



Towards Sustainable Textile System with Telavalue

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Preface

This is the final report of the ‘*Value Chains for Sustainable Production, Use and Cycles of Textiles*’ (Telavalue) project, a Co-Innovation project funded by Business Finland (BF) from NextGenerationEU funding instrument. The Telavalue project was a part of the larger research continuum and Telaketju network, which can be considered started almost a decade ago in 2015. The Telavalue project was carried out during February 2022 - July 2024.

The project consisted of company projects and public research project. The research and development (R&D) partners of the project were VTT Technical Research Centre of Finland Ltd. (VTT, BF diary number 6478/31/2021), Turku University of Applied Sciences (Turku UAS, BF diary number 6536/31/2021), and LAB University of Applied Sciences (LAB, BF diary number 5238/31/2021). The company partners were involved either through their own project supported by Business Finland and/or by participated funding of the public research project. The companies with their own project were Kemira Oyj, Pure Waste Textiles Oy, Touchpoint Oy, Rester Oy, Image Wear Oy, and Fiare Solutions Oy. Companies and other organizations who participated by funding were Reima Oy, Fortum Power and Heat, Metsä Spring Oy, Valmet Technologies Oy, Mirka Oy, Freudenberg Home and Cleaning Solutions Oy, Lounais-Suomen Jätehuolto Oy (LSJH), Helsingin seudun ympäristöpalvelut -kuntayhtymä (HSY), Saimas Spinnery Oy, Coveross Oy, and Finnish Textile and Fashion.

The Telavalue project was coordinated by VTT. The project manager was Pirjo Heikkilä (WP8 leader), and the responsible leader was Katariina Torvinen. The VTT key personnel also included Hannamaija Tuovila (WP1 leader), Taina Kampuri (WP5 leader), Eetta Saarimäki (WP6 leader), Ali Harlin, Marjo Määttä, Päivi Petänen, and Satu-Marja Mäkelä. The project managers (WP2 & 4 leaders) at LAB University of Applied Sciences were Anna Keskisaari, Enni Arvez and Niko Rintala, and the key personnel also included Lea Heikinheimo, Helena Kalliomäki and Annariina Ruokamo. The project manager at Turku University of Applied Sciences was Piia Nurmi (WP3 & WP7 leader), and key personnel included Marketta Virta, Inka Mäkiö, Eerika Heinonen and Erika Raitala. A large group of other researchers as well as students and technical staff, also participated in the project work. We would like to thank all contributors for excellent cooperation and solid work!

The results and outcomes of the Telavalue project are summarized in this report. Most parts of the work have been published with more details as separate reports, presentations and/or other publications, and links to these other, more detailed publications are included in this report.

Tampere 2.10.2024

Authors

Contents

Preface.....	3
Abbreviations.....	6
1 Introduction.....	8
1.1 Sustainable and Circular Textiles	8
1.2 Telaketju Research and Telavalue Project.....	9
1.3 Targets and Outcome of the Project	13
2 Circular Textile Ecosystem	15
2.1 Impacts of Moving from a Linear Towards a Circular Value Chain.....	16
2.1.1 Social Impacts.....	16
2.1.2 Environmental Impacts	17
2.1.3 Economic Impacts.....	17
2.2 Value Proposition and Customers	18
2.2.1 Value Proposition for a Circular Textile Value Chain.....	18
2.2.2 B2B Customer Perspective of Local European Circular Textile Value Chains.....	20
2.2.3 Consumer Perspective Towards Circular Textiles.....	21
2.3 Textile Production.....	22
2.3.1 Expected Product Lifetimes	22
2.3.2 Future Textile Manufacturing	23
2.4 Role of Data and Information in Circular Ecosystem.....	23
2.4.1 MVP for Data Model.....	24
2.4.2 Traceability, Transparency and Product Data	24
3 Circular Business Models	27
3.1 Sustainability	27
3.1.1 Social Aspects	27
3.1.2 Environmental Aspects	28
3.1.3 Economic Aspects	30
3.2 Other Aspects.....	30
3.2.1 Design Aspects	30
3.2.2 Data Aspects.....	31
3.2.3 Consumer Aspects.....	31
3.3 Multifactor Study on Business Models	34
3.4 Startup Study.....	34
4 Recycling and Products Made Using Secondary Raw Materials	36
4.1 Identification	36
4.2 Quality Improvement	37
4.2.1 Separation of Fire Retardant and Water Repellence Finishing	37
4.2.2 Sterilization of Waste Textiles.....	37
4.2.3 Enzyme Treatments of Fibres, Yarns and Fabrics	37
4.3 Recycling.....	38
4.3.1 Recycling Technologies and Optimal Cycling Model.....	38
4.3.2 Mechanically Recycled Fibres	39
4.3.3 Chemical Recycling of Cellulose-based Textiles	40
4.4 Textile Production.....	41

4.4.1	Spinning	41
4.4.2	Fabrics and Textile Products	42
4.4.3	Quality of Textiles Containing Recycled Fibres	44
4.5	Other Products	44
4.5.1	Nonwovens	44
4.5.2	Plastics and Composites.....	45
5	Project Impacts.....	48
5.1	Impact in Partner Organizations	48
5.1.1	Impact of Company Projects.....	48
5.1.2	Impact in Companies and Other Organizations Who Co-Funded the Project.....	52
5.2	Telavalue and the Sustainable Development of Textile Sector	55
	References	57
	Annex Communication and Dissemination Activities	59
	Dissemination	59
	Science and Technology Board	62
	Researcher Mobility	62
	Other International Activities and Events	63

Abbreviations

AI	artificial intelligence
ANN	artificial neural network
B2B	business to business
B2C	business to consumer
BOD	biochemical oxygen demand
CO	cotton
COD	chemical oxygen demand
CV	viscose
DADC	dodecyl dimethylammonium chloride
DNSH	do no significant harm
DP	degree of polymerization
DPP	digital product passport
DSC	differential scanning calorimetry
EA	elastane
EC	European Commission
ECoP	European Community of Practice
EPR	extended producer responsibility
EU	European Union
FR	fire-retardancy and fire-retardant agent/finishes
FTIR	Fourier-transform infrared spectroscopy
GHG	greenhouse gas
HSY	Helsinki Region Environmental Services
IFC	Infinited Fibre Company
IoT	internet of things
LAB	LAB University of Applied Sciences
LCA	life cycle analysis
LSJH	Lounais-Suomen Jätehuolto Oy
MMCF	man-made cellulosic fibres
MODIX	modular mixed cylindrical extruded technology developed by VTT
MVP	minimum viable product
NIR	near infra-red
NIRS	near infra-red spectroscopy
NMR	nuclear magnetic resonance
OECD	the Organisation for Economic Co-operation and Development
PA	polyamide
PaaS	product-as-a-service
PAN	polyacrylic
PES	polyester
PET	polyethylene terephthalate, polyester type
POM	polyacetal
PP	polypropylene
PUR	polyurethane
PVA	polyvinyl alcohol
R&D	research and development
r-CO	recycled cotton

r-PET	recycled PET polyester
RFID	radio frequency identification
RT	room temperature
SCBA	social cost benefit analysis
SEM	scanning electron microscopy
SME	small and medium sized enterprise
SotA	state-of-the-art
SRIA	Strategic Research and Innovation Agenda
STB	Science & Technology Board
STJM	Finnish Textile & Fashion
SWOT	strength, weaknesses, opportunities & threats
TGA	thermogravimetric analysis
TUAS	Turku University of Applied Sciences
UAS	University of Applied Sciences
UNEP	United Nations Environment Programme
UV	ultraviolet (radiation)
WO	wool
WP	a work package of the project (WP1–WP8)
WR	water-repellency and water repellent agent/finish
XRF	x-ray fluorescence

1 Introduction

This report is a final report of Telavalue project. This first part of the report includes a short introduction to the circularity of textiles as a background (Chapter 1.1), and it describes the Telaketju research, the current Telavalue project and gives an introduction to our consortium (Chapter 1.2), and summarized targets and outcome of the project (Chapter 1.3).

1.1 Sustainable and Circular Textiles

Textiles are one of the high-pressure categories for the use of primary raw materials and water, and for Greenhouse Gas (GHG) emission (EEA, 2020). Use of recycled fibres is estimated to be less than 10 % most of which are coming from r-PET from PET bottles (Textile Exchange, 2022), and only around 1 % of textile waste is recycled in closed loops, i.e., into secondary raw material for textile industry (Ellen McArthur, 2017). Most water in textile production is used in processing, 90-96 %, and approximately 65 % of that is used in textile dyeing, printing, and finishing. Textile effluent is described by high alkali or acidic pH, vibrant colour, high chemical oxygen demand (COD), high biochemical oxygen demand (BOD) and presence of metals and other impurities. Wastewater treatments include physical, chemical, and biological methods, as well as their combinations, and primary, secondary, and tertiary treatments are used when necessary. (Kärkkäinen & Heikkilä, 2024). Textile dyeing and finishing is also the stage producing most CO₂ emissions, followed by yarn preparation, fibre preparation and fabric preparation (Quantis, 2018).

Within Telavalue project a literature study regarding water use in textile production and recycling was carried out. Results have been published in project webpage: <https://telaketju.turkuamk.fi/telavaluen-tuloksia/tekstiiliteollisuuden-jano-valmistusprosessien-vedenkulutus-ja-jatevesien-laatu/>.

Sustainable and circular approaches are necessary for reduction of negative environmental and also impacts of textile sector. Circular economy of textile is focusing on more sustainable textile value chains and waste prevention. This is done by 1) promoting the longevity and extended textile product use cycles, and 2) recycling materials of discarded textiles into secondary raw materials. Such development is in line with EU's waste hierarchy, green transition and green deal goals, and Do No Significant Harm (DNSH) principles¹. Legislation and restricted substance lists aim at eliminating or limiting certain chemicals from ending up in drinking water or in groundwater.

Circular economy can be summarised to aim for maintaining value of materials and products as high as possible and as long as possible with minimal environmental impacts. Circular economy business models division as described by OECD (2019) include five models two of them focusing on material recycling, and three of them on product cycles.

- Circular supply meaning replacement of traditional material inputs with renewable, biobased and/or recycled ones.
- Resource recovery referring to production of secondary materials from waste.
- Product life extension.
- Sharing to increase utilization of existing products and assets.
- Product service systems where services rather than product are offered. In these models, ownership usually remains with supplier.

All of these can and should be applied in textiles as well. Textile recycling ecosystem is currently building to Europe, and at least in-house recycling of production wastes is done globally. Europe and other high-income countries have also woken up to unsustainable consumption model for textiles, and product life extension is in the agenda of EU countries. Sharing of textile products and product service systems for textile are emerging and increasing slowly.

¹ EC Waste hierarchy https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en; EC Green deal https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en; DNSH-principles e.g. in <https://eeb.org/wp-content/uploads/2022/04/Do-No-Significant-Harm-to-Circular-Economy-in-the-Climate-Taxonomy-EEB-report-April-2022.pdf>

Furthermore, 9R-Strategies for circular economy (Potting *et al.*, 2017) cover smarter manufacturing and use of products; extension of lifespan of products and its parts and utilization of materials at end-of-life (see Figure 1), thus, adoption of multiple models and inclusion circular thinking into all business activities. Different strategies may be applied into production, use and cycling stages of the product lifetime. Also, these can and should be applied to textiles, and are built-in into Telavalue project work.

Circular	Smarter product use and manufacture	R0 Refuse	Make product redundant: abandon function or use other product
		R1 Rethink	Make product use more intensive: sharing or multi-functionality
		R2 Reduce	Consume less through efficient manufacture or use
↑	Extend lifespan of products and its parts	R3 Re-use	Re-use of functioning discarded products by another user
		R4 Repair	Repair and maintenance of defects to keep original function
		R5 Refurbish	Restore and update
		R6 Remanufacture	Use parts in a new product with same function
		R7 Repurpose	Use products or parts in a new product with a different function
Linear	Utilization of materials	R8 Recycle	Process materials to obtain the same or lower quality
		R9 Recover	Incineration of materials with energy recovery

Figure 1 R-strategies for circular economy, adopted from Potting *et al.* (2017).

1.2 Telaketju Research and Telavalue Project

Telaketju network and earlier Telaketju research (Figure 2) have been focusing on supporting circular economy transformation in Finland. Research continuum have consisting of several funded projects with different funding sources, but the active network and development carried out within its companies and other actors within this ecosystem is not restricted to funded projects. Telavalue project² is part of third phase of the Telaketju collaborative research funded by Tekes/Business Finland (BF), but collaboration started earlier between Relooping fashion and Textile 2.0 projects. More information about activities can be found from Telaketju webpages³.

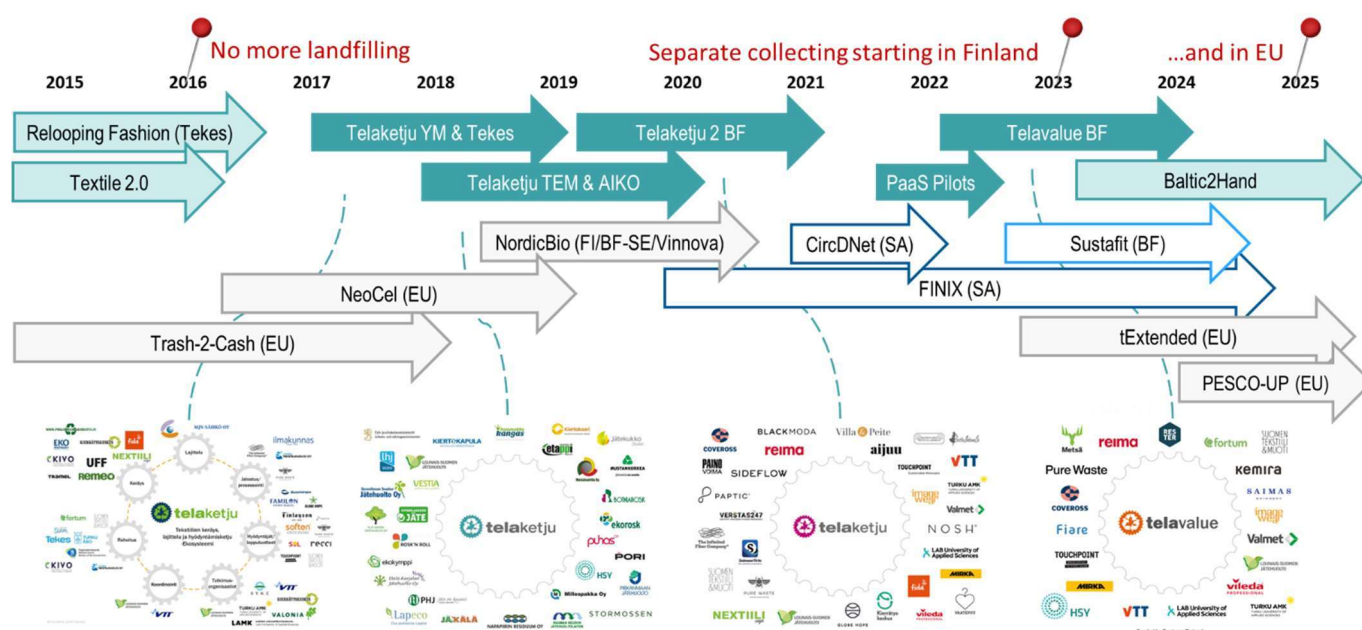


Figure 2 Telaketju network and earlier Telaketju research.

² Total budget of public project was 1.8 M€ and duration 2/2022-7/2024. See <https://cris.vtt.fi/en/projects/value-chains-for-sustainable-production-use-and-cycles-of-textile>

³ Telaketju webpages <https://telaketju.turkuamk.fi/>

Telavalue was an independent research project with its specific scope and themes determined by participating companies, even though it also built on the work carried out within Telaketju network and earlier projects. Telavalue project was fully compliant with Telaketju road-map made within Telaketju 2 project (Heikkilä *et al.*, 2021) carrying out activities needed to reach Telaketju vision 2035. The main objective of the Telavalue project was supporting and building of value chains for sustainable production, use and cycles of textiles. This was done by:

1. Combining recycled and bio-based raw materials as a basis for renewed Finnish textile production - spinning mill(s) as a next step,
2. Supporting product circulation circular thinking and novel business models, and
3. Ensuring efficient textile material circulation by supporting emerging textile recycling industry.

Telavalue consortium consisted of three research organizations, and 17 other organizations collaborating within six research themes (corresponding work packages - WPs) and forming value chains for textile manufacturing from bio-based and recycled fibres to sustainable textile products and textile recycling from recovery of textiles to textile and non-textile raw materials and products (Figure 3). Companies interested in more sustainable products and circular business models covered wide range of products from clothing to work-wear and technical products. SMEs and large companies collaborated actively for common goal - building value chains for circular textile ecosystem. Consortium consisted of six large (Kemira, Reima, Metsä, Fortum, Valmet, Mirka), one mid-cap (Image Wear), seven SME's including four micro-sized companies (Touchpoint, Pure Waste, Freudenberg, Rester, Fiare, Saimas Spinnery, Coveross), as well as two municipal waste management companies (LSJH & HSY), and one sector head organization (STJM). The project partners showed a strong will to work together towards common goals and have started to form new collaborations already. Business Finland funding was obtained from NextGenerationEU funding tool.

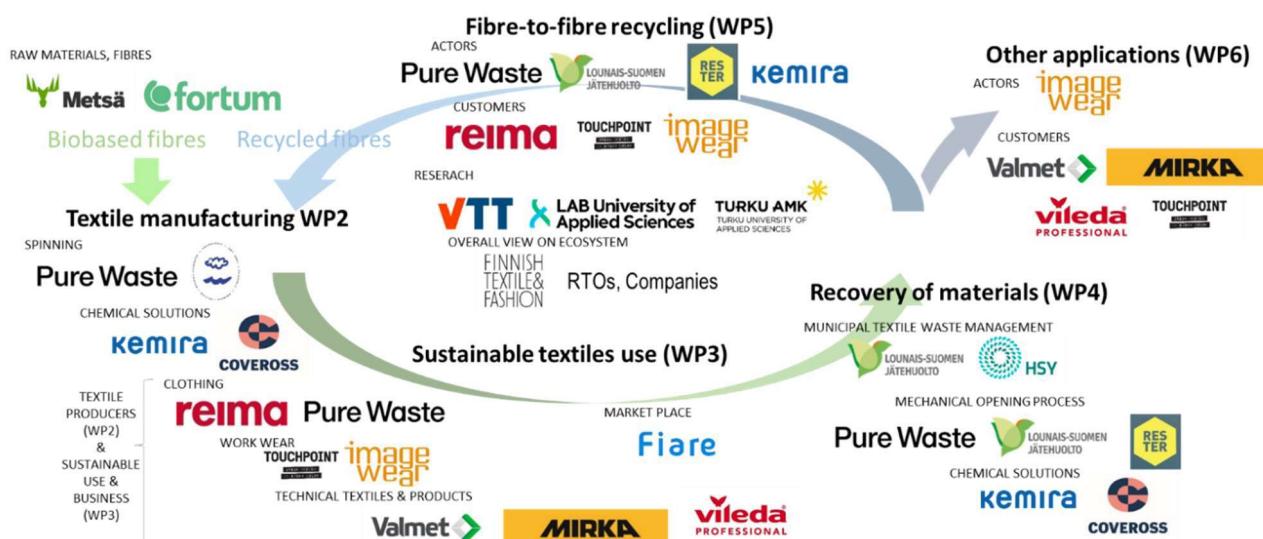


Figure 3 Telavalue project themes, research WPs, and consortium.

Research partners:

- **VTT - Technical Research Centre of Finland Ltd** is a state owned non-profit multi-technological company focusing on applied research (<https://www.vttresearch.com/en>) and aiming to solve the world biggest challenges, creating sustainable growth, jobs and well-being. In Telavalue VTT acted as coordinator and participated research in all WPs. Our focus areas were extending our systemic understanding of circular economy of textiles and also developing our processes and capabilities in chemical processing and recycling of cellulose based textiles, and in thermo-mechanical recycling of synthetic materials including technical textiles.
- **Turku University of Applied Sciences (TUAS)** is a multidisciplinary educational community of around 10.000 students and 1000 experts (www.tuas.fi). TUAS is located in Southwest Finland, but nowadays it operates globally in various development activities. Circular economy is in TUAS strategy, namely 'Green Economy'. TUAS has a research group which focuses on research and development of circular economy.

The name of this group is *Circular Business Models*. This research group is one of the largest research groups from the over 20 existing research groups at TUAS. TUAS is a member of the Ellen MacArthur Foundation. In Telavalue TUAS led work in WP3 and WP7 and participated strongly in WP1. In WP3 we conducted very topical research on novel business models and WP7 work coordinated the communication and interaction activities in the project.

- **LAB University of Applied Sciences (LAB)** is a higher education institution focusing on innovation, business, and industry, located in Lahti and Lappeenranta (www.lab.fi). Part of LAB's RDI activities are circular economy and design. The research aims at finding, developing, and producing new and improved products, production systems, methods, and services. In Telavalue, LAB has been involved in every work package. Our main role in the project has been to conduct research related to recycling, identification, and end-product requirements of textiles. In addition to this, the project has fostered our knowledge in novel circular business models.

Companies and their business/activity areas and/or role in the project:

- **Kemira** is a global leader in sustainable chemical solutions for water intensive industries. We provide best-suited products, expertise, and services to improve our customers' product quality, process, and resource efficiency. We have served the pulp and paper industry and water treatment for decades with our chemistry expertise. Now, we are leveraging our expertise in cellulose-based processes and products in the transformation of the textile industry. In Telavalue, we aimed to explore how chemistry solutions, such as bleaching, fibre pre- and post-treatments, microbiological control, and water purification, can support the emerging textile recycling business.
- **Pure Waste.** We create recycled products and closed-loop solutions to inspire change towards a world without textile waste. Our goal is ambitious and requires a radical shift in production and consumption habits, but we firmly believe we can achieve significant changes. Together. At Pure Waste, we produce garments of 100% recycled fibres. We are a Finnish company working with sustainable fashion since 2013. Our responsibility refers to continuously improving our operations by looking at things from a comprehensive and sustainable perspective. Whether it's a fellow manufacturer, clothing brand, B2B customer, or one of our consumers, we pride ourselves on transparency and sharing knowledge to empower a positive change. We ought to understand the industry's downsides to alter our consumption patterns. By pursuing more sustainable solutions, we question the norms and traditional ways of producing and using textiles.
- **Touchpoint** is a Nordic forerunner in sustainable workwear & textile solutions. As a company founded in 2008, we've come a long way in supporting our clients from different industries with the best solutions in terms of sustainable and efficient collection as well as a range of additional services, according to client needs. We put a lot of effort into fine-tuning our service model and helping to make the textile industry more sustainable for example by innovating circular workwear fabric. Touchpoint was one of the founders of textile recycling plant Rester, which has a crucial role in processing recycled textile fibres. Touchpoint (www.touchpointww.com)
- **Rester Oy** is producer of recycled fibres. Rester facility in Paimio is modern mechanical recycling plant with big shredding line for textiles. First buttons, zippers, etc. are removed from the textiles. After that textiles are cut into patches and textiles are mechanically opened to fibres. During the process, textile grades can also be mixed so that desirable outcome is achieved. Our circular economy plant refines B2B textiles into new, high quality raw material. The recovered fibres can be used to manufacture yarn, fabric, and various non-woven materials, such as insulation, acoustic panels, and filter fabrics, as well as composite. We currently handle cotton, polyester, cotton-polyester, wool, polypropylene, and mixed materials. Rester has had an own sub-project in Telavalue -project. In our own project we have been ensuring the material quality from receiving the textiles to warehouse and all the way to fibres for different end products. This has also meant development work for optimizing the fibre properties for the end use, also with using different treatments to widen the possibilities for re-use.
- **Image Wear Oy**, Finland's, and Estonian leading workwear manufacturer has been producing high-quality work apparel since 1959. As a family-owned company, we have expanded our product range to nearly 5000 items, so we can serve various industries globally. Our commitment to sustainability drives us to extend the lifecycle of our products and recycle end-of-life workwear into new materials. In the Telavalue project, Image

Wear was focused on developing and testing the use of recycled textile granulate on an industrial scale. Our own project included plans and calculations for possibility to create a new recycling facility to transform used workwear into reusable granulate, promoting a circular economy. Through this initiative, we aim to support international growth and sustainability by collaborating with various partners to overcome the challenges of textile recycling. www.imagewear.fi

- **Fiare Solutions** is a digital solutions provider with over 20 years of experience. As a technology partner in the Telavalue consortium, Fiare recognises the potential for a digital platform utilising indexed data to connect textile recycling stakeholders efficiently. Leveraging past circular economy projects and found partnerships, Fiare developed a customised extranet solution for the industry. This extranet aims to connect holders of recycled textiles directly to manufacturers and retailers, transforming “waste” into a resource. Participation in Telavalue allowed Fiare to understand user needs in the global value chain. By collaborating with research and industry partners, Fiare optimises its proven digital tool. Through data indexing and analytics tailored for the textiles industry, the goal is to support circular business models and efficient recycling by facilitating optimal matching of supply and demand.
- **Reima** is a globally recognized company that specializes in creating innovative, high-quality sportswear for kids between the ages of 0 and 12. Reima was founded in 1944 and at first produced clothes using materials that were surplus to the army, demonstrating an early use of the circular economy concept. In the decades that followed, the business expanded its product line to include a full "tip-to-toe" line that includes outerwear and outdoor apparel, shoes, accessories, and a range of family-friendly products and services. Sustainability is a key component of Reima's core values. We believe that textile recycling is one of our main responsibilities, when looking at the impact it has created on the environment. Therefore, the Telavalue project is very important to Reima, as the project aims to enhance understanding of all aspects related to the circular economy model. This, in turn, enables the company to effectively integrate these principles into its brand concepts through the establishment of robust processes and procedures.
- **Fortum Power and Heat.** Fortum Oyj is a Finnish state-owned energy company located in Espoo, Finland. It mainly focuses on the Nordic region. Fortum operates power plants, including co-generation plants, and generates and sells electricity and heat. The company also sells waste services such as recycling, reutilisation, final disposal solutions and soil remediation and environmental constructions services, and other energy-related services and products, for example, consultancy services for power plants and electric vehicle charging. Fortum is listed on the Nasdaq Helsinki stock exchange.
- **Metsä Spring.** Metsä Group (www.metsagroup.com) focuses on growth sectors of the forest industry: wood supply and forest services, wood products, pulp, fresh fibre paperboards, as well as tissue and greaseproof papers. Metsä Spring was established in 2018 as Metsä Group's innovation company. Metsä Spring invests in and supports potential sustainable innovations and technologies that find new purposes and higher value for Nordic wood to replace fossil-based materials and chemicals in everyday products. To date, Metsä Spring has made six external startup investments and has launched two in-house development projects Muoto and Kuura. Kuura project (www.kuura.io) is developing the process for producing sustainable man-made cellulosic fibres in a kraft pulp mill integrate. The role of Metsä Spring in the Telavalue project has been to represent the potential future producer of biobased fresh textile fibres that are needed in the future circular textile value chain.
- **Valmet Technologies'** Fabrics Unit has participated in Telavalue, as sustainability is at the core of Valmet's business strategy and operations. We enhance circularity and environmental efficiency through the entire value chain, also in Valmet's technical textile business: felts, fabrics, and filter cloths. We are actively developing and seeking new ways to recycle our production side streams and used fabrics in co-operation with other organizations. That's why we are especially interested in Telavalue cleaning and recycling tests, for which we have provided used paper machine clothing as well as our expertise regarding technical textiles.
- **Mirka** is a family-owned Finnish company and a part of the KWH Group. We have been dedicated to the finish since 1943. With constant improvement and innovation, Mirka has become a world leader in abrasives technology. Our commitment to social responsibility and ethical business practices have been a part of our business culture for a long time. Our dust-free innovation has sparked a sustainable transformation within surface finishing that has an impact on the health and safety of thousands of people around the world. Mirka joined Telavalue to find solutions and partners to recycle Mirka's textile-based side streams. Those side

streams consist of pure PA and PES knits, and also used discs. Finished products are made of textile backing with resin and abrasive grains on top, and after usage can have sanding dust on them.

