D1.5 Vision for H4C for Textiles

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LIST OF ABBREVIATIONS

Abbreviation	Definition
AI	Artificial Intelligence
CO	Cotton
DIY	Do-it-yourself
DPP	Digital Product Passport
EU	European Union
ECoP	The European Community of Practice
ESPR	Ecodesign for Sustainable Products Regulation
ETP	European Technology Platform
H4C	Hub for Circularity
ICT	Information and Communications Technology
JRC	Joint Research Centre
KPI	Key performance indicator
LCA	Life Cycle Analysis
LCC	Life Cycle Costing
NGO	Nongovernmental organization
NIR	Near Infra Red
PES	Polyester
PET	Polyethylene terephthalate
PRO	Producer Responsibility Organization
PU	Polyurethane
PVC	Polyvinyl chloride
UNTP	The United Nations Transparency Protocol

Executive Summary

The overall objective of the tExtended project is to develop a knowledge-based Blueprint: a master plan for a sustainable textile ecosystem in which textile flows are optimised to retain material value in a safe and sustainable manner. Within the tExtended project, we develop technological and digital solutions that enable efficient textile cycles, demonstrate textile circularity, and show the potential to reduce textile waste by 80%. More information about the project is available at https://textended.eu/. This deliverable documents the tExtended vision of a Hub for Circularity (H4C) for textiles. It also integrates knowledge gained through the project's research activities to create a solid foundation for a future hub.

In this context, a Hub for Circularity (H4C) is envisioned as a coordinated ecosystem that connects stakeholders, technologies, infrastructure, knowledge and data to close resource loops and accelerate the transition towards a circular and climate-neutral textile sector. For textiles, the hub would serve as a trusted focal point for knowledge exchange, networking, innovation and practical circular activities, helping stakeholders identify the most suitable uses and destinations for textile products, materials and waste flows.

Three geographical models were assessed: local, national and international hubs. Local hubs provide proximity and strong networks but may lack sufficient volumes and expertise, while international hubs enable cross-border coordination but face complex governance and longer transport distances. A national hub was identified as the most feasible core model, linking local and European actors and coordinating textile flows, common practices, regulation, investment and circular markets. The hub would be developed in phases. Initially, it should establish its mandate, leadership, governance, funding, stakeholders and shared targets. During operation, it should monitor legislation, markets, technologies and material flows, update its business model and support skills development. In the longer term, it should promote cross-border cooperation, shared investment and demonstrations, and guide emerging hubs.

The tExtended project demonstrated that textile circularity is a system-level transition requiring coordinated progress in technology, infrastructure, regulation, business models, data sharing and stakeholder behaviour. Technological solutions alone are insufficient: effective collection, sorting, reuse and recycling depend on collaboration across the value chain, reliable material information, harmonised practices and viable markets for secondary raw materials. The work also showed that textile diversity, inconsistent waste streams and limited data availability complicate material routing and technology scale-up.

Although several recycling and pre-treatment solutions achieved promising results, their performance remained highly dependent on feedstock quality and composition. Achieving substantial waste reduction therefore requires simultaneous advances in waste prevention, product longevity, collection, sorting, reuse and recycling capacity. These findings highlight the value of a Hub for Circularity in coordinating actors, knowledge, infrastructure and material flows and in translating emerging solutions into practical circular systems.

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1 Introduction

Processes4Planet SRIA 2050 (A.SPIRE, 2021) determines Hubs for Circularity (H4Cs) as *'self-sustaining economic industrial ecosystems for full-scale Industrial-Urban Symbiosis and Circular Economy, closing energy, resource and data loops and bringing together all relevant stakeholders, technologies, infrastructures, tools and instruments necessary for their incubation, implementation, evolution and management'*. Hubs are facilitated regional initiatives that involve regional stakeholders and aim to realise ambitions related to circularity and/or climate neutrality around their industries. Hubs look also across regions, whenever the necessary loops for building circular value chains need it according to the availability of resources, LCA and for knowledge exchange. P4Planet will support the creation of H4Cs and will aim at 15 mature hubs by 2030 and 50 hubs by 2050.

H4C according to H4C Community of Practice[1]: *'Hubs4Circularity (H4Cs) support a paradigm shift both in terms of material sourcing and the organisation of interconnected production and recycling networks, aiming toward climate neutrality, circular economy, net zero competitive industries and strategic autonomy of Europe'*. H4Cs should share best practices and support replication. They play an enabling role to significantly enhance European resilience, reduce Europe's material footprint, overall emissions and create new employment opportunities. The creation and implementation of H4C is a long-term process that requires coordinated actions from many participants and commitment from the private sector and from regional authorities.

Within tExtended we determined a textile hub for circularity as *'A Centre/ focal point/ one-stop/ go-to source/ platform for the collection, sharing and exchange of knowledge, information, support, development, learnings and ideas. Enabler of networking among various industrial and urban stakeholders. Textile hubs for circularity also bring together technologies and infrastructures and can conduct activities related to circular textile processes.'*

There are already, and have previously been, several hubs, communities, initiatives and networks that aim to share knowledge and improve textile circularity. The tExtended project group collected the examples considered most relevant by its members in Table 1. While A.SPIRE defines an H4C as a more concrete industrial ecosystem, most of the hubs, communities, initiatives and networks listed by the tExtended partners focus primarily on knowledge sharing and therefore also include temporary or short-term collaborations built around projects. Of the collaborations included in Table 1, the ReHubs initiative, with more than 30 industrial partners from across the value chain, comes closest to A.SPIRE's definition of an H4C.

Table 1 Textile knowledge and circularity supporting hubs communities, initiatives and networks (collected within tExtended project workshop 10th Dec 2025)

Name	Short description	Ways of knowledge sharing and supporting circularity
Textile exchange[2]	A global non-profit working closely with every sector involved in the fashion and textile supply chain. It started as Organic Exchange for organic cotton 2002, an expanded its focus in 2010 to diverse selection of fibres and materials.	A knowledge platform. Organized annual conference. Tools and reports.

1 https://www.h4c-community.eu/wp-content/uploads/2024/12/What-is-an-H4C.pdf

2 https://textileexchange.org

Name	Short description	Ways of knowledge sharing and supporting circularity
ReHubs[3]	ReHubs is a partnership-based collaboration hub working to industrially scale up the collecting, sorting, processing and recycling of textile waste in Europe. It unites players from the whole textile value chain, who share joint ambition to recycle 2.5 million tons of textile waste by 2030.	Coordinating the European Textile Recycling Roadmap. Facilitating the development of investment projects for fibre-to-fibre recycling among the ReHubs members. Initiating common knowledge projects related to textile recycling.
Textile ETP[4]	Europe's largest network of professionals driving research and innovation in the textile and clothing industries. As the European Technology Platform for the Future of Textiles and Clothing, it unites researchers, industry leaders, and innovators shaping the future of the sector.	Enable networking. Supports learning e.g. via webinars and innovation hubs. Supports it members in forming of strong consortia for EU projects. Coordinates Textile of the Future partnership.
ECOSYSTEX[5]	The European Community of Practice (ECoP) for a Sustainable Textile Ecosystem, formally launched in early 2023, have a mission to accelerate collaboration in the textile sustainability and circularity field. It consists of EU-funded member projects focusing on textile sustainability.	Foster interproject collaboration by sharing best practices and knowledge. Engage with policymakers and public programme managers. Provides channels for EU research projects dissemination.
TCBL[6]	TCBL (Textile and Clothing Business Labs) association. Connects people and organisations together to nurture a community and create a truly sustainable Textile & Clothing industry.	TCBL Association – A network of member laboratories and SMEs that test and deploy innovations in real conditions. Cedecs-TCBL SAS – A group of European experts (business, technology communication, public policy, etc.) that supports and structures strategic projects for the sector.
Ellieconnect.com[7]	Membership based digital platform with the goal to inform and connect with a strong emphasis on supporting SMEs.	Organising workshops, webinars, and training Offering tools and services Maintain actor database
Re_fashion[8]	Refashion is the certified eco-organisation for clothing, household linen and footwear. As PRO it monitors the prevention and end-of-life management of textiles placed on the French market.	ERP scheme in France for clothing. Knowledge transfer. Support for circular businesses.

3 https://www.rehubs.eu/
4 https://www.textile-platform.eu/what-we-do
5 https://www.ecosystex.eu/
6 https://tcbl.eu/
7 https://ellieconnect.com/
8 https://pro.refashion.fr/en/

Name	Short description	Ways of knowledge sharing and supporting circularity
Circular Textile days[9]	The Circular Textile Days is a business event that offers an opportunity for meeting new partners in the sustainable textile business and for discovering and discussing innovative circular textile solutions.	Publish newsletters. Annual event Circular Textile Days as platform for talks, discussions, presentations and sharing innovative ideas. Watch over the quality of the shared information and avoidance of greenwashing.
Telaketju network[10]	Telaketju is a Finnish cooperation network that have been advancing textile recycling by developing collection, sorting and processing solutions, circular business models, and a multidisciplinary knowledge ecosystem.	Have included several jointly funded research projects. Webpages for sharing results and knowledge generated in projects. Events, study trips, and newsletter.
RegioGreentex[11]	RegioGreenTex is a project promoting research and development collaboration across the textile industry to establish systematic circular economy business models throughout the EU.	Regional support and hubs. SME support and coaching. AI matchmaking tool.
TEX-DAN[12]	TEX-DAN is a project aiming to increase awareness of the importance of circular textile management and bring the Danube region closer to the best EU and global good practices. It will test technology solutions within circular textile and fashion value chain.	Pilot projects and campaigns. Study trips. Joint action aims to continue as a transnational hub for textile SMEs for assistance on technology upgrade.

