China Council for International Cooperation on Environment and Development

SPECIAL POLICY REPORT

Promote High-Quality Development with Circular Economy

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China Council for International Cooperation on Environment and Development (CCICED)

Promote High-Quality Development With Circular Economy

CCICED Special Policy Study Report

CCICED

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Executive Summary

The **Special Policy Study (SPS) "Promote High-Quality Development with Circular Economy"** conducted under the umbrella of the China Council for International Cooperation on Environment and Development (**CCICED**) Task Force on Sustainable Production and Consumption aims to identify key pathways toward a high-quality, resource-efficient, and inclusive circular economy by analyzing international best practices, conducting comparative policy assessments, and focusing on sector-specific insights in textiles and chemicals.

The global economic system remains largely linear, driving unsustainably high levels of resource extraction, greenhouse gas emissions, and environmental damage, thereby exacerbating the triple planetary crisis. In this context, to decouple economic growth from resource consumption, the circular economy has gained political momentum globally, with more than 75 countries (including China and Germany) adopting circular economy-related strategies and roadmaps and building regional alliances.

Since China is a leading manufacturing hub and consumer of raw materials worldwide, its role in transitioning to a circular economy is pivotal. China's circular economy development aligns with its constitutional "ecological civilization" concept, in which economic growth should not come at the cost of environmental degradation. Additionally, a series of national laws supporting this concept have been issued, and the Circular Economy has already been integrated into high-level policies, including the "14th Five-Year Plan for Circular Economy Development." Domestically, China's circular economy policies contribute to its long-term economic development strategy. Significant progress has been made in recycling infrastructure, digitalization, and resource efficiency. For example, in 2024, China's resource recycling industry reached a scale of 401 million tonnes, with a total value of 1.33 trillion yuan, with over 260,000 enterprises in the sector. Internationally, China's policies have large consequences on global supply chains. Therefore, advancing a high-quality circular economy in China carries regional and global significance, offering pathways for sustainable development, competitiveness, and international leadership.

The European Union (EU) is the major driver of circular economy adoption in Europe. Over the past decade, circularity has become integral to the EU's broader sustainability and industrial strategies, including the Green Deal, the Circular Economy Action Plan, and the Clean Industrial Deal, which highlight the circular economy as a key to future economic competitiveness and climate neutrality. A series of horizontal and sector-specific legislations, including the Ecodesign for Sustainable Products Regulation (ESPR), has been introduced to realize the implementation of the underlying policy objectives. In Germany, the National Circular Economy Strategy (NCES) is guided by the overarching goal of significantly reducing primary raw material consumption by 2045 and outlines ambitious targets for increasing the total share of secondary raw materials, enhancing raw material sovereignty and supply security and preventing waste.

Globally, however, circularity remains limited, with only 6.9% of material flows being circular. National efforts are often fragmented, underfunded, and lack binding targets. Key issues such as social equity, just transition, and global coordination remain underdeveloped. Advancing a high-quality circular economy requires strong governance frameworks and targeted policy interventions to level the playing field between linear and circular models while internalizing environmental costs. The circular economy policies of Germany and China hold the potential to foster structural changes, reduce primary raw materials, close material loops, and strengthen the competitiveness of circular systems. However, in the context of international value chains, it requires strong global partnerships and binding commitments to develop a high-quality circular economy which benefits all while also respecting planetary boundaries.

In the textile sector, fast fashion continues to promote overconsumption and low-quality garments. Hazardous substances complicate reuse and recycling, while the willingness for consumer engagement in circular textile development is low. In both the EU and China, technical limitations (such as the lack of recyclability and underdeveloped sorting and recycling technologies and infrastructure) are slowing progress. Promising technologies, like depolymerization for recycling synthetic fibres or automated sorting infrastructure, are still in development and have not been scaled yet. Furthermore, fragmented policy frameworks and supply chains, insufficient financial incentives, and a lack of digitalization in the entire value chain hinder progress.

The chemical industry, which is a key economic sector in Germany and China, still relies largely on fossil resources. Thus, a key strategic question is to diversify its feedstock to support a switch to non-fossil and sustainable alternatives. The key challenge is to integrate strategies, such as chemical recycling, carbon capture use and storage, and the use of biogenic materials in the waste hierarchy. A systemic transformation of the chemical industry requires a good mix of innovative approaches based on a robust assessment of environmental and economic impacts, as well as of potential risks and future market development. From the environmental point of view, waste prevention, reduction, reuse, and mechanical recycling must be preferred and supported.

Recommendations

In the following, overarching policy recommendations are summarized to support a wide-scale implementation of a circular economy in China and globally. The policy recommendations seek to provide impulses to the Chinese government for consideration in the 15th Five-Year Development Plan and in the reform of the Circular Economy Promotion Law. The recommendations highlight areas where bilateral cooperation between China and Germany in the field of circular economy, as part of the Sino-German Environment Partnership, can be taken forward.

1. Strengthen top-level design and high-quality development of the circular economy, linking it with the "Dual Carbon" strategy during the 15th Five-Year Plan period (2026-2030)

Firstly, recommend setting the overall goal of "Circular Development," as well as specific targets such as improving resource productivity, increasing the proportion of recycled materials, and raising the recycling rate of renewable resources in the 15th Five-Year Plan. For instance, establish quantitative targets, preferably mandatory, for primary raw material consumption, secondary raw material use, waste prevention and use of safe, high-quality recycled materials, including control of and substitution of hazardous chemicals and recycling incompatibilities, in selected consumer goods sector (e.g., textiles, consumer electronics, home appliances) as well as in high-impact sectors (e.g., building/ construction, vehicles and batteries). Further develop sector-based roadmaps in the 15th FYP for the Circular Economy toward achieving the goals. Define socio-economic indicators to monitor progress, such as investments in circular technologies and industries, contribution of circular industries to the gross domestic product, and generation of employment.

Secondly, deepen and expand the pilot programs of "Zero-Waste City" and "Key Cities for the Construction of Waste Materials Recycling Systems" by adding incentive policies, e.g., allocating the resources of the “Two Major Incentives” and the “Two New Engines” to favour “Zero-Waste City” pilots, to promote the coordination of solid waste management and circular economy. Select representative cities to pilot the establishment of infrastructure for a circular economy and link them with modern, automated, and digitalized sorting and recycling systems, for instance, exploring and piloting the sustainable model of used textile collection and sorting, and improving used home appliance collection systems. Also carry out national procurement pilots for the supply of waste raw materials (e.g., used textiles, used electronics, used EV batteries).

Thirdly, on the basis of the Ecological Environment Code, accelerate the revision of the Circular Economy Promotion Law, expand pilots for extended producer responsibility systems and further strengthen the establishment of some fundamental regulations, such as ecodesign and the requirement of mandatory utilization of recycled materials, including a clear distinction between different options of recycling for achieving recycling targets. This will provide a legal foundation for comprehensively advancing and implementing a high-quality circular economy.

Fourthly, link circular economy development with the "Dual Carbon" goals, and incorporate circular economy measures into China's carbon emissions reduction goals. Accelerate and improve research into carbon emission calculation methodology, emissions factors, accounting standards and market trading mechanisms related to solid waste resource utilization, develop a model for calculating emissions reduction of recycling solid waste, evaluate the contribution of emissions reduction, and establish a "Double Carbon" evaluation and assessment system by incorporating the construction of Zero-Waste Cities.

Fifthly, promote the development of China’s carbon trading market by conducting research into methodologies for China Certified Emission Reduction (CCER) projects, in particular the CCER for key bulk industrial solid waste and low-value recyclables with significant emission reduction potentials to enhance market competitiveness. This work can be linked closely to the carbon pricing mechanisms in the EU, such as the Carbon Border Adjustment Mechanism (CBAM).

Sixthly, establish a Central Leading Group for the Circular Economy and set up a national special fund for comprehensive treatment of solid waste, strengthening coordination between circular economy development and economic, industrial, energy, environmental, climate, and other related aspects.

2. Actively promote high-quality circular economy transformation in line with the principles of the waste hierarchy in key industries, cultivate new engines for economic growth, and achieve synergies between economic growth and green, low-carbon development

Firstly, promote the in-depth integration of the circular economy in the green transformation of key industries. Promote the coordinated transformation of resource recycling and energy efficiency improvement in traditional high-energy-consuming industries (such as the iron and steel, cement, and chemical industries), for example, vigorously promoting the green manufacturing of circular economy industrial chains in the chemical industry. In emerging industries (such as new energy and semiconductors), plan the recycling system of renewable resources in advance.

Secondly, encourage and support the development of high-quality, high-performance and high-value products and business models based on circular economy principles, including replace, reuse, refill, refurbish, remanufacture, repurpose, as well as recycling (e.g., fibre-to-fibre, bottle-to-bottle, chemical-to-chemical). Define and establish a hierarchy of different recycling technologies based on robust environmental and economic assessment of treatment options. Explore the development of "the closed-loop" path suitable in China’s context and gradually expand the scope of pilot demonstrations.

Thirdly, jointly establish a circular economy R&D platform and talent training system, which brings together government, university, research institutions, and enterprises, with enterprises as the core. Vigorously develop technologies for high-quality recycled materials, defossilized materials, and promote technological innovations and research for "the closed loop" of high-impact materials. Accelerate and expand the professional and skillful talents training for the circular economy, and ensure training initiatives actively target gender responsiveness.

Fourthly, accelerate the construction of integrated industrial chains encompassing "eco-design—remanufacturing—recycled raw materials—product use services (e.g., reuse, maintenance, and repair)—collection—recycling." Increase technological and institutional innovation, strengthen the development and extension of circular economy industrial chains.

Fifthly, actively cultivate leading enterprises in the circular economy industry through demonstration of "Zero-Waste Enterprises," "Zero-Waste Groups," "Zero-Waste Industrial Parks," and "Large-Scale Demonstration Parks and Enterprises for Comprehensive Utilization of Solid Waste." Expand the scale of the circular economy industry to achieve economies of scale, reduce the costs of recycled products, and improve market competitiveness.

Sixthly, increase dedicated investment in resource utilization and treatment of bulk industrial waste. Accelerate R&D and demonstration of recycling technologies. Encourage strong collaboration and partnerships among industrial waste producers, resource recovery technology owners, and local governments.

Seventhly, expand and accelerate the cultivation of demand markets for recycled raw materials or products through demand-side guidance and management. For example, establish circular product labelling and subsidy mechanisms to encourage and guide consumers to choose more circular products, and guide public institutions to prioritize green public procurement of products with ecolabels of high circularity.

Eighthly, accelerate the integration of digital technologies in the circular economy. Establish a digital traceability system for materials and products based on raw materials and the entire industrial chain (e.g., draw upon the experience of the "Battery Passport" and gradually extend it to other industries or products like textiles and building materials). Concurrently, conduct research and demonstration applications of blockchain-based data management and sharing technologies to address data issues such as security, quality, credibility, privacy protection, and sharing.

3. Accelerate the establishment of standards and assessment systems for circular economy technologies and products at the national and local levels

Firstly, expedite research into and establish standards of design and production for circular products. Clearly stipulate requirements for product durability, repairability, recyclability, quality of recycled raw materials, and usage percentages.

Secondly, expedite research into and establish standards specifying required levels of quality for recycled raw materials and circular products.

Thirdly, expedite research into and establish standards of testing, analyzing and rating the recycled materials and products, along with the establishment of a robust network of third-party testing facilities, with laboratories with the equipment and trained personnel necessary to perform compliance testing.

Fourthly, expedite research into and establish a robust market supervision system, including comprehensive assessment and certification schemes, to ensure rigorous market supervision. Supervision efforts should prioritize high-risk sectors and products with significant environmental impacts.

Fifthly, expedite research and establishment of product databases based on raw materials and chemicals.

4. Accelerate innovation in green finance and financing mechanisms to support the establishment of circular economy business models

Firstly, develop specialized financing instruments (e.g., Circular Economy Transition Bonds) to provide preferential financing for establishing circular economy business models.

Secondly, enhance the market competitiveness of circular economy enterprises through supportive economic incentives such as tax incentives and targeted subsidies. For example, provide specific economic incentives for measures such as substituting fossil-based raw materials with scientifically proven, environmentally friendly alternatives, increasing the proportion of recycled raw materials used, and remanufacturing products.

Thirdly, leverage the carbon market to support circular economy projects, promoting synergy between carbon reduction, pollution control, and green growth.

Fourthly, increase the efforts of green bonds and green loans to serve resource recycling projects, establish the "Classification Catalog of Green Finance Supporting Circular Economy," clarify the classification standards of circular economy projects in "green finance," establish a project financing performance evaluation method and system based on recycling effect, carbon emission reduction effect and data efficiency improvement effect, and encourage "green + circular" financial innovation.

5. Strengthen international cooperation to promote global circular economy development and green, low-carbon transition

Firstly, strengthen the alignment and mutual recognition of domestic recycling product certification standards with international standards (e.g., EU standards).

Secondly, explore the potential form of global trade flow of waste materials; and establish strict control standards to prevent trade flows of chemicals, materials and waste that are illegal according to multilateral environmental agreements (Basel, Rotterdam, and Stockholm Conventions), or harmful to the environment and human health in the destination countries.

Thirdly, actively participate in and promote circular economy topics within international processes. For example, China and Germany, together with relevant stakeholders, should actively and jointly promote updating the work plan of the G20 Resource Efficiency Dialogue to ensure the circular economy remains high on the G20 agenda in the coming years; leverage the UN Environment Assembly (UNEA) to support establishing an international process aimed at reducing global raw material consumption while ensuring a just circular economy transition. Promote bilateral and multilateral cooperation on the plastic circular economy after the negotiation of global plastic treaty, and take the plastic circular economy as a key means to control plastic pollution.

Fourthly, incorporate the circular economy into international cooperation frameworks such as the "South-South Cooperation." Build cross-border renewable resource standards and regulatory systems with partner countries to promote international green resource circulation; promote the construction of green industrial parks and disseminate China's successful experience in "Zero-Waste Cities."

Fifthly, actively conduct Track 2 dialogues on the circular economy, and actively create opportunities for Track 1.5 and even Track 1 dialogues. Through bilateral or multilateral dialogues, clarify doubts, enhance mutual trust and understanding, and jointly advance global multilateral processes on the circular economy and climate change. For example, China and Germany should continue deepening their cooperation under the "Sino-German Dialogue on Circular Economy and Resource Efficiency" and "Sino-German Circular Economy Partnership," strengthen bilateral cooperation within the Sino-German environmental partnership, and deeply exchange circular economy practices at business and policy levels, to promote the development of a circular economy roadmap for the industry. It is recommended to strengthen China-EU dialogues on international trade, deeply discussing the potential impacts of measures like the Carbon Border Adjustment Mechanism (CBAM) and Extended Producer Responsibility (EPR) on developing the circular economy, and the response measures China should adopt.

Apart from overarching policy recommendations for promoting the circular economy in China and globally, the SPS also formulated **sector-specific recommendations for textiles**:

Firstly, promote circular design and improve market conditions of circular textile production to counter fast fashion: Policy-makers should support the development of textile design standards that improve product quality and circularity, addressing durability, repairability, recyclability, and recycled content quotas. Economic mechanisms should be implemented to enhance the competitiveness of circular textiles, such as tax incentives, extended producer responsibility schemes, subsidies for circular manufacturing, and preferential tariffs for circular products. Demand for circular textiles should be boosted by integrating circularity criteria into public procurement and ecolabels, while also fostering the second-hand market through digital platforms. Finally, it is vital to develop action plans involving all textile sector actors to increase transparency on hazardous chemicals and on the use of hazardous chemicals in the textile value chain, for instance, by using digital product passports. Harmful group of substances, such as PFAS, should generally be avoided and phased out as far as possible, or strict control measures of any use and recycling stream must be in place, where applications are still essential and alternatives are lacking, and targeted research should be done where uses are considered critical for society and no suitable alternatives exist yet.

Secondly, build and scale up collection and sorting capacities and integrate digital solutions: Textile waste collection infrastructure should be scaled up to ensure sufficient quantity and quality of material input for fibre-to-fibre recycling. China should scale up textile waste collection infrastructure by strengthening household waste classification and expanding dedicated recycling bins for textiles. Efforts should focus on extending recycling operations to third- and fourth-tier cities to improve waste textile collection at the source. To improve sorting and recycling efficiency, China and the EU should invest in automated textile sorting systems. Key industry players like China Resource Recycling Group can **lead** in building waste textile sorting centres and support the "Waste-Free City" initiative in selected cities. Implementing Digital Product Information Systems (DPIS) with material composition data is crucial for efficient textile recycling. These digital systems should be simple, cost-effective, and interoperable across markets to enhance sorting efficiency and traceability in the recycling value chain. The introduction of an EPR scheme for textiles is essential to address the economic viability of textile recycling and must cover both domestic and imported goods with effective monitoring.

Thirdly, promote preparation for reuse, develop standards and scale up various textile recycling technologies: Preparation for reuse should always be the preferred option over recycling. The effectiveness of preparation for reuse can be achieved by establishing quality standards for textiles and developing skills and technologies for identifying good-quality textiles that are deemed ideal for reuse. As textile recycling faces technical barriers and lacks infrastructure, it is crucial to develop and scale various recycling technologies. The selection of recycling processes should be guided by technical, economic, and environmental factors. Promising methods, like depolymerization for fibre-to-fibre recycling, should be advanced. The waste textile recycling industry needs a stronger standard system, including quality regulations. This should address market bottlenecks for recycled products and improve hygiene and disinfection standards for second-hand clothes. Finally, it is essential to expedite the development of an information-based traceability system for recycled fibres that meets international standards, ensuring higher-quality management and certification for recycled textile products.

Fourthly, implement export regulations for textile waste: Restrict textile waste exports to countries that cannot prove proper end-of-life treatment of textiles. Establish clear, internationally aligned End-of-Waste criteria for textiles to differentiate between reusable textiles and waste. Support should be provided to importing countries for the development of environmentally sound recycling and end-of-life treatment infrastructure.

Fifthly, phased approach to implementing recycled content quotas: Financial incentives and economic tools are essential to increase recycled content in textiles. Recycled content quotas depend on the availability of high-quality, affordable, and clean fibres. Quotas should be fibre-specific. PET fibres should be excluded from quotas to maintain the PET bottle-to-bottle recycling loop. Binding quotas must be traceable and monitorable to avoid market distortions. If recycled fibre content cannot be reliably traced at the product level, setting sector-specific recycled content targets could be a transitional solution.

Sixthly, cross-cutting measures: Increase support for national R&D programs focused on circular economy technologies, especially for textile recycling. Accelerate the R&D of chemical recycling methods for waste textiles, aiming to achieve large-scale, low-cost production of recycled fibres. Advance technologies for fibre separation, decolourization, traceability, and contaminant removal. Promote recycling of standardized clothing like uniforms through pilot programs with capable enterprises. Enhance training in circular economy, textile design, and digital skills.

Furthermore, the report separately elaborates on Germany's reflections and initiatives in addressing the plastic circularity crisis, as well as the efforts of Chinese chemical enterprises to achieve green and low-carbon transformation through the practice of circular economy principles. It highlights that the circular economy is crucial for the chemical manufacturing industry to tackle environmental challenges, enhance resource security, foster economic growth, promote innovation, and align with national sustainable development goals. When advancing the circular economy through chemical approaches, it is essential to avoid path dependency, ensure a level playing field, and strengthen policy support and implementation coordination.

Key words: Circular Economy, Textiles Industry, Chemical Industry, Recycling, China

Nomenclature

ACEA	African Circular Economy Alliance
AEC	Framework for Circular Economy for the ASEAN Economic Community
AFIRM RSL	Apparel and Footwear International RSL Management Group – Restricted Substances List
AI	Artificial Intelligence
AR	Augmented Reality
ARE	Group of Seven Alliance for Resource Efficiency
ASEAN	Association of Southeast Asian Nations
BMBF	Federal Ministry of Education and Research (Bundesministerium für Bildung und Forschung)
BMUKN	Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (Bundesministerium für Umwelt, Klimaschutz, Naturschutz und nukleare Sicherheit)
BMUV	Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz)
CAD	Computer-Aided Design
CAS	Chemical Abstract Service
CBAM	Carbon Border Adjustment Mechanism
CBM	Circular Business Model
CCER	China Certified Emission Reduction
CCICED	China Council for International Cooperation on Environment and Development
CCU	Carbon Capture and Use
CE marking	European Conformity（Conformité Européenne）marking
CEA	Circular Economy Act
CEAP	Circular Economy Action Plan
-CF3	fully fluorinated methyl (-CF3)
CID	Clean Industrial Deal
CLP	Classification, Labelling and Packaging of chemicals
CMUR	Circular Material Use Rate
CNY	Chinese Yuan
COM	European Commission
COP	Conference of the Parties
COP28	28th Conference of the Parties to the United Nations Framework Convention on Climate Change
COVID-19	Coronavirus Disease 2019
CPC	Communist Party of China
CRMA	Critical Raw Materials Act
CTC	Catalytic Tribochemical Conversion
DPIS	Digital Product Information Systems

DPP	Digital product passports
DSP	Disodium Hydrogen Phosphate Dodecahydrate
DWR	Durable Water Repellent
EA	Environment Assembly
EC_1	European Community
EC_2	European Commission
ECHA	European Chemicals Agency
EEA	European Environment Agency
EEB	European Environment Bureau
EEC	European Economic Community
ELINCS	European List of Notified Chemical Substances
EPR	Extended Producer Responsibility
ESPR	Ecodesign for Sustainable Products Regulation
ETC CE	European Topic Centre on Circular Economy and Resource Use
EU	European Union
EV	Electric Vehicle)
FECO	Foreign Environmental Cooperation Center
FONA	Research for Sustainability (Forschung für Nachhaltigkeit)
Fraunhofer ISI	Fraunhofer Institute for Systems and Innovation Research
FYP	Five-Year Development Plan
G20	Group of Twenty
G7	Group of Seven
GACERE	Global Alliance on Circular Economy and Resource Efficiency
GDP	Gross Domestic Product
GFC	Global Framework on Chemicals
GHG	Greenhouse Gas
GIZ	German Corporation for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit)
GOTS	Global Organic Textile Standard
HD Institute	Beijing Huanding Environmental Big Data Institute
ICCA	International Council of Chemical Associations
IEA	International Energy Agency
IOMC	Inter-Organization Programme for the Sound Management of Chemicals
IRP	International Resource Panel
IUPAC	International Union of Pure and Applied Chemistry
JRC	Joint Research Centre (of the European Commission)
LCA	Life Cycle Assessment
MEE	Ministry of Ecology and Environment
MIIT	Ministry of Industry and Information Technology
MMCF	Man-Made Cellulosic Fibre
MRSLs	Manufacturing Restricted Substances Lists
NABU	Nature and Biodiversity Conservation Union (Naturschutzbund Deutschland)

NCES	National Circular Economy Strategy
NDCs	Nationally Determined Contributions
NDRC	National Development and Reform Commission
NFC	Near Field Communication
NGO	Non-Governmental Organization
NIR-based technologies	Near-Infrared-based technologies
NKWS	Nationale Kreislaufwirtschaftsstrategie
NLP	No Longer Polymer
NRW	North Rhine–Westphalia
OECD	Organisation for Economic Co-operation and Development
Oeko-Institute	Oeko-Institut – Institute for Applied Ecology (Öko-Institut e.V.)
OEWG	Open-Ended Working Group
PAN	Pesticides Action Network
PCBs	Polychlorinated Biphenyls
PET	Polyethylene Terephthalate
PFAS	Per- and Polyfluoroalkyl Substances
PFC	Perfluorinated Compounds
PFCA	Perfluorocarboxylic acids
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctanesulfonic acid
PSA	Pressure Swing Adsorption
PTFE	Polytetrafluoroethylene
PV	Photovoltaic
QR	Quick Response (code)
R & D	Research and Development
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RED	G20 Resource Efficiency Dialogue
RES	Renewable Energy Sources
RFID	Radio Frequency IDentification
RMC	Raw Material Consumption
RSL	Restricted Substances List
SAICM	Strategic Approach to International Chemicals Management
SCIP	Substances of Concern in articles as such or in complex objects (Products) database
SDG	Sustainable Development Goals
SMEs	Small and Medium-sized Enterprises
SoCs	Substances of Concern
SOE	State-Owned Enterprise
SPS	The Special Policy Study
SUSTech	Southern University of Science and Technology
SVHCs	Substances of Very High Concern

UBA	German Environment Agency (Umweltbundesamt)
UMSICHT	Fraunhofer Institute for Environmental, Safety and Energy Technology (Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik)
UN	United Nations
UNDP	United Nations Development Programme
UNEA	United Nations Environment Assembly
UNEP	United Nations Environment Programme
UNEP/EA.5/Res.11 (2022)	Resolution 11 adopted at the 5th United Nations Environment Assembly of UNEP, 2022
UNFCCC	United Nations Framework Convention on Climate Change
UNIDO	United Nations Industrial Development Organization
USA	United States of America
VR	Virtual Reality
VTT	State Technical Research Centre (Valtion Teknillinen Tutkimuskeskus)
WCA	Waste Composition Analysis
WEEE	Waste Electrical and Electronic Equipment
WWF	World Wide Fund
ZDHC	Zero Discharge of Hazardous Chemicals

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1. Foreword

The Special Policy Study—Promote High-Quality Development With Circular Economy—under the research umbrella of the CCICED Task Force on Sustainable Production and Consumption, was launched in January 2025. The goal of this SPS is to compile the best practices for the circular economy in different countries, examine and identify the potential for the high-quality development of the circular economy in textiles and chemicals, and make recommendations for implementing the circular economy in China and globally.

In 2025, the research team carried out research on comparing the policies of circular economy development among China, Germany, the European Union (EU) to identify the key issues and challenges, as well as in-depth field investigations and case studies with selected companies in the textile and chemical manufacturing sectors respectively to further understand the pathway and enablers for how to make the transition toward a circular economy. In addition, the research team also organized several workshops, discussions, and study tours to gather insights from both Chinese and international experts on how to develop a high-quality circular economy.

1.1 Research Background

In recent years, the idea of a systemic **shift toward a Circular Economy** and away from the linear "take-make-waste" economy has attracted growing international attention. The linear "take-make-dispose" model, characterized by high raw material consumption and significant environmental impacts, remains dominant across most economic sectors. According to the International Resource Panel, resource extraction could rise by 60% until 2060 compared to 2020 levels (UNEP 2024b). This trend is expected to exacerbate the ongoing triple planetary crisis of climate change, biodiversity loss and pollution and waste. In general, there is a broad consensus on the relevance of developing a circular economy to respond to these challenges, and many countries, including China and Germany, have adopted national strategies and policy measures with the aim of reshaping their economies. **However, despite growing awareness**, **global material use is still increasing, and the circularity of the global economy is actually in decline** (Circle Economy 2025).

Transition to a circular economy, therefore, urgently requires the alignment of a comprehensive set of policy measures addressing all aspects of economic development. While many issues are cross-cutting—including the need for innovation, regulation and financial incentives—the transition to a circular economy also presents sector-specific challenges and opportunities that require targeted analysis. This report, therefore, concentrates on the textile and chemical manufacturing sectors as examples, highlighting specific opportunities and challenges in these value chains, while also drawing out wider lessons that can be applied to other sectors.

The global textile industry consumes about 3.25 billion tonnes of materials annually, with over 99% coming from virgin sources. Globally, roughly 61% of textile waste ends up in landfills or is incinerated (Circular Economy, 2024). As the world's largest textile producer and exporter, China is a major player in global textile production and trade, and its policies affect not just the domestic economy but also have far-reaching consequences for the world market. The Chinese government announced in 2022 that the recycling rate for used textiles should be 25% by 2025. By 2030, a rate of 30% and 3 million tonnes of recycled fibres are to be achieved (State Council of the People's Republic of China 2022). In Germany, approximately 1 million tonnes of used textiles are collected annually, reflecting a collection rate of around 64%. The majority (about 62%) is prepared for reuse, while roughly 26% of collected textiles are recycled (Wagner et al. 2022).

The chemical manufacturing sector also plays a foundational role in many product value chains, and is particularly important to many national economies, including Germany and China. Since 2000, the global production of the chemical industry has nearly doubled from about 1.2 to 2.3 billion tonnes (UNEP 2019). The chemical industry also contributes to extensive resource depletion, huge energy consumption, and heavy environmental pollution and climate change challenges. Promoting best practice and developing a model for the chemical industry via implementing circular economy principles will ensure a transition toward a greener, more efficient and low-carbon economy in China, Germany, and the global market.

1.2 Research Objective

The SPS "Promote High-Quality Development with Circular Economy" 2024-2025 aims to compile the best practices for a circular economy in different countries, examine and identify the potential for the high-quality development of the circular economy in textiles and chemicals, and make recommendations for implementing the circular economy in China and globally.

1.3 Structure of This Report

In order to consider the conditions necessary for high-quality development of the circular economy, this report will first provide an overview of circular economy policies and progress, considering and comparing the international status of circular economy as a policy goal, the extent to which it has been addressed in policy in the German, European, and Chinese levels, and the extent to which the impacts of these policies can be observed (Section 2). It is concluded that strong governance frameworks and targeted policy interventions are required to level the playing field between linear and circular models while internalizing environmental costs, as well as strong global partnerships and binding commitments which address global value chains.

In sections 3 and 4, the textiles and chemicals sectors are considered as examples of critical product value chains where a circular economy is needed. In these sections, the specific drivers and challenges present in these value chains—both in the German and Chinese context, as well as the interlinkages between these geographies driven by trade dynamics—are considered, and sector-specific policy recommendations are devised. As part of this analysis, case studies from both sectors were also prepared.

In Section 5, gender aspects which must be accounted for when addressing the circular economy are addressed. This is essential not just in relation to the social benefits which should be central to sustainable development, but also for building more resilient and inclusive economic transitions.

Finally, in Section 6, the overarching recommendations developed as a result of this SPS are presented. These recommendations seek to address the general and sector-specific challenges and gaps identified in sections 2-5. The result is a comprehensive framework of practical recommendations which address the full spectrum of policy levers available to governments

In addition to the SPS report, the study team has also provided a range of relevant annexes, with the goal of enriching the information provided in this report on relevant policies, laws, studies, and initiatives. These annexes are referred to throughout the text.

2 Progress of Circular Economy Development: Policy Perspective

2.1 Progress of International Circular Economy Initiatives

Circular economy strategies play a critical role in addressing climate change by reducing resource extraction, minimizing waste, and cutting greenhouse gas emissions across value chains. Up to 45% of global emissions come from the production of goods, making material efficiency and circularity essential mitigation levers. Applying circular economy strategies in just five key sectors (cement, aluminum, steel, plastics, and food) could cut emissions from goods production by nearly half by 2050 (saving 9.3 billion tonnes of CO_2e, equivalent) (GACERE, 2021). Circular economy strategies are also helpful to significantly reduce the carbon footprint of the textile sector (3.5% of global carbon emissions) and the chemical sector (5% of global carbon emissions). Thus, at the global level, circular economy efforts have gained significant momentum. According to the **Global Stocktake** of National Circular Economy Roadmaps (2024), by UNIDO and Chatham House, **75 national circular economy initiatives** (calls to action, roadmaps, and operational strategies[1]) have been published since 1999, with most emerging after 2016[2] (Barrie et al., 2024). European countries account for the greatest share (70%), while a growing number are published across Latin America, Africa, and Asia since 2018. The national strategies cover diverse policy actions across several sectors and themes. The most proposed measures involved knowledge exchange, multistakeholder cooperation, fiscal instruments, and innovation and research support. Extended Producer Responsibility (EPR) was the most frequently mentioned individual policy measure. Policy priorities slightly varied across regions: in Latin America, the focus tends to be on workers' and consumers' rights; in the Asia-Pacific region, on trade policy, circular infrastructure, and international governance; while in Europe, greater emphasis is placed on policy design and governance, monitoring, and fiscal instruments (Barrie et al., 2024).

