André Matthes · Katja Beyer ·
Holger Cebulla · Marlen Gabriele Arnold ·
Anton Schumann *Editors*

Sustainable Textile and Fashion Value Chains

Drivers, Concepts, Theories and Solutions

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Foreword by Dr. Maria Flachsbarth

Dear Readers,

Fast, cheap and always dernier cri—that is fast fashion. Affordable clothing that is produced in short fashion cycles has been in existence since the 1990s, led by brands that specialize in this. Through globalization, competitive pressure has increased and the production of clothing has moved from Germany to lower-cost places abroad, often in emerging economies and developing countries.

Today, garments are produced in dozens of stages across multiple countries. The garment and textile industry is globally integrated; value chains are complex. A simple T-shirt often travels up to 18,000 km before it ends up in a store in Germany.

This development towards a short-lived, high-competition, resource-intensive industry has massive impacts on humans and the environment. High levels of raw material, pesticide, water and energy use constantly enlarge the ecological footprint of textile production. And yet many garments are thrown away after having been worn just a few times.

Fashion must become more sustainable! In times of increasing resource scarcity and climate change, we can no longer afford the type of fast fashion we see today. There must be global compliance with social and environmental standards. We can only achieve that through cooperation. The Federal Ministry for Economic Cooperation and Development (BMZ) therefore works with German and international partners and with organizations such as the International Labour Organization (ILO) in order to improve conditions on the ground. In addition to supporting environmental, chemical and water management, we also work for living wages, decent working hours, strengthened labour rights and the elimination of child and forced labour.

In October 2014, German Development Minister Gerd Müller launched the partnership for sustainable textiles. Together with some 130 partnership members from the textile and garment industry, the retail sector, labour unions, non-governmental organizations and standards organizations, we are working to bring about sustained improvements along the textile supply chain.

The scientific community has a special role to play in developing resource-saving technologies. So I am pleased that Chemnitz University has decided to expand its focus on sustainability and its Textile Technologies Professorship.

Our cooperation has already borne fruit: together with Chemnitz University, the BGMEA University of Fashion and Technology (BUFT) and the University of Liberal Arts Bangladesh (ULAB), we have made sustainability a focus of textile programs at institutions of higher education in Bangladesh. Moreover, we have jointly launched research projects on textile technologies in cooperation with industry in Bangladesh.

The present book is an important contribution to improving resource conservation in the textile industry. It shows how vital issues such as environmental technologies and a circular economy can be addressed in textile production. These issues will play a growing role in the textile and garment industry in the future.

Berlin, Germany

Dr. Maria Flachsbarth
Parliamentary State Secretary to the
Federal Minister for Economic
Cooperation and Development

Foreword by Mauro Scalia

Dear Readers,

Never like in our modern times, the textile value chain is being driven to come together and deliver new solutions.

Our world society keeps growing at the speed of approximately 1 Billion people every generation and through the consumption of, generally, more resources. That is why we need changes applicable at large scale and across borders.

Decoupling growth from resource consumption while acting in law compliance appears to be the most logical option to benefit the environment, the people and the businesses.

Recently, and for three years in a row, the world witnessed decoupling of CO_2 emissions from economic growth. A combination of increased efficiency, pressure and diffusion of new technologies has enabled global growth without releasing more emissions in the atmosphere.

While this unprecedented virtuous trend froze in 2017, decoupling has shown an example, namely how policy and market factors can lead to structural changes in the global energy system. Crucial for this success was the involvement of the major world players, government and business alike.

What about the global textile system?

Manufacturing of textile products appears to operate in one of the most complex, mutual-dependent and diverse industry value chain. Within the EU only, 176.000 companies, mostly SMEs, deliver an amazing variety of textile products, from a T-shirt to a jet turbofan engine parts. Textiles are more than garments, textiles wear people, homes and other industries alike.

The world textile industry is large, ruled by different market cost pressures, and operates in very diverse regulatory frameworks. Researches carried out in Western regions show growing segment of consumers fancying sustainable textile goods made with sustainable processes. However, little or no evidences are available of the average world buyer opting for less items or more expensive products.

The calls for rethinking the global textile value chains are loud and boosted by society and workers organizations, by international policy agenda, responsible businesses and conscious consumers. These calls include unusual cooperation as shown in the first *Joint Industry Manifesto*[1] and ask for unprecedented partnerships to boost sustainable purchasing practices, to create a demand for circularity of products and processes, to deliver world chemical management systems and test traceability.

Today, the challenges still outnumber the solutions, yet spontaneous partnerships across the textile world are showing what can be done, using the best combination of textile resources of energy and creativity. This offers the basis for unprecedented level of interaction and a new form of dialogue between policy actors and market players.

This book addresses sustainability in textile and fashion value chains from an interdisciplinary and holistic viewpoint. It provides deep insights into sustainable textile process chains and shows how these can be transferred into a functioning recycling economy. In particular, combining scientific articles and practical reports, the readers experience close at hand the overall complexity and vivid current discussions about opportunities and challenges in the context of textile sustainability.

In this sense, the book significantly contributes to mirroring a much needed new business development based on the guiding principle '*Sustainability is the new Quality!*'.

Brussels, Belgium

Mauro Scalia
Director, Sustainable Businesses at
European Apparel and Textile
Confederation, EURATEX

[1]Simultaneously announced in Frankfurt and Copenhagen in May 2019 by EURATEX, FESI, GFA, IAF and SAC, it is the first joint declaration representing the world garment value chain from fibre to retail.

Foreword by Karla Magruder

Dear Readers,

Sustainable Textiles and Value Chains is a book the textile industry needs. It is a book that will be useful to both students and industry professionals who need to gain an understanding of the push for more sustainable systems within the textile value chain. These systems include everything from raw material developments through consumers and end of life choices for textiles. The variety of topics covered will provide facts and information for interested parties to see current capabilities along with those that are missing. Hopefully, it will encourage its readers to see areas where the industry needs to make progress and where they need to advance more sustainable initiatives in their own area of expertise. This book should also be a reminder that no one system will solve the textile industry's social, environmental and economic issues. We will need to use all the solutions that have science and facts behind them. Using a variety of tools will provide the progress that supports significant changes, thereby allowing for an industry that contributes positively to the global community.

Hoboken, NJ, United States

Karla Magruder
Founder, Fabrikology International

Acknowledgements

The world is for change, not for endurance.
—Harald Welzer

In 2017, the editors launched as a team the Sustainable Textile School (STS) in Chemnitz, Germany. The primary objective of the congress was and is to develop a science-based exchange of knowledge, ideas and experiences regarding sustainable production and sustainable business models for the value creation stages of the global textile industry. Almost 100 participants from 30 nations were enthusiastic about the committed, fruitful discourse on important and urgent topics in the textile industry among educational institutions, companies, governmental authorities and international organizations.

Under the heading 'Sustainable is the new quality!', sustainability was not only enhanced by the STS as a topic for the communications department, but also as a topic for product developers, engineers and supply chain managers and scientists. The third conference in the series was held in Zurich in 2019 as the World Textile Forum. Concerned with addressing sustainability and digitization, the forum reflected and further developed the editors' founding spirit of providing a knowledge exchange platform. The 2019 forum brought together global industry leaders for discussing business transformation by incorporating new and digital technologies.

Passing the current knowledge to a larger circle of interested people in the field of textile sustainability is the main goal of this book. With this in mind, the book primarily addresses scientists and established companies by featuring a great variety of topics and issues relating to a sustainable and systemic transformation of the textile industry. Thereby not only findings from recent scientific studies are covered, but also various practical experiences from business and management experts as well as consultants in the global textile industry.

We, the editorial team, would like to say thank you to all the contributors who made this book possible by sharing their insights, research and practical activities. We are also very grateful to our Parliamentary State Secretary to the Federal Minister for Economic Cooperation and Development Dr. Maria Flachsbarth, Mr. Mauro Scalia, Director Sustainable Businesses from EURATEX and Ms. Karla Magruder, Founder and President of Fabrikology International, for their introductory words to this book. It is an honour for us and a signal for urgent and ground-breaking changes in the textile chain. We also thank Springer that made our work possible and publishable. Finally, we thank the many helpers, especially Simon Fronczek, Marcus Krahl, Sabrina Schmidt, Denise Pircher and Sören Jonas, and all the helping hands from the editors' teams.

About This Book

Part I—*Designing Sustainable Fibres and Fabrics*—focuses on material innovations as they will fundamentally change textile processes. With the advent of synthetic fibres in the 1960s, such a transformation process was already completed. The new manufacturing technologies and the changed properties of the fibre material forced the manufacturers of all subsequent processes to make extensive adjustments in the textile formation processes and, above all, in the finishing and dyeing area. In the new millennium, the challenge now is to develop new materials and design fibre combinations in such a way that healthy, safe and recyclable textiles are created that allow circularity. At the same time, this requires a deeper understanding of the interdependencies.

In their study, Seisl and Hengstmann give an insight into the different **man-made cellulosic fibres (MMCF)** and especially their **manufacturing processes**. This fibre group currently represents one of **the most promising sources of sustainable fibre materials** produced from renewable raw materials. MMCF, such as viscose/rayon, lyocell and modal, but also cupro and acetate, are the second most important group of cellulose-based fibres after cotton. The pulp used for MMCF production, however, currently mostly comes from controversial or illegal sources and is converted into fibres in a water-, chemical- and energy-intensive, multi-stage process using highly toxic chemicals. The authors argue for more sustainable procurement of raw materials for pulping and more sustainable production processes for MMCF, including wastewater, solid waste and air emissions. It presents approaches on how alternative raw materials, textile waste before and after consumption, but also non-textile raw materials such as agricultural residues or even liquid manure are used to produce cellulose.

The second contribution by Haverhals shows how a young start-up from the USA with a revolutionary idea is taking the **demands for global circularity** a step further. The **new manufacturing platform uses renewable natural resources**—including recycled cotton—**to produce durable textiles** that are superior to established petroleum-based synthetic fibres because they feel good on the skin. Particularly noteworthy is the fact that the patented **closed-loop** manufacturing solution offers low unit costs. They thus facilitate a new circular flow economy that (re)uses natural, sustainably produced inputs at regional levels. NFW is currently building a new textile factory near Chicago to prove that circularity and regional textile recycling are possible.

The third article presents Haegbloom and Budde's most important drivers for the creation of a **systemic change towards a genuine recycling economy in the textile sector**. The aim of their company is to create a clever, innovative and responsible system in which resources are kept in circulation at maximum value for as long as possible. **Recycling requirements** must be translated into design strategies and material decisions to ensure fibre-to-fibre recycling and waste design from the outset. In order to achieve real collaboration on system changes, there should be collaboration between all stakeholders involved in the fashion supply chain. The Circular.Fashion system connects material suppliers, designers and brands, consumers and recyclers to ensure that every step positively influences the circular fashion systems.

The chapter concludes with a short practice report on the production of **non-violent silk** by Prakash and Matthes. It shows how **an enduring commitment to a structurally weak region** can foster the creation of **sustainable silk products** for the European market, thereby improving the living conditions of the simplest farmers in India and at the same time preserving the natural metamorphosis process for silkworms.

Part II—*Sustainable Sourcing in the Textile and Fashion Value Chain*—encompasses three contributions. The textile and fashion industry features complex structures and globally interlinked supply chains with multiple players. The increasing competitive pressure associated with the fast fashion business model has led to unsustainable practices along the supply chain, resulting in negative environmental and social impacts. In recent years, pressure has increased on the industry to address these issues, particularly on retailers and apparel brands. As a result, sustainable procurement practices have become increasingly important in addressing sustainability issues; and thus, the purchasers of multinational retailers now take into account not only price, delivery time and quality, but are increasingly obliged to take social and environmental considerations into account in their decisions. In their study, Koep et al. give an overview of **traditional and sustainable purchasing practices** in the textile and clothing industry. Proposals will be made as to which additional elements should be taken into account. Thereby, the authors call for a **more comprehensive approach to sustainable procurement** in the textile industry.

While the textile sector is growing and producing more and more articles, the quantities and variety of chemicals used as building blocks or functionalized as products are also increasing. This development has more than ever a global dimension. On the one hand, it leads to socio-economic development in the Global South. On the other hand, these processes are accompanied by major sustainability challenges across different spatial and temporal dimensions. The importance of chemicals for the textile sector and the current approaches to **chemical risk management** are presented and discussed in the article by Keßler and Kümmerer. The authors illustrate the specific characteristics of the sector that represent the current sustainability challenges related to chemicals in textile production. A particular emphasis is put on the concepts of **green and sustainable chemistry**, which open up new perspectives for the production, use and management of chemicals in the textile sector. The properties of green and sustainable chemistry and their specific application potential in the field of textile chemicals are described and highlighted. Moreover, various green and sustainable chemistry practices show the current efforts of the sector itself and of science to provide concrete examples on the one hand and starting points for further innovations on the other.

The quantity, nature and processing conditions of chemicals have a significant impact on environmental performance as well as on occupational and consumer safety. For this reason, chemicals management should be focused on the essentials and approached jointly and in a coordinated manner. The contribution by Schäfer and Herter examines the extent to which **input-oriented chemicals management** represents a solution for the highly complex and apparently impenetrable global textile supply chain. The relevant stakeholders—chemical suppliers, textile manufacturers and brands—are defined by their tasks and interactions within the supply chain. In addition, instruments for chemicals management and their effectiveness are explained. Those tools can range from **compliance with legal requirements** to voluntary measures such as testing and a system-oriented approach. In particular, the study defines the basic elements of a system-oriented approach by assigning responsibilities to stakeholders for the selection and use of textile chemicals. A positive list of the analysed and evaluated textile chemicals is introduced as an efficient tool. It becomes clear that the **concept of 'product responsibility**' and its consistent implementation throughout the textile supply chain is the key to an increasingly sustainable textile production. All players in the supply chain must be prepared to tackle alternatives and pursue a chemical management strategy that goes hand in hand with chemical change management and encourages companies to think one step further, reconsider and above all not think in the short term.

Dyeing processes or wet processes, in general, determine the sustainability balance of a textile end product to a considerable extent due to the heavy use of synthetic chemicals. Almost 20% of global wastewater is produced by the fashion industry. A large proportion of this is still discharged unfiltered into rivers in the producing countries. In particular, the contamination of process water with substances that are more or less harmful to humans as well as to animals and plants increases the risk of secondary diseases among the people living there and the extinction of species.

Part III—*Sustainable Production in the Textile and Fashion Value Chain*—focuses, as a small excerpt from the various production processes, on the particularly ecologically critical dyeing processes and the resulting wastewater treatment techniques: firstly, in the form of a general overview of the prevailing processes, and secondly, as a scientific study of the effectiveness of sustainable innovation. Thirdly, the developments towards sustainable jeans production are illustrated.

Höhn provides a systematic overview of the methods for avoiding, minimizing, reusing and purifying may in the textile finishing industry in his contribution. The focus is set on the **purification of dyestuff wastewater**. The article excellently shows the current state of the art and represents a clear addition to the conventional methods based on generally accepted rules of technology. Methods are presented, which may be used on a pilot or even laboratory scale. Furthermore, the article summarizes the **current wastewater situation and the legal situation** in Germany dealing with the criteria for small and medium-sized enterprises as well as indirect and direct importing enterprises. The used processes or combination of processes depend on the respective operating and wastewater situation. For a tailor-made solution, the specific technical, economic, environmental and legal aspects must be taken into account. This is the only way to achieve the goal of minimized wastewater costs and even positive amortization by suitable wastewater specialists after a thorough operational analysis.

Stimulating consumer awareness of the sustainability balance of differently coloured clothing is a simple step that has a great relief effect. Unfortunately, it is not generally known that dark colours, in particular, contribute to the environmental impact of the dyeing process, and thus, to the end product. Here, the consumer could just as easily improve his ecological footprint as he could by avoiding disposable, single use coffee cups. Another possibility to reduce environmental influences is process innovation through new natural-based colouring substances or the clever use of natural materials for the purification of waste water.

In Bagiran's study, the removal of pollutants from the wastewater of a **denim washing plant using pumice stones** is presented, thus, making it possible to use process water in the cycle. The idea is to **utilize the adsorption effect of the pumice stones** through their large surface and thus purify the wastewater from the dyeing liquors. The study shows the water treated in this way has the potential to be used several times in the dyeing of jeans.