In the tExtended project we saw that H4C needs to have high level of knowledge of the whole textile system. The hub needs to provide information to participants. An orchestrator of the hub is critical; a coordinator is needed. In a circular system information is needed about the value of the materials and what is the best way to get the highest output. The companies do not have the capacity to search the whole market; this information could be provided by the hub. Now information might be country-specific and local (in some countries), but also European-level information is needed. To create a vision for Hub for Circularity for textiles we started to consider location, information channels, themes and activities of the hubs (see Figure 1).

9 https://www.circulartextiledays.com/
10 https://telaketju.turkuamk.fi/en/front-page/
11 https://www.regiogreentex.eu/dashboards/home
12 https://interreg-danube.eu/projects/tex-dan

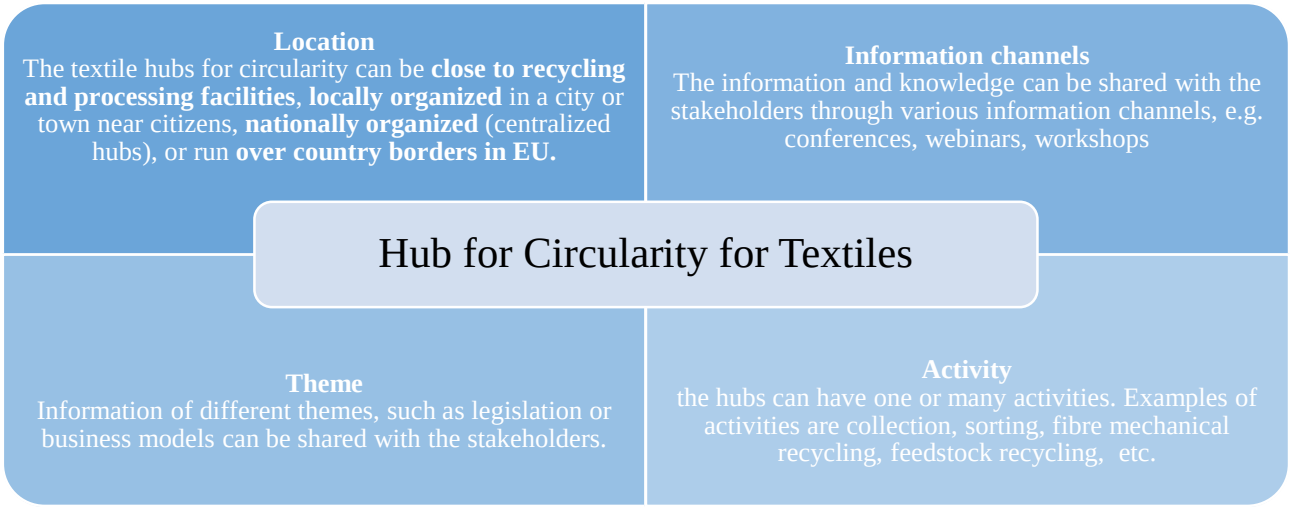


Figure 1 Visioning of H4C of textiles focused on determining location, information channels, theme, and activities of such Hub.

Within the tExtended project we started the visioning of H4C for textiles without considering the existing hubs and initiatives. Initially, we determined three geographic approaches – local, national, international - for which we determined main themes, activities and key stakeholders, and evaluated strengths and weaknesses. Some activities like extended producer responsibility (EPR) systems will be put up by each European country, so in that sense a national hub could be practical. However, the whole circular systems need to be involved and heard, and typically systems are not confined by country borders. A European hub could facilitate a wider collaboration among actors and harmonize the regulation (so that there would not be different regulation/ways of working in diverse areas). The perspective can also be global, as current textile value chains are global. The national hub was selected as the most probable one for further study, and we determined actions needed to support building of such hub for that. Many of these activities may also apply to local and international hubs.

Another contribution of the tExtended project to this report is systemic understanding and knowledge gained and collected during the project. This understanding and knowledge would support any type of H4C and participants and stakeholders of such Hub. Therefore, the main lessons learned and a summary of our major results publications are collected also to this report.

This deliverable report, thus, contains the tExtended vision for Hub for Circularity for textiles in Chapter 2, and Chapter 3 summarizes lessons learned from different activities of the tExtended project which may be useful in building up of such Hub. Finally, a Chapter 4 with conclusions wraps up the report.

We applied several qualitative data collection methods in this deliverable. These methods include workshops, interviews and questionnaire. AI tools have been used to support writing of parts of the report.

2 Vision for Textile Hub for Circularity

In tExtended we consider a textile hub for circularity to be a central platform for collecting, sharing and exchanging knowledge, information, support, expertise and ideas. It enables networking among industrial and urban stakeholders involved in textile manufacturing, use, and recycling. It also connects technologies and infrastructure and supports activities across circular textile system (see Figure 2).

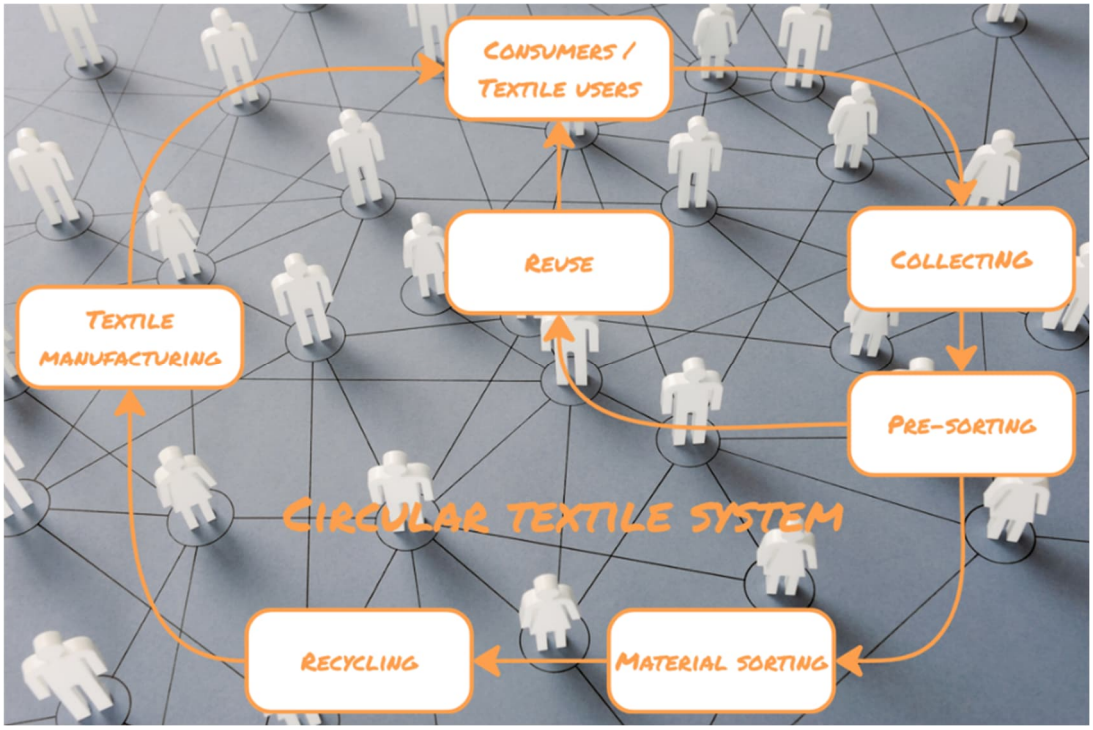


Figure 2 Textile hub for circularity connects and supports activities across circular textile system.

At the time of writing of this report (2026) the demand of markets for circular solution is low. Businesses are waiting for implementation of new EU regulation like EPR, which is happening in coming years. Brands are having hard times because of Chinese imports and ultra-fast fashion. War in Ukraine affects economics in European market in general.

At the same time circularity needs efforts. The supply chain for circular production is much more complicated than linear with several extra process steps. Thus, the cost to make products with recycled content is higher than with virgin material, and this could be the case for the next three to five years. An orchestrated hub with allocated resources would provide support for circular transition especially in such challenging marked situation.

This chapter describes the vision for Hub for Circularity (H4C) for textiles. Three geographic approaches – local, national, international – are described[13] in sub-chapter 2.1. The national hub was selected as most probable

[13] Descriptions are mainly based on tExtended internal workshop held 10th December 2025. tExtended project group views are complemented with comments and views obtained from stakeholders in interviews and within public workshop held within ECOSYSTEX Annual Conference 2025 in Gothenburg Sweden.

scenario of these three[14]. Thus, more detailed determination[15] as well as actions needed for national hub is included as sub-chapter 2.2.

This vision of an H4C for textiles was built independently of existing hubs and initiatives. In real life, the establishment of an H4C should be closely linked to existing hubs, initiatives and networks instead of building a fully new structure from the beginning. Several textile-related initiatives (see There are already, and have previously been, several hubs, communities, initiatives and networks that aim to share knowledge and improve textile circularity. The tExtended project group collected the examples considered most relevant by its members in Table 1. While A.SPIRE defines an H4C as a more concrete industrial ecosystem, most of the hubs, communities, initiatives and networks listed by the tExtended partners focus primarily on knowledge sharing and therefore also include temporary or short-term collaborations built around projects. Of the collaborations included in Table 1, the ReHubs initiative, with more than 30 industrial partners from across the value chain, comes closest to A.SPIRE's definition of an H4C.