- **Freudenberg** Home and Cleaning Solutions Oy Vileda Professional develops and manufactures top-quality cleaning utensils designed for professional use in several sectors, such as healthcare, cleanrooms, general buildings and the hotel and restaurant industry. The company has more than 60 years of experience in meeting the needs of cleaning professionals in various environments. Vileda Professional's products enable fast, efficient, and cost-effective professional cleaning. Along with efficiency, cleaning innovations in line with sustainable development have always been close to Vileda Professional's heart. The wide range of products include, for example, microfiber mops, microfiber cloths, cleaning trolleys, waste bins and entrance mats. Vileda Professional has sales offices and a wide representative network in all major European countries, North America, Asia, and Australia. In Telavalue we have created a network around handling recycled fibers and will soon be closing the loop with new products using fibers from our used products.
- **Lounais-Suomen Jätehuolto (LSJH)** is a municipal waste management company that coordinates the separate collection of household end-of-life textiles in Finland by combining the locally pre-sorted material streams to content sorted materials that are offered as raw material to industry. LSJH has been part of the Telaketju projects from the beginning and has through the collaboration, research, and pilots, created the Finnish waste management partnership solutions model. In recognising that textiles need to be recovered from mixed waste streams and utilized as valuable materials, LSJH has worked on finding the best circular solution to all sorted material fraction in various applications. In the Telavalue project, LSJH has brought their practical knowledge and expertise in best ways to collect and sort textiles for various recycling applications as well as provided materials to the project. This process of recovery through collection to creating material fractions means making textile to textile recycling possible for the largest volumes which are mixed post-consumer end-of-life textiles from households. postconsumertextile.com
- **Helsinki Region Environmental Services (HSY)** is a municipal waste management company that provides waste and water management services to over one million people in the Helsinki Metropolitan Area. HSY also provides air quality information, produces spatial data on the development of the region, and promotes climate action. HSY is the largest public operator in the environmental sector in Finland. As a municipal waste management operator, HSY collects end-of-life textiles from residents of the Helsinki Metropolitan Area in shopping centres. HSY is developing collection and pre-sorting opportunities in cooperation with other actors. HSY employs approximately 800 workers and is active in the circular economy field.
- **Saimas Spinnery** is a spinning mill based in Puumala. In its product development, spinnery is strongly committed to ecology and "Saimaa" locality.
- **Coveross** develops functional garment and textile solutions for brands, retail, and work wear.
- **Suomen Tekstiili & Muoti - Finnish Textile and Fashion (STJM)** The Finnish Textile & Fashion Association, STJM, is the central organisation for textile, clothing and fashion companies in Finland. Our main goal is to promote the Finnish textile and fashion industry and our member companies globally. We are committed to ensuring that Finnish textile and fashion companies have a beneficial business environment and opportunities to grow, internationalise and succeed.

1.3 Targets and Outcome of the Project

The main goal of the Telavalue project is supporting and building of value chains for sustainable production, use and cycles of textiles. This was done by combining recycled and bio-based raw materials as a basis for renewed textile production; supporting product circulation circular thinking and novel business models; and ensuring efficient textile material circulation by supporting emerging textile recycling industry.

In order to achieve this goal, we set seven targets and respective expectations for results and outcome. Our work package structure was built in a way that there were one WP answering each target. The seven targets and related results and outcome are listed in Table 1. Table also includes links into which chapter of this report these specific results are summarized.

Table 1 Seven targets and specific results and/or outcome related to these targets.

Target		Specific results and/or outcome
1	Create knowledge on value chains and ecosystem for sustainable and circular textile business.	• Mapping of (at least 500) relevant actors & infra for new value chains (Task 1.1) – see introduction of Chapter 2 • Impact and value for customers evaluation of new value chains (T1.1) – see Chapters 2.1 and 2.2 • Customer and consumer studies (T1.1) – see Chapter 2.2 • Data MVP model (T1.2) – see Chapter 2.4.1
2	Obtain expertise in application of novel bio-based and recycled fibres in high quality, sustainable and long-life textile end-products.	• Technical requirements and product life-time expectations (T2.1) – see Chapter 2.3.1 • Experimental data about quality improvement treatments, spinning of various biobased and recycled fibres into yarns (T2.2) and further into fabrics and products – see Chapters 4.3 and 4.4. • Exploring future textile manufacturing via literature review, webinar and workshop (T2.3) – see Chapter 2.3
3	Obtain competence for implementation of new circular business models in companies.	• Multifactor study of implementation of novel circular business models including operational principle, economics, design aspects and data needs and consumer attitudes (T3.1-T3.3) – see Chapter 3.3
4	Ensure high quality and value in textile material recovery.	• Model of utilization of discarded textile flows based on value & quality, and environmental aspects (T4.1) – see Chapter 4.3.1 • Technology review (SotA & SWOT) of identification and sorting (T4.2) – see Chapter 4.1 • Process studies and development regarding fibre opening, quality improvement finishing treatments, cleaning processes and separation of fibre blends (T4.3) – see Chapter 4.2
5	Facilitate high value fibre-to-fibre recycling instead of down-cycling.	• Technology review on fibre-to-fibre recycling (T5.1) – see Chapter 4.3.1 • Literature review on water treatments in textile recycling (T5.2) – see Chapter 1.1 • Process studies and development of chemical recycling of cellulose based textile fibres – see Chapter 4.3 • Demonstrations base on chemical recycling of cellulotics – see Chapter 4.3
6	Facilitate high value non-textile recycling options for technical materials and fractions that are not suitable for textile application.	• Technology review on open loop recycling (T6.1) – see Chapter 4.3.1 • Process studies and development of thermoplastic processing of textile wastes to composite applications (T6.2) – see Chapter 4.4.3
7	Improve business and export opportunities of Telavalue consortium and Finnish textile industry by active networking and collaboration.	• Active networking and interaction nationally and internationally (WP7) – see Annex • Summary of impact in partner organizations in Chapter 5.1

In Telavalue project we built knowledge on value chains for sustainable and circular textile business (WP1). We created expertise in application of novel bio-based and recycled fibres in high quality, sustainable and long-life textile end-products (WP2), and competence for implementation of new circular business models in companies (WP3). Efficient material circularity is achieved by ensuring high quality and value in textile material recovery (WP4); and facilitating high value fibre-to-fibre (WP5) and non-textile recycling (WP6). Significant (over €1 bn) business and export potential is expected for Finnish textile sector by renewal of industry, for example, via bio-, circular, and digital transformation. We aimed to improve business and export opportunities of Telavalue consortium and Finnish textile industry by active networking and collaboration (WP7).

This report summarised research results carried out within these WP's organized under the following themes circular textile ecosystem in Chapter 2, circular business models in Chapter 3, and recycling and use of secondary raw materials in Chapter 4. Work carried out is shortly described and other, and in many cases more detailed publications are listed in orange boxes included into report. Impact of project is summarized and Chapter 0, and dissemination activities are summarized as an Annex of the report.

2 Circular Textile Ecosystem

Textiles are one of the high-pressure categories for the use of primary raw materials and water, and for GHG emission (EEA, 2020). Sustainable and circular approaches are necessary in order to reduce negative impacts of textile sector. The vision of Telavalue consortium was to solve sustainability and waste problems related to current textile system through circular economy.

To move towards a circular textile economy and building circular textile ecosystems, it is important to understand what kind of actors are needed in a circular value chain. In examining the organisations that have activities in circular textiles, actors were identified under four main categories: 1) textile production and manufacturing; 2) textile use phase business models and services; 3) textile (waste) recovery and recycling; and 4) support for textile circularity. These categories were further divided into 24 subcategories, listed in Table 2.

Table 2 Categories of circular value chain actors.

TEXTILE PRODUCTION AND MANUFACTURING	
Fibres	Producer/manufacturer of fibre raw materials, fibres, and spinning of fibres
Yarns	Producer/manufacturer of yarns, and yarn spinning
Fabrics	Producer/manufacturer of knitted and/or woven fabrics manufacturing
Nonwovens	Producer/manufacturer of nonwoven and felt materials
Coloration & finishing	Dyeing, printing & finishing of textiles
Textile products	Producer/manufacturer of textiles, including clothing, home textiles and technical products
TEXTILE USE PHASE BUSINESS MODELS AND SERVICES	
Second hand	Second hand retailer
PaaS	Service provider with of Product as a Service (PaaS) model
Remanufacturing	Remanufacturing, repurposing, refurbishing of textiles
Repair	Repair services for textiles
Laundry	Laundry and cleaning service
TEXTILE (WASTE) RECOVERY AND RECYCLING	
Collecting	Collecting of discarded textiles
Sorting	Sorting of textiles for reuse and/or recycling
Purification	Hygiene and cleaning services for textile waste
Mechanical recycling	Mechanical recycling i.e. method where textile materials are opened to fibre level
Thermo-mechanical recycling	Thermo-mechanical recycling i.e. polymer level recycling for synthetic fibres via melting
Chemical recycling	Chemical recycling including dissolution process for cellulosic fibres and repolymerization for synthetic fibres
Recycling equipment	Equipment suppliers for sorting and/or recycling processes
SUPPORT FOR TEXTILE CIRCULARITY	
Market places & platforms	Market places & platforms
Research	Research (RTOs, UASs, Universities, companies active in public research)
Chemicals & dyes	Producer/manufacturer of chemicals and dyes for textile processes
Quality & certification	Testing, quality control, certification services for textiles
Digitalization	Digital services, 3D modelling, etc.
Consultation & support	Consultation, expert and support services related to sustainable and circular textiles

We collected information of over 500 actors focusing on Finland and the Nordics and Baltics regions into a digital map. Many of the organisations had activities in multiple categories. The actor listing did not include fashion brands or retailers, as it focuses on actors that can support them in the transformation towards circular economy. The purpose of the map is to help organisations working in the textile value chain to find good partners to collaborate with in contributing to the circularity of textiles. The visual outlook of the map can be seen in Figure 4.

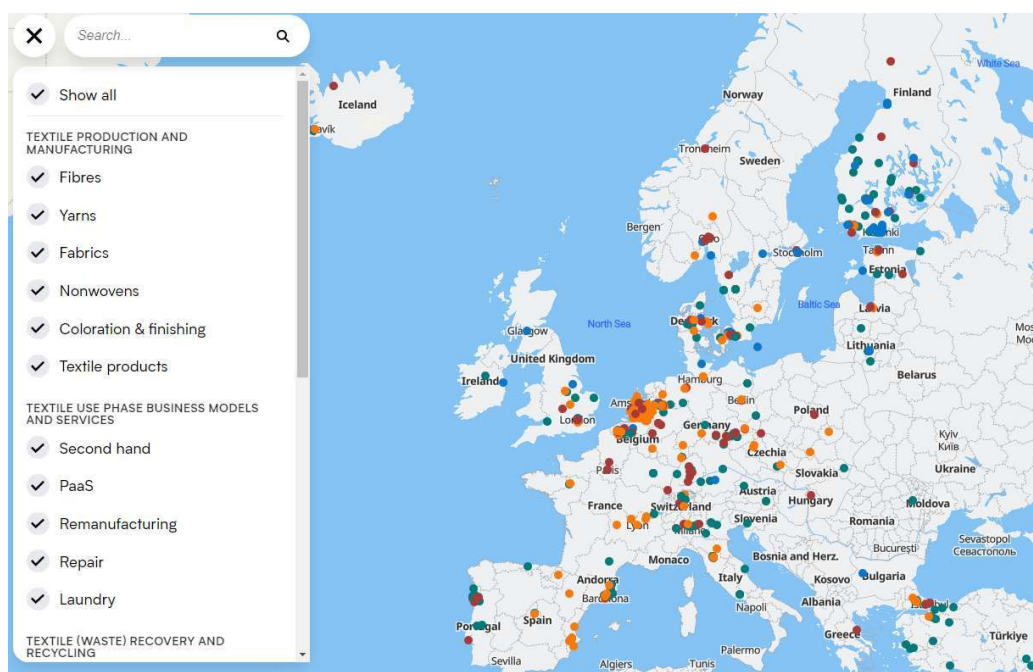


Figure 4 The visual outlook of the digital actor map.

The actor listing was done in collaboration with VTT, TUAS and LAB researchers during the year 2022. As a methodology, a desktop study was utilised. The researchers utilized the knowledge of search engines and existing networks and partners from other projects. The actors were listed in an excel database. The actors can be found from a digital map on the Telaketju webpage: <https://telaketju.turkuamk.fi/en/value-chain-map/> (digital map is available online only until 28.2.2025). An introduction to circular value chains and to the use of the actor map was presented in a public webinar, found in the Telaketju webpage: <https://telaketju.turkuamk.fi/webinaarit/tekstiilien-kiertotalous-ja-arvoketjut/>.

In this chapter we review impacts of moving from a linear system towards more circular (Chapter 2.1), study value proposition linked to circularity and customer views (Chapter 2.2), and view the textile production aspects (Chapter 2.3), as well as role of data and information in circular system (Chapter 2.4).

2.1 Impacts of Moving from a Linear Towards a Circular Value Chain

The impacts of moving from a linear production chain towards a circular value chain were explored from social, environmental, and economic perspectives.

2.1.1 Social Impacts

There are many problems in the fashion and textile industry as it is, and these issues should be evaluated when moving towards circularity. It can, however, be stated that circular value chain enables many positive impacts from the social perspective, for example, a more local production can result in new jobs and stronger legislation and decrease in the use of virgin raw materials. There are still risks which should be considered, such as the economic effects from the consumers' perspective, increase in prices causing inequality in the market, and the effects on traditional production countries and their employment possibilities.

Therefore, the companies moving towards circularity and more local value chains, should keep in mind the risks in changing the traditional infrastructure and production line. For example, from the perspective of working conditions in collecting and sorting textile waste, the healthy and safe workplace together with paying the living wage should be guaranteed. It also needs to be remembered, that even though EU law and regulations cover the member states and guarantees the baseline for working conditions etc., it does not go without saying that these will be followed blindly in each member state. The companies need to be aware of how the local laws affect the employees, for example, is there a right to strike, or how employees of different gender are treated in the job market, is there a risk of corruption or not having binding contracts.

The study on the social impacts of circular textile value chain was made in the fall 2022. In this study the social impacts of circular textile value chain, compared to a linear one, were evaluated. This qualitative study was based on the UNEP's Guidelines for Social Life Cycle Assessment of Products and Organizations (2020). This study worked as a basis for the value proposal analysis, which was done later in the project. The target group for this study were textile businesses moving towards circular value chain. The results, together with the data collected during this study, can be found at <https://telaketju.turkuamk.fi/en/telavalue-results/sosiaalisten-vaikutusten-arviointia/>

2.1.2 Environmental Impacts

The environmental impacts of recycled textile fibre feedstock are not obvious: to make reliable claims, each situation should be studied as their own case. Linear and circular value chains for a reference product (grey sweatshirt) were formed in this work package, to study possible changes in the production chain's climate impact. Only the production stage (cradle to gate) was included in comparison.

A circular value chain would generate less GHG emissions during fibre production and clothing manufacture, but there is also a risk of higher transportation emissions due to more kilometres driven by truck. Our study showed a 25 % decrease in GHG emissions, if the production chain's feedstock and locations would change as assumed. The biggest difference came from avoided dyeing process. If recycled fibres would decrease the need of virgin cotton, there may be a lot more emission saving potentials in circular production. This would also avoid pressure on land and water resources, which were not estimated in the current study.

The key outcome of this study is better knowledge of clothing production chains' climate impact. If a company wanted to shift their production from Asia to Europe, and to use more sustainable feedstock materials, extra attention should be driven to optimized logistics and avoidance of dyeing processes. Mechanical recycling surely has its place in the circular textile ecosystem, but it is not indifferent how the surrounding value chain is managed. Also, more real-life data should be gathered, when this kind of production gets more common. That would enable comprehensive life cycle analysis (LCA) studies, ensuring that there are no hidden impacts in circular textile production.

The emission calculations were made for two different value chains: linear production in Asia, and circular production in Europe. The same scenarios were used in the social impacts study. All process data was scaled against a reference product: grey sweatshirt, weight 305 g. The linear feedstocks were 70 % cotton and 30 % PET polyester, whereas the circular options were 70 % mechanically recycled cotton and 30 % lyocell fibres. It was assumed that the recycled content would be sorted by colour, thus avoiding a dyeing process in the circular scenario. See other details in the original web publication: <https://telaketju.turkuamk.fi/en/telavalue-results/environmental-impacts-asesment-for-two-value-chain-scenarios/>

2.1.3 Economic Impacts

Moving towards a circular value chain would have direct and indirect economic impacts, resulting from several factors. Potential direct positive impacts would include easier and more efficient work processes as production and R&D would be closer to each other; cost savings due to shorter transportation distances; and improved possibility to produce products based on demand, as closer production facilities would enable shorter delivery times and better availability to customers. Potential direct negative impacts would include the overall increase of costs due to, for example, higher labour costs in Europe; difficulty in competing with virgin material prices; effects of Eco-design criteria on costs of material, R&D, and design. (Kielo, 2023)

Potential indirect impacts include the easiness of controlling social and environmental factors of the value chains, resulting in better transparency; easier risk management as the production would be closer; easiness to adapt EU-regulations; improved transparency in purchasing; dealing with textile waste generated in Europe, not needing to import it; possible increase of repair service providers and help to secure the future availability of raw material to produce recycled textile fibres; cost savings due to shorter value chain; increased transparency due to digital product passport; and increased resilience of company operations due to European production. Potential indirect negative impacts include the lack of availability of recycled textile material (particularly technical textile); the availability of recycled textile material producers (infrastructure does not yet exist in Europe in large scale); lack of skilled sewing workforce in Europe; challenges of cost effectiveness of fibre production in Europe; lack of current circular value chain in large scale; higher fibre production costs (higher labour costs; tighter environmental regulations; higher energy costs); development costs of digital product passports; and generally the transition costs towards circular economy for SME and micro companies (i.e. majority of Finnish textile companies). (Kielo, 2023)

The research on economic impacts was performed as part of a master's Thesis by TUAS student Anu Kielo. The research work and writing were done in 2023 during the Telavalue project. The thesis is based on research data collected through semi-structured interviews with experts. The topic of the thesis is: *Assessing the economic impacts when changing from a linear to a circular textile value chain - analysis from the perspective of a hypothetical Finnish textile company*, and can be found from Theseus database: <https://urn.fi/URN:NBN:fi:amk-2023090925540>. A Finnish summary of the thesis can be found from the 'Turku AMK Talk by Students' -webpage: <https://talkbystudents.turkuamk.fi/liiketalous/vastuullisessa-tekstiiliteollisuudessa-pitaisi-muistaa-myos-taloudellinen-vastuu/>.

2.2 Value Proposition and Customers

2.2.1 Value Proposition for a Circular Textile Value Chain

As a part of studying the circular textile ecosystem in Europe, the value proposition of a potential Europe -based circular textile value chain was examined with Telavalue company partners. A sustainable value proposition is the promise of economic, environmental and social benefits of a solution to customers and society (Patala *et al.*, 2016).

Social perspective

From a social perspective, the European circular textile value chain was seen to provide more employment, i.e., jobs for the European residents. There could also be new types of jobs, as different phases of the value chain would operate in Europe as well. There would be mutual rules of the game, as actors would share the same legal demands and standards. In addition, there would be more transparency to the supply chains, which would benefit all actors operating in the value chain. The awareness of circular economy would increase, and the citizens could see their responsibility and role in material circulation more clearly.

Challenges from the social perspective were related mainly to the employment and production in the Global South, where most of the production is currently done. If the circular textile value chains would operate mainly in Europe, some jobs will be lost in the countries operating in the beginning of textile production, unless new circular employment types are developed. Responsibility should be taken for these countries, and they should not be left alone dealing with the textile industry transformation. There were also questions related to the geopolitical relationships if the production is transferred away from the Global South. In addition, the circular material choices were seen to potentially limit people's original styles, as there would be less choices in materials. Are end users ready for mixed coloured products, that would result from the recycling processes? Clothing suitable for the recycling processes should consist only of one or two fibre materials, which limits the material choices. It was also acknowledged, that fast fashion must be given up, but the higher prices of clothing (resulting from a more local production) could increase inequality among citizens.

Environmental perspective

For potential environmental benefits, the European circular textile value chain was seen resulting in saving material, energy and water compared to the linear model. It would enable less land use and release it for nature or food production. The production processes would also require less chemicals. Having mutual regulation and demands for using waste as a raw material for production would reduce the production of new raw materials for textile products. The value chain would enable the returning of locally occurring waste back to circulation and to new raw materials for production. This would result in less pollution, as textile waste would not be incinerated but utilized for creating new products. More local value chains would result in smaller distances, and thus put less pressure for the environment, as there would be less emissions originating from transportation and logistics.

Challenges from the environmental perspective were identified as for example the increase of land use in Europe, which is limited, if the production is transferred completely from Global East to Europe. If the value chains would be too long, they would bring stress to the environment with chemicals and energy use in different phases of the process. The energy consumption would increase if all production is transferred to Europe. The sufficiency of raw materials was also questioned – would there be enough raw materials in Europe? If there would be a rapid shift to circularity, it might result in abandoned production sites, which would potentially harm the environment. To achieve a sustainable circular economy, fast fashion and overproduction of bad quality textiles should stop. This was not seen possible with the current production amounts. It was also stated, that in a worst-case scenario, new circular economy services would only increase consumption and logistics.

Economic perspective

As potential economic benefits, having nearby actors was seen beneficial, as it could provide a better functionality to the value chain. Bringing the European industry players together to form a value chain was seen beneficial. A more local value chain was seen to provide more control over the supply chain through transparency. It would also provide more jobs in Europe, thus contributing to increasing employment. New businesses would arise, as the need for logistics and warehousing would increase. If the value chain would operate in Europe, it would operate under a common legal environment and contract procedures, which was seen very beneficial. Security of supply was also mentioned as a benefit, as the European value chain would secure the supply of textile products in crisis situations.

Potential challenges related to the economic perspective were higher material and manufacturing costs, which also result in the rise of clothing prices. The higher costs in different phases of the circular supply chain also impact productivity, as competing with cheap virgin raw materials is difficult. There might also be more limited options regarding materials in a circular value chain. The functionality of the product value chain and possible communication challenges between value chain actors were also raised as potential challenges. There were also questions related to the mandatory Extended Producer Responsibility (EPR) schemes and their effect on different parts of the value chain: who pays for the textile waste? The sorting processes of household waste were also seen as potential challenge: how to automatize the process to create efficiency and enable the waste to be sorted where it is created? How to automatize the sorting process of customer waste to create efficiency and enable waste to be sorted there where it is created.

Unique customer value drivers

As unique customer value drivers of a European circular textile value chain, a variety of factors were identified. For example, more transparent and traceable information regarding the origin of textile products was seen as an important factor. Also having a local production and employing companies and industry close by were seen as value drivers. Having a European circular value chain would enable a possibility to make more sustainable and environmentally friendly purchasing decisions. It would thus provide a possibility to impact environmental issues of the textile industry. Additional service offerings provided by companies were also seen as value drivers. These could be for example different kinds of repair, take-back, end-of-life and recycling services.

As challenges related to the value drivers, several issues were identified. If products are made more sustainable, this could result in increasing consumption, which puts pressure on the environment. As the value chains would be more local, the prices of clothing would increase due to larger costs. Are end users ready to pay the real price for the textile, after being accustomed to low priced fast fashion? In addition, there would be fewer colour choices resulting from the recycling processes. Due to this and the higher prices, the customer segment could be limited. A large mindset change is required from consumers and there is still a lack of general knowledge on circularity and the role consumers play in circular economy. In addition, there are challenges related to communication from brands: the small amounts of recycled content can be seen as green washing by consumers, even though it is still good progress. The image of recycled fibres can also be a barrier, as they can be considered as ‘unclean’. The customer value drivers and related challenges are visualised in Figure 5.