Despite this potential, circular economy approaches are not yet widely integrated into countries' Nationally Determined Contributions (NDCs) under the Paris Agreement. As of 2023, only 28% of NDCs explicitly mention the circular economy, while they are often limited to waste management and lack concrete measures. This leaves significant untapped potential for integrating circularity across sectors like agriculture, industry, and transport. (UNEP, UNDP and UNFCCC secretariat 2023). Thus, there is a need to link the circular economy holistically to climate commitments.[3]

Alongside national plans, several **regional and international initiatives** have been launched to foster greater cross-border collaboration and coordination, such as the EU's Circular Economy Action Plan (CEAP) (see Section 2.2), the African Circular Economy Alliance (ACEA)—a government-led coalition of 15 African nations working together to catalyze the shift to a circular economy (African Circular Economy Alliance n.d.), or the Association of Southeast Asian Nations' (ASEAN) Circular Economy Framework—in which the 10 member states have established a common long-term vision and priority areas (ASEAN Circular Economy

[1] According to the classification in the 2024 global stocktake "Calls to action" are initiatives that kickstart dialogues and coordinated efforts on Circular Economy, often laying the groundwork for future strategies or roadmaps. "Roadmaps" provide a long-term vision for circular economy development, highlighting key priorities and policy actions to guide future detailed planning. 'Operational strategies' detail time-bound actions, responsible actors, governance, and financing, and are often part of official government programs.

[2] This includes China's (operational strategy according to global stocktake classification) "14th Five-Year Plan" Circular Economy Development Plan (2021-2025), laying out (among others) quantitative targets for resource productivity, circularity, energy and water consumption, and recycling output; and Germany's NKWS (roadmap according to global stocktake classification).

[3] To support this, UNEP (together with UNDP and the UNFCCC Secretariat) have developed a toolbox (Building Circularity into NDCs – A practical toolbox) to guide policy-makers in identifying negative trends and entry points for circular economy interventions, prioritizing sectors, quantifying benefits using suitable indicators, exploring financial options, and tracking and reporting of progress to accelerate ambition and implementation of their NDCs (UNEP, UNDP and UNFCCC secretariat 2023).

Stakeholder Platform n.d.). In addition, the topic of circular economy is increasingly being taken up in multilateral forums, including the **G7 Alliance for Resource Efficiency (ARE), G20 Resource Efficiency Dialogue (RED)**, and COP 28, where **circular economy was officially recognized for the first time** in a UN climate negotiation outcome. Furthermore, ongoing UN-level negotiations (since 2022) on an International Plastic Treaty aim to establish a legally binding agreement to end global plastic pollution while addressing the full life cycle of plastics. Germany plays a leading role in these talks, having co-founded the **High Ambition Coalition to End Plastic Pollution** and advocating for a strong and ambitious treaty (UNEP, 2025a; BMUV, 2024). A list of regional and international circular economy initiatives can be found in **Annex A.**

In short, the circular economy has achieved widespread recognition as a solution to achieving material well-being while respecting planetary boundaries and has arguably become mainstreamed as a political priority. However, at the national level, many initiatives **lack assigned owners**, while **binding targets and secured funding are often missing**. Only 48% of "roadmaps" and "operational strategies" set quantitative goals, and few include clear financial commitments (Barrie et al., 2024). Implementation often suffers from **weak governance** structures, short-term political cycles, and **limited** cross-ministerial coordination. Moreover, essential aspects like **social equity** and just transition are frequently sidelined. In addition, there is not yet a governance structure for **global coordination and collaboration on the circular economy** when compared to the other two axes of the triple planetary crisis (climate change and biodiversity loss). In the context of our highly integrated global economy, multilateral and unified approaches will be essential for achieving true transition.

2.2 Circular Economy Policies in the European Union

The transition to a circular economy has become a central pillar of the EU's broader agenda for sustainable growth, economic competitiveness, and climate neutrality. At a high level, the EU has developed a series of strategies which outline a common vision for its 27 Member States. Since the adoption of the first Circular Economy Action Plan (CEAP) in 2015, circular economy policy in Europe has been updated and elaborated in several key policy initiatives, including:

- **European Green Deal** (2019): Outlines the EU's overarching growth strategy to become the world's first climate-neutral continent by 2050 and transform into an efficient and competitive economy, where economic growth is decoupled from resource use and no person or region is left behind. Circularity is one of its key elements, recognizing the role of reuse, repair, and recycling in reducing waste and conserving resources across key sectors (e.g., construction, food, transport) (European Commission, 2019, n.d.c).
- New **Circular Economy Action Plan** (CEAP, 2020): As a core building block of the Green Deal, the CEAP serves as a framework and future agenda for making circular and sustainable products, services, and business models the norm and keeping resources in the EU economy for as long as possible. It sets out strategic goals and proposes actions in key sectors with high circularity potential and impact, which are to be achieved through the subsequent adoption and implementation of legislative acts.[4] It promotes a circular economy approach that spans the entire product life cycle—from design and production, through the use

[4] Through these specific legislative measures, the CEAP aims to double the EU's circular material use rate by 2030, significantly reduce the consumption footprint, reduce pressure on natural resources, protect biodiversity, contribute to the 2050 climate-neutrality target, and boost economic resilience and job creation. Proposed measures include expansion of ecodesign requirements; banning the destruction of unsold goods; strengthening of EPR schemes and green public procurement; setting waste reduction targets, modernizing EU waste laws; mobilizing EU funds and private financing; empowering consumers through a right to repair and better product information; supporting and leading global circular economy and resource governance efforts.

phase, to recycling and lifetime extension via reuse and repair (European Commission 11 Mar 2020; n.d.a).

- **Clean Industrial Deal** (CID, February 2025): As part of the EU's industrial strategy, the CID provides a roadmap to accelerate industrial decarbonization while reinforcing the competitiveness and resilience of the European economy. Circularity is one of the six drivers for EU competitiveness in the Deal,[5] placing emphasis on the promotion of circular business models, technological innovations, and regional circularity hubs. It further includes plans to build an EU critical raw materials centre for joint procurement and create a harmonized EU market for recycled raw materials (European Commission 2025).
- Upcoming **Circular Economy Act** (CEA, COM proposal expected in 2026): The European Commission has announced in the CID a proposal for an EU CEA, aiming to strengthen the circular economy through targeted amendments of existing legislation. Ongoing discussion indicates three possible pillars and focus areas of the EU CEA: (1) Waste Framework Directive and Landfill Directive (2) Waste from Electrical and Electronic Equipment (WEEE) Directive, and (3) so-called "Flanking Measures" that include the harmonization of environmental tax bases and harmonize requirements for extractive waste management and critical raw material recovery. Specific measures currently examined include the expansion of EPR schemes, promoting circular public procurement, the harmonization of the End-of-Waste criteria, and incentivizing recycled content in production.[6] A stakeholder-driven consultation process will guide its development (European Commission 2025; 2 Jul 2025).

In terms of realizing policy aims—in particular the CEAP—the EU has also introduced a series of **horizontal and sector-specific regulations** (i.e., binding requirements applicable to all Member States of the EU) and **directives** (i.e., binding goals to be implemented in each Member State via national legislation by a specific date). Examples are listed in the **Annex B.**

In particular, the **Ecodesign for Sustainable Products Regulation** (ESPR) is the centrepiece of the EU's product policy framework. The ESPR represents both an update of existing rules on energy labelling and ecodesign (in place since 2009) to account for a broader range of circularity requirements, and an expansion of the range of product groups regulated within the framework (in particular, the expansion of ecodesign requirements from energy-related products to virtually all product types). Important to note is that the ESPR itself does not contain product-specific requirements. Rather, it **sets the general legal framework** for allowing performance and information requirements related to circularity. Product-specific requirements can now be set via secondary legislation (called delegated acts). Priority product groups—including textiles—and indicative timelines for the regulatory process are given in the ESPR and Energy Labelling Working Plan 2025-2030[7] (The European Parliament and the Council of the European Union, 2024). The delegated act on textiles is expected to be adopted in 2026 and will also include requirements for a digital product passport.

In short, the EU is the major driver of circular economy adoption in Europe. By taking action at the European level, sustainability goals can be pursued in a harmonized manner without creating barriers to the cross-border flows within the European single market (i.e., the trading block of European Member States as well as states in the European Economic Area. In practice, the regulatory requirements for items placed on the

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[5] The CID covers six key topics: Making energy affordable; creating lead markets and demand for green and clean products; financing the clean transition through public and private investments; powering the circular economy and securing access to materials; diversifying supply chains and ensuring the economic resilience of the EU industry; developing and investing in necessary skills and creating quality jobs.

[6] Objectives include, for instance, simplifying the movement of circular products and secondary raw materials within the EU; boosting availability and demand for recycled materials; making secondary raw materials cheaper and more competitive.

[7] Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52025DC0187&qid=1744814743855

EU market also have global ramifications, as to export to Europe, global value chains must adapt and improve the circularity of their products. For instance, the CE marking is a conformity mark that indicates that a product meets EU-wide requirements for safety, health, and environmental protection and may be freely traded on the European market. The Ecodesign Regulation (ESPR) sets specific requirements for environmentally friendly design and the environmental compatibility of energy-related products and is therefore a prerequisite for these products to be allowed to bear the CE marking. By combining sustainability goals with the economic goals of competitiveness and resilience, and the social goals of the just transition, the goal of the circular economy has won broad consensus across stakeholder groups in Europe, who participate actively via stakeholder consultation in the design of the tangible measures and requirements necessary for achieving high-level policies in practice.

2.3 Germany's National Circular Economy Strategy

Germany's National Circular Economy Strategy (**NCES**), adopted by the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (**BMUV**)[8] in 2024, provides a **comprehensive, cross-sectoral roadmap** and **strategic framework** for advancing circularity across the entire value chain—from product design to reintegration of secondary raw materials. Developed through an inclusive multistakeholder process,[9] the NCES integrates environmental, economic, and social perspectives and aligns with national and EU-level initiatives and legislation[10] to embed circular economy and resource-related objectives across all relevant raw material policies (BMUV, 2024; n.d.).

The NCES outlines **specific targets**, **actions**, and **instruments** across **key areas of implementation**[11] and defines a set of **cross-cutting issues**[12] with corresponding goals and measures for each. The strategy is guided by the **overarching goal** of **significantly reducing primary raw material consumption** by 2045 (aligning with the UNEP International Resource Panel's target of 6-8 tonnes per capita by 2050)[13] and additionally sets out three main objectives (BMUV 2024; n.d.):

1. **Closing material loops**: Doubling the total share of secondary raw materials by 2030 relative to 2021.
2. **Enhancing raw material sovereignty and supply security**: Reducing import dependencies by meeting key targets of the EU's Critical Raw Materials Act (CRMA)[14], including (1) domestic production of 10% of strategic and 40% of processed raw materials; (2) 25% of strategic raw materials from EU recycling by 2030; (3) no single non-EU country supplying more than 65% of any raw material.
3. **Preventing waste**: Promoting circular product design and reducing municipal per capita waste (**-**10% by 2030; **-**20% by 2045, relative to 2020).

Central to the NCES are the **10 R-strategies**, which classify circular economy measures (including refusing,

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[8] The NCES was published under the BMUV. The ministry has since been renamed the Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety (BMUKN).

[9] Ensured a diversity of perspectives and expertise by involving representatives from industry, civil society, academia, and policy-making.

[10] e.g., German Resource Efficiency Programme and Raw Materials Strategy; EU Waste Framework Directive and Ecodesign Regulation.

[11] Key areas of implementation: Digitalisation & the circular economy; circular & resource-efficient production; vehicles, batteries & mobility; ICT & electronic devices; renewable energy systems; clothing & textiles; construction & buildings; metals; plastics; public procurement.

[12] Cross-cutting issues: 10 R-strategies; product design for circularity & longevity; sustainable consumption & trade; standardization; economic instruments & financing; pollutant removal; circular bioeconomy & biogenic raw materials; global material flows; research & development; qualifications & training; waste prevention & recovery.

[13] Starting in 2030, this goal will be evaluated every 5 years with the involvement of the business sector and adjusted if necessary.

[14] Examples of strategic raw materials include battery materials (e.g., lithium, nickel, natural graphite, manganese, and cobalt), technology materials (e.g., rare earth elements for magnets, tungsten, germanium, and gallium), and enabling materials (e.g., copper, silicon metal, magnesium metal, and platinum group metals) based on the March 2023 proposal.

rethinking, and reducing) by their impact on circularity, reflecting a broad understanding of the circular economy beyond waste management. Through its circularity pathway, Germany seeks to promote **sustainable consumption**, **cut** industrial **carbon emissions**, and achieve its legally binding **climate goals**. At the same time, the circular economy is a key instrument to strengthen Germany's **economic resilience** and **competitiveness**, and **reduce reliance** on volatile **raw material imports** (BMUV, 2024; n.d.). In this way, the NCES embraces the previous work of other international institutions, such as the United Nations Environment Programme (UNEP/EA.5/Res.11 2022) and the European Commission (European Commission 2019; n.d.c), for including the key elements of a circular economy in its scope.

In addition, Germany seeks to become a leader in the transition to a circular economy by advancing a resource-efficient circular economy through strengthened bi- and multilateral partnerships, active engagement in international forums, and ambitious advancement of international progress (BMUV, 2024).

2.4 China's Circular Economy Strategy and Policies

In China, the circular economy has emerged as a key building block for integrating environmental sustainability into its long-term economic development strategy. Indeed, the concept of an "ecological civilization"—in which economic growth, human society, and the natural environment coexist in a state of harmonious balance—has been ingrained in China's Constitution, and the circular economy has been grounded by the National People's Congress in a series of national laws. In particular:

- The **Circular Economy Promotion Law** (enacted in 2008) established industry planning, assessment and management systems, and authorized fiscal support and government procurement incentives to advance reduction, reuse, and resource recovery in production, circulation and consumption.
- The **Environmental Protection Tax Law** (enacted in 2016 and revised in 2018) exempts solid waste utilization taxpayers that meet national and local environmental standards from environmental protection taxes.
- The **Solid Waste Pollution Prevention and Control Law** (revised in 2020) promotes a national green development approach, encourages clean production and circular economy development, and implements a waste classification system. It also sets systemic arrangements for the reduction, resource recovery, and treatment of industrial, agricultural, construction and household solid waste.
- The **Ecology and Environment Code** (draft under development) has set up a stand-alone chapter on Developing Circular Economy under the Part of *Green and Low Carbon Development*. Ongoing discussion calls for industrial policies to be consistent with the requirements of developing a circular economy, in addition to developing ad hoc circular economy plans, and indicates three pillars of clean production, recycling of waste, and green consumption. It proposes building several systems such as statistical indicators for tracking and evaluating circular economy development (e.g., material consumption, material use rate, waste generation); standards and/or guidelines for green design, green manufacturing, comprehensive use of industrial waste, and collection and recycling of municipal waste; extended producer responsibilities in selected sectors (e.g., electronic equipment, lead-acid batteries, automotive power batteries); mandatory circular material use in selected products (not specified yet); and information system for waste exchange.

The Chinese government has also been progressively setting goals and targets for the circular economy, updating these regularly to reflect the country's progress:

- In 2021, the State Council issued the **Guiding Opinions on Accelerating the Establishment and Improvement of the Green, Low-Carbon, and Circular Development Economic System,** which proposed that by 2025, the market-oriented green technology innovation system will be further developed, and a preliminary green, low-carbon, and circular production, circulation, and consumption system will be formed.
- In 2024, the State Council issued the **Opinions on Accelerating the Construction of a Waste Recycling System,** proposing that by 2030, a comprehensive, efficient and orderly waste recycling system will be established, with significantly increased scale and quality in the resource recycling industry.
- In 2024, the Central Committee of the Communist Part of China (CPC) and the State Council issued the **Opinions on Accelerating the Comprehensive Green Transformation of Economic and Social Development,** which further proposed a strong push for the development of the circular economy, with the goal that by 2030, the annual utilization of bulk solid waste will reach approximately 4.5 billion tonnes, with a 45% increase in major resource output compared to 2020.
- In 2024, the Central Economic Work Conference proposed to "promote carbon reduction, pollution control, greening, and growth, accelerating the comprehensive green transformation of economic and social development."
- In October 2024, a new state-owned enterprise (SOE) **China Resources Recycling Group Co., Ltd.,** was established. This new SOE, with a registered capital of CNY 10 billion, will focus on resource recycling and creating a national platform for resource reuse.
- In 2025, the **Government Working Report** calls for strengthening the reuse and recycling of waste and promoting the use of recycled materials.

Finally, the circular economy has already been integrated into high-level policies, in particular, the "14th Five-Year Plan for Circular Economy Development," the "14th Five-Year Plan for Zero-Waste City Construction," and the "14th Five-Year Plan for Urban Household Waste Classification and Treatment Facility Development." These plans are supplemented by policies such as the "Green Industry Guide Catalogue" and "Industrial Structure Adjustment Guide Catalogue." The government has also developed a resource utilization tax reduction catalogue for enterprises and a value-added tax reduction catalogue for resource utilization products and services. The government continues to increase funding for key circular economy projects through special funds and central budgetary support. Investment and financing policies, such as green credit, green securities, green bonds, and green insurance, have been introduced to support the development of the circular economy. Over 100 key technological projects for the circular economy have been launched through plans such as the "Circular Economy Special R&D Plan" to inject strong innovation momentum into the sector.

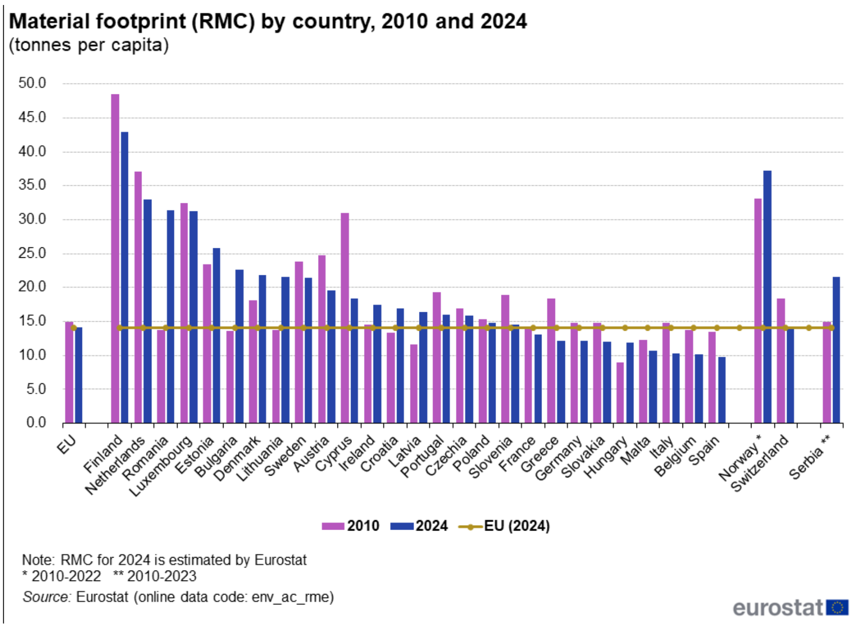
2.5 Circular Economy Progress in the EU, Germany, and China

In Germany and the EU, circular economy progress is assessed using comprehensive indicator frameworks. The **EU's Circular Economy Monitoring Framework** includes **11 statistical indicators**, some with additional sub-indicators, across five thematic areas.[15] **Germany's NCES** proposes similar indicators, aiming to capture environmental, economic, and social impacts. Key metrics to track progress toward a circular

[15] Thematic areas: (1) production and consumption; (2) waste management; (3) secondary raw materials; (4) competitiveness and innovation; (5) global sustainability and resilience.

transition include raw material consumption, circular material use rate, material productivity, and waste generation (BMUV, 2024; n.d.; European Commission n.d.a; eurostat n.d.; Prakash et al., 2023b; Lutter et al., 2022).

Raw Material Consumption (RMC) measures a country's material footprint, meaning the annual per capita amount of raw materials needed to satisfy a country's final demand (including domestic extraction and imports).[16] As a core indicator of the NCES, it reflects the strategic objective of reducing primary raw material use. In 2024, Germany's RMC stood at 12.2 tonnes per capita—slightly below the EU average (of 14.1 t/cap) but still significantly exceeding the UNEP's target of 6–8 tonnes by 2050. Over the years, progress in Germany has been limited, with stagnating numbers from 2010 (14.8 t/cap) to 2021 (15.19 t/cap), but a following positive trend to 12.2 t/cap in 2024. A comparative overview of RMC across European countries is provided in Figure 1.

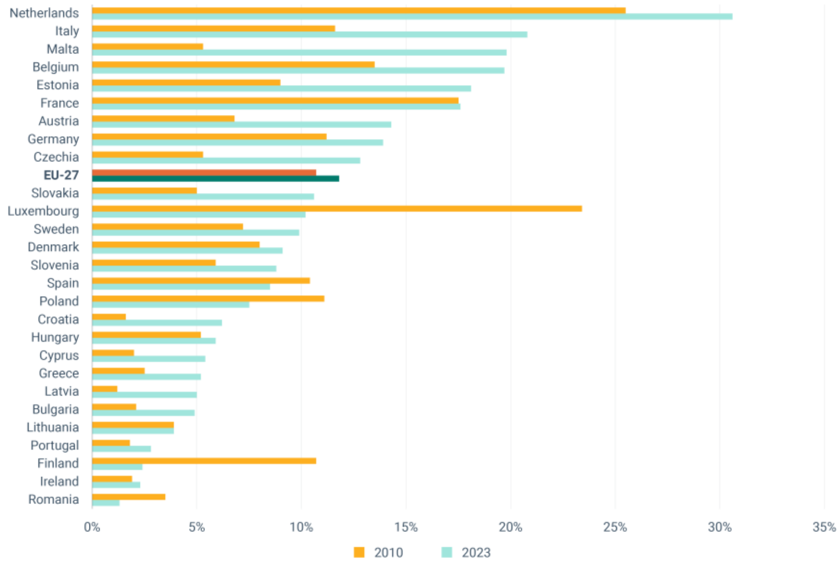


Source: Eurostat (env_ac_rme)

Figure 1: Material footprint (RMC) by country, 2010 and 2024 (tonnes per capita)

- **Circular Material Use Rate (CMUR)** indicates the share of secondary raw materials in total material use and is a key target under both EU and German circular economy strategies, with the goal of doubling the rate by 2030. In 2023, Germany recorded a CMUR of 13.9%, exceeding the EU average of 11.8%. However, the rate has remained largely stagnant since 2010 (11.2%), indicating limited progress. By contrast, countries like the Netherlands (30.6% in 2023) and Italy (20.8% in 2023) have achieved substantial gains. A comparison of CMUR developments across EU27 member states from 2010 to 2023 is provided in Figure 2.

[16] The RMC expresses the total amount of raw materials, in raw material equivalents (RME), required domestically and abroad to produce the goods and services consumed within the reference area. RMC is calculated as Raw Material Input (RMI) minus exports in RME.



Source: European Environmental Agency (EEA)[17], based on Eurostat data (env_ac_cur).

Figure 2: Circular material use rate by EU country, 2010 and 2023.

- **Total Material Productivity** links economic output to material input.[18] Germany's material productivity increased by 15% from 2010 to 2021. However, the current growth rate (1.3% annually) falls short of the 1.6% annual increase needed to meet the 2030 target of Germany's national sustainability strategy.
- **Municipal Waste Generation**: Preventing waste at the source and reducing municipal waste are key objectives of Germany's NCES. Yet, in 2023, Germany generated 601 kg of municipal waste per capita, well above the EU average of 511 kg, with little change since 2010. By contrast, Sweden (392 kg/cap), Spain (465 kg/cap), and the Netherlands (468 kg/cap) report significantly lower levels.
- **Other Indicators**: Germany is the European leader in municipal waste recycling (68.2% vs. 48.2% EU average) and recycling patents, but has a higher material import dependency (37.5% vs. 22% EU average).

According to a status report 2024 on circular economy in Germany, the circular economy achieved a turnover of around 105 billion Euros in 2021. The sector currently employs almost as many people nationwide as the energy industry and almost four times as many people as the water and wastewater industry. Furthermore, the circular economy, with around 310,000 employees, is one of the most important employers in the environmental sector, and the trend is rising (Prognos AG, 2024).[19] At the EU level, there is a clear increase in the number of people employed in the circular economy from about 3.3 million in 2025 (1.7% of total EU employment) to about 4.3 million in 2021 (2.1% of total EU employment).[20]

In China, progress toward a circular economy can be analyzed on the basis of the following data:

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[17] https://www.eea.europa.eu/en/analysis/indicators/circular-material-use-rate-in-europe

[18] Defined as GDP plus the monetary value of imports divided by primary raw material input, it is a measure of resource use efficiency.

[19] Prognos AG (2024): Statusbericht der deutschen Kreislaufwirtschaft, in cooperation with INFA GmbH, INZIN e.V., Breer visuelle Kommunikation, TafelmitKollegen, commissioned by ASA, BDE, BDSAV, BDSV, BRB, bvse, DGAW, IFAT Munich, IGAM, InwesD, ITAD, VDMA, VHI, VDM, VKU. Available at: https://www.prognos.com/de/projekt/statusbericht-der-deutschen-kreislaufwirtschaft-2024

[20] European Environment Agency, based on Eurostat [CEI_CIE011]: https://ec.europa.eu/eurostat/databrowser/view/CEI_CIE011__custom_6290509/default/table?lang=en; Available at: https://www.eea.europa.eu/en/circularity/thematic-metrics/business/employment-in-the-circular-economy?activeTab=230b8465-152e-4079-8377-3d63e44f39a1

- **Growth of the recycling sector**: The **China Recycling Materials Collection Industry Development Report 2025** indicates the scale of China's material recycling industry reaching 401 million tonnes in 2024, with a total value of 1.33 trillion yuan and a year-on-year growth of 6.5% (China National Resources Recycling Association, 2025)[21]. In 2024, the added value of the waste comprehensive utilization grew by 10.2% compared to the previous year (National Bureau of Statistics Industrial Statistics Division, 2025). There are more than 260,000 enterprises in the material recycling sector nationwide, making it a key sector for stable employment and improving people's livelihoods. Through enhancing the resource recycling chain and creating regional clusters, the industry has shifted from a fragmented, weak state to one of scale, high value, and intensification.
- **Use of circular materials:** In 2024, the total amount of recycled resources for 11 major categories, including scrap steel, scrap non-ferrous metals, and waste plastics, reached about 401 million tonnes, with a year-on-year growth of 6.5% (China Recycled Materials Association, 2025).
- **Municipal waste management**: According to data from 196 cities, the average coverage rate of household waste classification reached 92.9% in 2023 (Solid Waste and Chemicals Management Technology Center of the Ministry of Ecology and Environment, 2024). About 150,000 recycling points have been established in major cities, and reverse logistics systems are thriving. Internet and IoT technologies are widely used in the recycling network.
- **Resource utilization efficiency:** From 2012 to 2023, China's resource utilization efficiency continued to improve, with energy consumption per unit GDP decreasing by 26.8%, CO_2 emissions per unit GDP dropping by over 35%, and the output rate of major resources increasing by more than 60% (Liu Dechun, National Development and Reform Commission, 2024). In 2024, the comprehensive utilization of general industrial solid waste increased to 2.65 billion tonnes, with a utilization[22] rate of 59.3% (Ministry of Ecology and Environment, 2025). In **Annex C,** the case study of Fuhua Group Co. Ltd. is presented to show a good practice on increasing the efficiency of resource utilization.
- **Piloting programs progress:** Several ministries of China have set up various piloting programs to promote circular economy practices throughout the country and made significant progress. For instance, led by the Ministry of Industry and Information (MIIT), nearly 6,430 **Green Factories** and over 490 **Green Industrial Parks** have been established.[23] A number of **Zero-Waste Factories** and **Zero-Waste Industrial Parks**, jointly led by the MIIT and the Ministry of Ecology and Environment (MEE), have been advanced in provinces and cities. More than 25,000 **Zero-Waste Units** (e.g., communities, schools, official buildings, hotels, sightseeing, etc.), which are guided by the MEE, have been established. 117 out of 129 **National Pilots of Industrial Parks with Circular Economy Transformation**, led by National Development and Reform Commission (NDRC), have been well reconstructed, with a total of 230 million tonnes of solid waste reused, together with a total energy consumption reduction of 208 million tonnes equivalent, and coal and water use reduction of 408 million tonnes.
- **Other indicators relevant to the circular economy:** By 2023, over 150 million tonnes of outdated steel capacity had been phased out, and 134 million tonnes of steel production processes had been

[21] http://www.sh-recycle.org/articledetail.asp?id=5662

[22] The comprehensive utilizations of general industrial solid waste mainly include producing recycled building materials, incinerating as energy, soil conditioner, and others.

[23] CNII (2025). MIIT - China has cultivated a total of 6,430 national green factories and 491 green industrial parks, 9 September 2025. Online available at https://www.cnii.com.cn/yw/202509/t20250909_683782.html

transformed for ultra-low emissions. Agricultural circular economy development is a key focus, with straw comprehensive utilization reaching 88.3%, and livestock and poultry waste utilization reaching 79.4%. A total of 300 national modern agricultural industrial parks, 180 specialized industry clusters, and 1,509 strong agricultural towns have been built, enabling both the construction of beautiful villages and the transformation of ecological agricultural economies.

2.6 Comparisons of Circular Economy Policies Between China, the EU and Other Countries

Despite differences between Germany/EU and China in terms of economic structures and industrial development stage, the circular economy has become a policy priority across both geographies, demonstrating the compelling vision presented by the concept of a circular economy for high-quality development. In both geographies, the circular economy has been well linked to the top green development strategy and climate policies, as well as waste management policies. Figure 3 summarizes the key policies supporting circular economy development in general, as well as the ones in the textile and chemical sectors in particular, in the EU, Germany, and China.

The circular economy has primarily emerged from resource efficiency and waste agendas and can be understood as having an overarching goal to decouple economic growth from resource use. However, it can also be observed that the conceptual framing and implementation requirements of the circular economy differ between the geographies. In Germany/EU, the circular economy has primarily emerged from resource efficiency and waste agendas and can be understood as having an overarching goal to decouple economic growth from resource use. As such, Germany and EU policies set up mandatory requirements and tend to emphasize, for instance, strategies for designing out waste (i.e., ecodesign), extended producer responsibility schemes (EPR) for contributing to waste management, and the setting of binding targets for recycling and the use of recyclates. In China, on the other hand, existing circular economy policies focus more on achieving recycling volume and adopt more voluntary approaches, such as clean production in industrial planning, and waste collecting, sorting, and recycling. Moreover, China is also making efforts to find various pathways and modes for achieving circular economy transition by summarizing 60 circular economy cases of remanufacturing, utilization of food waste, and/or construction of materials recycling bases. A new circular economy with high-quality recycling is now under discussion and expected to be considered in the near future in China.

