. Instead, collecting data in the waste streams, and estimating if a product has been used for six months or ten years, actually establishing its duration of service (DoS), can provide the database for modulation fees. (Researcher, EE)*

Data on to all materials, processes, and resources are required for efficient environmental impact assessment. However, it is highly important to make a detailed use-of-data plan beforehand, because collecting a large amount of data also has a negative impact on the environment. There should be a clear understanding of where the data will be used. For example, will it be used for finding the optimal recycling technology or recycling pathway or reducing the environmental and toxic risks, or optimising the CF?

> *Data regulations should be built within various policies and the initiatives should include detailed methods. Policy mix should be used. (Leading Researcher, Research Institute)*

5. Future possibilities in data use

It is clear that new EU regulations will transform business. There are many challenges in collecting and sharing data, but data is sorely needed for this business transformation. It also provides opportunities for more sustainable practices in the textile sector. Harmonisation and standardisation are needed to reach relevant data. Accurate data enables better decisions. Developing a baseline for LCA studies of different materials as well as constructing an LCI library to store the data from LCA studies would ease data access in connection to LCA calculations. An open-access source provides options for different stakeholders to add additional data to fill in the gaps regarding the GHG emissions of raw material. Collecting credible, actionable social and labour data increases transparency and supports stakeholders' efforts to redeploy resources into improving working conditions in global value chains. Transparency and data sharing can increase trust between different stakeholders and also help communicate sustainable actions to consumers.

> *Business as usual is not an option anymore. (Head of European Textile Association)*

Data in connection to the EU's new regulations also promotes the fight against fast fashion. The ESPR and regulations in connection with it push this sector towards more sustainable business models, investing in higher quality and longer product lifetimes, and taking responsibility throughout the product lifetime by, for example, providing repair services, informing consumers about better maintenance practices, and collecting products at the EOL. Eco-modulation fees could be used to fight against short lifetimes and premature disposals of garments.

> *Product circularity will become more important in regulations. (Leading Researcher/UK)*

It is also important to consider how data can change industrial practices on the system level. Shifting to a CE can be enhanced by using data to plan actions and make decisions, evaluate business opportunities linked to textile waste, or improve product circularity. Three levels of information are needed in this transition from a linear model to a circular one: business, system, and product level. "The continuous development of circularity and connecting this to global data standards will help industries turn liabilities into prospects, which will make products and organisations more productive, efficient or even sufficient. At least data connected to sustainability can provide opportunities to create a better balance in the textile system by longer-lasting products and more accurate production, and by designing closed-loop products that are suitable for recycling" (Jain et al., 2024, pp.192–193).

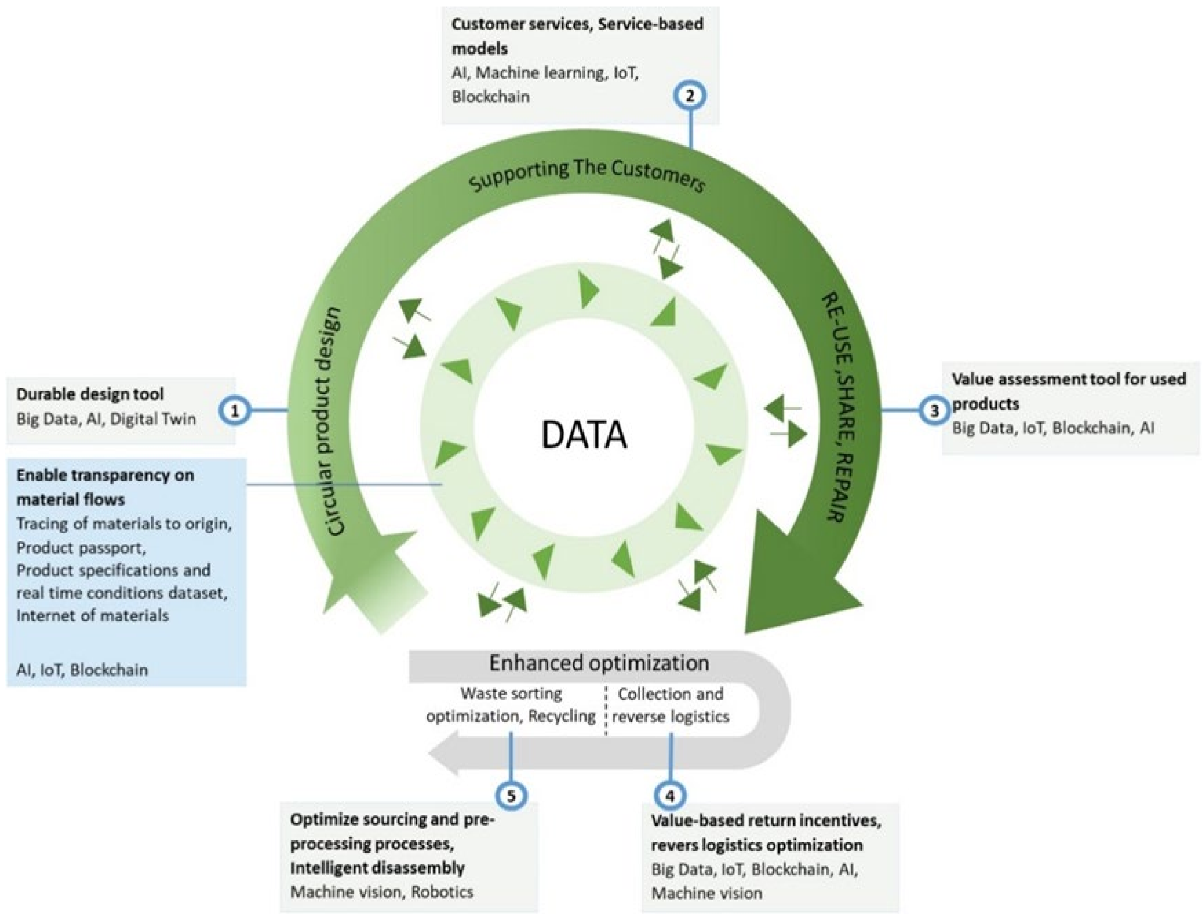
> *There are two distinct orientations toward the use of technology by multinational corporations (MNCs) in creating sustainability transparency within their global supply chains: control and relational. A control orientation views technology as a tool to gather the ever-increasing levels of sustainability data on supplier practices in an efficient, secure, and progressively automated manner. A relational orientation adopts a view where technology is a tool to help build social relations and improve dialogue and collaboration on sustainability throughout the supply chain. (McGrath et al. 2021, p. 67)*

