ETP
Fibres Textiles Clothing
EUROPEAN TECHNOLOGY PLATFORM

Ready to Transform

A Strategic Research and Innovation Agenda to underpin the EU Strategy for Sustainable and Circular Textiles

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Foreword

Dear reader,

Just over 5 years have passed since we published the preceding edition of the Textile ETP's Strategic Research and Innovation Agenda in late 2016 entitled "Towards the 4th Industrial Revolution of Textiles and Clothing".

Already at the time we singled out digitalisation and sustainability as major innovation drivers for our industry for at the least the next 10 years. But still we underestimated what acceleration both trends would experience already in the following 5 years. And of course we could not have predicted how a global pandemic with prolonged lock-downs, global supply chain disruptions, regular home working and massive online consumption would turn many traditional consumer behaviours and business practices upside down.

We did also not anticipate that European policy makers would focus their regulatory efforts on our industry in such a comprehensive and transformative way, as it is the case now with the EU Strategy for Sustainable and Circular Textiles that has been adopted in March 2022.

For this reason we now present a new and significantly revamped Strategic Research and Innovation Agenda for the European Textile and Clothing sector. We need to be "Ready to Transform" in a comprehensive and rapid way, if we want to maintain this centuries-old but evergreen industry as a vital economic actor in the European economy. Manufacturing of textiles and clothing provide 6% of all manufacturing jobs in Europe, we annually export beautiful, technically advanced high quality textile-based products worth over € 50 billion to the rest of the world and if there is a continent that is universally credited for its textile innovation and creativity, it is certainly Europe.

If we want to maintain our global innovation lead also in a future digital and sustainable world, we will need to massively increase our efforts in research, technology development, innovation, creativity and skills development. The present document describes in which specific knowledge domains and technical fields these investments should be prioritised. It also makes a series of concrete recommendation on how policy makers and public programme managers can smartly support the on-going industry transformation driven by an SME-dominated sector and a diversified non-profit research and higher education community.

Michael Kamm

President of the European Technology Platform
for the Future of Textiles and Clothing

Executive Summary

The European and global textile and clothing industry is undergoing its most profound transformation since the mass production of man-made synthetic fibres and industrial-scale manufacturing and distribution of textile-based consumer products in the 1950-60's. The industrial age concept of efficient provision of a growing consumer class with affordable and fashionable textiles and clothing, taken to an unsustainable level by the cheap, fast, and disposable fashion push of the last decades, will have to be replaced by a more sustainable, value-based operational model that favours quality, durability, resource efficiency, and resilience. At the same time, textile materials provide new solutions for the sustainable transformation of many other sectors of the economy, such as healthcare, construction, energy and transport, agriculture, defence and security, leisure and sports.

Recovering from a highly COVID-disrupted year 2020, the EU textile and clothing industry in 2021 realised an annual turnover of € 147 billion, exported goods worth almost € 60 billion to the rest of the world and employs 1.3 million people in some 143,000 companies. The European textile sector and its research, technology and education provider community is a large organically grown and internationally interconnected ecosystem that cannot be transformed in a few years. The sustainable textile transformation is a truly systemic challenge that requires resolve to change and massive investments over a long period of time by all involved stakeholders.

Innovation is the most important lever to make this transformation rapidly and smoothly. It has to be based on a combination of radical and incremental technological advances in materials and processes, non-technological improvements or transformations of business models, value chain operations, customer engagement, product life cycle management, and applied creativity and skills by textile professionals and consumers.

The members of the European Textile Technology Platform from the textile and clothing industry and related sectors applied research and higher education have collectively worked through surveys, interactive workshops, and collaborative document drafting for several months to produce the present Strategic Research and Innovation Agenda, designed to underpin the industry transformation targeted by the EU Strategy for Sustainable and Circular Textiles.

Four strategic Innovation Themes have been singled out as particularly impactful for the successful and rapid transformation of the European textile ecosystem.

- Smart, high-performance materials for new growth markets
- Digitised textile materials, products, manufacturing, supply chains and business models
- Durable, circular and biobased materials and processes
- Safe, low footprint products, processes and responsible supply chains

For each theme several research and innovation topics and subtopics are defined followed by a listing of concrete research and innovation targets, promising technology approaches to be applied or problems to be solved. Some of these specific targets and objectives apply broadly for many textile products, operations or end markets, other are more specific to niches that are of critical importance or high value for Europe's textile sector.

Many innovations are dependent on parallel advances in several knowledge domains or technology areas with interdependences and feedback loops. Given the extremely diversified material, product, and end-market range of textiles and in the interest of general technological openness, the identification of individual fibre types, product categories, or specific end market niches has been avoided. Similar innovation objectives may also be achieved through alternative design, material, process, manufacturing, and business model approaches. Also, for this reason, the

indication of technology readiness levels, development timelines, or investment levels has been avoided.

In the field of Smart, high-performance materials for new growth markets, the key topics identified include:

- Low-cost and low-impact high-performance fibres and textiles
- Textile surface multi-functionalisation for technical applications
- Rapid, small-scale manufacturing of advanced textile and hybrid materials and components
- E-textiles for smart wearables and surfaces and their efficient industrial manufacturing
- Bio-engineered and biocompatible functional materials for medical applications

Theme 2, Digitised textile materials, products, manufacturing, supply chains and business models includes the following main topics, each with several subtopics:

- Digital product creation
- Digital manufacturing and learning factories
- Digital supply chains and business models

Theme 3, Durable, circular and biobased materials and processes comprises 7 subtopics clustered around the two main topics:

- Textile circularity
- Biobased and natural fibres and textile materials

Finally theme 4, Safe, low footprint products, processes and responsible supply chains is divided into the 3 main topics of:

- Safe materials and better chemistry
- Low impact textile operations
- Transparent supply chains and new working environments

Beyond the pure technological capacity to realise new materials, products, processes, or business models, industrial innovation can only flourish if companies dispose of a sufficient, adequately educated, skilled, and motivated workforce. A steadily ageing workforce combined with the need to rapidly acquire new competences and skills can represent the biggest bottleneck for the industry transformation. Attraction, retention and continuous professional development of human talent is of the highest priority and all measures to support companies, especially SMEs in this process will be highly impactful.

The implementation of the EU Strategy for Sustainable and Circular Textiles must be accompanied by a policy framework that fosters innovation and skills development at all levels and an investment programme that is apt to deliver on the massive systemic change expected. Key lessons from historic industrial transformations and successful large scale public interventions into societal challenges such as the recent COVID pandemic should be applied including: clear objective definition and communication, rule setting and coherent enforcement, smart incentivising of economic actors, lots of small scale experimentation and rapid scaling of promising approaches, technological openness and agile situational adaptation as well as a broad multiple helix stakeholder engagement model with transparent governance.

A list of 10 concrete research and innovation policy recommendations is being provided with the objective of mobilising up to €5 billion in public funding over 2023-2030 from existing EU, national and regional support programmes. The recommended actions include:

- Significantly increased and textile-targeted research, innovation, demonstration and skill development funding for collaborative projects and capacity building through HORIZON EUROPE, ERDF and ERASMUS+
- Set-up of regionally-based but EU-wide connected sustainable innovation and recycling hubs and a large-scale cascading funding programme for small-scale rapid innovators
- Built resilience and strategic autonomy for the European textile value chain through new EU natural fibre and biomass sources and innovation, education and standardisation partnerships with diversified international partners in neighbouring countries and around the globe.

The task of the systemic sustainable transformation of the textile sector is daunting, but Europe has all the ingredients to make it happen. We can demonstrate to the rest of the world that a different operating model is not only imaginable, but also practically achievable with multiple benefits for people, plant and the economy.

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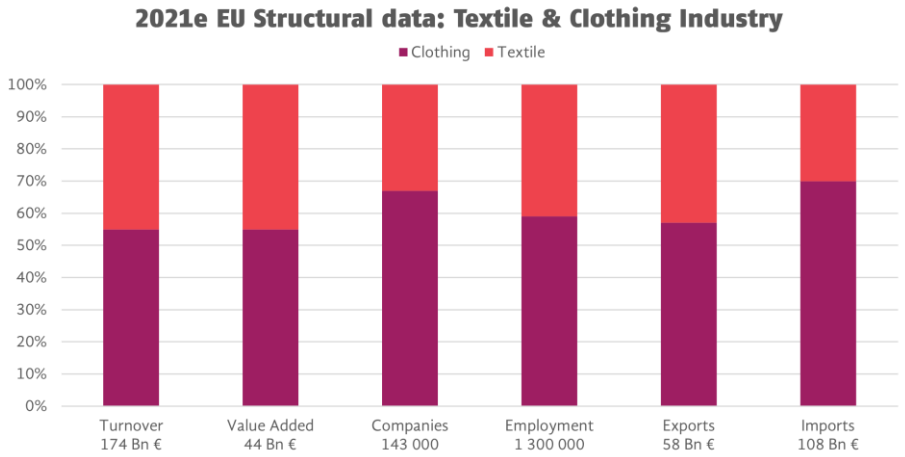
1. The Transformation of the European Textile and Clothing Industry

Recent evolution and trends

Since the publication of the previous Strategic Research and Innovation Agenda the EU textile and clothing industry has continued to evolve and transform rapidly, partially driven by technological, regulatory, and end-market trends, partially through external shocks such as Brexit or the COVID-19 pandemic. Especially as a result of the latter two events, industry key figures such as turnover, investments and exports have been extremely volatile. Turnover and investment plunged in 2020 as a result of supply chain disruptions, production stops, and overnight closure of major end market outlets such as high street shops. Certain subsectors on the other hand such as medical and protective textiles and nonwovens did exceptionally well.