Imagining a world without jeans clothing seems impossible these days. Blue jeans have achieved a global presence. Jeans have become a popular garment worldwide and a fixture in the trendy, ever-changing fashion world. Consumer demands for performance, style, fit, weight and design have completely changed the denim business. **The denim industry** as a whole has undergone a major transformation in recent years, attempting to elaborate sustainable and environmentally responsible practices throughout the life cycle of products, from the cradle to the end of their life. New and sophisticated technologies and methods are developed and applied to reduce negative environmental impacts without compromising on trends and aesthetics. Chaboune's contribution describes the practical experiences she has gained during her many years of activity in the field and in which she herself has played her part in changing the processes. **Disruptive technologies, new waterless dyeing and finishing processes, innovative fibre blends**, product innovations and increased efficiency have significantly reduced the previous negative effects of denim and jeans production.

With fast fashion, the textile and clothing industry exploits enormous amounts of resources for satisfying its needs, thereby impelling mass production and accelerating trends. As a consequence, these resources leave their textile use phase in ever shorter time spans and end up in garbage disposal. In Germany, for example, although there is a well-developed collection system for old textiles, more than

300,000 tons of old clothes are still thrown away into the garbage. The aim must therefore be to reduce the overall amount as quickly as possible by better recycling in a closed-loop system.

Part IV—*Sustainable End-of-Life Concepts and Strategies in the Textile and Fashion Industry*—focuses on the challenge of textile waste streams and recycling efforts by covering three contributions.

Gloy and colleagues discuss in detail in their article the **existing process chain for the treatment of old textiles**. For this purpose, the **material flows** of textile wastes in Germany and the quantities currently processed are presented. In addition, the authors introduce concrete used **textile sorting systems** with their crate and belt sorting systems and discuss the **technologies and machines** currently available. Moreover, the materials that are typically produced as the **output of a recycling plant** are characterized. Their main areas of application and the resulting quality requirements are highlighted. Another section is devoted to the **recycling of carbon fibre** waste, which will increase in the future as a result of technical applications. Due to their high consumption of resources, in particular energy, recycling appears to be extremely desirable and necessary. Finally, an overview of the latest research projects in the field is given.

The study by Turnball and colleagues offers a qualitative assessment of the **current post-consumer waste models**, the **recycling streams** and the challenges associated therewith. This includes an evaluation of **new innovations in recycling technologies** and a discussion on the viability of integrating such innovations into current economic models. For example, the authors explain in detail the **requirements for improved sorting techniques**. Future changes are particularly necessary in the procurement behaviour of brands, textile producers and consumers. In the future, innovation will not only focus on the technological side, but will also be necessary in the social field. In particular, **changes in consumer behaviour** are necessary to enable the textile industry to achieve a **circular economy** in the future. In addition, it will be essential to adapt the processes that are largely established in Europe to those in emerging and developing countries. In this context, the authors point to the importance of establishing **regionally adapted circular models**, thereby also considering the respective natural environments as well as production conditions.

In his contribution, Ahmed describes the **nature of consumer engagement** in various phases of the textile value chain. The author qualitatively examines whether the traditional form of commitment is detrimental to achieving environmental sustainability. The study aims to identify those consumers who can support sustainable textiles. In doing so, the study evaluates the current literature on the integration and **role of consumers in the textile value chain**. It states that consumers are primarily involved in three stages of the textile value chain, namely the purchasing decision before consumption, the care of consumer products and the **disposal habits after consumption**. The study shows that over-consumption of particularly cheap, inferior, unsustainable and fast fashion products impairs environmental sustainability. In line with this, the research highlights the **benefits of**

purchasing slow fashion products, sustainable ways of product care and virtuoso practices of reuse and recycling.

Part V—*Sustainable Business Models and Communication Strategies*—encompasses three contributions, which address new ways of implementing innovative business models for sustainability and stress the need for a clear communication towards sustainability in order to change consumption patterns. The first article provides scientific insights into sustainability communication and is followed by two practical perspectives on innovative communication strategies and circular business models.

The global textile and fashion industry is related to many problems such as unsafe working conditions and immense negative environmental impacts. A transformation of the industry requires organizational shifts, changes across multiple levels of the textile and fashion value chain as well as changes in consumption patterns, including new strategies for dealing with the information and knowledge deficits in the market. Morris and colleagues discuss **labels in the textile and fashion industry and the role of communicating sustainability to effect sustainable consumption**. The authors propose awareness and information strategies, such as sustainability labelling, as a crucial step in promoting sustainable consumption through improved information provision. They argue for a facilitation of institutionalized shifts towards an embedment of sustainability criteria into consumer decision-making processes.

Innovative communications strategies towards sustainability in the textile industry also require an **individualistic, human-centred orientation**. In this regard, the role of transparency and traceability in the global textile and fashion industry may be seen as a prerequisite of the sector's transition. Along with advancing digitization, **changes in consumer behaviour** as well as an **increase in awareness and consciousness** may be promoted. From the perspective of textile companies, datafication processes may harbour new opportunities of sustainable value creation, thereby fostering corporate social and ecological responsibilities. In this regard, the contribution by Tamborrini and colleagues focuses on a **data systemic and communicative approach** in the global fashion industry proposing an information flow strategy based on data and information processing technologies. Transforming the entire industry towards textile circular systems requires the integration and coupling of a wide range of information and data within and beyond the textile and fashion system. In doing so, the authors propose a '*Systemic Innovation Design*' as a way to organize a significant and comprehensive data set structure, redefine processes and design customized products based on **transparency, interconnectedness and circularity**.

Circular business models can generate new value by including sharing, product life extension, resource recovery, circular supplies and product as a service. The contribution by Bassett argues that current business models of the apparel industry have contributed to harming people and the planet. In particular, in her article on **sustainable fashion through circular business innovations,** she criticizes the linear approach of economy relying on raw materials to generate financial value, but driving down wages and cheaper practices to access raw materials in order to generate more revenue. She sees a new opportunity to accelerate sustainability in the industry by a shift towards circular business models. So, she calls for emerging leaders to create new circular business models, thereby changing the way apparel is bought and sold in order to increase the sustainability of the apparel industry.

Part VI—*Behavioural and Societal Aspects in the Textile and Fashion Value Chain*—provides the framework for three contributions.

Rathinamoorthy grounds his research in the fact that the most popular and dominant paradigm in the global fashion industry currently is the **fast fashion system**. This system, driven to extremes by fashion companies, motivates customers to consume more than they need. Rapid fashion changes, weekly new collections and falling prices are encouraging them to dispose of their garments more often than necessary, increasing the amount that is still landfilled in most countries. Many initiatives and strategies have been developed and implemented in society by various governments and private organisations around the world in order to enhance the sustainable production and use of clothing. One of these sustainable approaches is the '*Slow Fashion*' concept. The article focuses on this by analysing and discussing various obstacles and **challenges in the implementation of slow fashion on a large scale**. In doing so, a survey was conducted **among the '*Generation Z*' in India about their environmental awareness, their purchasing and disposal behaviour** and the slow fashion concept. The results of the study show that consumers especially in India appear to not have sufficient knowledge about the environmental impact of clothing products. The preference of fast fashion products is mainly based on their behaviour such as the latest trend, personal lifestyle and fashion knowledge. The results, however, also show that respondents are concerned about environmental problems and are willing to adapt purchasing decisions under certain conditions in order to facilitate change in the textile industry.

In their report, Siddique et al. focus on the development of the **textile industry in Bangladesh**, which in recent decades has been more accompanied by an increase in capacity for clothing production and thus jobs in the textile industry than by **sustainable development in the country**. Bangladesh is one of the countries in which the actual costs of consumer behaviour in industrialized countries are absorbed by workers in textile factories. In recent years, particularly after the devastating Rana Plaza factory collapse in Dhaka in 2013 and other major fires causing numerous fatalities, several steps have been taken in the field of textile technologies to reduce the burden on the environment and workers. Several measures have been implemented to **improve the working conditions and safety of textile workers**. Yet, there is still a long way to go before workers will sustainably benefit from the increasingly growing textile industry in Bangladesh.

In a similar vein, the article by Beyer and Arnold also deals with the fact that the global textile industry is typically confronted with a **negative image due to ethically questionable working and procurement conditions in predominantly Asian low-wage countries**. The collapse of the Rana Plaza building in 2013, the DETOX campaign by Greenpeace as well as the promotion of alternative business and economic strategies in the textile industry by NGOs and scientists mainly affected companies such as H&M, but not exclusively. This spurred a change in corporate strategies as regards the **communication of sustainability** activities and strengthened engagement in multi-stakeholder initiatives to improve social and environmental sustainability in sourcing and producing countries. At the same time, circular approaches have been emerging which, however, focus mainly on economic and environmental sustainability. Thereby, the concept's current application largely disregards the social dimension of sustainability and the systemic change that is particularly necessary in the textile industry. In their study, the authors examine how the discussions on **circular approaches and business models for social sustainability** in the textile industry developed in parallel in theory and practice between 2008 and 2017. The research uses a **systematic software-based qualitative literature analysis** and highlights the vivid example of the fast fashion retailer H&M. The study's results emphasize the increasing importance of circular business models in the textile industry and, thus, a change in communicated corporate activities towards increasing sustainability in the textile sector. However, the authors note that social aspects are particularly underrepresented in scientific publications on the circular economy.

Part VII—*Sustainability and Systemic Approaches in the Global Textile and Fashion Industry*—encompasses four contributions which coincide by employing primarily a **practical view** on sustainability and systemic changes in the global textile and fashion industry based on best practice and case examples. Given severe ecological and social challenges and risks of the global textile and fashion industry sustainability as well as the sector's global reach, a **macro-level perspective** on this sector entails a joint vision on aspects relating to the **perceived ethicality, and integrity** as well as **governance of actions, decisions and behaviours** among *all* involved. One fundamental question in this context, thus, relates to *how* business is actually done in the global textile industry and *how* textile companies achieve their goals. The article by Ravasio builds on this premise and discusses the '*Fair Process Leadership*' model and its application against the specific background of the global textile industry. The author highlights the relevance of aspects primarily relating to **social sustainability** in this particular sector such as transparency, communication, fairness, organizational routines and processes when assuming leadership and (personal) accountability. According to her, the sound application of the '*Fair Process Leadership*' approach at both strategic and operational levels may eventually improve overall (organizational) performance of textile companies, among others.

Against the background of enormous textile wastes across the globe, circularity has been considered a key trend for systemic changes in the global textile and fashion industry. In this regard, the chapter features two more contributions primarily focusing on textile circularity. The first study by Hall and Boiten primarily adopts a **technological and business view on recycling and circular economy** in the textile industry. The authors focus on the EU H2020-project '*Resyntex*' in order to illustrate the industry's need of advancing the development of **innovative recovery and processing technologies** to depart from landfill and incineration. In doing so, they adopt a '*Strategic Investment Decision-Making*' perspective to assess the technology's business case and market potential. One major result of their study is the critical role of **stakeholder engagement** throughout the value chain to capture secondary raw materials and alternative revenue streams from valorizing textile waste. At the same time, the authors point to **process efficiency or IP exploitation** as only two of several strategic consequences likely to influence technology scale-up and commercialization.

Another contribution relating to circularity by Kumar and colleagues refers to the **international dimension** of sustainability and the capability of **multiple stakeholders and industry initiatives** to drive transition processes in the textile industry. By focusing on one of the largest textile and apparel manufacturing nations globally, the authors point to the multiple influences, mandates and obstacles both at a national as well as an international level that become apparent in India's textile and apparel sector and its efforts concerning implementing sustainability and circularity. The authors focus on the only recently launched '*Circular Apparel Innovation Factory (CAIF)*' which promotes **new collaboration models and innovation infrastructure** including process facilitation and capacity building between various players in India's textile and apparel sector to explore circular solutions and to overcome the sector's inherent supply chain fragmentation. The authors also highlight the initiative's potential to promote the creation of an **ecosystem for circular apparel and circular innovators across the supply chain** based on social aspects such as mutual dialogue, interaction, knowledge exchange and partnerships while recognizing India's particular local context.

Schumann et al. emphasize **digital platforms as future drivers** in the textile industry towards more sustainability. They argue the textile manufacturing industry is just beginning to embrace digital, sustainable and circular business models, and these trends are already boosting one another. The authors are sure that digitalization will expand the opportunities of **a sustainable global textile supply chain through transparency, real-time communication and predicted demand**. The real-time textile supply chain will be able to cut out inefficiencies as intermediaries, certifications and wasting of resources and materials, and thus enhancing the transparency of supply chains for resource- and cost-efficient business models.

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Part I
Designing Sustainable Fibers and Fabrics

Introduction

Material innovations can affect the entire fashion system as they have an impact on processing, use and recycling. Although we are permanently surrounded by textile materials, we often find it difficult to understand them and their influence holistically. Healthy, safe and cyclable material innovations are necessary to implement circularity, but a deeper understanding of interdependencies is also required.

A fibre is a linear, elementary structure. Fibres are the basic component of all textile materials, which is why their selection, treatment and modification play a central role in the sustainability of a textile end product. In addition, the type of fibre influences all surface formation processes, which must also be adapted to the specific fibre. The fibres to be used therefore play a central role in the design process of textile products, especially when it comes to designing cyclable textile products.

Natural fibres still offer the best properties for wearing comfort and "feeling" in the clothing sector. Due to limited capacities, however, the use of natural fibres can hardly be increased. Cotton only grows under specific climatic conditions, and the ecological and social consequences of genetically modified seeds, the use of pesticides and, above all, the immense consumption of water during cultivation are serious. Similarly, the production of fine wool suitable for clothing is limited to few regions of the world. The "highly functional" wool fibre is currently in great demand due to its diverse functions. However, this is mainly reflected in price increases as capacity expansions are hardly possible, especially for the most frequently used merino fibre. A worldwide search for alternative natural fibres is currently in progress. The fibre materials previously used in various regions of the world will be reassessed. The most important of these are hemp, flax and nettle fibres as well as pineapple, kapok and other exotic fibre materials. However, their economic use requires research and investment in new equipment in order to make them more competitive with cotton and synthetic fibres. China, for example, currently sees opportunities to reduce its dependence on cotton primarily by expanding the use of hemp fibres.

In the synthetic fibre sector, polyester and polyamide fibres have gained acceptance in many areas due to their very low fibre price and some very advantageous properties such as abrasion resistance and moisture transport. The worldwide demand for fibres can no longer be met without the use of synthetic fibres, especially as consumption continues to grow in threshold and developing countries with very large populations. Recycled fibres are slowly conquering various markets, as they can now take up the price war with the still extremely cheap virgin fibres through efficient plants. Especially in the outdoor sector, a strong growth can be seen and announcements by major sport equipment manufacturers to only use recycled materials by 2025 promote process innovations in this area.

Fundamental fibre developments in the bio-based fibre sector are also expected in the coming decades. The large spectrum of possible starting materials such as a wide variety of vegetable oils or algae species that can be produced in almost unlimited quantities indicates that new competitive fibre materials can be expected in the future.

One of the most interesting areas at the moment is the MMCF. Cellulose fibres score with their good biodegradability and high wearing comfort. With the development of the lyocell process, sustainable production with the recovery of the harmful chemicals in the process is also feasible. Current efforts are primarily focused on the use of residual materials from various areas as a source of cellulose for lyocell production.

In the following chapter Seisl and Hengstmann give an insight into the different man-made cellulosic fibres (MMCF) and especially their manufacturing processes. The subsequent article by Luke Haverhals shows a revolutionary idea that uses renewable natural resources—including recycled cotton—to produce long-lasting textiles that feel good on the skin. Haegbloom and Budde present in the following article which intelligent, innovative and responsible system is to be created in which resources are kept in circulation as long as possible and at maximum value. Finally, Prakash and Matthes report on how the production of non-violent silk can be a social commitment for a structurally weak region.

Chapter 1
Manmade Cellulosic Fibers (MMCF)—A Historical Introduction and Existing Solutions to a More Sustainable Production

Simone Seisl and Reiner Hengstmann

Abstract Forecasts of the use of manmade cellulosic fiber (MMCF) like viscose suggest a rise in the next few years, due to its performance and price compared with other fibers. MMCF, such as viscose/rayon, lyocell and modal (as well as cupro and acetate), are the second most important group of cellulosic fibers after cotton, with an average annual demand of 5–6 million tons. MMCF is produced from natural feedstock such as trees and plants using a chemical process, unlike cotton. Recent reports from non-governmental organizations (NGO), like Canopy. On the nature of viscose production, covering the sourcing and origin of feedstock, the threat to endangered species and environmental pollution created by the pulp and fiber production process, raised awareness among textile and apparel companies. Dissolved pulp used for MMCF production, sometimes from controversial or illegal sources, is transformed or regenerated into fiber by a water, chemical and energy intensive, multiple step process using highly toxic chemicals. Although the process is more than 100 years old, the industry still relies on the very same kind of toxic chemicals considered dangerous for the environment and humankind. The production of lyocell fiber uses a different chemical process which is considered eco-friendly. In their 2017 and 2018 reports, the Changing Markets Foundation claim that the Viscose industry is using non-sustainable feedstock and that fiber production in Asia heavily pollutes the environment and is endangering human health. One life cycle assessment (LCA), commissioned by the brand Stella McCartney, evaluating the impact of ten different variants of MMCF global production, it was concluded that the current viscose production system carries very different but serious risks. All this underlines the need for a more sustainable sourcing of feedstock for dissolving pulp as well as more sustainable production processes for MMCF that include alternative feedstocks, better control and efficiency of inputs as well as a better management of the manufacturing process, including waste water, solid waste and air emissions.