While many developments in this context are proceeding simultaneously, we also want to illustrate some future opportunities in this section. We will present some new avenues for data use, which are still in their infancy, but developing quickly. These methods can be understood as future ways of data sharing and doing business based on data.

5.1. A data-driven ecosystem to trace product life cycle

In the future, the aspect of functioning ecosystems between different actors will be a reality, especially in textile circularity. Companies must rethink how their supply chains are managed and organised and how sustainability could be better grounded in their supply chain. For a full understanding of the demand-driven strategy[15] and more accurate production and implementation of sustainable solutions, companies will have to restructure their ecosystems and identify the value of data for meeting consumer demands while increasing the efficiency of their operations (Cura et al., 2022). In this regard, implementing digital solutions can help in managing a data-driven ecosystem that plays a key role in enhancing circularity and sustainability of the textile industry and, at the same time, help apparel companies gain a competitive advantage. Digital technologies such as artificial intelligence (AI), the internet of things (IoT), big data, block chain, and digital twins[16] can help companies improve CE solutions by utilising data that make material flows transparent in, for example, circular product design, service-based models, circularity value assessments, and the optimisation of reverse logistics (Ghoreishi et al., 2022).

Figure 3 – Data-driven technologies for CE



Source: Ghoreishi et al., 2022, p. 87.

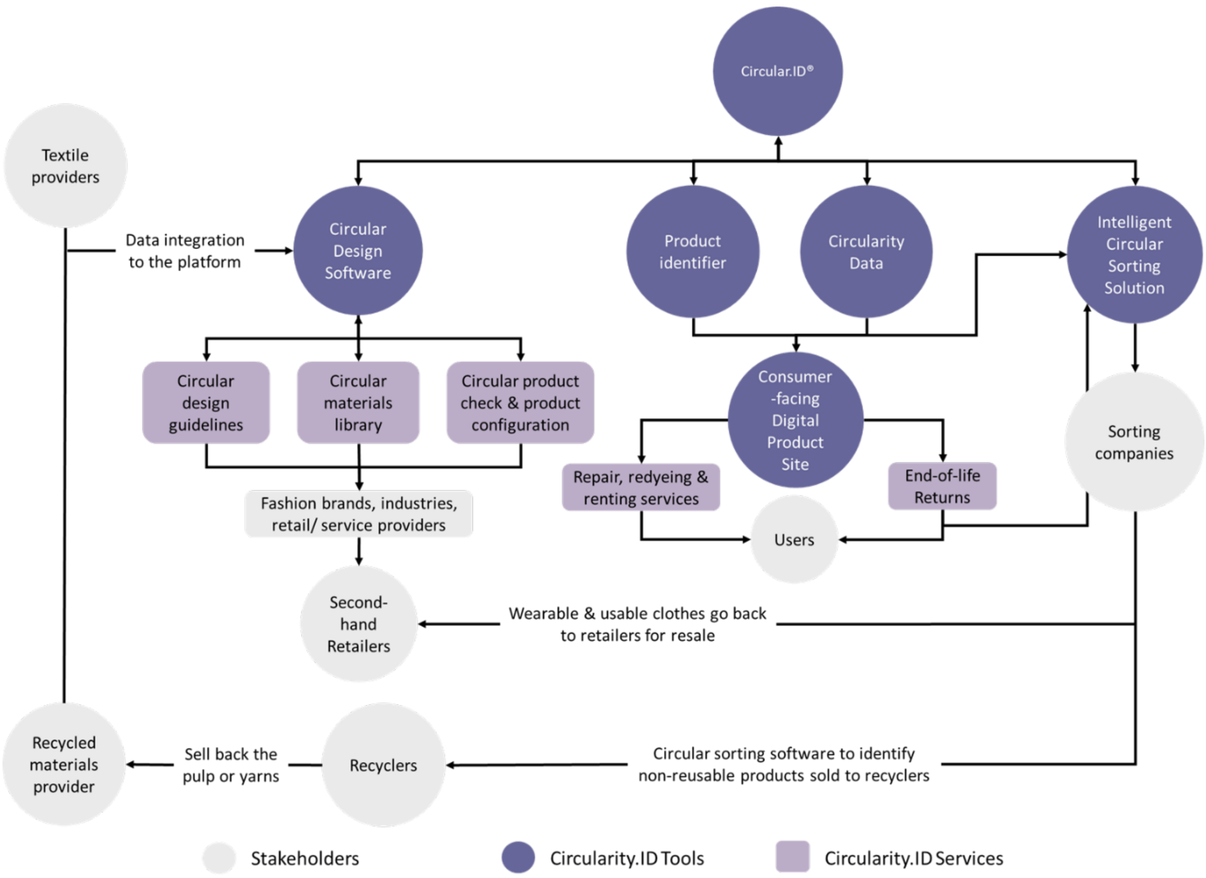
15 Demand-driven strategy is based on real-time demand or customer orders, and the aim is to limit overproduction.