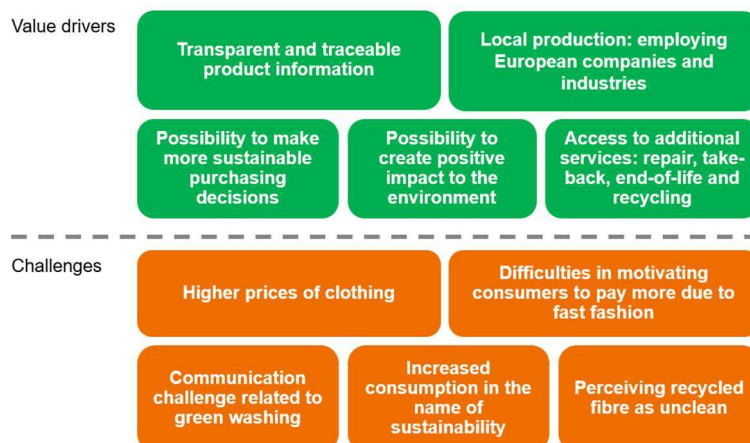


Figure 5 Customer value drivers and challenges related to a European circular textile value chain.

To overcome the challenges described, the role of communication was identified as significant. The customers (consumers and B2B customers) should be educated on the issues, to create stronger awareness of the circular textile value chain. This is particularly relevant regarding the collection of discarded textiles, to enable more efficient sorting processes. Also, the role of data was seen as an important factor – transparency and validation of circular benefits was seen crucial.

The elements for the value proposition were constructed during an internal Telavalue workshop, consisting of company and research participants in December 2022. A Miro board was utilized to record the views of participants. The work loosely followed the development stages of sustainable value propositions by Patala *et al.* (2016). As the Telavalue-project looked at the circular value chain as a whole, the value proposition was explored on a general level, without focusing on the perspective of one single actor.

2.2.2 B2B Customer Perspective of Local European Circular Textile Value Chains

The perceptions of B2B customers on a circular textile value chain and a more local production in Europe was examined from the viewpoint of companies acquiring workwear. Regarding the strengths and opportunities, generally, the companies saw the local production in Europe a thought worth supporting, as it would improve sustainability. The interviewees also saw the perspective of security of supply as a strength, as the COVID-pandemic already brought some activities closer to Europe. It is more difficult to operate under exceptional circumstances if the supply chain is too long. They also acknowledged the need to operate in a sustainable manner – their own customers will choose the company who they see as a sustainable operator. The sustainability actions affect the customer image of the company, and the interviewees reported that they are already facing customer pressure for sustainability from specific forerunner customer groups. Eco-criteria, for example, needs to be proven to the end-customers.

Having activities that resonate with end-customers' values provide competitive advantage. From an environmental point of view, the companies saw that by utilizing the existing textile material, the use of virgin raw materials can be avoided, which was seen as part of enhancing nature's biodiversity. If the value chain would be more local, it would result in less logistics, and thus cost savings for the company. Cost savings would also occur if the recycling degree was increased, as it would decrease material going to municipal waste, which is the most expensive type of waste. The recycling companies were also seen to benefit from the local circular value chain, as recycling would become more common, not only something a small group does.

The companies also highlighted the longevity of workwear garments – workwear should act as workwear for as long as possible. The material needs to be durable, and it should be easy to fix and reuse. Long lifetime of textile products is thus of central importance. Also, the companies own practises were seen essential in extending the life of garments, for example not having new shirts for each special campaign and avoiding the excessive renewal of the workwear selection. Though the companies saw many opportunities in a more local circular textile value chain, they acknowledge that a lot of textile waste is still being produced and fast fashion continues to dominate. Changing the overall consumption culture is thus central. The more this topic is being spoken about, the easier it will stream down to all sections of society. Teaching on a societal level is important, as it increases the awareness and understanding of people: waste is not actually waste.

Regarding the doubts and challenges the companies saw in local European circular textile value chain, the higher costs were highlighted. The cost of material may be high and recycling practises also result in more costs. The price level is significantly higher also if the Finnish operators are compared, for example, with Baltic operators. This has an effect on the tendering result. Referring to the current economic situation, it was mentioned that money matters, when all costs rise. The quality of recycled materials also raised questions – can good quality be provided in Europe for workwear? It was also acknowledged, that while using recycled materials in the company workwear is important to the customers and employees, it is not the main reason in coming to work or becoming a customer.

The recycling processes were also mentioned as possible barriers if they are too difficult. Recycling has been made easier for some product groups like plastics, but it requires rethinking of processes. In the case of plastics, for example, it has to be made sure that there is enough space for cleaning and drying the material. There is a requirement for guidance and education on proper processing of textile waste. The unbalanced recycling practises within Finland were also mentioned, as the situation is not equal in all locations. Not all operators have similar possibilities or resources to recycle, which results in difficulty to meet the recycling expectations when the society is not backing it up everywhere. A European circular value chain was also mentioned not to be without problems, though the

conditions might be better than somewhere else. This view is in line with the impact studies done regarding the social perspective (Chapter 2.1.1). Some companies also found the ‘closed-loop’ in Europe to be too restrictive, as Europe is a small place and development work should be done in collaboration with other actors globally.

2.2.3 Consumer Perspective Towards Circular Textiles

The consumer perspective was studied by examining consumer’s 1) views on future garments made according to circular economy and EU’s textile strategy; 2) attitudes towards recycled fibres in garments and recycling of textiles. In addition, we studied the views of Finnish respondents on the national separate collection of end-of-life textiles, which started during the Telavalue project.

Views of consumers on future garments made according to circular economy and EU’s textile strategy.

The respondents were presented with a possible future scenario of a garment that is manufactured in accordance with circular economy and the EU’s textile strategy. Generally, all elements in the scenario were regarded very positive, as most of the respondents reported them to have some effect or very large effect on the purchasing decision of such a product. The recyclability of the garment at the end of life was seen as most effective factor, alongside with the fact that it is manufactured locally in Europe. Also, the fact that a part of the material comes from textile fibre recycled in Europe was seen as one of the strongest factors.

In addition to asking the respondents to evaluate the effects of the elements on their purchasing decision, they were asked with an open-ended question: what would prevent them to purchase such a garment. The main barriers in purchasing such a garment were reported to be price and own financial situation; scepticism towards sustainability claims; concern related to the design and aesthetics of the garment; availability of such clothing; concern about the quality and durability of the clothing; other purchasing habits, for example, second hand; scepticism towards digital tools and the lack of opportunities to use them; lack of information and knowledge of such garments, concern about fit and comfort; concern about the effects of environmental and social sustainability; little interest in the matter and concern about the purity of the material.

Attitudes towards recycled fibres in garments and recycling of textiles.

To understand the consumer’s attitudes towards recycled content in garments, the respondents were asked to assess specific claims related to the topic. Almost half of the respondents found clothes containing recycled material interesting. A third of the respondents reported that they had already bought clothes made from recycled textile fibres and nearly half were interested in buying such clothes. Regarding the quality of the clothes, 45% of respondents reported a neutral opinion, while 43% reported no clear worry on the quality of the fibre. More than half of the respondents also did not doubt the cleanliness of clothes made from recycled textile fibres, indicating that there is no strong worry regarding the quality or cleanliness of the recycled material.

Regarding differences between countries and age groups, the Dutch respondents found garments containing recycled materials slightly less interesting than the Finnish, Swedish and German respondents. Respondents aged 18-24 found them most interesting. Compared to other countries, the Finns were most interested in purchasing garments made from recycled textile fibres, particularly compared to the Dutch respondents. The age group most interested in purchasing such garments was respondents aged between 18-24.

Consumer views on separate end-of-life textile collection in Finland.

The separate end-of-life textile collection started in Finland January 2023, meaning that it has been possible for Finnish consumers to deliver their discarded textile to separate collection points (following the EU waste legislation obligating the establishment of separate collection of textile waste by January 2025⁴). As a part of the survey, 300 consumers from Finland were asked about their knowledge and willingness to take discarded textiles to municipal collection points.

Most of the respondents had been aware, that there is a separate collection for discarded textiles in Finland. However, a high number of respondents indicated that they had not heard of it. The lowest awareness of such a collection

⁴ See EU’s Textile Strategy communication eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52022DC0141

system was in age group 25-34 and highest awareness among respondents aged 65-75 years. The respondents were also asked about the main reasons for not delivering discarded textiles to collection points. These were, for example, being unaware that such a collection system exists and poor access to collection points; logistical challenges or not knowing where to find collection points; other purposing of discarded textiles, for example as rags; not having a need to discard anything; and lack of time and low interest in doing so. When asked about the disposal habits of the respondents, many indicated that they often put broken garments in the mixed/energy waste bin. Still, most respondents reported that they are ready to deliver discarded textiles to the collection points in the future.

The method for collecting data from the B2B customers was semi-structured interviews. The interview topics focused on the benefits and opportunities regarding the textile offering provided through a potential local circular value chain and the challenges and doubts around the topic. The interviewees were recruited via Telavalue partner companies. Altogether five people participated in the interviews held by VTT researchers. The industries represented by the interviewees were HoReCa and R&D, and the interviewees acted as, e.g., procurement managers or sustainability managers in their own company. The interviews lasted approximately 45 minutes and were held during March and May 2023. A pdf-summary of the results can be found here: <https://cris.vtt.fi/en/publications/circular-textile-value-chains-views-of-b2b-customers-summary>.

To study the consumer perspective, the data was collected with an online survey in four European countries: Finland, Sweden, Germany and the Netherlands in June 2023. Altogether 300 responses were received from each country, resulting in a total N=1200. The recruitment of participants was done via Bilendi Oy to ensure a representative sample of age, gender and area of living in each country. The summary of the consumer study results can be found in report: <https://cris.vtt.fi/en/publications/consumer-views-on-circular-textiles>, and was also published as part of a Telaketju blog: <https://telaketju.turkuamk.fi/telavalueen-tuloksia/tulevaisuuden-vaatehankinnoissa-vaatteen-materiaalin-kierratettavyys/>.

2.3 Textile Production

2.3.1 Expected Product Lifetimes

Only little research has been done on the use phase of clothing and consumer expectations on product longevity or quality. The aim of the survey was to gain further insight into consumers' expectations and thoughts on product longevity and maintenance routines in different clothing categories. The survey confirmed some expectations but did not reveal anything new. The survey by clothing category supported the view that clothing category, material and purpose are essential when studying the use of clothing.

The results of the survey support existing research on this topic in that, although such a survey is more effective than a more detailed wardrobe survey (interview), a more detailed understanding of clothing use would be required to investigate the time of use of clothing. However, the method could be used, for example, to study the after-use of clothing in the future, as separate collection and textile recycling increases and consumer awareness of clothing disposal increases.

The expected product lifetimes were first approached by a literature review on how the use phase and consumer expectations on product longevity are previously studied. The literature review was used to determine which methods should be used to study the lifespan of clothing and consumer expectations. Next, based on the literature review findings, a consumer survey was conducted to gain more insight into consumers' expectations and thoughts on product longevity and maintenance routines in different clothing categories. The intended, assumed and expected life of products was investigated by collecting information on clothing use by asking questions about selected types of clothing in the respondent's own wardrobe. There were four product types, representing the following categories: functional clothing (running shirts), seasonal clothing (shell jacket), casual clothing (sweatshirt and t-shirt) and formal clothing (collared shirt or blouse). The method used was a wardrobe survey, which provided quantitative data focusing on individual items of clothing and their characteristics. The functional units used to determine the usage data were estimates of frequency of use, number of years and number of washings. The end-of-use phase was also considered by asking about the ways and reasons for disposing of the garments.

Results are discussed in an article Towards the unknown – How to study clothing's use phase: https://www.theseus.fi/bitstream/handle/10024/787662/LAB_2022_57.pdf?sequence=2&isAllowed=y Other publications on the topic available: <https://blogit.lab.fi/labfocus/vaatteen-kayttoian-tutkiminen-avaa-ovia-vastuullisen-kuluttamisen-ymmarrykseen/>

2.3.2 Future Textile Manufacturing

The importance of new technologies in future textile manufacturing is rising, as they offer potential solutions to many of the challenges faced by the textile industry, such as efficiency of production and flexibility in manufacturing. By leveraging these technologies, the industry can move towards more sustainable practices, improve efficiency, and offer more customized products to meet the diverse need of consumers. New technologies like digitalization, artificial intelligence (AI), robotics, and automation can be integrated into existing processes. Modifications to existing processes could be necessary to enable the utilization of recycled fractions as primary resources. This study examined the application of automation, robotics, AI, and digitalization throughout various phases of textile production, encompassing spinning, weaving, knitting, coloration, finishing, and sewing. The utilization of new technologies in various stages of textile manufacturing has been identified as yielding significant advantages. These benefits include enhanced quality, increased production efficiency at reduced costs, energy conservation, predictable production and inventory management, improved machine uptimes, reduced environmental impact, as well as the implementation of self-diagnostics and predictive maintenance.

In addition to the literature review and SotA review, this task included a webinar and a workshop on the topic of *Future Textile Manufacturing*. These events deepened the understanding of the use of new technologies in the textile industry. The webinar included over 50 participants, who gained knowledge on the use of digitalization, robotics, and AI in the textile industry, and the webinar worked as a learning opportunity also to the workshop's participants. The workshop served as a continuation of the webinar, and in the workshop case-specific challenges were offered from a few Telavalue companies, together with also a few other from the industry and academia. The participants included experts and people interested in the use of new technologies in the textile value chain, and the challenge owners together with participants found ways to continue working on or solve the case-specific challenges. The workshop also provided a platform for networking and collaboration, as well as exploration of new projects in this field was examined in the end of the event.

The key outcomes of the workshop were 1) there are many data gaps in textile supply chain – currently it is rather complicated to gather data, and it should be more simplified. End-of-life information, and data on product durability and traceability together with data that helps decision-making based on environmental impacts were seen important to be gathered, 2) data sharing models and tools for automated manufacturing line should be considered carefully – data collecting causes costs, and some data is considered sensitive. Testing laboratories are needed for classification and quality control from incoming and outgoing data, 3) the implementation of automation at the industry level requires focused attention and learning more about the possibilities – automation may be used for simple tasks such as the production of loading and unloading, and AI also has the potential to assist in the development of future robots, 4) in exploration of AI-optimized quality control in fibre production, some other methods could be suitable as well than AI – correlation, optimization, or multivariate analysis could be used. Also, to understand how much data is statistically enough, several similar runs are needed, 5) the big volumes of household waste make it difficult to get reliable textile waste stream of good quality material and control it as the full-scale production is not there yet, and the hard or other non-textile parts of textile waste is a common issue – possible solutions were discussed to tackle challenges in pre-sorting: robots cutting the hard parts, eco-design principles and theoretical fast way to recognize compositions.

The task undertaken in the project was aimed at exploring sustainable, efficient, and flexible manufacturing of textiles in the future. In addition to the desktop work and expert interactions, the task also included a webinar and workshop on the topic of *Future textile manufacturing*. The events held in the task, webinar and workshop, offered a platform for discussion among experts, researchers, and companies, fostering innovation and collaboration in the industry. The findings from this task can guide future research collaboration and development efforts, together with exploring new projects in this field. More information can be found from here: <https://telaketju.turkuamk.fi/in-english-en/future-textile-manufacturing-use-of-recycled-materials/>.

2.4 Role of Data and Information in Circular Ecosystem

Data is expected to play a crucial role in enhancing the circular economy of textile products by providing insights and enabling informed decision-making throughout the lifecycle of textile products. Data enables better tracking, lifecycle management, recycling, consumer education, innovative design, and sustainable business practices. By leveraging data, stakeholders in the textile industry can reduce waste, improve resource efficiency, and promote a more sustainable and circular economy. In Telavalue project, the studies related to data included a review on regulation and current initiatives related to data in circular textile economy, development of a data model to support selected textile R-strategies and a set of data-driven service concepts focused on Telavalue business models.

2.4.1 MVP for Data Model

The study on data modelling focused on exploring the utilization of product data within product and material life cycles in the context of the circular economy. A Minimum Viable Product (MVP) approach was adopted to determine the essential data elements required. A starting point for a data model was established by examining existing models used for garments to assess their suitability for circular economy purposes. Additionally, two specific use cases were selected: consumer re-use perspective and sorting for automation, aiming to enhance circular economy initiatives through data insights.

The results revealed that different use cases necessitate distinct datasets with different data elements, making it challenging to minimize data requirements. It was also noted that to obtain useful data for circular economy, new data elements are needed to provide insights into the garment's usage phase, which are absent in current data models. The following two data categories/elements were defined:

- **Maintenance Book:** Contains information on how the garment is maintained, repaired, modified, and by whom.
- **Circularity Information:** Requires quality data elements to describe the current condition of the garment (e.g., New, Like New, Ok, Poor).

These new data elements necessitate a dynamic data model that can be updated during the usage phase. This imposes additional requirements on data management systems, necessitating capabilities for uploading and modifying data, verified access rights management, data exchange APIs, and other software infrastructure. While the focus was on two specific use cases, supporting all use cases within circular economy could result in a large data model, posing additional challenges in data maintenance and management, leading to extra costs.

The study on data-driven service concepts examined the current utilization of data from the use phase, particularly the tracking of clothing, in both B2B and B2C environments. Additionally, business models of *Product as a Service* and *Take Back* were explored, focusing on how data can be leveraged within these models and identifying barriers and value propositions (see also other aspects of business model studies in Chapter 3).

In current B2B environments, such as workwear and laundry services, clothing tracking is a common practice, typically using RFID technology. The limited scope of these environments facilitates the implementation of the necessary technical infrastructure for data collection. However, currently the primary focus of tracking is on optimizing workflow and services for workwear providers and users, rather than supporting garment longevity or sustainability. There is significant untapped potential to support circularity management, such as optimizing future durability (e.g., washing cycles) and garment recycling.

In B2C environments, although smart home technologies for automated tracking are available, they are rarely utilized. Manual or app-based self-tracking is more common among fashion enthusiasts. Barriers to implementing clothing tracking in consumer environments include consumer reluctance (related to privacy concerns) and infrastructure costs. However, having such information—such as usage levels of clothing—could enable new types of services from brands to consumers.

For the *Product as a Service* business model, the value of data lies in assessing environmental impact and identifying process pain points. Notable technology investments would be required for data collection if it is not a core aspect of the business. Additionally, extensive data collection, management, and sharing can negatively impact sustainability, and privacy considerations for clothing users must be carefully addressed.

In the *Take Back* model, brands can engage customers responsibly, gather feedback on product designs, and redirect less-used products with remaining predicted lifecycle to new users. Consumers could identify and resell unused garments, facilitating the second-hand market. Similar to B2C environments, barriers include data collection challenges and sustainability concerns associated with extensive data management and sharing.

2.4.2 Traceability, Transparency and Product Data

Within Telavalue project we studied the importance of data sharing and digitalization in EU-level activities and the adoption of digital product passports for tracking in a circular economy. The objective was to outline the current status of traceability and transparency of product data in European textile industry, including the EU regulation and data transparency initiatives, existing traceability tools and actors, as well as prevalent technologies for tracing textile products throughout the circular textile economy value chain.

The global textile ecosystem has strategic significance to national economies, especially for low-income countries, and the social impact in developing countries. While the existing linear economic model has been successful in the past, it has clearly reached its limits. The current ‘take-make-dispose’ model is based on irresponsible use of natural resources, leading to excessive amounts of unused products and waste. The need for change is widely recognised, and the textile and clothing industry is currently going through a significant transformation from traditional linear value chains to more circular and sustainable practices. As the current model is intertwined throughout all global processes related to politics, economics, logistics, manufacturing, and retail, the required systemic change is not simple to implement. The challenges related to sustainability are well known in the textile industry and there is increased public attention on initiatives aiming to transform the linear textile value chains into circular economy.

Data should be seen as an enabler for circularity and related technology concepts. As circular economy aims to reduce use of resources by recycling materials and reusing products, to successfully manage a circular economy it is of outmost importance to have precise information about the products and materials that are in circulation, as well as their quantities, locations, and qualities. A circular economy also aims to maintain the value of products and materials as long as possible, minimizing waste and resource use. Essential to this is transferring material information between actors, which can be supported by technology. The technological advancements enable tracking the use of raw materials and products in an unprecedented fashion. Technologies such Internet of Things (IoT), 5G, RFID, data spaces, and distributed ledgers can be used to gather data related to practically any product anywhere in the world, in real-time. The critical role of data in supporting all aspects of circular economy, particularly in the textile industry, is discussed. The chapter highlights the need for data sharing and digitalization to optimize resource use, enhance recycling processes, as well as support the design, sourcing, and life extension of products. It calls for a shift towards improved data sharing practices to facilitate the transition to a more sustainable and circular textile industry.

European initiatives such as GAIA-X and IDS that aim to support data sharing among companies, supply chains, and ecosystems. EU sees utilisation of data spaces as a significant step towards getting full advantage of the massive amounts of data created in various domains throughout Europe. If data can be securely shared across sectors, machine learning and artificial intelligence can be utilised to create applications and services that can take the European prosperity to another level. EU has been promoting secure, federated data sharing for some time, and has funded several large-scale programmes boosting both technology implementation as well as supportive activities related to data sharing such as data governance, contractual and legal processes, and the required cultural change.

Digital Product Passport (DPP) is a key innovation that is essential for tracking products throughout their lifecycle. The European Commission's proposal for Eco-design Requirements outlines that a DPP will be mandatory for all physical goods in the EU market, excluding food, feed, and medicinal products. It will affect both European and non-European manufacturers, implying global changes in production practices. The EU-funded CIRPASS project⁵ is working towards defining DPP's technical aspects, including a unique ID, persistent data carrier, digital connector, and IT architecture for data exchange. The DPP will contain sector-specific data, accessible at varying levels based on user roles, and will be open, interoperable, machine-readable, and searchable. For textiles, data carriers like QR codes or RFID tags will be used, attached to the product or packaging. Decentralized systems are increasingly being recognized for their potential to enhance transparency and traceability in supply chains while retaining the data ownership. Decentralised Identifiers, blockchains and Distributed Ledger Technologies are introduced in more detail as potential technology solutions for decentralised DPP.

There are various tools and solutions that are currently being used to ensure product traceability in the textile industry. The unique identifier systems as a corner stone of global traceability systems. While there are many potential options for data carriers from the technological viewpoint, the immense pressure for lowest possible costs in textile industry may narrow the potential solutions to optical codes, for example, bar codes or QR codes, and RFID tags. While neither of these two options is a perfect match, both are mature technologies, based on open standards, and already widely used in the textile industry. The need for reliable data to support circular economy practices and the role of technology in enabling this transition are highlighted. The validity of data is imperative as it enables not only the traceability of products in short term, but also works as a basis for any long-term estimates and decisions on systemic level.

While DPP is seen as a key technology for achieving traceability and transparency, and as a major contributor to achieving a more circular economy, there are currently very few estimates available on the potential costs of

⁵ CIRPASS project <https://cirpassproject.eu/>

implementing a global DPP system. Deloitte has published a commissioned report (Deloitte, 2024) where they outline different scenarios for DPP systems with varying premises such as proprietary vs. open standards, and existing vs. from-scratch identifier systems, highlighting benefits like cost minimization, speed to market, and data interoperability. According to their estimates, by utilising existing systems such as identifier systems by GS1, and by developing open standards, the cost of implementing a global DPP system would not become overly expensive for textile industry. As EU legislation progresses, industries will better understand compliance requirements, aiding the establishment of tracking and traceability systems.

However, the technology must be made accessible to everyone in the industry, and the transition must be supported by governments and authorities also financially. Especially for SMEs, that comprise more than 95% of all textile companies, the lack of ICT skills and infrastructure is a serious challenge. Adoption requires time, effort, and investment that many SMEs cannot afford alone. Clear definitions for data content and formats, legacy system integration, and secure data transfer are crucial factors. Legislation and common standards are the foundation for safe and sustainable industry practices. Transitioning to a circular economy also faces barriers due to entrenched industrial systems and consumer behaviour. Digital technologies and novel business models offer solutions but require attention from stakeholders. Managers and policymakers must understand digitalization's role in circular economy adoption. Consumer education and empowerment are vital, needing awareness campaigns and accessible DPP data to promote sustainable decisions.

It can be concluded that data sharing is a key enabler for circular economy, supporting product design, sourcing of materials, shared product usage, product life extension, efficient processes, and enhanced recycling processes. It calls for improved data sharing and digitalization to support the transition towards a circular economy in the textile industry and recognises that the adoption of data sharing is not only regulatory action, but it should be orchestrated by legislation so that it supports and benefits the companies as well.

The study on regulation and current initiatives related to traceability and transparency was created by combining literature study, web searches, and knowledge acquired by networking with stakeholders. Telavalue partners were interviewed to collect information on current practices for textile product tracking. The data modelling activity was done in collaboration with Traci Kinden from TEXRoad. The main activity was a two-day expert workshop in Espoo, Finland, in April 2023 between Traci Kinden and VTT researchers. The data-driven service concepts have been iteratively developed using the results from the business modelling tasks in Telavalue, studying state-of-the-art and workshopping among the task participants. The results can be found from a blog post <https://telaketju.turkuamk.fi/telavaluen-tuloksia/kestavampia-tekstiilipalveluja-datan-avulla/>

3 Circular Business Models

The research made in novel circular business models was based on the desire to understand the future possibilities for companies to create value and maintain profitability when the production decreases. The novel circular business models included to the study were product as a service, reuse, take-back, on demand production and sharing platforms models, and two business models that take a different view on ownership the material of the product were chosen to closer investigation. This meant intensive research on the business models from six different viewpoints: environmental, social, economic, consumer, design, and data (Figure 6).