A practitioner's perspective

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Alternative feedstock and recycled feedstock include pre- and post-consumer textile waste but also non-textile feedstocks such as agricultural residues or even manure. So far alternative feedstocks play a marginal role. Even though technologies seem ready, a significant investment is required scale them to a commercial level. The following chapter will reflect on the pros and cons of MMCF production processes and will provide some possible solutions to a more environmentally friendly future for MMCF. This chapter cannot claim to be complete nor comprehensive. In a constantly evolving industry, we highlight some relevant innovations where industry success and scaling potential still needs to be proven. It is imperative that more scientific data on sustainability attributes and impact on the environment, through independent LCAs, for example, need to be gathered in order to allow assessment and better comparability.

Keywords Manmade cellulosic fiber · MMCF · Viscose · Modal · Lyocell · Cupro fiber · Acetate fiber

Abbreviations

MMCF	Manmade cellulosic fiber
NGO	Non-governmental organization
GRS	Global Recycling Standards
CS_2	Carbon disulfide
H_2S	Hydrogen disulfide
NMMO	N-Methylmorpholine N-oxide
ZDHC	Zero discharge of harmful chemicals
BAT	Best available technique
LCA	Life cycle assessment
R&D	Research and development
NaOH	Sodium hydroxide

1.1 A Historical Overview—Manmade Cellulosic Fibers

Manmade fibers are fibers where the basic chemical units have been formed by chemical synthesis from crude oil followed by fiber formation or are made from carbon, ceramic, glass or metal. These fibers are called manmade synthetic fibers.

Manmade fibers can also be obtained from polymers of natural sources after dissolving and regenerating subsequent to passage through a spinneret to form fibers. Such fibers include viscose, lyocell, modal, acetate and cupro and are generically known as manmade cellulosic fibres (MMCFs).

Due to the increasing need for silk in order to serve the growing demand for silk textiles, scientists around the world tried to develop a material with similar characteristics to silk but that was less expensive in an attempt to become independent from the Chinese and Indian silk market. In 1664, the English naturalist Robert Hooke published a theory that artificial silk filaments can be spun from a substance which is similar to the one silksworms use to make silk. Based on Hooke's theory, scientists (Swicofil 2018) tried to develop an artificial silk, but no one succeeded. It took another 200 years until George Audemars discovered the first crude artificial silk around 1855 by dipping a needle into a liquid mulberry bark pulp mixed with gummy rubber. However, since this method was slow, it never developed on commercial scale. Thirty years later Hilaire de Charbonnet, a French chemist, patented an artificial silk which was the first known cellulose-based fabric. Although attractive to look at and comfortable, it was very flammable and therefore removed from the market (Bellis 2008). The British inventors Charles Cross, Edward Bevan and Clayton Beadle finally developed and patented a methodology for producing artificial silk that came to be known as viscose rayon (Shaikh 2012). The name rayon was derived most probably due to its brightness and structural similarities to cotton (Shaikh 2012) (Sun = ray and on = cotton). The name viscose comes from the Greek word *viscous* and describes a gummy liquid of sticky consistency, referring to the honey-like spinning solution used within viscose process from which the fibers are made. Therefore, viscose fiber is considered the oldest manmade fiber in the world and is a non-synthetic fiber.

Nowadays, viscose and modal are made from the cellulose of a wide range of different plants. The majority of global viscose and modal fibers are produced from natural feedstock such as eucalyptus, southern pine, acala, birch, beech, aspen and maple as well as other trees or bamboo. Recent research and development (R&D) approaches within the MMCF industry are exploring the use of different natural fibers for MMCF production. However, viscose as the most commonly used MMCF is derived from wood pulp. According to the Rainforest Action Network 150 million trees are logged every year for the manufacturing of manmade fibers. MMCF such as viscose/rayon, lyocell and modal (but also cupro and acetate) from the second most important cellulosic fiber group after cotton, with a demand of between 6 and 7 million tons annually (Fig. 1.1).

- Viscose is the most commonly used MMCF and makes up more than 80% of MMCF used in the market.
- Lyocell is a generic fiber made using a different non-toxic solvent. It is produced mostly from eucalyptus tree pulp.
- Modal is a fiber which is produced from beech trees using a slightly modified viscose process.
- Acetate is a fiber derived by reacting purified cellulose from wood pulp with acetic acid and acetic anhydride (the reason for its name) in the presence of other chemicals.
- Cupro is different to the other fibers since it is a regenerated cellulose fiber produced by treating cotton cellulose with cuprammonium salt. Its correct name is cuprammonium rayon due to the associated manufacturing process.

Fig. 1.1 Global production of MMCF in 2017 (Textile Exchange 2017)

Though there was a drastic decline in the demand for MMCF at the beginning of the twentieth century, because of the development of synthetic fibers, the viscose industry is currently in a healthy state due to its use of new plants sourced from Asia. Actual growth forecasts for viscose are already exceeding those of many other fibers, including polyester staple fibers, expecting to reach an output of 10 million tons in the next 15 years.

From 2015 to 2016, Viscose saw a double-digit growth due to increased production in China. Based on the Preferred Fiber Markets Report 2017 (Textile Exchange 2017), the global production of manmade cellulosic fibers was estimated at 6.7 million metric tons in 2017 with viscose alone making up to 80% of the production volume. MMCFs are produced mostly in Asia (over 80%) (Freitas 2017) with the highest percentage produced in China (over 60%).

1.2 From Hard Wood to Soft Fiber—The Chemical Transformation Process

In order to understand the transformation from hard wood to soft cellulosic fiber, it is necessary to elaborate on the entire process from the raw material to the final MMCF (Fig. 1.2).

For the production of MMCF, such as viscose, modal and lyocell from natural feedstock, use of materials with a high content of α-cellulose is the main criteria.

1.2.1 Feedstock Assessment—The Pros and Cons of Feedstock Used for the Production of MMCF

Beside the MMCF cupro, which is produced from cotton linter, which is the fine and silky fibers sticking to the seed after the ginning process, the remaining MMCFs, such as viscose/rayon, modal, lyocell and acetate, are produced mainly from wood, with a small percentage from bamboo.

According to the environmental organization CANOPY (Canopy 2018), more than 150 million trees are logged every year and turned into cellulose fabrics. The non-governmental organization claims this logging includes endangered and ancient forests, used for feedstock for MMCF production through its international Canopy-Style campaign. CANOPY is urging international fashion brands to ensure that their purchasing decisions are ethically and environmentally responsible. CANOPY has developed a set of guidelines, the so-called CanopyStyle Audit Guidelines, that verify producers are meeting requirements and are therefore recognized as unlikely to source from endangered and ancient forests. Since the establishment of CANOPY,

Fig. 1.2 From wood to fiber

more than 750 companies globally, including the paper industry, changed their sourcing practices toward more sustainable feedstock.

Besides the change in sourcing policies toward a more responsible and sustainable raw material, MMCF producers globally are intensifying their R&D activities to focus on alternative feedstock for cellulose production. Promising natural fibers with high α-cellulose content and low hemi-cellulose content are found in the fibers of banana leaves, pineapple leaves and abaca leaves, which is a plant similar to the banana plant. Other experiments with straw as feedstock have been carried out. Although these alternative solutions are actually at the laboratory stage and relevant scale ups have to be conducted, the use of alternative fibers could become an interesting option for the production of MMCF.

1.2.2 The First Step—The Pulping Processes

Prior to the production of MMCF from α-cellulose, it is important to transform wood into so-called pulp, which is a lignocellulosic fibrous material that can be considered a pure cellulosic fiber. The main goal in the pulping process is to separate wood fibers from one another in order to prepare fibers, with the help of chemicals, for further processing. Common processes used in the industry to de-lignify woody material are the KRAFT and SULFITE processes. The major pulping method is the KRAFT process, developed by Dahl in Germany in 1879, whereby late in the process the lignified middle lamella, which is situated between wood fibers, is removed using an alkaline solution and high temperature. Within the KRAFT pulp process most of the chemicals, especially the inorganic chemicals, are recovered and reused. Due to its design, the KRAFT process can accept a wide variety of wood as feedstock (Fig. 1.3). The SULFITE pulping process is used for approximately 10% of the global pulp production.

The basic difference between the pulping processes is the pulping liquor used for dissolving the wood chip feedstock. In the SULFITE process the liquor is produced by stoichiometric burning of sulfur in order to produce sulfurous acid. The cooking liquor is then adjusted by adding hydroxides or carbonates to the watery solution.

Although the yield of the pulp from the SULFITE process is higher compared to the KRAFT process, the cellulose fibers generated by this process are not as strong as the fibers from the KRAFT process, due to hydrolysis. However, the SULFITE process is not as destructive as the KRAFT process, resulting in a better use of process by-products. Typical bio-based products from the SULFITE process are acetic acid, furfural, soda, xylose or wood sugar and sodium sulfate (Sjoestroem 1993). Many of these products are used in the food industry.

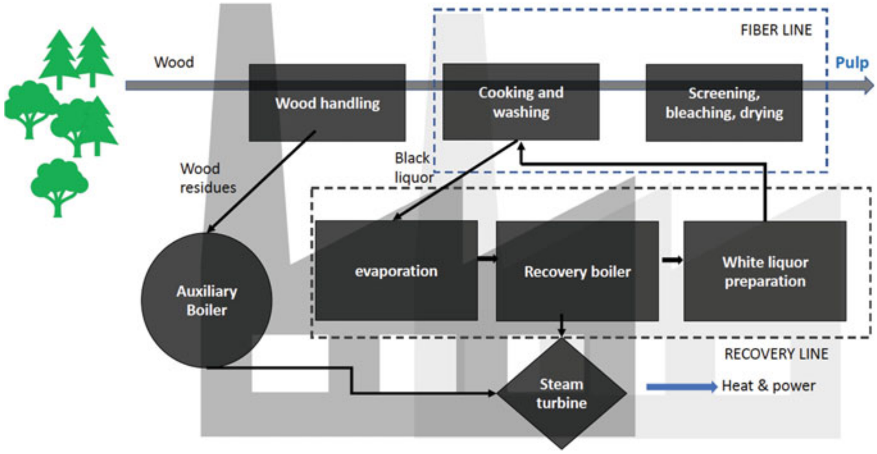

Fig. 1.3 Simplified overview of the conventional KRAFT pulp process (author's own graphic)

1.2.3 The Production Process of Manmade Cellulosic Fibers or MMCF—Viscose/Rayon, Modal, Lyocell, Acetate and Cupro

This section describes MMCF production processes in more detail. It needs to be mentioned that the modal fiber production process is similar to that of viscose production process, albeit with a few differences. Modal fibers are only produced from beech wood and the regeneration process for cellulose, the part in the process where zink is added, is artificially slowed, resulting in very soft fibers. Therefore, only the viscose production process (Oekotextiles 2012) will be explained in detail (Fig. 1.4).

1.3 The Viscose Fiber Manufacturing Process

The pulp from the pulping process is dissolved in caustic soda. The NaOH reats with the cellulose forming Na-cellulose. After the soaking process, the solution is pressed through a filter system to remove excess liquid and the remaining Na-cellulose, as a white crumb, is aged through exposure to the air. This aging process influences the viscosity of viscose and modal. The longer the exposure to air, the lesser will be the viscosity of the Viscose.

Mixing the N-cellulose with carbon disulfide, CS_2, under a controlled temperature produces a honey colored xanthate, with a consistency similar to sodium cellulose, in a process called xanthation. The sodium xanthate is again dissolved in caustic soda, NaOH, for ripening. This process is called regeneration and in the presence of water

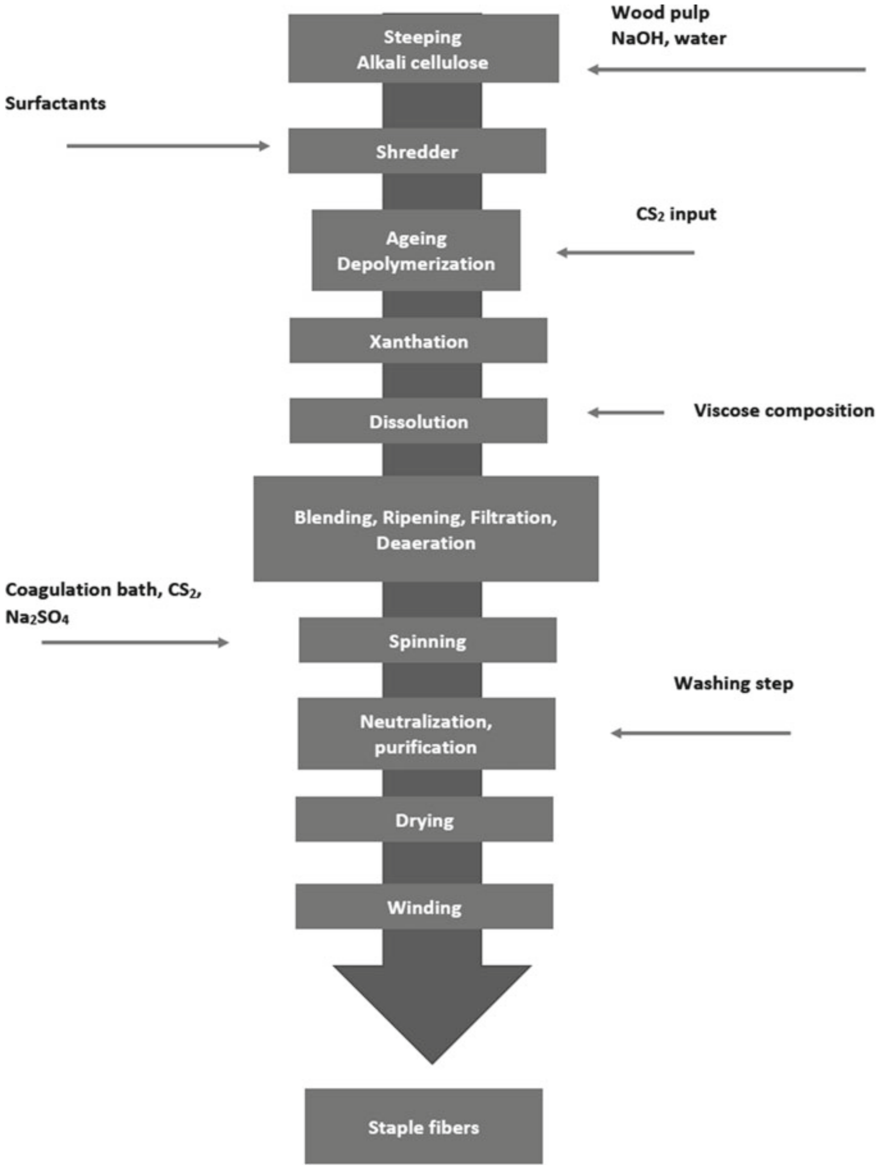

Fig. 1.4 Simplified viscose process (author's own source)

cellulose is formed from sodium xanthate. The process of decomposing is controlled by adding zinc to the solution.

This process releases carbon disulfide, CS_2, and hydrogen sulfide, H_2S, which are considered to be decomposition by-products. Due to the high toxicity of CS_2 (Lay 2000) and H_2S (National Institute 1997) emissions, it is imperative are recovered using state-of-the-art production technology. Reported recovery rates for CS_2 are from 64% to 97% (Bartsch 2018). According to Lenzing AG, their ECOVERO™ fibers generate up to 50% less emissions and have a lower water impact compared to generic viscose.

Carbon disulfide is used in large quantities as an industrial chemical for the production of viscose rayon fibers. In this technological process, for every kilogram of viscose produced about 20–30 g of carbon disulfide and 4–6 g of hydrogen sulfide are emitted (National Institute 1997), and if not treated properly are released into the air.