16 A digital twin is a virtual representation of an object or system designed to accurately reflect a physical object. It covers the object's life cycle and is updated from real-time data.

Three categories in which digital technologies could be utilised in order to offer circular solutions for textile industry are waste mapping, supply chain traceability, and DPP. These could be enabled by supporting tools such as ERP, product life cycle management (PLM), impact tracking, and design capabilities. The utilisation of these tools enables essential data collection and analysis that increase functionality and efficiency through digital platforms (Vellanki and Gopinath, 2023). In addition, a digital platform helps textile industries to measure, track, and compare a company's sustainability progress related to fibres and materials.

To this end, *Circular.fashion* has developed a Circular Material Library in which material suppliers can showcase their innovative and sustainable materials to manufacturers. Through the Circular Material check, which is the first digital platform for checking textiles, fabrics, yarns, trims, leathers, and leather alternatives, companies can select materials that have been tested and validated for future recyclability. Different manufacturing companies and textile suppliers can provide data and information on textiles on this platform, which will be further available for textile designers and different fashion brands to improve their circular textile strategies. The digital platform also enables different brands to be connected to the right material providers that produce high-quality products via recyclable materials. Increasing data accuracy for material and design will increase transparency in the entire ecosystem of the textile and leads to better decision-making. *circularity.ID*® contains material and product data that can enable reuse, resale, and recycling (Circular.fashion, 2020; Ghoreishi et al., 2022).

Figure 4 – Data-driven ecosystem for circularity.ID®



Source: Ghoreishi et al., 2022.

5.2. Tools for traceability

The ISO 9000:2015 standard defines traceability as follows: "the ability to trace the history, distribution, location, and application of products, parts, materials, and services" and especially in textiles to "identify and trace the history, application, location and distribution of products, parts and materials to ensure the reliability of sustainability claims in the areas of human rights, labour (including health and safety), the environment and anti-corruption" (UN, 2014, p. 6). "The process by which enterprises track materials and products and the conditions in which they were produced through the supply chain" (defined by OECD, 2018) is essential for transparency (Cura et al., 2022, p.13). End-to-end product traceability can be enabled through digital ID. The concept of value chain traceability goes beyond merely mapping out the supply chain. For example, value stream maps, which are graphical representations of material and information flow in a process, are frequently employed in manufacturing to eliminate activities that do not add value. Traceability involves tracking the origins and journey of products and their components, starting from the very beginning of the supply chain, through all the stages, up to final use. Traceability tools and digital technologies enable information about various process steps in the supply chain to be gathered, stored, and disseminated throughout the supply chain. Distributing this information in a format and content suitable for various stakeholders enhances a company's supply chain transparency. Accessing real-time data can help track a product's life cycle through production, customer use, resell, repair, reuse, and recycling. This can enable circularity in the textile and fashion industry (Cura et al., 2022; Kauppila et al., 2022).

In this regard, a digital traceability interface helps improve the cybersecurity of the supply chain while increasing the tracking of goods produced through by child and forced labour. This could be done by:

- Using blockchain technology, advanced encryption for data, robust system of data backup.
- A platform designed to allow the tracing of goods from fibre to retail.

Examples of different digital tools and platforms for supply chain traceability are presented in the following.

TextileGenesis™ — "TextileGenesis™ is a pioneering traceability platform custom built for the textile ecosystem."

The company offers a solution for traceability of textile from fibre to retail by engaging five to six tiers of the supplier ecosystem through five key principles.

- Digital Tokens called Fibercoins™ that verify the origin of the fibre. Utilising a digital twin enables tracking the flow of products and materials through mirroring the physical flows. Furthermore, digitalising textile assets such as fibre, filament, yarn, fabric, and garment create tracking and management of textile products.
- The Textile Genesis platform enables real-time transactions within the 5–6 supply tiers while securing shipments, starting from verified sustainable fibre. This enhances 'fibre forwards' traceability at product-article level and enables following the products.
- An AI-based solution enables the value chain modelling of 300+ 'product flows' in textile value chains for individual 'wastage loss factors'. Integrating GS1 traceability

standards and HS[17] codes enables modular design that enhances circularity within the supply chain as well as new circular business models.

- This creates a cross-industry ecosystem through global traceability partnership. For example, between leading sustainable fibre producers based on ESG standards focusing on various textile materials such as "man-made cellulosic, recycled synthetics, cotton and wool".
- The platform provides independent verification in two ways: identifying fibre origin by integrating technologies such as "pigment or DNA markers, isotope mapping, etc" and third-party audits for ESG credentials verification of suppliers (TextileGenesis, 2023).

trustrace "TrusTrace provides supply chain traceability for global fashion and apparel brands that want to overcome challenges of tracing deep tiers in the value chain and reach sustainability goals."

The company offers step-by-step solutions for brand companies to increase end-to-end traceability of the textile supply chain.