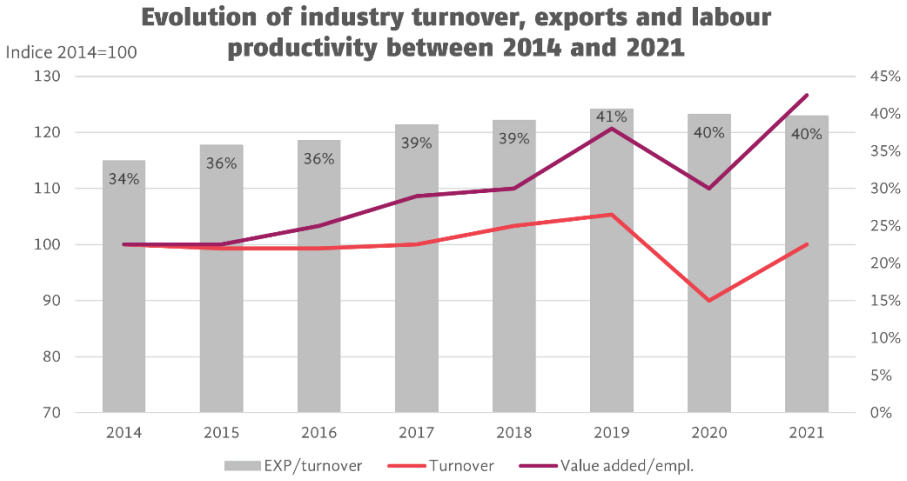
Source: Euratex estimates, based on Eurostat STS and SBS data

Also sports and activewear as well as home textiles benefitted from consumers seeking to be active and comfortable during lock-downs and remote work periods. Textile products sold through online channels such as branded web and mobile shops, e-commerce platforms, or social media-driven direct-to-consumer channels received a massive boost, while traveling and event-driven sales plunged and stationary retail suffered structural losses.

Textile trade between the EU and the UK suffered from Brexit, but relatively speaking the EU textile and clothing export quota increased significantly as a result of sales to the UK becoming part of extra-EU export rather than intracommunal trade.

Rapidly increasing costs of raw materials, process chemicals, and especially energy is driven by supply chain constraints and geopolitical tensions. They are greatly impacting producers as well as consumers facing production cost and end product price inflation at levels not seen for a long time.

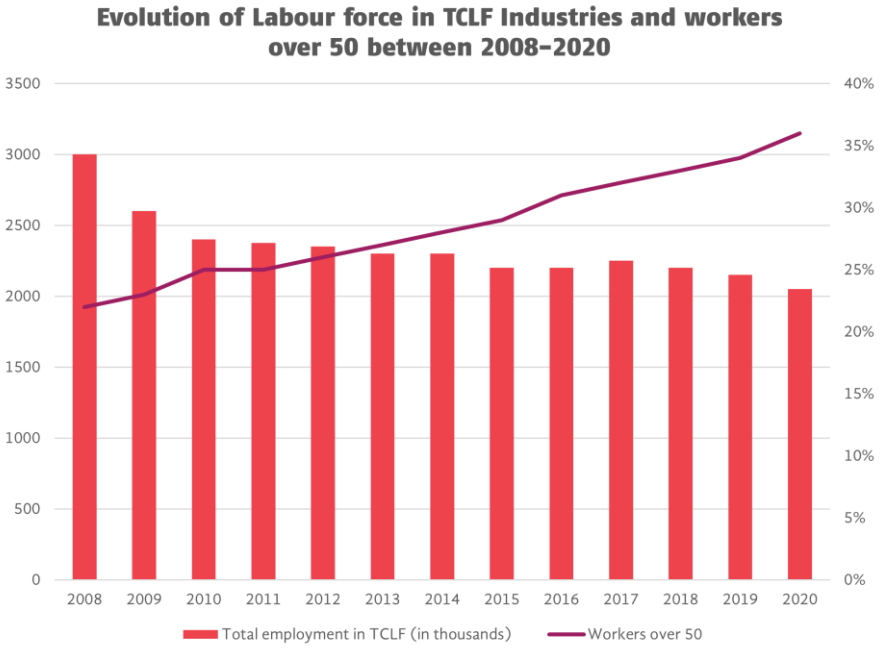
In 2021 the EU-27 textile and clothing industry realised a turnover of € 147 billion, recovering most of the losses from the 2020 COVID impact, employing some 1.3 million people across 143,000 companies. The industry keeps shifting away from low-value added mass production and commodity markets and successfully defends its global lead in the higher value-adding positions in the supply chain such as premium and luxury fashion and interiors as well as highly customer-specific niche products for technical end markets. These markets require levels of knowledge, advanced technological capabilities, highly specialised skills, and close supply chain collaboration for which Europe is uniquely positioned.



Source: Euratex

As a result, the industry's labour productivity has continued to increase steadily, having cumulatively increased by almost 30 % since 2014.

Difficulties to access skilled labour have become one of the most pressing issues for the European textile and clothing industry. While digitalisation and automation in production continue to replace manual labour, with the exception of garment assembly which remain labour-intensive, job profiles that require deep technical knowledge, as well as creative and soft skills, are in increasing demand. Design, product development, marketing, customer relationship management, and value-added services play a much bigger role in all types of companies along the European textile supply chain. Pure contract manufacturing or finishing, as well as CMT business in the clothing industry, continue to provide flexibility and responsiveness, especially in the fast-moving fashion business but become a smaller and smaller part of the industry in Europe. A rapidly ageing workforce and the exit of highly skilled senior experts put companies under pressure to raise their game in terms of young talent attraction and retention including intra-company career development and training programmes.



Source: Eurostat

Future Industry Drivers

Sustainability & Circularity

The times in which companies could primarily focus on the economic dimension of the business while giving the environmental and social impacts of its operations only secondary thoughts are over. The three P's – people, planet, and profit - need to be balanced both on the micro-level of the individual enterprise as well as the macro-level of an entire industrial sector. The European and global textile and clothing industry can positively impact several of the 17 Sustainable Development Goals adopted by the United Nations in its 2030 Agenda for Sustainable Development, such as GOAL 12 - Responsible Consumption and Production, GOAL 8 - Decent Work and Economic Growth and of course GOAL 9 – Industry, Innovation, and Infrastructure. Conversely, unbalanced, exploitative, or short-term focussed operations can create risks for several goals such as Climate Action, Good Health and Well-being, Clean Water and Sanitation, or Life on Land and Below Water.

Especially the inefficient and wasteful use of resources such as land, water, fossil-based materials and energy in a primarily linear take-make-dispose supply chain to satisfy steadily increasing end market demand of a growing and prospering world population is difficult to reconcile with the premise of operating within sustainable planetary limits.

Pressure to align business operations with principles of sustainability and circularity arises both from market and regulatory requirements and massive technological, financial and human efforts will have to be made by the textile sector in the coming years to bring about a systemic change of its global operational model.

Digitalisation

The shift from a primarily analogue and physical to an increasingly digital and virtual human-made world is likely the deepest and broadest transformative trend of the 21st century. Based on exponential innovation and efficiency gains of digital hard and software, foundational technologies and business models across literally all industries are being disrupted at unprecedented speed. The textile and clothing industry is no exception to this trend and several key technological building blocks such as virtual fabric and fashion design, digital printing, electronic machine control and supply chain management or e-commerce are already firmly established. Other innovations such as remote factory monitoring and maintenance, automated supply chain and system interconnection through APIs, virtual fairs and product showrooms, direct-to-consumer business models and last mile delivery capacities have gotten a strong boost during the wide-spread physical contact restrictions of the COVID period. Others such as big data exploitation and machine learning, AR/VR and IoT use in factories, supply chains and end user interactions, the sale of virtual textile and fashion goods or the use of blockchains, NFTs or other distributed security and authentication systems are still in very early stage, but have massive potential in the next decade.

Textile businesses that are not ready to embrace the brave new digital world are likely to be rapidly overtaken and marginalised by its more nimble competitors. The fusion of the textile and digital world also brought a rapid influx of new competitors, large and small, into the textile and fashion business. Armed with a superior digital tech stack and skills, they outmanoeuvre traditional industry players through speed, scale, cost and superior customer service and acquire textile material, product and process capacities as needed.