1.4 The Lyocell Manufacturing Process—A Different Fiber

Due to the use of highly polluting and toxic chemicals in the viscose/modal process toxic effluents were frequently released into the environment. In the 1920s researchers started in the 1920s to set up a different, less toxic, process for the production of fibers (Owens 2013). This was based on the idea of dissolving cellulose directly with chemicals that were easy to use and recover, instead of breaking down the cellulose in wood pulp. In 1939, two Swiss chemists suggested the use of non-toxic amine oxide. Later, the scientist Dee Lynn Johnson filed the first patent for the use of non-toxic N-methylmorpholine N-oxide (NMMO) to directly dissolve cellulose.

Lyocell can be considered a form of viscose produced from bleached eucalyptus and a small amount of beech wood pulp, as the only wood source, derived either through the KRAFT or SULFITE process. Lyocell was finally developed in the United States in the early 1970s and became famous under the name Newcell. Today, the lyocell fiber has found increased use within the fashion industry and is known under the name TENCEL™ Lyocell from Lenzing AG or Birla Excel™ from Aditya Birla Group.

Different to the viscose/modal process, cellulose is dissolved in a hot organic solvent, NNMO, in the lyocell process, creating a clear but viscous solution. This viscous solution is filtered and pushed through a spinneret drawing the fibers into the air and giving the fibers their strength. Fibers are then placed into a water-bath containing a dilute solution of NMMO followed by a drying process where any remaining liquid is evaporated, resulting in the final lyocell fibers (Fig. 1.5).

The NMMO solvent used in the process is recycled and reused. Recycling rates differ slightly but a rate of 98% for NNMO is possible using the best available technique (BAT).

1.5 The Acetate Fiber Production Process

Acetate was first produced in 1923 by the English Company Celanese as part of a wider industry approach designing fibers from cellulose. At the beginning of the

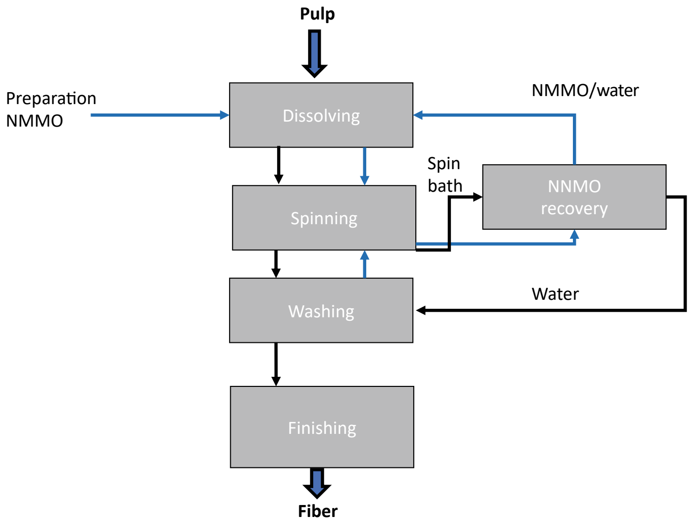

Fig. 1.5 The lyocell process (simplified)

1930s, several companies in the United States started producing acetate making the United States the world leader in Acetate production. Acetate is produced from cellulose derived from wood pulp with acetic acid and acetic anhydride in the presence of sulfuric acid. Through controlled hydrolysis, the sulfate and acetate groups are subsequently removed (Changing Markets 06/2017). Hydroglucose is the repeating structure in cellulose, having three hydroxyl groups which can react in order to form an acetate ester. The most common cellulose acetate fiber has an acetate group on every three hydroxyl groups and is known as diacetate or simply “acetate fiber.” Such fibers have an esterification degree of between 2.22 and 2.76. When the three hydroxyl groups form an acetate ester, the fiber is called triacetate with an esterification degree of between 2.76 and 3.0.

After the diacetate or the triacetate is formed, the fibers are dissolved in acetone. In the extrusion process, the solvent evaporates creating acetate fibers (Fig. 1.6). Acetate fibers represent the second highest share of MMCF but are most often used for non-textile applications. For fashion and textiles, the branded acetate fiber Naia, from Eastman Chemicals, is gaining attention through its application of integrated chemical management and a life cycle assessment (LCA) that has been third-party reviewed by Quantis International.

1.6 Cupro Fiber Production—The Bemberg Process

Within the search for artificial silk at the end of the nineteenth century, a scientist named Schweizer discovered that cellulose dissolves in a solution of copper and

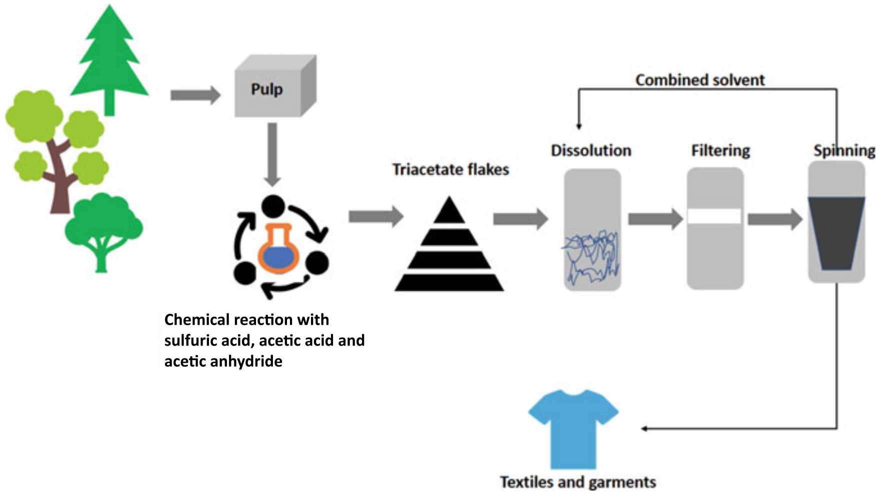

Fig. 1.6 The acetate production process (own chart)

ammonia, forming so-called cuproammonium, Cu $[(NH_3)_4]$ $(OH)_2$. Basically, cupro can be considered a type of viscose produced using a completely different technology, the so-called Bemberg process. It is the first ever fiber production process using regenerated cellulose. Today, the only remaining global cupro producer is a company called Asahi Kasei. They successfully implemented the Bemberg process within their production in 1931.

Today, cupro is made using cotton linter which are the short and downy fibers attached to cotton seeds after the grinning process. Cotton linter is soaked in a bath of caustic soda, NaOH, steamed and bleached. The cellulose is then dissolved in a mixture of copper hydroxide and ammonium hydroxide, Cu $[(NH_3)_4]$ $(OH)_2$. The clear polymer solution is then filtered using a slightly alkaline bath and undergoes an aging and de-aerating procedure. Coagulated cuproammonium fibers are washed in a 5% sulfuric acid solution. The fibers are then ready for spinning into staple and filament yarn (Fig. 1.7). The main advantages of the Bemberg cupro process over the viscose process are the use of a cellulose pulp with a lower degree of polymerization, Degree of Polymerization (DP), content. In addition, since cupro is made using cotton fibers it can be dyed using reactive dyestuff.

The main disadvantage of the cuproammonium process is the toxicity of the copper sulfate, requiring the full recovery of copper salts used. It is imperative that waste water treatment removes any copper compounds, thereby observing national waste water standards. This requirement limits the large-scale production of cupro.

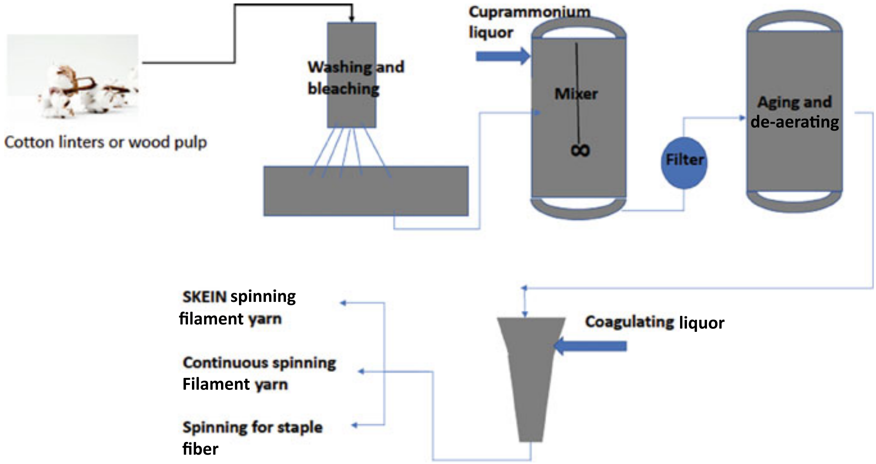

Fig. 1.7 Manufacturing process for cuprammonium rayon (cupro) (author's own diagram)

1.7 Environmental Impact—MMCF in the Spotlight

A recent LCA for the brand Stella McCartney, conducted by SCS Global Services, evaluated the impact profile of ten different MMCF production variations derived from five completely different natural feedstocks (wood from different forest regions, bamboo pulp, cotton linter, flax by-products, recycled clothing), with supply chains across four continents. This published LCA was the first of its kind to assess the global MMCF sourcing scenarios where terrestrial and freshwater ecosystems from specific forests of origin were included. The study was completed in October 2017 and was made available to the public online. It showed that all current commercial viscose production systems carry very different but serious risks.

Recent campaigns by the environmental organization CANOPY (Canopy 2018), considering unsustainable feedstock for MMCF production in terms of endangered trees and forests, and the Changing Markets Foundation, an environmental organization working in partnership with NGOs (Changing Markets 06/2017) with a focus on global environmental pollution and harm to human health through the production of MMCF, have raised global awareness of MMCF production in general. With its critical reports on the global textile industry and especially the viscose industry (Changing Markets 06/2017, 12/2017, 02/2018, 07/2018, 11/2018), Changing Markets has requested brands work with their viscose suppliers in order to establish a responsible and sustainable chain of production to protecting the environment and human health. Based on the research of Changing Markets, global viscose production is causing tremendous damage to the environment through water, soil and air pollution associated with the toxic chemical carbon disulfide and its by-products formed during the viscose process.

The Changing Markets reports created momentum toward increasing awareness not only globally at the buyers end but also within other organizations such as the association known as the Zero Discharge of Harmful Chemicals and the Stichting ZDHC Foundation, with its Roadmap to Zero Program. Within the Roadmap to Zero Program (ZDHC 2018), the ZDHC take a more holistic approach when tackling problems related to hazardous chemicals in the global textile, leather and footwear supply chain through the Manufacturing Restricted Substances List, MRSL.

The ZDHC established a MMCF working group in 2018 where, alongside its signatory member brands and the global MMCF industry, it is working on a unified standard and roadmap for the discharge of hazardous substances into water and the air, as well as solid waste products like sludge.

Another call to action from the supply side of the industry is the Chinese initiative CV, the Collaboration for Sustainable Development of Viscose. CV is a collaboration of ten major viscose fiber producers—collectively representing over 50% of the world's viscose staple fiber production—in partnership with two trade associations. This self-regulating initiative aims to see its members adopt a recently launched roadmap focusing on available standards and programs, increased transparency and continuous improvement toward a best available technique (BAT) (CV 2018).

1.8 The Characteristics of Different MMCF Fibers

MMCF has many competitive advantages: viscose has many great characteristics including its versatility, high level of absorption, smoothness, strength, color retention, breathability, lightness and low cost (Ramos 2018). MMCF combines the comfort of natural fibers with the advantages of synthetic fibers, such as purity and consistent quality. Thus, MMCFs are strategically positioned between natural and chemical synthetic fibers. The most important fact relating to the excellent physiological properties of cellulose fibers is their reversible absorption of moisture, which is different to synthetic fibers like polyester where moisture condenses on the surface of the fabric producing a film. Due to its physical properties, MMCFs such as viscose, modal and lyocell can be blended with almost all natural and synthetic fibers such as cotton, linen, silk, wool, polyester and polyacrylic. The major applications of MMCF include yarns and sewing and embroidery threads, fabrics and apparel including linings, domestic textiles of any kind, industrial textiles for medical applications, as reinforcement materials used in rubber tires and belts and as a major feedstock in the production of carbon fiber. In this chapter we focus on apparel, where MMCF has gained momentum in the industry because it is considered a skin-friendly and environmentally friendly option—advantages that are expected to drive market growth for the years to come. In addition, MMCF will continue to be used to replacing other fibers in the commercial landscape, such as more expensive and less easy-to-care-for silk, especially in women's wear and lingerie, and synthetics. MMCF claims to be

Table 1.1 Main characteristics of MMCF (author's own illustration)

Fiber characteristics	Viscose	Modal	Lyocell	Cupro	Acetate
Feels like silk	×	×	×	×	×
Has a matt finish	×		×	×	
Flows softly	×			×	
Crease resistant				×	
Strong				×	
Flame resistant		×			
Absorbs moisture		×	×		
Retains shape		×	×		
Feels cool on the skin		×			
Produced in an environmentally friendly way			×[a]		
Biodegradable/compostable	×	×	×	×	×

[a]Refers to the production processes. Lyocell production uses NNMO as a solvent but recovers almost all of it. Viscose and modal processes use toxic CS_2

biodegradable and renewable offering a cotton-like feels. This represents a significant advantage for MMCF in the future since rising demand of cellulose based fibers cannot be met by cotton due to price and availability (Table 1.1).

As the industry is investing at a fast pace and output is increasing, there has been an expansion in applications due to increased varieties of fiber finishes and blends. In particular, blends with synthetic fibers have flooded the retail space—being attractive from a price and comfort perspective—thus further fueling demand.

Especially complex blends, used for inexpensive fast fashion items, are expected to pose a significant challenge in terms of waste and recycling.

The vast amount of viscose available on the current international market, produced relatively cheaply using processes described earlier, are having a devastating impact on workers, local communities and the environment. This is why conventional viscose (including bamboo viscose) was given "D" and "E" scores for sustainability in the Made-By Environmental Benchmark for Fibers.

1.9 Recent Innovations for a More Safe and Sustainable Production of MMCF

There is no question that the production of fibers in the future needs to have a reduced social and environmental impact, challenging the industry to adopt a more sustainable sourcing procedure in terms of the feedstock used for the MMCF production as well as the production process itself. Interesting alternatives for a more sustainable feedstock through the use of different fibers, and also pre- and post-consumer cotton products, are already available and in use. Such options might not be able to totally replace the existing feedstock but could serve as a promising substitute.

In terms of the production process new cellulose dissolving techniques are needed that replace the currently used toxic chemicals. But the most important steps are to ensure that the chemical production process is being carried out in in a "closed-loop" process ensuring the highest recovery rates for the chemicals used.

1.9.1 Feedstock Alternatives and Recycling Options

Non-wood-based cellulose input can be derived from alternative feedstock plants such as flax or algae, plant residues considered as agricultural waste like straw, or leaves and by-products from the food industry like citrus peel or fruit skins. Obviously, textile waste with high cellulose content, mainly from cotton, can also be used as an alternative feedstock for MMCF production: recycling of post-production (e.g., cotton scraps in the cutting room), pre-consumer (e.g., samples or stock that cannot be sold) or post-consumer (disposed textiles after being used) textiles is increasing but still faces many barriers to scalability (Fig. 1.8). Barriers include for example impurities and possible contamination with residues from wet-processing or the use phase. There are costs associated with identifying and resolving such issues, presenting a new financial barrier. For example, it requires an expensive chemical processes to prepare dyed textile feedstock for the dissolving process.

Fig. 1.8 Alternative cellulose feedstock examples (different sources 2018)

1.9.2 *The Use of Textiles as Feedstock for MMCF Production*

Cellulosic waste is generated throughout the textile supply chain. Spinning, weaving and knitting, as well as other cotton and MMCF manufacturing processes, generates waste, 25% of which can be mechanically and chemically recycled. Recycled textile feedstock has various advantages including the mitigation of impacts of any virgin feedstock. Furthermore it supports the principles of the Circular Economy through recycling of textile excess and regional manufacturing opportunities.

A mechanical process that re-spins or just tears material into shorter fibers would not be classified as an MMCF process. The chemical recycling process of cellulose content into MMCF includes a dissolving process and can offer many opportunities no matter whether completed post-production, pre-consumer or post-consumer, as long as a very high cotton content, typically around 90%, is used.

The first commercially available lyocell fiber, containing recycled cotton, was launched by Lenzing AG in 2017 and more and more of their Refibra™ branded products are making their way to the marketplace (Lenzing 2018).

Fashion Positive (Fashion+) has identified viscose as a desirable material with high economic potential. Fashion Positive considers chemically recycled cellulose from post-consumer waste a new and innovative material. Their goal is to:

- reduce the use of raw materials sourced from natural feedstock,
- divert waste from landfill, and
- use safer chemistry.