- The platform offers high-quality data from different suppliers, which helps brand companies map and identify all suppliers, including those beyond Tier 1, through custom assessment and analysis of third-party audits.
- Brands can trace their product through the platform by visualising their product journey and collecting a validated certificate from each tier of their supply chain.
- Real-time traceability of material is enabled by the platform for material batches, which helps companies' risk management and agreements related to purchase orders, certificates, and reports in production processes.
- The platform enables sharing confidential information and validated data that helps companies take relevant actions to achieve sustainability goals.
- Integrating AI and Optical Character Recognition (OCR) technologies enables transcription of transactions and certificates to make a verified digital chain of custody. This facilitates automated data validation through the extraction of relevant and trained data from various documents.

The TrusTrace platform provides a powerful technology and Software as a service (SaaS) that enables collaboration between supply chain actors on a global level. Transferring the supply chain operations into the cloud enables accessibility and availability of updated information and software at any time. TrusTrace does this by utilising Amazon Web Services and Microsoft Azure. Moreover, the platform is developed based on the GS1 standard to ensure the integration of different *retailers, manufacturers, and supplier systems and third parties such as certification agencies, life cycle datasets, and other sustainability solution providers*. In this way, a partnership ecosystem of enabled through a PLM system[18] and an openAPI[19], which connects the supply chain that integrates data workflows to maximise the value of data. (TrusTrace, n.d).

[17] HS harmonised system

[18] PLM=Product Lifetime Management. Product life cycle management (PLM) software system is a tool that is used for managing products and all the relevant data throughout the life cycle of a product or service across the global supply chain (what is product life cycle management (PLM)? Or https://www.sap.com/products/scm/plm-r-d-engineering/what-is-product-life cycle -management.html

[19] OpenAPI=C++ program interface to IC design data stored in an electronic design database. Enables integration of various companies' contributions. openAPI or the so-called the public API provides a formal set of standards to describe how API works (The world's most widely used API description standard or https://www.openapis.org/).

Alves et al. (2021) have mapped data-driven tools for traceability and circularity. Table 10 presents these through the aspects of technology in use, and the other aspects they enable or cover, and whether they are meant to share information in business-to-business (B-2-B) or business-to-consumer (B-2-C) actions.

Table 10 – Data-driven tools for traceability and circularity of textile value chain

	Blockchain-based framework for supply chain traceability	Secured tag for implementing traceability in textile and clothing supply chain	Developing a framework for implementing traceability in the textile supply chain	Blockchain enhanced emission trading framework in fashion apparel manufacturing industry	Traceability of ready-to-wear clothing through blockchain technology	Non-hazardous solid waste traceability platform (SWAN)
Technology	Blockchain	QR Code & Data Server	RDBMS & XML	Blockchain	Blockchain	N-Tire Application Architecture (Web Browser)
CE optimisation	X	√	X	√	√	√
Traceability	√	√	√	X	√	√
IoT integration	√	√	√	X	√	X
B2B/B2C apps	B2B	B2C	B2B + B2C	B2B2C	B2B2C	B2B2C
Features	N/A	QR Secure Counterfeit Code	N/A	Multi-operator carbon emission coverage & Industry 4.0 compliant	N/A	Matching algorithms, best practices and decision support services
References	Agrawal et al. (2021)	Agrawal et al. (2018)	Kumar et al. (2017)	Fu et al. (2018)	Bullón Pérez et al. (2020)	Angelis-Dimakis et al. (2021)

Source: Alves et al., 2021.

5.3. Tools for transparency

Richero and Ferrigno (2017) describe transparency as relevant information about the supply chain that is made available for all elements of the value chain in a harmonised way, which in turn enables common understanding, accessibility, clarity, and comparison.

When supply chains are transparent, organisations have better insights into the activities that occur at the beginning of the supply chain, and this information can be relayed to pertinent stakeholders, including consumers. Information on transparency reveals where, by whom, with what resources, how, and when a product was manufactured (Cura et al., 2022).

Effective communication with all stakeholders is crucial for transparency. For instance, consumers are increasingly seeking more details about the origins of products. Obtaining reliable information is the initial challenge, and conveying this information to consumers in a user-friendly manner is another hurdle, necessitating simpler communication methods. This principle applies to all stakeholders, meaning that data and information must be converted into a format suitable for each stakeholder. This way, transparency not only enhances trust and credibility among consumers and other stakeholders but also enables businesses to identify and address potential issues early, leading to more sustainable and ethical practices. This could be done using the following tools:

- Employing circular textile measures enhances clarity in the fashion and textile value chain by offering harmonised standards, metrics, data, and best practices (WBCSD, 2024).
    - A cloud platform guarantees that crucial data about products and materials is uniformly conveyed throughout the industry. This allows for the digital identification of products for purposes such as resale, reuse, and recycling (Circular Product Data Protocol, 2021). This data could be collected using a QR Code, NFC, RFID, and IoT.
- Tools and systems for a high-quality comparable data set on working conditions: Data Collection Tool, verification methodology, and guidance documents, unique data sharing ecosystem that links different platforms.
    - Early developments in data platforms, machine learning, and AI technology present an innovative solution to mapping, analysing, and connecting the use of forced labour to corporate value chains at scale, accelerating a brand's ability to act and holding them to greater account.

One of the main tools that could be implemented to enhance transparency in the supply chain while increasing circularity is the DPP.

EON "EON is connecting the world's products to make every item traceable, intelligent and valuable."