Resilience and Strategic Autonomy

Disrupted global supply chains, surging demand in certain product categories with evaporating demand in other segments due to the COVID-19 pandemic exposed a lot of rigidities, fragilities, and related business risks in the European and global textile and clothing value chain. The COVID aftermath characterised by persistently high inflation in raw material, energy, and logistics costs exacerbated by geopolitical tensions, makes it clear that supply chain resilience and strategic independence are crucial objectives that were too often neglected by business and political leaders eager to harvest the fruits of a freer and smoother global trade. Also, retailers and consumers mistook the absolute or at least relative price deflation in many commodity textile and clothing products over the last 20 years on the back of manufacturing automation and offshoring to low labour cost countries as an eternal law of nature. The coming years are more likely to be characterised by a reset that will balance volume growth and low-cost manufacturing efficiency with a more value-based business approach integrating sustainability, quality, local circularity and resilience.

Europe's textile and clothing industry is closely interconnected with global supply chains and end market. This has and will continue to bring many opportunities to diversify demand. But it is also contributing to creating supply dependencies for both basic manufacturing inputs such as fibres, dyestuffs and processing chemicals as well as critical intermediate and final products as the shortage of PPE and surgical masks during the early stages of the pandemic has shown. To ensure the long-term health and competitiveness of Europe's textile industry, the sector, supported by policies and funding programmes, must develop a strategic programme for critical input supply security and diversification, incentivise establishment or reshoring of missing capacities, guaranteed availably of European manufacturing capacities for indispensable end products and strengthening of vulnerable operators and skills on which many up- or down-stream players depend.

A new Policy Framework

The Green and Digital Transition of the European economy is also at the heart of EU policy-making with a cascade of policies, legislative initiatives, and specific regulations started with the announcement of the EU Green Deal in late 2019. Core policies under this umbrella include the Circular Economy Action Plan (CEAP) and the European Industrial Strategy announced in early 2020. These policies have been further complemented by the EU Recovery Plan in response to the COVID crisis adopted in late 2020.

The textile sector, as one of the most affected by the Green and Digital Transition and hard hit by the measures to fight the COVID pandemic, was singled out as one of 7 product markets in the focus of the CEAP and one of 14 industrial ecosystems in need of particular measures under the EU Recovery Plan. As a result, the most comprehensive industry-specific EU policy package ever targeted this industry was prepared in 2021 and finally published in March 2022. The EU Strategy for Sustainable and Circular Textiles lists and describes all sector-specific policies, legislations, and support measures the European Commission proposes to pave the way in the green and digital transition of the textile sector. In addition to various legislative initiatives to enable, enforce and incentivise more sustainable and circular operations, it also targets the development of a Transition Pathway for the Textiles Ecosystem co-created by all sectoral stakeholders in Europe. One of the core elements for a successful transition highlighted in the strategy is an intensification of research, innovation, and skills development in the sector supported through various public funding programmes at the EU, national and regional levels.

The research and innovation priorities presented in the following chapter and the policy recommendations of chapter 4 are intended as a direct input into the co-creation process of the Transition Pathway by the EU Textile and Clothing industry and its research, innovation, and higher education stakeholders.

2. The Strategic Innovation Themes and Research Priorities

In a process involving hundreds of textile industry, research, technology, cluster, and association experts from across Europe over several months, 4 major Strategic Innovation Themes and a total of 26 corresponding Research Topics have been identified, structured, and described in detail. For each Research Topic there are further sub-topics and concrete objectives, needs or targets defined.

Significant technological progress, successful pilot demonstration and subsequent rapid industrial adoption across this broad field of innovation themes and research topics will contribute to a rapid and successful transformation of the European textile and clothing industry into a renewable, circular, digitised resilient industrial ecosystem.

Innovation Theme I - Smart, high-performance materials

- Topic 1. Low-cost and low-impact high-performance fibres and textiles
- Topic 2. Textile surface multi-functionalisation for technical applications
- Topic 3. Rapid, small-scale manufacturing of advanced textile and hybrid materials/components
- Topic 4. E-textiles for smart wearables and surfaces and their efficient industrial manufacturing
- Topic 5. Bio-engineered/biocompatible functional materials for medical applications

Innovation Theme II - Digitised Textile Materials, Products, Manufacturing, Supply Chains, and Business Models

- Topic 1: Digital product creation
- Topic 2: Digital manufacturing and learning factories
- Topic 3: Digital supply chains and business models

Innovation Theme III - Durable, circular, and biobased materials and processes

- Topic 1: Textile circularity
- Topic 2: Biobased and natural fibres and textile materials

Innovation Theme IV - Safe, Low Footprint Products, Processes & Responsible Supply Chains

- Topic 1: Safe materials and better chemistry
- Topic 2: Low impact textile operations
- Topic 3: Transparent supply chains and new working environments

Innovation Theme I: Smart, high-performance materials for new growth markets

Fibres, filaments as well as the 2D or 3D materials manufactured from them increasingly find applications across almost all material end markets from commodity volume-driven use cases such as packaging, construction, agriculture, or geotextiles to the most mission-critical high added value uses in areas like filtration, bioengineering, healthcare, microelectronics, photonics, aerospace, defence or renewable energies. High-performance fibres and advanced textiles become materials of choice for an enormously large spectrum of high added value end uses.

This extremely wide array of uses requires an equally broad spectrum of fibre and textile material types. Such variety can be achieved through different raw materials such as natural or synthetic polymers or inorganic materials such as carbon, glass, ceramics, basalt, etc. Also, the physical shape of fibres and filaments, the blending or other combination of materials as well as the physical structure of the 2D and 3D materials realised from the fibre or filaments can all dramatically alter the performance and use characteristics of the resulting flexible or rigid high-performance components or products.

"New growth markets such as sustainable transport, renewable energy, robotics, IoT and wearable computing, personalised medicine and others offer enormous growth opportunities for the European technical textiles industry".

Another highly effective and versatile way of realising purpose-built textile materials is the physical or chemical engineering of the surface of fibres and textiles using a sheer endless list of available and emerging processing technologies. Combining textiles with non-textile materials to realise composite or hybrid materials components and products is another major innovation pathway especially when weight-performance ratios need to be optimised in applications like automotive, aerospace, and other transport use cases, in light-weight construction or renewable energy systems.

Combining textiles with micro-and nano-electronic components and systems enables the realisation of smart surfaces or smart wearables with promising future markets in interiors, sports and personal protection, defence, healthcare and well-being, and numerous industrial applications. Combing fibre and textile materials with living cells and organisms, especially their use on the surface or inside the human body starting from the first wound dressings thousands of years ago to the most complex and intricate textile-based implants, offers massive innovation potential, especially when common problems such as biocompatibility or controlled biodegradation or resorption can be successfully addressed.

Europe's fibre and textile industry, the developers and manufacturers of textile production technology and specialised performance chemistry as well as their research community are world-leading in material and process innovation. They serve the most advanced and most demanding global customers across all high-tech end markets. They have a particular ability to innovate in very specific niche markets of low volume but high added value due to intimate knowledge of the customer or end-user needs and a long history of customer-driven collaborative design and product development. New growth markets such as sustainable transport, renewable energy, robotics, IoT and wearable computing, personalised medicine, and others offer enormous growth opportunities for the European technical textiles industry. To maintain Europe's lead in this domain, the strengthening of our technical textile research and innovation ecosystem is a high

priority as is public support to lower TRL flagship research projects to build the knowledge base and technological prowess for coming waves of technical textile innovation.

Topic 1. Low-cost and low-impact high-performance fibres and textiles for technical end-markets

- Fibres and textiles for weight-performance improvement of technical components and products and their efficient production
- Fibres and filaments with active or smart functionalities
- Long-life low-impact fibre-based materials
- Long-life low-impact fibre-based materials
- The effective circularity of technical textiles and composites
- Innovative nonwovens and composites
- Biobased high-performance fibres, textiles, nonwovens, and composites

Topic 2. Textile surface multi-functionalisation for technical applications

- Efficient low resource utilisation processes and technologies
- Innovative processes and technologies for targeted (multi)functionalisation of fibres and textiles
- Sustainable and durable high-performance textile chemistry

Topic 3. Rapid, small-scale manufacturing of advanced textile and hybrid materials/components

- Flexible manufacturing processes and technologies
- Adaptation of non-textile manufacturing techniques
- Rapid assembly, de-, and re-manufacturing of complex advanced textile products

Topic 4. E-textiles for smart wearables and surfaces and their efficient industrial manufacturing

- Effective basic e-textile materials and components
- Reliability, durability, and safety of e-textiles
- Efficient manufacturing of e-textiles
- Integration of e-textiles with non-textile components, software, and services
- New applications for e-textiles
- Sustainability and circularity of e-textiles and smart wearables

Topic 5. Bio-engineered/biocompatible functional materials for medical applications

- Textile materials with effective and sustainable basic biological/medical functionalities
- Textile materials with complex and smart medical functionalities
- Fibres and textiles for artificial tissues and implants
- Textile products for hospitals and other acute care environments
- Textile products for chronic care and home care environments

Innovation Theme II: Digitised Textile Materials, Products, Manufacturing, Supply Chains and Business Models

Textiles are physical materials made of atoms and molecules and no textile material or product can be made without mechanically moving machine parts such as engines, frames, shuttles, spindles, needles, cutters, etc. Even before electric and electronic systems reached factories, textile production had attained levels of productivity, efficiency, quality, and reliability that served as a role model for many other sectors. The punch cards used in Jacquard looms since the early 19th century are widely credited as an inspiration for the punch-card-based data processing machines of the early 20th century which then led to the fully digital programming and data storage of modern computers.