In addition, they want to implement different chemical recycling technologies for apparel made from cellulose fibers in order to generate new virgin-quality viscose fibers that meet the requirements for C2C gold or platinum certified products (Fashion Positive 2018).

Within the recycling process of re:newcell™, cotton and other natural fibers are dissolved into a new, biodegradable, raw material called re:newcell™ pulp. It can be transformed into textile fibers and introduced into the textile production cycle, meeting all industry requirements (Re:newcell™ 2018).

New technologies have recently started to chemically recycle fiber blends containing polyester and cotton. To ensure full fiber–fiber recycling, cotton and polyester have to be separated chemically. One example from Mistra Future Fashion is the Blend Re:wind process, which has been developed using existing industrial processes and aims to reduce waste as much as possible in order to minimize both environmental and economic costs, while boosting business. A scaling up to industrial production is the biggest challenge since processes are very costly (Tecycling Magazine 2017).

Other innovators in textile recycling and MMCF production techniques include, but are not limited to, Evrnu, Worn Again, Saxcell, HKrita, Tyton BioSciences and the Infinited Fiber Company. Other promising results from R&D at universities include WSU's Department of Apparel, Merchandising, Design and Textiles in Washington DC.

1.9.3 Cotton Linter as Feedstock

Cotton linter, also referred to as "cotton wool" in the United Kingdom, is formed from the short fibers remaining on the seed after ginning. It is used for spinning (first cut) or pulp production (second and third cut) as well as for medical, cosmetic and many other practical uses (Balajicottonlinter 2012). Cotton linter pulp is used for paper and for the cupro production process as the sole feedstock, as mentioned earlier in the chapter. Cupro fibers are exclusively produced by one supplier, Asahi Kasei from Japan, under the trademark "Bemberg". An Innovhub third party laboratory test recently proved (Knitting Industry 2017) that cupro fibers are fully biodegradable, and as such can be used to produce caskets for end of life option. Cupro is also GRS certified (Global Recycled Standard) and Asahi Kasei commissioned an LCA study prepared by Istituto per la Certificazione Etica, ICEA, Italy.

1.9.4 Other Alternative Feedstock

Alternative feedstock plays a marginal role in MMCF production today. Although many laboratory innovations are available and are being tested by international brands or are gaining attention through scaling programs, supported by grants from industry and governments, quality issues, feedstock collection logistics and purity, cost competition and questions around impact still persist.

One example of using agricultural waste for acetate fiber production is the use of orange fiber from orange peel. Table 1.2 shows cellulose, hemicellulose and lignin content found in alternative feedstocks.

Other early stage innovators include: Agraloop, a company using various types of agricultural waste; Mestic, focusing on cow manure as a feedstock; BJMC, working with jute; and Aalto University considering algae.

Each feedstock presents its own advantages and challenges.

Table 1.2 Cellulose, hemicellulose and lignin content (Textile Exchange 2017)

	Cotton seed linter (%)	Hardwood stems (%)	Wheat straw (%)	Orange peel (%)
Cellulose	80–95	40–55	30	13
Hemicellulose	5–20	24–40	50	6
Lignin	0	18–25	15	<2

1.9.5 Processing Technology Alternatives

Next to certification of an integrated (often referred to as “closed-loop”) process or using a non-toxic solvent as explained in the section about Lyocell, the industry is still lacking alternatives to convert feedstock into a MMCF. More than 90% of MMCF is still produced with all the environmental and social risks discussed earlier in the chapter.

Innovative, yet early stage, alternatives to dissolving cellulose include the utilization of an ionic liquid, for example, Ioncell-F.

“Cellulose is a supermaterial of the future,” according to the VTT Technical Research Center of Finland, Aalto University, Tampere University of Technology and the University of Vaasa. Researchers are collaborating to develop new biomaterial applications as part of the Design-Driven Value Chains in the World of Cellulose (DWoC), seeking new design-driven applications for cellulose and developing related technology as well as exploring new ways to create value in cellulose-based ecosystems. These new materials and innovations can replace traditionally used raw materials in textile products, interior decoration elements and car interior materials (VTT 2015).

Crailar FTI has invented enzymatic processing of flax fibers, drastically reducing the use of chemicals and water. The Crailar process transforms bast fibers into soft and fluffy fiber, composed of thousands of individual bast fibers, resembling the feel and appearance of cotton (Bastfibretech 2019).

Nanollose is a biotechnology start-up which has developed a process using a non-hazardous and non-infectious bacterium that converts biomass waste from beer, wine and other liquids into microbial nanocellulose fibers, thus creating a “plant-free” cellulose, branded “Nullarbor.”

Another alternative to the traditional dissolving process has been introduced by Spinnova. In this process defibrillated cellulose goes through mechanical spinning. Spinnova represents a disruptive, ecological innovation that turns cellulose into textile fiber simply, without harmful chemicals. Currently, the fiber is still in the R&D phase, being developed together with respective brands to suit demand from commercial products (Spinnova 2018).

1.10 Conclusions and Outlook for Manmade Cellulosic Fiber

While conventionally produced MMCF currently aims to use sustainably sourced wood pulp feedstock and ensure integrated processing technologies, in the future we do not want arable land transformed into monocultures of fast-growing trees.

We need to look at alternative feedstocks that do not compete for land, we need non-toxic, integrated production of pulp and fiber, and we have to continuously try to replace virgin inputs. Recycling cotton products could theoretically replace all virgin feedstock.

There are many promising innovations and start-ups that have introduced their products to the industry. Most are still at a very early stage and need a set of strong partners to scale up production. We expect governments, industry initiatives and companies investing and testing, as well as supporting, for example, "Fashion For Good," a platform for sustainable innovation based in Amsterdam, to accelerate the adoption of new, safer technologies that represent the work of over a hundred young innovative companies (Safermade 2018).

Currently, it is imperative to generate a clear picture of industry, identifying the big issues and impacts and how innovation and new technologies can address such issues successfully. This picture will give an indication of potential, will allow comparison and also help innovators attract investment capital. Action is required from a broad group of actors, both within and outside the industry, such as brands, retailers, suppliers and R&D as well as investors, governments and the cummunity advocacy. We believe the conventional MMCF industry must not continue producing low-cost MMCF at the detriment of the people and planet.

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Chapter 2
Natural Recycled Super–Fibers: An Overview of a New Innovation to Recycle Cotton

Luke M. Haverhals

Abstract In their report 'A New Textiles Economy: Redesigning Fashion's Future' (Ellen MacArthur 2017a), the Ellen MacArthur Foundation describes the need for the global textile industry to mobilize 'moonshot' innovations. Natural Fiber Welding (NFW) is a disruptive technology and materials company that is answering this call. In particular, NFW is developing technologies which enable abundant natural materials to be utilized in applications that are presently dominated by resource intensive plastics. In so doing, NFW is connecting production of textiles and other materials to regenerative agriculture. This has the potential of greatly reducing plastic pollution, significantly reducing the carbon footprint of the industry, and offers new cost-effective options for circularity—all while providing material performance and tunability that was not possible before.

Keywords Natural composites · Ionic liquids · Textile recycling · Plastic pollution · Startup

2.1 Introduction

In their report 'A New Textiles Economy: Redesigning Fashion's Future' (Ellen MacArthur 2017a), the Ellen MacArthur Foundation describes the need for the global textile industry to:

> Mobilize large-scale, targeted 'moonshot' innovations. In areas where existing innovation is sparse but a significant impact could be expected, innovation 'moonshots' should be mobilized. Stakeholders from across the industry would gather and spark innovation. One area for such innovations could be the search for a 'super-fiber' with similar properties to mainstream ones, but suitable for a circular system, with no negative externalities.

A practitioner's perspective

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The Ellen MacArthur Foundation report goes on to identify four key areas of innovation that must be addressed in order to realize sustainability on a global scale. These areas are to:

- Phase out of substances of concern and microfiber release
- Increase clothing utilization
- Radically improve recycling
- Make effective use of resources and move toward renewable inputs.

In this report, Natural Fiber Welding, Inc. (NFW) will share data that demonstrates our team's revolutionary answers to calls for global circularity. In short, the NFW fabrication platform uses renewable natural inputs—including recycled cotton—to produce great feeling, durable textiles that outperform petroleum-based plastic incumbents. Importantly, NFW's patented closed-loop manufacturing solutions are both atom and energy efficient and thus positioned with favorable unit economics to enable penetration into global markets. NFW is focused on enabling a new circular economy that (re)uses natural, sustainably sourced inputs at a regional level. Using the cardboard recycling industry as a model, NFW is scaling a new type of textile mill Peoria, IL which is in close proximity to Chicago, IL (which is a significant source of waste textiles). NFW is pleased to be working with partners such as Fashion for Good (FFG) (Fashion for Good 2018, 2019) and within the FFG network of partners. NFW is not just demonstrating that circularity and regional textile recycling is possible, it is the most economically favorable way forward.

2.2 Scalable Sustainable Technology

NFW technologies combine new ionic liquid-based chemistries with automated hardware that executes patented closed-loop processes. In short, NFW technologies utilize very small, controlled amounts of eco-friendly ionic liquids to controllably fuse fibers within spun yarns. Fusion happens when intermolecular hydrogen bonding networks are controllably extended to bridge neighboring fibers. This is accomplished even while preserving microstructure of natural fibers and with complete recovery and recycling of ionic liquid-based chemistries. This has the effect of making short fibers (e.g., 'waste' and recycled cotton) behave as though they are long fibers and creates finer, stronger, more abrasion resistant yarns and fabrics. This is a major advance, one that positively impacts every key summary point outlined in the Ellen MacArthur Foundation report to realize greater sustainability.

The NFW platform offers revolutionary opportunities to engineer high-performance composites using renewable inputs from sustainable agriculture as well as reusing fibers already grown. NFW, located in Peoria, IL USA, is positioned to be the exclusive provider of this scalable fabrication platform (Haverhals et al. 2010; Haverhals et al. 2012a, b, c, d). NFW's proprietary technologies are contextually linked with profound discoveries that ionic liquid chemistries are extraordinarily tunable and cost effective for biopolymer manipulation (Swatloski et al. 2002, Phillips et al. 2004). NFW leverages the existing capacity of nature which already produces gigatons of biopolymers (e.g., cellulose) and thousands of billions of pounds of high-performance fibers annually (Cox et al. 2000; Griffith et al. 2008). Instead of denaturing natural materials or utilizing expensive biotechnologies (Edlund et al. 2018) that must produce commodity materials starting from scratch, NFW solves major manufacturing problems while finding proprietary new ways to retain complex order and hierarchies exhibited by natural fibers such as cotton, flax, silk, and industrial hemp (Haverhals and Sulpizio et al. 2012a, b, c, d, Haverhals and Nevin et al. 2012a, b, c, d, Haverhals and Foley et al. 2012b). This approach not only enables new performance applications with virgin fibers, it also enables recycled natural fibers to outperform their (conventional) virgin counterparts (Table 2.1).

It is well understood that petroleum-based synthetics have changed the world in complex ways (Ellen MacArthur Foundation 2017b). During the past 50 years, innovations that leverage fossil resource-based synthetics (e.g., polyester) have displaced natural material inputs because synthetic polymers can be 'formatted' into geometries (e.g., filaments) that make strong, abrasion resistant, moisture wicking fabrics. While plastics are significantly more energy intensive to produce than natural materials (Table 2.1), the performance associated with filament-type geometries has led to large-scale adoption. In 2019, the textile industry will utilize about 100 billion pounds of polyester for filaments and staple fibers (Plastic Insight 2019). If the data in Table 2.1 were not enough of a call to action, it can be noted that the empirical formula of polyester is approximated as C_2H_2O (varies slightly depending on specific formulations) and means that roughly 57% of the mass of a metric ton of polyester, roughly 570 kg, is carbon which is derived from fossil sources. Plants, in contrast, remove carbon from the atmosphere as they grow. Of course, the empirical formula of cellulose is ~$C_6H_{10}O_5$ and means roughly 440 kg of carbon are sequestered in a metric ton of cotton. Moreover, agriculture can be accomplished in regenerative ways that also sinks carbon on longer timescales within healthy soils. Importantly, Table 2.1 also does not communicate important context about plastic microfiber pollution. In particular, polyester microfiber released from over one billion washing machines worldwide means that synthetic textiles—including recycled plastic textiles—are a major source of pollution into the world's watersheds and oceans (Browne et al. 2011). (Even if synthetics could 'safely' biodegrade, it is apparent that a major new problem would emerge as fossil carbon from synthetic materials would become a substantial new greenhouse gas emission source.) Synthetics are known to absorb and concentrate toxins such as microcystins (Kohoutek et al. 2008). Scientists around the world are now reporting that overdependence on nonbiodegradable plastics comes at great cost and risk to virtually every ecosystem (Cole et al. 2013; McCormick et al. 2014; Rochman et al. 2017; Jeong et al. 2016). Pollutants have been documented in seafood (Smith et al. 2018), sea salt (Yang et al. 2019), and tap water (Tyree and Morris 2019) samples from around the world.

Of course, some in the industry have raised alarm about some natural materials as well. While apologists for polyester often downplay the larger context and statistics of land use associated with petroleum extraction, distribution, and processing versus agriculture (US Department of Agriculture 2018a, b) and the potential for crops like cotton to produce food (Wedegaertner and Rathore 2015; Charles 2018), they do correctly point out the (over) use of pesticides in industrial production of cotton as well as the intensive use of water in many of the dye processes that color cotton. Fortunately, regenerative forms of agriculture that use less water and eliminate the need for pesticides are on the rise and many scalable solutions are being explored. In contrast, the large carbon footprint of synthetics and including the resource footprint for recycled plastics is stubbornly not tractable and cannot be ignored. At the same time as regenerative agriculture is on the rise, NFW is solving relevant water use problems at their root by enabling efficient recycling of cotton and even while simultaneously enabling new zero-waste dye processes. With the NFW platform, it can be argued that the 'super-fiber' the world is looking for has actually been in plain sight all along, or perhaps just hidden away in the back of our closets—it is the natural fiber that can be reused multiple times before being regrown by nature. NFW is pioneering a circular system, whereby fabrics can be mechanically broken down and then (re)manufactured into fabrics that can even outperform conventional fabrics made from virgin fibers. As will be shown, NFW is demonstrating 'super-natural' performance from materials that are today destined either for landfill or incineration.

2.2.1 Fiber Welding Technology

A core 'pillar' of the circular NFW platform is detailed in Fig. 2.1. NFW technologies 'reformat' natural materials into composites that exhibit superior performance. It has long been known that the quality of a spun yarn is largely determined by the length and quality of the fiber utilized. The industry pays a premium for extra-long staple fibers that lend to strong, even yarns. It is a well-known problem that short fibers reduce the performance of yarns both during manufacturing (e.g., weak yarns that shed during knitting) and subsequently during use (e.g., consumers do not want fabrics that pill). In fact, sometimes as much as 20% of short virgin fiber is combed out of sliver prior to spinning. This short virgin fiber is often sold at a loss to, for example, manufactures of Q-tips and rags. Given that there were over 55 billion pounds of cotton produced globally in 2018, these losses account for many billions of pounds of 'waste' fiber that does not even get used once as a garment. Of course, short fiber is also the reason why mechanical recycling of cotton is not wide spread today. Processes that break down post-industrial and post-consumer waste fabrics tend to shorten fibers. Aggressive combing can enable some recycled content to be used, but greatly limits economic relevance. Short fibers are particularly problematic for finer (lighter weight) yarns. As such, mechanical recycling has had a difficult time expanding into fashion markets.