Figure 6 The six different viewpoints: social, environmental, economic, consumer, design, and data.

The output from the research on circular business models is a multifactor study on the business models from the social, environmental, economic, consumer, design and data viewpoints and a summary of the researchers' findings.

The research on novel circular business models started in 2022 summer with desk research. The literature found on different types of novel circular business models and the different impact of them where listed. Based on the desk research and discussions with researchers, as well as research done in past projects, 25 hypothetical cases were conducted. These included product as a service (10 cases), reuse (10 cases) and take-back (5 cases) business models. A workshop was held in Autumn 2022 with researchers to discuss the different aspects of how the business models should be studied going further. After the workshop with researchers, the models were presented to and reflected with the companies. In Spring 2023, a workshop was held with companies and researchers, based on which two hypothetical cases were selected for further studying from the perspective of design, economics (economic, social, and environmental costs), and data. These two cases were: 1) business-to-business case with product as a service (workwear) - A comprehensive solution for companies, and 2) business-to-consumer case - Reuse and Take-back.

3.1 Sustainability

3.1.1 Social Aspects

Social responsibility strategies in circular textile business are collected into Figure 7. It gives viewpoints on social sustainability, not just taking one point of view of working conditions but trying to consider all different stakeholders in the service model. A company or organisation could base their social responsibility evaluation on this framework. The company could focus on selected variable(s) for implementation, but in the best-case scenario, they would take into consideration all the variables and aim to implement them all excellently. For the novel business to be truly a sustainable choice, all the different points of views need to be considered.

This table should be read from left to right. On the left side, the name of the variable is stated. On the top, the implementation of each variable is stated. The company or other actor can implement the variables on four separate stages (ok, good, very good, excellent). The stages are cumulative, each level must materialize for the actor to move onto the next stage. The company or other actor can at the same time be on different stages at different variables.



Social responsibility stages in circular business of textiles

NAME OF THE VARIABLE	IMPLEMENTATION OF VARIABLES			
	OK	GOOD	VERY GOOD	EXCELLENT
Code of Conduct	Code of conduct in effect	CoC followed	Implementation evaluated (possibly via 3rd party)	Results reported publicly
Internal feedback	Grievance mechanism	Measuring and monitoring	Interference with problems	Changes in company policies and operation
External feedback	Grievance mechanism	Reaction to feedback	Procedure	Changes in company policies and operation
Remuneration	Employees with employment contract	Living wage	Equal pay	Employment of locals
Stakeholders	Transparent and public value chain	Established partnerships	Partners involved in development work	Economically viable business ecosystem
Product as a service	The product is sustainable, comfortable and safe	Repairable and refurbishable	Sustainable material	Closed loop system
Reusable product	The product is sustainable, comfortable and safe	Remains its value (even repaired)	Recyclable material	Closed loop system
Accessibility in reuse	Promise of product durability	Platform supporting reuse	Product used up	Valuable material returns to the company
Transparency of product data	Internal trackability of products	Link to up-to-date product data within the product	Product data includes scope 3	Product data during use-phase collected
Business model	Test	Pilot	Established part of business	Decreases the production of new products
Sustainability communications	Communication on the current situation	Communication on the development	Communication on the future	Communication on the results and reaching the targets set

Figure 7 Social responsibility stages in circular business of textiles.

The hypothetical circular business cases selected during Spring 2023, were further studied from the perspective of potential social impacts. As a basis for this study, the framework of social life cycle assessment of products and organisations by UNEP (2020), was used. The different impacts were also cross-checked with the Global Reporting Initiative's social standards. This study did not consider the impacts on traditional production countries, as the study limited only on the use-phase, which hypothetically took place in Europe, more accurately in Finland. As a result, a table or visualisation was made, and it included the potential social pain points of the business models, which each company could base their social sustainability evaluation on. The original tale can be found online <https://telaketju.turkuamk.fi/en/yleinen-en/how-to-evaluate-social-responsibility-of-novel-business-models/>

3.1.2 Environmental Aspects

The two studied circular business cases were hypothetical, so this time there was no data for LCA or emission calculations. Instead, the environmental analysis focused on different factors that would affect the environmental performance. These include, for example, transportation modes and distances, washing process energy consumption, storage time of the product etc. We noticed that both circular business cases consist of similar main processes: washing, repairs, storage, maintaining the sales platform, transportations, and end of life treatment for unusable items. Some of these processes can occur multiple times during the clothes' use phase.

We examined the environmental factors of two circular business models: the *Product-as-a-Service* (PaaS) and *Take back* business model. Figure 8 shows the modelled life cycle of the *Product-as-a-Service* model and Figure 9 shows the modelled life cycle of the *Take back* model. Each process of the life cycle was examined separately, and variables related to the environmental impact of each process were listed. The listings of factors help companies to recognize all the relevant environmental factors, if implementing these circular models and aiming for sustainability. They also serve as a basis for future life cycle inventories.

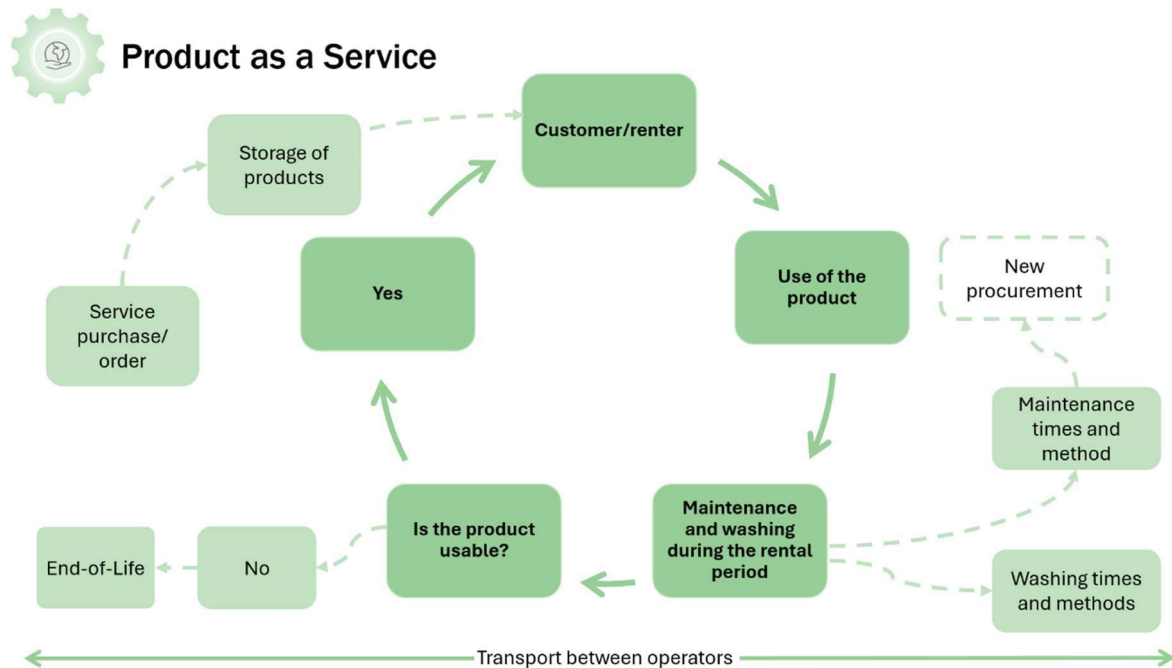


Figure 8 Environmental aspects in Product-as-a-Service business model.

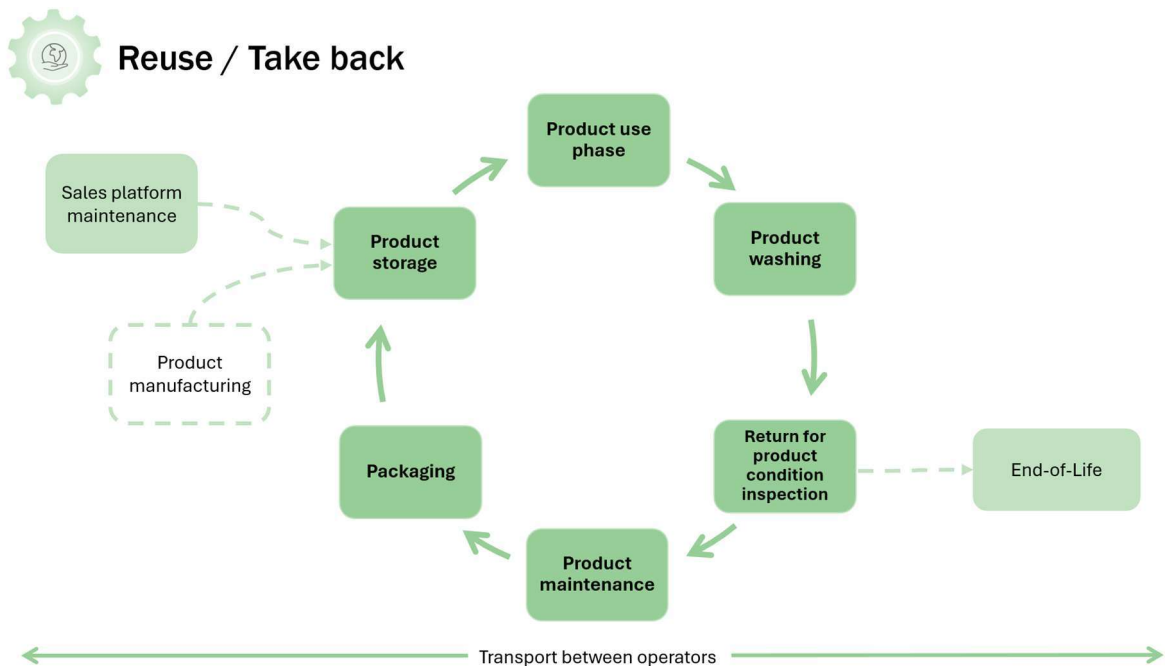


Figure 9 Environmental aspects in Take Back business model.

We examined the environmental factors of two circular business models: re-use and product as a service. To study these models, detailed example cases were created of each model. They were a take-back system for consumers, and a textile service for enterprises. To form realistic life cycles, both models were tweaked together with companies and researchers. As a result of brainstorming, workshops and interviews, the Product-as-a-Service (PaaS) and Take back business model were chosen for an environmental study. The research started by examining two different business models and the factors that cause environmental effects in them. The factors were found using literature and interviews. Based on the similarity of the variables, as a final result in the study, one list was created that include the variables for both business models. Out of the examined product life cycles, a total of 29 environmentally relevant factors were found. These are listed in the original web publication (<https://telaketju.turkuamk.fi/en/telavalue-results/environmental-impacts-of-circular-textile-models/>). Most of the factors (17) are quantitative, and the result tables suggest suitable measurement units for them. The rest of the factors (12) are qualitative, related to the choice of energy form, among others.

3.1.3 Economic Aspects

We carried out literature review to find published information considering the economic aspect of circular economy business models. By economic aspects we mean profitability, cost accounting and pricing. In order to make more use of circular economy business models, the monetary benefits of the models should be highlighted, as well as what economic factors should be taken into account when moving to a business model. In triple-bottom-line decision-making, the economy is also one of the decisive factors in the sustainable development of companies, along with the social and environmental perspective. We found out that there are only a few articles on economic perspectives to be found, and the need for this kind of material clearly exists.

Three business model types, i.e., sharing platforms, product as a service and product life extension were looked for the literature review. The aim of the literature review was to find out how much literature is available in the databases that takes into account the economic aspects of circular economy business models. The search was conducted mainly from the central databases of business administration and sales, with the keywords circular economy, business model, profitability, cost accounting and pricing. Only articles available online that are not related to previous studies or publications in the Telaketju project were taken into account in the search. A total of five articles were found in the searches, and some of these articles covered the topic more extensively than others. More information on this can be found online. <https://telaketju.turkuamk.fi/en/telavalue-results/the-economic-aspects-of-new-ce-business-models/>

3.2 Other Aspects

3.2.1 Design Aspects

The role of product design in novel business models is crucial. As there are numerous variables and operational variations in the emerging new business models, two novel business models were selected for further analysis in this study. The selected business models were 1) the PaaS model and 2) the Take-Back-Reuse business model. When looking at the variables of novel business models, it all comes back to the product. Business models are therefore also product-specific and product categories differ considerably.

In addition to sustainable material choices and structural solutions, new business models require product design to consider the emotional and social needs of the user. Especially in sharing economy models, where a product has multiple users, it is important to design products that meet the needs of the user and are suitable for the intended use. It is also important to consider how design can be used to create added value for the customer in rental business models. This approach may involve not only designing the product but also developing a service concept solution. To innovate integrated solutions, feedback is needed directly from the end users of the products and service concepts.

We found out that design thinking is not yet widely used. The study revealed that the user feedback was collected to varying degrees, but the feedback is mostly not considered in product design or product development. The importance of Design Thinking in circular business models is still either not internalized or not seen as essential. However, integrating user insights into the development of product and service concepts can contribute to the vitality and competitiveness of new business models. The research themes, practices and conclusions of the role of product design have been visualised in Figure 10.

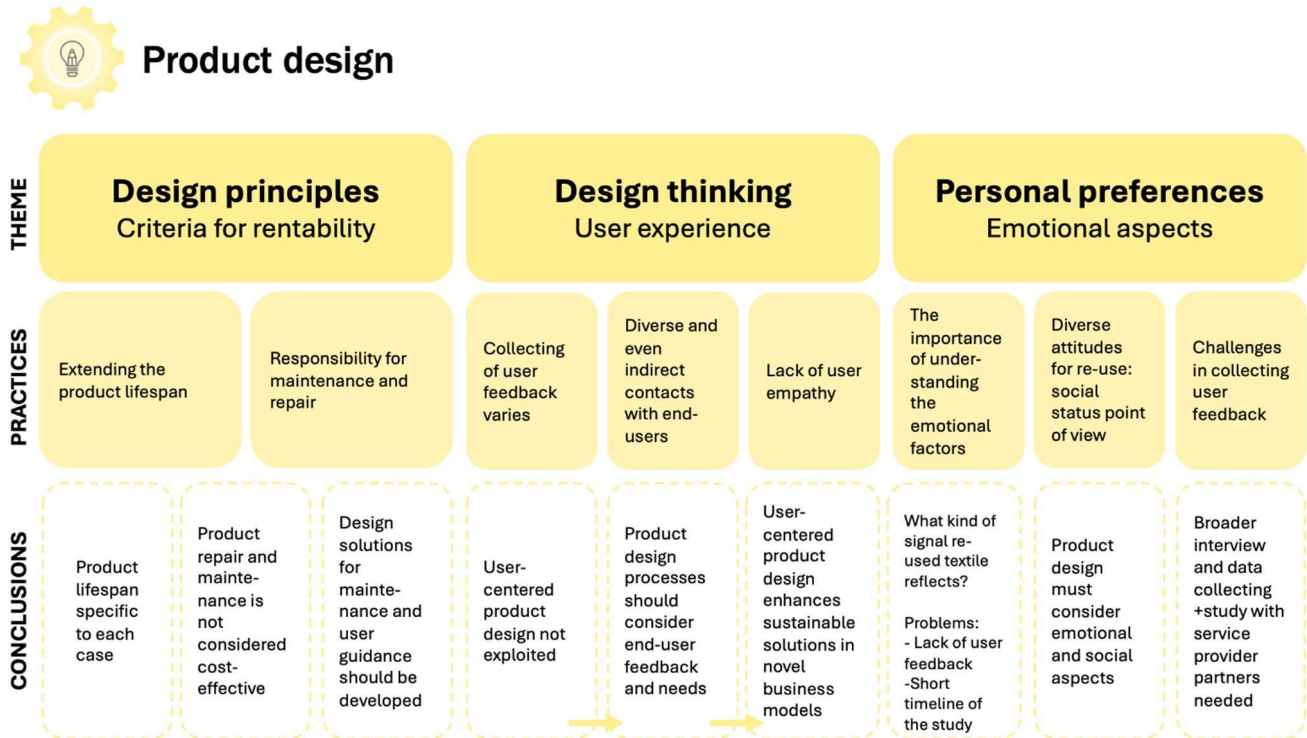


Figure 10 Research themes, practices, and conclusions of the role of product design.

The research started by organizing a workshop in the beginning of the year 2023. In the workshop Telavalue researchers and companies dived into those two selected business models mentioned above. Considering the role of product design in those novel business models, three design related themes emerged at the workshop and based on the previous study: 1) criteria for rentability 2) feedback collection of the user experiences 3) emotional aspects of a rental product. All the emerged themes are directly linked to product design. Based on those defined themes, four semi-structured theme interviews were conducted for the companies working in the casual wear, workwear and childrenswear sectors. The interviews were conducted during the period of Spring-Autumn 2023. The interviews were then analysed and as a result the visualisations (figures above) were made based on the conclusions.

3.2.2 Data Aspects

Data aspects were also studied intensively within the business model research theme. The data work was done in cooperation with the ecosystem research in Telavalue. This work is summarised in Chapter 2.4.2.

3.2.3 Consumer Aspects

Novel circular business models need to be appealing to the end-users of garments, the consumers. The consumer acceptance of business models is a complex process, which needs to be understood and taken into account in developing new ways of consuming fashion. Three novel business models were chosen to be evaluated with consumers in the Telavalue project: 1) Linear model with a circularity guarantee; 2) Peer-to-peer rental; and 3) Clothing libraries.

1) Linear model with a circularity guarantee

In this model, a fashion brand offers additional repair and take-back services to extend the lifetime of the garment, as visualised in Figure 11.



Figure 11 Visualisation of the linear business model with a circularity guarantee.

In general, consumers regarded the model very positively and it was seen as an interesting way for brands to stand out. The model was found to increase trust in the brand's products, as the model suggests that the products are originally designed to be high-quality and long-lasting. The take-back services were considered to bring various benefits to the consumer, for example, in the form of saving time and money related to the second-hand selling process. The consumers saw the complexity of the model as a challenge, as delivering clothes for repair, reuse or recycling was perceived to be burdensome and time-consuming. The reward system (gift certificate) was also seen as problematic because it would increase total consumption and would not help improve the sustainability of the fashion industry. Still, the consumers felt that some kind of reward system would be required to help the acceptance of the model. By clear and transparent communicating, the consumers' trust in the brand could be increased.

2) Peer-to-peer rental model

In the peer-to-peer rental model, consumers rent their own wardrobe to other consumers via a digital platform (smartphone application), as visualised in Figure 12.

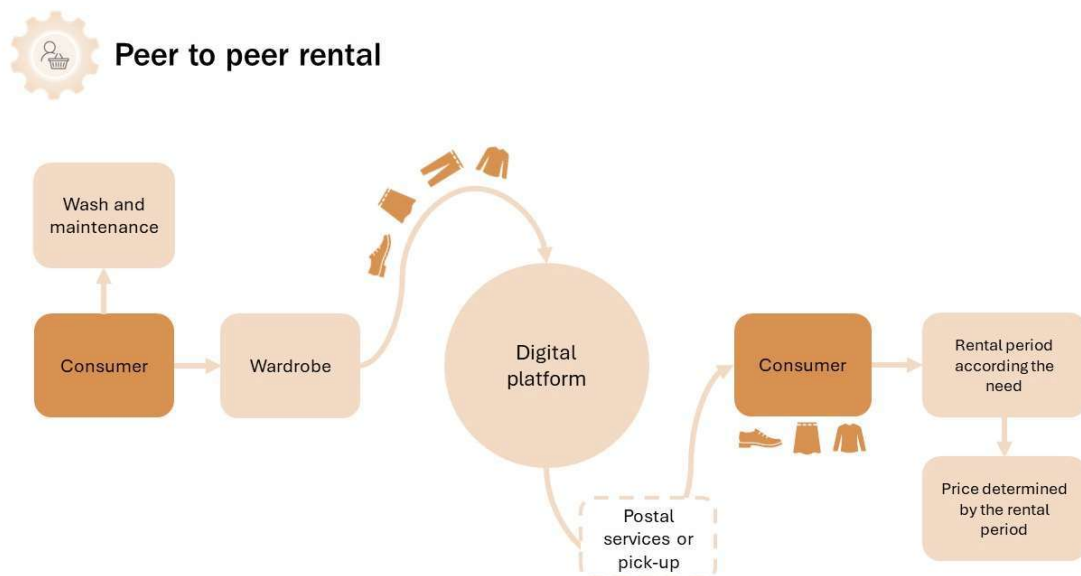


Figure 12 Visualisation of the peer-to-peer rental business model.

As a benefit for the owner of garments, the consumers saw that the model offers a new earning opportunity, particularly for garments that are worn irregularly. This earning opportunity, however, presents risks of potential damage to the rented clothes, and in addition, organizing the renting of your own clothes may take a lot of time and energy. For the renter of the garment, the model offers an opportunity to wear expensive luxury clothes, try out different styles or to use the service for a short-term need, for example for a party. However, the liability issue was seen to be unclear in rental activities between consumers. The need to build trust between the owner and renter of garments, as well as with the provider of the digital service platform were highlighted.

3) Clothing libraries

Business models offering clothing rental in the form of a curated 'library' can already be found both in Finland and on international markets. Usually, they focus either on the clothing selection of one specific brand or offer a wider selection of garments from various selected brands, as visualised in Figure 13.

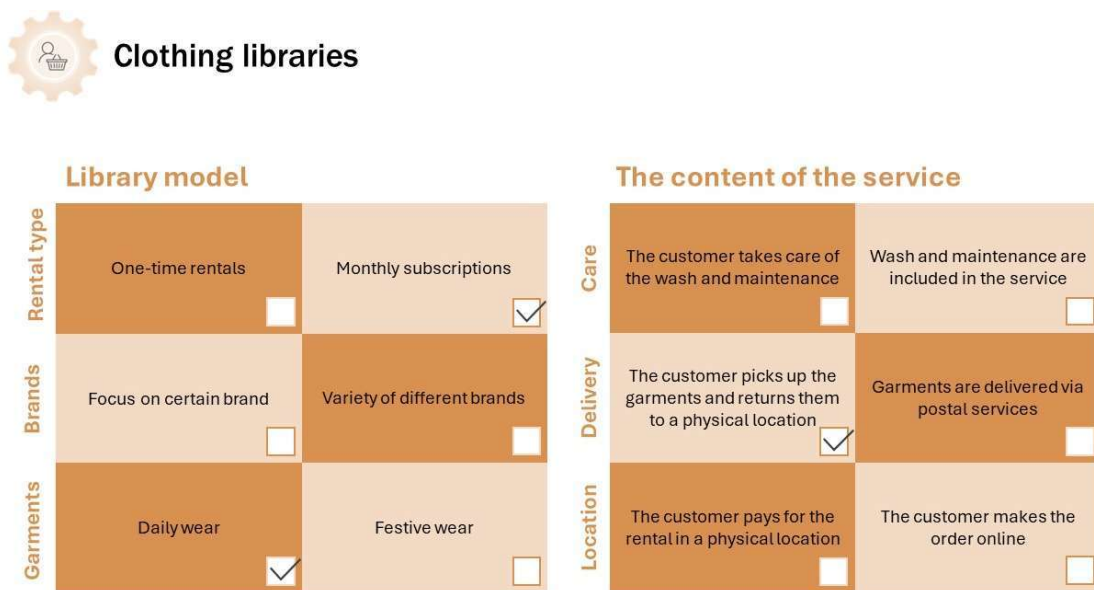


Figure 13 Visualisation of the business model of clothing libraries.

From the consumer point of view, the benefits of clothing libraries are very similar to those of the peer-to-peer rental model, but the difference is in this type of model, the rental activity takes place between a company and the consumer. Being involved with a company was seen to bring more trust and clearer rules and conditions to the rental process, compared to the peer-to-peer rental model. In clothing libraries, the rental process includes several different service elements, such as style guidance and repair services. These were seen to increase the overall attractiveness of the model. One of the biggest challenges for model was seen to be the required change in beliefs and attitudes of consumers related to ownership of garments. Fashion was generally perceived as a factor that builds identity, and many consumers are attached to the garments they own. The consumers described that it can be difficult to build your own, personal style and stand out from others in a model where the garments are shared with other consumers.

The novel circular business models chosen for the consumer research part were selected based on discussions with the Telavalue consortium partners. The methodology used to study the consumer perspective was focus group discussions. Altogether four focus groups were organized during Fall 2023, and 14 consumers participated the study. The focus group discussions targeted consumers that have a special interest in sustainability of the textile industry and circular economy. The discussions lasted approximately 1-1.5 hours and were conducted via Microsoft Teams platform. The discussions were moderated by Telavalue researchers, and the business models were introduced to the consumers as a narrative description. A summary report on the results can be found here: <https://cris.vtt.fi/en/publications/consumer-perceptions-on-novel-circular-business-models>, published also as part of the Telaketju blog series: <https://telaketju.turkuamk.fi/telavaluen-tuloksia/kiinnostavatko-muodin-kiertotalouden-uudet-liiketoimintamallit-kuluttajia/>.

3.3 Multifactor Study on Business Models

Telavalue research on business models focused on obtain competence for implementation of new circular business models in companies. This was obtained by benchmarking and deep analyses of principles, economics, and role of design, as well as managing and utilization of product data in the novel circular business models, to study feasibility and implementation. This work was summarised into five messages aimed at the society, companies, researchers, and decision makers.