Irrespective of why the development of circular economies has become a priority, it is essential to question whether they are having the desired impact. The ***Circularity Gap Report 2025*** offers data-based insights into the state of global material flows and circularity. As of 2021, only **6.9% of global material inputs** are **secondary materials** (down from 9% in 2015), highlighting a growing **circularity gap of 93.1%.** This decline is mainly driven by rising virgin material extraction (in absolute numbers)—now exceeding 100 billion tonnes annually—which continues to outpace the increase in secondary material use. Furthermore, **fossil fuel use remains high and subsidized**, **energy demand, emissions and waste generation are increasing**, and **only 11.2% of global waste is recycled**. Material stocks (long-term storage in buildings and infrastructure) rapidly accumulate, accounting for 38% of inputs now (Circle Economy 2025). For a more detailed examination of the global state of the circular economy, see **Annex D.**

Year	EU	Germany	China
1984	Supervision and Control within the European Community of the Transfrontier Shipment of Hazardous Waste		
1991		Packaging Ordinance	
1994		Closed Substance Cycle and Waste Management Act (KrW-/AbfG) German Waste Shipment Act	
1997		End-of-life Vehicle Ordinance	
2000	Directive on end-of-life vehicles		
2002		First Germany's Sustainable Development Strategy End-of-life Vehicle Act	Law of the People's Republic of China on the Promotion of Clean Production
2003	First Directive on the Restriction of Hazardous Substances in Electrical and Electronic Equipment (RoHS) First Directive on Waste from Electrical and Electronic Equipment (WEEE)		
2005		German Electrical and Electronic Equipment Act	
2006	Waste Shipments Regulation Batteries Directive Regulation on the registration, evaluation, authorisation and restriction of chemicals (REACH)	New German Waste Shipment Act	
2007		Adaptation of the National Chemical Law for REACH enforcement	
2008	Waste Framework Directive (WFD).		Circular Economy Promotion Law of the People's Republic of China
2009		Battery Act	
2010	Industrial Emissions Directive (IED)		
2011	New RoHS Directive		
2012		New Circular Economy Act	Revised the Law of the People's Republic of China on the Promotion of Clean Production
2013		Waste Prevention Programme	Circular Economy Development Strategy and Near-term Action Plan
2014	New WEEE Directive		
2015	European Commission adopted the first Circular Economy Action Plan (CEAP)	German Electrical and Electronic Equipment Act Amendment	
2017		New German Sustainable Development Strategy	Extended Producer Responsibility (EPR) Implementation Plan Circular Development Leading Action
2018	European Strategy for Plastics in a Circular Economy Amended EU End-of-Life Vehicle Directive Revised the Waste Framework Directive (WFD)		Revised Circular Economy Promotion Law of the People's Republic of China
2019	Directive on single-use plastics European Green Deal EU monitoring framework for the circular economy	Packaging Act Federal Climate Action Act (KSG)	
2020	CEAP 2.0 EU Taxonomy Regulation Chemicals Strategy for Sustainability	Circular Economy Act Amendment	Revised of the Law of the People's Republic of China on the Prevention and Control of Environmental Pollution by Solid Wastes
2021		Updated the Waste Prevention Programme Further revised the Sustainable Development Strategy Single Use Plastic Ordinance Revised the KSG German Packaging Act Amendment	Guiding Opinions on Accelerating the Establishment of a Sound Green, Low-Carbon, and Circular Development Economic System 14th Five-Year Plan for Urban Household Waste Classification and Treatment Facility Development 14th Five-Year Plan for Circular Economy Development Working Guidance for Carbon Dioxide Peaking and Carbon Neutrality in Full and Faithful Implementation of the New Development Philosophy 14th Five-Year Plan for Zero-Waste City Construction
2022	EU Strategy for Sustainable and Circular Textiles Revised Monitoring Framework for the Circular Economy	Amended German Electrical and Electronic Equipment Act	Implementing Opinions on Accelerating the Recycling of Waste Textiles Guiding Opinions to Promote the High-Quality Development of the Petrochemical and Chemical Industries during the "14th Five-Year Plan" Period
2023	Transition Pathway for the Chemical Industry Revised monitoring framework for the circular economy Proposal for the ELV Regulation New Batteries Regulation Revised the REACH Regulation	Standardization Roadmap Circular Economy Single-Use Plastics Fund Act	Work Plan for Stable Growth in the Petrochemical and Chemical Industry
2024	WEEE Directive Amendment New Regulation on Waste Shipments Directive on Repair of Goods Ecodesign for Sustainable Products Regulation (ESPR)	Further revised the KSG National Circular Economy Strategy (NCES)	Opinions on Accelerating the Construction of a Waste Recycling System Opinion on Accelerating the Comprehensive Green Transition in Social and Economic Development
2025	Clean Industrial Deal Packaging and Packaging Waste Regulation (PPWR) European Chemical Industry Action Plan		

Source: Compiled and developed by Beijing Huanding Environmental Smart Data Institute, 2025.

Figure 3: Circular Economy Policies Comparison among the EU, Germany and China[24]

Compared to this global picture, Germany and China can be considered leaders in the development of circular resource flows. For example, despite limited increases over the last 10 years, the share of recycled resources in Germany is still twice than the global average. In China, the use of recyclates is also accelerating, with year-on-year growth of recycled resources reported. However, in terms of overall extraction of virgin materials, neither Germany nor China has succeeded in reversing broader global trends. **Without increasing the use of secondary material while also simultaneously reducing virgin resource consumption, a true circular economy is not achievable**.

Despite different starting points in terms of material use and consumption, as well as different political priorities, common **key barriers and market failures** have been identified by this SPS across both Germany and China,[25] which continue to hinder the broad implementation of the circular economy.

- **Low cost of primary raw materials**, largely due to unpriced environmental externalities. This undermines the competitiveness of secondary raw materials, which are often subject to stricter environmental regulations. Likewise, while waste recycling has significant carbon reduction benefits, a unified methodology and carbon trading standard have not yet been established.
- **Consumers are unwilling to pay a premium for environmentally friendly products, and market demand for bulk recycled resources is weak.**
- **Limited investments in research and innovation for circular solutions,** in particular R&D investments in new technologies for a high-quality circular economy. For instance, technologies for reusing and recycling bulk industrial waste (e.g., coal gangue, phosphogypsum, used PV and wind power equipment, etc.) are not in place. SMEs have limited self-financing opportunities, and companies may prefer to wait and adopt innovations as a "second mover" rather than carrying the costs themselves.
- **Lack of a scaled leading enterprise and a stable market in the circular economy industry.** Fluctuations in market demand for recycled materials also lead to unstable industry profits and act as a disincentive to investment.
- **Lack of infrastructure for circular practices**. Investments in preparation for the reuse, collection, and processing of used products are typically unattractive to private actors unless mandated by regulation or driven by municipal investment.
- **Some enterprises have insufficient environmental protection measures and process**

[24] The figure encompasses several important CE policies in the EU, Germany and China. The list is, however, not complete in order to reduce the overcomplexity of the figure. The figure also does not include all updates and revisions of the mentioned policies. It is to be noted that many product-specific aspects, for instance, for electrical and electronic appliances, are entailed in the overarching legislations, such as ESPR and WFD. Furthermore, EU directives and regulations are transposed into national laws in Germany, all of which are also not presented in the figure.

[25] An overview of specific challenges for Germany and China can be found in Annexes G and H, respectively.

management systems, which hinders the improvement of recycled product quality but also increases environmental pollution risks. The resulting lack of confidence in recycled materials dampens their demand.

- **Absence of common standards for circular products** and a **lack of cooperation among actors**. No regulatory requirements exist for the use of recycled content.
- **Insufficient transparency and information sharing** across value chains. Important data on extraction, product design and production is often unavailable, impeding later life cycle stages like repair, reuse, and recycling.

In short, the circular economy **requires strong governance frameworks** and **targeted policy interventions to level the playing field between linear and circular models** while **internalizing environmental costs** (Prakash et al. 2023b). The circular economy policies of Germany and China, if implemented ambitiously and coherently, already hold the potential to foster structural changes, reduce primary raw material demand, close material loops, and strengthen the competitiveness of circular systems. However, in the context of a global economy and international value chains, progress will also require strong global partnerships and binding commitments which address both the consumption and production patterns driving the linear economy, and in its place, develop a high-quality circular economy which benefits all while also respecting planetary boundaries. As an example, two value chains—textiles and chemicals—will be explored further in the rest of this SPS.

3 Circular Economy in the Textile Sector

3.1 Significance of Circular Economy in the Textile Sector

3.1.1 The Traditional Linear Model in the Textile Sector Has Significant Impact on Environment and Society

The global textile industry is characterized by complex globalized value chains. The industry employed around 140 million people in 2023 (Huygens et al., 2023) and valued at €1.7 trillion (US$1.8 trillion) (Circular Economy, 2024). China is the largest exporter of textiles, and the United States is the leading textile importer. In 2022, the EU imported approximately 11 million tonnes of new textile products worth €153 billion, mainly from China, Bangladesh, and Turkey. Clothing accounted for 45% of volume, followed by household textiles (21%), and footwear (17%) (Eionet 2025b). Still, in the same year, the EU exported only around 4 million tonnes of finished textiles worth €73 billion. Main export destinations include Switzerland, the UK, the US, but also China (Eionet 2025b). As for the consumption of textiles in the EU, EU's per capita household textile consumption averaged 19 kg in 2022,[26] while textile waste reached 16 kg, with the majority ending up in the mixed household waste (Eionet, 2025a; 2025b). German households averaged an annual textile consumption of 18.8 kg per person, while ranking among the EU's top five textile waste producers (Oeko-Institute e.V., 2023; UBA, 2022b). In contrast, Chinese processed more than 60 million tonnes of fibre, consumed 37 million tonnes of fibre (averaged 26 kg per capita) in 2024,[27] and generated more than 22 million tonnes of waste fibre (iGDP, 2024)[28].

The textile sector has a significant impact on the environment and society, largely due to its traditional linear "take-make-dispose" model[29] (see Figure 4). This model, especially fuelled by fast fashion, involves systemic overproduction and significant waste generation (Ellen MacArthur Foundation, 2017). For instance, global fibre production has doubled since 2000, reaching a record 124 million tonnes in 2023. This rise is primarily driven by increased virgin fossil-based synthetic fibre production (67% market share), mainly polyester (57%). Natural fibres make up 25% of fibre production, with cotton contributing 20% (Textile Exchange, 2024).

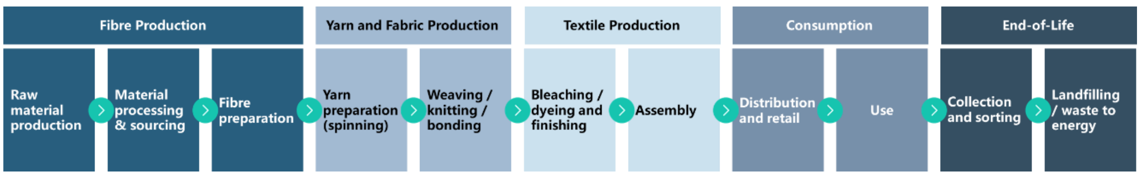

Figure 4: The "Take-make-dispose" Linear Model in the Textile Sector

The textile industry's **raw material footprint** accounts for over 3% globally, consuming around 3.25 billion tonnes of materials annually (99% from virgin sources) (Circle Economy, 2024). In the EU, textiles are the fifth-largest consumption category for raw materials, requiring 234 million tonnes in 2022 to meet European

[26] Of which 8 kg is clothing, 7 kg household textiles, and 4 kg footwear.
[27] https://www.xinhuanet.com/fashion/20250224/70de0ae543664d6099b529214fbfce75/c.html
[28] Green New Productivity: Circular Economy and Recycling Technology Supports Emissions Reduction from Textile and Plastic Sector, December 4, 2024, Source: https://www.igdp.cn
[29] A detailed overview of textile production, consumption, trade flows, and the management and processing of used and waste textiles in Germany and the EU is provided in Annex I.

household demand (523 kg per person). Only 32% of these materials are sourced from within Europe (Eionet, 2025b).

Other key environmental impacts include substantial greenhouse gas emissions (esp. from fossil fuels, fertilizers, and pesticides), significant water and land use, microplastic pollution, eutrophication of water bodies, air pollution, biodiversity loss, and the acidification of terrestrial and freshwater ecosystems.[30] For instance, the textile industry was responsible for more than **3.5%** of **global greenhouse gas emissions** (Circle Economy, 2024), while there are also significantly higher estimates of 8-10% (Lead Filho et al., 2022). In the EU, in 2022, the production of textiles for EU households generated 159 million tonnes of CO_2-eq. emissions (355 kg CO_2-eq. per person), making it the sixth largest source of household climate impacts. Of these emissions, 70% occur outside Europe (Eionet, 2025b). In China, the textile sector contributes 2% of total carbon emissions and 2.8% of total industrial carbon emissions (Economic Investigation Newspaper, 2025).[31] Furthermore, textile production contributes to **global water scarcity** (4% of global water use) due to processes like dyeing and finishing (Circle Economy, 2024). Additionally, the industry contributes to **marine** (5%) and freshwater eutrophication (4%) and significant land use, particularly for cotton and animal-based fibres like wool (Circle Economy, 2024). The land required for EU household textile consumption in 2022 totalled 144,000 km^2, with 86% of this land use occurring outside Europe, primarily in China and India (Eionet, 2025b).

Microplastic pollution is another major environmental impact of the textile sector, with synthetic fibres being the primary source. Globally, synthetic textiles account for 16%–35% of microplastics entering the oceans, with an estimated 0.2 to 0.5 million tonnes of microfibres released into the oceans each year through washing, wearing, and disposal (Circle Economy, 2024). Textiles release the most microplastics during their first wash. According to the European Environmental Agency, in Europe, an estimated 13,000 tonnes of textile microfibres (equivalent to 25 grams per person) enter surface waters each year, representing 8% of all primary microplastic emissions to water (EEA, 2022).

Other environmental impacts of the industry include over 2% of **global air pollution**, and over 3% of **biodiversity loss** and **terrestrial and freshwater acidification**. Textile production is also closely tied to human health issues, through exposure to hazardous chemicals, air and water pollution, and climate-related impacts like heatwaves and malnutrition, particularly in key production regions like China, the United States, and India. In the EU, textiles rank the 4th to 6th highest household consumption category for different environmental impacts. Hazardous substances like Per- and polyfluoroalkyl substances (PFAS) in textiles further hinder safe reuse, recycling, and the extension of textile lifetimes, challenging efforts to improve textile circularity (Circle Economy, 2024; Eionet, 2025b).

In addition to these environmental concerns, the textile industry is also marked by severe social and socio-economic impacts, including poor working conditions, low wages, and harmful labour practices (esp. in regions with weak environmental and labour regulations)[32] (UNEP, 2020).

In the EU—despite some efficiency improvements in recent years—rising consumption levels (+15% from

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[30] More details on the environmental and health impacts of the global and European textile industry can be found in Annex J

[31] Economic Investigation Newspaper, Carbon Emissions Intensity Reduced More Than 60% in 2005-2022 – An Insight from Sun Ruizhe. Source: https://zhuanlan.zhihu.com

[32] For a detailed breakdown of environmental and socio-economic hotspots along the entire textile value chain and insights into the relevance of different impacts in different value chain stages, refer to UNEP's *"Sustainability and Circularity in the Textile Value Chain – Global Stocktaking"* report (UNEP (2020)), which has been published under the umbrella of UNEP's Textile Initiative (https://www.unep.org/topics/chemicals-and-pollution-action/circularity-sectors/sustainable-and-circular-textiles). The Stocktaking Report also maps out initiatives working to address those impacts and identifies priority actions needed to advance circularity and sustainability in textile value chains.

2010 to 2022) have partially outweighed environmental and climate benefits. Absolute decoupling was achieved between 2010 and 2022 for greenhouse gas emissions (-22%) and raw material use (-24%), while only relative decoupling occurred for land (+3%) and water use (-1%). This underlines the urgent need to address overconsumption and accelerate progress toward textile circularity (Eionet, 2025b).

Box 1: Trade of used clothing

In 2020, the **largest net exporters of used clothing** were the United States, China, the United Kingdom, Germany, and South Korea. On the other hand, the **largest net importers of used clothing** included Ghana, Ukraine, Nigeria, Kenya, and Tanzania. Between 2000 and 2019, **exports of used textiles from the EU** nearly tripled, reaching **1.4 million tons in 2023**, with the majority intended for reuse (Eionet, 2025b). Around 50% of textiles collected and pre-sorted in the EU are exported to third countries (**primarily Africa and Asia**), while only 10% (in Germany, just 1%–2%) of the highest quality textiles remain in the EU for local reuse (Huygens et al., 2023; EEA, 2023; UBA, 2022). Within the EU, **trade dynamics** are influenced by **differences in sorting and recycling capacities** and **labour costs** (European Environment Agency, 2024). **Germany** is a **major exporter of used and waste textiles** to countries both within and outside the EU. Due to limited domestic sorting capacities, Germany exports most separately collected textiles to countries with larger sorting infrastructure, like Poland and the Netherlands[1] (EEA, 2023; 2024c; JRC, 2023). These countries function as hubs in a complex reverse value chain, often re-exporting textiles **to the Global South**, mainly to **Africa** (45%) and **Asia** (43%), with an **unknown final fate**[1] (Circle Economy, 2023). In Africa, textile imports are primarily intended for reuse, but still often end up in unmanaged landfills or are openly burned. A Greenpeace investigation found that exports to countries like Ghana, Kenya, and Tanzania contribute significantly to pollution, contamination, climate change, and health risks. **In Ghana and Kenya**, **30%–40%** of imported clothing is **deemed worthless** and **goes directly to a landfill** (Greenpeace e.V., 2022). In Asia, textiles are typically sorted, recycled locally, or re-exported with non-recyclable or non-reusable textiles likely landfilled. In the EU, the volume of used textiles collected separately is expected to increase in the coming years. **Without regulatory action**, rising textile collection volumes in the EU will lead to an **increase in textile waste exports** and the associated **environmental and social impacts** in importing countries. (EEA, 2023; Manshoven et al., 2025).

In short, the textiles value chain is highly global and highly linear. Overall, it ranks highly as a sector in terms of its contribution to global greenhouse gas emissions and raw material use. Many of the environmental impacts are concentrated in the manufacturing phase, which is geographically concentrated in a few countries, including China. This creates local issues, including overuse of land and water resources, microplastic pollution, eutrophication of water bodies, air pollution, biodiversity loss and the acidification of terrestrial and freshwater ecosystems. However, the cause of these problems is global. Many of the products produced are exported, particularly to Western consumer markets, including Germany, where overconsumption is rife and significant waste is being created as a result. In turn, textile waste is being exported to countries which, in many cases, lack the appropriate waste management infrastructure to manage these flows, thereby creating local environmental and health risks.

Thus, while the textile value chains are global, priorities as well as opportunities for impact differ between geographies. For countries like China, where textile manufacturing is an important economic base, circularity strategies which focus on cleaner, less resource-intensive production are of greater relevance to addressing local environmental impacts as well as meeting climate goals. In consumer countries, like Germany, strategies which reduce resource consumption and waste are more relevant, both reducing pressure on waste collection infrastructure as well as contributing to a reduction in per capita environmental and raw material footprints. By working together, countries along the textile value chain can all benefit from the application of circular economy strategies, i.e., by improving the quality of textiles produced and consumed and increasing the capture and re-circulation of products and materials, thereby creating new sources of economic value while also reducing environmental impacts and waste.

3.1.2 Implementing Circular Economy in the Textile Value Chain

The circular economy, as a sustainable development model, minimizes resource consumption and environmental costs while effectively improving resource utilization efficiency through the continuous reduction, reuse, refurbishment, and recycling of products and materials. **Reduction** is the most effective strategy to lower the substantial environmental impacts of the textile industry, aligning with the waste hierarchy's top priority (waste prevention). For instance, it was shown that implementing a set of circular measures for textiles in Germany has the potential to reduce impacts in different categories by at least 35% by 2045. Thereby, **reducing** textile production and consumption—by extending product lifetimes and shifting the way consumers use products (e.g., sharing economy)—is most beneficial and was modelled to lower greenhouse gas emissions, resource consumption and land use by approximately 30% by 2045 (Oeko-Institut e.V., 2023a).

Reusing textiles outperforms recycling environmentally and economically. Reselling wearable textiles not only ensures the economic viability of collection and sorting, but it also extends product lifespans and conserves resources by avoiding primary production, which significantly reduces the environmental impacts of textile production[33] (van Duijn et al., 2022; Wagner et al., 2022). Closely connected to reuse is the diversion of damaged textiles from waste via repair.

At the end of their use phase, textiles need to be separately collected from other waste streams and afterwards sorted so they can be **prepared for reuse** or serve as an input to recycling operations.[34] [35] **Preparation for the reuse** of used textiles is environmentally and economically superior when compared to recycling or the production of native fibres, even though the environmental benefits of second-hand clothing mainly occur abroad, where items are actually worn. This is in line with the **waste hierarchy**, which prioritizes preparation for reuse over material recycling (Löw et al., 2024; Oeko-Institut e.V., 2023a). By reusing textiles, their lifetime is prolonged, contributing significantly to the conservation of resources and the reduction of environmental burdens associated with production (UBA, 2022). Economically, reselling wearable clothing is the most profitable option for managing post-consumer textiles right now, making up the primary source of revenue for textile sorting operators (Circle Economy; Fashion for Good 2022).

Finally, when textiles are no longer suitable for reuse, **recycling options** can substitute the use of primary

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[33] According to Sandin et al. (2019), doubling the average wear time of garments could lower their climate and water footprint by around 50%. Similarly, the 2024 Circularity Gap Report models a "slow fashion" scenario (reduced consumption, extended product lifespans) through reuse, repair, rental, and less overproduction. In the most ambitious case (5% consumption reduction, 50% less overproduction), climate impact decreased by 10.1%, material footprint by 10.3%, and water scarcity by 11.9% (Circular Economy, 2024).

[34] According to the German Circular Economy Act (KrWG), preparation for reuse involves checking, cleaning, or repairing products or components that have become waste so they can be reused without further processing for their original purpose (Wagner et al., 2022).

[35] A detailed description of the status quo on preparation for reuse and recycling is given in Annex I.

raw materials (UBA, 2022b). Recycling **should, therefore, be promoted as a complementary strategy in achieving circularity**[36] **(UBA ongoing).** In addition, wastewater, liquid waste, and solid waste generated during production and processing can be comprehensively utilized and recycled through advanced treatment. It is calculated that recycling 1 kilogram of waste textiles can save 1.1 tonnes of oil, reduce CO_2 emissions by 3.6 kilograms, and conserve 6,000 litres of water (Economic Daily Paper, 2023).[37]

Box 2: Collection and preparation for reuse of textiles in Germany and the EU

Germany collects approximately 64% of used textiles at the end of their life. This rate significantly exceeds the European average of around 38%, where most textile waste is not separately collected but instead incinerated or landfilled, making it unavailable for reuse or recycling (Deckers et al. 2024; Duhoux et al. 2025; Huygens et al. 2023; Wagner et al. 2022). Across Europe, the collection of post-consumer textiles is managed by **private entities, charitable organizations, or public waste management authorities**, mainly via **drop-off points** and **recycling centres**. Bring points yield high collection volumes but have a higher risk of contamination; still, they are generally considered the most suitable to obtain an acceptable quality at a sufficient amount of post-consumer textiles (Deckers et al., 2024; van Duijn et al., 2022; Wagner et al., 2022). **Collection and sorting** are primarily financed by the sale of second-hand clothing, which accounts for up to 90% of sorting companies' revenues (van Duijn et al., 2022).

Despite its low efficiency, high costs, and reliance on skilled personnel, **manual sorting** remains the dominant method for sorting textile waste in Germany and EU. Accurate sorting by fibre type, which is an essential prerequisite for high-quality recycling, can be enabled by automated sorting technologies (e.g., NIR spectroscopy, RFID), but most approaches are still in the development phase. Textiles intended for reuse are typically sorted into several hundred categories based on quality, colour, size or fashion trends to meet market demands (Köhler et al., 2021; Huygens et al., 2023).

van Duijn et al. (2022) estimate that **55%** of separately collected textiles in the EU are destined for reuse, of which the majority is exported to third countries, and only 10% (the highest quality share) are reused locally (Huygens et al., 2023). In Germany, a significant share (62%) of collected and sorted textiles is prepared for reuse, but only 1%–2% is reused domestically.

Globally, less than 1% of textile waste is recycled into new textiles (Circle Economy, 2024; Ellen MacArthur Foundation, 2017). In 2023, recycled fibres made up just 7.7% of the global fibre market (approx. 9 Mt), mostly recycled polyester. Polyester fibre is the most widely used chemical fibre globally. Its primary component is polyethylene terephthalate (PET), and its production accounted for 57% of total global fibre output in 2023. Global polyester fibre production in 2023 was approximately 71.1 million metric tonnes, but only 12.5% was recycled fibre (Textile Exchange, 2025).[38] However, 98% of **rPET in textiles** comes **from PET bottles**, not textile waste (Textile Exchange, 2024). While clean and consistent, this input stream diverts material from closed-loop bottle-to-bottle recycling and **fails to tackle the core issue of high textile waste**

[36] The potential to recycle otherwise landfilled or incinerated post-consumer textiles is substantial. Several LCA studies conclude that using recycled fibres can reduce the greenhouse gas emissions of textile production compared to virgin fibres (UBA, ongoing).

[37] http://paper.ce.cn/pad/content/202308/22/content_279701.html

[38] https://textileexchange.org/app/uploads/2024/09/Materials-Market-Report-2024.pdf

volumes (Klinge et al., ongoing). Given polyester fibre's significant share of the textile fibre market, achieving comprehensive recycling of polyester fibres will play a crucial exemplary and leading role in building a circular economy system for textiles.

Box 3: Recycling and end-of-life treatment of textiles in Germany and the EU

In Germany, around **26%** of collected textiles undergo some form of **material recycling** (mainly open-loop), often into industrial cleaning rags or shredded fibres (EEA 2023; Wagner et al. 2022), while **8%** are incinerated for **energy recovery** purposes and **4%** are **disposed** of (Wagner et al. 2022). **In the EU**, approximately **30%** of collected and sorted textiles are **recycled**, primarily through open-loop processes. An estimated **14%** are **incinerated** and **12%** end up in **landfills** (Deckers et al. 2024; Huygens et al. 2023; Wagner et al. 2022). Due to current technical limitations in recycling, only a small proportion of recycling output in the EU are spinnable recycled fibres. Additionally, a great share of input materials used for fibre-to-fibre recycling (at least 50%) doesn't come from post-consumer but from post-production and pre-consumer (unsold goods) textile waste (Huygens et al. 2023; Löw et al. 2024).

In short, implementing a circular economy in the textile sector will require systemic action across production, consumption and end-of-life management. In terms of environmental impact, reduction and reuse strategies have the greatest potential. Reuse is also essential for the economic viability of collection and sorting (under current market conditions). However, in the context of current market dynamics and consumer behaviours, closed-loop fibre-to-fibre recycling is also a critical strategy for circularity, providing a means to capture textile waste which cannot otherwise be reused. All three strategies—decreasing consumption while increasing reuse and recycling—must be pursued across the textiles value chain in order to achieve a circular economy.

Annex G provides an overview and **specific figures** on the **management and further processing of used and waste textiles** for both Germany and the EU (incl. collection, sorting, preparation for reuse, etc.).

Box 4: Classification of recycling technologies

Textile recycling technologies can be broadly classified into two main groups: material recycling and feedstock recycling. **Material recycling** yields solid outputs like pellets, fibres, or defined molecules and can be divided into mechanical recycling, solvent-based recycling, and depolymerization. In contrast, **feedstock recycling** breaks down fibres into gaseous or liquid hydrocarbon mixtures (Löw et al., 2024). The annex includes examples of recycling operators involved in the different textile recycling technologies.

Material recycling:

- **Mechanical recycling**, the dominant recycling method in the EU and at an industrial scale, physically breaks down textiles, mainly in open-loop applications like insulation, non-wovens, or cleaning cloths. While it can produce some spinnable fibres from pure cotton or synthetic streams, the process reduces fibre quality, and blends are generally unsuitable for fibre-to-fibre recycling (Huygens et al., 2023; Löw et al., 2024; Wagner et al., 2022).
- **Solvent-based recycling** selectively dissolves specific fibres within blends (e.g., polyester-cotton) to recover intact polymers like PET or cellulose with virgin-like quality. However, it remains industrially immature, energy- and chemical-intensive (Huygens et al., 2023; Löw et al., 2024; Duhoux et al., 2021).
- **Depolymerization** chemically breaks down fibres into monomers (particularly suitable for PET/polyester), enabling contaminant removal and virgin-quality fibre recovery. Despite high energy demands and currently limited scale, it holds significant promise for fibre-to-fibre recycling (Duhoux et al., 2025; Huygens et al., 2023; Löw et al., 2024; Systemiq, 2025).
- **Combined approaches** can treat **fibre blends**, e.g., by depolymerizing one fibre type and isolating another through solvent-based methods (Löw et al., 2024).

Feedstock Recycling:

- Feedstock recycling (**gasification** and **pyrolysis**) thermochemically converts fibres into gaseous or liquid hydrocarbons for use as substitute fuels or chemical feedstock. Due to high energy and environmental burdens, it is currently limited in textile applications (Löw et al., 2024).

Due to its lower energy demand, **material recycling** is generally **preferred over feedstock recycling**, which serves only as a last resort under specific conditions. Within material recycling, **mechanical recycling should be prioritized** because of its lower energy, chemical, and technical expenses than solvent-based recycling and depolymerization (Löw et al., 2024). However, recycling methods are complementary rather than competing, as different textile waste streams require tailored recycling solutions.[1] Mechanical recycling is limited by fibre quality degradation, while **depolymerization** shows the **most promise** for **high-quality fibre-to-fibre recycling** and should be further supported to enable scaling (van Duijn et al., 2022; Huygens et al., 2023; Löw et al., 2024). Given current capacity constraints and the varied suitability of textiles for closed-loop recycling, open-loop recycling remains important and environmentally viable (Klinge et al., ongoing).

3.1.3 Chemicals-related Considerations for Textiles

Chemicals play a critical role in textile production, influencing material properties, durability, and aesthetics;

however, many are hazardous and hinder reuse, recycling, and safe disposal. Addressing chemical use is therefore essential to enable circular economy strategies that prioritize non-toxic, recyclable, and long-lasting textile products. The following section covers overall approaches to address chemicals in the textiles industry (via the Global Framework on Chemicals), provides further information on key concepts including Substances of Concern (and how these are being dealt with in Europe's ESPR) and Per- and polyfluoroalkyl substances (PFAS) – which represent a specific priority to be addressed in terms of circularity and chemicals in textiles.

Relevance of the Global Framework on Chemicals (GFC) for textiles

The Global Framework on Chemicals – For a Planet Free of Harm from Chemicals and Waste (GFC), like its predecessor, Strategic Approach to International Chemicals Management (SAICM), is a multistakeholder and multisectoral approach which enables governments to cooperate with intergovernmental and civil society organizations, the private sector, and other stakeholders on the ground to support chemicals action globally (ICCM5, 2023a; UNEP, 2023; ICCM5, 2023b) and seek to better integrate chemicals-related efforts into the 2030 Agenda for Sustainable Development (ICCM5, 2023b; United Nations General Assembly, 2015) The GFC strengthens and specifies the ambition by providing a system of **5 strategic objectives and 28 targets** (see **Annex J**).

Several GFC targets can directly be applied to the textiles sector, as presented in **Annex G**. In this regard, the UNEP Textile Initiative (UNEP, n.d.b), which is also supporting the implementation of the GFC, is coordinating efforts to engage stakeholders from the textile sector to contribute toward concretizing the GFC for its application for textiles. Other international actors, such as Zero Discharge of Hazardous Chemicals (ZDHC), Pesticides Action Network (PAN) UK, and Ambition Loop, are supporting this endeavour, lately at the first meeting of the Open-Ended Working Group (OEWG) under the Global Framework on Chemicals (GFC) in Uruguay.

In the following, the holistic approaches of GFC, as relevant and beneficial for the textiles sector, are summarized for the operationalization by means of:

- **Cooperative approaches**: Multistakeholder partnerships and business partnerships (cf. other parts of this study for some more details).
- **Voluntary tool**: ChemSelect[39] is an online tool for assessing and comparing the sustainability of substances and mixtures. ChemSelect is primarily aimed at users of chemicals: companies that manufacture mixtures and use substances or mixtures in their products or processes (i.e., auxiliaries).
- **Regulatory tool**: ESPR (see Section 2.2 for further background).
- **Economic approaches**: Reporting, Investment & Finance (cf. other parts of this study for some more details).

To implement all such approaches and tools on the ground, it is highly recommended to develop and agree on mandated roadmaps or action plans which enable all relevant actors in the textiles sector to cooperate in an outcome- and impact-oriented manner, preferably with an overall supervision and coordination by a governmental entity.

[39] ChemSelect is accessible via https://chemselect.uba.de/, (last accessed on 5 Jun 2025).

Addressing Substances of Concern (SoCs) in Textiles in ESPR

As part of the EU's broader circular economy policy (see Section 2.2 for background), textiles have been identified as a priority product group for the development of sector-specific minimum Ecodesign requirements. Product aspects which can be subject to specific requirements are defined in Article 5 of the ESPR and include the presence of substances of concern.[40] Additionally, Annex I of the ESPR on product parameters requires that the use of substances—especially substances of concern—whether used alone, as constituents of substances, or in mixtures during product manufacturing, and their resulting presence in products and waste, must be evaluated with regard to their effects on human health and the environment. Work to develop ecodesign requirements for apparel textile products is underway (household textiles and footwear are out of scope for now), with final requirements expected to be set in 2026 (the requirements will come into force after a transition period of at least 18 months).