One of NFW's game-changing capabilities is to promote greater circularity as a 'drop-in' solution that enables large-scale mechanical recycling of cotton. 'Welding' processes tunably fuse neighboring fibers within a yarn. This creates adhesive forces that are more robust than simple friction that comes from mechanically spinning (twisting) fibers together. Because only the outermost portions of fibers need to be

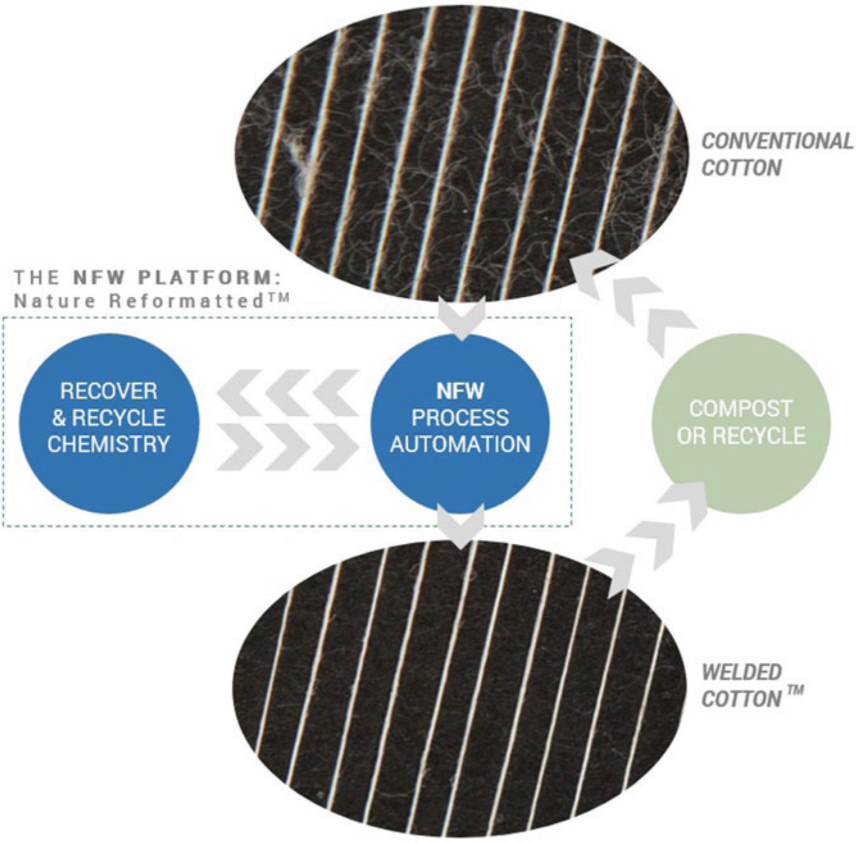

Fig. 2.1 Natural fiber substrates such as the conventional ring spun cotton yarn (top) are tunably converted to Welded Cotton™ composite yarn (bottom) using closed-loop manufacturing. NFW has developed automated processes that continuously recover and recycle the chemistries that impart a physical change to the natural fiber-containing substrates. In the meantime, natural fibers retain key structures and hierarchies even as they are 'reformatted' into new composite geometries. This yields, for example, Welded Cotton™ composite yarns that exhibit superior wet strength and abrasion resistance. (own source)

fused, fibers do not need to be dissolved. This saves time, money, and preserves the nano- and micro-sized structures that give natural fibers many of their advantageous properties. Moreover, the fusion of fibers produces a stronger, finer, more even yarn structure even when using short cotton fibers. Welded Cotton™ composite yarns thus exhibit the best of all possible worlds: all of the comfort of cotton, but with never before possible morphologies that mimic what is today only available using synthetic polymers.

Figure 2.2 plots data 'before' (gray bars) and 'after' (blue bars) fiber welding processing for three different yarn substrates. The left-most gray bar is the strength normalized by cross-sectional area for a 26/1 NE cotton yarn containing 30% recycled

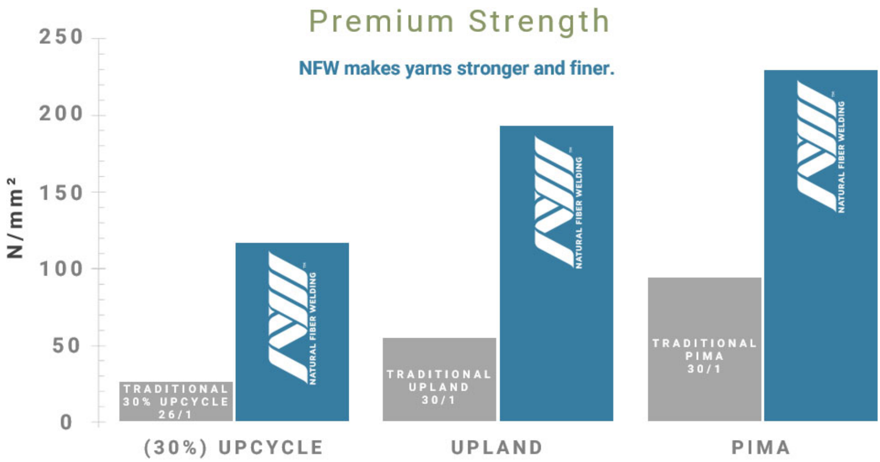

Fig. 2.2 Strength normalized by cross-sectional area is compared for Welded Cotton™ composite yarns (blue bars) versus their conventional controls (gray bars). It is observed that a Welded Cotton™ composite yarn which contains 30% post-industrial waste (left-most blue bar) outperforms a comparable conventional extra-long staple (Supima, right-most gray bar). (own source)

(post-industrial) cotton content. The middle gray bar is similar data for a 30/1 NE ‘Upland’ cotton substrate, the right-most gray bar represents a 30/1 NE ‘Supima’ (‘Pima’) yarn substrate. It is clear that the strength of a conventional yarn is directly proportional to the length of fibers therein. The Welded Cotton™ composite yarn data, in blue, show significant improvements. While the results do indicate that the quality of fiber does matter to the ultimate (maximum) performance, the Welded Cotton™ composite yarn with 30% post-industrial content exhibits a superior profile compared to conventional extra-long staple yarn. This is an outstanding achievement that is a quantum leap forward for the textile industry and that could never be attained by incremental improvements to yarn spinning frames.

Figure 2.3 shows images from Martindale Abrasion Testing. The jersey knit cotton fabrics were produced using Upland 30/1 NE Welded Cotton™ (top) and convention Upland 30/1 control. The results demonstrate the superior durability of Welded Cotton™ and are directly applicable to proving NFW produces ‘super-fibers’ that promote greater sustainability (increased clothing utilization). Several types of NFW’s brand of Clarus™ fabrics are found to have a great feeling hand and exhibited an acceptable appearance even after 30,000 cycles.

Fig. 2.3 Martindale abrasion testing results for Clarus™ jersey knits produced using Welded Cotton™ composite yarns and from conventional upland cotton control fabrics. Clarus™ fabrics continue to look and feel great long after traditional fabric controls have developed both pills and holes. (own source)

2.2.2 Fiber Welding Platform Breadth

The NFW platform is not limited to just producing superior yarns and woven or knitted fabrics. NFW has demonstrated both ‘practical’ and ‘exotic’ functionalization of natural fiber-containing substrates. For example, on the practical side, patented closed-loop indigo dyeing (Haverhals et al. 2018) and on the exotic side, supercapacitor energy storage (Jost et al. 2015; Durkin et al. 2014) and catalytic waste water treatment (Durkin et al. 2018, 2016) using peerless ‘welded’ natural substrates. The company is actively developing a range of other functional additives that utilize the proprietary platform approach. In all cases, NFW is particularly focused on delivering performance in ways that outcompete and eliminate harmful incumbent chemistries that are utilized by the textile industry today.

Figures 2.4 and 2.5 further demonstrate some of the practical aspects to the NFW platform. Figure 2.4 shows a table top made from 100% denim. The rigid and strong composite contains no glues or resins. Instead, cotton fibers in the denim were fused using welding processes that simultaneously recovered the ionic liquid solvents for reuse. The result is a beautiful visual depth (even though the composite is quite flat, as shown in the inset) that shows textiles can be functional for decades, and even centuries if desired, in building applications that are higher value than insulation or sound dampening. Of course, when composites are 100% natural, they can be composted for natural recycling at the end of their useful lifetime.

Figure 2.5 highlights a different side to the NFW platform: the production of plastic-free vegan leather-type materials. However, instead of using plastics like

Fig. 4 Welded Cotton™ composite table tops are made from 100% scrap denim without any resins or glues. The inset shows the table is flat even while it displays a visual depth that comes from the layering of the starting materials. Images courtesy of turnstone® a Steelcase brand. (own source)

polyvinyl chloride or polyurethane like other 'vegan' leather-type materials available today, NFW's Mirum™ materials are 100% made from natural materials and nutrients and are plant-based and thus biodegradable. For this material class, NFW is scaling a unique type of process automation that will enable millions of square meters of annual production of tunable, differentiated materials. NFW is developing footwear, belts, wallets, handbags, and other accessories, even automotive interiors in collaboration with global brands, OEMs and a select group of independent designers and upstarts. In every application, the NFW team is focused on solving the manufacturing limitations that have prevented 100% biodegradable materials from being adopted at scale. In most applications, the NFW team is able to recycle cotton and even food waste and other agricultural 'waste' byproducts into these truly vegan materials and makes them extremely cost competitive. Moreover, a recent agricultural law has legalized industrial hemp to be grown in the state of Illinois. NFW is well located to benefit from the large-scale production of fiber that can be produced in the USA and, in particular, the Midwest where materials can be grown regeneratively at large scale.

Fig. 2.5 Mirum™ is 100% plant-based leather-like composite. NFW is able to produce scalable materials that do not use harmful plastics like polyvinyl chloride and polyurethane. NFW believes 'vegan' should mean 'plants' not 'petroleum' nor 'plastic'. (own source)

2.3 Summary

Natural Fiber Welding, Inc. is a technology and materials company that is positioned to be the exclusive driver of a circular materials revolution. Using innovative chemistry paired with efficient proprietary automation, NFW is able to leverage the abundance of nature in ways that were previously not considered. NFW is particularly focused on utilizing the large-scale availability of 'waste' fibers that exist and is creating systems to reuse, recycle, and regenerate high value materials at a regional level. In so doing, NFW is achieving:

- Eliminating substances of concern and microfiber release by instead using biodegradable plant-based inputs

Table 2.1 Carbon dioxide emissions in kilograms per ton of spun fiber (Oekotextiles 2011; Zamani 2011)

Filter type	Filter cultivation	Filter production	Total
Polyester	–	9.5	9.5
Arcyclic	–	12.4	12.4
Conventional cotton	4.2	1.7	5.9
Conventional hemp	1.9	2.2	4.1
Organic cotton	0.9	1.5	2.4
NFW recycled cotton	–	1.9	1.9

- Increasing clothing utilization with high-performance 'welded' fibers
- Radically improving recycling into a variety of material classes
- Making efficient use of resources and exclusively using renewables.

NFW understands that to truly solve sustainability issues at the global scale, new processes and materials must deliver performance at price points that can outcompete petroleum-based incumbents. NFW technologies are peerless in their ability to deliver and our team's mission is to create the circular system that will last for as long as the sun shines.

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Chapter 3
Circular Design as a Key Driver for Sustainability in Fashion and Textiles

Jonna Haeggblom and Ina Budde

Keywords Circular fashion · Circular economy · Recycling · Textiles · Circular Design

3.1 Introduction

Similar to many industries of today, the fashion industry predominantly follows principles of a linear economic model. Large amounts of resources are extracted from nature, quickly manufactured into clothing, worn on average just a few times before being disposed of, out of which 73% ends up in landfill or is incinerated (Ellen MacArthur Foundation 2017) or are incinerated. This way of operating is reaching its limit. The environmental impact of relying upon a linear economy on a planet with finite resources is disastrous and results in increasing amounts of hazardous waste, resource degradation, pollution, violation of human rights—to name a few (Cobbing and Vicaire 2016; Fletcher 2014).

Over the last decades, promising innovations have been arising in the form of less impactful fibres and textiles, improvements in production and manufacturing technologies, efficiency improvements in recycling technologies, amongst others. Even if these innovations are important to halt environmental impacts, the problem still remains that massive amounts of garments are produced and consumed each year, out of which only less than 1% are recycled. In addition to environmental impacts, such a 'take-make-waste'-approach also leads to an enormous loss of economic value, estimated to 500 USD billion per year (Ellen MacArthur Foundation 2017).

A practitioner's perspective.

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We need to be more clever, innovative and responsible in not only the products we design, but also the systems they circulate in so that resources are kept in the loop with maximum value retained, for as long as possible, before being able to safely re-enter the system and being used as feedstock for new textiles.

The aim of this paper is to present key drivers for creating systemic change in the fashion industry. In doing so, particular attention is given to the example of *circular.fashion*—a sustainable design agency creating product and system innovation for a circular economy in fashion and textiles. The study adopts a primarily practice perspective by qualitatively illustrating hands-on business experiences.

3.2 The Need for a Circular Fashion System

A circular economy is an economy of regenerative systems in which products are able to recirculate with maximum value retained for as long as possible, before being able to safely re-enter the system through reuse or recycling. Circular fashion, based on the main principles of circular economy and sustainability, is a term for fashion that occurs in cycles. A garment and its materials is designed already from the outset with the intention to circulate and being regenerated at the end of life into new raw material and looped back into the economy (Green Strategy 2020).

However, even if the concept of circularity is gaining increased attention amongst brands, companies, consumers and regulators, still less than 1% of clothing is actually recycled into new clothing today. To transition towards circularity, three core challenges need to be overcome and will be further explained in the following sections:

(1) Firstly, clothing needs to be designed for circularity. Designers need to have the right tools, resources and knowledge to be able to make the right decisions.
(2) Secondly, product life must be extended and customers need to know in which channels to return the clothing for reuse or recycling.
(3) Thirdly, sorting systems for closed loop recycling need to be established.

The three challenges make evident, that for realizing unlimited cycles for clothing the actors of the fashion supply chain need to be connected in the system, so that crucial information transparently can be shared, such as recycling requirements for designers, take-back options for consumers and material specifications for sorting companies.

To address these challenges, *circular.fashion* is developing an industry-connecting platform that enables a transparent flow of information between material suppliers, designers and brands, retailers, users and recyclers to overcome hurdles that hold back the transition towards a circular economy for fashion and textiles. Within such an interconnected system, well thought-through decisions are needed in every step of a garment's life—from choosing the material, to design, use and recycling. This presents innovative and creative opportunities in each step of how to recirculate textiles and clothing. Design is recognized as the starting point and as such a key

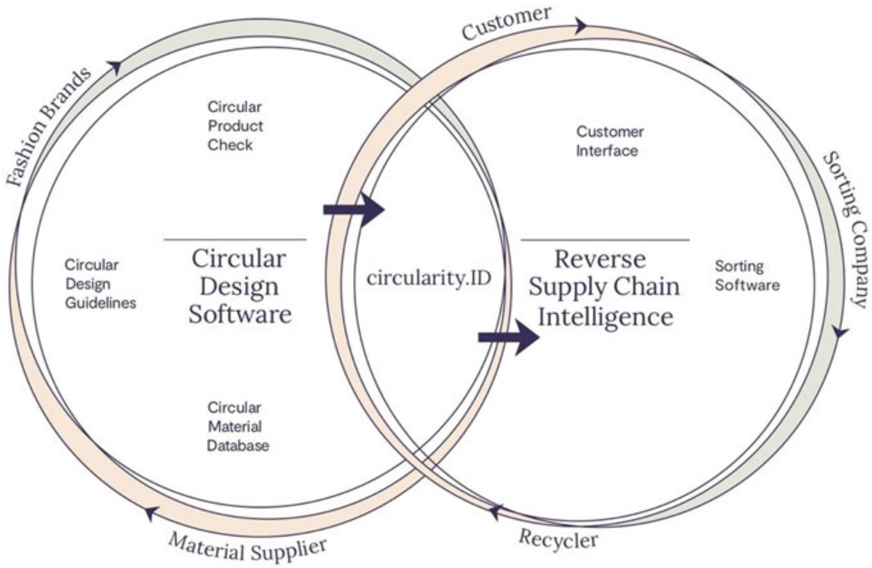

Fig. 3.1 Infografic *circular.fashion* system (*circular.fashion* 2017)

driver to move away from the traditional way of producing and consuming and enable circular systems in the fashion industry.

Figure 3.1 illustrates the core features and components of a circular economy in fashion and textiles as developed by *circular.fashion*. The following sections introduce single elements of the circular system in more detail. For this purpose, the authors of the present report shed particular light on design and product lifetime extension and highlight several practical examples elaborated by *circular.fashion*.

3.3 Selected Elements of a Circular Textiles and Fashion System

The following section highlights important aspects related to circular textiles and fashion. In the beginning, several different aspects and strategies concerning circular design are illustrated (Sect. 3.1). Next, selected ideas and approaches concerning the extension of product lifespans and reverse supply chains will be presented (Sect. 3.2).

3.3.1 Design for Circularity

To design for circularity is about using design strategies that keep garments in the loop at highest possible value at all time—ultimately designing out waste from the system from the very beginning. The various strategies are influenced by the requirements of recyclers. *circular.fashion* has set up a network of innovative fibre recyclers and analyses hundreds of textiles according to the criteria of the recyclers. Requirements are gathered and translated into circular design strategies suitable for product development. These are digitally available in the circular design software, as physical tool kits and used in workshops and training on-site with fashion brands. Designing for material cyclability, longevity and adaptability are all examples of such circular design strategies.