The five key messages:

1. The phenomena are wide and important: The phenomenon is very interesting and vast there are ‘more than 12 cases in a dozen’ of different variations of the circular business models on business level. We do not know enough about the phenomenon yet.
2. The need to do the change together: If customers will not change, then the society and the companies will not change either. On the other hand, how could consumers make the changes if it is not available. Society has an important role as enabler and regulator. We need to make the systemic change together.
3. We need to decrease consumption to be sustainable: Many contradictions must be resolved at the same time. Consumption and production must be reduced. However, the society do not aim for this yet. The new business model must reduce the production volume of the new products, otherwise the novel business models are not a better option at all. The delimitation of the research cases should be narrowed, and on the other hand, the effects on different themes should be deepened. The question is also about this for example: is a fast fashion model ever possible to be sustainable business?
4. Consumers have a leading role: In many ways, the companies do offer if consumers want. A dialogue with consumers is needed. What are their concrete needs and hesitations?
5. All aspects need to be taken seriously and developed together and separately: All perspectives must be considered when looking at a new business model. Everyone is part of the change. The new business model is not in itself the answer to a more sustainable business, but the actions there are within the business model are the answer.

The research team come from TUAS, VTT and LAB. They started the work together in 2022 and concluded in spring 2024. During that time, they had multiple interactions with each other, the companies, other stakeholders discussing and sharing the results. So, during spring 2024 the research team was able to summarize their understanding of the phenomena into five important messages to the research community and the society as a whole. We have put the results of the work together in Finnish into a webinar <https://telaketju.turkuamk.fi/telavalueen-tuloksia/multifactor-study-on-business-models/> and in summary report available in Telaketju webpages <https://telaketju.turkuamk.fi/uploads/79520120-01-multifactor-study-23.9.2024.pdf>.

3.4 Startup Study

According to our study, sharing and other digital platforms are very popular with startups in the field of circular economy of textiles. The platforms can be used to combine a wide range of services, such as clothing rental, sales, maintenance and repair. The users of these platforms are both consumers and clothing brands.

Technology is an important part of companies, and, for example, a digital wardrobe is at least part of the concept of a few companies, together with, for example, a repair and maintenance service. We want to make repair and maintenance services attractive to consumers but also to clothing brands, so that they would resell or repair clothes either for resale or back to the product owner. Transparency is also seen as an important issue in the circular economy of textiles, as it helps to avoid greenwashing and makes it easier for the consumer to choose a truly responsible company from among others. For example, a digital product passport increases transparency.

It was interesting to notice that among the startups there were not many companies focused on the manufacture or production of clothes, but rather companies offering the use and maintenance of clothes. It could be concluded from this that probably in the near future the primary focus will be on encouraging consumers to reuse and recycle, to increase the length of the life cycle of clothes through clothing repair and maintenance, and to shape consumer attitudes and habits in general. Manufacturing and production cannot be modified until consumers’ attitudes and

beyond the obvious

habits are modified. Laws and regulations can interfere with the development of fast fashion to some extent, but as long as there is demand, there are also parties who take advantage of this.

The exceptional conditions experienced during the pandemic made trading move quickly online. This was also noticeable in the operations of startup companies, as many of the companies were founded during the pandemic and many of their operations were focused on the web. The pandemic may have led to the enhancement of value chains in the clothing and textile industry when product selections have been narrowed and production has moved more closely to consumer demand.

Consumer attitudes are an important part of the future of the circular economy of textiles because each consumer can steer the future in a certain direction with their choices. These attitudes need to be modified and the problems of the textile industry should be brought to the fore more, especially among young people. Consumers can make a lot of changes with their own choices, as demand directly affects the direction in which brands in the textile industry take their products or what kind of concept they create.

The future of the textile circular economy was examined through startup companies in the field. The startup companies for this research were found from the online Ellen MacArthur Foundation's Circular Startup Index⁶. We included only those companies that were linked to textile sector in some way. The company listing was done in summer 2023. There were 76 companies found in the Ellen MacArthur Foundation's Circular Startup Index. The PESTE analysis was used as an aid in the review of the companies, which was used to get a broader and all-inclusive picture of sector and its future. The report and an excel of the companies can be found online <https://telaketju.turkuamk.fi/en/telavalueen-tuloksia/startupien-kautta-katse-tekstiilien-kiertotalouden-tulevaisuuteen/>

⁶ Circular Startup Index <https://www.ellenmacarthurfoundation.org/resources/business/circular-startup-index>

4 Recycling and Products Made Using Secondary Raw Materials

Commercial recycling cases can be found in the textile sector as use of recycled materials, but the closed loop textile-to-textile recycling is still merely focused on *pre-consumer* waste streams. The adaptation of recycling technologies from pre-consumer to *post-consumer* is still limited due to inhomogeneity of such textile waste and/or limited techno-economic viability of existing processes. Mechanical recycling (fibre recycling) is still a dominant method, while fibre raw materials recycling, such as chemical processes, are emerging and mostly still in pilot scales.

In this Chapter we review results obtained in Telavalue project related to textile identification (Chapter 4.1), quality improvement (Chapter 4.2), recycling (Chapter 4.3), and textile and other products made using secondary raw materials (Chapters 4.4 and 4.4.3).

4.1 Identification

To find best utilization possibilities for post-consumer textiles, it is essential to sort them to different categories depending on their quality as well as their material composition. Identification technologies give the support that manual sorting is missing as they can identify textile properties and affect positively on overall costs and efficiency of the sorting process. During the Telavalue project information related to current state and prospects of identification technologies (SotA) was gathered and the technologies were compared to each other by different factors such as usability and accuracy (SWOT).

Identification of textile materials and their coatings were tested with near infra-red spectroscopy (NIRS) and some results were cross-referenced with x-ray fluorescence (XRF) analyser. The aim was to study identification capabilities and separation potential of fire-retardant samples to further clean heterogenous textiles streams. It was determined that thick layers of coating can be used to determine a sample as *impure*, but not enough data could be collected with available NIRS machinery to differentiate between coatings aside from polyurethane (PUR). In case of polyester (PES) curtains, it was noticed that molybdenum could be identified with XRF analyser, but no definite data could be collected to filter such samples as impure with available NIRS. It was determined that the amounts of fire-retardants were consistently low and would not be noticed from beneath allowed variance in data analysis.

Wool and acrylic mixes was an interest as separatable fractions and NIR identification methods were improved upon. It was determined that monomaterial wool and acrylic should be easily separatable and similarly to CO/PES blends, categories for certain blending ratios could be created, i.e., 20/80 blends, 40/60 blends and so on. A quantitative sorting method was tested but remains inaccurate in determining compositions of blended textiles, likely due to their structures. NIRS is surface reading and creation of quantitative method for blend samples requires fine tuning when in blend samples one component may seem over-represented on textile's surface.

NIRS can be used to easily and relatively quickly to separate mono material samples out of heterogenous streams. Issues lie in determination of blend samples, where the announced total composition of the sample may differ from what the observed sample surface area is. A quantitative material sorting method may be created but remains inaccurate due to heterogenous sample surfaces. This problem also is present in determination of coatings, where impregnated materials can be determined without the base material, but thin coatings, such as sprayed-on moisture-seals remain mostly undetected.

The identification technologies study comprised SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and State-of-the-art (SotA) review. The investigation of identification technologies started by doing literature search in the second half of 2022. Furthermore, networking with stakeholders fostered the understanding of current state as well as prospects of these technologies. Information gathered in the SotA review was used as a source to make SWOT of identification technologies and included in a report, and summarize as a blog post (<https://telaketju.turkuamk.fi/telavalueen-tuloksia/tunnistusteknologiattaitettiin-suurennuslasin-alle/https://www.labopen.fi/lab-pro/tunnistusteknologiattaitettiin-suurennuslasin-alle/>).

NIR identification methods were improved upon by creating a category for wool (WO)-acrylic (PAN) blends. LSJH collected and provided LAB with post-consumer test-materials. Manual material sorting yielded 30 pieces of 100% PAN and 20 pieces of WO-PAN blends, mostly in 40/60 ratios. Materials were analysed with NIRS, and it was determined that monomaterial WO and PAN should be easily separatable and similarly to CO/PES mixes, categories for certain mix-ratios could be created. Creation of quantitative sorting method for mixed WO/PAN textiles was attempted and the initial model seems to remain 75-85% accurate, similarly to CO/PES quantitative method. Quantitative method was built by analysing spectra of all collected samples and previously collected WO samples.

4.2 Quality Improvement

4.2.1 Separation of Fire Retardant and Water Repellence Finishing

The study examined textile waste containing water-repellent (WR) and fire-retardant (FR) finishes. Generally, WR and FR compounds are durable, not susceptible to removal or chemical degradation, and able to endure diverse environments, making their removal is difficult. For example, in the case of chemical recycling of cellulosic textiles, cross links between finishing chemicals and cellulose fibres prevent dissolution and followed by the extrusion of fibre regeneration. Thus, textile waste must be free from those compounds before recycling for fibre regeneration.

The FR removal treatment results showed indication that the treatments may have been overly harsh and affected the base structure of the fabric. With WR finishing higher alkali concentration resulted in better finishing removal whereas the acid treatment had completely no effect on the removal. Further studies should be conducted to optimize the alkali treatment conditions to ensure complete removal of the finishing. Also, the effect of different finishing chemistries on the conditions should be further studied as the specific chemistries are often trade secrets which causes challenges on choosing the right removal technique (alkali or acid). Having textiles with and without known finishing chemical would be advantageous for the development of the identification and removal of finishing chemicals. The Fourier-transform infrared spectroscopy (FTIR) and spray test were found as complementary methods for each other in tracking the WR finishing removal. Solid-state Nuclear magnetic resonance (NMR) on the other hand was found insufficient in detecting the finishing. To identify the finishing from the textile, complementary methods for FTIR are thus needed. Future study might utilize Thermogravimetric Analysis (TGA) and chromatography to investigate the removal of FR to cross-validate the results.

In the separation of finishing treatment, the literature on FR and WR on textiles and their chemistry to guide the removal experiments. Image Wear and Reima provided samples containing finishes and few technical data. FR and WR samples were alkali and acid treated at various temperatures for 30 to 120 minutes. Untreated and chemically treated FR and WR samples were characterized using FTIR, spray testing and solid-state NMR.

4.2.2 Sterilization of Waste Textiles

Microbes can cause health problems, unpleasant odours on textiles, decolorization and loss of textile tensile strength, therefore it is important to find ways adopt sterilization in the textile mechanical opening process. Three possible sterilization ways were identified: heat treatment in blending stage, use of liquid sterilization chemicals in pre- or post-wetting stage or gas phase treatment if a closed system can be installed in the process or the gas treatment can be done in a container. The heat and prewetting treatments with ozonised water, hydrogen peroxide, dodecyl dimethylammonium chloride (DADC), and chlorine dioxide were selected for the laboratory tests. Screening the efficacy of different sterilization methods was performed using worst case scenario in which a high concentration of various microbe types was added to textile before disinfection treatments. The survival of microbes showed that dry heat treatment and steam heat treatments were the only effective ways to sterilize the textiles.

In the sterilization of waste textiles task, based on the literature review and discussion with LSJH and Kemira, the sterilization of pre-opened cotton textile materials (delivered by LSJH) was tested with using dry (170°C for 1h) and steam (121°C for 15 min) heat treatments, hydrogen peroxide vapour (RT for 1h) and wetting treatments (10% moisture content) with ozonised water, hydrogen peroxide, DADC, chlorine dioxide for 15 min at RT. Microbes were mixed (10 min) with dry textile sample before sterilization treatment and number of microbes was analysed before and after disinfections.

4.2.3 Enzyme Treatments of Fibres, Yarns and Fabrics

Cellulases are commonly used in textile processing of cotton to obtain better surface appearance (depilling), and stone washing effects (bio stoning of denim). Enzyme treatments of mechanically opened fibres were studied in the Telavalue project for smoothening of the surface roughness of mechanically opened fibres. It has been reported earlier that cellulase treatment of pretreated virgin cotton fibres improved the yarns quality by decreasing the hairiness (Pere *et al.*, 2001). Our results showed that the mechanically opened cotton (blue, from Rester) was less prone to enzymatic hydrolysis by cellulases than the virgin cotton. Scouring (under 2 M NaOH) clearly improved the enzymatic action both on recycled and virgin cotton fibres. The blue colour in recycled fibres seemed to inhibit the enzymatic action, similarly, as observed by others (Yamada *et al.*, 2005), and indicating that cotton was dyed with reactive dyes that form covalent bonds in hydroxyl groups of cotton. As part of Susanna Raiskio's thesis work (Raiskio, 2023), commercial textile enzymes for depilling and denim wash were tested in treatment of yarns prepared

from recycled cotton/polyester fibres according to manufacturer's instructions. No visible difference was seen in yarns, and the enzymatic treatments had no clear effect for the yarn tensile properties.

In the fabric trials the aim was to study the effect of commercial cellulase on the cotton textiles made from recycled fibres. In the first test, commercial coloured woven towel fabrics were used. The towels were made from linen (warp) and virgin cotton or mechanically recycled denim cotton 80%/rPET20% (weft), a kind gift from Jokipiin Pellava. In the second test, plain jersey fabrics made from 50% mechanically recycled cotton blended with 50% virgin cotton (50/50), and reference 100% virgin cotton were used. Fabrics were knitted in Aalto University from 35 tex yarn. In these tests, no pronounced effect on pilling was observed. However, both fabrics made from recycled materials had more pronounced weight losses than the reference materials made from virgin materials after enzyme treatments. In addition, the enzyme-treated knitted fabrics had notably reduced abrasion resistance compared to the untreated knitted fabrics.

The enzyme treatments of fibres were carried out with purified cellulases (VTT, in-house) or a commercial cellulase mixture (Cellic CTec2). After the enzyme treatment, the activity was assessed by measuring the soluble sugars released by the enzymes, and by studying the fibres with light and scanning electron microscopy (SEM). Enzyme treatments of fabrics were carried out in Gyrowash machine using Ecostone® OSB7 (a kind gift from ABEnzymes) in dosages of 0.1% and 0.2% of fabric weight. Weight loss of the fabrics was measured as the difference in the dry weight of the samples before and after treatment. The pilling tendency of the woven fabric was measured by the Martindale method by rubbing the samples 2000 times. The abrasion resistance of knitted fabrics was studied by using the Martindale method and rubbing the samples 11000 times or until a yarn break occurred. The results can be found at <https://cris.vtt.fi/en/publications/mode-of-action-of-cellulases-on-recycled-cotton-fabrics>

4.3 Recycling

4.3.1 Recycling Technologies and Optimal Cycling Model

Textile recycling will be one of the solutions making textile industry more sustainable, even though extension of products' lifetimes and prevention of waste should be emphasized over recycling. Fibre-to-fibre, or in other words, closed loop recycling method enable using of recycled textile materials to replace primary raw materials in textile production. Fibre-to-fibre technologies can be divided based on the level through which materials are taken apart. In fibre mechanical recycling textile structure is taken apart into fibre level, and in thermo-mechanical and chemical methods recycling is done either in polymer or monomer level. In open loop methods textile are taken apart into molecule level, and/or materials are recycled to be used in other than textile applications.

Fibre mechanical recycling is the simplest method, but do not enable restoration of fibre length or strength, while other methods are more complex, thus also more expensive and causing more environmental impacts, but enable restoration of fibre properties. Evaluation and comparison of different recycling approaches in general level is shown in Figure 14.

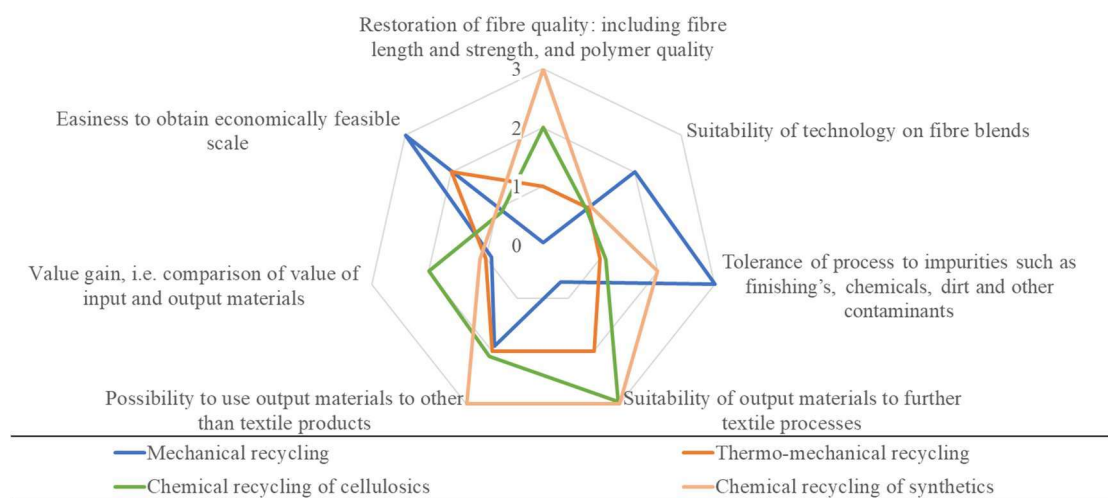


Figure 14 Evaluation and comparison of different recycling approaches in general level. Three/outer ring=Very good/Positive effect, Two=Good/Somewhat positive effect, One=Ok/None or slightly positive effect, Below one/in the centre=Poor/Negative effect.

Technology review was carried out by combining literature study, workshop with Telavalue partners, and networking with STB and other stakeholders. Model for sustainable recycling was made based on technology review and knowledge built within all Telaketju projects in collaboration with Telavalue companies. Recycling technology review results has published in presentation Aachen Dresden Denkendorf International Textile Conference 2022 (<https://cris.vtt.fi/en/activities/technology-review-of-textile-recycling>), and also as book chapter (<https://cris.vtt.fi/en/publications/textile-recycling-technologies>) is based on the work. Technology review and model for sustainable cycling of textile has been published as separate report (VTT research report VTT-R-00941-22 <https://cris.vtt.fi/en/publications/technologies-and-model-for-sustainable-textile-recycling>) and model will be used as basis for development of Conceptual Framework in EU project tExtended⁷.

4.3.2 Mechanically Recycled Fibres

Selected mechanically opened cotton fibres were studied to characterise them and to evaluate their feasibility for further processes such as spinning. The harsh mechanical recycling processes are often said to decrease the important properties of fibres, such as length and tenacity (Kahoush & Kadi, 2022; Kamppuri *et al.*, 2019), thus leading to less efficient textile-to-textile-recycling. The lack of efficient technologies and the difficult sourcing of homogenous material are further challenges related to mechanical recycling of textiles (Heikkilä *et al.*, 2024).

The length analysis of mechanically opened fibres and a reference fibre (100% virgin cotton) showed that the virgin fibres were the longest, and the general length results were shorter for mechanically opened cottons (see Figure 15). While the lengths were shorter for mechanically opened fibres than for virgin cotton, the length uniformities were 54-59% for the mechanically opened fibres and 64% for the virgin cotton fibres. The linear densities and breaking tenacities showed little to no difference between the tested fibres, and no conclusion for the disadvantage of using mechanically opened fibres for yarn spinning should be made from these results. The elongation results were similar, although a statistical analysis revealed a difference in the breaking elongations of two fibres, namely a pre-consumer (100% cotton, knitted) fibre and a post-consumer (90-100% cotton, <10% elastane and other fibres, denim) fibre.

The FTIR and differential scanning calorimetry (DSC) analysis revealed the pre-consumer cotton samples consisted of cotton as expected, but the post-consumer samples collected as cotton also included traces of other fibres. Round, symmetrical fibres were also detected in the scanning electron microscopy (SEM) analysis suggesting there are some other fibres than cotton in the some of the fibre samples. These other fibres may derive from seam yarns and embroidery. Nevertheless, textiles deriving from municipal waste collection are rarely 100% cotton. The visual SEM analysis revealed there is some breakage to the mechanical opening fibres, but it was not excessive, and it cannot be identified whether the damage is from the opening process or, for example, the use phase. Some dirt was visible on the post-consumer fibres in the SEM pictures. Overall, the characterisation of mechanically opened fibres proved successful, and the greatest challenges remain in estimating the textile flows of the future.

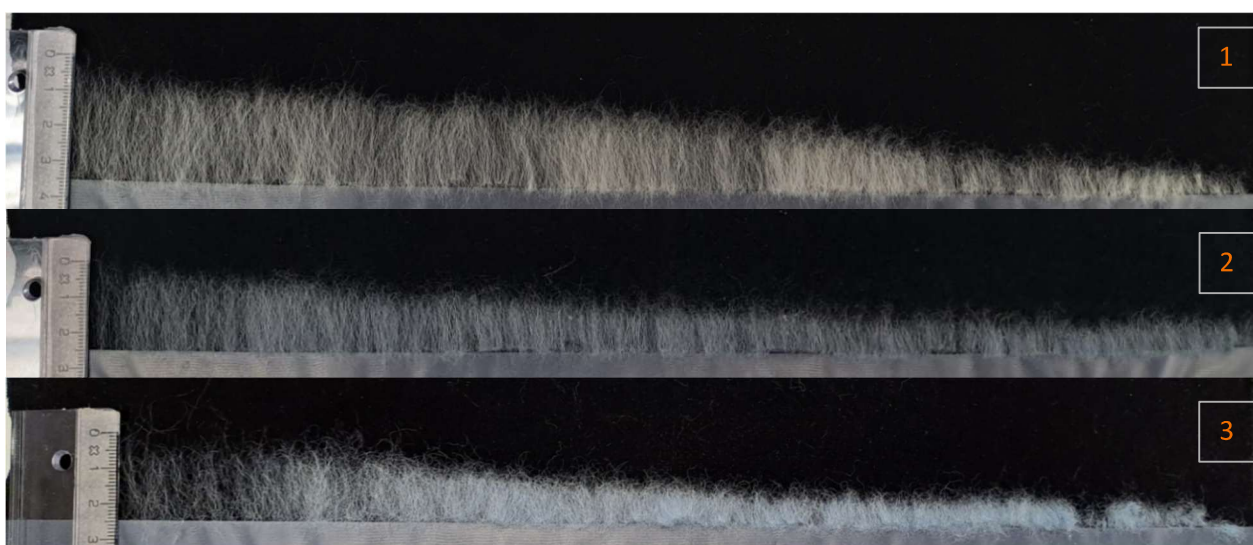


Figure 15 Fibre length and its distribution for 1) virgin cotton fibres, 2) pre-consumer (100% cotton, denim) fibres, and 3) post-consumer (>98% cotton, <2% other fibres, denim, opening with softener) fibres.

⁷ tExtended project <https://textended.eu/>

The mechanically opened cotton materials were obtained from Rester, LSJH, Pure Waste and Citeve (member of Telavalue Science & Technology Board (STB)), and from both pre- and post-consumer flows with focus on cotton fibres. Additionally, a virgin cotton fibre was chosen and evaluated using the same methods to obtain results for a reference fibre. The analysis of spinning feasibility was conducted theoretically assuming the mechanically opened fibres could have been used for the same applications as the virgin fibre prior to the opening process. The fibres were studied for their lengths, linear densities, breaking tenacities and elongations. Fibre compositions were qualitatively evaluated by Fourier Transform Infrared (FTIR) analysis and differential scanning calorimetry (DSC). Moreover, the quantitative test results were analysed statistically and a visual inspection using scanning electron microscopy (SEM) was conducted. The methods and detailed results can be found at <https://urn.fi/URN:NBN:fi:tuni-202310128820> and at <https://telaketju.turkuamk.fi/blogi/mekaanisesti-avattujen-tekstiilikuitujen-karakterisointi/>.

4.3.3 Chemical Recycling of Cellulose-based Textiles

We investigated the chemical recyclability of waste textiles containing both natural and man-made cellulosic fibres (MMCF), with ionic liquids and Biocelsol process determining the changes in properties of recycled fibres after cycles of dissolution and regeneration. It was demonstrated that the waste textiles containing MMCFs such as viscose and lyocell can be chemically recycled with both methods, even with low intrinsic viscosity (110 ml/g) of starting feedstock. With ionic liquids mixing feedstocks containing regenerated fibres with cotton seems to decrease the spinnability of dopes and mechanical properties of recycled fibres whereas with Biocelsol process the properties were increased.

Recycling and regenerations were both shown to decrease the degree of polymerization (DP) on the first recycling cycle, but only negligible changes were observed after the second cycle of recycling. Recycled fibres from ionic liquid process (Figure 16) showed excellent values for tenacities and elongation, from which elongation tended to decrease with subsequent cycles of recycling. Even though the fibres recycled by Biocelsol process (Figure 17) did not reach the excellent values of ionic liquid recycled fibres, promising results for further optimisation were obtained. Overall, chemical recycling of textile waste feedstocks resulted in fibres of sufficient quality for textile applications.

Recycling of blended Infinna-CO fabric was unsuccessful with ionic liquids likely due to the high DP difference of the fibres in the dissolution stage. Recyclability of Biocelsol and Infinna fibres and Biocelsol blends with virgin and recycled cellulose based fibres remains to be studied.

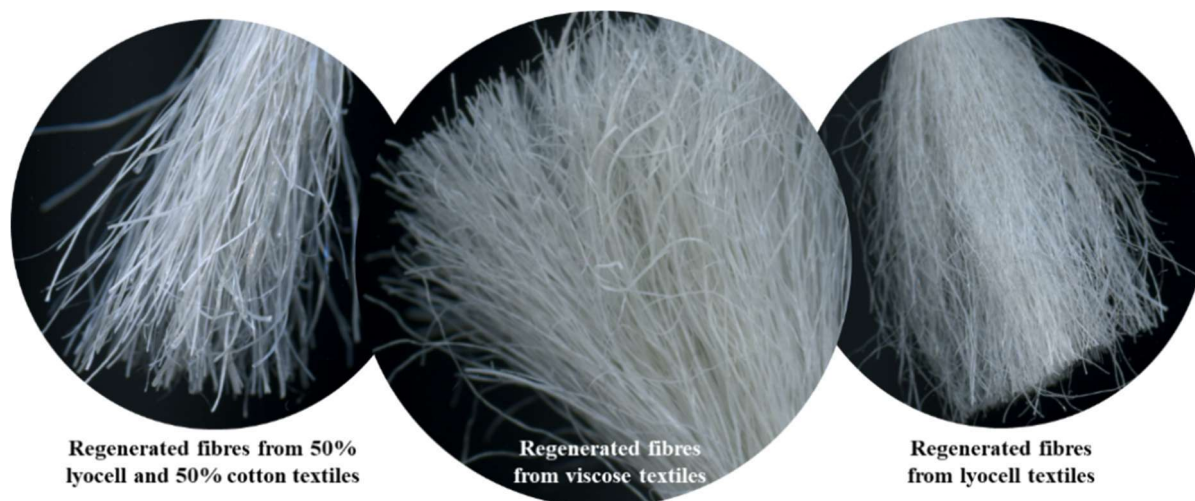


Figure 16 Secondary regenerated fibres using ionic liquid.