Although product-specific requirements are still under development, **Article 7 (5)** of the **ESPR** already details **information requirements** which shall make it possible to **track the substances of concern throughout the life cycle** of the products concerned. The information required shall include a unique substance identification[41] as well as information on, e.g., the concentration in the final product and information relevant for—among others—recycling and the environmentally sound management of the product at end-of-life. To conclude, the ESPR sets an ambitious level regarding the data collection and communication of substances of concern used in the manufacturing process.

A current project of the German Environmental Agency (UBA) on the development of ecodesign requirements for textiles (Umweltbundesamt, ongoing), highlights that the current practices of textile companies and brands to deal with substances of very high concern and other restricted chemicals are predominantly followed by approaches via **restricted substances lists**. Here, the ZDHC MRSL (Manufacturing Restricted Substances List) list of the "Zero Discharge of Hazardous Chemicals" has often been mentioned, as well as the AFIRM RSL (Restricted Substances List) list or other voluntary standard RLSs or MRSLs. According to the information from companies, some of them apparently set up contractual requirements that SVHCs may not be used, and suppliers have to provide certificates of clearance for the article. It was explained that the restricted substances approach in textile products is then used as the basis for **risk-based testing on the final article**. Furthermore, **positive lists via selected environmental labels**, e.g., Global Organic Textile Standard (GOTS), different standards, of Oeko-Tex or Bluesign, are also used by the companies. One of the most common ways to ensure compliance with restricted substances requirements is through the **transfer of documentation**. A handling of substances that negatively affects recycling or reuse is so far only addressed in very specific cases,

[40] Substances of concern are defined in Article 2(27) of the ESPR and include four letters that define independent criteria for a concern: The definition refers on the one hand to the hazardous properties of substances as defined in the European chemicals legislation, namely the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), Classification, Labelling and Packaging of chemicals (CLP) and Persistent Organic Pollutants (POP) Regulations. In addition to the substances of very high concern (SVHC) under REACH (SVHC or candidate list substances), further hazard classes are listed, e.g., carcinogenic, mutagenic, or toxic for reproduction (CMR) substances of category 2, substances of so-called new hazard classes (e.g., endocrine disruptors with effects on human health or the environment, or persistent, mobile and toxic properties) or sensitizing substances, all which are listed in Annex J of the CLP regulation. In addition to these substances classified as hazardous to the environment or human health, the last criterion for Substances of Concern (SoCs) mentions "adverse effects on the reuse and recycling of materials in the product in which they are contained." The wording of the definition and additional explanation is shown in Annex M.

[41] "(a) the name or numerical code of the substances of concern present in the product, as follows: (i) name in the International Union of Pure and Applied Chemistry (IUPAC) nomenclature, or another international name when IUPAC name is not available; (ii) other names, including usual name, trade name, abbreviation; (iii) European Community (EC) number, as indicated in the European Inventory of Existing Commercial Chemical Substances (EINECS), the European List of Notified Chemical Substances (ELINCS) or the No Longer Polymer (NLP) list or the number assigned by the European Chemicals Agency (ECHA), if available and appropriate; (iv) the Chemical Abstract Service (CAS) name and number, if available."

but not systematically, due to an overall knowledge gap.

On the basis of the above-mentioned analysis, recommendations are devised for SoCs. For example, **information requirements on SVHCs** (identity, concentration and occurrence in articles and their parts, as well as accessories) in the public part of the **Digital Product Passport** should be introduced to make information available to end consumers. This would relieve industry from the need to respond to individual consumer requests on the presence of SVHC according to Article 33 of the REACH Regulation. This would also require **interoperability of the DPP and the SCIP database**[42] in order to avoid the need to enter data into more than one system.

The second recommendation proposes an **internal documentation** of the effect because they are intended to remain in the product to fulfill a function. This should be a **starting point in a step-wise approach toward more transparency**, which links knowledge about textile chemical usage during the design phase of the article to chemical management systems within the supply chain. To achieve this, retailers and other operators should include a description of the relevant effect (functional) chemicals (such as the often-mentioned water repellents) in the technical product specification during the design phase of the product and pass this information on to the respective producer (production/wet processing). In wet processing, any information about required effect chemicals should be integrated into the respective production recipes. The chemical products required are usually maintained in the chemical inventory in production. Information on chemical properties (such as toxicity or reactivity) is extracted from the safety data sheets, which are provided by the chemical suppliers. This approach places responsibility for the impact of the product at the design stage of the product itself (Umweltbundesamt, ongoing).

Addressing Per- and Polyfluoroalkyl Substances (PFAS) in Textiles

Per- and polyfluoroalkyl substances (PFASs, also termed highly fluorinated substances) are a group of thousands of synthetic chemicals used in many products and are very persistent in the environment. The OECD defines PFAS as fluorinated substances containing at least one fully fluorinated methyl ($-CF_3$) or methylene ($-CF_2-$) carbon atom, without any hydrogen, chlorine, bromine, or iodine attached to it (Wang et al., 2021).

PFASs are used across a wide range of applications and sectors. The largest volumes are used in heat pumps and air conditioners, textiles, medical devices, and in manufacturing (see Annex L). PFASs are widely used in textiles due to their water- and grease-repellent properties. Examples of applications are sportswear, outdoor apparel, umbrellas, tents, vehicle upholstery, shoes, carpets, and impregnation agents. A variety of PFAS are used in textiles, including fluoropolymers, such as polytetrafluoroethylene (PTFE; commonly known as Teflon), and side-chain fluorinated polymers. The latter can be precursors to perfluoroalkyl carboxylic acids (PFCAs).

However, PFASs possess properties that can adversely affect human health (including higher cancer risk) and the environment. All PFAS are extremely persistent in the environment,[43] earning them the nickname "forever chemicals." Some are also highly mobile in the environment. Moreover, many of them have documented toxicity and accumulate in humans and other living organisms. Perfluorooctanesulfonic acid (PFOS) and Perfluorooctanoic Acid (PFOA) are classified as reproductive toxins and suspected carcinogens.

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[42] SCIP is a database of the European Chemicals Agency (ECHA) of information on substances of very high concern (SVHC) in articles that are present in a concentration above 0.1% by mass. SCIP stands for "Substances of Concern In articles as such or in complex objects (Products)." Manufacturers, importers, and suppliers are obliged to provide information about these products (https://echa.europa.eu/de/scip).

[43] All PFASs are either persistent themselves or degrade to other persistent PFAS.

Studies of mammals show effects on, e.g., the liver, blood lipids, thyroid hormones, the immune system, and the reproductive system. Observational studies conducted on humans exposed to high levels of PFOS and PFOA due to local water contamination demonstrate a correlation between increased levels in the blood and impaired immune function. Research also shows correlations between elevated levels of PFOA in the blood and effects on the liver and cholesterol levels. Effects on birth weight have also been observed. However, knowledge about the health impacts of many other PFAS remains limited.

In many European countries, PFAS have been found in groundwater and drinking water close to airports, stemming from firefighting foams. Another well-known source is the manufacturing of fluoropolymers. However, PFAS are released during their whole life cycle and can even be found in remote areas, far from their production or use sites. As a result, PFAS contamination represents a global problem.

Over the past 5 years, PFAS have been among the most intensively debated chemical issues in Europe, drawing significant attention from scientists, environmental NGOs and policy-makers alike. PFOA, PFOS, and PFHxS are among the most well-studied PFAS substances. They are all regulated in the Stockholm Convention. In May 2025, the long-chained Perfluorocarboxylic acids (PFCA) were added as well.

In January 2023, national authorities from five European countries presented a proposal for a universal ban on PFAS within the European Union's REACH regulation (European Parliament and the Council, 2025) with different transition periods for different sectors, depending on the availability of alternatives and their importance for society. The restriction dossier is currently evaluated by the scientific committees in the European Chemicals Agency (ECHA), and their proposal to the European Commission is expected by the end of 2026.

The main argument for a universal ban on PFAS is their extremely high persistence. PFASs may remain in the environment longer than any other man-made chemical. Should these substances continue to be released, their concentration in the environment will further accumulate, as mineralization under natural conditions does not take place. Once present in the environment, the removal of PFASs from surface water, groundwater, soil, sediment, and biota is technically extremely difficult, if at all possible, and also very costly. Moreover, as a matter of scientific principle illustrated in earlier cases, with, e.g., PCBs or brominated flame retardants, scientific knowledge about hazardous properties of technically beneficial substances often emerges only later, when these substances are already widely spread into material streams and released into the environment, having already caused significant damages directly and indirectly. This often also applies to initially less scrutinized—and just for this reason allegedly less hazardous—substitutes from the same group of chemicals. If technically possible at all, then the very high removal costs are often shifted from earlier polluters to society.

For most textile applications, alternatives to PFAS are available, particularly in the consumer segment. Many well-known brands have voluntarily excluded PFAS from their products. One example is the ChemSec PFAS Movement, a business group including companies like H&M and IKEA, that is moving toward PFAS-free textile products. Likewise, outdoor brand VAUDE has committed to eliminating PFAS along with other hazardous chemicals from its products – a case study is provided in **Annex M**.

Recommendations:

- PFAS should be treated as a group of substances to avoid regrettable substitution from replacing one PFAS-substance with another with a similar impact on health and the environment.
- There is too little known about the (eco-)toxicological effects of these man-made substances. Due to their extreme persistence in the environment, using and recycling PFAS-containing materials should be avoided. Where applications are still essential and alternatives are lacking, strict control measures

of any use and recycling stream must be in place. This includes minimizing exposure for workers and consumers as well as preventing environmental releases.
- The aim should be to phase out the use of PFASs as far as possible. Where uses are considered critical for society and no suitable alternatives exist yet, targeted research is needed.

3.1.4 Policy Instruments for Addressing the Environmental Impact of Textiles in the EU

The **EU Strategy for Sustainable and Circular Textiles**, adopted in March 2022, aims to transform the textile sector into a more sustainable and circular industry. It provides an overarching strategic framework, introducing several legislative initiatives. The following section outlines three EU-level policy measures and initiatives relevant to textiles (European Commission, 2022).

- **EU Ecodesign for Sustainable Products Regulation (ESPR)** (ongoing): Establishes a framework for mandatory product-specific sustainability requirements (incl. for textiles); expected to set minimum design requirements for durability, repairability, recyclability, and recycled content (European Commission, n.d.). The first Ecodesign requirements for apparel textiles will not enter into force before mid-2028 at the earliest. The ESPR also contains a ban on the destruction of unsold goods and the setting up of more information disclosure through digital product passports. The digital product passport for textiles will be considered at the same time as a revision of the Textile Labelling Regulation, which will see additional aspects made mandatory for both physical and digital product labels (EEB, 2024).
- **EU Waste Framework Directive** (revised in February 2025): Establishes the waste hierarchy; requires EU member states to implement Extended Producer Responsibility (EPR) schemes for textiles within 30 months; **mandatory separate collection** of used textiles in all member states from January 2025 (European Commission, n.d.b).
- **EU Waste Shipment Regulation** (entered into force in 2024): Will restrict exports of textile waste to non-OECD countries from May 2027 unless proper waste treatment is proven; "end-of-waste" criteria to distinguish reusable textiles from waste are currently under development (European Commission, n.d.c).

Thus, the EU is addressing the environmental impact of textiles from a holistic perspective by developing policies and measures targeting the whole value chain. In this regard, the ESPR gains enormous importance as it is targeted toward the design phase, which also has an impact on recycling and end-of-life treatment of textiles. For instance, the design plays a decisive role regarding material diversity, separability of the components and the presence or absence of impurities. After the end-of-use phase, there is a great need to improve collection, promote preparation for reuse, and increase recycling capacities, and particularly F2F recycling capacities. Thereby, an ambitious implementation of the Waste Framework Directive will be required. Measures need to be put in place to support technical developments on the sorting side that enable the automation of sorting by fibre composition. Ultimately, there is a need for efficient sorting of used textiles according to their suitability for reuse on the one hand and sorting of used textiles that are not suitable for reuse for the various recycling processes on the other. Regarding a permanent and long-term reduction in the environmental impact of textiles, however, a focus on recycling and recyclable products is not enough. The greatest impact can be achieved by reducing consumption. This requires a cultural change toward a higher value of textiles and an active promotion of sufficient clothing consumption.

Box 5: Digitalization in the textile industry

The digital transformation of the textile industry will be a key driver in Europe's shift toward a circular and sustainable economy. Industry 4.0 technologies—like **AI, IoT, blockchain, robotics, computer-aided design, sensors**, and digital product passports (**DPPs**)—drive improvements in efficiency, productivity, resilience, and market responsiveness. They also enable real-time supply chain optimization, increased transparency, and consumer empowerment, and facilitate informed decision-making. Digital tools can be valuable across all textile life-cycle stages—from **optimizing and automating manufacturing** and **logistics** to enabling **circular product design**, **digital prototyping**, and advanced end-of-life solutions, such as **high-quality recycling** and **automated sorting**. Digitalization can help extend product lifespans, reduce waste, lower costs, and facilitate more efficient use and sharing of resources. Moreover, it supports the **development of new circular business models** (like repair, reuse, and sharing). Some textile companies are already building their business case around digital technologies, offering innovative services, and unlocking new revenue streams. **Yet the digital shift also involves several risks and trade-offs**. The high energy and material demand of data centres and AI, as well as potential rebound effects from efficiency gains, can counteract sustainability goals. Moreover, uncertainties around data verification and enforcement (especially regarding DPPs) remain, and SMEs face substantial barriers in adoption, including high investment costs, fragmentation of supply chains, and limited digital skills. Unlocking the full potential of the digital transformation will **require not only innovation, but also behavioural changes and supportive policy frameworks** (EEA, 2025; Manshoven et al., 2025; European Commission, 2022). More detailed information on opportunities for digital technologies in the textile industry can be found in Annex P. In addition, a list of German Federal Ministry of Education and Research (BMBF)-funded projects related to digitalization in the textile industry can be found in **Annex O**.

3.1.5 Policy Instruments to Address the Environmental Impact of Textiles in China

In China, the textile industry is an important industry for improving people's livelihoods. In 2024, China's textile and apparel exports totalled $301.1 billion (China National Textile and Apparel Council Research Department, 2025). However, the conventional linear textile industry has high energy and water consumption, with significant pressure on raw material consumption, including cotton and petrochemical-based materials, leading to heavy environmental pollution and emissions. It was estimated that approximately 24 million tonnes of oil could be saved annually and reduce the associated 80 million tonnes CO_2e if all used fibre could be reused and recycled.[44] In recent years, there have been several initiatives in China to green the manufacturing of textiles. The nationwide policies on promoting the circular economy (see Section 2.4) provide top guidance and general requirements for the textile sector. The following section summarizes key policies specified in the textile sector.

- In 2022, the National Development and Reform Commission, Ministry of Commerce, and Ministry of Industry and Information Technology jointly issued the **Implementation Opinions on Accelerating the Recycling and Reuse of Waste Textiles**, detailing concrete measures and setting goals: By 2025, the recycling rate of waste textiles is to reach 25%, and the output of regenerated fibre from waste

[44] http://paper.ce.cn/pad/content/202308/22/content_279701.html

textiles is to reach 2 million tonnes; By 2030, the recycling rate should reach 30%, and regenerated fibre output 3 million tonnes.

- In 2023, the Ministry of Industry and Information Technology and three other ministries jointly issued the **Implementation Plan for the Upgrading and Quality Improvement of the Textile Industry (2023–2025).** It prioritized the task of promoting and building a green and circular system in the textile sector, proposing several policy measures, including standards for labelling circular textile products, green design to reduce the difficulty of collecting and sorting used textiles, and standards for the quality of circular fibres. It also encouraged the relevant organizations to set up goals and develop a roadmap for circular textile products and a research method for quantifying resource values of circular textile products, while expanding the application areas of recycled textile products.
- A series of codes of conduct guiding a healthy circular textile sector and market has been developed since 2009. The **Code of Conduct for Reprocessed Fiber Quality** (Trial version, the former China Fiber Inspection Bureau, 2009) forbids reusing and recycling used textiles that come from hazardous and/or toxic sources such as hospitals*,* funeral homes, epidemic areas, and others. The **Measures for the Supervision and Administration of Fiber Product Quality (2016)** explicitly prohibit the use of waste fibre and reprocessed fibres in medical and infant products. In 2019, the Ministry of Industry and Information Technology revised the **Norms for the Recycling and Reuse of Chemical Fiber (Polyester) Industry,** effectively promoting greener development in the textile recycling industry. In 2021, the State Council issued the **Guiding Opinions on Accelerating the Establishment and Improvement of a Green, Low-Carbon and Circular Development Economic System**, making top-level arrangements for green transformation in the textile sector and building a circular economy logistics system. In 2022, the National Development and Reform Commission and the Ministry of Commerce jointly included textile waste sorting, recycling, and utilization in the **Catalogue of Industries Encouraged for Foreign Investment (2022 Edition)**.

To ensure policy implementation, national and industry technical institutions have jointly developed and issued a series of technical standards. These fall into several categories:

- **Product technical standards**: These define technical requirements for waste textiles and recycled fibre products, including the mandatory national standard *General Technical Requirements for Stuffing Fiber Products*, the recommended national standard *Basic Safety Technical Requirements for Reprocessed Fibers*, and industry standards like *Reprocessed Short Fibers from Waste Textiles* and *Technical Specifications for Eco-Design Product Assessment – Recycled Polyester Products*.
- **Recycling system standards**: These lay the foundation for textile waste recycling, such as the recommended national standards *Classification and Codes for Waste Textiles*, *Technical Specification for Waste Textile Recycling*, and *Technical Specification for Recycling of Textile Waste*.
- **Regulatory and identification standards**: These include the mandatory *Basic Safety Technical Specifications for National Textile Products* and the recommended *Identification Method for Recycled Polyester (PET) Fibers*.

Thus, the Chinese government has been quite active in implementing policies and standards to develop a green, low-carbon circular path for the textile industry to address the national ecological and resource security, as well as to contribute toward the goal of constructing an ecological civilization. Looking at China's major role in textile manufacturing and exports, the circular approach followed by China has the potential to improve the quality of textile products globally and contribute toward the cost-effective sustainable development, as well as establish secondary utilization markets, building local supporting industries, such as repair and resale. This is of great significance in promoting the inclusive development of local industry chains and their green transformation.

3.2 Key Challenges for a Circular Economy in the Textile Industry

The transition to a circular economy in the textile sector faces significant challenges across multiple dimensions, including reuse, recycling, material input quality, and systemic issues.

3.2.1 Challenges for the Reduction of Material Consumption

Reducing textile consumption faces significant **behavioural and economic barriers**. Consumer habits are shaped by business models that promote **trend-driven overconsumption** and the **premature disposal of clothing**, often after only a few wears. At the same time, **product lifespans have declined** due to reduced garment durability, driven by **lower-quality materials** and design choices that prioritize speed and cost over longevity. The **decline of local repair services,** coupled with the loss of repair skills among consumers, further limits opportunities to extend use. Repair is often perceived as inconvenient or uneconomical, particularly when replacement items are readily available and inexpensive. Together, these dynamics create a systemic lock-in to linear consumption patterns, undermining efforts to promote sufficiency and circularity in the textile sector (Circular Economy, 2024; Ellen MacArthur Foundation, 2017).

3.2.2 Uneven Development Layout of the Collection System

China has not yet built up a mandatory separate collection system for used textiles. Currently, it has initially established a combined online-offline waste textile collection system (a hybrid model that blends web-based platforms with physical collection points). However, online collection services and offline collection points are mostly concentrated in first- and second-tier cities, leading to uneven geographic coverage. Compared with traditional recyclable materials like metals, waste textiles have relatively **low economic value**. When recycling is inconvenient, public willingness to participate in waste sorting is low, and many waste textiles remain idle at home, unused. Furthermore, most recyclers are micro or small enterprises or individuals, facing issues such as small scale, fragmentation, and weak capabilities—similar to other recycling sectors—indicating that the overall recycling capacity and system still need significant improvement.

In the EU, mandatory separate collection is expected to increase the volume of used textiles, but **average quality will decline**, driven in part by low-value fast fashion and peer-to-peer resale platforms like Vinted,[45] which divert high-quality items away from formal collection streams. This **threatens the economic viability** of sorting systems reliant on revenues from second-hand sales. **Local reuse** is constrained by **limited domestic demand** (partly because of low fast fashion prices). Meanwhile, large volumes of collected textiles are **exported for reuse**, but their **fate is often unclear,** ending up in countries lacking adequate waste management infrastructure. This undermines circularity and shifts environmental and social burdens from the global north to the global south (EEA, 2024b, 2025; Wagner et al., 2022).

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[45] Vinted is an online platform where users can buy, sell, or swap used clothing, shoes, and accessories, mainly targeting private individuals who want to trade second-hand fashion easily and securely (https://www.vinted.de/).

3.2.3 Overall Low Technical Level of the Recycling Industry

Garments are typically **not designed for recycling**. The **heterogeneity of post-consumer textiles** makes sorting complex, which remains largely manual, costly and time-intensive. **Automated sorting technologies** are not fully developed yet, while **material composition** often remains **unclear,** with labels on clothing frequently incorrect. The use of **fibre blends**, **chemical finishes**, **dyes**, and **coating**s further impairs recyclability and output quality. **Currently, only mechanical recycling operates at an industrial scale, but recyclates may contain hazardous substances with limited options for decontamination. Fibre-to-fibre mechanical recycling plays a minor role** (then using relatively homogeneous post-production industrial waste streams) **as it shortens fibre length and lowers output quality. In contrast, depolymerization technologies** have the potential to produce fibres of virgin-like quality but are still in development or the process of scaling up (Huygens et al., 2023; Löw et al., 2024; Klinge et al., ongoing)**.**

In China, some innovative enterprises have made progress in successfully making high-quality fibre-to-fibre recycling. However, the average technical level of the recycling industry mainly relies on simple, low-value-added physical methods. Advanced, higher-value-added chemical recycling methods have yet to achieve large-scale industrialization. This can’t meet the increasing requirements for sorting textile products of the preparation for high-quality recycling. Additionally, over 85% of waste textiles are blended fabrics (e.g., cotton, linen, wool, polyester, acrylic, spandex), which are low in value, difficult to divide and typically dyed and processed. This makes fibre separation and decolourization technically challenging. Meanwhile, consumer understanding of the quality of recycled textile products is still inconsistent. Due to hygiene and other concerns, most consumers prefer textiles made from virgin materials, weakening the market competitiveness of recycled textile products.

3.2.4 Challenges for the Manufacturing of Circular Textile Products and the Urgent Need to Improve the Standards System

The use of recycled fibres is not economically viable due to lower virgin fibre prices, fluctuating supply and demand, and a lack of regulatory or financial incentives for recycled fibre use or design for recyclability (most recycled polyester currently comes from **PET bottles**). The economic viability of sorting facilities (which rely on second-hand sales) is increasingly challenged by the rise of cheap fast fashion textiles, growing private resale markets, and the expected decline in average quality of collected textiles resulting from the EU’s mandatory separate collection. Moreover, the textile value chain **lacks efficient integration** between sorters, recyclers, and yarn producers, hindering cost reductions through an “economy of scale” (Deckers et al., 2024; Löw et al., 2024; Textile Exchange, 2024; Klinge et al., ongoing).

China has developed and revised several standards for textile recycling, such as *Classification and Codes for Waste Textiles*, and some local governments (e.g., Zhejiang Province) have issued standards like the *Technical Specification for Recycling Donated Textiles*. A preliminary national standard system is in place. However, gaps remain in standards for composition testing, sorting, labelling, and trading of waste textiles. In 2017, the first national recommended standard for green textile product evaluation, *Green Product Evaluation – Textile Products*, was issued, launching a green product certification program, but this does not cover recycled materials. China has yet to establish a national standard or certification system for traceability of recycled materials and reprocessed fibres, and currently relies on overseas certification bodies for quality assurance.

3.3 Recommendations for Building a Circular Economy in the Textile Sector

Without regulatory and collaborative outcome-oriented measures, current textile production and consumption trends will continue to increase waste volumes and harm the environment. A holistic strategy is needed to both minimize environmental impacts and resource use, and at the same time ensure the competitiveness and economic resilience of the textile industry.[46] In the following, recommendations are drawn to address the environmental impacts of textiles in China:

3.3.1 Promote Circular Design and Improve Market Conditions of Circular Textile Production to Counter Fast Fashion

- Policy-makers should **support the development of standards for product design** to improve the quality and circularity of textiles placed on the market.[47] Standards should be based on robust evaluation of life-cycle impacts, and should address the **durability, repairability, and recyclability of textiles**—such as mono-material use or limits on substances of concern—while also considering minimum **recycled content quotas**.
- To improve market conditions for **circular textiles and circular business models**—while at the same time ensuring the accessibility and affordability of high-quality, circular textiles—economic instruments should be deployed to improve the competitiveness of circular business models compared to linear take-make-waste approaches. The goal of such mechanisms should be to internalize the environmental externalities of textile production and create a level playing field in the market for circular textiles. Suitable mechanisms could include tax incentives for green production, extended producer responsibility (EPR) schemes that reward ecodesign, subsidies or low-interest loans for investments in circular manufacturing capabilities, and preferential tariffs or no tariffs on products that comply with circular production requirements, and technologies that enable circular manufacturing.
- To incentivize production of circular textiles, **demand-side measures** should be implemented to increase demand for circular textiles. This includes introducing and strengthening circularity criteria in **Green Public procurement and ecolabels.** For example, criteria on durability, repairability, recyclability and use of recycled content could be piloted in the procurement of textile products in schools, hospitals, government offices, etc. In addition, **consumer awareness programs** should be launched to educate the public about the importance and benefits of sustainable consumption and should focus on the decoupling of consumption with resource use (i.e., reducing overall material consumption in favour of high-quality, sustainable consumption). Leverage the benefits of the digital economy, combining both online and offline models to regulate the development of the domestic second-hand market and cultivate second-hand product trading platforms, allowing individuals and families to maximize the use value of idle items.
- Chemicals-related orientation should observe the GFC objectives and targets (ICCM5, 2023b).It is recommended to develop and agree on mandated roadmaps or action plans that enable all relevant actors in the textiles sector to cooperate in an outcome- and impact-oriented manner, preferably with overall

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[46] UNEP's "Sustainability and Circularity in the Textile Value Chain: A Global Roadmap" (2023) builds upon the Global Stocktaking Report. It outlines how different stakeholder groups can individually and collectively contribute to building a circular textile sector. It identifies three overarching and interconnected priorities - (1) shifting consumption patterns, (2) improved practices, and (3) infrastructure investment - and breaks them into nine actionable building blocks. Stakeholder-specific annexes, including one tailored for policy-makers, outline the key actions linked to these building blocks ((2025c) Available online via https://www.unep.org/resources/publication/sustainability-and-circularity-textile-value-chain-global-roadmap, last accessed on 22.07.2025. Find a short summary of UNEP's "Global Roadmap" in Annex R.

[47] For example, as also envisioned in the ongoing implementation of the EU's 'Ecodesign for Sustainable Products Regulation' (ESPR). Refer to the ongoing JRC preparatory study for more details: Preparatory Study on Textile Products. Available online via https://susproc.jrc.ec.europa.eu/product-bureau/product-groups/467/home, last accessed on 05.05.2025

supervision and coordination by a governmental entity. It is deemed necessary to increase transparency on the use of hazardous chemicals in the textile value chain, for instance, by using digital product passports. Harmful group of substances, such as PFAS, should be avoided and phased out as far as possible, or strict control measures of any use and recycling stream must be in place, where applications are still essential and alternatives are lacking, and targeted research should be done where uses are considered critical for society and no suitable alternatives exist yet.

3.3.2 Build and Scale Up Collection and Sorting Capacities and Integrate Digital Solutions

- Textile waste **collection infrastructure** should be scaled up to ensure sufficient quantity and quality of material input for fibre-to-fibre recycling. For China, further strengthen the effectiveness of household waste classification, increase the deployment of dedicated recycling bins for waste textiles, and guide recycling enterprises to expand their operations into third- and fourth-tier cities, improving waste textile collection at the source.
- To improve sorting and finally recycling efficiency, a shift from manual to automated textile sorting and efficient pre-treatment processes is essential. **Investments in automated sorting** facilities, using, for instance, advanced NIR-based technologies, are essential and should be supported through **financial instruments** (e.g., investment premiums, tax benefits or depreciation schemes). Scaled-up automated sorting by fibre composition is key to enabling advanced material (particularly fibre-to-fibre) recycling with effective technologies for decontamination from hazardous chemicals and other contraries. In the context of China, fully leverage the leadership and demonstration role of industry giants like China Resource Recycling Group and China Recycled Resource Development Group Co., Ltd., and strategically build waste textile sorting centres to improve the precision of recycling and sorting. With the "Zero-Waste City" initiative, select cities with suitable conditions to pilot waste textile recycling and sorting systems, creating a model for efficient recycling and refined sorting that can be widely adopted. This approach should foster the development of a waste textile recycling system driven by government guidance, market operation, and broad public participation.
- **Digital product passports** (DPP) or Digital Product Information Systems (DPIS) must contain information relevant to sorters and recyclers (e.g., material composition), to enhance the efficiency and economic viability of the recycling value chain. Integrating digital identification technologies enhances the efficiency of sorting and traceability. It is important that the information storage and sharing is kept as **simple** and **low-cost** as possible to ensure feasibility for all stakeholders. It is also essential that digital systems are developed to be interoperable with other markets to facilitate trade.
- To address the current lack of economic viability in textile recycling, the swift implementation of an **Extended Producer Responsibility (EPR) scheme** for textiles is crucial. EPR obliges producers to cover the full life-cycle costs of their products, thereby financing collection, sorting, and recycling. Its effectiveness will depend on clear responsibilities, the eco-modulation of fees, robust independent monitoring, and the prevention of free riding. The scheme must necessarily **include imported goods** to ensure effectiveness and must be implemented with minimal bureaucracy while also ensuring strong stakeholder coordination.

3.3.3 Promote Preparation for Reuse, Develop Standards and Scale Up Various Textile Recycling Technologies

- **Preparation for reuse should always be the preferred option over recycling**. The effectiveness of preparation for reuse can be achieved by establishing quality standards for textiles and developing skills and technologies for identifying good-quality textiles that are deemed ideal for reuse.

- Textile recycling faces several challenges, including technical barriers and missing infrastructure. Therefore, the **development** and **scale-up** of diverse **textile recycling technologies** is essential and should be supported **without prior restriction** to a single technology. Different recycling processes may be appropriate, depending on input material, quality, and the intended application.
- The selection and promotion of recycling processes should be **based on technical**, **economic**, and **environmental criteria**. Promising fibre-to-fibre recycling options (like depolymerization) should be further advanced. Besides closed-loop recycling, open-loop approaches that produce alternative products from used textiles should be permitted if they offer greater environmental and economic benefits than new clothing.
- **Improve the standard system for the waste textile recycling industry** and refine the product quality standards for the chemical recycling of waste textiles, addressing bottlenecks in the downstream market for recycled products. Promote the development of technical standards and regulations for the recycling, disinfection, sorting, and comprehensive utilization of waste textiles, providing guidance for the development of the waste textile recycling industry. Revise and update standards for the cleaning and disinfection of second-hand clothes, strengthening supervision on hygiene and disease prevention, and improving market transaction management regulations for second-hand clothing.
- Expedite the exploration and development of an **information-based traceability system for recycled fibres that meets international standards** and enhances the quality management of recycled textile products by employing methods such as quality traceability and certification.