Now the tables have turned and it is up to the textile industry to take inspiration and adopt principles from the electronics and ICT industries to reach the next levels of productivity, speed, versatility, resource efficiency, and customer value creation. Going from mechanical to electronic or photonic processes, from physical to virtual designs and materials, from sending paper and fabric samples to bits and bytes along the supply chain and presenting customers with virtual rather than physical products in e-shops or virtual fairs is a radical shift that needs as much technology development as it requires learning and adaptation from designers, machine operators, supply chain managers, marketing and sales staff as well as consumers.

> *"Given a long enough time frame, it is not inconceivable that more economic value is created by virtual textile and fashion goods than their physical counterparts".*

Software is eating the world, is a well-known slogan emanating from Silicon Valley, but it is true that software is also gradually 'eating' the physical world of textiles and fashion. Designers, producers, brands, and retailers ignore or resist this trend at their own peril. At least since COVID forced millions of people around the world into digital distance work and online shopping, it should have become clear to everybody that digitalisation and virtualisation in all sectors of the economy are here to stay.

Textile materials are among the most intrinsically complex materials and their realistic simulation and rendering in 3D or even in movement is a technically complex challenge. In the past, when most processes in the industry were mechanical and analogue and customers insisted to see and touch the product in reality before making purchase decisions, textile virtualisation did not offer sufficient added value in relation to its cost and difficulty. However, a consumer and incoming professional generation that grew up with screens, smartphones, online shopping, and virtual interaction from a young age is set to change this paradigm drastically.

Now that the world of business and consumption is going radically digital, the case of virtual textile materials and products that are only manufactured once a customer has expressed a clear interest or even commitment to purchase them, becomes extremely compelling. How far the process of virtual value generation can go is best demonstrated by the world of gaming, where virtual goods are already bought in their billions and can in certain cases fetch astronomical prices.

The world of textiles and fashion is certainly no stranger to intangible value creation. The market price of premium or luxury goods is not necessarily related to the cost or physical property of the materials they are made of and consequently many brands actively explore the potential of digital fashion goods collected or worn in virtual worlds. Given a long enough time frame, it is not inconceivable that more economic value is created by virtual textile and fashion goods than their

physical counterparts, with obvious dramatic impacts – positive and negative – on (physical) textile production and distribution on the one hand and resource consumption on the other.

Beyond the world of clothing and fashion, textile virtualisation can also create much value in the design and development of technical textiles for sectors such as aerospace, automotive, and medical device manufacturing or civil engineering where virtual product development includes simulation of (non-textile) material performance characteristics during design, production, and use has been commonplace for some time.

Once textile products are virtually designed, it is only logical to directly transfer this digital product data into the production process with literally no loss of information, time, material, or energy. This of course requires seamless data flow between design and machine software including feedback loops with ERP, CRM, production planning and other enterprise system to ensure the product will be made in the most efficient way when and where it is needed. All data generated from the first design stage of a product throughout all its manufacturing and logistics steps all the way to the end-user must be stored, processed, and exchanged. It will result in a digital twin of the product that can serve a multitude of valuable purposes such as customer and end-user information, reliable data provision for certification, legal or administrative procedures, insights into re-use, repair, or recycling options at the end of the product life, rapid and legal reproduction of identical copies or quick alterations and optimisations in response to changing market demand.

"Many digital textile innovations will benefit from the exponential efficiency gains inherent in the rapidly increasing computing power coupled with diminishing costs of data processing and transfer as well as zero marginal costs of digital reproduction and distribution".

The evolution from a machine-readable bar code or a human-readable product label to a digital product twin or derived digital passport can be compared to the difference between a black and white photograph and an immersed 3D representation of the same scenery in virtual reality. Endless opportunities for all stakeholders in textile value chain can result, but they must be balanced against the costs of producing them and the risks of false, incomplete, inconsistent, misleading information or the misuse of the data provided.

The digitalisation of the world of textiles is inevitable and already in full swing. The potential for enhancing creativity, improving manufacturing and supply chain efficiency and resource footprint, enabling new business models, adding value to customers and end-users, preventing fraud and IP infringement, and providing workers with safer, more meaningful, and valuable jobs is boundless. Many digital textile innovations will benefit from the exponential efficiency gains inherent in the rapidly increasing computing power coupled with diminishing costs of data processing and transfer as well as zero marginal costs of digital reproduction and distribution. The digital revolution will also speed up the transfer of slow, monotone, hazardous and error-prone human work to computers and computer-controlled machines and enhance attractiveness, education and training for the prevailing or newly created higher added value creative, manual and service-oriented jobs in the industry.

This paradigm shift still requires an enormous amount of technological innovation such machine and software development and their integration, better human-machine and machine-machine interfaces, maturing of virtual and augmented reality, domain-specific data models, AI and machine learning as well as robotics. Non-technological innovation needs to focus on (global) standardisation, enabling regulation, new service and business models, new ways of stakeholder

interaction along the value chain, and new approaches to life-long learning, re-skilling, and up-skilling.

Topic 1: Digital Product Creation

Simulation, modelling and visualisation of textile material properties

- Modelling and realistic simulation of textile structures
- Dynamic simulation and visualisation of textile materials
- Simulation and prediction of functional properties and use characteristics

From fully digital 3D prototyping to rapid production

- Virtual prototyping in 3D
- AI, ML, AR & VR in design and prototyping
- Digital Twins
- Rapid digital sample and short-run production

Topic 2: Digital Manufacturing and Learning Factories

Digitised data-driven textile manufacturing environments

- Data models and environments
- Basic digital tools and technologies for textile manufacturing environments
- Digital production optimisation, planning, and control
- Digital troubleshooting and maintenance
- Robotics

Digital micro factories for local on-demand textile and fashion production

- Technologies for digital micro factories
- System integration and optimisation of digital micro factories
- Networked micro-factories and maker spaces

Digitally enabled training tools and learning factories

- Digital training tools
- Digital learning factories and competence centres

Topic 3: Digital Supply Chains and Business Models

Rich digital data generation and exchange along the supply chain

- Data capture, tracking, and tracing tools and systems
- Supply chain communication systems
- Models and strategies for data representation and exploitation

Digitally enabled service business models and sustainability

- Data and tools for service-based textile business models
- Digital tools and platforms enabling sustainability and circularity

Innovation Theme III: Durable, circular and biobased materials and processes

Fibres, textiles, and textile-based products have been surrounding human beings around the clock and around the globe since prehistoric times. The first mechanisation, later automation of agriculture and industrial production combined with the capacity to produce man-made fibres in large quantity and at low cost have pushed fibre and textile consumption continuously upwards, today reaching well over 100 million tonnes of textile fibres globally per year. Resource extraction and agriculture, textile, and clothing production, global distribution and logistics, use, care, and disposal of textiles create a massive environmental footprint, placing the sector at 4th position in terms of global impact after the food, housing, and transport sectors.

Since the advent of large-scale man-made fibre production mostly from fossil resources in the early to mid-twentieth century, the share of these synthetic fibres has grown massively reaching over 65% percent of global annual fibre production today, with the rest made up of natural fibres, mostly cotton, and a relatively small but steadily growing share of mostly wood-based man-made cellulosic fibres.

As the global population and with it global textile consumption keeps growing, significant efforts are needed to reign in the carbon and environmental footprint of the sector and at the same time reduce its dependence on fossil hydrocarbons.

"To defossilise the textile sector, all fibres must originate from renewable carbon."

The energy required for fibre or renewable feedstock production, the processing and manufacturing of textile products, their distribution and logistics to the consumer as well as the entire use and end of life phase must be rapidly decarbonised. This requires CO2-neutral energy generation and transport systems, whose development is largely beyond the scope of the stakeholders in the textile sector. The types and amounts of energy used in specific industrial textile processes however can be more directly influenced by the development and adoption of low and mostly electric energy-powered processing technologies. At the same time, the water consumption of traditional wet processes must be minimised or replaced by completely water-free processing options.