Table 1) already provide knowledge-sharing channels, stakeholder networks, project collaboration models, regional support structures and, in some cases, industrial-scale circularity ambitions. Furthermore, a role as central organization that regulates the legal obligations for the collection and recycling of textiles on behalf of clothing brands, retailers, and manufacturers, Producer Responsibility Organizations (PROs) may have an important role in the formation of H4Cs. However, existing ERP systems in EU countries vary, and system has not been fully implemented in all EU countries yet.

2.1 Three Geographic Approaches for H4C

A textile Hub for Circularity can operate at different geographical levels, each offering distinct roles, benefits and limitations. This section compares local, national and international approaches in terms of their activities, stakeholders, strengths and challenges, providing a basis for selecting the most feasible model for further development. Stakeholders and funding opportunities in three different approaches vary. Also, the types of recycling activities are important for the approach. While fibre mechanical recycling, including both traditional and soft processes, can work for local and national hubs only, thermo-mechanical recycling requires national or international scale, and chemical recycling can only work on international scale.

2.1.1 Local Hub

A local textile hub operates close to citizens and local collection, sorting, repair, reuse and recycling facilities (see Table 2). Unlike national and international hubs, a local hub could concentrate on practical material circulation within a city or region. Its core activities would include organising collection and take-back systems, connecting locally available textiles with repairers, reuse operators, recyclers and material users, and providing citizens with guidance on repair, reuse and remaking. Its main strengths would be trusted local networks, direct citizen engagement and short transport distances, which can reduce logistics costs and emissions. However, its limited geographical scope could result in smaller material volumes, gaps in the value chain and restricted access

[14] Selection was made by voting during tExtended internal workshop held 10th December 2025. Local hub obtained 0%, national hub 56% and international hub 44% of votes.

[15] Drafts of determination was first carried out by task core group during Spring 2026 and common vision with whole consortium was obtained during internal project workshop in May 2026. Complementary comments have been included from interviews and public workshop in ECOSYSTEX conference.

to specialised expertise, requiring cooperation with national or international hubs when local solutions are unavailable.

Table 2 Main themes and activities, key stakeholders, as well as strengths and challenges of a Local hub.

Local Hub		
Main themes	• Recycling techniques for technical textiles (multiple textiles and compositions) • Technical specifications	
Main activities	• Organize local collection • Facilitate sorting and reuse • Link different actors together to "save" materials from incineration • Organize bring back systems • Platform to link together local available materials and material end-users • Guidance and information for citizens on the repair, reuse and remaking activities and services and companies offering these services	
Key stakeholders	• Users • Retailers • Repair shops and other actors preparing for reuse • Social enterprises • Collectors • Sorters • Recyclers	• Citizens • Industrial partners • Research organizations • Academia • NGOs • Municipalities • Charity organizations
Biggest strengths	• Easy networking because the local actors know each other better • Helping actors to find solutions that they would not have resources for on their own • Keep track of the relevant stakeholders in the local area • Short transportations resulting in low CO_2 emissions and smaller costs of transportation • Close to citizens → enables their education and guiding	
Biggest weaknesses/ challenges/ barriers	• Gaps in the value chain if only local actors are involved • Less textile waste for reuse • Less knowledge and expertise if only local actors are involved • Competition between the companies involved → Less willingness to cooperate? • Local funding may lead to imbalance and unhealthy competition with other regions • Possible own rules of local hubs may lead to contradictions and inconsistencies with EU level rules currently built up by EU.	

2.1.2 National Hub

A national textile hub would coordinate circularity activities across the country, connecting local collection and processing systems with national policy, investment and extended producer responsibility (see Table 3). Unlike a local hub, it could consolidate textile flows from multiple areas to create sufficient volumes, harmonise collection and sorting practices, and support consistent implementation of regulation. Compared with an international hub, its activities would remain aligned with national legislation, infrastructure, funding mechanisms and market conditions, while cooperation with other countries help fill value-chain gaps. Its key strengths would be access to national investment, systematic collaboration and the ability to coordinate

stakeholders and waste flows at scale. However, long transport distances, incomplete national value chains, and the need to demonstrate concrete benefits to participating actors may limit its effectiveness.

Table 3 Main themes and activities, key stakeholders, as well as strengths and challenges of a National hub.

National Hub		
Main themes	• Public policy and regulation • Investment for circularity	
Main activities	• Implementation of national roadmaps and ambitions • Act as an EPR organization and organise the EPR for the country, or at least communicate with the EPR organisation • Communication towards end-users to create awareness • Collect national flows of certain waste streams to create volume (optimisation) • Optimise the local collection points • Ensure collaboration with other EU countries beyond the national operations • Keep track of waste flows • Platform to link together local available materials and material end-users • Looking at regulatory obstacles and opportunities	
Key stakeholders	• Policy makers • Research organizations • Academia • NGOs • Textile PROs • Transportation companies • National EPR organization	• National government • Waste management companies • Municipalities • Retailers • Textile producers • End-users
Biggest strengths	• Funding for investments often comes from national governments • There is a need for more collaboration for systematic improvements (not just projects, silos) • If transported with good fill rate, less transports with be less CO_2 emission and with a smaller cost tonne/km • More waste to consolidate than in the local level • New directives may be easier to implement than in the local level, as the whole country "works the same way” • Greater promotion of circularity in business sectors • Uniform local collectors and make sure information is ending up with the correct stakeholder	
Biggest weaknesses/ challenges/ barriers	• Long distances in certain countries • Limited waste composition (what is consumed, there may be differences between countries) • Actors seeing value and concrete gains for this investment • Some gaps in the value chains may exist • National funding may lead to imbalance and unhealthy competition with other countries • Possible own rules of national hubs may lead to contradictions and inconsistencies with EU level rules currently built up by EU	

2.1.3 International Hub

An international textile hub would coordinate circularity activities across national borders, linking national hubs, governments, logistics operators, recyclers and European-level organisations (see Table 4**)**. Unlike local and national hubs, it would focus on optimising textile waste flows according to available volumes, technologies, facilities and labour across several countries, while harmonising collection practices, transport arrangements and regulatory approaches. Its main strengths would be the ability to fill value-chain gaps, support EU-level goals, exchange national experience, and facilitate strategic cooperation across Europe. However, differing policies, readiness levels, and national priorities could make governance and harmonisation complex. Longer transport distances may also increase environmental impacts and distance citizens from circularity activities, requiring careful optimisation of material flows and close coordination with local and national hubs**.**

Table 4 Main themes and activities, key stakeholders, as well as strengths and challenges of an International hub.

International Hub		
Main themes	• Legislation related to waste transports • Legislation for circularity • Legislation on the use of sustainable materials in industry • Product security	
Main activities	• Optimize flows according to volume of waste, facilities, technology and labour • Uniform collecting systems so that the same habit is created all over EU • Transport optimization • Transport of materials • Facilitate strategic cooperation across EU	
Key stakeholders	• European Commission • National PROs • NGOs • Customs services • Logistics companies • Storage hubs • National hubs	• Recyclers • EU government • National governments • Non-EU governments • Euratex • Textile ETP • AUTEX - Association of University of Textiles
Biggest strengths	• Possibility to support EU level goals and regulation • Collaboration across country borders in EU • Exchange of local and national experiences • Least gaps in value chains compared to local and national level hubs • Uniformization and optimization of practises and guidance across EU • Optimization of the textile waste flows	
Biggest weaknesses/ challenges/ barriers	• Lot of work in harmonising policies between countries • Countries have different readiness levels • Contradicting ambitions/ views/ emphasis of different countries • Too many transports for too long distances • The far-away-from-consumer operations may distance the consumer from the circularity thinking	

2.2 Vision for National Hub and Future Actions Needed

A national level textile H4C is a nationwide cluster that brings together recycling technologies, collection and sorting facilities, textile manufacturers and brands, logistics providers, policymakers, government and municipalities, research organisations and consumers/citizens. The main purpose of a national level textile H4C is to enable full textile circularity, for example, by keeping textile products and materials in use for as long as possible and reducing waste and emissions.

2.2.1 Hub Initiation Phase

The very beginning, the **first 1-3 years** of the hub, consists of actions targeted for establishing the playing field and structure of the hub. The hub needs to assume a high-level coordinator and ensure funding, while also start forming its business plan, mapping the national stakeholder field, and forming its key targets. The milestones and the respective main activities for the hub for circularity in its initiation phase are listed in Table 5.

Table 5 The milestones and the respective main activities for the hub for circularity in its initiation phase (1-3 years).

#	Milestone	Main activities and actions needed
1	Establish overall mandate and leadership for the hub.	Identify who has the **mandate to start the hub initiative** (e.g., government, national textile organisation, NGOs, industry coalition, or a funding body). Motivate the **high-level coordinator** for the H4C. Interact with European organisations (e.g. European textile organisations or industry coalitions). Assume **local representatives.** **Secure initial funding** and resourcing to start coordination work (e.g. via projects). **Create awareness and demonstrate the benefits** of establishing the hub to motivate actors (policy, industry, municipalities, consumers).
2	Identify and map the key stakeholders and resources.	**Identify the main stakeholders** (collectors, sorters, recyclers, reuse operators, municipalities, logistics, funding agencies, EPR operators, manufacturers, policy makers, research organisations, educational organisations, NGOs, brands, citizens etc.) to be involved and bring these together. Map **current capabilities, infrastructure and opportunities** across the country. Identify the **streams**, ways of collecting/sorting (e.g. criteria). **Identify what is missing** nationally (e.g., missing recycling capabilities, missing data systems, missing stakeholders). Identify **co-operative activities** with other hubs **Map the risks** related to the hub activities and the current state of textile ecosystem Identify the **barriers** country-level/EU policies Focus on **promotion of European production**
3	Define initial business model and governance structure for the hub.	Identify **the roles and responsibilities** of the stakeholders. Develop a clear **operating structure** for decision-making, collaboration, and coordination. Establish **common rules** for measurement, mandatory data collection. Set and unify **common targets**, determine the flows (e.g., collection rates, recycling rates, reuse rates, uniform sorting criteria). Prioritise **uniform sorting criteria.**

#	Milestone	Main activities and actions needed
		Determine **the implementation model**, including setting KPIs. Establish **national waste flow mapping** (collection points, reuse operations, volumes, logistics) and **waste characterisation.**
4	Determine the location and form of the hub.	Decide whether the hub is a **physical or virtual/collaborative entity** (probably not physical). Decide on **where to place** or **how to organize** the virtual/physical hub geographically within the nation, criteria include e.g. existing infrastructure, population density, easiness to cooperate with other hubs over country borders.