EON is transforming physical items into smart assets which can be constantly monetised, utilised, and regenerated. By connecting each product to the digital ecosystem, EON enables full traceability of the product life cycle, the ability to share data, and embedded services that generate revenue. This way, the objects become more efficient, functional, and can be utilised to their full potential, which will align with business and environmental incentives. The company is creating the "world wide web for products". The platform enables creating a comprehensive digital ID for all products, which is then used to capture data from the product life cycle. This is enabled by an end-to-end

API[20] for data validation, transformation, and sharing. A digital ID can be created by integrating data into the PLM, PIM, and ERP[21] systems which could then further be merged with data from suppliers, certifiers, and material providers. Data could be further structured using different standards such as GS1[22] or policies and required business models. In addition, recording all the events of the product life cycle enables higher efficiency in sales, resales, and recycling processes. Manufacturers can benefit from implementing NFC[23] in their products, which in turn can digitise their products that can be linked to an app and utilised for identity activation and further tracking the product. Blockchain technology is used for intelligence-based analysis and event driven architecture as well as data storage.

5.4. Tools for textile recycling

Data-driven tools are crucial in processes such as waste stream mapping. They can be utilised for identifying the origin of the waste and materials, hence creating more traceability in the supply chain: for example, systems that are used to analyse fibres. In such systems, blockchain technology such as Relational Database Management Systems (RDBMS) and eXtensible Markup Language (XML) are used for logging actions related to items that can be tracked throughout the value chain. Additionally, IoT technology is utilised for effortlessly recognising the digital counterparts of these trackable items (Alves et al., 2021). Hardware and software technologies based on AI (Artificial Intelligence) and cloud services also make a smart ecosystem of waste management, which optimises decision-making features based on live data in each step (from waste collection to disposal). In the collection phase, AI helps optimise routes. In the separation phase, which is more complex, hardware technology linked with cameras and AI connected to IoT sensors optimise accurate identification and sorting of specific items, which leads to higher efficiency of recycling and material recovery (Heikkilä et al., 2023).

Satma^{CE} offers SaaS-based operational software for CE materials that can be used by recyclers and waste processors to capture operational data utilising *QR-based traceability, optional blockchain integration, and live third-party audits*. The platform is used for waste management operations from the initial collection and sorting of waste to recycling as well as further production of products out of substitute materials. Therefore, Satma^{CE} plays a significant role throughout the waste management life cycle, promoting more efficient, sustainable practices. This software is an excellent demonstration of how technology can help environmental preservation (SatmaCE, n.d.).

20 API = Application Programming Interface

21 PLM = Product Life Cycle Management, PIM=Product Information Management, ERP=Enterprise Resource Planning

22 GS1 = Standardised way of sharing data

23 NFC = Nearfield communication technology (uses RFID technology)

6. Policy options

The use and application of data in the textile supply and value chains involves many challenges. The transformation towards sustainability needs data to enable changes in, for example, current supply and value chains and how the business is operating, makes data and its availability and reliability critical issues. A sustainable transformation needs transparency, circularity, and more demand-driven operations, which can decrease textile and fashion production and consumption figures. Customer-centric product design and production challenge the fast fashion business model, but they also they need new operations and business models based on more accurate data. Moreover, a CE requires new partnering and open data sharing between actors in the ecosystem. However, data collection, owning, sharing, and use present various challenges and obstacles. "Understanding of various technologies and their limitations, such as poor data quality, limited analytical expertise, infrastructure that will be needed to store and manage the data, and data security to improve the current business operations (Labrinidis and Jagadish, 2012; Sivarajah et al., 2017), are just some of many challenges also textile and apparel industry are facing in their digital transformation" (Cura et al., 2022, p.11).

Each LCA phase or value chain process generates huge amounts data, which are owned by the actors themselves and cannot be owned by others unless certain indicators and specific data sets have to be collected.

In the global and saturated textile and fashion system, obtaining accurate and precise data from upstream actors or from the supply chain might be a challenging task. Most of the textiles and garments that are produced outside Europe, or that include materials or components imported to Europe, face this challenge. For example, climate labelling (based on LCA and PEF) needs accurate, credible data from all producers, throughout the supply chain. "Tools and databases must also be applicable to imported products on equal terms with EU produced goods, and accessible to non-EU enterprises on equal terms with EU enterprises. A barrier for this is the current lack of international harmonisation of sufficiently precise (interpretations of the) standards for climate foot printing" (Weideman and Eliassen, 2023, p.21).

On the other hand, data connected to downstream actions do not currently exist. To collect this data, completely new tools and measures and even standards need to be developed. Collecting this data is important, so that the actions and options related to the CE can be evaluated and their impact calculated. Higher product quality and extending the use, reuse, resale, and recycling lifetimes need measurements and figures that not only help the industry make accurate decisions but also inform consumers and perhaps inspire them to make conscious consumption actions. Moreover, environmental impact figures related to textile recycling would enable us to estimate and optimise different recycling options for textile waste.

Not only bigger brands but also SMEs in the EU will face challenges in collecting data from all around the world in order to be ready for the ESPR implementation. Even if the new regulations only concern bigger companies, the influence of the regulations will still spread throughout the supply chain and reach all tiers of business, including smaller companies in other countries. To obtain accurate information and full transparency in this sector, bigger companies need to collect information throughout their supply chain, including data from smaller companies.

Figure 5 summarises our study and combines information from different collected data sources. It lists the environmental, social, technological, political, and economic aspects and challenges in data use. It also points out the main policy options in data issues in the textile and fashion sector. These will be discussed in more detail in the following text.

The important issue is to obtain **harmonised, standardised data**. This requires collection criteria, communication principles, and data usage methods to be defined throughout the textile sector. These should be principles that all actors can approve and contribute to, but privacy issues also need to be considered and defined. It would help if the existing data standards could be used as the basis for new regulations, so that all initiatives would not need their own platform and data standards.