"Significant scientific and technology breakthroughs, will be necessary to make a meaningful dent into today's fossil carbon consumption of the textile sector over time."

While energy and transport can be decarbonised, this is not possible for the actual materials this industry processes. Literally, 100% of fibres used in the textile sector are carbon-based and no amount of imagination and ingenuity will change this fact, lest humans decide to become entirely virtual creatures. For this reason, the only viable strategy can be the gradual reduction and eventual phase-out of all directly fossil-based carbon used for textiles. To *defossilise* the textile sector, all fibres must originate from renewable carbon. Three principal sources of such renewable carbon are available: (1) the carbon inherent in previously produced and used textile materials i.e. recycling; (2) the carbon captured and transformed into fibres or renewable feedstocks by the

biosphere i.e. natural or bio-based man-made fibres and (3) further into the future, directly captured carbon from the atmosphere. Significant scientific and technology breakthroughs, near term especially in strategies 1 and 2, will be necessary to make a meaningful dent into today's fossil carbon consumption of the textile sector over time. This includes agriculture and biotechnology, new processing technologies along the entire fibre-textile-clothing value chain as well as the use and end of life stages of textile-based products. And since the global textile sector is huge and complex, this will be a multi-decade marathon, not a sprint.

While this process is ongoing, the potential for optimisation of resource footprint in production and use of current materials and processes is still massive and needs to be unlocked through better design, more durable products, more resource-efficient processing and manufacturing, regionally closer value chains, smarter purchasing decisions, new business models favouring longer and more intense use of each produced item – in short, less but better production and consumption.

The following research and innovation topics and sub-topics address primarily defossilation strategies through recycling and biobased materials. Decarbonisation strategies as well as the resource reduction and optimisation strategies on our way towards a fossil-free CO2-neutral textile economy are mostly addressed in Theme 4.

Topic 1: Textile Circularity

Design, manufacturing concepts and business models for product quality, longevity and circularity

- Design for product quality, use intensification and longevity
- Design for recycling
- Design with recycled materials
- Business models and management systems for effective circularity

Efficient sorting, separation and recycling concepts and technologies for all types of textile waste

- Collecting and sorting processes and technologies
- Separation and pre-treatment processes and technologies
- Recycling processes and technologies

Quality standards, identification and tracing of recycled materials

- Standards development
- Analysis, identification and prediction systems
- Tracing approaches and tools

Innovation to increase durability and reduce fibre release of textile products

- Fibre and yarn technology for durability
- Textile processing for durability and low fibre release
- Reduced impact of fibre release

Topic 2 : Biobased & Natural Fibres

Biomass and waste incl. agricultural residues and captured carbon as fibre feedstock

- Agricultural crops and forest resources as fibre feedstocks
- Agricultural residues, food production and other biological waste streams

- Exploitation of renewable carbon sources from other industrial processes incl. captured CO2

Process and application-specific innovation of biobased manmade fibres

- New and improved biobased man-made fibres
- Processing of textiles made of biobased fibres

Agricultural and industrial processing innovation to valorise EU natural fibres

- Hemp, flax and other EU-origin bast fibres
- Wool and other animal-based fibre sources
- Standards and industrial value chain

Innovation Theme IV: Safe, Low Footprint Products, Processes & Responsible Supply Chains

As shown under theme 3, the textile and clothing sector has a significant cumulative CO2 and resource impact at the global level. However, textile materials and products also have a very local or personal impact on the health and well-being of individuals, communities, and the environment we live in.

Whether as a farmer on a cotton field, a machine operator in a textile processing plant, a seamstress in a garment factory, a fashion designer in a studio, a shop assistant in a high street store, a fashion consumer, a medical professional, or patient, firefighter or soldier, billions of people around the world derive income, comfort, protection, and self-expression from textiles on a daily basis. Our built and natural environments benefit from textiles that decorate and furnish, that protect from cold, rain, sun, or heat, that isolate and sound-absorbing, that protect crops from insects and soils from erosion, that hold cargo and absorb shocks, that filter pollutant, bacteria, and even viruses.

At the same time, textile production, use, and end of life treatment creates water, soil, and air pollution, exposes workers and consumers to potential health hazards from chemicals used in the processing and contained in textile articles, exploits workers in precarious jobs with insufficient workplace safety, damages biodiversity through unsustainable farming practices and disrupts local economies and communities when factories close and production gets off-shored to lower-cost locations.

"Many interactions between textile materials, human health, and environmental impact are highly complex, insufficiently studied, poorly understood, strongly context and exposure specific, and dynamically changing over time."

Many of these negative effects of textile production and consumption are largely or entirely avoidable. It is the responsibility of the industry to constantly strive for greater safety, sustainability, and responsibility in their operations and their products, as it is on workers and consumers to claim them. Policymakers need to set legislative frameworks from the local to the global level that limits and disincentivise negative impacts of the textile business, weighted against the benefits of economic prosperity and improved comfort and quality of life that industrial activity and textile consumption generate.

"Many interactions between textile materials, human health, and environmental impact are highly complex, insufficiently studied, poorly understood, strongly context and exposure specific, and dynamically changing over time."

However, not all negative impacts can simply be outlawed overnight. Many interactions between textile materials, human health, and environmental impact are highly complex, insufficiently studied, poorly understood, strongly context and exposure specific, and dynamically changing over time. Examples include potentially carcinogenic or skin-sensitising effects of different textile chemicals, the release, dispersion, living organism uptake, and disposal of fibrous microparticles

(aka. microplastics), or the long-term effect of persistent per- and polyfluorinated alkyl substances (PFAS) in soils and groundwater. In these and other cases, significantly more basic research is needed to better understand and assess the nature and scale of the risk and to devise mitigation or remedy actions.

Even in cases where health and environmental risks are well understood, they must be weighed against the benefits derived from the use of such substances or materials, especially when functionally equivalent substitutes are unavailable. Examples include heat and flame-retardant treatments for protective clothing or certain anti-bacterial or anti-viral finishes used in medical applications. Industry-wide efforts to detoxify textile chemistry must be supported by public research and innovation and realistic phase-out processes in cases of market failure or persistent technical challenges. Closed loop or effective end of pipe treatment solutions may be intermediate steps until fully functional non-toxic alternatives are industry-ready.

Beyond pure safety concerns, it also vital to develop a sounder understanding of the parameters and determinants of broader resource impacts of textile materials, products and processes to devise strategies to minimise them. Methods such as life cycle assessments or concepts such as product or process environmental footprints, need to be fully mapped out, practice tested and adapted to specific cases. Risks of overwhelming complexity and variability as well as misinterpretation or misuse of data (aka. green-washing) must be addressed through a regulatory level playing field, widely adopted practical standards, open data access and constant improvement processes.

"As no large-scale reshoring of traditional textile and clothing manufacturing to Europe is imaginable due to a sheer lack of available skilled labour, new manufacturing concepts powered by highly digitised and flexibly automated technologies such as microfactories are needed."

The relative ease by which many textile products can be globally transported and the low- to medium technology nature of their production, especially garment making, has driven the textile business to develop complex geographically far-flung supply chains to exploit comparative advantages in input costs, especially labour. This global expansion has created a first industrialisation wave and millions of manufacturing jobs in countries whose economies before were mostly dominated by subsistence farming and small scale artisanal activities. Countries such as Turkey, China, India or Mexico used the textile and clothing sector as a stepping stone towards a more diversified technologically advanced industrial economy. As average wages rose in these countries, the most labour cost sensitive garment making operations moved on to less developed countries, which may in time follow a similar economic trajectory.

The complexity of the global textile supply chain with its many participating countries on various levels of economic development also brings with it a host of challenges to ensure optimal levels of safety, sustainability and responsibility. Lack of transparency as well as availability and reliable traceability of data is a major impediment that needs to be addressed through adoption of global standards, use of information and communication technologies and extensive training of all actors.

Like the decarbonisation and defossilisation of the textile industry, this can only be a long term process given the widely differing starting conditions in terms of economic development, education, political stability and regulatory and administrative sophistication of the global players involved. More accessible, user-friendly, intuitive technology solutions combined with a general

move towards greater global transparency and regulatory harmonisation will provide the main underlying drivers.

Risk and vulnerabilities of complex global supply chains were exposed by recent global disruptions such as the COVID pandemic, military conflicts or environmental disasters. This leads to a rethinking of political and business leaders in all world regions, recognising the importance of more strategic regional independence and the resource access and complete manufacturing capacities needed for it. As no large-scale reshoring of traditional textile and clothing manufacturing to Europe is imaginable due to a sheer lack of available skilled labour, new manufacturing concepts powered by highly digitised and flexibly automated technologies such as microfactories are needed. Closer regional loops will also benefit the circular economy paradigm and provide scope for closer collaboration between designers, makers and users.

The following topics and subtopics highlight concepts and technologies that can make low footprint, safe and responsible textile products, processes and supply chains a reality in Europe and world-wide.