Establishing the mandate and the leadership of a national hub should be done at a high enough level for it to be believable. Reputable organisations as initiators or coordinators could also help with initial funding. If the initiation is done on a European level, even for a national hub, interaction with large European textile organisations and industry coalitions, such as Euratex or Textile ETP, could offer irreplaceable knowledge and overview of the textile sector. This would also offer a possibility to provide funding through projects, and high-level coordination for all activities, further ensuring that the hubs operate in the EU regulatory framework.

The activities with the funding could be rather different depending on the time when a hub is initiated. Currently, recycled textile fibres are lacking a market, directly offering the hubs a chance to affect the demand, for example through incentives. Hubs with high-level coordination could make a difference in conversations with policy makers and legislators and either increase the supply through recycled content quotas or financial benefits for acquiring recycled fibres. Funding should also be used in campaigns for the public. As soon as textile consumption patterns shifts into more sustainable ones, the sooner the companies will also realise the benefits. More emphasis is currently needed for the companies already conducting circular activities.

The operational environment for the national hubs is challenged by intra- and interconnections. Imports from outside of European markets affect the market, making the business model definition activities important. The hubs should ensure European production is supported, so that the reuse operators and recyclers have a market. Taxation for imports or other rules could be defined and/or managed by the hubs to ensure reduction in imports.

Although the milestones listed in these chapters describe the key targets for national hubs, the European national hubs operate in a European regulatory and financial environment. EU member states are expected to transpose the EPR requirements into national legislation by April 2027 and those legislations to be operational by April 2028. This means that European textile stakeholders are now actively monitoring and anticipating the changes. The hubs forming soon could have the opportunity to solve the funding issue by establishing an initial funding from the EPR schemes, as their main target is eventually supporting textile circularity.

Hubs could offer cross-border advantage in the European market. The cross-border operations and commerce in Europe are sometimes manageable and sometimes characterised by the abundance of red-tape and mismatch of rules. Therefore, the hubs could have the opportunity to serve as the co-operation enabler between the parties and ensure the regulatory costs related to for example commerce are reduced. The hub's role as a co-operation enabler could also mean that countries lacking certain stakeholders would have no trouble finding an operational partner nearby in another country nearby. Moreover, provided that the hubs keep the systems running nationally, it should not be too difficult to learn directly from other hubs, for example about risks and barriers related to the textile ecosystems.

Even if the hubs do have the opportunity to link operators to other countries and their national hubs, it can be beneficial to establish and ensure that some operators are always available in the country. The funding should be allocated so that the key operations are managed in all situations. For example, recycling, in terms of physical facilities, can be one of those operations that gives advantages to the country: short distances reduce logistics

costs, rules on waste and resource management are easier to comply with inside a country than cross-the-border, and the country has either resources for their own manufacturers or an exportable product. Whatever the operations deemed indispensable for the hub, a good mapping of operators at an early phase would ensure efficient use of the hub's budget and create meaningful interconnections. In general, regardless of hubs, stakeholders in circular textile value chains are hoping to easier mapping of potential collaborators.

Nationally, the hubs should ensure that they communicate with societies effectively. The recyclers, reuse operators, research organisations, municipalities and logistics partners may be some of the obvious stakeholders to activate. The NGOs and educational operators should be engaged in the hub's work to ensure that companies produce sustainably and that knowledge is passed down. Simultaneously, the perspectives and opinions of citizens are important for a holistic approach to hub operations. Interaction with the national government and the EU could result in clear legislation, that is also easy to implement. Delayed implementation of legislations may delay any incentives for circular transition or even result in ending of operations due to uncertainty. The hubs need to ensure that legislation is helping rather than hindering growth. With the versatile requirements and activities of the hubs for circularity, hubs should still be realised so that their role and benefit are clear for society. A clear agenda attracts the attention of national stakeholders and ensures that taxpayers know what their money is used for.

A key problem that the hubs could solve is the mapping of textile waste flows and waste characterisation. If the fibre contents are known to some level, waste utilisation is easier: flows can be directed to those able to reuse or recycle them, and the amount of waste ending up incinerated decreases. To fully implement flow utilisation, uniform criteria for sorting are necessary. The formalisation of the criteria could be done together with the government, so that the legislation that follows is easy to put into action. The hubs could map the most demanded fibres or waste types, thus not only regulate the market, but also offer the chance to focus on materials with a high supply or demand. Having uniform criteria could ensure data from different recycling operations is comparable.

2.2.2 First Operational Years of the Hub

In the near future, **3-5 years** from the initiation phase, the hub needs to evolve and establishes its position in society and the business environment. The milestones and the respective main activities for the hub for circularity in its first operational years are listed in Table 6.

Table 6 The milestones and the respective main activities for the hub for circularity in the near future (3-5 years).

#	Milestone	Main activities and actions needed
5	Follow the status of legislation.	**Keep up to date with legislative changes** and status of the most important legislation (e.g. Waste legislation, DPP, Ecodesign). Ensure that **the activities of the hub are following the legislation.** Identify **what changes in the legislation are coming up.** **Keep the stakeholders up to date** with the newest legislation and the upcoming changes. Make **yearly reporting on the legislative status** (What has happened? What is good? What is the impact? How can we improve?).
6	Follow status of the operational environment	Evaluate **the gaps and status of the technologies** etc. to optimize the waste flows (should be done regularly). Keep up with **the latest data** on recycling technologies, impact assessments etc. Set up a **regular questionnaire for the stakeholders** collecting this data. Establish regular/annual **check-ins.**

#	Milestone	Main activities and actions needed
7	Revise the business model.	Follow the **impact metrics/KPIs** of the hub (as part of the business model). Ensure alignment on sustainability targets through **sustainability metrics.** Define **the fundamental/most relevant operations/targets** of the hub (Which activities should be prioritized). **Revise the start-up phase business model** (is it still valid or should the business model change).
8	Determine the long-term investment and funding model.	**Investment planning**: checking which investments are needed to be able to keep up to date (e.g. new technologies/should be linked to the analysis of new technologies, also changes in the stakeholder groups etc.), which investments are supported, assessing the impact of past investments. **Investment planning responsibility to governments.** **Conduct trend surveys** helping to identify material and technology development.
9	Influence on the national level textile education and workforce strategy.	Identify the **required skills and needs for workforce** at the national level. Contribute to **renewing the educational system and building curriculum for textile workers** (in all educational levels, e.g. vocational education, adult education, universities, education for unemployed people). **Educating the general public** (e.g. repair and reuse skills). **Promote the hub and the concept** towards decision makers.

In the first working years, the hub activities include monitoring and establishing the conditions to keep the hub active. Monitoring of legislation should have the benefit of the hub following the changes for the members of the hub. This way, the regulatory costs could be reduced for the stakeholders. The hubs should be aware of new requirements and limitations that may affect stakeholder operations and ensure efficient loophole scanning, so that operations remain fair to everyone. On the other hand, the hubs could also engage stakeholders, such as municipalities to take part in legislation forming at the EU level by providing as a communication channel between the governments and the EU. This way, the hubs work is not only monitoring but also shaping relevant legislation.

To ensure fairness in the textile sector, the hubs could interact with the stakeholders frequently, for example, through surveys and questionnaires, so that the stakeholders could provide their opinion in shaping the national business life. For example, eco-design requirements may come from a higher level, but countries usually set their own taxing systems, an opportunity for the national hub to collect opinions from their members and communicate them further to the government. This way, taxing can be set to promote sustainability, circularity, and control imports resulting in a fair playing field.

When it comes to ensuring that required skills and workforce as well as the technologies are in place for the hub to operate, someone may argue that their relevancy is important even before the 3-5 years period. Early mapping of the operational field and understanding its limitations will result in better coordination and collaboration within the hub and with other hubs.

At the same time, the operations to be included in the hubs are likely very different from one another, for example, a charitable organisation taking clothing donations may ship the textiles in hand-me-down fruit carton boxes and not be able to keep up with reporting CO_2 savings, while a textile manufacturing plant knows exactly how much is produced and how much needs to be produced to keep the production efficient and emissions to a minimum. The hub needs to be able bridge the gap between the different metrics and decide which numbers best suit and promote its operations. The metrics relevant for the national hubs could be mutually agreed upon within the European framework.

2.2.3 Long-term Hub Operations

With an established status, the national hubs in business for **over five years** should then transition into something of a "lighthouse". The hubs could ensure staying relevant as the operational environment changes, expand their collaboration within the EU and within different sectors, and provide guidance and motivation to new hubs. The milestones and the respective main activities for the hub for circularity in its initiation phase are listed in Table 7.

Table 7 The milestones and the respective main activities for the hub for circularity in the long term (5+ years).