3.3.2 Material Cyclability

To ensure circularity of fashion, the designer or product developer first of all needs to make sure that all material that goes into a garment is safe and healthy to re-enter the economy in closed-loop material systems. Design for material cyclability therefore aims to redefine the concept of waste and the need for virgin resources, by enabling garments to be either recycled in a technical cycle or decomposed in a biological cycle (Braungart and McDonough 2002). Careful consideration of all materials, additionals and parts that go into a garment is needed in the design phase to ensure endless cycles. A garment designed for material cyclability needs to be made in a mono-material design or in a multiple-cycle material combination, which then requires to be designed for easy disassembly at the end of use.

3.3.3 Design for Mono-Material

Mono-material refers to a design strategy where a garment and all its parts are entirely designed within one cycle, through either biodegradation or recycling. This strategy is suitable for garments where there is no need for materials of different cycles. The chosen main fabric determines in what cycles the lining, trims and additionals should be in order to match and ensure material cyclability.

3.3.4 Design for Disassembly

For garments that are more complex in their design, pattern construction or that need the functions of textiles and parts from different cycles, a mono-material solutions might not be an applicable strategy. Such garments should rather be designed for disassembly, so that parts and material can easily be disassembled at the garment's end of life. Many garments today consist of multiple materials providing either aesthetic or functional criteria. A common example is a closure mechanisms. To design such a piece for circularity, it needs to be designed for disassembly in a way that the different parts can be separated at a garment's end of life allowing them to go into different recycling cycles. In these cases, a designer needs to consider ways of how the parts or trims, i.e., the zipper or buttons, are easily removable from the main fabric. Achieving this either can be done by making detachable parts, refusible closure mechanisms or by the use of stitching techniques that easily separates the different parts.

A strategy like design for disassembly opens up for easier repair of the piece, as only the broken part and not the entire garment can be removed and repaired. In addition, it can enhance the longevity of the garment and provide the user with the possibility to update one's piece by exchanging the detachable parts for other ones. Against this background, the box below highlights a jacket designed for disassembly by *circular.fashion.*

***Circular.fashion design example*: Jacket designed for disassembly**
Pictured is a coat designed for disassembly by *circular.fashion* design strategist Alberte Laursen Rothenborg. The coat is made in two layers, the outer layer is suitable for biodegradability while the detachable under layer is fit for polyester recycling. The thermo coat, the under layer, is made in monomaterial of recycled polyester and polyester zippers and ensures monomaterial recycling. Both the hoodie and sleeves are detachable from the piece, providing additional multifunctionality and making it suitable to wear over seasons by being transformable. It features long side vents, a high collar and slightly open armholes aiming to fit and adopt to everyday activities.

The coat as a whole and in parts, works both as an outer and mid-layer, encouraging multi and trans-seasonal use (Fig. 3.2).

Fig. 3.2 Jacket designed for disassembly (Alberte Laursen Rothenborg, circular.fashion 2018)

3.3.5 Design for Longevity

To design a garment for circularity is on the one hand about changing technical factors, such as the material, manufacturing processes or technical aspects as explained in the strategies above. However, on the other hand, it is also about challenging common perceptions of what fashion is and how we can engage with it. Most garments today are thrown away because the user loses interest in them and on average a piece is used 4–7 times before being discarded. Using a piece by just three more months leads to a 5–10% reduction in carbon, water and waste footprint (WRAP 2015). Fashion is a massively underutilised product, and it is therefore crucial to extend the useful product lifetime of a garment. Designing for longevity is about creating garments to last, both in style, quality and in function. In order to achieve this, several different strategies can be used to enhance both the functional and emotional durability.

3.3.6 Design for Functional Durability

Functional durability refers to the physical aspects of a garment. This also includes whether it is made to last and whether it can resist damage due to wear. The functional, or physical durability, is affected by the garment pattern construction and the choice of materials and trims. When designing functional durability a designer needs to consider the use of high-quality fabrics and trims in term of strength, abrasion resistance and shape resilience. Parts that are liable to stress, such as the crotch or elbows can be reinforced by extra stitches to enhance durability. High-quality knitted trims at neck, hems and cuffs can help avoid T-shirts and sweatshirts losing shape. Fabric finishes that address moisture, stains and odour can be used for T-shirts, sweatshirts, blouses and shirts. Providing care instructions that communicate simple care, wash and laundry practices and encourage repair or reuse of the piece might influence the users' behaviour and effect the physical durability of a garment. Even in cases where increased physical durability is considered from the beginning, an item might need repair in the future to ensure it is not being discarded because of damage, stained or worn-out. A strategy for functional durability is therefore to design already at the outset an item that can be easily repaired. The box below highlights such a design approach by illustrating the example of denim footprint developed by *circular.fashion.*

***Circular design example*: Denim footprint**
Denim footprint by Melissa Ortuno is a project exploring ways of designing for easy reparability. The items are designed with detachable parts and constructed in ways that makes these parts easy to disassemble. As a result only the worn out or broken pieces can be repaired or replaced instead of having to discard of the whole piece. Parts such as collar on shirts, cufflinks or ribs are suitable examples for this strategy. The denim is designed in raw 100% organic denim, with extra stitching on parts liable for stress. Every pair of denim comes with care instructions and information about the piece, to engage the customer in the repair and maintenance activities. Promoting reparability has the possibility to strengthen brand

loyalty as it builds on a brand's image in creating items designed to last.

3.3.7 Design for Emotional Durability

Within an industry closely dependent on rapidly changing trends and obsolete styles, designing garments to last is far away from the predominant rhythm of the fashion industry. To increase the durability in terms of long-lasting styles and emotional bonding, different strategies can be followed. Choosing classic, timeless design, colours and trims as well as using high-quality durable material increases the aesthetic durability of a piece. Emotional durability refers to consumers' connection to their items. In case of a strong connection and adherence, consumers are considered to keep their items in use for a longer time. 'Designing in' emotional durability is complex, as it is by nature personal what creates stronger emotional connection. However, a few strategies can be used to increase emotional durability. If the user for example was part in the design process, by choosing the colour, logo or embroidery, the item would have a stronger personalized experience. This can also be achieved via DIY-kit, information material or open source design patterns. Such participatory design strategies have the potential to increase emotional connection, resulting in pieces that are cherished and kept for a longer time. A stronger emotional connection can also have a trickling-down effect in other aspects of sustainable behaviour, thereby promoting stronger interest on the part of consumers to take care of their items, and repair or mend it if needed.

Circular design strategies have the potential to influence many other aspects of the garment's life cycle. Therefore, it is important that the question of sustainability will be already raised in this stage in design teams. *circular.fashion* works on-site with design teams of global brands as well as SMEs of various sizes to embrace circularity into every aspect of their collections. In addition, the circular design software can be used digitally as an inspiration, providing guidelines for circular design.

3.4 Extended Product Life and Recovering Resources

3.4.1 Circularity.ID

Even if circular materials and design strategies are used, the actions of the consumers during the use phase are crucial for a garment's environmental impact and its chance to be reused or recycled in a circular economy. To keep garments in use for a longer term is the most direct way to cut down waste and lower fashion's footprint. To max out the potential of items that are designed for longevity, innovative business and retail models have great potential in contributing to increased utilisation and prolong the life of a product. Such business models can be second hand resale, renting services or subscription services that challenge ownership.

Keeping the conversation going also after point of sale, via a digital tag in a garment, has great potential to prolong the use period. By enhancing both, emotional durability through telling a garment's story and functional durability by presenting information about how to care and repair the item. This also enables exciting business opportunities of reusing, redesigning or reselling—ways in which consumption can be detached from (new) material resource use while opening up new revenue streams and creating greater brand loyalty.

To support such strategies and to create the transparent flow of information, *circular.fashion* has developed a circularity.ID. The circularity.ID is a digital tag that is integrated into a garment and which stores all needed information of a piece; where it is made, what it is made of, who made it, material specifications, care information, and recycling and reuse options. This tag opens up for reverse supply chain logistics and enables the item to circulate and ultimately to be used for fibre-to-fibre recycling.

3.4.2 Reverse Supply Chain Logistics

Less than 1% of garments are recycled into new clothing today, while the majority is landfilled and 12% mechanically recycled, a down-cycling process, meaning the fibres lose value (Ellen MacArthur Foundation 2017). *Circular.fashion* works with innovative recycling partners that already from the beginning check if a textile is recyclable, biodegradable or not. This information is stored on the circularity.ID, integrated into each piece that is designed through the platform. By scanning the circualrity.ID sorters retrieve all needed information to send the piece to the right fibre-to-fibre recycling. A standardized system for sorting companies that are using the circularity.ID to identify a garments material specification is currently being developed and tested with the partner network of *circular.fashion.*

3.5 Conclusion

Due to environmental, economic and social challenges, the fashion industry urgently needs to transform into circular practices where resources are kept in the loop. Embracing circular design practices can be seen as a key driver for innovation and creativity. As such, the role of designers has changed—from creating aesthetically beautiful products to consider also the system around those products and their possibility to recirculate and be regenerated in order to be used as feedstock for new yarns, textiles or products.

A connected system amongst all actors is needed, so that crucial information can transparently flow. Recycling requirements need to be translated into design strategies and material choices to ensure fibre-to-fibre recycling and to design out waste from the very beginning. To achieve true system changes, collaboration is key since innovations created in silos will not have the desired impact. Thus, collaboration amongst all stakeholders involved in the fashion supply chain is needed.

The circularity-oriented approach developed by *circular.fashion* and introduced in this study connects material suppliers, designers and brands, consumers and recyclers to ensure that each step positively influences circular systems of fashion. The *circular.fashion* system consists of a circular design software including a circular material database, design guidelines for circularity, a circular product check, the circularity.ID and reverse supply chain logistics. The aim is to support fashion brands and designers to perceive design as a key driver of sustainability and to build up a connected system that enables garments to circulate.

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Chapter 4
Cruelty-Free Silk and Guilt-Free Fashion

Chandra Prakash and André Matthes

Abstract To enable a stable coexistence of people and ecosystems, an intelligent and sustainable economy of ecosystems and biodiversity is crucial. The article describes how socially and environmentally responsible entrepreneurship can make silk production sustainable and at the same time create employment opportunities in one of the poorest areas of India. Non-violent silk is now expanding the range of sustainable natural-based fashion fibres alongside organic cotton or hemp.

Keywords Natural Fibre · Non-violent silk · Sustainable fashion · Cocoon · India

4.1 Introduction

The fast fashion industry has put the earth's biodiversity at great risk. The rise of mass production of fashion is a major cause of the destruction of the earth's biodiversity. The excessive use of chemicals has destroyed or threatened the existence of many species of herbs, plants, birds, animals and insects (Sukhdev et al. 2014). Improper use and non-compliance with regulations and the immense use of water lead to more frequent unexpected environmental disasters and droughts in the world's textile regions. Biodiversity plays an important role in our ecosystem, as the different plant and animal species are interdependent. Different species provide a natural balance in habitats. Healthy biodiversity can recover naturally if appropriate environmental conditions are created. So, smart and sustainable economics of ecosystems and biodiversity are crucial to enable a stable coexistence of men and ecosystems. Silk is one raw material among others. Social entrepreneurship can help to transformed silk

A practitioner's perspective.

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industry into an organic silk industry over time. The way the world perceives sustainable fashion and carries the term non-violent silk around the world has changed." This unique business model has also created abundant employment opportunities in one of the poorest areas of India. Non-violent silk is now expanding the range of sustainable fashion fibres, alongside organic cotton or hemp. The Indo-German company Cocccon (Cocccon 2019) is based on a social responsibility platform in which the sustainable use of labour and natural resources is one of the most important tasks.

4.2 Non-violent Silk—Guilt-Free Fashion

The Cocccon project is a modern form of rural cooperation with decentralized production. It enables silk farmers, spinners and weavers to work directly from their own homes. All these different units are well connected to the headquarters where cocoons, yarns and finished textiles are stored. Sericulture or silk farming is the breeding of silkworms for the production of silk. It is carried out mainly in the wild and in some cases also indoors. The leaves of the mulberry tree are normally used to feed the silkworms. The Arjun tree, which occurs naturally in India, is better adapted to the climatic conditions prevailing there and provides the necessary food for the silkworms, as shown in Fig. 4.1.

Fig. 4.1 Silkworm on a tree (*picture source* André Matthes)

Fig. 4.2 Cocoons on a Arjun tree, semi finished left, finished right (*picture source* André Matthes)

With a view to a sustainable environment, health and development, certain innovative technologies have been developed to control pests and fungi for the host plant Arjun. For the cultivation of the tree stands, the use of any kind of conventional pesticides, i.e. spraying over leaves or trees, is prohibited. However, a natural alternative in liquid form has been developed by mixing plants with medicinal properties such as Guizotia abyssinica (Ramtilla), Azadirachta indica (Neem) and Brassica juncea (India mustard). This unique blend provides 90% similar results to chemical fungicides and pesticides, but without toxic side effects to the ecosystem. Additionally, the host tree is covered with a large net to improve protection against potential predators (Yadav 2011).

The biggest benefit of using non-toxic chemicals over the past five years has been the enormous growth of grass on the ground, which is now used as animal feed. The unique blend is also effective in curing root rot diseases of host trees. Additionally, Arjun leaves and silkworm litter or faucal matter are utilized as high-class organic manure for farming (Madan et al. 1989). The villagers take care of the silkworms while they feed on the trees. The villagers must ensure that the silkworms always find enough leaves and, if necessary, move the worms to other trees until the silkworms start spinning the cocoons, as shown in Fig. 4.2.

As soon as the cocoons are finished, the villagers “harvest” them from the trees and place them indoor. In the case of tussar silk, the cocoons are hung vertically from the ceiling with jute cords. After about a week, the silk butterflies (moths) hatch out of the cocoons themselves, or in some cases, they are pierced by well-trained personnel to help the animals hatch. Only after checking each empty cocoon, they go to the degumming department. Therefore, this silk can be called Peace Silk or non-violent silk. In conventional silk production, the cocoons with the living animals inside are placed in hot water or steam to degum the cocoons and all moths get killed (Gulrajani 1992).

The procedure for eliminating “gum (sericin)” and impurities from raw silk is known as the removal of silk slime. This is done by adding natural organic soap to the hot, boiling water. Occasionally hydrogen peroxide is used to make different shades of silk yarn uniform. This is environmentally friendly and a process approved by REACH & GOTS. In conventional silk production, toxic metals are used during the degumming process to make silk yarns heavier through the so-called ´silk-weighting´ and thus increase weight-related sales revenues. The addition of the typical additives such as chromium, barium, lead, iron or sodium magnesium is prohibited in Cocccon's silk production (Miller et al. 1989; Hacke 2008).

The toughest part of the project is a sustainable way of wining luxury silk fibre from broken cocoons. This requires a lot of time, patience and investments into new spinning machines. First fine count yarn was achieved in 16 months after multiple failures. Spinning of the silk yarns is done in a complex combination of manual technique and mechanical finishing. The process is under patent. Once the patent process is done, it can be explained elaborately. The project has also upgraded four out of twenty weaving looms currently in use with solar-powered motors. This means that 70% of our spinning and weaving operations are carried out without a CO_2 footprint. The packaging and storage of the products is mainly done with jute sacks or recycled cartons. The transport of cocoons or finished yarns to weavers in various areas of Jharkhand is carried out by public transport via state roads or the Indian railway. The water consumption in the production process is minimized by the recovery of used water. By filtering the old process water, the residues from the cocoon degumming can be reused as compost for agriculture.

4.3 GOTS-Certified Environmentally Friendly, Gentle Digital Printing

Digital printing machines are used in our factory to process the non-violent silk fabrics. The printing system is GOTS-certified and has little effect on nature or human skin. This system uses very little ink, electricity and water. The printing floor is equipped with a zero-waste system. Wastewater from the print is recycled and reused for further use by the own Bio-Effluent Treatment Process.

4.4 A Silk Project Changes Its Ecological and Social Environment

The Cocccon project took over a conventional silk farm in India in 2011. At the time, the soil was completely infertile due to the excessive and unnecessary use of chemicals. Microorganisms were also removed from the area. As a result, the Cocccon project stopped and banned the use of all these so-called high-percentage sericulture sprays. Since then, a natural compost has been used as a substitute for chemical fertilizers and the entire sericulture has been rebuilt using pre-industrial methods. In the interests of sustainable development, a number of innovative methods have been developed to control pests and fungi from the host tree.