Topic 1: Safe materials and better chemistry

Development of 'safe and sustainable by design' textile materials

- Product safety including absence of restricted substances
- Low emissions during production, use and disposal/recycling
- Certified material and energy inputs incl. recycled content
- Longevity, repairability and recyclability
- Social responsibility

Methods and technologies for contaminant identification and removal

- Contaminant identification
- Contaminant removal
- Standardisation and management

Development of non-toxic/biobased alternatives for textile chemistry

- Substitution of restricted or substances of concern in textile chemistry
- Biobased textile chemistry

Topic 2 – Low impact textile operations

Data, methods and tools for carbon footprint and environmental and human health impact assessment and management of textile products and processes

- Basic research and data needs
- Harmonised methods adapted to textile materials, processes, and products
- Management and education tools to generate, monitor, optimise and communicate impact data

Resource-efficient low emission processing technologies incl. closed-loop recovery systems

- Innovative low-energy or waterless processing technologies
- Resource-recovery and closed-loop processing systems
- Flexible, small-footprint processing technologies
- Intelligent machine planning, control, and monitoring systems

Topic 3 – Transparent supply chains and new working environments

Technologies for transparent, fully traceable impact-optimised textile supply chains

- Conceptual & technological capacities for supply chain transparency
- Technologies for identification and tracing of textile materials/products
- Standards and training for supply chain transparency and traceability technologies

Innovative collaborative technologies and working environments for textile design, manufacturing, repair and upcycling

- Technologies to replace monotonous, hazardous and low added value manual labour processes in textile/garment manufacturing, repair and recycling operations
- Technologies for micro-factories, prototyping labs, digital ateliers and maker spaces where designers, makers and consumers can co-create

3. Human Resources and Skills for a Successful Transformation

The European textile and clothing industry before the Covid-19 pandemic employed well over 1.4 million people. In 2021, the figure dropped to 1.3 million. However, the long-term consequences of the last two years are yet to be seen, as many governments implemented protective measures to mitigate the crisis impact on the workforce and companies adopted ad-hoc changes to the types of products made, suppliers used and markets served. Preexisting forecasts for sectoral employment evolution, therefore, require reevaluation. Nevertheless, certain characteristics remain unchanged – the average age of the European textile and clothing workforce is rapidly increasing. According to EUROSTAT, in 2020, 37% of the workforce was over the age of 50, which means that in the coming decade the industry will lose almost 500,000 of its employees, as well as their skills, and knowledge, simply due to retirement. Consequently, the textile and clothing industry will be facing the challenge of retaining existing competences, on top of necessary adaptation to the new needs and increased demand for green and digital skills. This affects other sectors with links on the level of production or services with the textile ecosystem.

One of the greatest challenges of the industry is therefore the attraction and retention of talent. The deep sector restructuring and reduction of employment that took place since the beginning of the 21st century left a negative impact on the general image of the textile-related jobs in terms of their attractiveness and safety, leading to a decreasing interest of young people to seek career opportunities in the industry, with the exception of design and marketing-related job profiles. This decreasing demand influenced also sectoral education and training infrastructure. Vocational schools were closed or downsized, and textile and clothing departments at colleges and universities were often combined with other departments or faculties and lost their focused identity and significant resources in terms of teaching and research staff and budgets.

Despite the challenges, Europe continues hosting the most diversified and world-leading textile higher education infrastructure, which attracts top students and researchers from around the globe. On top of that, with the increasing need to access scientific and advanced technological knowledge, the collaboration with other PIE (Policy, Industry, and Education providers) stakeholders is generally strengthening. Initiatives both on the national and European levels play a key role in turning the tide.

In Northern and Western European countries in which the higher added value transformation of the industry has advanced the most, student numbers are increasing over the last couple of years, recreating a virtuous circle of higher education and training demand leading to the strengthening of the institutions providing it.

This trend is further fuelled by the establishment of the leadership of specialised education and training in regional innovation clusters and industry-supported initiatives to attract high potential

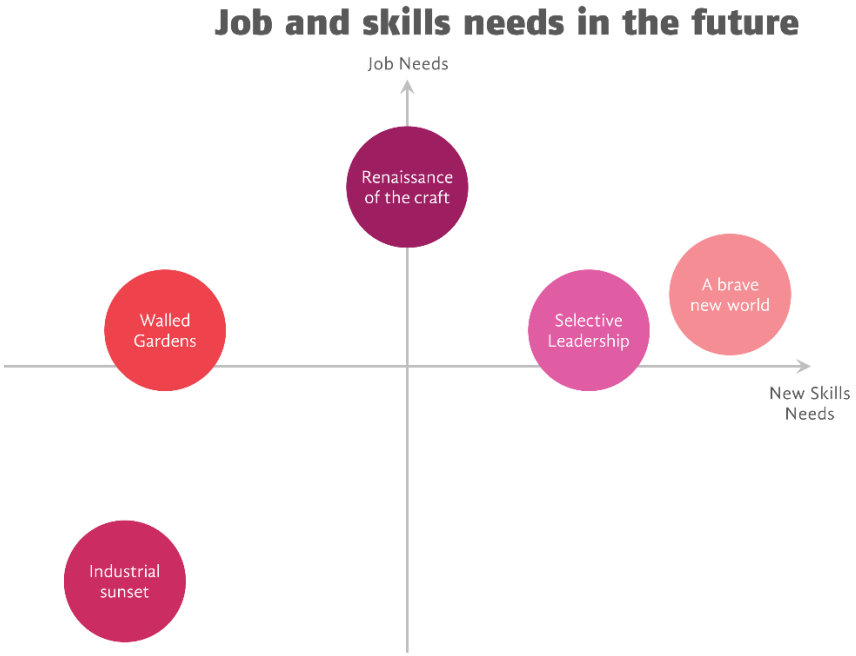
young talent. However, in some countries, especially the EU Member States in Eastern Europe, a collaboration between stakeholders still requires setting up or reinforcement.

From the European perspective, the European Commission continues to support the textile and clothing industry both on the policy and project level. It dedicates its resources to supporting equal upskilling opportunities, as well as initiatives focused on sectoral sustainability and innovations to increase its global competitiveness.

In 2012 the Commission launched the European Skills Council for the Textile, Clothing, and Leather (TCLF) sectors, which has done extensive work to assess the skills and qualification situation and future needs in the industry. It concluded that apart from professionals with higher education levels in technology, management, and creative disciplines, the market needs also qualified personnel at operation and technical levels covering all functions of processing and assembly, packaging and logistics, quality assurance, and maintenance. The research results were further updated and translated into eight MOOCs (Massive Open Online Courses) within the Skills 4 Smart TCLF Industries 2030 Erasmus + project, launched under the Blueprint for sectoral cooperation on skills.

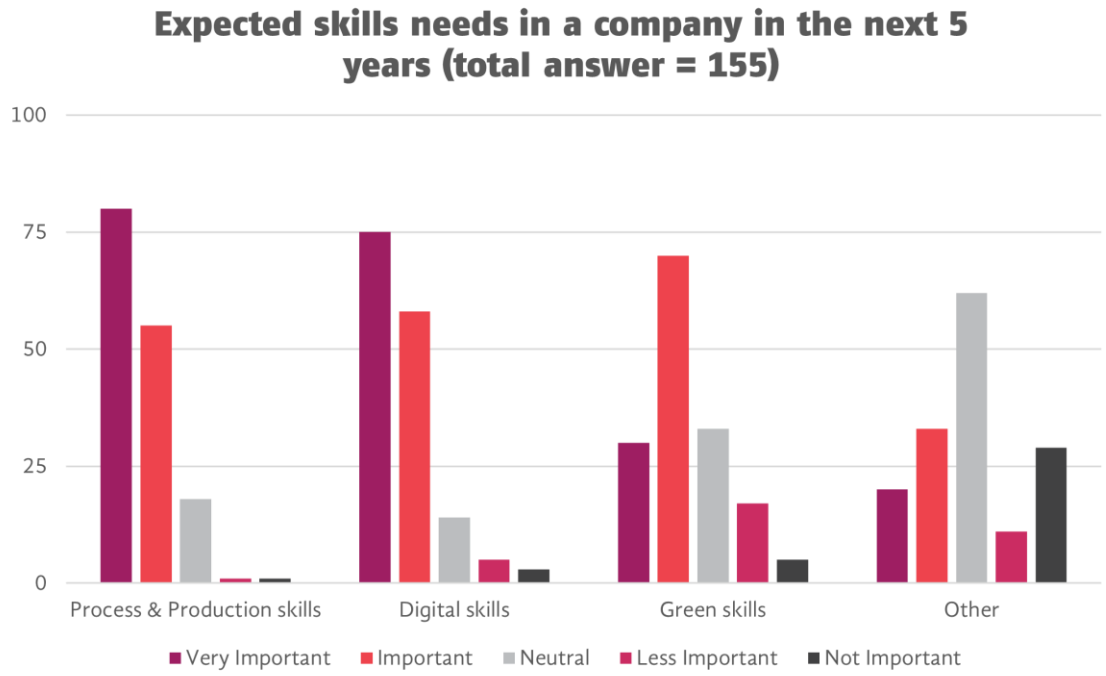
A supplementary result of the project is the establishment of the Sectoral Skills Strategy for the TCLF industries, which consists of European level analysis and nine corresponding national strategies of the partner countries. Results of the extensive research included an analysis of the macroenvironment trends, that guided the development of five potential future scenarios of how the industries will look like by 2030, in terms of production, but also employment and required skills and competences (See graphic below).