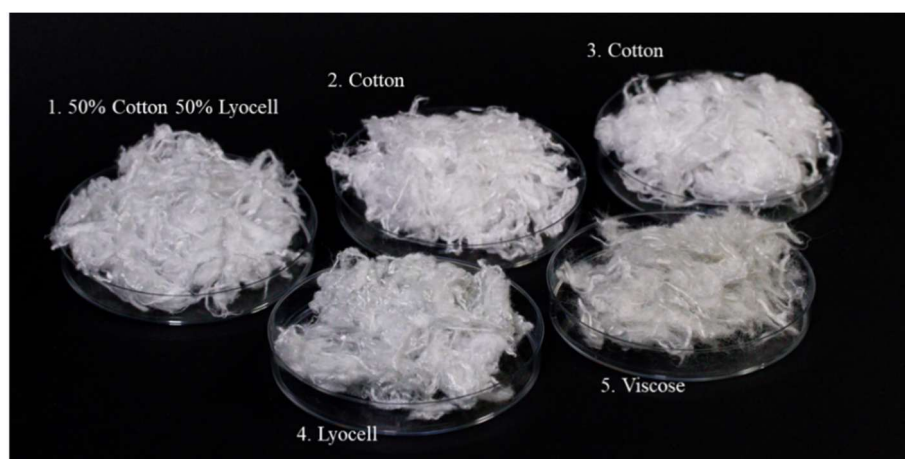


Figure 17 Secondary regenerated fibres from cotton and MMCFs using the Biocelsol process.

The waste textile materials were received from Lounais-Suomen Jätehuolto, Reima, and Rester for the practical studies. The materials were mechanically refined and chemically pretreated to remove metals, increase brightness, and if needed also to lower the intrinsic viscosity.

In Biocelsol trials the chemically pretreated samples were enzymatically treated in an extruder with enzymes to activate the cellulose and adjust the final intrinsic viscosity. Viscose and lyocell were dissolved using alkaline direct dissolution and cotton using alkaline freeze-thaw method. All the dopes were filtrated and regenerated to filaments using wet spinning. The regeneration of lyocell/cotton blend was demonstrated by mixing their filtered dopes before spinning. The spun filaments were cut to staple fibres, washed, finished, and dried. The mechanical properties of fibres and their intrinsic viscosities were analysed.

Pre-treated textile waste feedstocks were studied for their solubility into ionic liquid [EMIM][OAc], after which spinning dopes were prepared either from individual solutions, or by mixing viscose/lyocell -containing solutions with cotton. Samples were spun by dry-jet wet-spinning method, after which they were freeze-dried for second cycle of recycling. Changes in intrinsic viscosities and mechanical properties of recycled fibres were assessed before and after dissolution and spinning trials, after which the most promising samples were further studied after repeated cycles of chemical recycling. The results can be found at <https://cris.vtt.fi/en/publications/chemical-recycling-of-cellulosic-textile-waste-by-dry-jet-wet-spi>

4.4 Textile Production

4.4.1 Spinning

In our first ring-spinning trials (Figure 18) the aim was to use mechanically opened fibres from post-consumer denim fabrics, increase the recycled fibre content in the yarns and compare the spinnability of mechanically opened fibres from pre- and post-consumer denims. The amount of recycled fibres in yarn was increased up to 75% with both pre- and post-consumer samples. The yarn tenacities of yarns containing recycled fibres were slightly lower compared with yarn from primary cotton, but all the yarns performed well in the knitting trial.



Figure 18 Yarns obtained spinning trials of mechanically opened fibres from post-consumer denim fabrics.

Yarns and knits from mechanically opened fibres in collaboration with CITEVE⁸. LSJH provided the mechanically opened post-consumer fibres for the spinning trials. Pre-consumer fibres were opened at CITEVE as well as the yarn spinning and knitting trials were carried out at CITEVE. Eight yarns were spun and knitted samples were obtained from all eight yarns. More information can be found in Tekstiilehti 2/23 (Kamppuri & Heikinheimo).

In the second yarn ring-spinning trial (Figure 19), the aim was to use mechanically opened fibres with biobased fibres instead of primary cotton. Yarns were successfully spun from mixtures of mechanically opened cotton and linen obtained from post-consumer textiles, viscose, polyvinyl alcohol (PVA) fibres, and degummed and softener-treated hemp, indicated in Figure 19. The yarn tenacities of yarns containing recycled fibres were slightly lower compared with yarn from primary viscose fibres, and clearly colour of the yarns is based on the colour of either mechanically opened fibres or colour of hemp fibres.



Figure 19 Yarns from mechanically opened (MO) and bio-based fibres.

Yarns were spun in collaboration with Tampere University of Applied Sciences (TAMK). LSJH provided the mechanically opened post-consumer fibres for the spinning trials. Viscose fibres (originally from Kelheim) were provided by TAMK, and hemp fibres were a kind gift from HOGENT, Belgium. They were degummed at VTT. The results can be found at <https://cris.vtt.fi/en/publications/creating-yarns-using-bio-based-and-mechanically-recycled-fibres-i>

4.4.2 Fabrics and Textile Products

Fabric demo was done to test the knittability of yarns made from recycled materials on an industrial scale. In the demo, plain knit (gauge 12) was knitted from three different materials in Borås knitting laboratory, one of which was made into T-shirt (Figure 20).

⁸ <https://www.citeve.pt/citeve/confidence#About-us>



Figure 20 T-shirt yarn: 60% mechanically opened r-CO 40% r-PET, 20 Ne, (33 Nm, 30 tex), Pure Waste.

Knitted fabric samples from mechanically opened cotton fibres (Figure 21). The demo explored the production of knitted fabrics using yarn made of mechanically opened cotton fibres from post-consumer denim. The yarn was successfully produced into various knit structures that can be used in knitwear. It was observed that the knit structure significantly influenced the yarn knittability and overall appearance and feel of the fabric samples.



Figure 21 50% mechanically opened post-consumer denim cotton fibres 50% virgin cotton.

The opened fibres were mixed with virgin cotton to enhance their spinnability into yarn. After that, the fibre blend was processed into yarn on a lab-scale ring spinning machinery. The yarn was knitted into different fabric samples using an industrial flatbed knitting machine. This work was carried out by Susanna Raiskio as a Master's thesis (Raiskio, 2023) and it is available at <https://urn.fi/URN:NBN:fi:aalto-202401281792> A scientific article based on the study will also be submitted.

4.4.3 Quality of Textiles Containing Recycled Fibres

In everyday wear and fashion, the definition of quality is complex. A good quality product is perceived as durable, fit for purpose and meets expectations, while a poor-quality product is perceived as having inferior characteristics and may therefore break down more easily in use than a good-quality product. On the other hand, even if one person thinks a product is of good quality, it is not necessarily the same for everyone, since the interpretation of quality is strongly influenced by each person's subjective experience of the product. The Euratex Technical Clothing Group (Euratex, 2006) has made recommendations to help define what characteristics a particular garment should have from technical point of view. We can consider, however, also product-oriented, user-oriented, value-oriented, production-oriented and manufacturing-oriented quality approaches. (Arvez, 2021) And at the moment, EC is preparing ecolabel criteria for textile products, which will have technical quality aspects included, but it will also consider circularity etc. requirements.

Mechanically recycled fibres are significantly shorter than virgin fibres, especially when obtained from post-consumer textiles. However, mechanical properties may not have necessarily suffered too much for textile-to-textile recycling (see Chapter 4.3.2). Due to the reduced length, mechanically recycled fibres are commonly blended with virgin cotton or synthetic fibres, or, for example, with r-PET fibres (made of recycled bottles = open loop recycling) in order to make spinnable blends. One future prospect is that instead of virgin fibres chemically recycled or thermo-mechanically recycled fibres (made of textile waste = closed loop recycling) will be used to enhance spinnability of mechanically recycled fibres. With these methods length and in many cases also strength can be restored (see Chapter 4.3.1).

In earlier Chapter 4.4.1, wide range of trials have been reported including blends of recycled fibres with other fibres including mechanically recycled cotton and linen, viscose, and r-PET. Even though open-end spinning is the typical method used for spinning of recycled fibres (Heikkilä *et al.*, 2024), we used ring-spinning in order to obtain higher quality yarns. Tenacities of yarns containing recycled fibres were typically somewhat lower compared with reference yarns. It was, however, still possible to produce yarns that performed well in knitting (see Chapter 4.4.2).

Knitting tests showed us that knit structure influences the knittability of yarns containing recycled fibres, and also affected appearance and feel properties. Testing of knitwear containing recycled fibres also showed changes in durability. While we obtained knitted fabrics with good abrasion resistance well above the Euratex (2006) minimum quality standards for to abrasion resistance, the weight loss of the sample was 2-2.5 times higher compared to knitted fabric made of virgin fibres⁹. This is most likely not a big quality issue especially, if compared lifetime expectations of consumers (see Chapters 2.2.3 and 2.3.1) and taken into account a very poor quality of current ultra fashion textiles.

Use of recycled fibres (made from textile waste) in textile production will be increasing in Europe near future with implementation of EC green deal and waste regulation (see Chapters 1.1 and 5.2). Building knowhow for designing products with recycled fibres is, thus, essential in future especially if aiming for high recycled contents. Furthermore, modifications to existing processes could be necessary to enable the higher utilization of secondary fibres. Increased automation, robotisation as well as utilization of AI is seen a possibility for quality optimization and control in future manufacturing (see Chapter 2.3.2).

4.5 Other Products

4.5.1 Nonwovens

Production of nonwovens was demonstrated using the two different types of dust fractions, cellulose rich and synthetic rich, of mechanically opened fibres. Short fibre fractions were suitable in air- and foam laying processes (see Figure 22).

⁹ Euratex (2006) minimum quality standards for knitwear 8 000 cycles with Martindale method EN-ISO 12947-2.
'Yarn 1' in Figure 18 (50/50 recycled/virgin) >20000 cycles and weight loss 18%
'Yarn 2' (25/75) 14000 cycles and weight loss 15.7%
'Yarn 4' (50/50) 17000 cycles and weight loss 19.6%,
'Yarn 3'/Ref (virgin CO) >20000 cycles and weight loss 8.6%

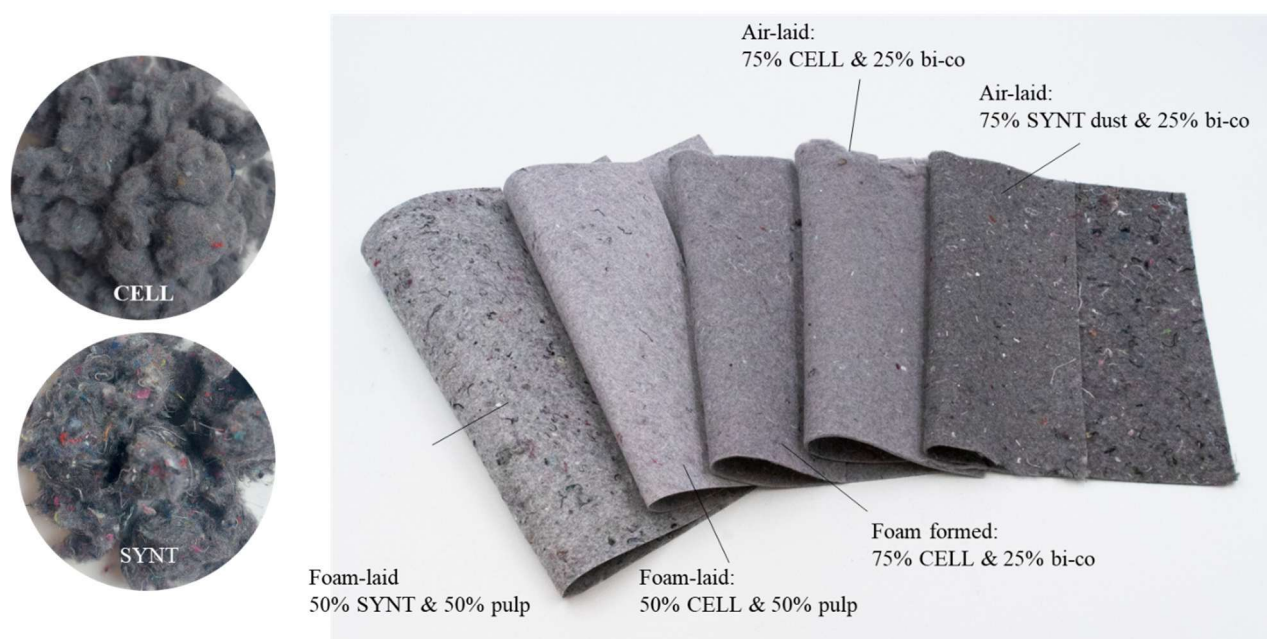


Figure 22 Foam- and air-laid nonwovens from post-consumer, fine fibre fractions (CELL refers to cellulosic mix, SYNT for synthetic mix, and bi-co to bicomponent binder fibres).

Two post-consumer, fine fibre fractions from LSJH's mechanical opening line, cellulosic mix (CELL) and synthetic mix (SYNT), were processed with air laying and foam forming into nonwoven webs. The webs were bonded either by adding bi-co fibres (PP/PE, 3 mm Fibre Vision) and pulp (softwood kraft) into the webs (100 g/m²). More information available in <https://telaketju.turkuamk.fi/kuitukankaita-mekaanisen-avausprosessin-hienokuiduista/>

4.5.2 Plastics and Composites

Aim was to facilitate high value non-textile recycling options for technical materials and fractions that are not suitable for textile application. Process studies concentrated on complicated, dirty, blended and multicomponent thermoplastic materials (PES and PA) presented in Figure 23. Preliminary analysis revealed the complexity of the recycling, due to the fact, that some samples contained foreign substances and/or degraded during hot processing steps.



Figure 23 Examined sample materials. Majority content in the samples was either polyester (PET) or polyamides.

The work started with thermal analysis to sort out the melting behaviour of different structures. IR-analysis were also performed specially to insure, if additional fibre fractions are present and which PA grades have been used in fabrics. The preliminary assumption was that the material content is known in studied textile fractions and the dirt will reduce the quality of the recycle or prevent the recyclability of the of the materials.

Analysis revealed the complexity of the recycling, because some samples contained foreign substances – either foreign polymer or cotton. Cotton can be easily distinguished from polymeric fibres, for example, in SEM imaging as shown in Figure 24. Textile labelling with PES contain very large group of polymers, where the most common polyester in textiles is PET. DSC showed, that one of the 100 % PES sample most probably contained some other PET due to the additional significantly lower melting peak compared to PET. Textile standards also allow small amount of foreign materials in the structure. Work clothes 100 % PES-labelled contained cotton in the middle layer, pockets and ribbing. Zippers were most probably made of polyacetal (POM).

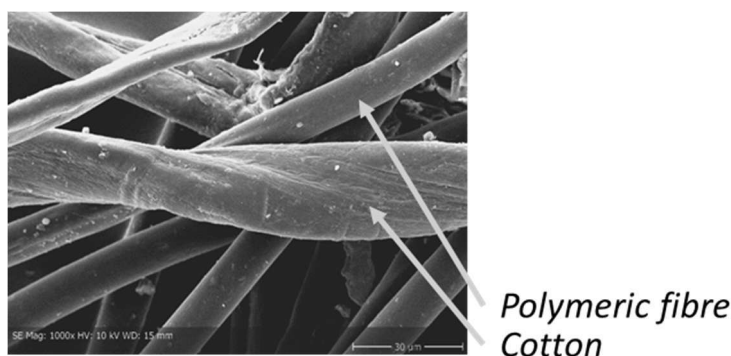


Figure 24 Fabric sample containing cotton, although it is not mentioned in the material content.

Washing trials were performed after preliminary analysis. Dirty materials were washed in standard washing machine using standard washing program at 40°C. Rigid technical textiles with dirty clumps were put into the machine in too large pieces, because washing did not form any friction between the sample surfaces. Washing with and without washing detergent without scrubbing did not clean the samples. Loose dirt was though easily removed in washing trials, like from grinding discs.

Selected materials were compacted with MODIX-extruder. Compacting trials concentrated on PES and PA samples. Both polymers have a lot of variety in polymer chain structure and hence properties. Melting temperatures of different types can vary tens of degrees. Due to the moisture sensitivity of polyesters and polyamides, extremely thorough drying and compacting at lowest possible temperature where the material is compacted, but barely melted, is optimal. This is possible for thin fabrics without hard seams. Additivation and foreign substances caused big problems during compacting. Sanding discs contained so high amount of abrasive (non-melting material), that the melting process needed a starting aid in the beginning of the compacting. MODIX was also able to compact work clothes, but presence of cotton degraded the materials during hot processing step. Injection moulded demo samples wear very week and brittle due to the moisture intake (see Figure 25).



Figure 25 Demo samples from work clothes and damage caused by moisture intake (swelling/foaming).

Composite trials showed again that new (unknown) recycled content arises new challenges in recycling processes. Moisture removal and keeping the material dry are key factors in success of thermo-mechanical recycling process for polyesters and polyamides. If returning back to textiles is not possible due to additives, dirt etc., probably mixture with lower melting plastics recyclates (e.g., PP or PE) would be feasible way to recycle challenging materials before the separation techniques are economical.

Demo sample was designed to test the recyclability of selected materials. The requirement was that the demo piece must be sufficiently strong and tough so that it does not break during use (both bending and tensile). Small surface shapes were also introduced into the demo piece, so that the copying of the material according to the mould could be verified. The size of the sample was restricted to the VTT's injection moulding research equipment capabilities. For this purpose, VTT planned and further sub-contracted an injection mould that could be used as a demo part (shopping cart token, Figure 26).

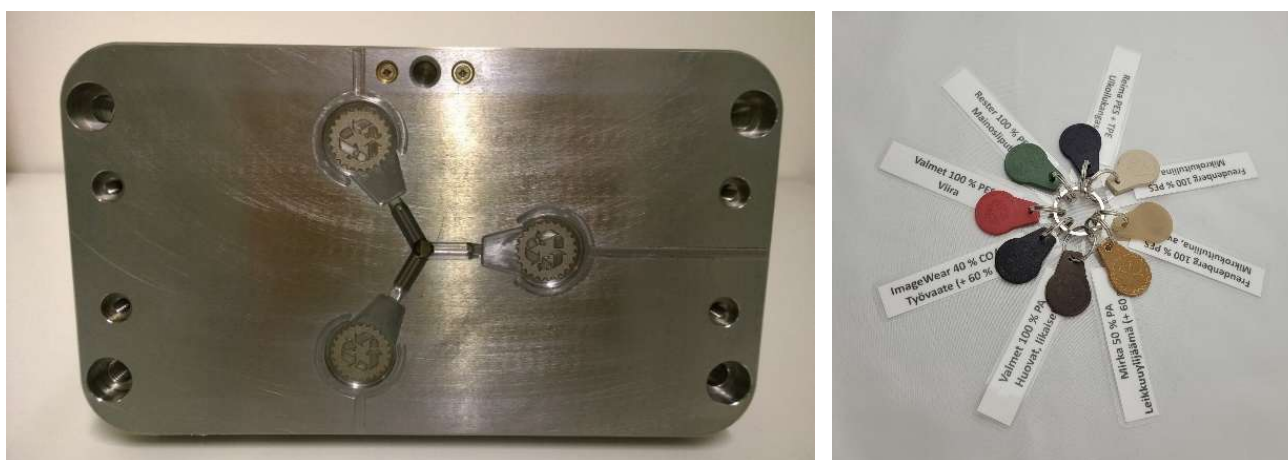


Figure 26 Injection mould of the shopping cart token (with three nests) and demo samples moulded from different type of recycled thermoplastics.

Several clean and dirty material samples were received from project partners. Dirty materials were washed in the standard washing machine at 40°C (with and without detergent). Materials were dried and compacted with MODIX extruder (temperatures from 250 to 280°C depending on the material). Compacted materials were grinded and selected materials were injection moulded to demo samples (shopping cart token).

5 Project Impacts

The main objective of the Telavalue Co-Innovation public research project was to support and build value chains for sustainable production, use and cycles of textiles. Adoption of circular economy strategies and business models makes it necessary to also, for example, form new kinds of value chains and partnerships also to handle reverse logistics; engage and commit customers whether they are consumers or other businesses; collect, handle, and utilize more product data and other types of information than are used in linear economy; and have common terminology and understanding of quality properties of recyclates and recycled intermediate products.

Within the project we aimed to improve business and export opportunities of Telavalue consortium and Finnish textile industry by active networking and collaboration. In this Chapter our partners organizations have evaluated impact of project and given feedback (Chapter 5.1), and it also includes summary of how our activities are linked with European level and wider scope (Chapter 5.2).

5.1 Impact in Partner Organizations

The companies involved in the Telavalue project have evaluated their feelings on the project in general as well its impacts. Writers of this chapter are company representatives even though they are not mentioned in author list.

5.1.1 Impact of Company Projects

Kemira

Through the Telavalue consortium project, Kemira has acquired know-how from various aspects of the evolving textile value chain. Mapping actors across different textile application areas has helped identify relevant collaboration partners. Additionally, Kemira carried out an internal study on start-up companies in the textile recycling field during the co-innovation project, which supports and guides our business planning.

The technical quality requirement review conducted in Telavalue provided valuable guidance for planning future applications relevant to Kemira. The summary report on how textile quality and sustainability can be achieved through the combination of biobased and recycled fibres and the utilization of new technologies has been significant. The report's findings align with Kemira's long-term vision.

Insights gained from the Textile waste recovery and processing work package have encouraged Kemira to actively engage also with the latter part of the textile value chain. Kemira's products underwent testing in the textile material hygienisation tests in Telavalue WP4 and in the real processes at textile recycling companies. This experience has provided Kemira with insights into textile recycling processes, substantially increasing our understanding of Kemira's role and the role of chemistry within them.

While the textile recycling value chain is still evolving, Kemira recognizes great potential as a provider of chemistry expertise. The specific role will be defined based on future textile business models and end-use applications of recycled fibre.

In Kemira's own co-innovation project, 12 inventions were made, 5 patents were filed, and 23 internal research reports were published. Kemira participated in several textile manufacturing and/or recycling conferences showcasing the research results.

Pure Waste

Evaluating the results of the Telavalue project in this situation is at least ambivalent and partly unfair. In terms of the project, the desired results have been achieved to say the least, but in many respects the goal was to have a clear path to commercialization at the end of the project. The timetables and implementation of these final market entries and commercialization plans have had to be postponed or put on hold.

The last few years have been quite a roller coaster with all the crises and the sudden ups and downs of the economy. The operating environment has changed a lot and is still undergoing strong changes. All this creates a really challenging situation for small and medium-sized companies that invest in the growth and R&D all of their results.

Everybody is waiting, everyone is saving costs and playing it safe, out of necessity or just to be sure. What we are waiting for?

- Certainty about the direction and implementation of the legislation?
- Direction of the market and overall economic situation?
- Direction of the geopolitical situation?

These uncertainty factors are not going to disappear in an instant, we just have to learn to work with them and make the most of the opportunities they bring.

Our project was divided into three parts,

- New business models and digitalization,
- Spinning mill
- Quality optimization in recycling, yarn production and fabric production.

In all respects, the goals were met from an R&D point of view, how the investment, commercialization and schedule plans, which have already been updated several times during the project, can be implemented still determines the final effectiveness of the project. Regarding these, the results will be obtained for several more years.

One major positive impact that was previously unrecognized has been the project community, during the unstable operating environment, we have been able to focus on research and development together and have kept to our original goals. This has helped a lot in achieving goals and "keeping your eye on the ball". This working together and the forward-moving force of the community also works against a very unstable operating environment.

Touchpoint

The aim of the project has been to create an international workwear service model/concept, with the assumption that the needs of workwear clients vary from one market to another. Additionally, we wanted to study how the end-of-life textile take-back model should be considered in markets outside Finland, where we already had the possibility to take-back and process those textiles.

A vast amount of resources during this project were used into studying the Swedish market, while also the neighboring countries were investigated to some extent. During the project we established a company in Sweden and met with dozens of potential clients and business partners.

Our studies quite quickly revealed the main differences between the Finnish and Swedish workwear market, which enabled us to create a market entry strategy with a clear focus. Having focused on specific customer segments, we are now in a good position to be able to start piloting our new service concept in Sweden in H2/24, right after finishing the Telavalue project. As concrete actions, we have participated in a few Nordic tenders, one of them waiting for award decision as we speak. At the moment we are also in contract negotiations with a couple of potential clients in Sweden.

Touchpoint has benefited from the project in several ways. We had five WPs, including market study & actor analysis, service & product concept development, closed-loop fabric development, improvement of support functions and reporting, and environmental calculations. Short descriptions of the WPs follows:

WP1 has included market study and actor analysis in Sweden, as well as to some extent in Norway and Denmark.

This has included hundreds of meetings with potential clients and business partners, dozens of trips within the Nordics to meet and negotiate with potential partners, visits to fairs and exhibitions within Europe to meet potential partners, meetings with textile related unions, advisors, etc. As a result, we've been able to build the market entry strategy to Sweden, as we learned the market dynamics and our possibilities in the market. Quite a lot of work has also been done in clarifying our positioning and concept in the Nordic market, in relation to our

competitors. As we now have a company in Sweden and a lot of info on the market, we are confident in the possibilities to start piloting our service model in Sweden during autumn 2024.