3.3.4 Implement Export Regulations for Textile Waste

- It is important to **restrict textile waste exports** to countries that cannot prove proper end-of-life treatment of textiles according to the waste hierarchy. End-of-Waste criteria are highly relevant to prevent fraud.
- Support in developing environmentally sound **recycling and end-of-life treatment infrastructure in importing countries.**
- The development of **End-of-Waste criteria** for textiles is essential to clearly define and differentiate between used textiles for reuse and textile waste. End-of-Waste criteria should be internationally aligned.
- Actively participate in the global policy dialogue on textiles facilitated by UNEP in order to build global policy coherence in the textile value chain.[48]

3.3.5 Phased Approach to Implementing Recycled Content Quotas

- **Financial incentives and economic instruments** are needed to boost recycled content in textiles. **Recycled content quotas** could be a valuable addition in the future, provided that high-quality, contaminant-free, and competitively priced recycled fibres are available in sufficient quantities. These quotas should not be the same for all textiles but rather **fibre-specific** and consider the textile's function and recycling approach. Recycling content requirements should also be market-oriented and designed with minimal bureaucracy.
- **PET fibres should not count** toward recycling quotas to preserve the PET closed-loop system, though using PET from bottles in textiles should remain allowed.

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[48] https://buildingcircularity.org/global-policy-dialogue-for-textiles/

- Binding quotas must be **traceable** and **monitorable** to **avoid market distortions**. **Imported textiles** should be thoroughly checked, while self-declarations and certifications should not be accepted. As long as recycled fibre content can't be reliably traced at the product level, setting and monitoring sector-specific recycled content targets could be a transitional solution.

3.3.6 Cross-cutting Measures

- Increase support for the national key **R&D plans** on "Circular Economy Key Technologies and Equipment" to boost the development of waste textile recycling technologies. Accelerate the R&D of chemical recycling methods for waste textiles, aiming to achieve large-scale, low-cost production of recycled fibres through chemical processes. Additionally, speed up breakthroughs in key technologies for the high-value utilization of waste textiles and their industrial development. Focus on improving the technologies for fibre separation, decolourization, and decolouring[49] of waste textiles, traceability of recycled fibres, and contaminant removal.
- Increase efforts in the recycling and utilization of used military uniforms, school uniforms, police uniforms, workwear, and other standardized clothing, and organize capable enterprises to pilot the recycling of used uniforms, improving the high-value utilization of typical waste textiles.
- **Training of skilled personnel** in circular economy, circular textile design, and digital skills must be enhanced.
- There is a need for **stronger coordination and dialogue between all stakeholders** along the textile value chain. This includes strengthening collaboration on existing gaps between policy-makers, brands, and other key stakeholders.[50]

[49] In practice, the terms, decolourization, and decolouring, are sometimes used interchangeably because both involve removing color, often using similar chemical or physical method. While both processes aim to remove unwanted color, decolourization generally refers to treating liquids (like wastewater), whereas decolouring is about removing color from the textiles themselves. Common methods used for decolourization include chemical oxidation, adsorption, biological treatments, and advanced filtration, while for decolouring, technologies, such as chemical stripping, bleaching, or enzymatic treatments, are commonly used.

[50] See for example: 'Sustainability and Circularity in the Textile Value Chain: A Global Roadmap' (2025c); and the ongoing UNEP-facilitated global policy dialogue series 'Policy Action on Textiles – A dialogue series facilitated by UNEP' (available online via https://buildingcircularity.org/global-policy-dialogue-for-textiles/, last accessed 22.07.2025).

4 Circular Economy in the Chemical Manufacturing Sector

The chemical industry is foundational to the global economy, contributing approximately 7% to global GDP (ICCA, 2019). However, it is also a major source of industrial carbon emissions, with direct emissions from primary chemical production reaching around 935 million tonnes in 2022 (IEA, 2023). Driven by the global imperative for carbon neutrality, the circular economy has become central to addressing resource scarcity, mitigating environmental pressures, and achieving sustainable development. The European Union is leading this shift, embedding circular economy principles into its regulatory framework. This drives key sectors—including chemicals—toward more resource-efficient, longer-lasting, and waste-minimizing business models. The following chapter introduces the circularity in Germany's chemical industry within the plastics context, as well as the circularity requirements in the Chinese chemical industry.

4.1. Circularity in the German Chemical Industry – the Transformation Toward Defossilized Raw Materials

4.1.1. Context: The Circular Plastics Crisis

Germany is taking a leading role in global greenhouse gas emission reduction and has committed to the goal of climate neutrality by 2045. While Germany considers the proactive leadership of a leading industrial nation as a key signal to the world, it also aims to gain strategic advantages by pioneering important industrial transformations. In this context, the chemical industry is a key sector as it not only relies on energy but also on a resource base that is still widely sourced from fossil sources. Since the extraction and use of fossil resources will have to be minimized drastically around the globe, a key strategic question is how to diversify the feedstock of the industry with a mid-term view to a switch to non-fossil and sustainable alternatives.

However, the German chemical industry is currently facing a deep structural crisis, including stagnating demand in key markets, global overcapacities, structural cost disadvantages, and high transformation costs. This situation makes the search for new, economically viable and ecologically sustainable business models increasingly challenging.[51] For instance, increasing volumes of lower-cost polymer imports are exacerbating the economic situation.

The **coalition agreement of the Federal Government and the National Circular Economy Strategy** acknowledges the importance of the chemical industry for the national economy and in contributing toward achieving climate and environmental goals. Especially the following aspects will be important for the national chemical industry, and in particular for the plastics sector:

- Adjustment of consumer behaviour due to demographic developments and changing purchasing power based on changing priorities of national and private households.
- Decline in monomer and polymer production due to the maximization of mechanical recycling of increasingly recyclable products.
- Increasing substitution of fossil raw materials for monomer production by chemically recycled plastics, biogenic and synthetic materials.

Against this background, one of the currently discussed circularity options is **to advance chemical recycling as an additional building block of the circular economy—in addition to prioritizing the establishment of mechanical recycling as the preferred recycling option**. The term "chemical recycling"

[51] Sievering (2024)

encompasses various processes that allow plastic waste to be converted into a feedstock for the petrochemical industry. These feedstocks can then be used to produce monomers and polymers in their original quality and without the contamination of additives, dyes, and contaminants from previous life cycles. Contamination of plastics by hazardous additives, such as flame retardants, often makes recycling difficult because the range of applications for the resulting recyclates is severely restricted. Especially in these material flows, options for chemical recycling are currently considered because it offers the chance to obtain basic chemical compounds for plastics production from these fractions.[52] **In comparison to mechanical recycling, this process requires much more energy but avoids a loss of material quality and downcycling**.

In Germany, over 90% of plastic waste is no longer landfilled; instead, about 40% of it is recycled—however, even more is thermally recovered, e.g., in waste incineration plants. Given today's functional requirements for plastics, such as strength, flexibility, semi-permeability or impermeability, reduced flammability, and many more, polymers are treated with numerous additives and combined to form composite materials. This currently makes **recycling not feasible for all of the plastics used, with multi-layer packaging as the most prominent example**. At this point, the establishment and ramp-up of chemical recycling could significantly advance the circular economy of the chemical industry. Furthermore, it offers the opportunity to develop a building block for a defossilized raw material portfolio based on national resources. For instance, **the energy demand for synthetic raw materials is many times higher and requires significantly higher investment compared to chemical recycling[53]**.

Against this background and in order to mobilize the necessary private investment, Germany's National Circular Economy Strategy is focusing on the creation of green lead markets, which would, among other things, **create substantial and reliable demand for high-quality plastic recyclates through the use of minimum recycling quotas** at the national and European levels. In particular, contact-sensitive plastic packaging would only be technically producible using chemical recycling processes.

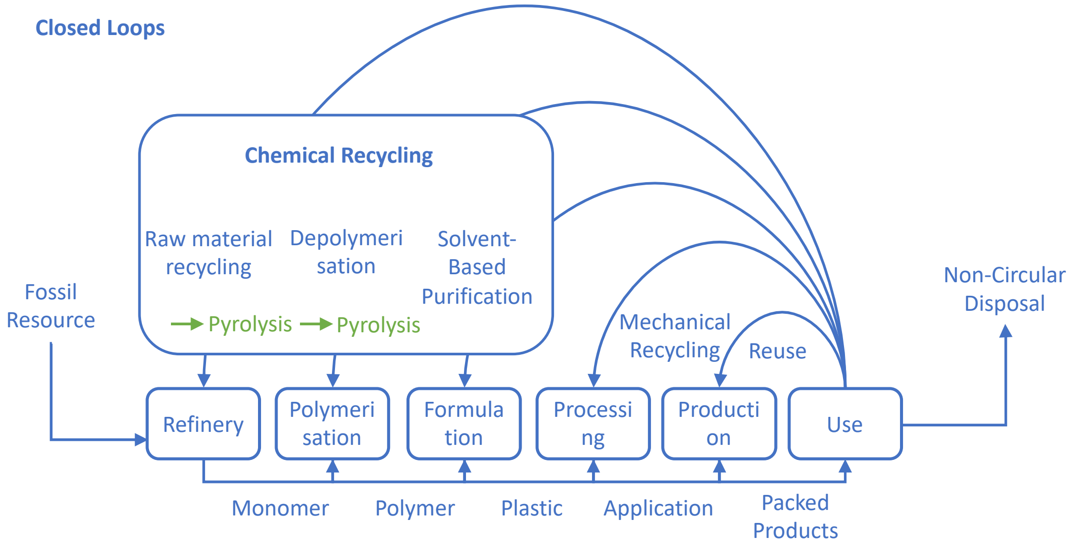
However, the **potential of chemical recycling is offset by risks, particularly with regard to the necessary energy consumption and the potential cannibalization[54] of mechanical recycling**. Both in mechanical and chemical recycling, mutually complementing and differentiated demand-driven strategies might be beneficial for maximizing circularity of major material flows. Thus, overall, **a differentiated analysis of the technology with environmental and economic considerations, the necessary regulatory framework and future market development is required**.

4.1.2 Chemical Recycling As a Building Block for Circular Plastics Solutions

The term "chemical recycling" does not refer to a specific technology, but is a collective term for all processes that, on the one hand, utilize more than just material or physical processes to recycle the starting material, but, on the other hand, do not result in complete chemical conversion (combustion) with atmospheric oxygen.[55] These include, among others, **depolymerization, pyrolysis, catalytic cracking or hydrocracking, and gasification**. Different technological approaches seem to be suitable for different streams of plastic waste, e.g., depolymerization for polyamide used as nylon. The following figure illustrates the level at which different

[52] Fraunhofer UMSICHT (2025)
[53] Hermanns et al. 2023
[54] Cannibalization here refers to chemical recycling drawing feedstock or investment away from mechanical recycling, potentially reducing its effectiveness.
[55] Acatech/ Systemiq 2021, p. 39

chemical recycling processes contribute to closing material cycles.



Source: In4Climate.NRW, 2020.

Figure 5: Closing plastic loops on different levels

Comprehensive life-cycle assessments commissioned by the German Environment Agency UBA demonstrate that chemical plastics recycling—in technically optimized and energy-integrated plants—"can fundamentally make a positive contribution to the circular economy."[56] **Greenhouse gas emissions and resource consumption can be reduced, particularly compared to thermal treatment**, which, as indicated, still dominates in Germany today. Analyses conducted inter alia by the Wuppertal Institute show savings of 46% compared to waste incineration, depending on the specific pyrolysis process.[57] However, the **specific environmental effects depend heavily on the selected feedstock, the integration into the chemical industry's production processes, and the assumptions made regarding the materials used to replace the currently common co-incineration of plastic waste in cement plants**, for example. Considering the high energy demand for such processes, an increased supply of renewable energies will be necessary for further optimization of its ecological footprint.[58]

4.1.3 Urgent Need for Reliable Policy Frameworks

The selected parameters and thus the range of the ecological assessment of chemical recycling underscore the crucial importance of a clear political framework to enable the ramp-up of this technology in the context of the future European, as well as specifically German, chemical industry. Particularly in view of the high investment costs, both for chemical recycling itself and for processing the products to meet the necessary quality requirements (in a steam cracker process), a high degree of long-term planning security would be required. A key factor in this planning security is the **extent to which these chemical recycling processes can also be counted toward the mandatory recycling quota.**

At the same time, **a viable business model for chemical recycling would also require secure demand**

[56] Quicker/ Seitz 2024, p. 21
[57] Meys et al. 2022, p. 57
[58] Quicker/ Seitz 2024, p. 21

for the recyclate produced in order to be able to pass on the currently significantly higher production costs (compared to fossil-based, linear processing routes) to the downstream value chain. To this end, the European Commission, in particular, is focusing on the development of green lead markets by specifying minimum recycling quotas. For example, in the future, 25% of the plastic used in beverage bottles must come from (mechanically) recycled materials. Similar regulations are being prepared for vehicles, textiles, and the building sector, among others.

An essential prerequisite for the recognition of recyclate from chemical recycling for such minimum recycling quotas is mass balancing. This balancing is necessary because the 100% use of chemically recycled materials in a steam cracker will not be possible, at least in the foreseeable future. A steam cracker typically processes 4-5 million tonnes of hydrocarbons per year, and chemically recycled volumes will not be available on this scale, so the application portfolio will always contain only a small proportion of recycled materials. Therefore, a virtual, mass-balanced approach will be required to leverage the potential of chemical recycling. Unlike mechanical recycling, tracing back to the polymer or monomer level in individual products makes it impossible to verify what proportion of the plastic used was actually recycled. **To ensure planning security for investments, but also to prevent greenwashing and fraud, clear and verifiable rules are needed regarding the measurement points at which the actual recycling of plastic waste must be demonstrated.**[59] For instance, the regulatory framework should clearly define the minimum allowable proportion of recycled content, differentiated according to mechanical, depolymerization, solvent-based purification and pyrolysis/gasification processes, for achieving the targets of a mandatory recycled content quota. The rules should also apply to voluntary claims, however, thereby strictly restricting the use of pyrolysis and gasification processes for claiming recycled content values in order to reduce the risk of greenwashing.

A key component for ensuring the necessary transparency of the value chain could be the digital product passport, which would have to be made available for every product when it is placed on the European market. The necessary information (e.g., on material composition, recycled content, and recyclability) would be uploaded to a secure data room. In the future, this data could help to significantly accelerate the exploitation of the potential of chemical recycling to defossilize the chemical industry. The chemical industry in Europe is considering investing a total of €8 billion in corresponding facilities by 2030 to produce up to 2.8 million tonnes of high-quality recycled material per year—provided the regulatory framework described is implemented promptly.[60]

In addition to the need for political and regulatory support for the ramp-up of chemical recycling, from the perspective of a sustainable circular economy, **care should be taken to ensure that only materials that cannot be used for mechanical recycling, which has a significantly better environmental impact, are used as input material** for such processes. Cannibalization must be prevented through clear guidelines. This also includes ensuring that the further development of the mechanical recyclability of products should not be postponed, and especially that investments in sorting capacities are increased. The European Packaging Directive stipulates full recyclability by 2030; accordingly, coordinated planning of the capacities of chemical recycling plants is required.

In this context, lessons can be learned from the **negative experiences of past developments**, such as the construction of large overcapacities in waste incineration in Germany in the early 2000s ("vacuum cleaner

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59 Plastics Europe 2024, p. 4
60 Ibid.

effect"). One option for achieving the necessary learning effects, not only technological but also regulatory, would be so-called **real-world laboratories for chemical recycling**, which would allow for spatially and temporally limited special permits, for example, for the construction and operation of such facilities, in order to better and more quickly assess the potential and risks of the technology.

4.1.4 Proof of Concept: Carboliq – Depolymerization of Multi-layer Films

As indicated above, large-scale investments are currently often hindered by a lack of political framework conditions. Nevertheless, innovative start-ups currently provide proof of concepts for the potential of different chemical recycling technologies for plastic waste—and at the same time of the limitations of such technologies. In Remscheid, a small city in North Rhine–Westphalia, Carboliq has developed direct oil conversion plants using the catalytic tribochemical conversion (CTC) process, rooted in existing expertise in industrial plant engineering. This specific plant, currently at technology readiness level of 7-8, is able to convert contaminated waste plastics (e.g., from household waste or packaging waste) on an industrial scale into a liquid resource that can be returned to existing material cycles. The focus is both on using the products as raw materials for the chemical industry and for the production of advanced, environmentally friendly fuels.

Carboliq uses a single-step process for the liquefaction of solid hydrocarbons. It is characterized by the combined application of thermal, catalytic, and mechanochemical (tribochemical) mechanisms, as well as its applicability to a wide range of feedstocks. The process energy is introduced into the system solely through friction. The system operates under atmospheric pressure and at process temperatures below 400°C and nevertheless achieves a relatively high oil yield. Only small amounts of gases are generated during the processing of plastic waste. Solid process residues are either further recycled or properly disposed of. Carboliq is being demonstrated on an industrial scale at a local waste disposal centre, providing a rather decentralized waste management infrastructure linked to the radius of municipal waste incineration plants.[61] Carboliq follows a modular concept for its systems engineering, potentially linked to municipal waste incineration plants. One module has a capacity of converting 600–1.000 kg/h infeed materials into 350–500 kg/h of the liquid resource. With four modules being run by one team, the full cost of operation will be < €400/t according to current German pricing. Such an installation will require an investment of €15 Mio. for a total capacity of 10.000 t/a.[62]

4.1.5 Next Steps: Closing Narrow and Larger Loops

The chemical recycling outlined here is a building block for the chemical industry on its way to a sustainable and climate-neutral circular economy. In the long term, this will involve significantly greater integration of value chains: To access defossilized raw materials, the chemical industry must develop new strategies not only to sell raw materials but also to recapture them at the end of their useful life. Such circular business models are characterized by significantly greater complexity; the digitization of information about the use and fate of, for example, plastic products will play a correspondingly important role.

The central challenge lies in the enormous time pressure and international competition.[63] The requirement

[61] Here, "radius" refers to the catchment area from which municipal waste incineration plants source their input materials and distribute outputs.

[62] Carboliq, 2024.

[63] The milestone Draghi report on EU competitiveness clearly describes the root causes of the declining competitiveness of the EU in energy-intensive industries, including chemicals. According to the report, the competitiveness of EIIs in the EU is primarily challenged by

to drive a systemic transformation of the chemical industry under these conditions requires a good mix of innovative approaches on the basis of a robust assessment of environmental and economic impacts, as well as of potential risks and future market development. There is now a consensus in the scientific community in Germany that chemical recycling plays an important role in defossilizing the economy and reducing the consumption of primary resources. However, there is also a consensus that chemical recycling is only one part of the overall solution and that it must be placed quite far down the waste hierarchy, e.g., after prevention, reuse and mechanical recycling, which must be prioritized where technologically possible. Apart from incorporating chemical recycling as an integral part of the carbon cycling pathway in the chemical industry, it will be important to consider complementary approaches in the future, such as closing CO_2 cycles through carbon capture and use (CCU).

Biogenic materials from sustainable sources will continue to be available only to a limited extent and will be subject to high competition for use from other sectors, such as food security systems. However, the use of biomass as a feedstock should not be excluded generally but considered as a pathway with particularly high sustainability risks. Thereby, biogenic residues (e.g., agricultural waste) that are not utilized in other sectors and applications should be preferred.

4.2. Circularity Helps Greening Improving Efficiency of Chemical Manufacturing: A Chinese Case

4.2.1 Requirements on Greening Chemical Manufacturing in China: Policy Perspectives

As one of the world's largest producers and consumers of chemical products, China's chemical industry faces challenges of large carbon emissions, significant energy intensity, and relatively low resource utilization efficiency. The sector accounts for approximately 13% of the country's total CO_2 emissions, highlighting its critical role in achieving national carbon peaking goals (China National Petroleum & Chemical Planning Institute, 2022). China's chemical industry remains dominated by a linear economic model, with insufficient recycling of raw materials and utilization of by-products and industrial residues.

In addition to the general requirements for a circular economy across all sectors, China has developed a series of policy documents to set forth more targeted measures specifically for the chemical industry. For instance,

- The **Guiding Opinions on Promoting High-Quality Development of the Petrochemical and Chemical Industries During the "14th Five-Year Plan" Period** (MIIT et al., 2022) and **Work Plan for Stabilizing Growth in the Petrochemical and Chemical Industries** (MIIT et al., 2023) explicitly call for promoting carbon emission reduction across the value chain, enhancing the utilization of by-products, and fostering synergistic development across related industries. These policies serve as concrete instruments to translate high-level strategies on circular economy and green development into measurable actions within the sector.
- Since 2022, the Ministry of Industry and Information Technology (MIIT) has repeatedly emphasized the need to promote the high-value utilization of industrial by-products like phosphogypsum. Building on the above policies, additional sector-focused documents have been issued, including **the Implementation Plan for Promoting the Efficient and High-Value Utilization of Phosphorus Resources** (MIIT, 2023) and

higher energy prices and emissions costs compared to global competitors, substantial investment needs required for decarbonization, as well as an overly complex regulatory system and an unlevel playing field for the industry, including limited markets for greener products and untapped potential for circularity. See: https://commission.europa.eu/topics/eu-competitiveness/draghi-report_en#paragraph_47059 (Part B: In-depth analysis and recommendations); accessed: 27.08.2025 t**he Action Plan for the Comprehensive Utilization of Phosphogypsum** (MIIT, 2024), thereby driving coordinated development between the chemical industry and sectors such as building materials and metallurgy, with the aim of establishing a closed-loop system of resource circulation.

Both the EU and China place strong emphasis on advancing the green transition and circular economy in the chemical industry, yet they differ significantly in policy architecture and implementation pathways (Figure 3). The EU prioritizes whole life-cycle management, focusing on green product design, raw material substitution through increasing use of recyclates and bio-based alternatives, increasing resource efficiency in manufacturing, ensuring safe use of chemicals, and promoting waste prevention. Through stringent regulations and market-based mechanisms, it seeks to reduce fossil energy and virgin raw material consumption while promoting collaboration across the value chain. By contrast, China emphasizes energy conservation and carbon reduction, comprehensive resource utilization, and cleaner production, combining top-level planning with sector-specific strategies. Its approach focuses on optimizing and upgrading traditional processes, encouraging enterprises to carry out energy-saving retrofits, enhance the resource utilization of industrial by-products, and advance the circular transformation of industrial parks, thereby improving overall resource efficiency and environmental performance across the industry.

4.2.2 Significance of Circularity in China's Chemical Manufacturing

Implementing the circular economy in China's chemical industry not only holds significant potential to address critical environmental and climate challenges and unlock opportunities for sustainable development, but also fully aligns with national priorities supporting the shift toward a more sustainable economy and meeting stricter environmental regulations.

- **Addressing environmental degradation and resource scarcity.** A traditional linear model of mass production, mass consumption, and mass waste generates significant environmental burdens in China's chemical industry, while it also contributes huge carbon emissions through its energy- and material-intensive processes. For instance, China has accumulatively stockpiled over 700 million tonnes of phosphogypsum together with additional 80 million tonnes generated annually (Bai et al., 2025). It brings about high environmental risks for water, air, and land pollution, while the country is facing challenges of phosphorus resource scarcity.
- **Driving economic benefits and fostering innovation.** Transitioning to a circular economy offers opportunities for cost savings by minimizing waste, improving resource efficiency, and developing new business models centred around resource recovery and reuse. In addition, circular practices in the chemical industry can also lead to the creation of new revenue streams through the reprocessing of discarded materials and the development of new services like product leasing and maintenance. For instance, **Fuhua Tongda Chemicals Co., Ltd.** (hereinafter Fuhua Chemical), a Chinese private chemical manufacturer, has made efforts and benefited from building up a circular chemical production system over the past decades. It has created and implemented the economics of chemical elements, successfully improving resource utilization efficiency (e.g., phosphorus from the industrial average 68% to 99.80%, chlorine from 87% to 92%, and sodium to over 96%) with technological innovation and diversified products. In the meantime, Fuhua Chemical significantly reduced waste generation with the circular economy, saving money for waste disposal and avoiding high environmental pollution risk. **Annex C** details Fuhua's practices in building up the circular economy and its associated economic and environmental benefits.
- **Contributing to a greener and healthier society.** Reducing pollution and promoting sustainable practices

within the chemical industry can significantly improve public health and the quality of ecosystems impacted by chemical waste and emissions. The transition to a circular economy can also generate new jobs and foster a more skilled workforce in areas related to resource recovery, green technology, and sustainable manufacturing, says the World Economic Forum.

In conclusion, the implementation of a circular economy in China's chemical industry is crucial for tackling environmental issues, enhancing resource security, stimulating economic growth, fostering innovation, and aligning with national sustainability goals. This shift represents a move toward a greener, more resilient, and healthier future for both the industry and the nation as a whole.

4.3. Policy Recommendations to Address Chemical Recycling in a Circular Economy

4.3.1 Preserving the Level Playing Field

A fundamental prerequisite for positive environmental impacts of chemical recycling is the avoidance of any form of cannibalization in the market for mechanical recycling of plastic waste. In Germany, this market segment is currently under enormous pressure, inter alia, caused by uncertainties about the future role of chemical recycling. Against this background, the introduction of mass balance approaches, e.g., for pyrolysis, will require a comparable mechanism for mechanical recycling to preserve a level playing field. As a concrete option, Germany´s national circular economy strategy mentions the possibility of tradeable recyclate certificates that could lower the costs for the uptake of secondary plastic.

4.3.2 Avoiding Path Dependencies

Chemical recycling offers relevant opportunities to divert plastic waste from incineration, or in most parts of the world, from landfilling. Nevertheless, any form of public support (R&D, venture capital, etc.) should be coordinated in a way that also takes into account the actual size of the potential market as well as potential impacts on current recycling flows. From a sustainability point of view, the key challenge will be how to integrate chemical recycling into an overall ecosystem of circular plastics—without undermining incentives for waste prevention, segregation, and efficient use of plastic applications that are necessary for the economy.

4.3.3 Strengthening and Harmonizing Policies and Regulations

To promote the circular economy in the chemical industry, in particular in China, it is necessary to strengthen the legal framework by setting clear and binding targets (e.g., mandatory use of circular materials) into national economic and development plans, adopting efficient measures (e.g., extended producer responsibilities, ecodesign, and etc.), setting economic incentives (e.g., subsidies, carbon emissions trading schemes, etc.), government-led initiatives (e.g., government-led R&D budget), and encourage the private sector to invest and participate in the circular innovation.

5 Gender Issues in Building and Implementing a Circular Economy

While the environmental and economic dimensions of the circular economy are often in focus, the social dimensions, especially gender, receive comparatively less attention. As countries work toward the goals of the 2030 Agenda for Sustainable Development, including SDG 5 (Gender Equality), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action), there is a growing recognition of the need to incorporate gender perspectives more systematically into circular economy transitions.

In the textiles sector, for example, women constitute a large proportion of the workforce, particularly in manufacturing roles. However, they are underrepresented in leadership, design, and innovation roles. Designing circular products and managing circular processes will require training and reskilling initiatives, and these should be designed to ensure equitable access for women and should actively seek to increase the proportion of women in leadership and technical roles.

Similarly, at the grassroots level, many informal and community-driven circular economy activities, such as second-hand textile markets, clothing repair, and upcycling, are often led by women. Despite the essential contribution of these sectors to a circular economy, these initiatives frequently lack formal recognition and policy support. Bringing these decentralized, often gendered, efforts into circular economy planning can enrich circular models with social inclusion and local relevance.

In the chemicals sector, gender dynamics play out differently. In both China and Europe, this sector remains largely male-dominated, particularly in engineering, regulation, and R&D roles. However, women are often disproportionately affected by chemical exposure, whether as workers in downstream industries or as consumers. Existing regulatory frameworks rarely integrate gender-specific health risks, and gender-disaggregated data on chemical exposure is still limited. Better data and more inclusive risk assessments would strengthen both policy and health protections.

China and the EU are active participants in international frameworks such as the Basel, Rotterdam, and Stockholm Conventions, which govern chemicals and waste. Although these instruments reference vulnerable populations, more explicit gender integration in implementation could enhance their effectiveness. National strategies such as China's Outline for Women's Development (2021–2030) and the EU's Gender Equality Strategy (2020–2025) offer entry points to make circular economy policies more gender responsive.

In summary, as China and Europe push forward with their circular economy agendas, integrating gender perspectives is essential not just for fairness but also to build more resilient and inclusive economic transitions.

6 Policy Recommendations

The high demand for raw materials in a largely linear economy is one of the main causes of the climate crisis, pollution, and biodiversity loss. According to UNEP (2024), over 55% of greenhouse gas emissions (GHG) and 40% of the health effects of particulate matter are caused by the extraction and processing of material resources. The recent Global Circularity Report 2025 revealed that the circularity has fallen from 7.2% in 2024 to 6.9% in 2025 worldwide. This means that only 6.9% of the materials entering the global economy are secondary. Despite improvements in secondary material use, significant challenges are observed in rising extraction, biomass consumption, and stock build-up.

The **transition to a circular economy is crucial** for the achievement of global and national climate and environmental goals as it reduces the use of primary resources and the associated emissions, as well as the pressure on ecosystems and biodiversity. In China, the concept of the circular economy has been at the centre of attention for several years. The strategic importance of the circular economy in China is also reflected in the 14th Five-Year Development Plan, where targets and indicators, for instance, for resource productivity, recycling and waste utilization, are set. Furthermore, the Chinese government has implemented a number of policies supporting the role of the circular economy in tackling climate change and achieving carbon neutrality by 2060.

Despite significant achievements in the field of circular economy in China, the scaling up of circular economy strategies remains a challenge. The challenges for implementing a circular economy are common for China and other regions, such as the EU, and are summarized below (see also Annex G for further details) (Prakash et al., 2023b):

- Low prices for primary raw materials and externalization of environmental costs,
- Lack of infrastructure for circular products and processes,
- Lack of investment (including in research and development) for a circular economy,
- Lack of transparency in terms of information and data sharing in value chains,
- Long-term path dependencies due to investments in linear technologies, and
- Lack of common standards for circular products.

In the following, overarching policy recommendations are drawn to address the key challenges that hinder a wide-scale implementation of a circular economy in China and elsewhere. The policy recommendations seek to provide impulses to the Chinese government for consideration in the 15th Five-Year Development Plan and in the reform of the Circular Economy Promotion Law in China. The recommendations also highlight areas where bilateral cooperation between China and Germany in the field of circular economy as part of the Sino-German Environment Partnership can be taken forward.

6.1 Strengthen Top-level Design and High-quality Development of the Circular Economy, Linking It With the "Dual Carbon" Strategy During the 15th Five-Year Plan Period (2026–2030)

Firstly, recommend setting the overall goal of "Circular Development," as well as specific targets such as improving resource productivity, increasing the proportion of recycled materials, and raising the recycling rate of renewable resources in the 15th Five-Year Plan. For instance, establish quantitative targets, preferably mandatory, for primary raw material consumption, secondary raw material use, waste prevention and use of safe, high-quality recycled materials, including control of and substitution of hazardous chemicals and recycling incompatibilities, in selected consumer goods sector (e.g., textiles, consumer electronics, home appliances) as well as in high-impact sectors (e.g., building/ construction, vehicles, and batteries). Further develop sector-based roadmaps in the 15th FYP for Circular Economy toward achieving the goals. Define socio-economic indicators to monitor progress, such as investments in circular technologies and industries, contribution of circular industries to the gross domestic product, and generation of employment.

Secondly, deepen and expand the pilot programs of "Zero-Waste City" and "Key Cities for the Construction of Waste Materials Recycling Systems" by adding incentive policies, e.g., allocating the resources of the "Two Major Incentives" and the "Two New Engines" to favour "Zero-Waste City" pilots, to promote the coordination of solid waste management and circular economy. Select representative cities to pilot the establishment of infrastructure for a circular economy and link them with modern, automated, and digitalized sorting and recycling systems, for instance, exploring and piloting the sustainable model of used textile collection and sorting, and improving used home appliance collection systems. Also carry out national procurement pilots for the supply of waste raw materials (e.g., used textiles, used electronics, used EV batteries).

Thirdly, on the basis of the Ecological Environment Code, accelerate the revision of the Circular Economy Promotion Law, expand pilots for extended producer responsibility systems and further strengthen the establishment of some fundamental regulations, such as ecodesign and the requirement of mandatory utilization of recycled materials, including a clear distinction between different options of recycling for achieving recycling targets. This will provide a legal foundation for comprehensively advancing and implementing a high-quality circular economy.