Brave New World, Selective Leadership, Renaissance of the Craft, Walled Gardens, and Industrial Sunset present distinct alternative pictures of the future of the industry that can embrace or disregard the upcoming changes in the areas of green and digital skills. A lot will depend on companies remaining secluded and traditional or fully open to the challenges of the green and digital transition and the required cross-industrial collaboration. According to the results of a series of interviews with PIE stakeholders, the likelihood of the latter happening is rather high, pointing in favour of the Selective Leadership and Renaissance of the Crafts scenarios, prioritising the importance of new green and digital skills while maintaining a strong grip on traditional material and manufacturing competences.



This means, that new and transversal skills and qualifications will need to be acquired by employees, which will be further implemented in digitisation of factories, workplaces, and supply chains as well as in sustainability, circularity, and resource-efficiency strategies in production and value chain management. However, special attention must be given to the preservation and generational transfer of highly specialised competences and rare skills related to traditional material and manufacturing techniques, to niche applications of textiles or unique design skills.

The importance of honing green and digital skills was also recognised within the Pact for Skills for the TCLF industries launched in December 2021 under the European Skills Agenda and reiterated in the EU Strategy for Sustainable and Circular Textiles. Under the five charter points, signatories of the Pact for Skills aim to promote a culture of lifelong learning with an increase in apprenticeship programmes and new tools and methodologies for the upskilling and strengthening skills partnerships, including cross-sectoral ones, monitoring skills supply/demand in fashion established by the European Skills Council. On top of that, signatories set the goal to work against discrimination and to support gender equality, crucial for the industry, which while employing mostly women (69%), faces consistent gender imbalance at the management level.



To succeed in the Green and Digital Transformation, it is important to include green and digital skills in initial education curricula, but also in continuous vocational training programmes. Moreover, the delivery of VET programmes must be flexibly adapted to the realities of the SME-based industry. They must be available in the proximity of the companies, ideally include practical hands-on sessions at technology-equipped training facilities, at learning factories, at digital learning labs, or directly at the workplace. They must also make use of online and virtual learning concepts and technologies such as MOOCs or follow the approach of gamification and edutainment of learning. The increase of interest of policymakers in the TCLF industries as well as various bottom-up initiatives opens new opportunities for the European textile and clothing manufacturers in the coming years.

4. Policy Recommendations

How Systemic Innovation Works

It is a common misconception that big paradigm shifts are due to some sudden life-changing event or one single grand idea, great inventor or leader. Crediting James Watt with the start of the industrial revolution, would be as misguided as making Marie Curie or Albert Einstein responsible for nuclear power or the atomic bomb or calling Gordon Moore the inventor of the IT revolution.

Nobody intentionally created the Renaissance in Northern Italy nor did anybody decide to launch Silicon Valley. No massive accident is required to create a huge traffic jam. It is the number, density and speed of travel of the cars on the road behind some disturbance that count. Equally it is not the resilience of a single seedling that guarantees the growth of a tall tree, but the millions of seeds that every single tree sends into the reproduction race every year and of which sometimes one finds all the right circumstances to germinate in fertile soil and grow into adulthood. So what can we learn from this for the likelihood and contributing factors for a successful sustainable transition of the textile sector in the coming decades?

When carefully studying past socio-economic shifts or so-called (sectoral) industrial revolutions it becomes obvious that many different factors need to come together for a lasting large-scale effect to emerge. What is needed are new scientific knowledge and available technologies, an abundance of players and resources, and favourable framework conditions over a sufficiently long period of time characterised by freedom to experiment, to fail, collect feedback, improve, exchange and compete until new stable patterns of successful operation and prosperity emerge.

Innovation happens at large scale when many economically incentivised actors collaborate and compete to solve new problems or satisfy new needs that an increasing number of people perceive. Necessity is the mother of all invention, but real economy-impacting innovation only arises if the invented solutions can be created at large scale, are reliably workable, affordable and ultimately useful for a massive customer population. The emergence of new problems or needs among a large population are typically the result of shifts of underlying cultural narratives in a society. Slightly differing narratives across cultures can lead to dramatic impacts on acceptance or rejection of fundamental technologies and related economic developments. Examples include the general acceptance of genetically modified food crops in the United States based on a dominant positive narrative of a more efficient and affordable food production vs. their general rejection in Europe based on a dominant negative narrative of perceived health or environmental risks from this technology. Dominant narratives leading to acceptance or rejection of nuclear energy are diametrically opposite even across neighbouring countries in Europe.

The push for a more sustainable and circular textile economy is based on the narrative that this industry is having an unacceptably high global resource impact which counteracts

European and global efforts to fight climate change, often amalgamated with seemingly related problems such as local pollution or biodiversity damage from intensive fibre crop cultivation or textile production emissions, degradation of human health or well-being due to use of toxic substances, poor working conditions or inadequate remuneration of workers.

Advocacy to address these problems by concerned politicians, scientists, non-governmental organisations, the media and even industry players themselves, who seek to satisfy changing consumer demand due to this narrative shift, have led to a broad enough societal consensus to submit the textile sector in Europe to a legislatively driven fundamental shift in its operating model in the coming years. The train towards a sustainable circular textile economy in Europe has been set in motion and it is likely to gather further speed.

The question therefore is not if, but how we can ensure that this train moves towards its intended destination at a speed that meets the set objectives and in a way that allows all committed and necessary stakeholders to come on board whilst mitigating unintended negative consequences or opportunities for free riders.

A Policy Framework for the Systemic Sustainable and Circular Textile Transition

An interesting and instructive parallel can be drawn to the global response to the COVID pandemic and its major success story, the creation of remarkably effective and safe vaccines in record time. Why was it that two previously small and unknown research-driven pharmaceutical companies in Europe and the US won the global vaccine race with an innovative technology that lacked any pre-existing large-scale use? And how could they succeed in the manufacturing and distributing billions of vaccine doses that allowed the world to emerge from this sanitary crisis?

,First, the objective was very clear and well-understood from the start. There was an urgency of large-scale need and a massive economic incentive for the eventual winners of the race. There was technological openness and, at least in Western countries, an absence of complex top-down planning or prospective picking of winners. There was an existing ecosystem of researchers, technology developers, established pharmaceutical companies, contract manufacturers and service providers that could cover all the aspects necessary for large scale testing, manufacturing and distribution of the new vaccines.

Regulators were massively supportive and accommodative using accelerated review and approval processes. Public and private investors provided massive funds, making high risk bets on hundreds of potential solution providers, most of which eventually failed. Policy makers and the media unleashed a supportive education and promotion campaign that succeeded to convince the vast majority of citizens that a mass-vaccination campaign was the best course of action to fight the pandemic. Public funds were used for ad-hoc set up of large-scale vaccination infrastructure and to pay for the vaccine and its delivery into billions of arms.

Which general recommendations can be made for a successful sustainable textile industry transformation based on the above-described historical evidence of significant past economic shifts and inspired by the COVID vaccine success story?

- The scope and objectives of the transition have to be clear, understood and agreed upon among all stakeholders, to avoid the "blind men and the elephant" problem. They have to be defined qualitatively and quantitatively with an evolutionary path that allows for regular milestone assessment and possibility for path correction. Too many sub-objectives, secondary 'battlegrounds' and alternative scenarios are likely counterproductive.
- The rules of the new game have to be set as clearly, transparently and unambiguously as possible, made known to all players and enforced reliably.
- Strategies and tactics however should be left as much as possible to the stakeholders to allow for the emergence of prospectively unimaginable solutions.
- Technological neutrality and openness as well as multidisciplinarity should be important guiding principles and experimentation at small and local scale should be encouraged, incentivised and rewarded – maximising the number of shots on goal is generally more promising than maximising the resources invested in a single shot.
- A gradual transition from conventional to sustainable and from linear to circular operation with phase out periods, exceptions for disadvantaged stakeholders (small scale operators, start-up's etc.) and transitory solutions must be acceptable.
- Long term public support for the solution of hard scientific, technological or operational challenges for which market stakeholders lack the means or time horizons must be provided.
- Losses from rigorous high risk - high reward, but ultimately futile bets must be acceptable.
- Ecosystems of knowledge providers, technology scouts, brokers and transfer agents, teachers, trainers and communities of practice must be developed at regional level and interconnected EU-wide.
- Intentional misinformation and use of poor, incomplete or misrepresented data must be effectively fought against across the entire spectrum from greenwashing to unsubstantiated industry bashing or environmental fearmongering.