#	Milestone	Main activities and actions needed
10	Staying relevant as the operating environment changes.	Continuously **adapting hub priorities** based on legislation, technologies, markets, digital infrastructure and societal needs. **Identifying what practices should be ended**, which best practices are not best practices any more or in the future. Identifying what **new opportunities** emerge, which functions/aspects need **support**, which **resources** could be reallocated, etc. Analysing the **long-term risks and opportunities.** Checking and updating the **KPIs** continuously. Making use of the **electrification (**e.g. transportation in countries with longer distances will benefit from electrification of transportation). Making use of the **digitalisation** (e.g. AI, databases).
11	Cooperation with other hubs and other sectors EU wide.	**Preventing competition between hubs.** Identifying **possibilities for co-investments** with other hubs to minimize the gaps e.g. in infrastructure. **Benchmarking** and **sharing best practices** between hubs and sectors, e.g. investigating what is working in other countries. Shared **cross-border demonstrations**. Implementing **cross-industry co-operation**, identifying **cross-industrial symbiosis opportunities.**
12	Acting as a lighthouse and influencer.	The hub should **help and motivate the initial/early-phase hubs** in their work. The hub should also **motivate other regions and other sectors** in adopting the H4C model and start building hubs. The hub should **impact the operational environment.** The hub should offer **financial and regulatory support for new and relevant actors** in the sector. **Communication** towards all stakeholders in an efficient and easy way is highly important, e.g. Host EU level circular economy conferences or summits, publish annual reports, best practice manuals, policy briefs, etc.

Once the hubs are fully operational and their place in the business field is established, the role could focus on developing and adapting to the changes, while still providing guidance and communication. Focus could be laid on ensuring that national hubs complement one another, rather than compete. Competition might not become a relevant challenge for national hubs, but it could be something to consider if more regional, local hubs emerge.

Collaboration and cross-industrial and cross-sector symbiosis opportunities could be mapped to develop the hub. Eventually, there will be textile material streams or other resources that do not find a suitable place for further processing in the textile sector, and there will be a need to find other uses for those streams.

In the far future, the hubs could direct the market into a more local setting. Local production and local demand could be realised with the help of digitalisation, automation and electrification. Digital logistics should be improved for resource efficiency, as data-driven routing, consolidation and transport planning, helping direct each material flow to the most suitable reuse or recycling option while reducing unnecessary handling, transport and loss of material value.

Performance assessment should be treated as a continuous process rather than a one-time exercise. As legislation, technologies, markets and societal expectations evolve, the criteria used to define good performance must also be reconsidered. Practices regarded as best today may become outdated as new evidence, solutions and opportunities emerge. Regular assessment therefore enables the hub to identify which practices remain effective, which should be revised or discontinued, and how its KPIs should be updated to reflect the latest knowledge and changing operating environment.

3 Key Lessons Learned and Knowledge Gained in tExtended Project

Currently, textile production and consumption are unsustainable, with the linear model generating large amounts of waste. The European Commission's Strategy for Sustainable Textiles aims to reverse this trend. Transformation towards more sustainable circular textile ecosystem require both new knowledge and practical development, and various technological and non-technological challenges needs to be solved. In this context, the tExtended project has developed a Blueprint, i.e. a masterplan for circular textile ecosystem, and an innovative knowledge-based conceptual framework for routing of for different discarded textile flows. It has been designed to optimise textile flows with ensuring retention the value of materials in a safe and sustainable way. We have also developed a wide range of technological and digital solutions necessary for a sustainable and circular textile industry. Our blueprint as well as our technological and digital solutions have been assessed, for example, by implementing a real scale demonstrator of a circular textile ecosystem.

The overall objective of the tExtended project has been to show potential of reduction of textile waste by 80% compared to stage before separate collection of textile waste was started. Such an ambitious goal has required us to aimed for creation of systemic view on circular economy. This kind of view is needed for building Circularity Hubs aiming for including all activities of circular value chains. Therefore, the project's key lessons learned have been included into the same deliverable report as vision of H4C for textiles.

Already from the beginning of the project, we have seen that actions needed to achieve this include reduction of waste in textile manufacturing and retail, extended reuse of textile products, and efficient material recycling of end-of-life textiles. We have focused on three pathways to impact of circularity: 1) **enablers of textile circularity**; 2) **efficient textile recovery**; and 3) **valorisation and recycling of textile waste**. Our key lessons learned and the knowledge gained are summarized in the following chapters. For further reading, we have included links to publications that are already available, and also indicated planned dissemination activities, not available in the delivery time of this report.

3.1 Enablers of Textile Circularity

The enablers pathway consists of circular economy knowledge and digital tools that aim to support the implementation and enablement of the circular economy.

3.1.1 Ecosystem Building

The Ecosystem. Work started by building the understanding of what circularity means for the textile value chain in defining the vocabulary and the R-strategies. We have explored how a circular textile ecosystem can be built through the redesign of value chains, development of circular business models, and strengthening collaboration across the textile sector for implementation of the circular strategies. Rather than focusing solely on recycling technologies, the project has adopted a system-level perspective, examining how material flows, regulation, business models, and stakeholder networks must work together to keep textiles in use for longer and retain material value.

We validated that technological solutions alone are insufficient to achieve circularity. The transition requires collaboration across the entire value chain, including brands, manufacturers, collectors, sorters, recyclers, policymakers, researchers, and consumers. The project identified multiple barriers to circular business models, including economic challenges, technological limitations, regulatory uncertainty, limited consumer demand,

and gaps in skills and resources. These findings highlight the importance of coordinated ecosystem development alongside technological innovation.

Blueprint. One of the main targets of the tExtended project has been to build a Blueprint i.e. masterplan for sustainable and circular textile system. In a circular textile system, optimisation of textile flows should follow the logic that each additional processing step increases costs and environmental impacts through energy use, chemicals, labour, logistics and potential material losses. Therefore, the preferred route is not necessarily the technically most advanced one, but the one that preserves the highest value with the lowest necessary intervention. Reuse should be prioritised whenever products remain suitable for continued use, followed by repair, remanufacturing and fibre mechanical recycling (soft and traditional processes) when material recovery is needed. More intensive thermo-mechanical or chemical recycling routes are important for specific fibre streams, like worn-out and contaminated materials, but they should be applied selectively, when lower-impact options are technically unsuitable or cannot retain sufficient material value. This hierarchy supports optimising textile circulation by matching each textile flow with the most resource-efficient and value-preserving route.

Description of ecosystem proved to be inspiring; however, it should be noted that priorities within different actors in value chain differ as well as different parts of Europe vary. Business of different kinds of actors may seem somewhat contradicting, for example, if discarded textiles should be forwarded to reuse or to recycling. Geographical differences, on the other hand, can be explained by differences in maturity of circular value chains within different parts of Europe vary.

Circularity hubs are widely regarded as a critical facilitator for implementing the blueprint in practice. Their role extends beyond connecting actors within the ecosystem; they provide the coordination, harmonisation and governance needed to ensure consistent decision-making and optimal routing of products and materials. By aligning stakeholders, infrastructure, data flows and regional capacities, circularity hubs can transform isolated initiatives into a functioning blueprint ecosystem. Without such harmonisation and coordination mechanisms, the implementation of the blueprint would be fragmented and considerably more challenging across regions.

Conceptual Framework. We built the Conceptual Framework (a model) and the Textendifier tool for optimization of routing of textile flows in textile system. The optimization of the utilization route for a given textile waste stream also considers economic, environmental and circularity impacts of the circular strategies. This proved challenging due to sheer amount of different textile waste characteristics and possible processing routes.

We really succeeded in building the theoretical, logical, and mathematical model. It turned out to be rather simple and robust. The user interface, on the other hand, still requires more work. *It was concluded that* better targeting would make the tool more valuable for its users. A particular development area for the content of the tool is to add more insights for interpreting the optimisation results.

We discovered that the challenge was to build the database; to collect environmental and economic data for all the possible circular strategies and specific textile waste characteristics. In the big picture, particularly recycling technologies are still quite immature and do not perform well in economic terms compared to waste incineration. Increasing the technological maturity is hence the key. Furthermore, the remanufacturing of textiles remains a rather broad and poorly understood concept. This cannot fully be captured in a tool like this at the moment. In conclusion, this work *validated our assumption* that finding optimal circular strategies for textile waste is complex, as the material itself is complex and the processes are still rather immature and rigid.

Social Innovation Spin-Off. The Social Innovation Spin-Offs were conducted in five tExtended partner countries: Finland, Belgium, Latvia, Portugal and Spain. The aim was to engage and raise awareness among garment users about the circularity of textiles and increase their involvement in circular textile activities. *This activity shows* that supporting the adoption and maintenance of these practices among garment users is important

for promoting overall textile sustainability and circularity. Further it learned that via good marketing added value can be found in waste streams that were in current business models considered of no value.

For example, in Finland, LSJH and VTT organised a Creative Garment Remaking Workshop facilitated by a Finnish fashion designer for local individuals. *The workshop participants expressed* appreciation for creating a space and time for garment remaking, as well as for creating a place to socialise with peers and an opportunity for creative activity. This kind of workshop can facilitate the adoption of new skills and encourage circular practices. *All in all, we learned that* there is interest among garment users in social activities that support the adoption and maintenance of sustainable and circular textile practices.