Different stakeholders' concerns

Designers; *How can we design products according to the criteria of the ecolabel (e.g. repairability, recyclability, product technical lifetime estimation) and where can we acquire the information?*

Textile waste recyclers; *How will the infrastructure on textile waste be constructed in different countries, and how will reverse logistics function, and who will cover the cost?.*

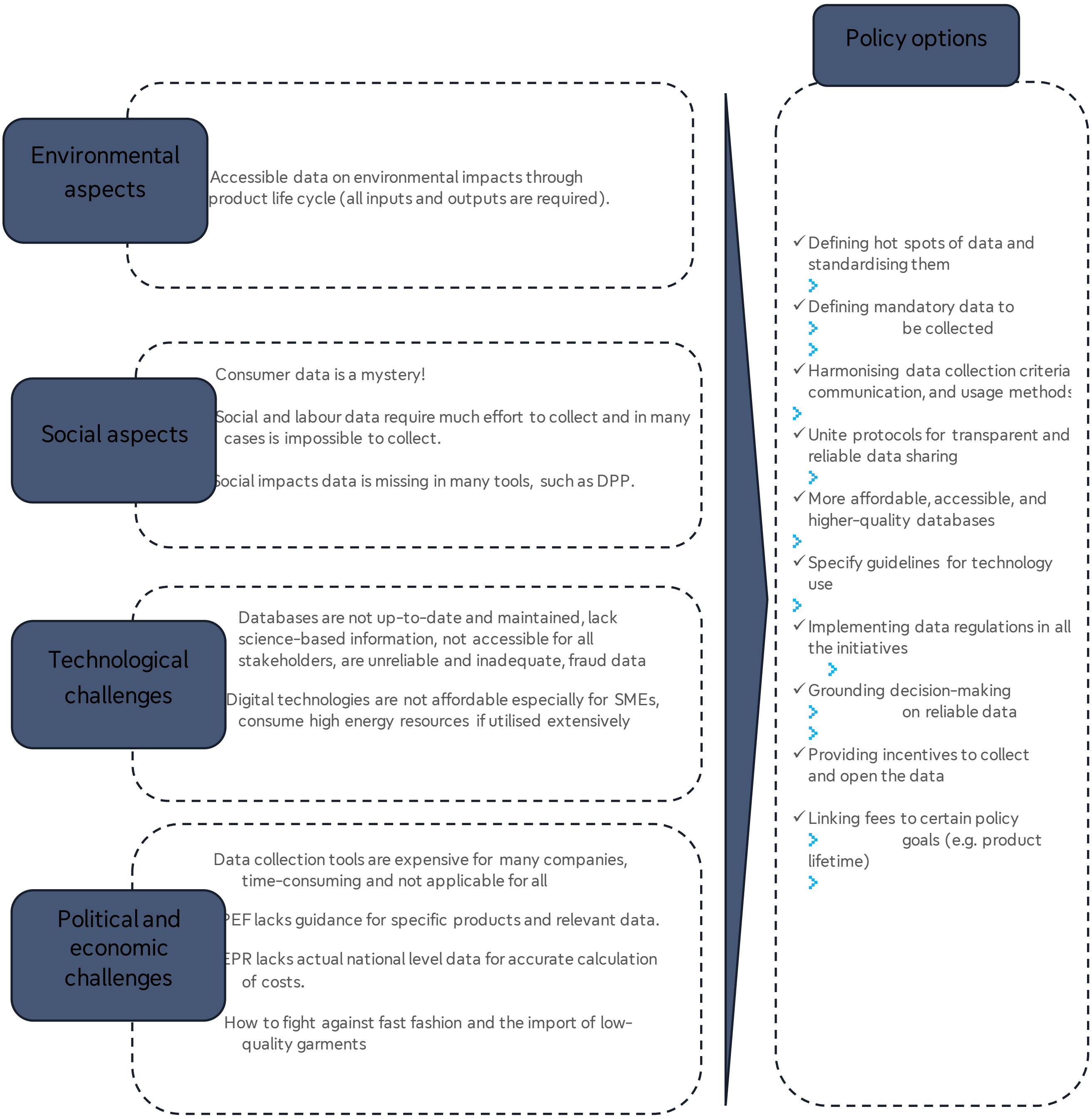
Fibre recyclers; *How can we get investments for scaling up production, how can we obtain stable, constant, and suitable material resource flows into the fibre recycling processes?*

Manufacturers; *How can we organise the reverse logistics, how can we acquire all the data throughout the supply and value chains? Are all the players playing the same game globally, and how heavy is the administrative burden of the new regulations?*

United protocols for **transparent, reliable data sharing** need to be defined. This requires expansive discussion on how to handle confidential data and on who owns the data in the system. How to secure data that links to a certain factory and their core business is another issue that requires further discussion. The reliability of data is a critical issue. We cannot make accurate calculations if the data is not reliable or up to date. If the data is unreliable, we cannot use it to make informed decisions. This would lead to a situation in which we possess no evidence of better sustainability solutions and our decisions remain based on guessing. Collecting data in certain standardised ways, from well-defined data hotspots, and through reliable technology can open up the data and create real transparency in the system. Data collection goals and uses need to be defined before collection begins, so that only the required data and accurate data is collected. Otherwise, there is a risk that data collection becomes too laborious an effort, and too much data is collected, which then requires resources for processing and creates an administrative burden for companies. and also increases their environmental impact.