A sustainable circular textile economy cannot be created by decree, nor will it emerge spontaneously just because we wish it to be so. The European and global textile sector is a huge industry with long established technologies, processes, supply chains, modes of operation and know-how and skills of professionals and consumers that were conditioned over years and decades. It cannot be reset overnight without creating disruptions such as bankruptcies, job losses, product shortages, consumer price increases and other non-intended consequences in Europe and around the world.

Only a concerted and sustained effort by all stakeholders over years and decades can bring about systemic change with a truly measurable impact on global climate change, biodiversity, environmental and human health and well-being, without undue losses of prosperity.

Ten Concrete Research and Innovation Policy Recommendations to Make The Systemic Green and Digital Textile Transition a Reality by 2030

Research and innovation, like in the fight against the COVID pandemic, is the most powerful and versatile tool in our transformation toolbox. Amara's law states that we tend to overestimate the impact of new technologies in the short run, but underestimate it in the long run. Most innovation is incremental. But incremental innovation accumulating over time can lead to truly disruptive outcomes. If the objectives and the rules of the game are clear and the resources are provided, many innovators will add their ideas and hard work towards a rapidly accelerating transformation of the textile sector over the coming years and decades. European policymakers should use their rule-setting capacity and the funds at their disposal to unleash the sustainable textile innovation race.

The below recommendations are concrete examples of how EU programmes for research and innovation can make an impact:

1. Set up a dedicated budget of **€50 million** under HORIZON EUROPE to carry out foundational empirical studies and rigorous meta-analyses of existing research into fundamental knowledge gaps and barriers of textile sustainability such as processing comparable GHG impact and environmental footprint data of major textile fibre types, manufacturing processes and products; release, the environmental and human health impact of fibrous microplastics; testing of innovative chemistry and processes which can substitute hazardous chemicals during production, use and recycling/disposal.
2. **Invest €1 billion** (equalling approx. 1% of the EU Research & Innovation Framework Programme budget in 2023-2030) into collaborative research and innovation projects for the systemic green and digital transformation of the EU textile sector until 2030.
3. **Invest €3 billion** (equalling 1% of estimated European Regional Development Funds ERDF from 2023-2030) **into regional sustainable textile research, education and technology transfer infrastructure**, collective support structures (clusters), and **operational programmes for SME innovation and investment**.
4. Set up a €**50 million cascading funding programme** in HORIZON EUROPE (2023-2026) to support up to 250 experimental SME and start-up driven projects in circular, biobased and digital textile innovation for sustainability.
5. Set up a **European network of Sustainable Textile Innovation Hubs** by 2024, based on existing textile research, higher education and vocational education and training as well industry association and cluster infrastructures in major textile and clothing manufacturing regions across Europe.
6. Set up a **network of Recycling Hubs** across Europe to bring innovative textile recycling processes and technologies for major categories of textile waste to a pre-industrial pilot scale by 2025 using the EU I3 funding instrument and national/regional funds from RSFF.
7. Set up a **European community of practice for textile sustainability and circularity** among researchers, education professionals, industry, policy, and civil society experts by 2023.
8. Dedicate a budget of **€100 million** from the Common Agricultural Policy in 2023-2030 for research and innovation programmes into **sustainable cultivation and development** of technologies and demonstration of a **complete industrial processing chain for major EU-based natural fibres** and biobased fibre feedstocks. Such fund should be complemented by measures in the European agricultural fund for rural development (EAFRD) directed at rapid scaling of available fibre and feedstock volumes.
9. Fund the development of **new and updated curricula, learning approaches, and tools** dedicated to initial and continuous **vocational and higher education for sustainable, circular, and digital textile** operations aligned with the TCLF Pact4Skills under the ERASMUS+ programme.
10. Strategically dedicate budgets from the EU's neighbourhood policy, trade, external relations, and development programmes to **collaborative research, innovation, education, and standardisation actions with partners in neighbouring and third countries** who play crucial roles as material, technology, service providers or key customers for the sustainability and competitiveness of Europe's textile and clothing industry.

Financial resources are not all that is needed. But incentives drive behaviour and financial incentives are the strongest behavioural driver of economic actors. Entrepreneurial activity is financial risk-taking in the face of uncertainty, but with promise of near-term reward. Innovation is risk-taking in the face of even higher uncertainty and generally longer-term reward. By shouldering some of the financial risks, public authorities can encourage more players, including SMEs, start-ups,s, and non-profits, to engage in sustainable textile innovation and thereby speed up technological

progress. If the sustainable and circular textile transition is a high priority for EU policies the above-described small percentages of available funds should be well worth spending and if this industry transformation offers the rewards for people, the planet, and profit that its proponents claim, this investment will pay back manyfold.

Beyond the bottom up incentivising and supporting of many small to large scale innovation projects, an overarching programmatic governance system must be set up to ensure that there is a sufficient level of EU-wide communication, best practice exchange and light-handed coordination between the multitude of actions and multiple helix stakeholders so as to prevent duplication of efforts, wasted resources or disconnected island solutions. Smart regulation and extensive use of green public procurement must ensure that successful new experimental and pilot solutions scale rapidly into common industrial practice.

Glossary of abbreviations

AI	Artificial intelligence
AR	Augmented reality
CNP	Carbon nano particles
CNT	Carbon nano tubes
CPS	Cyber-physical system
CRM	Customer relationship management
CVD	Chemical vapour deposition
EoL	End of life
EPR	Extended producer responsibility
ERP	Enterprise resource planning
ETP	European Technology Platform
FC	Fluor carbon
FR	Flame retardant
IoT	Internet of Things
IR	Infrared
LCA	Life cycle assessment
LED	Light emitting diode
ML	Machine learning
NFC	Near Field Communication
NFT	Non-fungible token
NIAS	Non-intentionally added substances
NIR	Near infrared
OLED	Organic light emitting diode
PA	Polyamide
PEF/PEF-CR	Product environmental footprint/ product environmental footprint category rules
PFAS	Per- and polyfluoroalkyl substances
PHA	Polyhydroxyalkanoates
PLA	Polylactic Acid
PP	Polypropylene
PPE	Personal Protective Equipment
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals.
SC-CO2	Supercritical Carbon Dioxide
SCM	Supply Chain Management
UV	Ultraviolet
VET	Vocational Education and Training
VR	Virtual Reality

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- Future needed skills and trends for the TCLF sectors, Report of Skills4Smart TCLF Industries 2030, 2019 https://s4tclfblueprint.eu/project/results
- Towards the 4th Revolution of Textiles and Clothing, A Strategic Innovation and Research Agenda for the European Textile and Clothing Industry, European Technology Platform for the Future of Textiles and Clothing, Textile ETP, 2016, https://textile-platform.eu/what-we-do

Useful further information sources

- The European Technology Platform for the Future of Textiles and Clothing, www.textile-platform.eu
- EURATEX – The European Apparel and Textile Confederation, www.euratex.eu
- Textranet – Textile Transfer Network, www.textranet.net
- NETFAS – Network of Textile and Fashion Universities of Applied Sciences, www.netfas.eu
- EU-TEXTILE2030 – European Network of Advanced Textile Materials Clusters, https://eu-textile2030.eu
- AUTEX – Association of Universities for Textiles, www.autex.eu
- European Commission, EU Strategy for Sustainable and Circular Textiles, https://ec.europa.eu/growth/industry/sustainability/strategy-textiles_en
- European Commission - HORIZON EUROPE Programme: https://ec.europa.eu/info/research-and-innovation/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en
- S4TCLF – EU ERASMUS+ funded project under Blueprint for Sectoral Cooperation on Skills initiative, https://s4tclfblueprint.eu

About the Textile ETP

The European Technology Platform for the Future of Textiles and Clothing (Textile ETP) is the largest European network dedicated to textile research and innovation. Its main objectives are to ensure the long-term competitiveness of the EU textile and clothing industry through collaborative research across national borders in Europe and a rapid translation of research results into industrial innovation.

Textile ETP carries outthink tank and roadmapping work as input to strategy development of its members and research and innovation policy development at EU and national level in Europe. In addition, it provides its members with information services about EU textile research funding opportunities, organises brokerage of partnerships for EU research funding applications and supports members in disseminating results of EU-funded textile research projects. Textile ETP currently runs two European Masterclasses on Smart Textiles and Innovation and Circular Biobased Textile Innovation, each with over 250 participating experts. In addition, it regularly organises physical and online conferences and seminars on textile innovation trends and new technology developments to enable knowledge exchange and networking among its members and other organisations interested in textile research and innovation in Europe.

Textile ETP currently has about 165 member organisations from industry, research, and higher education with over 700 registered individual experts. For more information, **visit:** www.textile-platform.eu

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