In Belgium, KLW opened temporary pop-up stores in shopping malls during the summer sales period, when consumers are most inclined towards cheap, high-volume clothing purchases. The explicit aim was to reach people who were not already engaged with — or who felt hesitant towards — second-hand clothing, rather than the network's existing, mission-aware customer base, which already bridges the gap of walking into a Kringloopwinkel store on their own initiative. Rather than expecting these new customers to seek out existing second-hand shops, the pop-ups brought a sustainable alternative directly into the retail environment associated with overconsumption, lowering the effort required for people already shopping there to engage with reuse. To support this, items were carefully selected and presented in a more boutique-style environment, creating a positive first experience with second-hand clothing. The pop-ups were well received, with customers valuing the closer proximity to their everyday shopping routines and proved effective in engaging a new customer segment beyond the shops' existing base. This demonstrates that physical proximity, timing and presentation — placing reuse alongside, rather than apart from, mainstream retail moments — can meaningfully broaden engagement with circular textile practices among audiences not yet reached by traditional second-hand retail.

In Latvia, ZALA organised a four-workshop co-creation cycle to explore how textile leftovers could be transformed into sustainable Latvian souvenirs. Design students and professionals, textile and circularity experts, reuse and waste actors, potential buyers and the social enterprise worked together with production leftovers and post-consumer textiles to develop and test product concepts. The activity showed that working directly with available textile streams is essential, as variations in material size, colour, composition and quality strongly influence what can realistically be produced. We also learned that involving the production partner from the beginning helps ensure that circular products can be produced in an inclusive working environment. Overall, successful circular products need to combine material reuse and a strong social and circular story with functionality, good design, quality and realistic production and market potential.

3.1.2 Assessment of the Ecosystem

Sustainability Assessment. The sustainability performance of the technologies and demonstrators developed in the project was assessed from the three dimensions of sustainability: environmental, social, and economic. The assessment was achieved via systems analysis life cycle tools, i.e. LCA, LCC, and Social LCA; by collecting data; modelling the life cycle of products using that data; and extracting impact assessment results and scenarios. The outcome of the sustainability assessment will support decision making in terms of data concerning the potential benefits of increased circularity of textile value chains.

The EU Product Environmental Footprint (PEF)[16] methodology provides a harmonised approach for applying life cycle assessment (LCA) to products. By defining detailed rules, datasets and calculation methods, PEF reduces flexibility in interpretation and improves the reliability of product comparisons.

[16] https://greencalculus.com/standards/eu-product-environmental-footprint-pef/

Symbiosis. The aim of the symbiosis activities was to assess the level of readiness of different technologies from the point of view of symbiosis. The methodology established in tExtended inspected the limits of emerging symbiotic interactions and pilot technologies with potential for growth. We created a readiness level methodology that responds to the complex textile sector and the creation of hubs for circularity and identifies symbiosis readiness of some technologies that could be implemented in textile hub for circularity. *We learned that* the technologies currently in lab scale are less ready for a symbiotic partnership, but have potential, nonetheless. Chemical recycling technologies are less ready for symbiosis than mechanical recycling technologies. *We also learned that* logistics could become an issue for material transports due to textile nature and availability, and therefore, the symbiosis should happen in a hub where is easier to transfer materials.

Industrial Urban Symbiosis Modelling. System dynamics *modelling showed* that achieving a substantial reduction in textile waste requires coordinated change across the entire system and cannot be accomplished solely by improving recycling technologies or individual material flows. The most effective scenarios combined reduced overall consumption and virgin material flows with longer product lifetimes, improved collection and sorting, and greater reuse and recycling capacity. The modelling *also revealed* important feedback loops, rebound risks, and the strong influence of assumptions about stakeholder behaviour. The results should therefore be interpreted as a means of identifying possible systemic pathways and effective intervention points, rather than as a direct assessment of feasibility or a policy forecast.

The modelling was implemented when assessing the potential of 80% textile waste reduction. *That experiment showed* that waste reduction needs a systemic change to accommodate it, and it still only possible under very demanding conditions. We mean simultaneous increase in recycling and reuse; improvement of collection and sorting; and reduction of consumption must happen, suggesting that waste prevention and circular capacity must develop together.

Barriers to Textile Circularity. The project studied the technological and non-technological barriers to textile circularity through workshops and interviews. The *study validated* that the transition towards circular textile industry is not limited to the technological challenges. Instead, the transition is hindered by a sum of technological, regulatory, economic and behavioural barriers. With the help of consortium partners, we were able to clarify the small aspects that make the circular transition difficult. For example, scaling up of operations is necessary for economically viable production, but scaling should happen in alignment with business partners, otherwise it's not feasible to anyone. At the same time, rules and requirements regulate the industry transition and future expectations, but many operators have the feeling they should be conducting circular economy already, even without the support. *A key lesson learned* is that the transition towards circular economy in the textile sector is a socio-technical coordination challenge.

3.1.3 Digital Tools

In development of traceability tool for circular systems, we *observed* that data models existing at the time we needed to apply them, we mostly focus on textile manufacturing, while processes and aspects needed to track and trace collecting, sorting and recycling were missing. To make data model for traceability of circular textiles, lots of development work needs to be done. For our purposes, tracking of the materials and processes in the real scale demonstrator, we generated simplified data model. We reduced data point for manufacturing, but needed to add data points for sorting, collecting and recycling. A lot a work is needed for existing data models to enable traceability of circular textile system.

Proof-of-concept Implementation of Digital Product Passport. Results were achieved by studying proposed DPP specifications (UNTP) as well as planned ESPR legislation and developing software that fulfils the requirements. Data sharing within the textile ecosystem is essential for achieving a more circular business model, and DPP is probably going to be a central tool for data sharing. Distributed architecture *seemed to be*

the most feasible way for implementing DPP, as it helps companies retain control over their data. The downside is that companies are also responsible for the data, meaning that they must invest time, effort, and budget for that. Also, if all companies in the supply chain are not committed to DPPs, it is likely that gathering and verifying all data will be a difficult task.

Data Sharing. An ICT application, deployed in the context of the previous data space, to gather traceability data of material, components and products processed in a textile value chain, was developed to enable the generation of the traceability history of textile materials. There was no ICT technology provided associated with the tExtended partners. Naturally, in a real environment, and in the cases where textile organizations have a business management system in place controlling its production activities, data gathering should be achieved by this business management system and then exported to the data space environment. We took the path of a manual data entry in the development of the traceability system. *Despite this strategic decision* in the project, manual data gathering worked well.

We discovered that the data model that was used in the traceability system proved to be well conceived. No major lacks were detected. *We noticed that* most of the data fields populated by the users were optional. In some cases, some of the data fields were not applicable (and thus not fulfilled by the users) but others were applicable and some users did not make use of them. Ideally, the manual data gathering process would need a different arrangement, where a prior categorization of the activity is done by the company followed by specific data forms asking for specific data fields, in a mandatory way. Naturally, the developed ICT application is a prototype, and some data fields do need a more ergonomic way of presenting and interacting with users.

Table 8 Publication examples related to 'The Enablers' pathway.
Links of the planned publications will be added to tExtended webpages (https://textended.eu/) once available.

Status	Reference information
Published	tExtended Blueprint (Part of D5.2 *Blueprint & public showcase of the real scale demonstrator*) https://textended.eu/textile-ecosystem-in-europe/
	Public deliverable (D1.2) report: *Redesigning Value Chains* https://textended.eu/wp-content/uploads/2024/10/tExtended_D1-2_Redesigning_REVISION1-.pdf
	Conference paper: Salo M. & Petänen P. (2024). Barriers for Circular Business Models in the Textile Sector. In *International Conference on Sustainable Design and Manufacturing* (pp. 161-170). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-96-4459-9_15
	Milestone MS3 post: https://textended.eu/2024/07/11/textended-reaches-milestone-on-future-data-driven-circular-ecosystem/
	Milestone MS6 post: https://textended.eu/2025/11/28/textended-starts-consumer-engagement-activities/
	Milestone MS7 post: https://textended.eu/2026/06/30/textended-reaches-another-milestone-80-waste-reduction-potential-requires-a-systemic-change/
	Blog posts: https://textended.eu/project-blog/
Planned publications	Upcoming Public deliverable D6.2 *Sustainability assessment report*
	Upcoming Public deliverable D6.3 *Circularity potential and symbiosis readiness report*
	Upcoming Public Deliverable D5.3 *Guidelines and workbook for application of the Conceptual Framework and Blueprint regionally*
	Scientific article by Vuorinen J., Mäkelä SM., & Heikkilä P. about Conceptual Framework and Textendifier tool

Status	Reference information
Planned publications	Scientific article by Raiskio S., Petänen P., & Heikkilä P., Designer-Facilitated Co-Creative Garment Remaking: A Case Study of Supporting Sustainable Clothing Practices Through a Participatory Workshop
	Scientific article by Wiman L., Kärkkäinen E., & Heikkilä P., The textile flow dynamics of ambitious pro-circularity changes in the European Union about system dynamic modelling
	Scientific article by Peñaloza D. & Lai C. about selected results from the sustainability assessment.
	Scientific article by Kärkkäinen E. about barriers to textile circularity transition
	Whitepaper by Kärkkäinen E., Periyasamy A., & Heikkilä P., From Symbiosis Gaps to Symbiosis Readiness: Enabling Circular Collaboration in the Textile Sector

3.2 Efficient Textile Recovery

The efficient recovery pathway consists of project results that support in collecting, sorting, and pre-processing of textile waste. The post-consumer textiles were collected, for example, at municipal waste stations, public recycling stations, shopping malls, libraries and recycling stores. Within the project work also post-industrial textile waste (JFA, ERT) and post-consumption textiles from organizational users (RES, KLW, PURF) have been processed. Textile identification (VTT, AIM, INES) and classification (RISE) are key parts in textile sorting, in that waste needs to be grouped together based on their common characteristics. These activities support the optimisation of textile flows towards reuse, remanufacturing, repurposing, and allow high-quality feedstock for recycling using different recycling routes.