Fourthly, link circular economy development with the "Dual Carbon" goals, and incorporate circular economy measures into China's carbon emissions reduction goals. Accelerate and improve research into carbon emission calculation methodology, emissions factors, accounting standards, and market trading mechanisms related to solid waste resource utilization, develop a model for calculating emissions reduction of recycling solid waste, evaluate the contribution of emissions reduction, and establish a "Double Carbon" evaluation and assessment system by incorporating the construction of Zero-Waste Cities.

Fifthly, promote the development of China's carbon trading market by conducting research into methodologies for China Certified Emission Reduction (CCER) projects, in particular the CCER for key bulk industrial solid waste and low-value recyclables with significant emission reduction potentials to enhance the market competitiveness. This work can be linked closely to the carbon pricing mechanisms in the EU, such as the Carbon Border Adjustment Mechanism (CBAM).

Sixthly, establish a Central Leading Group for the Circular Economy and set up a national special fund for comprehensive treatment of solid waste, strengthening coordination between circular economy development and economic, industrial, energy, environmental, climate, and other related aspects.

6.2 Actively Promote High-quality Circular Economy Transformation in Line With the Principles of the Waste Hierarchy in Key Industries, Cultivate New Engines for Economic Growth, and Achieve Synergies Between Economic Growth and Green, Low-carbon Development

Firstly, promote the in-depth integration of the circular economy in the green transformation of key industries. Promote the coordinated transformation of resource recycling and energy efficiency improvement in traditional high-energy-consuming industries (such as iron and steel, cement, and the chemical industry), for example, vigorously promoting the green manufacturing of circular economy industrial chains in the chemical industry. In emerging industries (such as new energy and semiconductors), plan the recycling system of renewable resources in advance.

Secondly, encourage and support the development of high-quality, high-performance, and high-value products and business models based on circular economy principles, including replace, reuse, refill, refurbish, remanufacture, repurpose, as well as recycling (e.g., fibre-to-fibre, bottle-to-bottle, chemical-to-chemical). Define and establish a hierarchy of different recycling technologies based on robust environmental and economic assessment of treatment options. Explore the development of "the closed-loop" path suitable in China's context, and gradually expand the scope of pilot demonstrations.

Thirdly, jointly establish a circular economy R&D platform and talent training system, which brings together government and university research institutions, and enterprises, with enterprises as the core. Vigorously develop technologies for high-quality recycled materials, defossilized materials, and promote technological innovations and research for "the closed loop" of high-impact materials. Accelerate and expand the professional and skillful talents training for the circular economy, and ensure training initiatives actively target gender responsiveness.

Fourthly, accelerate the construction of integrated industrial chains encompassing "eco-design—remanufacturing—recycled raw materials—product use services (e.g., reuse, maintenance, and repair)—collection—recycling." Increase technological and institutional innovation, strengthen the development and extension of circular economy industrial chains.

Fifthly, actively cultivate leading enterprises in the circular economy industry through demonstration of "Zero-Waste Enterprises," "Zero-Waste Groups," "Zero-Waste Industrial Parks," and "Large-Scale Demonstration Parks and Enterprises for Comprehensive Utilization of Solid Waste." Expand the scale of the circular economy industry to achieve economies of scale, reduce the costs of recycled products, and improve market competitiveness.

Sixthly, increase dedicated investment in resource utilization and treatment of bulk industrial waste. Accelerate R&D and demonstration of recycling technologies. Encourage strong collaboration and partnerships among industrial waste producers, resource recovery technology owners, and local governments.

Seventhly, expand and accelerate the cultivation of demand markets for recycled raw materials or products through demand-side guidance and management. For example, establish circular product labelling and subsidy mechanisms to encourage and guide consumers to choose more circular products, and guide public institutions to prioritize green public procurement of products with ecolabels of high circularity.

Eighthly, accelerate the integration of digital technologies in the circular economy. Establish a digital traceability system for materials and products based on raw materials and the entire industrial chain (e.g., draw upon the experience of the "Battery Passport" and gradually extend it to other industries or products like textiles and building materials). Concurrently, conduct research and demonstration applications of blockchain-based data management and sharing technologies to address data issues such as security, quality, credibility, privacy protection, and sharing.

6.3 Accelerate the Establishment of Standards and Assessment Systems for Circular Economy Technologies and Products at the National and Local Levels

Firstly, expedite research into and establish standards of design and production for circular products. Clearly stipulate requirements for product durability, repairability, recyclability, quality of recycled raw materials, and usage percentages.

Secondly, expedite research into and establish standards specifying required levels of quality for recycled raw materials and circular products.

Thirdly, expedite research into and establish standards of testing, analyzing, and rating the recycled materials and products, along with the establishment of a robust network of third-party testing facilities, with laboratories with the equipment and trained personnel necessary to perform compliance testing.

Fourthly, expedite research into and establish a robust market supervision system, including comprehensive assessment and certification schemes, to ensure rigorous market supervision. Supervision efforts should prioritize high-risk sectors and products with significant environmental impacts.

Fifthly, expedite research and establishment of product databases based on raw materials and chemicals.

6.4 Accelerate Innovation in Green Finance and Financing Mechanisms to Support the Establishment of Circular Economy Business Models

Firstly, develop specialized financing instruments (e.g., Circular Economy Transition Bonds) to provide preferential financing for establishing circular economy business models.

Secondly, enhance the market competitiveness of circular economy enterprises through supportive economic incentives such as tax incentives and targeted subsidies. For example, provide specific economic incentives for measures such as substituting fossil-based raw materials with scientifically proven, environmentally friendly alternatives, increasing the proportion of recycled raw materials used, and remanufacturing products.

Thirdly, leverage the carbon market to support circular economy projects, promoting synergy between carbon reduction, pollution control, and green growth.

Fourthly, increase the efforts of green bonds and green loans to serve resource recycling projects, establish the "Classification Catalog of Green Finance Supporting Circular Economy," clarify the classification standards of circular economy projects in "green finance," establish a project financing performance evaluation method and system based on recycling effect, carbon emission reduction effect, and data efficiency improvement effect, and encourage "green + circular" financial innovation.

6.5 Strengthen International Cooperation to Promote Global Circular Economy Development and Green, Low-carbon Transition

Firstly, strengthen the alignment and mutual recognition of domestic recycling product certification standards with international standards (e.g., EU standards).

Secondly, explore the potential form of global trade flow of waste materials; and establish strict control standards to prevent trade flows of chemicals, materials, and waste that are illegal according to multilateral environmental agreements (Basel, Rotterdam and Stockholm Conventions), or harmful to the environment and human health in the destination countries.

Thirdly, actively participate in and promote circular economy topics within international processes. For example, China and Germany, together with relevant stakeholders, should actively and jointly promote updating the work plan of the G20 Resource Efficiency Dialogue to ensure the circular economy remains high on the G20 agenda in the coming years; leverage the UN Environment Assembly (UNEA) to support establishing an international process aimed at reducing global raw material consumption while ensuring a just circular economy transition. Promote bilateral and multilateral cooperation on the plastic circular economy post the negotiation of the global plastic treaty, and take the plastic circular economy as a key means to control plastic pollution.

Fourthly, incorporate the circular economy into international cooperation frameworks such as the "South-South Cooperation." Build cross-border renewable resource standards and regulatory systems with partner countries to promote international green resource circulation; promote the construction of green industrial parks, and disseminate China's successful experience in "Zero-Waste Cities."

Fifthly, actively conduct Track 2 dialogues on the circular economy, and actively create opportunities for Track 1.5 and even Track 1 dialogues. Through bilateral or multilateral dialogues, clarify doubts, enhance mutual trust and understanding, and jointly advance global multilateral processes on the circular economy and climate change. For example, China and Germany should continue deepening their cooperation under the "Sino-German Dialogue on Circular Economy and Resource Efficiency" and "Sino-German Circular Economy Partnership," strengthen bilateral cooperation within the Sino-German environmental partnership and deeply exchange circular economy practices at business and policy levels to promote the development of a circular economy roadmap for the industry. It is recommended to strengthen China-EU dialogues on international trade, deeply discussing the potential impacts of measures like the Carbon Border Adjustment Mechanism (CBAM) and Extended Producer Responsibility (EPR) on developing the circular economy, and the response measures China should adopt.

Annex

Annex a. International Circular Economy Initiatives and Platforms

Examples of multilateral regional initiatives:

- **African Circular Economy Alliance** (ACEA): Government-led coalition of currently 15 African nations aiming to catalyze Africa's shift toward a circular economy to promote economic growth, job creation, and environmental protection. It serves as a platform to coordinate national, regional, and continental efforts (African Circular Economy Alliance, n.d.).
- **Association of Southeast Asian Nations** (ASEAN): Intergovernmental, regional association of 10 Southeast Asian member states. In 2021, the association launched its long-term vision for transitioning member states toward a circular economy ("Framework for Circular Economy for the ASEAN Economic Community"), which identifies priority areas and enablers to accelerate the adoption of circular economy principles across the region (ASEAN Circular Economy Stakeholder Platform, n.d.).

In line with the objective to drive a global circular economy transition, Germany supports and contributes to a range of formal international initiatives and platforms (BMUV, 2024):

- At the G7 level, the **G7 Alliance for Resource Efficiency (ARE)** was launched in 2015 under Germany's presidency—a forum to exchange knowledge and best practices on resource efficiency issues. Building on this, the 2022 **G7 Berlin Roadmap**, adopted under Germany's G7 presidency, sets out an ambitious roadmap that underscores the essential role of resource efficiency and circular economy in achieving the UN 2030 SDGs as well as global climate and biodiversity targets. It outlines concrete measures for G7 countries to implement between 2022 and 2025.
- At the G20 level, the **G20 Resource Efficiency Dialogue (RED)**, which was initiated in 2017 under Germany's presidency, serves as a central platform to coordinate efforts on resource efficiency and circular economy. It brings together G20 governments, the private sector, academia, and international organizations to promote sustainable consumption and production, align with the SDGs, combat poverty, and support environmental and climate action (G20 2017).
- At COP28, the **circular economy was officially recognized for the first time** in a UN climate negotiation outcome. This marked a significant breakthrough in positioning circularity as a key instrument in global climate policy.
- Ongoing UN-level negotiations (since 2022) on an International Plastic Treaty aim to establish a legally binding agreement to end global plastic pollution while addressing the full life cycle of plastics. Germany plays a leading role in these talks, having co-founded the **High Ambition Coalition to End Plastic Pollution** and advocating for a strong and ambitious treaty (UNEP, 2025a; BMUV, 2024).

Annex B. Examples of (Sector-specific) EU Strategies and Legislation Relevant to the Circular Economy

- **Waste Framework Directive**: Establishes the waste hierarchy, obligations for separate collection, and targets for recycling and waste prevention across sectors, including EPR schemes.
- **Critical Raw Materials Act** (**CRMA**): Aims to secure access to critical raw materials by boosting domestic extraction, processing, and recycling, and fostering circular use of resources.
- **End-of-Life Vehicles Regulation**: Sets binding rules for vehicle design, collection, reuse, and recycling at all stages of the vehicle life cycle.
- **Batteries Regulation**: Aims to make batteries sustainable throughout their entire life cycle, from the sourcing of materials to their collection, recycling, and repurposing.
- **Packaging and Packaging Waste Regulation**: Governs packaging design and waste management with requirements for recyclability, reuse, and recycled content.
- **Waste Electrical and Electronic Equipment (WEEE) Directive**: Sets rules and targets for separate collection, reuse, recovery, recycling, and exports of electric and electronic waste; harmonizes registration requirements; promotes efficiency and environmental performance throughout the life cycle.
- **Strategy for Sustainable and Circular Textiles**: Addresses environmental and social impacts of textile production and consumption through design, reuse, and recycling initiatives.
- **EU Plastics Strategy**: Aims to transform plastic value chains through increased recycling, reduction of single-use plastics, and minimization of environmental pollution.

(Source: European Commission n.d.b)

Annex A. Case Study Fuhua Chemical China – Greening and Upgrading with Circular Economy

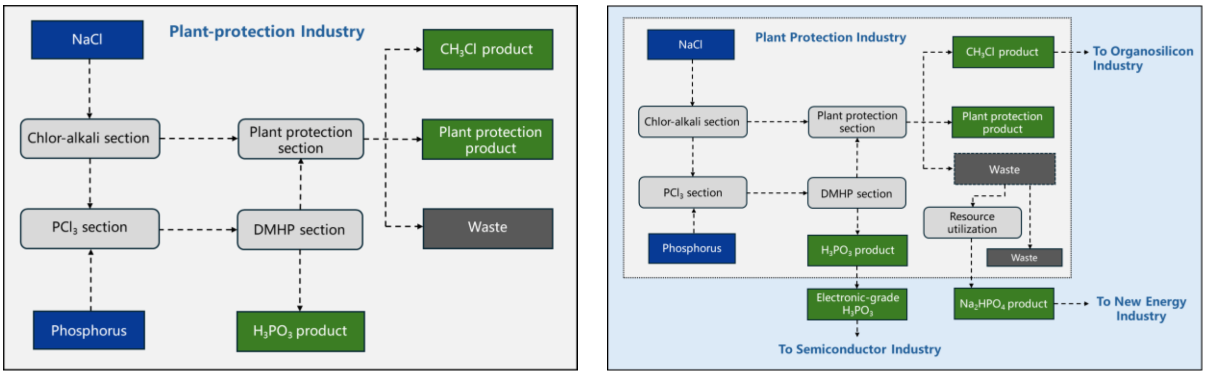
Abstract: Amid increasing resource and environmental pressures, coupled with the urgent challenge of carbon reduction, the circular economy has become a critical pathway for advancing the green and low-carbon transformation of the chemical industry. Fuhua Chemical, as a comprehensive chemical enterprise, has built a circular industrial chain centred on key elements such as phosphorus, chlorine, and sodium, thereby promoting efficient resource utilization and cleaner production. Through a series of technological upgrades, the utilization rate of phosphorus increased from 67.79% to 99.80%, and that of chlorine rose from 87.66% to 92.41%. Furthermore, by recovering organic waste liquids, reinjecting low-salinity brine into salt mines, and promoting the comprehensive use of by-products, Fuhua Chemical has significantly reduced both resource consumption and carbon emission intensity. The company's exemplary circular economy practices demonstrate that optimizing production processes around key elements, extending industrial chains, and fostering inter-enterprise resource circulation networks are effective pathways to achieve resource reduction, high-value utilization, and closed-loop recycling in the chemical sector.

Keywords: Elemental Economics, Waste-to-Resource, Green and Low-Carbon Transformation

Annex C1. Background

Fuhua Tongda Chemicals Co., Ltd. (hereinafter referred to as Fuhua Chemicals), a Chinese private chemical manufacturer, is located in Wutongqiao Economic Development Zone, Leshan City, Sichuan Province, China. It is a comprehensive chemical enterprise with products and services ranging from mineral resource development to basic chemicals, and fine chemical R&D and applications. Since 2003, Fuhua Chemical has been making efforts to upgrade its value chain and improve sustainability by implementing the circular economy. In particular, Fuhua Chemical creates the concept of Economics of Chemical Elements to maximize the utilization rate of resources (e.g., P, Cl, Na) by circular designing and investment in technological innovations. Thus, Fuhua Chemical reached a higher resource utilization than the peer average and significantly reduced waste generation.

Currently, Fuhua has expanded its products covering from plant protection to eight areas, including batteries, semiconductors, and photovoltaics (Figure 6-b).



(a) (b)

Figure 6: Changes of Product Chains of Fuhua Chemical

Annex C2. Main practices

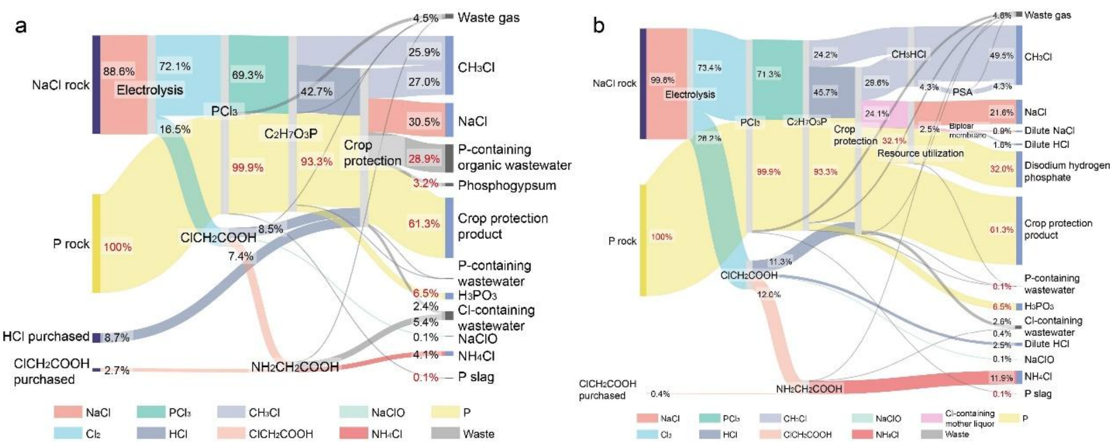
- **Economics of Chemical Elements as a Driver of Value Chain Extension**

Phosphorus Utilization

Phosphorus is the core element of Fuhua Chemical's industrial chain. Guided by the concept of "economics of chemical elements," Fuhua Chemical has continuously advanced technological upgrades and product diversification for phosphorus-containing products, expanding from two types of products to four types. Compared with 2011, total revenue from phosphorus-containing products in 2024 increased by a factor of 4.98, while the phosphorus utilization rate rose significantly from approximately 67.79% (Figure 7-a) to 99.80% (Figure 7-b). In 2012, Fuhua Chemical launched its first project to recover and reuse organic phosphorus-containing waste liquid, producing high-value disodium hydrogen phosphate dodecahydrate ($Na_2HPO_4 \cdot 12H_2O$, hereinafter referred to as "DSP") for the new energy industry. This initiative simultaneously reduced the generation of organics-derived phosphogypsum, achieving zero discharge of such phosphogypsum by 2016.

Chlorine Utilization

To improve the effective utilization of chlorine and reduce the output of industrial salt, Fuhua Chemical adopted a bipolar membrane electrodialysis process to electrolyze salts in organic phosphorus-containing waste liquid into dilute hydrochloric acid and low-salinity brine. As a result, the proportion of chlorine contained in industrial salt decreased from about 30.51% before the upgrade to about 21.58% of total chlorine input. In 2016, the company introduced Pressure Swing Adsorption (PSA) technology to increase the recovery rate of methyl chloride (CH_3Cl)—a volatile and toxic gas—from 92% to 99% by 2018, raising the proportion of chlorine in CH_3Cl by approximately 0.85% (Figure 7). When supplied to silicone producers in Southwest China, CH_3Cl generates about 7% higher economic returns, achieving both closed-loop recycling and high-value conversion of chlorine resources within the industrial chain. Consequently, the utilization rate of chlorine increased from 87.66% (Figure 7-a) to 92.41% (Figure 7-b).



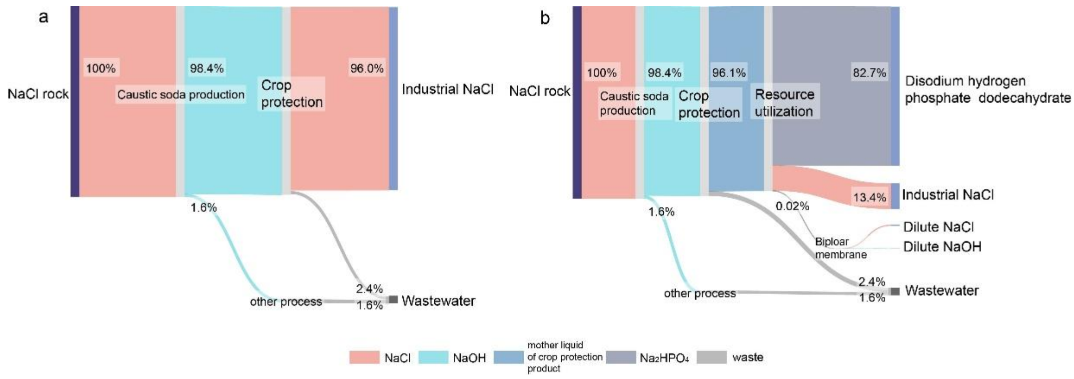
(a) before circular economy design (b) after circular economy design

Figure 7: Elemental balance of phosphorus and chlorine in Fuhua Chemical

Sodium Utilization

The organic waste liquid recovery project also enabled the high-value utilization of sodium, although the utilization rate remained largely unchanged at around 96.05%. Before the technological upgrade, sodium was primarily discharged from the production system in the form of industrial salt, accounting for about 96% of total sodium input (Figure 8-a). After the upgrade, most sodium was converted into DSP products, representing approximately 82.7% of total sodium input (Figure 8-b).

However, through technological upgrades, the original low-value sodium-containing industrial salt (market reference price approximately CNY 1 per ton) was transformed into high-value disodium phosphate products (market reference price approximately CNY 2,000 per ton). The technical upgrade project spanned four years with a total investment of 270 million yuan. In its first year of operation, the disodium phosphate product alone generated revenue of 350 million yuan. Compared to the mere 90,000 yuan in revenue from sodium-containing industrial salt before the upgrade, this transformation significantly enhanced the economic value of the element (annual sales revenue from sodium-containing by-products increased over 3,800-fold).

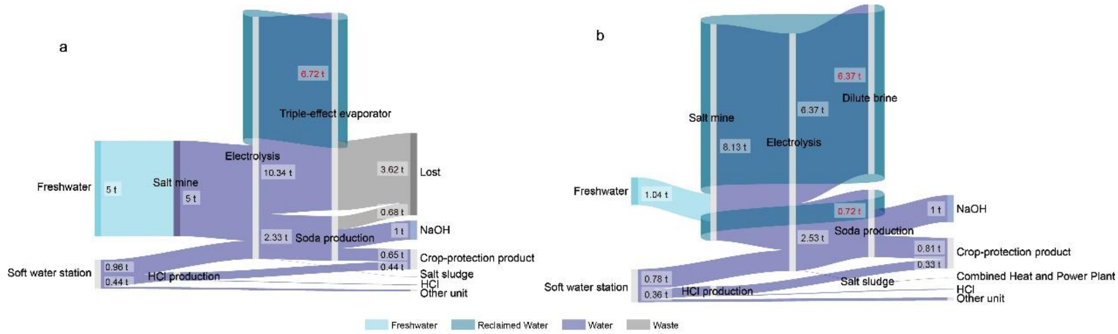


(a) before circular economy design (b) after circular economy design

Figure 8: Sodium element balance before and after technical upgrades

- **Water Conservation and Carbon Emission Reduction through the Dilute Brine Recycling**

Fuhua Chemical initiated a technological upgrade project for the recycling of dilute brine in 2021, with the project entering formal operation in 2022. By eliminating the triple-effect evaporation unit, the dilute brine and evaporative condensate from the caustic soda production process are directly reinjected into the salt mine. This approach reduces the intake of fresh water and the loss of steam while significantly lowering energy consumption. Prior to the upgrade, fresh water consumption was approximately 5 tonnes per ton of NaOH (100% basis) produced (Figure 9-a). After the upgrade, fresh water usage decreased to 1.04 tonnes (Figure 9-b), resulting in a comprehensive reduction of carbon emissions by approximately 415.88 kg CO_2 eq.



(a) before circular economy design (b) after circular economy design

Figure 9: Water balance before and after the dilute brine recycling project implementation

- **Resource Utilization of Salt Sludge**

Due to the presence of impurity ions such as calcium and magnesium in the salt mine, fresh water injected to dissolve salt forms a sodium chloride solution that requires purification to remove these impurities. The salt sludge generated during this purification process—primarily composed of calcium carbonate and magnesium hydroxide—can substitute for limestone ($CaCO3$) in flue gas desulfurization at the local thermal power plant (Figure 4.b). Before this initiative, salt sludge was treated as solid waste and transported together with sewage sludge to centralized disposal sites outside the park. Since 2022, Fuhua Chemical has utilized the salt sludge waste generated from its chlor-alkali production unit and has also accepted white mud waste from a nearby paper mill at no cost, thereby establishing a resource circulation chain among enterprises. This has enabled an annual avoidance of carbon emissions of up to approximately 15,166.02 tonnes CO_2 eq.

- **Regional Synergistic Supply of By-products**

Leveraging its own salt mine resources, Fuhua Chemical has gradually expanded NaOH production capacity to ensure a stable supply of key raw materials for plant protection products. Simultaneously, it has developed high-value utilization pathways for by-products centred on hydrogen and chlorine elements, promoting local raw material circulation and regional industrial synergy. Since 2009, Fuhua Chemical has operated a chlor-alkali plant electrolyzing brine to produce NaOH, with hydrogen and chlorine as by-products, and synthesizes hydrochloric acid (HCl). After meeting internal demands, these products are supplied to chemical and new energy enterprises within the industrial park, neighbouring provinces, and the southwestern region, enhancing regional raw material security. In addition, Fuhua Chemical commissioned an anthraquinone-based hydrogen peroxide production unit in 2013, providing a critical oxidant for the new energy and advanced materials industries.

Annex C3. Empirical enlightenment

- Optimizing production processes based on elemental flows helps identify opportunities for circular resource utilization.
- Upgrading product structures is key to high-quality and high-value resource utilization.
- Extending internal industrial chains and building inter-firm recycling networks enable synergistic pollution and carbon reduction.

Annex D. The Global State of Circularity

The **Circularity Gap Report 2025** provides a data-driven assessment of global material flows and the global state of the circular economy (reference year 2021). The report provides a set of circularity indicators which can be categorized into indicators of circularity, linearity, or potentially both. At the centre of the report is the global **Circularity Metric**, which is assessed annually and measures the rate of secondary materials consumed within the global economy. It serves as a reference for progress toward the circular transition. Since the first report in 2018 (9%, reference year 2015), the metric has declined every year, with now **only 6.9%** (reference year 2021) of global material inputs being **secondary materials**. This downward trend can largely be attributed to the **rising** absolute **volume of virgin material extraction** (now exceeding 100 billion tonnes), which continues to outpace the increase in secondary material use. As a result, the world faces a **circularity gap of 93.1%**. The share of fossil fuels burned for energy remains high (13.3%), while biomass extraction (though often carbon-neutral due to balancing carbon absorption), more than doubled over the last half-century, contributing to land-use change and biodiversity loss. Meanwhile, only **11.2% of global waste** is destined for **recycling**. **Stocks** (materials stored in buildings, infrastructure, or machinery for a long time) now **account for 38%** of total material inputs. In the 20th century, the weight of stocks has grown 23-fold and continues to increase with rapid economic growth and urbanization.

The report identifies several negative trends and shortcomings: **Recycling rates** are **declining**, while **material extraction** and **waste generation** are still **increasing**. There are no globally agreed-upon, science-based targets for material use reduction. **Fossil fuel use** continues to grow in absolute terms and **remains heavily subsidized**, with estimated global subsidies reaching US$1.4 trillion in 2021**. Increasing energy demand and emissions**, coupled with **rapid stock accumulation** and the inability to close the loop on emissions, present significant barriers to advancing global circularity.

In sum, despite growing awareness, **global circularity is in decline**. Without coordinated international policy action, investment in circular infrastructure, and systemic redesign of how we produce and consume, there is the risk of further undermining climate, biodiversity, and sustainability goals.

(Source: Circle Economy, 2025)

Annex E. Barriers and Market Failures for Circular Economy Development in Germany

The 2023 study **“Modell Deutschland: Circular Economy - Politik Blueprint”** outlines a range **of barriers and market failures** that hinder the broad implementation of the circular economy (in Germany), particularly regarding resource conservation, product lifespan extension, repair, and the use of secondary raw materials (Prakash et al., 2023b).

- One major obstacle is the **low cost of primary raw materials**, largely due to unpriced environmental externalities. These occur along the entire value chain, particularly during extraction and processing, where significant greenhouse gas emissions, biodiversity loss, and water and land degradation remain largely unaccounted for. This undermines the competitiveness of secondary raw materials, which are often subject to stricter environmental regulations.
- Another challenge is the **lack of infrastructure for circular practices**. Investments in preparation for the reuse, collection, and processing of used products are typically unattractive to private actors unless mandated by regulation or driven by municipal investment. In sectors like construction or furniture, circular infrastructure is still missing.
- Furthermore, **private investments in research and innovation for circular solutions are limited** due to weak incentives and positive externalities. Companies may prefer to wait and adopt innovations later as a “second mover” rather than carrying the costs themselves. Yet, significant advancements are needed in areas like waste prevention, circular product design, and service-based business models.
- Circularity is also constrained by **insufficient transparency and information sharing across value chains**. Important data on extraction, product design and production is often unavailable, impeding later life cycle stages like repair, reuse, and recycling, and incentives for information collection and exchange are currently lacking.
- **Path dependencies** pose another barrier that individual economic actors cannot overcome on their own. Existing industrial assets, infrastructures, and regulations are optimized for linear systems, creating advantages for certain practices and resistance to change. An example is the infrastructure for the collection and processing of packaging waste.
- Finally, the **absence of common standards for circular products** and a **lack of cooperation among actors** hinders market uptake. Without shared norms and coordinated innovation activities, the benefits of circular solutions remain limited. Furthermore, there is a need for policy action where regulations hinder circular technologies or practices, especially regarding material standards that may require revision to allow the use of recyclates.

Addressing these barriers **requires strong governance frameworks** and **targeted policy interventions to level the playing field between linear and circular models** while **internalizing environmental costs**. Both Germany’s NCES and the EU’s Clean Industrial Deal, if implemented ambitiously and coherently, hold the potential to foster structural changes, reduce primary raw material demand, close material loops, and strengthen the competitiveness of circular systems. However, progress also depends on strong global partnerships and binding commitments, especially from major economic regions such as the EU and China.

Annex F. Barriers and Market Failures for Circular Economy Development in China

China is vast and populous, with significant differences in resource endowments between urban and rural areas and across regions. The problem of unbalanced and inadequate development remains prominent. There are still many bottlenecks to achieving high-quality development, including insufficient technological innovation capacity, arduous ecological environment protection tasks, and significant challenges in further advancing the green and high-quality development of the circular economy. These include issues such as the circular industry being large but not strong, unstable market demand for bulk products, and weak high-value recycling capabilities of recycled products.

- **The Resource Recycling Industry is Large but Not Strong**

Domestic circular economy industry enterprises are small in scale and dispersed, which limits the efficiency of resource recycling and the improvement of green development levels. Data shows that nearly half of the relevant enterprises in China's waste resource recycling industry have registered capital of less than 1 million yuan, while only 0.5% of the total enterprises have registered capital exceeding 100 million yuan (National Organization Unified Social Credit Code Data Service Center, 2024). There is a lack of leading enterprises that are both large-scale and specialized. Small and medium-sized enterprises (SMEs) face limitations in research and development capabilities and technical levels, resulting in low-end and homogenized products, with fierce internal competition. The shortage of high-value products and relatively low profits from participating in the circular economy restrict the growth space of the industry to some extent. Additionally, some enterprises have insufficient environmental protection investments, and their environmental process management is not standardized, which not only hinders the improvement of recycled product quality but also increases environmental pollution risks. This creates a "bad money drives out good" effect, damaging fair market competition.

- **Weak Market Demand for Bulk Recycled Resources**

Some bulk waste recycling technologies and products are still relatively simple, and they are heavily affected by fluctuations in downstream market demand, leading to unstable industry profits. For example, the slowdown in the domestic real estate market has led to a reduced demand for construction materials such as cement, concrete, and partition walls, which in turn affects the comprehensive utilization of large-scale solid waste like fly ash, slag, construction waste, and desulfurization gypsum. Statistics show that in 2023, the national demand for sand and gravel aggregates decreased by 713 million tonnes, a drop of 4.49%, and the average price per ton fell by 6.4% (China Sand and Gravel Association, 2024). This has led to a decline in demand for products like tailings-based manufactured sand, non-fired bricks, coal gangue sintered bricks, secondary fly ash, slag powder, and aerated blocks made from fly ash (sand). Many traditional circular economy enterprises are facing survival pressure.