WP2 meant going deeper into market specific collection and product needs. In practice this means studying local tenders / product specifications and product related standards. We have developed local styles in the forms of samples for the Swedish market in order to be able to participate in specific tenders when they are published. We have also prepared some samples according to specific needs from certain customer segments, such as industrial laundries.

Studying the Nordic market needs has also led to several internal projects in relation to fabric sourcing, production and supply chain re-structuring as well as new sourcing models and modifying roles and responsibilities within our organization. Additionally, this work package included studying the local textile recycling infrastructure, and seeing how we can respond to client needs in this area, including how to develop our pricing model for the take back –service in Sweden.

In WP3 we partnered with Rester and Lindström as well as fabric manufacturer Klopman in order to create a closed-loop workwear fabric. The project was quite demanding and long, as developing a high-quality workwear fabric made partly of recycled fibers (which in this case originated from old workwear) is far from simple. However, after some iterations and fine-tuning we finally launched “ReTouch” fabric in January 2024, meaning that now we are actually able to offer this recycled fabric to our workwear clients. ReTouch is a true innovation as it is one of the first woven workwear fabrics in the world consisting of circular fibers. This is just the beginning, but the milestone is important not only for Touchpoint and Rester but the entire workwear industry in general. We’ve proven that it’s possible to build the supply chain in Europe for these types of circular materials, develop a commercially viable product and meet the high requirements of workwear fabrics while using circular materials. Furthermore, the emissions of this fabric are approximately 10% smaller than emissions of a similar fabric made of virgin materials.

Work wear WP4 evolved around the Support functions & reporting needs of the potential clients in Sweden, Denmark and Norway, as well as the impacts of those needs on our global supply chain. During the project we have done a lot of research, e.g., on potential client needs concerning webshop functionalities, ERP & invoicing systems, customer service requirements etc. Additionally, we’ve developed a new service concept description to support our communication towards potential customers and other business partners to be better able to describe the range of services we offer to our clientele. Finally in spring 2024 we were also able to renew the outlook of our website and included the new service concept description also on our website.

The WP5 included some research but also participation in trainings and workshops that concentrate on LCA and CO2 calculations. We have followed the development of EU regulation around these topics, and also participated in commenting different initiatives and regulation frameworks via Finnish Textile and Fashion. During the past years Touchpoint has enhanced its own emission calculation methods gradually. We offer our clients emission calculation reports not only based on the workwear they purchase from us but also based on the end-of-life textiles they return to Rester.

Finally, WP6 concentrated mainly on internal project management as well as follow-up of the Telavalue research led by VTT.

All in all, it is clear to see that during the past two years Touchpoint has gained an enormous amount of knowledge on the Nordic market, client needs, and textile & textile recycling industry infrastructure in these markets. Thus, our position and possibilities to serve the Nordic market are much more advanced, and we are confident that soon this work will result in new international business and turnover from the Nordic market.

Rester

Rester has been building up own start-up business side-by-side with Telavalue-project. Therefore, topics and project partners all are related to our daily business development. Being part of the studied circular value chains has been a great asset to Rester. All research and studies in the project have benefitted Rester in R&D and business level.

Rester has been active in networking and collaboration; it has been valuable to be able to benefit the Telavalue-network as a new company in the market. We have got benefit for business growth through concrete knowledge and expertise, e.g., in NIR-technologies, sorting and quality assurance.

beyond the obvious

Rester has studied fiber-to-fiber recycling in different fields. We have run tests together with Mirka with technical materials, with Freudenberg we have been piloting recycling of different, more challenging cutting waste materials and workwear tests are done by Touchpoint and Image Wear materials. We have also been part of Kemira research with their studies in microbiological control. Rester has provided materials to different research and development work package tasks, including also thermomechanical tests done by VTT.

The co-operation with Telavalue project group has been so important, that Rester wanted to participate to tExtended-project to widen the company prospects in Europe.

Image Wear

Participating in the Telavalue project has provided Image Wear Oy with invaluable insights and practical knowledge in the field of textile recycling and circular economy practices. We have gained a deeper understanding of the complexities involved in recycling textile waste, particularly in converting used workwear into high-quality granulate. The collaboration with various partners and stakeholders has expanded our expertise and allowed us to test and refine innovative recycling technologies. Additionally, the project has reinforced our commitment to sustainability and corporate social responsibility, aligning with our strategic goals.

The Telavalue project has significantly influenced our operational activities. This shift not only enhances our environmental sustainability but also improves resource efficiency. The possible establishment of a pilot recycling facility would enable us to streamline the collection, sorting, and processing of used workwear, would make the recycling process more efficient and effective. Telavalue has opened new business opportunities for Image Wear. The development of textile granulate from used workwear has allowed us to plan and introduce a new product line that would appeal to environmentally conscious customers. This innovation has the potential to attract new market segments and enhance our competitive edge. In the project we have calculated and made business plans for opening a pilot plant, but the current economic situation will postpone the investment decision later future point. Moreover, the project has strengthened our relationships with existing clients by offering them sustainable solutions for their used workwear. As a result, we have seen an increase in customer loyalty and satisfaction, which translates into long-term business growth.

The project has fostered new business collaborations and strengthened existing partnerships. Working closely with technology providers, research institutions, and other industry stakeholders has enabled us to leverage their expertise and resources. This collaborative approach has accelerated the development and implementation of innovative recycling technologies. Furthermore, these partnerships have created opportunities for future joint ventures and co-development projects, which are expected to drive future growth and innovation. Overall, the Telavalue project has had a profound impact on Image Wear Oy, enhancing our activities, business, and exports. The knowledge and experience gained from the project have empowered us to implement sustainable practices and develop new products that meet the growing demand for environmentally friendly solutions. The positive outcomes of the project are reflected in our improved operational efficiency, increased customer satisfaction, and expanded market reach. As we continue to build on these successes, we remain committed to advancing the circular economy and contributing to a more sustainable future.

Fiare Solutions

As a technology partner without core expertise in the textiles industry, the Telavalue project provided Fiare with valuable insights into the sector's key logistical and material flows. We gained a deeper understanding of textile production processes, supply chain stakeholders, waste streams, and the challenges and opportunities surrounding implementing more circular business models.

Our involvement positively impacted Fiare by facilitating new partnerships both within the consortium network and beyond. Leveraging the knowledge gained, we developed and tested tailored digital platforms.

One use of the platform is connecting textile waste volumes and locations with recycling facilities. By optimising waste aggregation into larger shipments, the platform increases the output and quality of recycled materials available for new textile production cycles. The research connections Fiare made while participating in Telavalue facilitated this impactful collaboration with textile service companies and organizations, helping lay the groundwork for future partnerships to advance circular solutions in the industry.

beyond the obvious

Through our participation in Telavalue, we have established valuable connections with prominent figures in the European circular textiles industry. This has greatly supported our business development efforts and opened up possibilities for future partnerships. Our involvement in the consortium has brought commercial networking advantages and allowed us to apply our platform in ways that can drive positive environmental and social change.

5.1.2 Impact in Companies and Other Organizations Who Co-Funded the Project

Reima

The Telavalue project has provided us with valuable insights into the circular economy and the textile value chain. As a leading brand in kids' activewear, we prioritize the sustainability of our products. By 2025, we aim for our main materials to consist of at least 50% recycled content across 100% of our styles. However, in terms of reducing CO₂ emissions, only using recycled materials will not help to meet our sustainability commitments.

We know that the majority of textile waste does not follow a circular economy model and ends up in landfills, creating a significant environmental impact. As part of the textile industry, it is our responsibility to find solutions for the waste generated by our sector. In this context, the findings of the Telavalue project are crucial for us as we seek to implement circular economy models in our products and services.

Moreover, the project's studies on the environmental and social impacts of the circular economy provide us with essential insights to better align our strategies with our value chain. From WP1 to WP6, we can understand the depth of the project through the number of ongoing activities and findings. Overall, the project offers us many valuable insights into circular ecosystems, helping us understand how we should advance our sustainability-related strategies.

Fortum Power and Heat

Fortum has been creating technology concept for biorefinery based on Chempolis Formico organosolv technology to produce, among other, lignin and hemicellulose-based products, textile grade pulp out of agriculture side streams, mainly wheat straw. Straw dissolving pulp product has been proven compatible with Lyocell process. Fortum has aimed to find appropriate consortium to invest in such production activity, but investors do not seem to be interested of that line of activity right now even if the concept seems well profitable. It seems that there are many interested technology providers as well as textile brands but the part of value chain from dissolving pulp production to fabric manufacturing seems to lack interest and potential participants.

Telavalue project has provided us a lot of useful information on clothing end users and circular economy within clothing business. Because of lack of investor interest this has not realized as investments or new business yet. However, the concept is now generated and stored to be used within Chempolis framework when times are better for that. Potential is clearly calculated in hundreds of millions if not billions. Currently we are concentrating on implementing and further developing the Formico organosolv production technology in projects with product portfolios not including textile raw materials.

Metsä Spring

Telavalue project has brought Metsä Spring contacts, network, competence and further understanding of the emerging circular textile value chains in Finland and Europe. Studies related to the social, environmental and economic impacts of moving from linear to circular textile value chain help to assess Metsä Group's future role and impact as part of the value network. It is evident that the future circular textile value chain continues to need a supply of fresh, sustainable sourced biobased fibres – a role which suits Metsä Group very well.

The actor & infra & ecosystem analysis made in WP1 is a good source for information about potential partners for Metsä Spring's Kuura product and process development. In WP2 the properties of blended yarns were studied, including a Kuura fibre / recycled PET blend yarn provided by Metsä Spring (produced in another project). The blend yarn was knitted to fabric at University of Borås, alongside with other blend yarn samples. It is likely that Kuura fibre, if commercialized, will be blended with recycled fibres to make blend yarns and fabrics so the information received during the project about different mechanical and chemical textile recycling technologies, their current maturity and challenges is relevant to Metsä Spring. Metsä Spring also got more confidence that Kuura-type of lyocell fibres withstand well chemical recycling, as studied in the WP5.

The project has supported Metsä Spring on its journey towards the commercialization of the Kuura textile fibre. During the Telavalue project the Kuura project has done dozens of pilot and demo trials and recently entered a pre-study phase where planning for a 100 000 t/a textile fibre plant in Kemi or Äänekoski is started. Telavalue project

has also been an integral part of the ExpandFibre ecosystem hosted by Metsä Group and Fortum, a key project in the textiles theme area of the Veturi-initiative.

Valmet Technologies

Participating in Telavalue project has given us in Valmet a lot of valuable information about circular economy and ecosystems among textile industry in Finland and Europe.

We have gained a lot of knowledge about textile recycling and new business models. Connecting with the Telaketju community and getting to know skilled textile and recycling experts is valuable in itself, and in the future, it will be easy to contact them for potential new projects or research-related matters.

Many of the research studies conducted in the Telavalue project have been very interesting and thought-provoking. In particular, 'Actor and Infra Analysis' is a useful tool also for us at Valmet, providing a comprehensive view of companies working in textiles and recycling.

The composite recycling demos were especially interesting for us in Valmet, as the tests included also our technical textiles; used dryer fabrics and press felts. It was good to get confirmation that our high-quality materials - even as used and dirty - can be recycled into good quality composites. The cleaning of the dirty used fabrics was studied as well, which gave us good information on the subject.

Mirka

Telavalue was Mirka's second Telaketju project, we were also in Telaketju2 project. Mirka has found several connections through Telavalue events when discussing with other companies with similar challenges. We are grateful that we could visit a Telavalue consortium member to learn more about their side stream sorting. We are happy that we were able to join Borås tour, and it gave us connections with Swedish textile knowhow.

We have learned about different textile recycling possibilities, such as mechanical, thermo-mechanical and chemical recycling. Also, we got to learn that our side streams are valuable and should be sorted as such. Therefore, we have developed our side stream sorting and handling.

Our own leading company (Veturi) circularity project SHAPE started during the Telavalue project, to give a boost to Mirka's green transition.

Freudenberg Home and Cleaning Solutions Oy

Freudenberg Home and Cleaning Solutions Oy has taken part to Telavalue as public funder (the same as for the Telaketju2 project). Telaketju2 participation created and led to most fitting co-operation with Rester: textile production side waste was delivered to Rester from the start of the operations. The biggest part of our waste sent to incineration could be recycled now meaning that hardly any waste is created at the factory anymore. Also, a trial of shredding used products to fibres again was realized and closed loop studies started.

The natural and necessary next step needed to be taken in the development side; how to use the newly created mechanically recycled fibres in our own products? The development continued with same or new partners during Telavalue; without the continuation project there would not have been such strong drive forward. The actions done have been presented in FHCS Magazine and will be published in short form in world-wide Freudenberg magazine soon.

Internal discussion took place and six separate development areas with mechanically opened fibres were found - for replacing the present new materials or fully new product ideas. Especially in Telavalue the focus was put to trials on the composite side as not all used products cannot be shredded to fibres. Defined products were selected for testing and in the tests it was clarified that there are possibilities in the area for plastic products and composites. Additionally testing places were found for plastic trials.

Specific impacts include:

- We have been able to create an important network within the textile recycling area and now it is possible to actualize the new product ideas with partners.
- The awareness of the responsibility and urgency of the textile waste handling has reached the top level in our company. This will support and sponsor the next activities in new developments with recycled contents of products.

- Front end studies started in 6 different product categories and 2 will be selected to next stage in the Gate process of New Product Development.

Lounais-Suomen Jätehuolto (LSJH)

In the Telavalue project LSJH focus was to offer recycled materials for the research and the pilots to enable product development, export and business growth in different value chains. During the project, many new processes have been developed in partnership with the supply chains both locally in Finland and with European textile industry partners, using both in mechanical and chemical recycling technologies. Quality assurance in the value chains is also very important research topic in the project, so the fibre qualities were analysed and all the LSJH sorted textile products are now all GRS certified to show that our process and supply are transparent.

LSJH's aim was to collect, sort and provide mechanical processing for all of Finland's end-of-life textiles from households and set up a nationwide waste management companies network. Since the beginning of 2023, the legal requirement for separate collection of end-of-life textiles in Finland has meant finding ways to find a joint solution for all collected and sorted materials. Today the integrated national partnership model covers 97% of the Finnish population through a network that includes 29 waste management companies who actively collect household textile waste in their operating areas. The collection and pre-sorting are done locally, sending the materials to LSJH to material content sort and combine for large streams for industry as recycled feedstock. LSJH proceeded to invest in a mechanical opening line that operated from November 2021 to end 2023 until it was sold to concentrate on the core business of collection and sorting. The uncertainties of proposed new EU legislation and particularly EPR has meant that during 2024, LSJH has decided it could not alone invest in the planned full-scale end-of-life textile processing plant in Topinpuisto. These legislative changes and uncertainties slowing down market developments have also been added to, by the slow uptake of recycled raw materials, mechanically opened fibre, continuing technological developments, to date lack of full-scale chemical processing facilities and long product development times. However, work with companies and practical trials have proved that these heterogeneous materials can be used in various products and processes.

Materials such as 'Denim', 'Cotton' and 'Wool' were spun mechanically from opened fibre into commercial yarns, 'Cell' and 'Synt' used in nonwovens and thermomechanical trials made with polyester. Providing custom feedstock, quality assurance sorting and material purity development work is ongoing with MMCF producers in the Nordics. Chemical recycling of viscose and polyester are also being tested using LSJH sorted materials. LSJH has also collaborated with various upcycling designers such as VAIN, Tyykki Design and Krista Virtanen to return the material back into use as fabric.

LSJH has gained a reputation for leading material content-based sorting for recycling and for creating successful commercial partnerships through practical trials. These have required building supply chains and collaboration among the different stakeholders. Knowledge sharing and meeting the market material specification and demand has also fed back to improvements in the processes and sorting development work. The Telavalue project has aided in getting important insights through research into technological and practical opportunities in the future. There have also been many new connections made and collaborations through online events and visits, that have enabled a broader network needed to find solutions. The project has also demonstrated the proof of concept in many value chains, which can now be commercialized. Overall, the project has given many valuable insights into the whole ecosystem of textiles circularity from consumers and markets to stakeholders and production processes.

Helsinki Region Environmental Services HSY

The project has brought HSY many valuable contacts and networks. The project has enabled knowledge exchange; we have learned a lot about what is being done with end-of-life textiles elsewhere in Finland and in other countries. HSY has been collecting end-of-life textiles in the Helsinki metropolitan area since 2019. The collection amounts have grown significantly in the past year.

Suomen Tekstiili & Muoti - Finnish Textile and Fashion (STJM)

STJM has participated in the Telavalue project to promote the circular economy of textiles and actively support the establishment of new profitable circular business models in Finland. During the project, our main goal has been to build bridges between the research sector and the Finnish textile and fashion industry and to communicate to key stakeholders about the development and measures that promote textile circularity at the material, product and business levels.

5.2 Telavalu and the Sustainable Development of Textile Sector

The vision of Telavalu consortium was find solutions to sustainability and waste problems related to current textile system through circular economy. The main goal of the Telavalu Co-Innovation public research project was to support and build value chains for sustainable production, use and cycles of textiles, especially looking for the opportunity to combine recycled and novel bio-based fibres as basis for sustainable Finnish textile production. We wanted to ensure efficient product use via circular design and novel business models and ensure efficient textile material circulation via recycling.

In the big picture the targets of the Telavalu project are in line with European level vision as stated in EU strategy for sustainable and circular textiles (Figure 27).

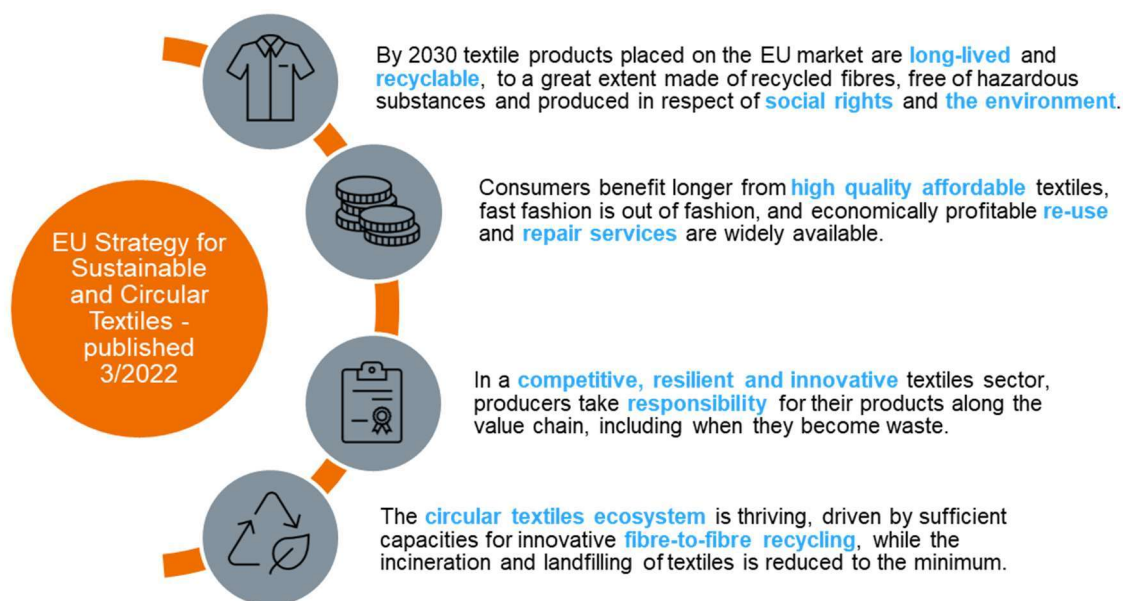


Figure 27 Vision of EC Textile strategy¹⁰.

EC is currently preparing and thus starting implementation of the strategy with multiple action. The Commission will for example, set design requirements for textiles to make them more increase their longevity and make them easier to repair and recycle, and is planning to set requirements on minimum recycled content. In addition, EC is aiming to incentivise circular business models for reuse and repair sectors. Furthermore, clearer information and a Digital Products Passport is to be introduced to textiles. Telavalu has provided information about all of these topics, thus supporting its consortium and Finnish textile sector for adapting to the new operating environment.

Also, EC waste regulation is currently transforming textile system when all EU members states are implementing separate textile waste collection by 2025. In Finland this was started in 2023 ahead of schedule, which was enabled by national activities as LSJH in collaboration with other municipal waste management organizations had created the conditions to make that possible. Even though the 2023 update to waste regulation indicates implementation of EPR system for textiles, thus making the operating environment slightly unknown, we have been able to create knowledge and technologies to support the textile waste collection, sorting and recycling.

It has been estimated (McKinsey, 2022) that amount of textile waste is to increase from 7-7.5 Mtons of 2020 to 8.5-9 Mtons by 2030 in Europe (EU-27+Switzerland). Amount of collected waste is expected to increase from 30-35% to at least 50% but could also increase up to 80% based on the upside scenario (McKinsey, 2022), while the share of fibre-to-fibre recycling could increase from less than 1% to 18% or even 26%, even though the aim is also to increase reuse significantly as explained above. There is room for new technological innovations for waste valorisation and recycling for all types of fibres in different methods (see Chapter 4.3.1) in order to achieve the upside scenario. However, there are shortcomings and inherent limitations to current recycling technologies and multiple

¹⁰ https://environment.ec.europa.eu/publications/textiles-strategy_en

other challenges in building up this system. Challenges are related, for example, to sourcing of materials from households and business users of textiles, inhomogeneity and low quality of textile waste, and lack of classification system. Furthermore, economically feasible scale may be difficult to achieve in some technologies, and environmental sustainability of technologies not known exactly.

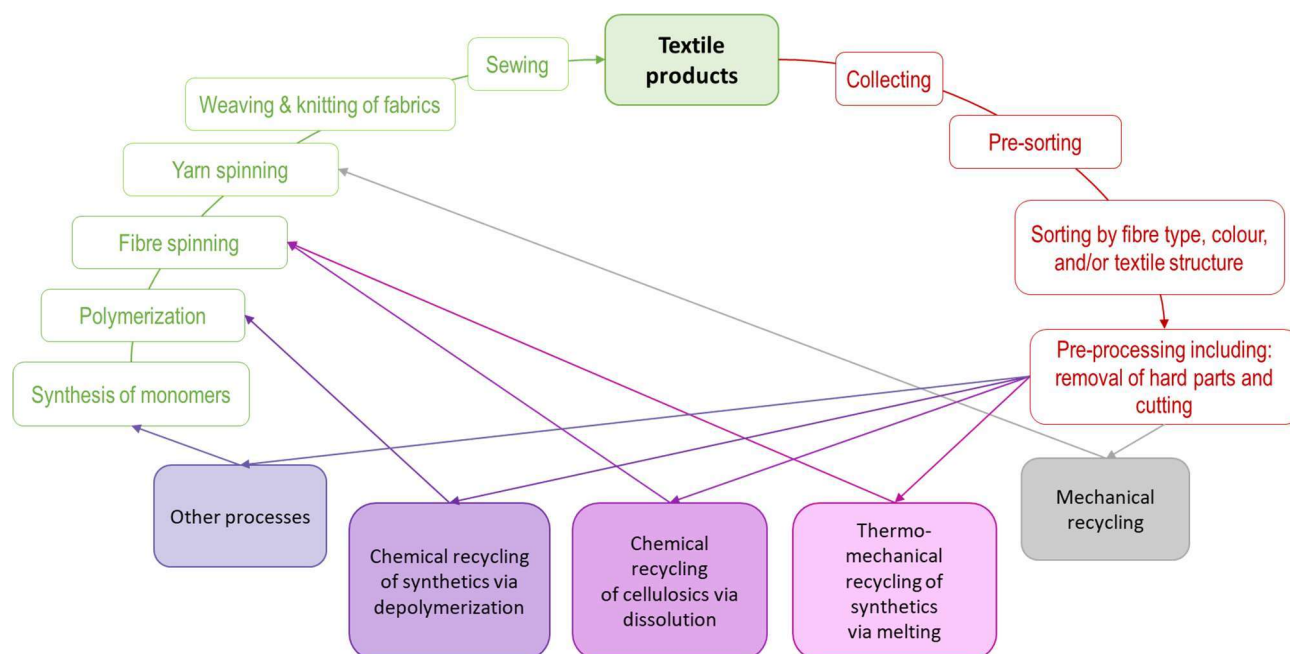


Figure 28 Textile recycling processing options.

Additional research is needed in national and European level since there are still lots of research gaps in related to this this green and digital transformation (ECOSYSTEM, 2023). Calls have launched under Horizon Europe to further develop technologies and processes increasing the circularity and sustainability of the textiles sector. VTT as well as other Telavalue consortium members have been participating to applications and at least two EU projects have been started during Telavalue project, namely tExtended ‘*Knowledge Based Framework for Extended Textile Circulation*’ and PESCO-UP ‘*Textile fibre recycling from mixed streams of CO/PES textiles*’¹¹. Both of the projects continue work which has been done in Telavalue project and its predecessors in Telaketju network and research continuum. It can, thus be said, that national research has been prepared us for EU level collaboration in textile circularity.

In 2023 ECOSYSTEM, European Community of Practice (ECoP) for a Sustainable Textile Ecosystem, has been founded. It is a new network of EU projects with topics involved textile circularity. It aims to create a long-term community of practice and ensure collaboration across project consortia and beyond the duration of individual projects. Both tExtended and PESCO-UP have joined this ECoP and been able to network, disseminate knowledge built in Finland, and also learn from other projects and stakeholders, thus being able to bring newest knowledge to Telavalue consortium and Finnish audience.

In 2024 new European partnership for textiles ‘Textiles of the Future’ have been launched in 2024. Its Strategic Research and Innovation Agenda (SRIA) (Textile ETP, 2024) will have an effect on EU textile research calls in coming years. Priority Areas determined in SRIA include 1) sustainable materials and clean processes, 2) digital supply chains and new business models, and 3) advanced manufacturing and high-performance textiles, and each of these have 4-5 strategic topics¹². Finnish companies and research institutes will be finding opportunities to contribute and gain more expertise, competitiveness, and network by participating calls and projects.