When sorting textiles for recycling, multiple features need to be considered to provide high-quality feedstock for recycling processes. Even though sorting based on fibre composition is paramount, equally important are various disruptors that exist in discarded textiles. These disruptors will affect which pre-treatment processes are required prior to actual recycling, and if not properly taken care of, will lead to process failures. As textiles encompass a very broad range of materials and products, each technological solution must clearly define its scope of application to ensure its effectiveness, as results cannot necessarily be replicated across different textile streams. For each specific product stream, the sequence of the recycling treatment steps must be carefully assessed, as it has a significant impact on the characteristics of the resulting material and, consequently, on its recyclability.

Most of the textile recycling technologies are either suitable for homogeneous input or the output is highly dependent on the homogeneity. Therefore, recycling of multilayer textiles remains a significant challenge within the circular textile ecosystem. Approaches in tExtended to overcome this challenge included 1) development of sorting machine (MTEX, INES, CIT) that identify and separate textile material after cutting, thus, enabling recycling of multilayered textile consisting of fabrics sewed together into garments, and 2) removal of coatings like PVC (CTB, AIM) from fabric, enabling recycling of laminated multilayer textiles. In some textile recycling also removal of colorants are considered beneficial for the quality and value of secondary raw materials, and we have studied removal of colorants from cotton and polyester materials.

Collection of Post-consumer Textiles. Amongst many things, *it was learned that* collection amount *vs.* collection quality play an important role in the collection decisions. If focus is on the collection of reusables, the collection bins or other methods need to be placed on areas with high frequency of people, and preferably indoors to preserve the quality due to better ambient moisture and social control. The social monitoring that naturally occurs in frequently visited places contributes to better quality of collected textiles. However, the means to operate collection of reusable clothing with just indoor collection is limited, as capacity of indoor

collection is still insufficient. If collection is focused on material recycling, outdoor collection is acceptable. Even then, storing periods should be maintained short to keep the material dry and to avoid contaminations. While large volumes are easier to achieve in municipal waste stations and public recycling stations in outdoors, better material quality can be achieved with indoors collection. *We gathered that* there is increasing public interest for reusable textiles, while the interest towards recycling textile materials is still developing.

Textile Waste Classification System. One of the tExtended goals was to establish a classification system regarding designations for recycled raw material fractions and coding systems for manufactured products. This classification system could serve as the basis for the textile management system of the future. The work led by RISE *demonstrated that* the most important parameters affecting material routing can be translated into a relatively simple coding system, making it easier to build decision trees and support data-driven decision-making. At the same time, the project highlighted the complexity of developing a classification system that can serve diverse market needs and support increased reuse and recycling across textile value chains.

We learned that a practical classification and coding system is essential for connecting industry data inputs with decision-making tools and demonstrators. Further development of classification system is needed to refine textile flow labelling and coding systems, and we *also see that* additional work is also required to harmonise industry practices for textile sorting and post-consumer textile condition assessment.

Textile Identification and Sorting. In tExtended project textile identification of post-consumer, end-of-life textiles was conducted by LSJH and VTT both manually and with the help of different technologies. Within this comparative study on manual and NIR sorting *we discovered* the manual sorting to be a reliable method compared NIR and camera based technological sorting for existing recycling schemes mostly focusing on fibre mechanical recycling. However, it is very time consuming and thus not economical feasible method for material recycling.

During the identification studies by AIM, although we were able to identify the composition of most of the materials in the stream, some items could not be identified. Furthermore, even when the composition was known, recyclability could not always be guaranteed due to the high proportion of blended materials. And even though sorting into many categories enables efficient recycling, there is still limited interest to buy large, sorted volumes.

Homogenization of recyclable textiles flows. Several sorting and pre-treatment technologies were evaluated and developed to improve the quality of textile waste streams prior to recycling. It *was learned that* through a combination of shredding operations, air-density separation and the removal of ferrous metallic components, it was possible to obtain a cleaner, more homogeneous textile waste fraction with a significantly reduced content of non-textile materials. This pre-treatment step facilitates subsequent recycling processes and improves feedstock quality.

The PolySep technology (CTB), based on the use of solvent followed by its fast evaporation, was investigated as a potential solution for the delamination of multilayer textiles, particularly artificial leather structures composed of a PVC coating bonded to a polyester fabric substrate. While the concept demonstrated potential, the trials revealed insufficient delamination efficiency that limited its applicability to PVC/polyester multilayer textiles. *We concluded that* no single technology can currently address all multilayer textile structures, since the effectiveness of a delamination process strongly depends on the type of materials, coating composition and bonding mechanism.

Regarding the colour removal, for example, *we learned that* when target is chemical recycling of polyester via depolymerization route (RISE), decolouring should happen on monomer level rather than as pre-treatment of textile input material. Regarding colour removal from 100% CO textile materials, demonstrated by CIT, we

found that effective colour removal can be achieved using aqueous-based solutions while preserving the properties of the original material.

Table 9 Publication examples related to the Efficient textile recovery pathway.
Links of the planned publications will be added to tExtended webpages (https://textended.eu/) once available.

Status	Reference information
Published	Sormunen T., Mahlamäki E., Mäkelä S.M., & Mäkelä M. (2025). Hyperspectral imaging quantifies blend composition change in workwear textiles. Resources, Conservation & Recycling Advances, 200282. https://doi.org/10.1016/j.rcradv.2025.200282
	Sormunen T., Mahlamäki E., Mäkelä S.M., & Mäkelä M. (2026). Introducing OpenTextile-NIR: Near-infrared hyperspectral imaging and photography dataset for optical identification of textiles. Data in Brief, 65, 112559. https://doi.org/10.1016/j.dib.2026.112559
	Exhibition Gallery: https://textended.eu/exhibition-gallery/
	Demo Gallery: https://textended.eu/demo-gallery-page/
	Blueprint: https://textended.eu/textile-ecosystem-in-europe/
Planned publications	Scientific article by Sormunen T., Mahlamäki E., Mäkelä S.M. Honkanen A., Mäkelä M., & Heikkilä P., Professional manual sorting of post-consumer textiles reaches high accuracy for commercially relevant fractions. Submitted to *Resources, Conservation & Recycling* journal for peer review.
	Whitepaper by Marchall C., DPP x Sorting data Gap analysis
	Gomes J.M., Rodrigues C., Felizardo T., Leite I., Mendanha D., Maria R., & Silva C.J., Sustainable Colour Removal from Cotton: Process Optimization and Circularity

3.3 Valorisation and Recycling of Textile waste

The recycling and valorisation pathway consists of technologies and process know-how needed to efficiently valorise and recycle textile waste. Various waste valorisation and recycling routes have been developed and demonstrated in tExtended, with the goal of recovering high-value secondary raw materials and support industrial scale-up for a more circular textile value chain. Through the optimisation of fibre-mechanical, thermo-mechanical, and chemical recycling processes, the quality and performance of recycled materials were improved, enabling their reintroduction into textile production cycles.

The quality, composition, and consistency of textile waste streams strongly influence both the suitability of recycling technologies and the quality of the resulting secondary raw materials. This highlights the importance of effective collection, sorting, and pre-processing systems as critical enablers of high-value textile recycling and future circular textile ecosystems. The project demonstrated that successful textile recycling requires an integrated approach combining sorting, pre-treatment, material recovery and product validation. Optimisation at each stage of the value chain is essential to ensure that recovered materials meet the quality requirements needed for their reintroduction into new products.

Several quick-win opportunities were identified. Nevertheless, the absence of eco-design principles in simple textile products, including plush toys, shopping bags, promotional materials, and sportswear, was found to be a significant barrier to efficient recycling. While these products are frequently considered mono-material articles, component analysis demonstrated that many contain small quantities of dissimilar materials or hard parts. Despite accounting for less than 1% of the total material content in many cases, these non-compatible components can hinder fibre-to-fibre recycling processes and limit access to higher-value recycling pathways.

Fibre mechanical recycling. The activities in fibre mechanical recycling (RES, PURF, CIT) improved the understanding of the key factors and parameters influencing the properties of the recycled fibres and enabled the successful upscaling of fibre opening assays to industrially relevant conditions. Predictive approaches for yarn performance based on fibre characterization data were also developed.

In general, we have been able to obtain quite high recycled contents using mechanically recycling post-consumer textiles within industrial scale textile production. The main question regarding the use of post-consumer waste in yarns and fabrics were whether the quality of post-consumer waste is good enough. It was *successfully shown* that up to 50% recycled post-consumer waste content with soft mechanical recycling (PURF), suggesting the suitable recycling options are already on the market, and that the traditional textile manufacturing could use more recycled content than it currently does. One question remaining is whether brands and consumers will adopt the recycled fibres.

It *has been shown that* the quality management of traditional fibre mechanical recycling (RES) can also make a significant difference in applicability of fibres as secondary raw materials with above 30 % recycled contents for textile processing (spinning and weaving) instead of using recycling fibres only to nonwovens, which still is the dominant us for them. Furthermore, *it was also shown* that soft mechanical recycling provides inherently long fibre lengths for secondary materials making them attractive option to be used in wide range of applications including work-clothing and technical textiles. Moreover, the feasibility of producing knitted and woven fabrics from different recycled yarn sources was demonstrated, while the strengths and limitations of each fibre source and spinning system were identified, confirming several commercially viable textile applications.