- **Insufficient Premium for Environmentally Friendly Recycled Products**

While waste recycling has significant carbon reduction benefits, a unified methodology system and carbon trading standards have not yet been established. The environmental value of recycled products has not been fully translated into economic benefits, and their price competitiveness is lacking. Currently, there are few high-value recycled products, and their production and processing costs are high. Although they have environmental benefits, these benefits are not reflected in their pricing. As a result, they are at a disadvantage when competing with primary products, and in some cases, price "inversion" occurs before scale benefits can be realized, making industry growth difficult. Therefore, in the process of exploring ways to incorporate the carbon reduction benefits of solid waste recycling into the carbon reduction market, technical challenges such as the involvement of multiple departments and sectors, the long value chain, and difficulties in accounting need to be addressed. Additionally, the diverse ways of solid waste recycling in the industry and the various self-organized accounting methods make it difficult to form a unified, authoritative, and recognized standard and methodology system.

Annex G. Textile Production, Consumption, Trade Flows, and End-of-life Management (Germany & EU)

It is important to note that the **available data** on the collection and further processing of used textiles is subject to **significant uncertainty**. Thus, caution is advised when interpreting and comparing this data. There are no harmonized methods and definitions for data collection between countries (e.g., for waste composition analysis, WCA), and there are no mandatory reporting requirements. These are mostly estimates or projections, and direct comparisons between countries are therefore difficult (Wagner et al., 2022; Duhoux et al., 2025; Huygens et al., 2023). Moreover, data on the processing of used textiles does not include the significant share of textile waste that is not separately collected but ends up in the mixed waste.

Status Quo of Collection and Sorting

At the end of their use phase, textiles need to be separately collected from other waste streams and afterwards sorted so they can be prepared for reuse or serve as an input to recycling operations. It is important to note that the **available data** on the collection and processing of used textiles is subject to **significant uncertainty**.[64]

Collection

Wagner et al. (2022) reported an **estimated collection volume** of used textiles in **Germany** of 1 million tonnes in 2018 (of which around 75% were clothing), corresponding to a collection rate of 64%. This rate significantly exceeds the **European** average of about 38% (UBA, 2022; Huygens et al., 2023).[65] Of the textiles not collected separately in Germany (36%), an estimated 67% end up in the residual waste. The estimated quantity of used textiles disposed of in the residual waste ranges between 4.5 kg per capita (UBA, 2022) and 6.8 kg per capita (European Environment Agency, 2024) annually. The remaining portion is either kept as unused clothing or privately passed on or sold as second-hand goods (UBA, 2022; European Environment Agency, 2024).

In the EU27 Member States, **most textile waste** is **currently not separately collected** and ends up in the residual waste. In 2022, only 4.6 kg per capita of textiles and shoes were separately collected in the EU, with more than double the amount (11.1 kg per capita) ending up in the mixed household waste and being processed as residual waste. This textile waste is incinerated or landfilled and is thereby unavailable for reuse or recycling (European Environment Agency, 2024; Eionet, 2025a).

Currently, most separate collection systems focus on **extracting the reusable fraction** because it is economically more profitable than textile recycling (Eionet, 2025a). Of a bag of donated textiles, over 50% of the economic value is provided by only 10% of textiles (Publications Office of the European Union, 2021b). The collection of post-consumer textiles, especially those suitable for reuse, often involves **charitable and social enterprises**. In the **EU**, countries like Austria, Belgium, Czechia, Iceland, and Sweden indicate that those are the main collectors (European Environment Agency 2024). The **German** collection system is primarily

[64] There are no harmonized methods and definitions for data collection between countries, and there are no mandatory reporting requirements. There are mostly estimates or projections, and direct comparisons between countries are therefore difficult (UBA, 2022; Eionet, 2025a; Huygens et al., 2023). Moreover, data on the processing of used textiles does not include the significant share of textile waste that is not separately collected but ends up in the mixed waste.

[65] Caution is advised when interpreting this data. The collection rate measures the relation between the total volume of separately collected used textiles and the total amount of textiles placed on the market in a given year. This approach overlooks the household textile stock, which could lead to overestimations of actual collection. The capture rate might be more useful in estimating the efficiency of collection systems. It puts the amount of separately collected textiles in relation to the total quantity of textile waste generated (separately collected textile waste plus textiles in the mixed municipal waste) (European Environment Agency, 2024). Eionet (2025a) report an average capture rate of only 15% in EU27 member states.

dominated by private actors (of which **29% charitable collectors**), accounting for around 73% of the collected volume, while public waste management authorities collect only 27% (UBA 2022). The most common collection system in Germany, accounting for about 96%, is the collection via **deposit containers**, including container collection at recycling centres (UBA, 2022). In the EU27, collection is typically done using **street containers** (bring points) and is, in many countries, supplemented by civic amenity sites (European Environment Agency, 2024; Eionet, 2025a). Bring points yield high quantities of collected textiles but have a higher risk of contamination; still, they are generally considered the most suitable to obtain an acceptable quality at a sufficient amount of used post-consumer textiles (UBA, 2022; Circle Economy; Fashion for Good, 2022).

Sorting

Collection and sorting are primarily **financed by the sale of second-hand clothing**, which presents the most favourable business model. Up to 90% of sorting companies' revenues are generated from the reusable share of collected textiles (Circle Economy; Fashion for Good, 2022). Textiles are often exported to be sorted in other (mostly EU) countries with large sorting capacities, like the Netherlands or Poland. Both countries imported over 200,000 tonnes of used textiles in 2018 (Publications Office of the European Union, 2021b).

Manual sorting is the most widely used method for sorting textile waste, although it requires experienced and trained personnel. Sorting facilities typically divide **textiles intended for reuse** into several hundred categories based on factors such as quality, colour, garment type, material, size, and fashion trends in line with market requirements. **Textiles designated for recycling** must be sorted primarily by their fibre composition. The sorting procedure, especially when intended as input for high-quality material recycling, can be supported by technology with varying levels of automation (**automated or semi-automated sorting**). This can be helpful for accurate material and fibre identification, which is a prerequisite for several recycling processes. Automated sorting processes are mostly based on **spectroscopic technologies** (mainly near-infrared, **NIR**) to detect material composition or can make use of **RFID-technology** (**R**adio **F**requency **ID**entification) to store and access information about textile products (see chapter 3.2.2, Digitalization). However, **most automated sorting technologies** are **still in the development phase**. In the EU, currently, less than 1% of used textiles is sorted by automated means, and the current capacity of automated sorting systems is limited to only a few thousand tonnes per year (Publications Office of the European Union, 2021b; Huygens et al., 2023).

Preparation for Reuse

According to the German Circular Economy Act (KrWG), **preparation for reuse** is defined as any operation of checking, cleaning, or repairing whereby products or components of products that have become waste are prepared so that they can be **reused without any further pre-processing for the same purpose** for which they were originally intended (UBA, 2022).

Preparation for reuse **extends the life cycle of textiles** and can save resources by **avoiding primary production**. This significantly reduces the environmental impacts associated with the textile production chain and is more environmentally friendly (and therefore preferable) than recycling (UBA, 2022). According to Sandin et al. (2019), **doubling the average wear time** of garments could lower their climate and water footprint by around 50%. The **2024 Circularity Gap Report for textiles** (Circle Economy, 2024) models a **"slow fashion" scenario** that combines reduced textile consumption and extended product lifespans by promoting increased reuse, repair, and rental, and reducing overproduction. Environmental impacts decreased across all categories. In the most ambitious scenario (5% reduction in consumption, 50% decrease in overproduction), climate impacts dropped by 10.1%, material footprint by 10.3%, and water scarcity by 11.9%. These findings highlight the considerable positive impact that reuse and longer use phases can have on resource consumption and emissions. Given that approximately **40% of clothing in private wardrobes is not used**, the potential for environmental relief through changes in consumer behaviour—such as buying second-hand clothing—is substantial (UBA, 2022).

According to Huygens et al. (2023), **in the EU**, around **10%** of separately collected textiles (the highest-quality share) are **reused locally**. In 2021, an average of 2.3 kg of textiles were reused in the EU per person,[66] around 13% of total per capita consumption (Eionet, 2025a). On the other hand, in 2021, **48%** of all textiles separately collected in the EU were **exported after** sorting, and a significant share of **around 50%** of all textile waste is **even exported without prior sorting** (Huygens et al., 2023). A substantial share of exported textiles to third countries is intended for reuse, but often enters a complex reverse supply chain with unclear fate (landfilling, open dumping, and incineration prevalent), making it challenging to track actual reuse rates of European waste textiles (see chapter 3.2.1) (EEA, 2025). The Publications Office of the European Union (2021b) reports varying reuse rates of separately collected textiles between **50% and 75%** in Europe, depending on the collecting country and method of collection. Circle Economy; Fashion for Good (2022) estimate that of the 38% of textiles collected separately in the EU, an average of **55%** of this amount is sold with the purpose of being **reused.**

In Germany, at least 50% of separately collected textiles are exported to other, mostly European, countries for sorting. According to UBA (2022), **around 62%** of collected and sorted used textiles are **prepared for reuse**. A significant share is exported, while **1%–2%** is **reused domestically**. Germany reported textile reuse data of **2.4 kg per capita** in the reference year 2021, comparable to the EU average.

Recycling

When textiles are no longer suitable for reuse, different **recycling options** can substitute for the use of primary raw materials (UBA, 2022). Thus, a**longside waste prevention, reuse, and altered consumption patterns, the recycling of used textiles should also be promoted as a complementary strategy in achieving circularity, since it can play a crucial role in reducing the demand for primary raw materials (UBA, ongoing).** The potential to recycle otherwise landfilled or incinerated post-consumer textiles is substantial. Several LCA studies conclude that using recycled fibres can reduce the greenhouse gas emissions of textile production compared to virgin fibres (UBA, ongoing).

In Germany, around 26% of collected textiles undergo some form of **material recycling**. The majority is open-loop recycled, with applications outside the clothing and textile industry. Downcycling into lower-value products such as industrial cleaning rags (14%) is the most common practice. Open-loop recycling into shredded fibres is done for 12% by mechanical means (UBA, 2022; EEA, 2023). If no material recycling is available, **energy recovery** represents the next level of the waste hierarchy. Germany reports that 8% is incinerated for energy recovery purposes (UBA, 2022).

In the **EU**, around **30%** of collected and sorted textiles are **recycled** in some form. **Incineration and landfilling** are reported to be the final fate for 10% of separately collected textiles that stay within Europe

[66] Since 2023, EU Member States must report textile reuse data to the European Environment Agency under Decision (EU) 2021/19, with 2021 as the first reference year. This is the first reporting cycle. Data quality varies and should be interpreted with caution (Eionet, 2025a). The individually reported country data on reuse is accessible via https://www.eea.europa.eu/en/circularity/sectoral-modules/textiles/textile-reuse-per-person-per-year?activeTab=658e2886-cfbf-4c2f-a603-061e1627a515.

(Huygens et al., 2023; UBA, 2022; European Environment Agency, 2024).

Collected post-consumer textiles mostly consist of fibre blends, commonly cotton-polyester mixtures or blending of elastane into cotton clothing, while only around 20% are made of homogeneous fibres (primarily cotton) (Circle Economy; Fashion for Good, 2022). According to Huygens et al. (2023), **approximately 0.7 to 0.85 million tonnes of textiles are currently recycled annually in the EU**. Over two-thirds of this volume undergoes open-loop recycling (i.e. 0.5 million–0.6 million tonnes annually), where textile waste is used in sectors outside the apparel industry, for instance, as cleaning rags, insulation material, or non-wovens. Huygens et al. (2023) estimate that the summed **capacity of recycling operations aiming for potential end uses in the clothing sector is at present around 0.2 Mt to 0.3 Mt per year (closed-loop recycling), i.e. only about 30% of the total recycling capacity in the EU**. When advanced fibre-to-fibre recycling is intended, the goal is to produce spinnable fibres. However, due to current technical limitations in recycling, including a shortening of fibre length, only a small proportion of recycling output in the EU is spinnable recycled fibres (Löw et al., 2024; Huygens et al., 2023). Globally, only around 1% of textile waste is recycled back into new textiles (EMF, 2017). Additionally, a great share of input materials used for fibre-to-fibre recycling (at least 50%) doesn't come from post-consumer but from post-production and pre-consumer (unsold goods) textile waste (Huygens et al., 2023).

Following years of growth, the market share of recycled fibres on the global fibre market declined slightly in relative terms, dropping from 8.5% in 2021 to 7.7% in 2023, with the great majority being recycled polyester. The absolute number of recycled fibres remained relatively constant over this time at 9 Mt–10 Mt. However, most of the recycled polyester used in the textile industry today does not stem from textile waste but from PET beverage bottles (98% of which is rPET). Recycled cotton made up only 1% of total cotton production in 2023 (Textile Exchange, 2024). While rPET from bottles offers a clean and consistent input stream, its use in textiles diverts material away from established PET bottle closed-loop recycling procedures and **does not address the core issue of high textile waste volumes** being sent to landfills or incinerated (UBA, ongoing).

Table 1: Overview of textile production, consumption, trade flows, and the management and processing of used and waste textiles in Germany and the EU

	Germany	**EU**
Textile production		
Turnover	€10.5 B (2024) (Statistisches Bundesamt, 2025)	€170 B (2023) (Manshoven et al., 2025)
Production volume	83,000 t of clothing only (2020) (bvse, 2020)	7.6 Mt of all finished textile products (8% clothing) (2020) (Manshoven et al., 2025)
Employees	45,000 (2024) (Statistisches Bundesamt, 2025)	1.3 M (140 M globally) (2023) (Manshoven et al., 2025; Huygens et al., 2023)
Companies	340 (2024) (Statistisches Bundesamt, 2025)	197,000 (99.7% micro- or SMEs) (2023) (Manshoven et al., 2025)
Textile consumption		
Overall consumption	1.56 Mt textile household consumption (2018) (Wagner et al., 2022)	8.5 Mt textile household consumption (2022) (Duhoux et al., 2025)
Per capita consumption	18.8 kg/capita (2018) (Wagner et al.,	19 kg/capita (2022) (Manshoven et al.,

	2022)	2025)
Trade dynamics		
Imports of new textiles	--	11 Mt (worth €153 B) (2022) (primarily from China, Bangladesh, Turkey) (Manshoven et al., 2025)
Exports of new textiles	--	4 Mt (worth €173 B) (2022) (mainly to Switzerland, UK, US, China) (Manshoven et al., 2025)
Exports of used textiles	--	1.4 Mt (2023) (45% to Africa; 43% to Asia) (Manshoven et al., 2025)
Textile waste generation		
Overall textile waste	among top 5 EU waste producers (Prakash et al., 2023b)	6.94 Mt (85% post-consumer) (2022) (Duhoux et al., 2025)
Per capita waste generation	--	approx. 16 kg/capita (2022) (Duhoux et al., 2025)
Collection		
Separate collection volume	1 Mt (2018) (Wagner et al., 2022) 12 kg/capita (2018) (Wagner et al., 2022)	1.95 Mt (2020) (EEA, 2024b) 4.6 kg/capita (2022) (Duhoux et al., 2025)
Textiles not separately collected	67%[67] of textiles not separately collected end up in residual waste Equivalent to 4.5 kg/capita (Wagner et al., 2022) to 6.8 kg/capita (Deckers et al., 2024)	11.1 kg/capita in mixed household waste (2022) (Duhoux et al., 2025)
Collection rate[68]	64% (2018) (Wagner et al., 2022)	38% (Köhler et al., 2021)
Capture rate[69]	18% (2020) (Deckers et al., 2024)	15% (2022) (Duhoux et al., 2025)
Collection actors	73% private actors (of which 29% charitable), 27% public authorities (Wagner et al., 2022)	Often involving charitable and social enterprises (Deckers et al., 2024)
Collection system	96% depot containers (bring banks) and recycling yards (Wagner et al., 2022)	Mostly street containers (bring points) complemented by civic amenity sites (recycling yards) (Deckers et al., 2024)
Sorting		
Sorting method	Manual sorting predominant; automated sorting <1% of EU sorting capacities (a few thousand tonnes per year) (Köhler et al., 2021; Huygens et al., 2023)	
Sorting capacities	190,500 t; majority exported to countries	Approx. 1.5 Mt (EEA, 2024b)

[67] The remaining portion is either kept as unused clothing or privately passed on or sold as second-hand goods.

[68] The **collection rate** measures the relation between the total volume of separately collected used textiles and the total amount of textiles placed on the market in the same year. This approach overlooks the household textile stock, which could lead to overestimations of actual collection (Deckers et al., 2024).

[69] The **capture rate** might be more useful in estimating the efficiency of collection systems. It puts the amount of separately collected textiles in relation to the total quantity of textile waste generated (separately collected textile waste plus textiles in the mixed municipal waste) (Deckers et al., 2024).

	with large sorting capacities (Köhler et al., 2021)	Netherlands (234,000 t) (Köhler et al., 2021) Poland (200,000 t) (Köhler et al., 2021)
Exports of used textiles pre- and post-sorting	50% exported before sorting (Löw et al., 2024)	50% exported before sorting (2021) (Huygens et al., 2023) 48% exported after sorting (2021) (Huygens et al., 2023)
Preparation for reuse	62%[错误!未定义书签。] (Löw et al., 2024)	55%, [70] (van Duijn et al., 2022)
Domestic reuse	1%–2% (Wagner et al., 2022) 2.4 kg/capita (2021) (Duhoux et al., 2025)	10% (Huygens et al., 2023) 2.3 kg/capita (2021) (Duhoux et al., 2025)
Material recycling	26% (Löw et al., 2024)	30% (Huygens et al. 2023); 0.7-0.85 Mt (Huygens et al. 2023)
Downcycling & Open-loop recycling	14% further used as industrial rags (Löw et al., 2024) 12% recycled into shredded fibres (Löw et al., 2024)	0.5-0.6 Mt used as cleaning rags, insulation, or non-wovens (Huygens et al., 2023)
Closed-loop recycling	--	0.2-0.3 Mt of recycling operations (30% of EU recycling capacities) aimed at end uses in clothing sector[71] (Huygens et al., 2023)
Incineration	8% with energy recovery (Löw et al., 2024)	14% with and without energy recovery (2022) (Manshoven et al., 2025)
Landfilling	4% (Löw et al., 2024)	12% (2022) (Manshoven et al., 2025)

[70] Köhler et al. (2021) report varying reuse rates of separately collected textiles between 50% and 75% in Europe, depending on the collecting country and method of collection. A substantial share of exported textiles to third countries is intended for reuse but often enters a complex reverse supply chain with unclear fate (landfilling, open dumping, and incineration prevalent), making it challenging to track actual reuse rates of European waste textiles (see chapter 3.2.1).

[71] That is, recycling operations with the goal of producing spinnable fibres; however, due to technical limitations such as fibre shortening during processing, only a small share of this output currently meets the quality required for spinning.

Annex H. Environmental Impacts of the Textile Industry

Table 2: Environmental and human health impacts of the global and European textile industry

Impact category	Impacts of textile industry	Region
Material use	**3.25 × 10^9t** (**>3%** of global material use; 99% from virgin sources)	Globally[72]
	234 × 10^6t or **523 kg/capita** (32% sourced within Europe)	EU[73]
Greenhouse gas emissions	**>3%** of global climate impacts (esp. synthetic fibres)	Globally[38]
	159 × 10^6t CO_2eq or **355 kg/capita** (70% outside Europe)	EU[73]
Water use	**93 × 10^9t** (**4%** of global water use; esp. from cotton)	Globally[38]
	5.3 × 10^9t m^3 'blue' water consumption (mostly in Asia)	EU[73]
	Residential washing: 6.2 kg water, 15.8 g detergent, and 0.405 kWh per kg laundry	Sweden[74]
Land use	**144,000 km²** (86% outside Europe; esp. cotton and animal-based fibres)	EU[73]
Microplastic pollution	**0.2-0.5 × 10^6t/yr** often released via washing, wearing, disposal (Synthetic textiles account for **16%–35%** of ocean microplastic pollution)	Globally[38]
	13,000 t/yr or **25 g/capita** of microplastics enter surface waters (8% of microplastic emissions to water)	Europe[75]
Water body eutrophication	**5%** (marine) and **4%** (freshwater) eutrophication	Globally[38]
Air pollution	**>2%**	Globally[38]
Biodiversity loss	**>3%**	Globally[38]
Acidification	**>3%** (Terrestrial and freshwater acidification)	Globally[38]
Human well-being	**Health risks** from hazardous chemicals (e.g., PFAS), pollution, and climate impacts (esp. in production areas like China, the United States or India) **Socio-economic impacts** incl. poor working conditions and low wages[76]	Globally[38]

[72] Impacts of the global textile industry were derived from Circular Economy (2024).
[73] The impacts of EU household textile consumption levels on the environment were derived from (Manshoven et al., 2025).
[74] The figures were derived from a study by Sandin et al. (2019) on the environmental impacts of Swedish household consumption.
[75] The figures were derived from EEA (2022).
[76] Besides the environmental concerns, the textile industry is also marked by severe social and socio-economic impacts, particularly in the early stages of the value chain. Cotton cultivation, yarn and fabric production, and garment assembly are associated with high social risks, including poor working conditions, low wages, and harmful labour practices, especially in regions with weak environmental and labour regulations. While the sector provides employment and human services in low-income regions, the current production model accelerates inequality and hinders sustainable development.

Annex I. Examples of Textile Recycling Technologies

The listed examples of textile recycling technologies are based on Löw et al. (2024).

Mechanical recycling

- **Wolkat** (Netherlands, sorting and recycling in Morocco): Wolkat engages in the full textile value chain, from post-consumer textile collection over sorting, reuse and mechanical recycling to yarn, fabric and textile manufacturing, without using dyes, chemicals, or water. The company operates in line with the waste hierarchy with a closed-loop focus, aiming to return materials to the textile sector. Their residual waste rate is only 4%. Wolkat collaborates with brands like Nike, Filippa K, and HEMA as well as municipalities, retailers, and other partners (Capacity approx. 9-30 kt/a).
- **Altex Textil-Recycling** (Germany): approx. 30–36 kt/a, mainly open-loop recycling (products include tear fibres, mixtures, or short fibres)
- **Antex** (Spain): Thermo-mechanical recycling process for textile waste, converting it into reusable polymers using post-consumer and post-industrial textile waste as input.

Solvent-based recycling

- **WornAgain** (Switzerland)**:** Scaling of a closed-loop chemical recycling technology using polyester-cotton blends as input to yield PET and recovered cellulose for spinnable fibre production. Demo plant in Switzerland (max. 1,000 t/a; in commercial installations, 50-100 kt/a are possible).
- **Circulose**: CIRCULOSE® is a new material (man-made cellulosic fibre, MMCF) made by recovering cellulose from worn-out clothes and production scraps and is made from 100% textile waste.

Depolymerization

- **Carbios** (France): The company has developed an enzymatic depolymerization process to recycle polyester from plastic waste and post-consumer textile waste with a quality comparable to virgin fossil-based PET. The process enables the manufacturing of products consisting of 100% rPET. In 2021, Carbios opened a demonstration plant with a capacity of approx. 40 kt/a in France. Compared to other depolymerization methods, enzymatic approaches require fewer chemicals and solvents, which can reduce environmental impacts (Duhoux et al., 2021). However, chemical inputs are still needed for repolymerization. While mechanical recycling results in lower PET quality, making 100% mechanically recycled PET products unfeasible, it still has a lower environmental footprint (Huygens et al., 2023).
- **BASF, Inditex**: Production of a jacket made from 100% textile waste. All textile components (incl. zippers, velcro, labels, …) are made from loopamid®, a recycled nylon-6 yarn, and are generated from post-industrial textile waste and used textiles (Huygens et al., 2023). The "design-for-recycling" approach from Inditex makes further recycling easier, as all components are made of the same material.

Feedstock recycling

- **Eastman Carbon Renewal Technology** (United States): Recycling of mixed plastic waste (including carpets) into monomers and processing together with wood pulp (60%) into regenerated fibres (Naia™)

Annex J. Strategic Targets and Objectives in the Global Framework on Chemicals (GFC)

The GFC presents a comprehensive plan with the following five strategic objectives and 28 targets (ICCM5, 2023b):

Strategic Objectives (ICCM5, 2023b):

A. Legal frameworks, institutional mechanisms and capacities are in place to support and achieve the safe and sustainable management of chemicals throughout their life cycle.
B. Comprehensive and sufficient knowledge, data and information are generated, available and accessible to all to enable informed decisions and actions.
C. Issues of concern are identified, prioritized, and addressed.
D. Safer alternatives and innovative and sustainable solutions in product value chains are in place so that benefits to human health and the environment are maximized and risks are prevented or, where prevention is not feasible, minimized.
E. Enhanced implementation occurs through increased and effective resource mobilization, partnerships, cooperation, capacity building, and integration into all relevant decision-making processes.

Targets (ICCM5, 2023b):

Table 3: Targets of GFC

	Target
A1	By 2030, Governments have adopted and are implementing and enforcing legal frameworks, and have established appropriate institutional capacity to prevent or, where prevention is not feasible, minimize adverse effects from chemicals and waste as appropriate for their national circumstances.
A2	By 2030, intergovernmental stakeholders develop guidelines to support the needs of interested Governments and relevant stakeholders to implement effective chemicals and waste management strategies, building on, among other things, updates of the Inter-Organization Programme for the Sound Management of Chemicals toolbox for decision making in chemicals management.
A3	By 2030, companies implement measures identified to prevent or, where prevention is not feasible, minimize adverse effects from chemicals throughout their life cycle.
A4	By 2030, stakeholders have effectively prevented all illegal trade and traffic of chemicals and waste.
A5	By 2030, Governments work toward notifying, regulating or prohibiting the export of chemicals they have prohibited nationally, in line with their international obligations.
A6	By 2030, all countries have access to poison centres equipped with essential capabilities to prevent and respond to poisonings, as well as access to training in chemical risk prevention and clinical toxicology.
A7	By 2035, stakeholders have taken effective measures to phase out highly hazardous pesticides in agriculture where the risks have not been managed and where safer and affordable alternatives are available, and to promote transition to and make available those alternatives.
B1	By 2035, comprehensive data and information on the properties of chemicals are generated and made available and accessible.
B2	By 2030, stakeholders make available, to the extent possible, reliable information on chemicals in materials and products throughout the value chain.
B3	By 2035, stakeholders generate data on the production of chemicals, including the use of chemicals in materials and products, in addition to data on emissions and releases of chemicals and waste to the environment, making these data available and publicly accessible.

B4	By 2035, stakeholders apply appropriate guidelines, best available practices and standardized tools for hazard and risk assessment and chemical and waste management.
B5	By 2030, educational, training and public awareness programmes on chemical safety, sustainability, safer alternatives and the benefits of reducing chemicals and waste risks have been developed and implemented, taking into consideration a gender-responsive approach.
B6	By 2030, all Governments have implemented the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) in all relevant sectors as appropriate for their national circumstances.
B7	By 2030, stakeholders generate, to the extent possible, and make available comprehensive and accessible monitoring and surveillance data and information on concentrations and potential exposure sources of chemicals in humans (disaggregated by sex, age, region, other demographic factors, and other relevant health determinants as feasible), other biota and environmental media.
C1	Processes and programmes of work, including timelines, are established, adopted and implemented for identified issues of concern.
D1	By 2030, companies consistently invest in and achieve innovations toward advancing sustainable chemistry and resource efficiency throughout the life cycle of chemicals.
D2	By 2035, governments implement policies that encourage production using safer alternatives and sustainable approaches throughout the life cycle, including best available techniques, green procurement, and circular economy approaches.
D3	By 2030, the private sector, including the finance sector, incorporates strategies and policies to implement the sound management of chemicals and waste in its finance approaches and business models and applies internationally recognized or equivalent reporting standards.
D4	By 2030, relevant stakeholders give priority to sustainable solutions and safer alternatives to harmful substances in products and mixtures, including in consumer products, in their research and innovation programmes.
D5	By 2030, governments implement policies and programmes to increase support to safer and more sustainable agricultural practices, including agroecology, integrated pest management and the use of non-chemical alternatives, as appropriate.
D6	By 2030, sustainable chemical and waste management strategies have been developed and implemented for major economic and industry sectors that identify priority chemicals of concern and standards and measures, such as the chemical footprint approach, to reduce their impact and, where feasible, their input along the value chain.
D7	By 2030, stakeholders implement measures and strive to ensure effective occupational health and safety practices as well as environmental protection measures in all relevant sectors and throughout the supply chain.
E1	By 2035, governments have mainstreamed the sound management of chemicals and waste through implementation in all relevant sectoral plans, budgets, and development plans and development assistance policies and programs.
E2	By 2030, partnerships and networks among sectors and stakeholders are strengthened to achieve the sound management of chemicals and waste.
E3	Adequate, predictable and sustainable financial resources from all sources needed to support achieving the sound management of chemicals and waste are identified and mobilized in alignment with the vision, strategic objectives and targets of the Framework in all sectors by and for all stakeholders, including by leveraging private finance and promoting innovative and blended-finance schemes.
E4	Funding gaps for the implementation of sound management of chemicals and waste are identified and considered for capacity building, including through the Global Framework on Chemicals Fund.

E5	By 2030, governments have taken measures to put in place policies to internalize the costs of the sound management of chemicals and waste through different approaches.
E6	By 2030, stakeholders identify and strengthen, as appropriate, synergies and linkages between chemicals and waste management and other key environmental, health, and labour policies, such as those related to climate change solutions, biodiversity conservation, human rights protection, universal health coverage or primary health care.

With a view to the textiles sector, quite a few GFC targets appear particularly relevant: A1, A2, A3, A4 on legal frameworks, institutional mechanisms, and capacities to support and achieve the safe and sustainable management of chemicals throughout their life cycle; all B targets B1-7 on generation, availability, and accessibility of relevant knowledge, data, and information; C1 on the establishment, adoption, and implementation of processes and programs of work including timelines, to address issues of concern in the textiles sector; D1, D2, D3, D4, D6, and D7 on safer alternatives and innovative and sustainable solutions in product value chains to maximize benefits to human health and the environment while preventing or, if impossible, minimizing risks; all E targets E1-7 on enhancing implementation resource mobilization, partnerships, cooperation, capacity building, and integration into all relevant decision making. Where raw materials for textiles like cotton are agriculturally produced, targets A7 and D5 apply in addition (ICCM5, 2023b).

Furthermore, several mechanisms as set out in Section VI of the GFC and stipulated by ICCM5 Resolution V/8, provide key considerations on how to organize processes and actors (ICCM5, 2023b; UNEP, 2024a). Alongside implementation programs on a global level, under joint development with presentations and discussions facilitated by the IOMC, relevant actors are encouraged to follow the GFC guidance on national implementation, regional cooperation and coordination, and in particular on enhanced sectoral and stakeholder engagement, thus creating impact and advancing toward the GFC targets and many Sustainable Development Goals (SDGs) of the 2030 Agenda (IOMC, n.d.; UNEP, 2025b).

Complementary orientation for implementation is provided by a discussion note on the integrated chemicals and waste management concept, focusing on national systems, industry engagement in the textiles sector, and sustainable development linkages (IOMC, 2024).