¹¹ Grant Agreement No. 101091575 <https://textended.eu/> and grant agreement No. 101138367 <https://www.pesco-up.eu/>

¹² <https://textile-platform.eu/news/textile-etp-unveils-the-strategic-research-and-innovation-agenda-for-textiles-of-the-future-european-partnership>

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Annex Communication and Dissemination Activities

The Telavalue consortium was actively communicating the project, textile recycling, circular economy and, of course, the project results. The Telaketju website (<https://telaketju.turkuamk.fi/>) and the Facebook pages (<https://www.facebook.com/poistotekstiili/>) were built for communication and to publish results of the project.

Dissemination

A wide range of themes were discussed in the webinar series which were held for the whole duration of the Telavalue project. The webinar topics are listed in Table 3. The recordings and presentation materials, including the contact information of the presenters, are available in Finnish on the project's website.

Table 3 Topics and summaries of Telavalue webinars (held in Finnish) held during the Telavalue project.

Date and presenters	Title and link
24.11.2022, Pirjo Heikkilä, VTT	Tekstiilien kierrätysteknologiat https://telaketju.turkuamk.fi/webinaarit/tekstiilien-kierratysteknologiat/
9.2.2023, Ali Harlin, VTT	Nousevan auringon polyesteri https://telaketju.turkuamk.fi/webinaarit/nousevan-auringon-polyesteri/
23.3.2023, Helena Kalliömäki, LAB UAS; Inka Mäkiö, Turku UAS	Tuote palveluna -pilotit https://telaketju.turkuamk.fi/webinaarit/tuote-palveluna-pilotit/
4.5.2023, Hannamaija Tuovila, VTT	Tekstiilien kiertotalous ja arvoketjut https://telaketju.turkuamk.fi/webinaarit/tekstiilien-kiertotalous-ja-arvoketjut/
2.11.2023, Ella Kärkkäinen and Susanna Raiskio, VTT	Mekaaninen kuitukierrätys - poistotekstiilin matka jätelajista neuleeksi https://telaketju.turkuamk.fi/webinaarit/mekaaninen-kuitukierratys-poistotekstiilin-matka-jatelajista-neuleeksi/
18.3.2024 Hannamaija Tuovila, VTT	Consumer views on circular textiles https://telaketju.turkuamk.fi/webinaarit/consumer-views-on-circular-textiles/
18.4.2024, Piia Nurmi, Eerika Heinonen, Erika Raitala, and Marjaana Launonen, Turku UAS; Hannamaija Tuovila, Päivi Petänen, and Satu-Marja Mäkelä, VTT; Annariina Ruokamo and Helena Kalliömäki, LAB UAS	Multifactor study on business models https://telaketju.turkuamk.fi/telavalueen-tuloksia/multifactor-study-on-business-models/

A large number of blog and result posts were written and published in Telaketju and other webpages. List of blog and results posts can be found in Table 4.

Table 4 Topics and summaries of blog posts and results posts published in our webpages.

Date and author(s)	Title and link
11.5.2022, Eerika Heinonen, TUAS	Kierrätyskuidun käyttö uusien tuotteiden materiaalina https://telaketju.turkuamk.fi/blogi/kierratyskuidun-kaytto-uusien-tuotteiden-materiaalina/
21.7.2022, Salla Piirainen, TUAS	Opintomatka Hollantiin kasvatti luottamusta omaan tekemiseen https://telaketju.turkuamk.fi/uutiset/opintomatka-hollantiin-kasvatti-luottamusta-omaan-tekemiseen/
13.9.2022, Eerika Heinonen, TUAS	Tekstiiliteollisuuden sosiaaliset vaikutukset uusien liiketoimintamallien näkökulmasta https://telaketju.turkuamk.fi/yleinen/tekstiiliteollisuuden-sosiaaliset-vaikutukset-uusien-liiketoimintamallien-nakokulmasta/
29.11.2022, Nelli Kontturi and Jenni Luotonen, Turku UAS	Antikuluttaminen - mitä se on ja miten se muuttaa käsitystämme kuluttamisesta? https://telaketju.turkuamk.fi/blogi/antikuluttaminen-mita-se-on-ja-miten-se-muuttaa-kasitystamme-kuluttamisesta/

16.12.2022, Pekka Kononen, Viivi Salomaja and Ella Rapo, TUAS	Vaatteen todellinen hinta https://telaketju.turkuamk.fi/blogi/vaatteen-todellinen-hinta/
13.1.2023, Jenni Luotonen and Emilia Suutari, TUAS	Ekologisen muodin liikkeiden kuulumisia Turusta https://telaketju.turkuamk.fi/blogi/ekologisen-muodin-liikkeiden-kuulumisia-turusta/
6.2.2023, Emilia Suutari, TUAS	Halpoja vaatteita, ihmisoikeusrikkomuksia ja luonnonvarojen tuhlaamista - näistä aineksista on ultrapikamuoti tehty https://telaketju.turkuamk.fi/blogi/naista-aineksista-on-ultrapikamuoti-tehty/
8.2.2023, Lea Heikiheimo, LAB	Telavalue-verkosto tutustui Luhdan vastuullisuustoimintaan https://telaketju.turkuamk.fi/blogi/telavalue-verkosto-tutustui-luhdan-vastuullisuustoimintaan/
17.2.2023, Riikka Ojala and Elsi Laine, TUAS	Uikkareita ja pikkareita merten muovijätteistä - hyvä vai paha? https://telaketju.turkuamk.fi/blogi/uikkareita-ja-pikkareita-merten-muovijatteista-hyva-vai-paha/
1.3.2023, Pirjo Heikkilä, VTT	Tutkijavierailu Saxionin ammattikorkeakouluun https://telaketju.turkuamk.fi/blogi/tutkijavierailu-saxionin-ammattikorkeakouluun/
29.5.2023, Piia Nurmi, TUAS	Tutkijavaihto ja yhteistyö kiertotalouden uusien liiketoimintamallien tiimoilta https://telaketju.turkuamk.fi/blogi-fi/tutkijavaihto-ja-yhteistyö-kiertotalouden-uusien-liiketoimintamallien-tiimoilta/
29.5.2023, Hanne Tanner and Satu-Marja Mäkelä, VTT	Korjattavia ja kestäviä tuotteita uudella asetuksella? https://telaketju.turkuamk.fi/blogi/tuotteiden-ekologisen-suunnittelun-asetus/
3.7.2023, Eerika Heinonen, TUAS	Tutkijavaihto ja sosiaalisen elinkaariarvioinnin salat https://telaketju.turkuamk.fi/blogi-fi/tutkijavaihto-ja-sosiaalisen-elinkaariarvioinnin-salat/
29.9.2023, Anu Kielo and Heidi Salokangas, TUAS	Vastuullisessa tekstiiliteollisuudessa pitäisi muistaa myös taloudellinen vastuu https://telaketju.turkuamk.fi/blogi/vastuullisessa-tekstiiliteollisuudessa-pitaisi-muistaa-myo-taloudellinen-vastuu/
17.10.2023, Ella Kärkkäinen, VTT	Mekaanisesti avattujen tekstiilikuitujen karakterisointi https://telaketju.turkuamk.fi/blogi/mekaanisesti-avattujen-tekstiilikuitujen-karakterisointi/
20.10.2023, Niko Rintala and Enni Arvez, LAB	Kansainvälisessä yhteistyössä on voimaa https://telaketju.turkuamk.fi/blogi-fi/kansainvalisessa-yhteistyossa-on-voimaa/
20.12.2023, Minna Leppälä, TUAS	Kuluttajan rooli tekstiilien kiertotaloudessa https://telaketju.turkuamk.fi/blogi/kuluttajan-rooli-tekstiilien-kiertotaloudessa/
22.1.2024, Susanna Raiskio, VTT	Tekstiilien kierrätys: Lankoja ja neuloksia mekaanisesti avatuista tekstiilikuiduista https://telaketju.turkuamk.fi/blogi-fi/lankoja-ja-neuloksia-mekaanisesti-avatuista-tekstiilikuiduista/
24.1.2024, Elina Lehtinen, TUAS	Startupien kautta katse tekstiilien kiertotalouden tulevaisuuteen https://telaketju.turkuamk.fi/blogi-fi/startupien-kautta-katse-tekstiilien-kiertotalouden-tulevaisuuteen/
9.2.2024, Enni Arvez, Annariina Ruokamo, Helena Kalliomäki, LAB	Tutkijavaihto laajensi näkemystä kansainvälisen yhteistyön merkityksestä tekstiilien kiertotaloudessa https://telaketju.turkuamk.fi/blogi/tutkijavaihto-laajensi-nakemysta-kansainvalisen-yhteistyön-merkityksesta-tekstiilien-kiertotaloudessa/
19.2.2024, Elina Lehtinen, Ella Rapo, Anna Rautee and Justus Kokko, TUAS	Supernopeaa vai hitaampaa muotia Turun seudulla? https://telaketju.turkuamk.fi/blogi-fi/supernopeaa-vai-hitaampaa-muotia/
22.2.2024, Minna Leppälä, TUAS	Kuluttaja, laita nukkuva pääomasi kiertoon! https://telaketju.turkuamk.fi/blogi/kuluttaja-laita-nukkuva-paaomasi-kiertoon/
22.4.2024, Hannamaija Tuovila, VTT	Tulevaisuuden vaatehankinnoissa vaateen materiaalin kierrätettävyys on tärkeä ostokriteeri kuluttajille https://telaketju.turkuamk.fi/telavalueen-tuloksia/tulevaisuuden-vaatehankinnoissa-vaateen-materiaalin-kierratettavyys/

24.4.2024, Päivi Petänen and Hannamaija Tuovila, VTT	Kiinnostavatko muodin kiertotalouden uudet liiketoimintamallit kuluttajia? https://telaketju.turkuamk.fi/telavaluen-tuloksia/kiinnostavatko-muodin-kiertotalouden-uudet-liiketoimintamallit-kuluttajia/
24.4.2024, Elina Lehtinen, Ella Rapo and Adeliina Piira, TUAS	Second hand – jälleen uusi kiihtyvän kulutuskulttuurin mahdollistaja https://telaketju.turkuamk.fi/blogi/second-hand-jalleen-uusi-kiihtyvän-kulutuskulttuurin-mahdollistaja/
8.5.2024, Niko Rintala and Enni Arvez, LAB	Tunnistusteknologiat laitettiin suurennuslasin alle https://telaketju.turkuamk.fi/telavaluen-tuloksia/tunnistusteknologiat-laitettiin-suurennuslasin-alle/
13.6.2024, Satu-Marja Mäkelä, Sari Järvinen & Hannu Tanner, VTT	Kestävämpiä tekstiilipalveluja datan avulla https://telaketju.turkuamk.fi/telavaluen-tuloksia/kestavampia-tekstiilipalveluja-datan-avulla/
22.7.2024, Aravin Periyasamy & Noora Raipale, VTT	Future Textile Manufacturing – Use of recycled materials and support from new technologies https://telaketju.turkuamk.fi/in-english-en/future-textile-manufacturing-use-of-recycled-materials/

The students that were involved in the Telavalue project through their work are presented in Table 5.

Table 5 The theses and other student works carried out by students related to Telavalue project.

Type	Student(s) / Author(s) and organization	Title / Information / Web link
Thesis	Anu Kielo, TUAS	Assessing the economic impacts when changing from a linear to a circular textile value chain: analysis from the perspective of a hypothetical Finnish textile company https://urn.fi/URN:NBN:fi:amk-2023090925540
Thesis	Ella Kärkkäinen, VTT	Fibre-to-fibre recycling: characterisation of selected mechanically opened cotton fibres https://trepo.tuni.fi/handle/10024/151863
Thesis	Susanna Raiskio, VTT	Circular textile materials: An interdisciplinary study of mechanically recycled fibres in yarns and knitted fabrics https://urn.fi/URN:NBN:fi:aalto-202401281792
Laboratory assistant	Babette Sperling, LAB	Laboratory assistance for WP4, research and practical work on fibre separation, washing and novel separation technologies.
Project assignment	Sanna Ermilä, LAB	Collection and analysis of consumer expected lifetimes data in WP2.
Project assignment	Nelli Kontturi and Jenni Luotonen, TUAS	Antikuluttaminen - mitä se on ja miten se muuttaa käsitystämme kuluttamisesta? https://telaketju.turkuamk.fi/blogi/antikulttaminen-mita-se-on-ja-miten-se-muuttaa-kasitystamme-kuluttamisesta/ 29.11.2022
Project assignment	Pekka Kononen, Viivi Salomaja and Ella Rapo, TUAS	Vaatteen todellinen hinta https://telaketju.turkuamk.fi/blogi/vaatteen-todellinen-hinta/ 16.12.2022
Project assignment	Jenni Luotonen and Emilia Suutari, TUAS	Ekologisen muodin liikkeiden kuulumisia Turusta https://telaketju.turkuamk.fi/blogi/ekologisen-muodin-liikkeiden-kuulumisia-turusta/ 13.1.2023
Project assignment	Emilia Suutari, TUAS	Halpoja vaatteita, ihmisoikeusrikkomuksia ja luonnonvarojen tuhlaamista - näistä aineksista on ultrapikamuoti tehty https://telaketju.turkuamk.fi/blogi/naista-aineksista-on-ultrapikamuoti-tehty/ 6.2.2023
Project assignment	Riikka Ojala and Elsi Laine, TUAS	Uikkareita ja pikkareita merten muovijätteistä - hyvä vai paha? https://telaketju.turkuamk.fi/blogi/uikkareita-ja-pikkareita-merten-muovijatteista-hyva-vai-paha/ 17.2.2023

Project assignment	Minna Leppälä, TUAS	Kuluttajan rooli tekstiilien kiertotaloudessa https://telaketju.turkuamk.fi/blogi/kuluttajan-rooli-tekstiilien-kiertotaloudessa/ 20.12.2023
Project assignment	Elina Lehtinen, Ella Rapo, Anna Rautee and Justus Kokko, TUAS	Supernopeaa vai hitaampaa muotia Turun seudulla? https://telaketju.turkuamk.fi/blogi-fi/supernopeaa-vai-hitaampaa-muotia/ 19.2.2024
Project assignment	Minna Leppälä, TUAS	Kuluttaja, laita nukkuva pääomasi kiertoon! https://telaketju.turkuamk.fi/blogi/kuluttaja-laita-nukkuva-paaomasi-kiertoon/ 22.2.2024
Project assignment	Elina Lehtinen, Ella Rapo and Adeliina Piira, TUAS	Second hand – jälleen uusi kiihtyvän kulutuskulttuurin mahdollistaja https://telaketju.turkuamk.fi/blogi/second-hand-jalleen-uusi-kiihtyvän-kulutuskulttuurin-mahdollistaja/ 24.4.2024
Presentation at an event	Laine Elsi, Lehtinen Elina, Kononen Pekka and Ojala Riikka, TUAS	Presentation at an event at TUAS: Student project studies with the textile circular economy with companies and students & BF project Telavalue's news

Science and Technology Board

The target of Tela3-STB activity was to enable international collaboration with research organization and with companies in order to widen networks of Telavalue participants, bringing industrial and technological experience outside of our consortium, and give feedback and guidance to the project work. Members of STB were The Swedish School of Textiles, University of Borås (SE), Circle Economy (NL), Saxion University of Applied Sciences (NL), Marchi & Fildi (IT), TEXRoad (NL), Reutlingen University, Fakultät Textil (DE), Centexbel (BE), CITEVE (PT), Fibre Innovation Incubator (JP), Infinited Fiber Company (FI), Seiko Epson Corporation (JP), Itochu Fashion System Inc. (JP), and Monordi Oy Ltd. (FI).

The STB members had a possibility to follow up progress of the project by receiving information of the project status and results, and to interact with the consortium within four STB meetings. With research and academic organization also research collaboration was planned, and it included researcher exchange and visits, and with Swedish school of Textiles also webinar and joint study trips in Finland and Sweden. STB meetings and short visits are listed in Table 6 and visits included into researcher mobility in Table 7.

Table 6 STB meetings and short visits – longer visits can be found from Table 7.

Date	Description
12.10.2022	First STB meeting (online), 28 participants - 22 from Telavalue consortium and 6 STB members
17.1.2023	Rudrajeet Pal/ Borås visited TUAS to intensify cooperation and plan for Piia Nurmi's visit in Borås in May and to plan the Finland x Sweden collaboration
30.1.2023	Two persons from Itochu Fashion System Inc. and one from Monordi Oy Ltd met VTT, TUAS and LAB project managers at VTT (both joined to STB after this)
25.4.2023	Second STB meeting (online), 38 participants - 27 from Telavalue consortium and 11 from STB
14.8.2023	Two persons from Marchi&Fildi (STB member) visited VTT
12.12.2023	Third STB meeting (online), 29 participants - 7 from STB and 22 from Telavalue consortium
26.4.2024	Fourth STB meeting (online), 25 participants - 7 from STB and 18 from Telavalue consortium

Researcher Mobility

We actively sought collaboration with regional, national and European/international projects and we have planned research exchange with several universities. Such research mobility was also expected by Business Finland. Telavalue research mobility and visits are listed in Table 7.

Table 7 Researcher mobility and visits - funding for visits were in some cases covered by other sources than Telavalue BF project.

Date	Description (person/ORG, host ORG, relevance to the project)	Duration (in PMs)
Autumn 2022	Ali Harlin/VTT visited multiple circular economy actors both companies and research organization in Japan within two separate visits in autumn 2022. Visits benefited Telavalue work, and information was obtained e.g. for recycling technology reviews (T5.1 and T6.1).	~1 ½ PM
19.8.-24.8.2022	Lea Heikinheimo & Anna Keskiäsaari/LAB visited Borås, Malmö and Wargön for mapping co-operations for processing trials in WP4, WP5 and WP6.	~ ½ PM
5.2.-18.2.2023	Taina Kamppuri/VTT and Lea Heikinheimo/LAB visited CITIVE related to processing trials (spinning & knitting) and demonstration with recycled fibres linked WP2, WP4 and WP5 work.	½ PM ¼ PM
19.-23.2.2023	Pirjo Heikkilä/VTT to Saxion UAS related to ecosystem building, circular value chains, and recycling technologies linked to WP1, WP4, WP5, WP6 and WP7 work.	¼ PM
23.-27.4.2023	Traci Kinden/TEXRoad to VTT related to data tasks in WP1 and WP4.	¼ PM
9.-12.5.2023	Lea Heikinheimo and Niko Rintala /LAB to Borås related to fibre-to-fibre recycling and demonstrations linked to WP5 and WP6.	~ ½ PM
19.5.-27.5.2023	Piia Nurmi/Turku UAS visit to Borås, Sweden related to business models studies (WP3).	¼ PM
4.-16.6.2023	Eerika Heinonen (TUAS) visited Manchester Metropolitan University (MMU)/UK, linked to social aspects of business models (WP3).	½ PM
27.11.-1.12.2023	Annariina Ruokamo, Helena Kalliomäki and Enni Arvez visited Campus of Alcoy of Universitat Politècnica de València related to work in circular business models, textile waste processing and interaction (WP3, WP4 & WP7).	¾ PM

Other International Activities and Events

The Telavalue project networked internationally within online and physical events and communicated about the project and results actively. Selected examples of our communication activities are listed Table 8. Results and work carried out in Telavalue project has also been published in more detail and results have been (and are planned to be) published in scientific forums. The conference and seminar presentations and papers as well as the separate technical and scientific publications and reports are listed in Table 9.

Table 8 The International Communication and Networking Activities.

Date	Title (of the event) and description
9.3.2022	Heikkilä P., Telaketju - collaboration network and textile circular economy research in Finland, Ringmajanduse KUIDAS? sessioon 8: Ringne tekstiilitööstus Eestis, Slides available: https://cris.vtt.fi/en/publications/telaketju-collaboration-network-and-textile-circular-economy-rese
6.4.2022	VTT News / press release: Creating a sustainable Finnish textile industry with bio-based and recycled fibres https://www.vttresearch.com/en/news-and-ideas/creating-sustainable-finnish-textile-industry-bio-based-and-recycled-fibres
25.4.2022	ExpandFibre News: Telavalue project develops value chains for sustainable production, use and cycles of textiles. https://www.expandfibre.com/news/item/telavalue-project-develops-value-chains-for-sustainable-production-use-and-cycles-of-textiles
23.-25.5.2022	TUAS Study trip to Netherlands https://telaketju.turkuamk.fi/en/in-english-en/study-trip-to-netherlands/
1.-2.12.2022	Pirjo Heikkilä/VTT and Ali Harlin/VTT attended Aachen-Dresden-Denkendorf International Textile Conference in Aachen Keynote speech by Ali about circular economy and recycling platform, and invited speech by Pirjo about textile recycling technologies based directly on work carried out in T4.1, T5.1 and T6.1

22.- 24.11.2022	Telavalue presentation at Nordic Circular Summit in Stockholm was invited by Business Finland. Core of the presentation was to introduce the Telavalue research to the audience. Inka Mäkiö from Turku UAS gave the presentation on site. Also Rester from Telavalue and Spinnova from Finland were introduced within this session., (WP3, WP7)
3.3.2023	Nurmi P., Circular economy of textiles, Aboatech Talks, Turku Business Region
28.3.2023	Keskisaari A., Call to collaboration: Transit to a green and sustainable economy, On-line conference – Uzbekistan collaboration
30.5.-2.6.2023	Niko Rintala & Enni Arvez talking about textile circular economy and Telavalue project, World Circular Economy Forum/Helsinki
28.9.2023	Piia Nurmi, Textile recycling Value Chains and Networks, Virtual Textile and Plastics Recycling Workshop with LA Sanitation & Environment (LASAN) and Finland.
3.10.2023	Heikkilä P., Telaketju A network and research continuum, TAIEX-EIR Flagship Workshop on Textile Waste Separate Collection, Treatment and Markets, https://cris.vtt.fi/en/activities/telaketju-a-network-and-research-continuum-2
20.11.- 24.11.2023	Lea Heikinheimo and Niko Rintala went to Innovatex 2023 - Innovative aspects of textile industry - conference held in Łódź, Poland
October 2023	Eetta Saarimäki and Pirjo Heikkilä will attend ECOSYSTEX conference in Barcelona, Spain
20.- 21.11.2023	Study trip to Finland: On the first day visits in Turku area to LSJH and Rester, Turku UAS and Lindström premises. Second day visit to Emmy in Lohja and Bioruukki in Espoo. 20 participants.
28.11.2023	Ali Harlin/VTT attended Sustainability Talks Istanbul event and gave presentation about textile circularity and especially its status in Finland.
28.2.-1.3.2024	Study trip to Sweden, seven Telavalue project group members including Pirjo Heikkilä and Eetta Saarimäki (VTT), Enni Arvez (LAB), and participants from Mirka and Fiare together with Borås faculty members. Study trip included visits to University of Borås, and Borås Science Park, Wargön Innovation, RISE, Erics Hjälp, and FOV Fabrics.
21.3.2024	Exploring the Future of Circular Textiles - Telavalue final seminar with New Cotton project. Demonstrations exhibition and multiple posters. https://newcottonproject.eu/news_article/exploring-the-future-of-circular-textiles-concluding-seminar-discover-the-programme/
25.-26.4.2024	Niko Rintala on study trip to Estonian textiles organizations. Trip included discussions and Telavalue presentations at Estonian Academy of Arts, Reet Aus, Reverse Resources and Tallinna Strateegiakeskus.
15.5.2024	Nurmi P., Presentation on rental service at the Nordic Textile Collaboration, Webinar & workshop - Active Textile Society

Table 9 The technical and scientific publications and reports of the project (published by end of September 2024).

Type	Event / Media	Authors / Title / Information / Web link
Scientific publication	Advances in Science and Technology	Lea Heikinheimo & Kirsti Cura, LAB; Linda Karlström, Salpakierto / Development of textile circular economy education in various networks in Finland / https://doi.org/10.4028/p-d5e8p5
Book chapter	Recycling and lifetime management in the textile and fashion sector	Pirjo Heikkilä, VTT / Textile Recycling Technologies / https://www.taylorfrancis.com/chapters/edit/10.1201/9781003044413-12/textile-recycling-technologies-pirjo-heikkil%C3%A4
Conference presentation	Aachen-Dresden-Denkendorf International Conference, December 2022	Pirjo Heikkilä, VTT, Technology review of textile recycling https://cris.vtt.fi/en/activities/technology-review-of-textile-recycling
Seminar presentation	11.1.2024 Nordic Textile Fibre Day	Heikkilä P., Sustainable Textile Value Chains, slides available https://cris.vtt.fi/en/activities/sustainable-textile-value-chains
Scientific article	Circular Economy and Sustainability	Petänen, P.; Sundqvist, H. & Antikainen, M. Deconstructing customer value propositions for the circular product-as-a-service model: a case study of the textile industry. https://doi.org/10.1007/s43615-024-00351-z
Conference paper	InnovaTex 2023 conference, November 2023	Niko Rintala, Lea Heikinheimo, Utilisation of textile identification and sorting pilot line in promoting textile recycling in Finland.

Technical report	VTT research report	Heikkilä P., Heikkilä J., Kamppuri T., Keskisaari A., Määttänen M., Saarimäki E., Heikinheimo L., Koivula A., Rintala N., Harlin A. (2024) Technologies and Model for Sustainable Textile Recycling. VTT Technical Research Centre of Finland. VTT Research Report Vol. VTT-R-00941-22 Available in https://cris.vtt.fi/en/publications/technologies-and-model-for-sustainable-textile-recycling
Scientific article	Cleaner Production Letters	Petänen P., Tuovila H., Heikkilä P. (2024) Strategic marketing of sustainable fashion: exploring approaches and contradictions in the positioning of fashion rental, https://doi.org/10.1016/j.cpl.2024.100075