Furthermore, yarns were impregnated to learn about the effect of impregnation to mechanical properties (RISE). For the, *the results showed* that higher recycled fibre content requires coarser yarn counts to facilitate a stable spinning process and maintain processability. For the impregnation of mechanically recycled yarns, *experimental trials demonstrated* that the impregnation process resulted in slightly improved mechanical properties compared with non-impregnated yarns, indicating the potential of impregnation as a method to enhance yarn performance.

Thermo-mechanical recycling of polyester was conducted by two partners, CTB and VTT. It was observed that the contamination of other fibre residues caused clogging of the filters due to non-melting behaviour, even after an additional filtration and increase of the intrinsic viscosity with solid-state polymerisation. *We concluded that* a very clean PET stream is needed for the thermo-mechanical recycling of PET. If the thermo-mechanical recycling is done with larger textile strips, and the material is not exposed to the shredding line, it is more likely to get clean streams of material.

Furthermore, if shredding is needed, the shredding capacity should develop to a large enough scale so that PET is opened on its dedicated line, and other materials would have their own line too. This would ensure clean material streams. In thermomechanical processing, fine filaments were successfully spun from recycled PES and PA6, even in the presence of contaminants, through optimisation of spinning parameters.

Chemical Recycling. Biocelsol process targets the separation of cellulose and PES from cotton-PES blends. VTT studied the use of Biocelsol process for dissolution of cellulose from cotton-PES blends and thus separate the solid polyester targeting recovery of both fractions for further utilization. Trials showed that regenerated cellulose fibres were produced, and after post-purification, the separated PES fraction was found suitable for glycolysis.

A dissolution-based process for PVC recycling was successfully developed, optimised and scaled up to a 200-litre reactor (AIM, ERT). The recovered PVC was successfully incorporated 20% recycled PVC into a final synthetic leather demonstrator. The physical properties of the synthetic leather produced meet the criteria for standard use in upholstery. Within this development we learned that there is no one-size-fits-all solution as

recycling outcome is highly material dependent. Success of incorporating PVC into the formulation of coatings for synthetic leather was found to be dependent on the particle size. *We concluded that* the particle size of the recovered material must be controlled and reduced to a powder-like consistency. Thus, future efforts should focus on optimizing material-specific recycling pathways.

The polyurethane solvolysis process development work (AIM) *demonstrated* that obtaining recycled polyols with sufficiently low hydroxyl (OH) values for demanding polyurethane applications is not straightforward and requires careful control of process parameters, reaction conditions and downstream purification steps. We learned that an additional purification step was needed for improved suitability of polyol for further polyurethane applications. It was *also learned that* solvent consumption can become a significant challenge when moving towards industrial implementation. Solvolysis for polyurethanes proved challenging and did not achieve all the expected results, showing that this route still requires further development.

ERT studied the use of polyols for making new foam materials. It was possible to obtain a polyol with characteristics reasonably close to those used by, and we demonstrated an efficient method for recycling flexible, laminated polyurethane foam. The choice of specific reagent and catalyst for the formation of this type of polyurethane waste proved to be crucial. The inclusion of agents that help to control the effects of side reactions is a key consideration. As part of the development of the target injection foam, different percentages of recovered polyol were tested successfully up to 30 % of recycled polyol. It was learned that the margin of difference between the specifications of the recycled polyol and the target polyol must be very small. Even a slight deviation, either above or below the target, has a significant impact on the mechanical properties of the foam.

Within the closed-loop recycling of polyester via glycolysis (RISE), the trials demonstrated that PET produced from coloured monomers had good processability and yielded fibres with mechanical properties comparable to virgin PET.

Real Scale Demonstrator was carried out as collaborative effort of whole consortium. The demonstrator activities supported the vision of a future circular textile ecosystem by translating the knowledge, experiences, and outcomes generated through the tExtended real scale demonstrator have been included into practical solutions developed by project partners and experiences have contributed to tExtended project publications.

Our key lessons learned regarding the Demonstrator activities were that firstly, effective circular solutions require active engagement among brands, recyclers, technology providers, researchers, policymakers, and consumers. Multi-stakeholder cooperation improves knowledge sharing, alignment of goals, and implementation of circular practices.

Secondly, Demonstrator activities provided valuable insights into the practical feasibility, challenges, and scalability of circular business models, recycling processes, and traceability systems under real operating conditions. *We concluded that* reliable product and material information supports informed decision-making, improves transparency, facilitates sorting and recycling, and enhances stakeholder trust throughout the value chain.

We believe increasing understanding of circular textile practices can improve participation in collection schemes, reuse initiatives, and sustainable purchasing decisions. In consequence, circular solutions can be transferred across regions, successful implementation depends on local infrastructure, market conditions, policy frameworks, and stakeholder capabilities.

Table 10 Publication examples related to the 'Valorisation and Recycling' pathway.
Links of the planned publications will be added to tExtended webpages (https://textended.eu/) once available.

Status	Reference information
Published	Demo Gallery (part of D5.2): https://textended.eu/demo-gallery-page/
	Exhibition Gallery: https://textended.eu/exhibition-gallery/
	Milestone MS2 post: https://textended.eu/2023/11/29/textended-reaches-milestone-on-upcycling-processes/
	Milestone MS4 post: https://textended.eu/2025/05/22/technology-development-and-readiness-for-testing-textended-reaches-new-milestone/
	Milestone MS5 post**:** https://textended.eu/2025/08/29/textended-reaches-milestone-on-upcycling-processes-implemented-on-a-pilot-scale/
	Blog post: https://textended.eu/2025/02/07/recycling-polyurethane-foams-via-solvolysis-key-advances-in-the-textended-project/
	Blog post: https://textended.eu/2026/01/29/thermo-mechanical-recycling-in-the-textended-project/
Planned publications	Gomes J.M., Felizardo T., Guise C., Rocha A., Costa A.F. & Silva C.J., Effects of Recycling Processes and Input Materials on the Quality of Fibres, Yarns, and Knitted Fabrics from Recycled Cotton, submitted to *Journal of Natural Fibres*
	White paper on Textile recycling technologies by CIT

4 Summary and Conclusions

This report contains the tExtended vision for a Hub for Circularity (H4C) for textiles, and it also summarizes lessons learned from different activities of the tExtended project which may be useful in building up of such Hub.

Since circular business requires close collaboration of multiple stakeholders within the value chain and cross sectorial collaboration hubs, communities, initiatives and networks aiming for sharing knowledge and/or improving circularity have a vital role in facilitation of collaboration. tExtended partners being involved in various hubs and networks (as summarized in There are already, and have previously been, several hubs, communities, initiatives and networks that aim to share knowledge and improve textile circularity. The tExtended project group collected the examples considered most relevant by its members in Table 1. While A.SPIRE defines an H4C as a more concrete industrial ecosystem, most of the hubs, communities, initiatives and networks listed by the tExtended partners focus primarily on knowledge sharing and therefore also include temporary or short-term collaborations built around projects. Of the collaborations included in Table 1, the ReHubs initiative, with more than 30 industrial partners from across the value chain, comes closest to A.SPIRE's definition of an H4C.

Table 1) gave us a good background to start envisioning the Hub for Circularity for textiles.

The tExtended vision identifies a national Hub for Circularity as the most feasible core model for coordinating textile circularity, while maintaining close links with local actors and European networks. We envisioned three geographical models - local, national and international hubs – and continued developing a more detailed model for the national hub, which was considered as the most feasible model. A national hub can consolidate material flows, harmonise collection, sorting and data practices, coordinate regulation and investment, and connect stakeholders without replacing their existing roles.

The hub should develop in phases. During the initiation phase (1-3 years), it should secure a mandate, leadership and initial funding; map stakeholders, material streams, infrastructure, risks and missing capabilities; and establish governance, shared targets, sorting criteria, data requirements, KPIs and a national overview of textile waste flows. During the first operational years (3–5 years), the hub should monitor legislation, technologies, markets and stakeholder needs; review its business model and performance; plan long-term investments and funding; and support the development of skills, education and workforce capacity.

In the long term (5+ years), the hub should operate as an adaptive lighthouse organisation. It should update its priorities and KPIs as knowledge and operating conditions change, make use of digitalisation to improve logistics and material routing, cooperate with other hubs through shared investments and demonstrations, and transfer effective practices to emerging hubs and other sectors. Overall, the hub's effectiveness will depend on continuous coordination, learning and performance assessment. By translating new knowledge into updated practices and connecting industry, policy, research, education and civil society, national hubs can help retain textile value, reduce waste and emissions, and strengthen circular textile value chains across Europe.

The lessons learned in tExtended confirm that the circular transition of the textile sector cannot be achieved through individual technologies or isolated actions. It requires coordinated development across the entire ecosystem, including progress in waste prevention, improved recovery, greater reuse and recycling capacities and alignment between the operators.

The project has demonstrated promising results in textile recovery and remanufacturing processes, as well as fibre-mechanical, thermo-mechanical and chemical recycling. Improving textile recovery and increasing reuse and recycling capacities are seen as a key step in improving circularity in the textile sector. Nevertheless,

technical capability alone does not guarantee implementation, but viable markets, stakeholder commitment, supportive regulation and infrastructure must develop alongside the technologies. This can be achieved with the enablers; creation of functional ecosystems and critical assessment. A Hub for Circularity could support the transition towards circular textile ecosystems by coordinating stakeholders, harmonising practices, sharing knowledge and data, identifying infrastructure gaps and connecting material flows with appropriate processing routes.

References

A.SPIRE (2021) Processes4Planet Strategic Research and Innovation Agenda 2050, Available https://www.aspire2050.eu/sites/default/files/users/user85/p4planet_07.06.2022._final.pdf