A **decentralised platform** for storing and communicating data could help different factories and stakeholders to contribute to data gathering through their own actions. Decentralised platforms are based on data autonomy. Certain data collection systems could be automatised and could connect to the IoT to ease, open, and secure the collection of data. Decentralised platforms could use, for example, blockchain technology with a customised smart contract and clear data transaction rules. We also need **more affordable, accessible, and higher-quality databases**. Currently, many databases are private; their use is costly and requires expert knowledge. Constructing more accessible databases would help and encourage stakeholders to use the data in their calculations and in their decision-making. This would also support companies' sustainability reporting and communication with consumers. It is important to establish quantitative data baselines that could be updated and used by stakeholders for data comparison over time. An up-to-date, easy-to-access background LCA database would help all stakeholders.

Figure 5 – Different challenges and policy options for data issues in textile and fashion sector



Specific **guidelines for data technology use** are needed and these should also be connected to the different data needs of EU regulations. It is challenging to gather data throughout the product lifetime, and this still needs a technological solution. How to collect, save, and share data throughout the product lifetime is a critical factor in, for example, the DPP and in a textiles circular economy. **Implementing data regulations** in all the initiatives and all tools that are under development and linked to EU regulations need to be considered carefully. This aspect connects to the issue of owning data or sharing data openly. Moreover, the aspect of **mandatory or non-mandatory** data collection is important to link to the accessibility theme, but it is also important for transparency. The collection and sharing of certain data needs to be mandatory in order to help this sector reach the demands of transparency. Can some technology help automatise data collection? Would the blockchain technology help this? And what are costs of data collection and sharing? This requires further research.

Interviewees also pointed out that attention should be paid to making circular and sustainable solutions scalable and viable, which requires a broader perspective that goes beyond data. Ultimately, lowering consumption and increasing the value of products are seen as the most important issues.

If these principles were followed, companies' and other stakeholders' **decision-making could be grounded on reliable data.** LCA and S-LCA are especially important tools, as they link to many new regulations in the textile sector. It is important to note that LCA lacks a great deal of information (e.g. biodiversity, use phase, circularity actions), and S-LCA is still under development and requires the collection of a new kind of data. The development of DPP extends a promise that solutions are on the way, and the collection of data and laying it open (at least on some level and for some stakeholders) might soon become reality, which will help implement the new EU regulations. Moreover, providing accurate, reliable data to consumers might help and support them in making more conscious consumption decisions. This is something in which ecolabels can help. It would also be valuable to possess data that can enable, for example, comparing various recycling options at the EOL stage. These considerations could be taken into account in the product design phase to enable making the correct choices regarding, for example, the selection of materials best suited for certain recycling processes.

Geopolitics is changing and resource costs are increasing. Regulations will change the game. This is a bigger change than in the 1990s when global trade opened, but it might take 20–30 years. (Head of European Textile Association)

All products coming to single markets (EU) should follow these regulations, especially the ecodesign directive and the DPP. (Policy Officer, EC)

The idea is that unsustainability cannot create competitive edge. (Sustainability Consultant/NGO investigating global impacts)

7. Discussion

This study identified data gaps in the textile sector, and the assessed current initiatives that are addressing these gaps. Missing data, accessibility of data, data management, data reliability and relevance, mandatory or non-mandatory data collection, sharing data, and data costs were the general findings of this study. They all present challenges that need to be if transparency is to be achieved and better data is to be used in this sector.

We would like to end this study by discussing how to use data to tackle the **fast fashion** phenomenon. In the textile and fashion field, the race towards the cheapest end price is serious (race to the bottom), and mandatory regulations might ease competition if the same rules concerned everyone. Mandatory regulations offer an opportunity to "level the playing field": not only preventing greenwashing and data frauds, but also exposing the real environmental or social impacts of each stakeholder. Mandatory principles will strengthen sustainability-minded companies' competitive position on the market. The same rules must apply to everyone in the supply and value chains. When the mandatory regulations concern everyone and the EPR is widely implemented, this will offer business opportunities to companies in the reverse logistics, reuse, repair, re-commerce, and recycling sectors. The EPR will shift the responsibility of a product's lifetime to the manufacturer or importer (and away from the consumer or society). This will provide opportunities to change the current business logic.

> *Garment A, with a production impact of 1000 - in GHG emissions, water scarcity, or whatever - worn 1000 times, has an impact per 'wear' of 1. Garment B, with a production impact of 100, that is only worn 10 times, has an impact per 'wear' of 10. Moreover, after 1000 'wears', only one of garment type A enters the waste stream. But at 10 'wears' each, to reach 1000 'wears', 100 of garment type B will first have to be produced (and 100x100= 10,000) and then disposed of. Consumers choosing Garment B over Garment A will result in 10 times the environmental impact and 10 times the waste. (Kassaty & Townsend, 2024, p.17)*

Data can realise **transparency and traceability**, and real, accurate information on environmental impacts or social sustainability issues can be connected to specific products, factories, or brands. In this way it is easier not only for producers to select more sustainable solutions or partners who can offer these but also for consumers to select more sustainable products based on data and reliable (and more transparent) communication. As proposed in the report on the DPP (Legardeur and Ospital, 2024, p.44), "international partnerships can help harmonise standards and practices across countries", and this is something DPP can truly change.

We must note that the use time of garments is a critical issue for the environmental impacts of the use phase, as can be seen in the quote above. Therefore, the **extension of a product's lifetime** should be the goal in the fight against fast fashion and in the attempt to invite consumers to join this fight. The ESPR creates the potential to shift the focus in design onto higher-quality and longer-lasting garments, but the most important stakeholders are ultimately the consumers, and their consumption habits need to align with this. Including the aspects of repairability and recyclability in the garment design is in line with CE goals and provides the opportunity to extend the lifetime of an item not only as a garment but also in fibre recycling. The EPR will make the waste issue the responsibility of manufactures and brands and will provide them with motivation to invest in higher product quality and longer textile lifetimes.