Annex K. Definition of Substances of Concern With Explanatory Notes

Table 4: **Definition of substances of concern with explanatory notes**

Definition of substances of concern in Article 2(27) of the ESPR	**Explanatory notes**
(a) meets the criteria laid down in Article 57 of Regulation (EC) No 1907/2006 and is identified in accordance with Article 59(1) of that Regulation;	This refers to the substances of very high concern (SVHC) under REACH. These substances are included in the so-called candidate list. Constantly, substances are added to this list, which can be found here: https://echa.europa.eu/candidate-list-table. According to Article 33 of REACH, the contents of SVHCs in products > 0.1% have to be communicated along the supply chain and, upon request, also to the end user. Articles containing SVHC above this threshold have to be notified in the SCIP ("Substances of Concern In articles as such or in complex objects (Products)") database established under the Waste Framework Directive (WFD): https://echa.europa.eu/de/scip.
(b) is classified in Part 3 of Annex VI to Regulation (EC) No 1272/2008 in one of the following hazard classes or hazard categories: (i) carcinogenicity categories 1 and 2; (ii) germ cell mutagenicity categories 1 and 2; (iii) reproductive toxicity categories 1 and 2; (iv) endocrine disruption for human health categories 1 and 2; (v) endocrine disruption for the environment categories 1 and 2; (vi) persistent, mobile and toxic or very persistent, very mobile properties; (vii) persistent, bioaccumulative and toxic or very persistent, very bioaccumulative properties; (viii) respiratory sensitisation category 1; (ix) skin sensitisation category 1; (x) hazardous to the aquatic environment —	CMR hazard classes are known. Additionally so-called new hazard classes are listed, e.g., endocrine disruptors with effects on human health or the environment, or persistent, mobile and toxic properties or sensitizing substances. Though it is understood that in China, these hazard classes do not exist according to information on the implementation of the GHS given by UNECE[77] This part of the SoC definition refers to substances with a harmonized classification under CLP which are listed in Annex VI. Annex VI is regularly updated and can be found here: https://echa.europa.eu/information-on-chemicals/annex-vi-to-clp Certain substances with CMR

[77] https://unece.org/sites/default/files/2023-11/GHS%20implementation%20by%20country_2023-11.pdf

categories chronic 1 to 4; (xi) hazardous to the ozone layer; (xii) specific target organ toxicity — repeated exposure categories 1 and 2; (xiii) specific target organ toxicity — single exposure categories 1 and 2;	
c) is regulated under Regulation (EU) 2019/1021; or	This refers to POP substances, which are basically taken up in the REACH candidate list. As POP substances are almost globally recognized, they are usually restricted by contractual obligations (see restricted substance lists further below in the text).
(d) negatively affects the reuse and recycling of materials in the product in which it is present;	Article 5(14) of the ESPR gives the following additional information: "For each product group concerned by ecodesign requirements, the Commission shall determine, where relevant, which substances fall under the definition in Article 2(27), point (d), taking into account, at least, whether: based on standard technologies, the substances make the reuse, or recycling process more complicated, costly, environmentally impactful, or energy- or resource-demanding; the substances impair the technical properties or functionalities, the usefulness or the value of the recycled material coming from the product or products manufactured from that recycled material; the substances negatively impact aesthetic or olfactory properties of the recycled material."

Source: ESPR; https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401781

Annex L. PFAS: Application Areas, Volume Used, and Emissions

Table 5: Application areas/sectors of PFAS with corresponding volume used (tonnage range), emissions in manufacturing and use phase and share of total PFAS emissions.

Application	Tonnage range	Emission range % emitted in manufacturing and use phase	Emission contribution Contribution to total emission [%]
Applications of fluorinated gases	> 10 000	5 – 25	> 50
Textiles, upholstery, leather, apparel, & carpets	> 10 000	5 – 25	10 – 50
Medical devices	> 10 000	5 – 25	5 – 10
Manufacture	> 10 000	0 – 5	1 – 5
Food contact materials and packaging	> 10 000	0 – 5	0 – 1
Transport	> 10 000	0 – 5	0 – 1
Construction products	1 000 – 10 000	25 – 75	1 – 5
Electronics and semiconductors	1 000 – 10 000	5 – 25	0 – 1
Lubricants	1 000 – 10 000	5 – 25	0 – 1
Petroleum and mining	1 000 – 10 000	0 – 5	0 – 1
Energy sector	1 000 – 10 000	0 – 5	0 – 1
Metal plating and manufacture of metal products	100 – 1 000	0 – 5	0 – 1
Cosmetics	10 – 100	> 95	0 – 1
Consumer mixtures	10 – 100	75 – 95	0 – 1
Ski wax	0 – 10	25 – 75	0 – 1

Source: REACH restriction proposal, submitted in January 2023: Submitted restrictions under consideration - ECHA

Annex B. Case Study VAUDE: Phasing out PFAS in the Outdoor Industry

Abstract: To phase out hazardous substances, VAUDE collaborates with chemical suppliers to develop safer alternatives and has created a strict restricted substance list. Since 2021, all VAUDE apparel fabrics are PFC-free.

Keywords: textiles; chemicals; restricted substances; performance testing; supplier collaboration.

The team would like to thank René Bethman, Senior Innovation Manager Materials and Manufacturing Consultant at VAUDE Academy for sustainable business, for his elaborate input and feedback.

Annex M.1. Background

VAUDE, a leading German outdoor brand, began its journey toward eliminating harmful chemicals from its supply chain over a decade ago. The spark came in 2011 with Greenpeace's Detox campaign, which highlighted the environmental and health risks of hazardous chemicals, including PFAS (per- and polyfluoroalkyl substances). VAUDE is committed to phasing out PFAS from its products, a mission that has evolved into a core part of the company's sustainability strategy.

PFAS have been widely used in outdoor gear due to their water- and stain-repellent properties. However, their persistent, mobile, and toxic properties create health risks for humans, animals, and ecosystems. This makes their elimination from VAUDE products critical. While removing PFAS from membranes was achievable early on, the real challenge was in replacing PFAS-based Durable Water Repellent (DWR) treatments—particularly given performance concerns, supply chain complexities, and a lack of regulatory pressure at the time.

VAUDE's approach was based on an incremental phase-out of polyfluorinated and perfluorinated chemicals (PFCs), which belong to the PFAS group:

- Phase-out of PFC in waterproof membranes since 2010.
- Phase-out of PFCs in dirt- and water-repellent finishes from water-repellent clothing (2015), sleeping bags (2016), waterproof clothing (2018), and footwear and backpacks (2020).
- Since 2021, all VAUDE apparel fabrics are PFC-free.

VAUDE considers the assurance of "no harmful chemicals" as a unique selling point and therefore considers it a **competitive advantage**, especially among eco-conscious consumers. Transparency and communication have been key, with a strong emphasis on protecting children.

The company continues to track and report its progress publicly (link) and is now working on extending PFAS-free solutions to tents—one of the last frontiers due to relatively high-performance requirements.

Annex M2. Main practices

Establishing Supportive Processes

- Restricting hazardous substances: the Greenpeace Detox campaign, started in 2011 and involved 80 fashion companies that took a pledge to phase out hazardous chemicals from their production lines by 2020. As part of the campaign, VAUDE delivered a Detox commitment and a specific action plan that involved, among other things, a stringent manufacturing restricted substance list (MRSL) in 2016, which regulates strict limits and/or usage bans of critical substances within the entire production process as well as finished goods. The MRSL was based on, amongst others, the work delivered by Bluesign as well as ZDHC.

- The search for alternatives: When exploring water-repellent finishes, VAUDE initially reviewed all current and emerging alternatives that could be integrated into its supply chains. It was realized that selecting a single solution for all textiles and suppliers was not feasible, as performance varies. Some suppliers achieve better results with one chemical formulation, while others perform better with another. Therefore, VAUDE defined clear performance requirements that all suppliers must meet. The approach includes a broad range of solutions, including those from Rudolf, 3M, Daikin, and several others.
- Investing in innovation: VAUDE collaborated directly with chemical suppliers—many of whom were unfamiliar with brands working this far upstream—to co-develop and implement PFAS-free alternatives. They organized round tables to bring together chemical suppliers in a pre-competitive setting and to discuss solutions beyond the boundaries of the individual businesses.
- Performance testing: Real-world testing revealed that standard production spray tests did not reflect actual conditions. VAUDE created its own realistic testing parameters to ensure functional performance. At the same time, performance is very dependent on the use phase and customer behaviour with the product.
- Cross-functional involvement: What began as a task force of three grew into a cross-departmental effort involving up to 30 people from quality management, product development, materials sourcing, and marketing.

Overcoming Obstacles

- Supply chain resistance: The process involved close cooperation with suppliers and industry leaders, as well as training, capacity building and auditing of supply chain partners. Many suppliers were unaware or unconvinced of the need for change, especially as VAUDE often represented a small share of their customer base.
- Technical hurdles: PFAS-free treatments affected fabric dyeing, seam slippage, and overall durability. This required intensifying the relationships with chemical suppliers and the need to enhance performance. It also required additional research to understand impacts at the level of the textile mill, including an understanding of the financial implications inherent to a reduced output and slower production process.
- Market skepticism: Early consumer expectations for high-performance gear made adoption risky, with concerns about increased returns and complaints. It is important to communicate clearly to consumers about the journey, including public reporting on results and progress made.
- Lack of regulatory support: Without a restrictive legal framework, many suppliers view VAUDE's demands as niche and optional rather than imperative. Governments are crucial actors as they can send out clear signals by imposing bans, providing an unprecedented push to R&D activities to develop alternatives.

- **Regulatory action is essential**: Stronger legislation at an earlier point in time would have driven industry-wide change based on scientific evidence at a bigger and faster pace. Mandatory policies, including bans of specific product groups, are essential to incentivize the market adoption of scientifically proven safe alternatives.
- **Supplier collaboration must scale globally**: The initial perception that PFAS elimination was a "European niche issue" slowed progress. Global alignment is necessary to ensure clean and consistent outputs across all mills and production facilities.
- **Rethink performance standards**: A shift in mindset is needed—accepting slightly lower performance in favour of significantly better environmental and health outcomes.

Annex C. Digitalization in the Textile Industry

Annex N1. Introduction & status quo

The EU Strategy for Sustainable and Circular Textiles highlights digital technologies as potential key drivers in shifting Europe's textile industry toward a circular and sustainable economy, offering opportunities for enhanced efficiency, productivity, resilience, responsiveness to market changes, and competitiveness (European Commission, 2022). Industry 4.0 refers to the incorporation of advanced digital technologies (like artificial intelligence (AI), the Internet of Things (IoT) or automation tools) into conventional manufacturing processes and business operations (Manshoven et al., 2025; EEA, 2025). There are several digital technologies emerging in the textiles sector, which can help with data collection and big data analysis, increase connectivity, or enable process automation, information accessibility, and data security. Those include, among others, 3D printing, robotics, IoT, Cloud Computing, AI, augmented and virtual reality (AR/VR), online platforms, sensors and tags (like RFID), digital twins and digital product passports (DPPs/DPISs), as well as computer-aided design (Manshoven et al., 2025).

The textile industry has already experienced substantial digital advancements in recent years. Some companies have already started to integrate digital tools like AI, blockchain, IoT, or automation solutions into manufacturing and logistics processes, aiming to optimize them. Others are starting to use technologies like digital design, prototyping or 3D-printing in design and production to increase efficiency and reduce resource consumption and waste volumes. Some textile companies build their business models around digital technologies, providing innovative services and thereby unlocking new revenue streams (Manshoven et al., 2025). Since the 2000s, the use of e-commerce and online platforms has steadily grown, offering greater product variety, lower prices, and enhanced consumer convenience (Manshoven et al., 2025). The proportion of revenue generated from online sales of clothing and other textiles in the EU more than doubled between 2009 and 2022, rising from 5% to 11% (Euratex, 2022) and four out of ten people in the EU who bought online during 2023 ordered clothes or shoes (Euratex, 2024). This development was further accelerated by the COVID-19 pandemic, driving forward the textile industry's digital transformation and encouraging more consumers to switch to online or mobile shopping (Manshoven et al., 2025). Since many online platforms sell fast or ultra-fast fashion, this has intensified environmental, climate, and waste problems through increased production, consumption, and globalized transportation (Manshoven et al., 2025). Additionally, lenient return policies and uncertainty about sizing led to high return rates (20% of clothing in Europe), which results in 22%–43% of returned clothing bought online being destroyed (EEA, 2024a).

Still, the integration of advanced digital technologies into the textile sector offers several potential benefits. These technologies can improve resource efficiency, increase transparency, inform decision making, and support communication with consumers, for example, by conveying sustainability information to influence more responsible purchasing decisions (e.g., via digital product passports). Digital tools can also foster circular product design, make production smarter by better aligning supply and demand, optimize supply chains in real-time, and better manage product life cycles. New circular business models like repair services can be advanced and supported by digital tools (Manshoven et al., 2025). From a circular economy perspective, digital technologies could contribute to environmental sustainability by extending product lifespans (slowing the loop), increasing resource efficiency, reducing waste (narrowing the loop), and enhancing recycling and reverse logistics (closing the loop) (Bocken et al., 2016; Manshoven et al., 2025). Economically, digitalization may offer cost savings and open new revenue streams through circular business models (CBM) (e.g., via savings and sharing resources, reuse, or recycling). From a social perspective, stakeholder engagement can be improved, helping to shape inclusive, sustainable business practices (Broccardo et al., 2023).

However, the increased use of digital technologies also involves potential trade-offs and significant risks, which will be discussed later in this chapter.

Annex N2. Potential applications for digital technologies throughout the textile value chain

In the following, selected examples of digital technologies in different life-cycle stages with the potential to contribute to a more circular textile economy will be discussed. Those examples stem from the ETC CE Report 2025/6 "Textiles and the environment – The role of digital technologies in Europe's circular economy" published by the European Environmental Agency (Manshoven et al., 2025).

Annex N3. Product Design

The product design and engineering process is highly iterative, traditionally requiring extensive manual work and physical sampling. This is economically costly, time-consuming, and creates a lot of waste, since it involves testing and evaluating designs, as well as sending samples around the world, creating logistical burdens (Manshoven et al., 2025).

A transition to digital design tools and creation of digital samples and prototypes, making use of technologies like computer-aided design (CAD), 3D modelling, and 3D printing could reduce resource consumption and waste generation since physical samples and associated logistics are avoided. Furthermore, the iterative design and sampling process could be accelerated. However, simulating the physical properties and behaviours of fabrics realistically remains challenging and is not yet fully accurate (Manshoven et al., 2025; Casciani et al., 2022). AI algorithms can support designers in sustainable and circular material selection and serve as a creative and technical assistant in the design process. AI can also optimize fabric utilization and reduce cutting waste by employing "zero-waste design" and "zero-waste pattern cutting" principles. Another emerging trend is smart textiles with integrated sensors & IoT systems for enhanced functionalities (e.g., temperature regulation or data collection for medical purposes). Although innovative, there are concerns about the recyclability and end-of-life management of smart textiles (Manshoven et al., 2025).

Annex N4. Textile Manufacturing

Inefficiencies in manufacturing, such as overproduction and poor process and quality control, cause significant amounts of pre-consumer waste. Digital technologies can optimize the production process (EEA, 2024a; Huygens et al., 2023).

Digital tools like AI, cloud computing, IoT, and sensors enable real-time process monitoring, enhancing production planning and reducing resource and energy use. They can optimize processes and supply chains, reducing costs and enhancing the traceability of production steps. Automatic fabric scanning and AI-driven defect detection systems can facilitate and improve quality control. Technologies like 3D printing and 3D knitting might reduce long-distance transports, stocks, and overproduction by producing more locally, fast, individualized, and less wasteful. Automation and robotics can enhance productivity, quality, and material efficiency by employing precise automated cutting technologies. This enables shorter lead times and potentially on-demand production of clothing, though this could also act as an accelerator of fashion trends and fuel customer demand and impulse buying (Casciani et al., 2022; Rantala et al., 2023; Ahmad et al., 2020; Manshoven et al., 2025).

Annex N5. Retail and Customer Interactions

The limited insight into consumer behaviour and preferences as well as long lead times make estimations about order quantities difficult. Around 4%–9% of textile products in Europe are never sold and destroyed before use (EEA, 2024a).

Virtual fitting rooms (using 3D body scanning, AR, and VR) have the potential to lower return rates by enabling virtually trying of clothes before buying. AI and big data analytics can improve demand forecasting, helping to better align production with demand, thereby reducing unsold stocks (Manshoven et al., 2025). Digital product identifiers like QR codes and barcodes, NFC chips, or IoT-enabled RFID tags allow for transparent information sharing with customers (e.g., about the presence of chemicals of concern, the entire value chain, environmental performance, etc.), more efficient internal inventory management, product authenticity verification, and tracking of products and consumer behaviour. Moreover, codes and tags will be crucial for the mandatory development of digital product passports (see below) (Manshoven et al., 2025).

Annex N6. Product Use

Such digital product identifiers and sensors might also be integrated with IoT and AI assistants to enhance textile maintenance through smart care labels combined with IoT-enabled washing machines, or detailed digital washing and care instructions for optimal textile handling. Online platforms, mobile apps, and AI-powered algorithms can make textile rental and repair services more convenient, trustworthy, and economically viable by facilitating scheduling, progress tracking, payment and remote damage diagnosis with accurate cost estimates. This is vital since smooth reverse logistics are thought to encourage people to repair more (Manshoven et al., 2025).

Annex N7. Collection, Sorting, and Waste Processing

Currently, textile waste management relies mostly on low-tech methods, with time-intensive, complicated manual sorting prevalent, and a lack of connection between collectors, sorters, and designers or manufacturers.

Digital technologies play a vital role in automating the sorting process of textile waste, by making it more efficient, cost-effective, and accurate. This is especially important considering the EU's obligation to separately collect end-of-use textiles starting in 2025, which is expected to increase the volume but decrease the quality of textile waste to be sorted and recycled. Digital identification technologies, such as labels, tags (e.g., RFID) or QR codes, can also be important for EoL management of textiles. Product and material composition of textiles could be identified in a transparent, fast, and automated way, thereby reducing processing time and costs, and increasing sorting capacities. They also enable precise tracking of the product life cycle, which can help to optimize CBMs. In this context, the digital product passport will be important as well for providing detailed information to sorters and recyclers. Machine vision using near-infrared (NIR) spectroscopy and hyperspectral imaging are also important enablers of automated sorting. NIR is currently the most advanced technology to identify and sort textiles quickly and accurately by fibre type and colour. This is an essential prerequisite for directing garments to appropriate recycling or remanufacturing processes and delivering high-quality recycling outputs. However, automated sorting technologies are still in development and not scaled up yet. Besides that, digital tools can support linking suppliers of high-quality recycled fibres with manufacturers seeking to integrate sustainable materials into their products, thereby establishing a mature marketplace for secondary resources (Manshoven et al., 2025; Rantala et al., 2023).

Annex N8. Value Chain Management and Transparency

Looking beyond individual life-cycle stages, digital technologies play a crucial role in enabling comprehensive value chain management and transparency.

Technologies such as blockchain, IoT, cloud computing, and AI are increasingly applied across the textile value chain to support detailed information management, provide data authenticity, and verify product identities and track sustainability. They can help enhance value chain transparency in companies, which will become essential under upcoming regulatory requirements, and facilitate automated collection, management, and sharing of product information. In addition, these technologies enable tracking and tracing of emissions, resource use, and social and environmental impacts, supporting informed decision making, increased consumer acceptance and stronger collaboration among value chain actors. For instance, IoT-enabled sensors can monitor fashion products over their entire life cycle and record every transaction securely on an immutable blockchain, thereby ensuring an authentic and transparent supply chain.

Intelligent digital labels, such as universal product codes, RFID tags, and barcodes play an important role in the entire value chain. They can enhance supply chain efficiency, verify product authenticity, support consumer engagement, enable traceability during collection and sorting for reuse and recycling, and provide insights into product availability and consumer behaviour. Forecasts suggest that within 5 years, over half of fashion products could be RFID-tagged due to improved cost efficiency. However, challenges remain, such as the durability of tags during washing and throughout the product life cycle or the environmental impacts of digital labels themselves.

The EU's Ecodesign for Sustainable Products Regulation (ESPR) introduces the mandatory development of digital product passports (DPPs). The DPP is a digital record that provides comprehensive, easily accessible product information through a unique identifier, utilizing technologies such as QR codes, NFC (Near Field Communication), or RFID. It will be a central tool for enhancing transparency and promoting circular practices across the textile sector, allowing stakeholders across the value chain to electronically access detailed information about a product's composition, age, origin, or environmental impact. It aims to support more sustainable production and consumption choices, improve repair and recycling processes, and foster collaboration across supply chains. It is also expected to increase consumer trust and help reduce overproduction by enabling better life-cycle management. In waste management, the DPP will facilitate more accurate sorting and recycling through comprehensive information about a product's material composition and recycling content, thereby supporting the development of secondary raw material markets. Nevertheless, challenges remain, including the complexity of textile supply chains, the difficulty of tracking materials beyond use and recycling, and the significant administrative efforts required for implementation. Also, ensuring the durability of data carriers throughout a product's life cycle will be crucial to ensure long-term traceability and information accessibility (The European Parliament and the Council of the European Union, 2024; Manshoven et al., 2025).

circularity.ID® is an example of a digital product passport that was developed by circular.fashion78. It contains immutable data, including material and chemical composition, and detailed, mutable product information such as care guidelines or service and sustainability information, which is accessible via QR codes or NFC tags. The open data standard ensures compatibility and interoperability between different software applications and stakeholders in the product life cycle, and consumers can access product information by

[78] https://circular.fashion/

scanning the embedded tags. Participating brands that already integrate circularity.ID® DPPs into their products include ARMEDANGELS, Besonnen, OTTO, The Slow label, or Vretena (circular.fashion, 2025).

Examples of BMBF-funded projects relating to digitalization in the textile industry can be found in Annex VI.

Annex N9. Trade-offs and risks of digital technologies

While digital technologies offer significant potential for supporting circularity in the textile sector, their adoption also comes with a range of trade-offs, risks, and implementation barriers that need to be carefully considered. Digital technologies themselves generate substantial environmental and climate impacts across their entire life cycle, including significant energy and water consumption to support data centres and AI systems, as well as greenhouse gas emissions and raw material extraction. With the growing adoption of advanced digital technologies, these impacts are expected to increase even further. The International Energy Agency (IEA) projects that global electricity consumption by data centres could more than double by 2026, especially driven by expanding use of AI. Digitalization also holds the risk of unintended rebound effects. Efficiency gains could even accelerate the fast fashion trend, resulting in even higher levels of production and consumption (i.e. Jevons' paradox) and undermining efforts to extend product lifespans and reduce waste. Furthermore, most digital technologies are not primarily introduced to enhance sustainability but rather to increase efficiency, profitability, and customized marketing. Furthermore, besides technological advances, behavioural changes and regulatory frameworks are equally essential to achieving meaningful environmental benefits (Manshoven et al., 2025).

Annex O. BMBF-funded Projects Related to Digitalization in the Textile Industry

As part of its **funding initiative "Circular Sustainable Textiles,"** the German Federal Ministry of Education and Research (**BMBF**) supports up to 3-year collaborative R&D projects between science, industry, and practice to develop and test holistic, ready-to-implement solutions for improved textile circularity. Many of the funded projects integrate digital technologies with the aim to transfer innovations into market-ready products and to foster sustainable circular business models. The following section presents selected example projects with a particular focus on digitalization (FONA, 2025).

Table 6: ReseT – Recycling solutions for synthetic blended fabrics

Project description	• Holistic, innovative **recycling solution** for **synthetic blended fabrics** made of **polyester**, **nylon**, and **elastane** through the integration of various recycling procedures. • High-quality recycling of materials and reintegration into the cycle without loss of quality.
Digitalization	• Development of a **Digital Product Passport** (DPP) by **project partner Xiphoo**, which is used for the recycled textiles produced within the project. • Provides detailed information on **material composition**, **sustainability**, and **end-of-life management options** for the textiles. • Informs consumers about proper disposal to make it available for recycling.
Project partners	• Xiphoo GmbH (DPP) • Maier Sports GmbH (Product design & integration of the DPP) • Matter GmbH (Further development of the revolPET® process for processing blended fabrics) • Technische Universität Braunschweig (Support recycling, material analysis, quality control) • Indorama Ventures Fibers Germany GmbH (Support in production of PET from recycled monomers)

Source: (BMBF 2025)

Table 7: HoliTexCycle – Holistic Standard and Software Solution for Circular Textiles

Project description	• Development of a **holistic standard** with criteria and requirements for circular products, as well as an **innovative software solution**. • Creation of a modular all-in-one solution that **connects systems** and **stakeholders along the entire product and life cycle**, to optimize product development, circularity, and recycling. • **Enables manufacturers** to integrate and scale circular products and recycling within their systems and business models

Digitalization	• Development of a software solution with automated decision support for circular product development (e.g., selection of suitable take-back systems and business models) and verification • Connection to the digital product passport circularity.ID for consumers • Digital networking of all partners through standardized data management
Project partners	• circular.fashion (Development of a holistic standard; system portfolio; software integration) • Hochschule für Technik und Wirtschaft Berlin & Hohenstein Innovations gGmbH (Development of a durability index & research) • Marc O'Polo SE (Associated industry partner; practical piloting) • Dachverband FairWertung e.V.; matterr GmbH; Gütegemeinschaft Verantwortungsvoller Textilservice e.V. (Supporting)

Source: (BMBF 2025)

Table 8: ZirTex – Modular Concepts and Circular Processes for the Protective Clothing Industry

Project description	• Development of a **platform** for the **textile protective clothing market** that enables **modular designs**, **individual configurations**, and **sustainability assessments**. • Objective: Custom-fit, comfortable protective clothing with extended service life and improved circularity.
Digitalization	• A **digital textile management system** (ZirTexCRM) records every item of clothing throughout its life cycle to **optimize circular process management** through repair, recycling, or repurposing. • Use of **user-specific body scan data** for the automated production of protective clothing from prefabricated modules. • **Digital recording** and **management** of **garments** over their life cycle via the ZirTexCRM system
Project partners	• ALSCO GmbH (Digital damage management) • Circular MTC e.V. (Environmental assessment and material flows) • Fraunhofer IWU (Innovative separation and recycling technologies) • Held GmbH (New business models for modular clothing) • Lions Spirit (Individual body scans) • TU Dresden; Müller Brandschutztechnik (Flexible body scan demonstrator for firefighter clothing) • DIN e.V. (Coordination; supporting with standardization) • Texulting GmbH (New business models for implementing the 10R strategies)

Source: (BMBF 2025)

Table 9: KISSTex – AI-Based Sorting of Used Textiles and Assessment of Wearability

Project description	• Development of an **innovative solution** for **sorting used textiles** using AI technology, multisensory data, and a highly precise robotic system. • The sorting process aims to replace existing inefficient manual methods and to **sort textiles efficiently** and **transparently according to wearability** and **recyclability.**
Digitalization	• Integration of **multisensory data** (optical and NIR sensors), **AI models** (including deep learning, Explainable AI, and federated learning), and **robotics** for **automated assessment and sorting** of textiles • Deep learning and Explainable AI ensure **transparent AI decisions**, while federated learning enhances **data protection**
Project partners	• Research institutes, including the "Institut für Textiltechnik" (Sensor technology and textile technical evaluation) • Companies such as Arnold IT (Robotics and pneumatics) • CarboScreen (Overall project coordination) • Hahn-Schickard-Gesellschaft (Algorithms and federated learning) • Carbon Minds (Ecological assessment)

Source: (BMBF 2025)

Table 10: ZirKuS – Digital artificial turf system with integrated management

Project description	• ZirKuS is developing a **circular** and **digitalized artificial turf system** with **integrated management.** • The goal is to **extend** the **life cycle** of artificial turf, use resources efficiently, and ensure recyclability at the end of use. • A **comprehensive monitoring process** is intended to ensure effective management of the turf system and determine the **optimal time for recycling**.
Digitalization	• **Digitalization** of the **entire product life cycle** of the artificial turf • Extensive **digital tracking** and **optimization** of the **turf's condition** throughout its entire service life

Project partners	• THINK TANK TECHNOLOGIES engineering & innovations • TFI Aachen e.V., Institut für Textiltechnik (ITA) der RWTH Aachen University • Hoffmann & Voss GmbH • Lömi GmbH • Labor Lehmacher | Schneider GmbH & Co. KG (LLS) • IANUS Simulation GmbH • LECO-Werke Lechtreck GmbH & Co. KG

Source: (BMBF 2025)

Table 11: zPP: – Circular, sustainable technical textiles made of polypropylene for the transport sector

Project description	• Development of **sustainable polypropylene (PP)-based textiles** for **technical applications** in the transport sector (e.g., car covers) • Creation of a "design-for-recycling" approach, including the use of **uniform materials.** • **Digital processes** aim to improve tracking of the entire product life cycle and facilitate recycling.
Digitalization	• Focus on **technological innovation** and **digitalization.** • Development of new technologies for the mechanical and thermal recycling of PP, preserving the material quality of the recycled fibres. • Development of a **digital process model** that maps the life cycle of the textiles across the entire value chain.
Project partners	• Interdisciplinary consortium with eight partners from industry and research, bringing expertise in fibre and textile technology, recycling, and process optimization.

Source: (BMBF 2025)

Table 12: UEBER-AUS – Utilizing Surplus and Scrap through Regional Circular Systems

Project description	• Exploration of various strategies for the **reduction** and **valorization** of **textile waste streams**, with a focus on post-industrial and pre-consumer waste. • Strategies include, for example, adaptations of business models and production processes, improved cascade use, tracking and recycling, as well as identifying new marketing channels for recyclates. • **Regional value** chains **connect key stakeholders** from science, production, logistics, and recycling, enabling economically and ecologically viable logistics solutions (e.g., through joint collection efforts).

Digitalization	• Planned **utilization of tracking technologies** for **improved monitoring** of textile waste streams. • Deployment of **state-of-the-art technologies** to optimize material flows in terms of sortability and recyclability, and to design efficient logistics concepts.
Project partners	• Hochschule Reutlingen, Hohenstein Innovations (Expertise in textile waste streams) • ifeu (Life cycle assessments) • IÖW (Business models and market analyses) • Südwest-deutsche Unternehmen der textilen Wertschöpfungskette: TEXOVERSUM Fakultät Textil (HSRT); Braun. Ku-Tex e.K.; Karl Conzelmann GmbH+ Co. KG; Polysecure GmbH; RÖKONA Textilwerk GmbH Co. KG (Empirical implementation)

Source: (BMBF 2025)

Annex D. Summary of UNEP's Report "Sustainability and Circularity in the Textile Value Chain: A Global Roadmap" (2023)

Roadmap:

- A roadmap provided by UNEP to guide all stakeholders toward transforming the global textile sector into a sustainable and circular model, applying a systemic value chain approach with over 140 textile value chain stakeholders to arrive at a common agenda for transformation.
- Builds on the analysis of UNEP's Global Stocktaking Report (2020) to address the environmental and socio-economic hotspots of the textile industry, while supporting people, prosperity, and equity.
    - This requires all stakeholders to work together and use their resources to achieve this common goal.

Priority areas: Three interconnected priority areas were defined to deliver systemic change in the entire textile value chain. This requires a coordinated approach by all value chain actors.

1. **Shifting consumption patterns**: Optimizing product design, business models and consumer behaviour to reduce pressure on production systems through reduced raw material demand and extended use phase.
2. **Improved practices**: Optimizing practices and behaviour in existing sites, companies and processes.
3. **Infrastructure investment**: Investing in shared physical technology and systems.

Building blocks: The roadmap dissects the three priorities into nine actionable "building blocks" to address environmental and socio-economic hotspots in the textile value chain, aligned with industry goals. It further outlines priority actions for each stakeholder to collectively drive a circular and sustainable transformation.

1. Global adoption of sustainable and circular textile business models.
2. Addressing textile overconsumption and overproduction.
3. All textile products are designed to minimize impacts and support circular models.
4. Better product care reduces impacts and improves product durability.
5. The textile value chain drives resource efficiency and eliminates production pollution, production waste, on-site fossil fuel use and chemicals of concern.
6. A just transition with skilled, safe, and empowered people takes place, and social issues in the textile value chain are addressed.
7. Textile raw materials are shifted to sustainable or recycled sources.
8. Significant improvements in shared infrastructure are made globally for a sustainable and circular textile value chain.

All textile waste is diverted from avoidable landfill and incineration.

Stakeholder-specific annexes: The roadmap includes seven annexes for key stakeholder groups. Each appendix outlines priority actions aligned with the nine building blocks, such as:

- **Brands & retailers**: New business models, sustainable revenue generation, design for circularity.
- **Policy-makers**: Circular policy instruments, investments and funding, policy design consultation, and stakeholder coordination.

- **Raw material producers & manufacturers**: On-site improvements, innovation for impact reduction, protect and empower workers, drive systemic change.
- **Innovators & recyclers**: Provide circular offers and technologies, accessible and scalable solutions, plan for market realities.
- **Non-governmental, representative, and technical organizations**: Advocate for rapid action from industry and policy-makers, provide priorities, and stakeholder collaboration.
- **Communication and consumer engagement actors**: Fostering behavioural change, differentiation between consumers, drive shifts in consumption narrative.

(Source: UNEP 2025c)

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