Ecolabels could contain the year of product manufacturing, which could then be checked at the end of the product's lifetime and linked to fees paid through the eco-modulation system. **Fees, as well as incentives,** should be used to push the development towards sustainability goals. For example, could some system incentivise companies that voluntarily provide access to their data? Fees and incentives could also guide companies in making end of product lifetime decisions, such as whether the product ends up in reuse, resale, or recycling. More pertinent data could also help companies make the correct decision in this (choosing EOL measures that have the lowest environmental impacts). Preventing the destruction of unsold textile products is a push towards a better balance between manufacturing and business. Using data to improve design (demand-driven strategies) and reduce production (more accurate production) could also help in this. Fees could push the change in business logic. In this way, using several regulations (policy mix) with the help of reliable and accurate data and incentives and fees could steer the mindset away from fast fashion and towards a sustainable and circular textile system, as well as fashion that is in a better balance with the environment.

There is a clear need and will to make the sustainable transition in the textile and fashion field, and this opinion comes from different stakeholders and European companies. Companies that already have sustainability as their core value and that also include sustainability in their actions desperately need these new regulations, as they can help them fight against cheap and low-quality fashion imports from outside Europe. Regulations, with the help of data, can bring the competitive edge back to the European textile and fashion industry.

> *We want to be part of the change in which recycled textiles and circular business models become the new norm and the desired option. (CEO, clothing brand with recycling actions)*

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Appendices

ANNEX A

INTERVIEW QUESTIONS

The interview questions were modified according to the interviewed person and their area of expertise, so the following questions were the starting point for each interview.

Name, date, position, affiliation

Please describe your role and expertise in the textile field

Questions

1. **What are the current data gaps in the textile industry in terms of evaluating environmental risks and climate impact?**

What data is currently missing from your field, but you would like for it to be collected?

How could the data be connected to environmental risks or climate impacts?

What data gaps exist from the viewpoint of the circular economy?

What data is needed to optimise tracking and tracing in circularity of textile?

To what extent do we need to use the traceable material for the full traceability of value chain, what is the challenge?

How important is textile user's sharing of data?

Do textile users want to share data with retailers during product lifecycle, e.g. how they use the products?

Which data needs to be shared with all the stakeholders of the ecosystem/value chain? Who is required to feed the data for whom?

What is your opinion about data ownership? Should the company own it? What type of policies could support this?

2. **What initiatives currently address the data gaps in the textile industry?**

Current ones like LCA

New ones like DPP, EPR, carbon taxation, avoiding green washing (GCD), Textile Labelling Regulation in accordance with sustainability and CE, Incentive circular business models (including reuse and repair sectors), Ecodesign for Sustainable Products Regulation (ESPR)

What should be the main function of a DPP (information on product's life cycle/design optimisation/enabling reusability, etc.)?

What details should a DPP include? (Supplier data, customer data, material data, product data, company-owned process data, LCA data, Waste data)

EPR aims for designing better products from the start. What supports are needed for circular design of products? Any existing unified standards?

What information should be included in specifications for physical and digital labelling to increase circularity & sustainability?

Is there something ongoing linking to the use phase (quality)?

Something new which is not under planning by the EU?

3. **How effective are these initiatives in addressing the data gaps in the textile industry?**

What data is covered and easy to collect, and what is not?

What data is totally lacking currently?

What information should we need in order to solve environmental problems in the textile supply chain?

(What are the barriers regarding transparency of these data?)

4. **How are the data gaps addressed by EU policy initiatives (like the digital product passport and others)?**

What EU tools are connected to data gaps?

What areas are not covered?

Can these tools have some harmful/negative outcomes? If yes, what kind(s)?

Regulations that support the reliability of shared data?

What global data standards will support the company?

Does EU regulation exist on sharing CE data? if not, what do you need?

ANNEX B

WORKSHOP QUESTIONS

Your area of expertise

What type of data are you receiving/sharing with other supply chain partners?

What data you wish to receive?

What type of data is missing?

What data should be mandatory to collect and open?

What data should not be mandatory?

What are the existing data gaps in your supply chain?

What should be the content?

In what formats and methods do you receive and share the data?

Formats and methods in terms of systems, software, platforms

Are these tools for assessing the environmental impacts or only tracking the product?

What are the current challenges in data collection?

Do you receive enough data for your environmental impact assessment?

Is the data relevant /useful?

Do you know how to utilise them?

Other challenges?

What are the initiatives or opportunities you are part of or willing to utilise?

For example, initiatives that are related to data standardisation.

DPP

S-LCA

PEF

Other?

Part 4: Are you ready to open and share e.g. following information

Quality of the product

Lifetime of the product

Repair information

Recycling information (linking to a product)

Other?

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This study identifies data gaps throughout the textile industry supply and value chains, from fibre to the end of product life stage and assesses current initiatives addressing them. It also exposes the following challenges: missing data, data accessibility, data management, reliability and relevance, mandatory or non-mandatory data collection, data sharing, and data cost issues.

Drawing on a literature review, 17 stakeholder interviews and 2 expert workshops, the study gathers essential insights from the field and evaluates current and forthcoming initiatives for addressing data gaps. It goes on to discuss policy options geared towards using data to help achieve a sustainable transition and circular economy in the textile sector. Views on how to use data to tackle the fast fashion phenomenon are presented at the end of the study.

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