This has led to the restoration of the lost biodiversity of nature in the region. In 2015, the first new grass appeared from the dead soil. Microorganisms came back to life. The rebirth of various wild grasses in the soil, which was also observed in 2015, is now used as animal feed. In addition, the silkworm litter is used as high-quality organic fertilizer for our agriculture. An excellent positive result was achieved in 2017 with rice cultivation after four years of testing. The first rice harvest was successful in the 2017–2018 cultivation period. The local farmers regarded it as a rebirth of local agriculture, and the village community achieved food self-sufficiency. In 2019, the villagers are already expecting overproduction of their rice crops. The Cocccon project promotes local villagers as entrepreneurs by establishing their own brand of organic rice for the mainstream market.

4.5 Conclusion

The project, which is now in its sixth year of operation, established an international standard for sustainable fashion made of silk. The workers have a pleasant lifestyle, and their children attend schools in the local area. The women in the villages are able to contribute new professional skills. The social and economic independence of the village communities is strengthened. Since Cocccon does not use chemical substances on the host tree for silkworms, there are opportunities for double plant production. For example, the cultivation of rice and potatoes in combination with the host trees of the caterpillars was successfully implemented. From an ecological point of view, the entire region appears much greener than before. The Cocccon project shows how fashion can be in harmony with ecology. Fashion that respects biodiversity is the only way to keep our planet safe and the fashion industry alive.

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Part II
Sustainable Sourcing in the Textile and Fashion Value Chain

Introduction
The textile industry is a globally operating industry involving a large number of different players. The procurement of technical textiles and fashion has become much more international over the past years due to price pressure, globalisation and industry growth. Not only retailers or brands buy-in so-called low-wage countries in order to achieve the desired margins on their domestic markets. Even technical textile items in the coating and automotive fields are now supplied to consumers via global trade flows.

A lot of companies no longer just pay lip service to sustainable procurement in the textile industry; sustainable procurement has also become a part of their entrepreneurial business model. Therefore, it is not just crucial for EU and NAFTA brands and labels to achieve favourable returns by purchasing in low-wage countries; the monitoring, control and corresponding development of the supply chain have a high communication and efficiency value for the respective purchasing organisations.

Development towards sustainable procurement will proceed further in the coming years not only because of the regulations of end-users and consumers, but also because of both international and regional legislation. It is now custom practice in Europe for all larger companies to demand sustainability from their suppliers by including a restricted substance list (RSL) or/and a manufactured restricted substance list (MRSL) as part of the purchase contract terms. Throughout the entire branch, from discount to fashion label and to techtex, the respective sustainability reports document control and naming across all quotas within supply chains.

Sustainable procurement has increasingly become part of sustainable and profitable business models within the textile industry. In future, overexploitation in low-wage countries and procurement under inhumane conditions will only be possible in isolated cases due to both the ever-increasing awareness among consumers and the regulation of the respective markets. Yet, at the end of the day what is crucial is what the consumer and the respective user expect from a product or an item and how the procurer, trader, label or brand develop, document and communicate the procurement of their supply chain. The textile industry is changing its procurements and the transparency of them to correspond with particularly the timber and food industries.

However, if the rules are ultimately made by the market, it must be observed which of these the consumer will be willing to accept. Sustainable procurement which no one wants to pay for will not develop a company or a label favourably.

In the following chapter, the authors will present different views on the worldwide procurement of textiles and show their development towards sustainable procurement and circular business models. Koep et al. give an overview of traditional and sustainable purchasing practices in the textile and clothing industry. Proposals are made as to which additional elements should be taken into account. Thereby, the authors call for a more comprehensive approach to sustainable procurement in the textile industry. The article by Keßler and Kümmerer deals with the use and management of chemicals in the textile sector. Release patterns and subsequent exposure routes are exemplarily described. Different functional substances will be presented and concepts as well as concrete examples of green and sustainable chemistry discussed. The contribution by Schäfer and Herter examines the extent to which input-oriented chemicals management represents a solution for the highly complex and apparently impenetrable global textile supply chain. The study explains the tools for chemicals management—ranging from compliance with regulatory requirements to voluntary measures such as testing and a system-oriented approach—as well as their effectiveness. The authors conclude that chemicals management should be focused on the essentials and addressed jointly and in a coordinated manner.

Chapter 5
Buying Practices in the Textile and Fashion Industry: Past, Present and Future

Lisa Koep, Jonathan Morris, Nina Dembski, and Edeltraud Guenther

Abstract The textile and fashion industry is characterized by complex structures, multiple actors and globally interlinked supply chains. Increasing competitive pressures associated with the fast fashion business model has led to unsustainable practices along the supply chains resulting in negative ecological and social impacts. In recent years, pressure has been mounting on the industry, specifically on retailers and clothing brands, to address these issues. Consequently, sustainable procurement practices have gained importance in addressing these sustainability issues and buyers at multinational retailers are now not only taking price, delivery time and quality into account but are also increasingly required to consider social and environmental aspects in their decision-making. In this section, we provide an overview of traditional, as well as sustainable buying practices in the textile and garment industry, as well as delineating suggestions on which additional elements to consider, calling for a more comprehensive approach to sustainable procurement in the textile industry.

Keywords Sustainable purchasing · Textile and garment industry · Sustainable supply chain management · Environmental and social impacts of garments

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5.1 Introduction

Sustainable procurement can best be defined as a special decision-making process, consisting of a range of steps (demand management, market research, award and procurement processing) involving a range of actors and actions against which sustainability criteria should be addressed (Guenther et al. 2013). Sustainable procurement decisions thus center around materials used in the products, where they have come from, who has made them, how they are made, how they are transported and how they are eventually disposed of. Most importantly, the procurement function holds a gatekeeper position in “greening the organization” as it is linked with all departments (Scheibe et al. 2010), and therefore, sustainable procurement strategies have considerable implications for the supply chain structure (Genovese et al. 2013). In the textile and fashion industry, this structure is complex, consisting of multiple actors and globally interlinked supply chains (Boström et al. 2012; Towers et al. 2013), which are characterized by high labor and low capital intensity. Contemporary trends in the fashion industry have greatly contributed toward vertical disintegration and networked structures due to the need for low-cost mass production driven by a high level of competition resulting in pressure to decrease prices (Doyle et al. 2006; Illge and Preuss 2012). Outsourcing of low value to where labor is cheapest and environmental standards are lowest leads to short-term buyer–supplier relationships that are said to be contributing to a race to the bottom (Guenther et al. 2012) and unsustainable practices with negative ecological and social impacts. In the textile industry, shifts could be observed from Turkey to Egypt (Tokatli and Kızılgün 2009), to Asian countries such as Bangladesh, Myanmar and Cambodia (Gereffi 1999), and more recently to East African countries such as Ethiopia and Kenya (Berg et al. 2015). Consequently, there is a trend toward buyer-driven sourcing networks, with a shift in balance of power in favor of the retailer at the expense of the producer (Gereffi 1999) as sourcing from multiple suppliers is based on price competition and bidding processes (Hines and McGowan 2005), creating unfavorable power structures for suppliers and contractors.

Addressing environmental challenges is crucial given that the industry accounts for 10% of the total carbon emissions and is responsible for approximately 20% of the industrial water pollution (Colin et al., 2016). The production of raw fibers, especially cotton-growing, plays an important role as it is environmentally problematic due to its intensive use of land, water and chemicals such as synthetic fertilizers, pesticides, defoliants and growth regulators, leading to lower groundwater levels, infertile soils, displacements or extinction of flora and fauna (Schaus 2013). The manufacturing phase, which includes yarn production (spinning and twisting), gray cloth production (weaving and knitting), textile finishing (pre-treatment, dying, printing and finishing) and manufacturing (cutting, assembly, finishing, packing), requires significant resources such as material, water, energy and chemicals (Schaus 2016). A further environmental impact is the release of non-purified sewage into the drainage system by dye factories, which pollutes the ground water and fields

(Diekamp and Koch 2010). Additionally, fiber waste, noise pollution and dust emissions occur during production and finishing processes (The Federal Environment Agency 2012). During distribution and retail, the transport of the products leads to carbon emissions. Transport emissions are on the increase due to the use of environmentally unfriendly transportation modes associated with short lead times (Turker and Altuntas 2014), as well as distant production locations which result in longer transportation journeys (Caniato et al. 2012). In addition, the use-phase of garments can also generate sustainability challenges including health risks to consumers resulting from chemical residues, which can also be released into rivers, seas, soil and plants through the washing processes and lead to the contamination of eco-systems (Schaus 2013). The washing process itself is also associated with impacts arising from the energy consumed (Pedersen and Andersen 2015) while the end-of-life phase has energy demands and pollution potential when products are either disposed, reused or recycled (Mastny and Prugh 2003).

Due to increasing information transparency and media attention, focus on unsustainable behavior in the textile and garment industry has increased. Consumers are progressively demanding that environmental and social issues are addressed (Gardetti and Torres 2013), a pressure which has mounted following the Rana Plaza building collapse in 2013 (Reinecke and Donaghey 2015), where a collapsed factory led to the death of more than 1100 people and injuring around 2400 mainly female garment workers due to poor building safety (Schuessler et al. 2019). Consequently, sustainable purchasing practices have gained importance for addressing these issues. Buyers at multinational retailers are increasingly required to consider social and environmental aspects in their decision-making (Boström et al. 2012) At a theoretical level, increased consumer demand and increased stakeholder pressures as the combination of expectations from stakeholders (for example by NGOs or the media) place additional pressures toward implementing sustainable practices across the supply chain. These pressures are often linked to image or reputational 2008 losses of retailers, and a drive toward improving corporate sustainability performance for legitimacy and reputational purposes (de Brito et al. 2008; Macchion et al. 2018). On the other hand, due to commercial pressures, buyers often remain focused on price negotiations (Perry et al. 2015) which can have multiple negative consequences as cost-savings are pursued—such as poor labor conditions for workers in developing countries have arisen (Pedersen and Gwozdz 2014) often attributed to weak governance mechanisms and a lack of stringent procedures for the protection of workers' rights (Perry and Towers 2013). Further impacts in the labor market include low wages, long hours, forced labor, discrimination and inhumane treatment or harassment conditions (Crane 2013; Trautrims et al. 2015; Köksal et al. 2017) and absence of freedom of association and collective bargaining (Perry et al. 2015). In extreme cases, retailers and buyers have been linked to driving modern slavery (Stevenson and Cole 2018).

Despite the potential for increased demand in sustainable practices from consumer pressures to drive a change toward sustainable purchasing practices across the overall industry (Hansen and Schaltegger 2013; Macchion et al. 2018), there exists a continued low-level demand for sustainable garments (Illge and Preuss 2012; Towers et al. 2013; Franco 2017) can serve as barriers toward an institutionalized sustainability shift. Apparel brands and retailers at the top of the garment supply chain are now seen as jointly responsible for the conditions in the factories of their suppliers and contractors (Anner et al. 2013) given that procurement managers and purchasers have the ability to shape the structure of the supply chain.

In the following overview, the role of buyers in tackling these sustainability challenges along the textile and fashion chain will be discussed in detail. We begin by exploring traditional, as well as sustainability orientated supply chain theories and strategies, synthesizing the state of the art on sustainable supply chain management in the textile and garment industry in order to compare and contrast the two competing paradigms. Drawing on academic literature, we then provide an overview of mechanisms for sustainable decision-making relevant to buyer and supplier relationships in textile and fashion industry sourcing, and present them in two categories: supplier selection and assessment and collaboration. We then outline some challenges and opportunities for implementing sustainable sourcing decisions as discussed in the literature and try to develop a holistic perspective which has been lacking in the academic literature. We conclude with recommendations on how buyers may better address the sustainability challenges in the future by embracing a strategic approach that covers the full procurement process further looking at integrating sustainability at the product conception and design stage, as well as material selection, production, retailing and end of life.

5.2 Purchasing Approaches in the Textile and Garment Sector

In order to explore purchasing approaches and paradigms in the textile and garment sector, a survey of academic literature on the key terms of supplier selection and assessment was carried out through identification of peer-reviewed academic journals returned through searches in databases such as Web of Science, Scopus and Google Scholar. This was supplemented with experiences from reports of exemplar companies chosen for their size and prominence of sustainability. The idea of the search was to be exploratory and free-flowing. This section serves to lay the foundations and inspirations for future research directions, and recommendations for future studies are provided in the concluding sections.

(a) *Traditional Purchasing Paradigm*

According to empirical research with senior purchasing managers in the textile and fashion industry, the traditional purchasing criteria of retail buyers are price, delivery time and quality (Winter and Lasch 2016) and are especially relevant in the fast fashion market segment of the textile and garment industry where the focus is on high speed turnover and marketing new lines and items on a frequent basis resulting in redundancy of old styles (Black 2012). These criteria, combined with the ability to respond to unexpected demand, are prioritized, leaving sustainability criteria such as ethical standards and suppliers' efforts in eliminating waste as less important (Kannan and Tan 2002). Alongside this remains the idea that buyers are "unwilling to increase prices paid to suppliers to reflect the increased cost of ethical production" (Perry et al. 2015, 740). However, catastrophes such as Rana Plaza are resulting in an increased focus on social issues due to buyers aiming to minimize reputational risks in their supply chains.

As the fast fashion business model entails shipping up to 24 fashion cycles into stores per year, the focus on lead times (Vaughan-Whitehead and Pinedo Caro 2017), costs, rigid negotiability (Towers et al. 2013), price renegotiating (Roloff et al. 2015) and order changes (Perry and Towers 2013) has increased. In addition to the above selection and assessment criteria, buyer and supplier relationships are often characterized by a lack of transparent information and absence of written contracts (Vaughan-Whitehead and Pinedo Caro 2017), ineffective communication (Boström et al. 2012) and ineffective audits (Roloff et al. 2015). Overall, it can be summarized that the aforementioned practices negatively impact on the suppliers in the sector, while favoring the buyer and is a "textbook" example of an unsustainable model which impacts on overall sustainability levels.

(b) *Sustainable Purchasing Paradigm*

The emerging attention toward sustainability topics led to growing focus on sustainability aspects within the supply chain theory in both practice and research over recent years. Terms such as *sustainable supply chain management (SSCM*), *responsible supply chain management (RSCM)* and *green supply chain management (GSCM)* and other related terms arose. While there is not one standardized model, Seuring and Müller's (2008) and Beske and Seuring's (2014) SSCM conceptual frameworks are cited frequently (e.g., Köksal et al. 2017) and are considered as a common framework (Rajeev et al. 2017, 300). From the starting point of SSCM, defined as "the management of material, information and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements" (Seuring and Müller 2008, 1700), two important categories emerge with high relevance to buyer–supplier relationships in the textile and garment sector. The first category includes topics such as supplier evaluation and assessment, such as evaluation schemes and minimum requirements (Seuring and Müller 2008). The second category includes topics such as supplier development programs and increased communication, which can be grouped under collaboration-based strategies (Beske and Seuring 2014). Examining the literature on sustainable procurement and supply chain in the context of the textile and garment industry, articles can be broadly classified into the categories of supplier selection and assessment and collaboration. These are illustrated in Fig. 5.1.

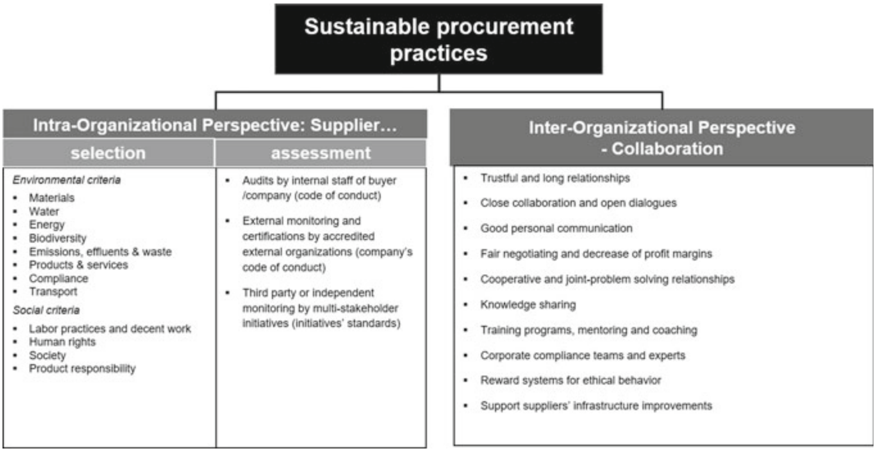

Fig. 5.1 Overview of sustainable procurement practices in the textile and garment industry (*source* developed by the authors based on the literature discussed in this study following the GRI criteria)

(c) *Supplier Selection and Assessment*

The first category of sustainable buying practices (defined here as buyer–supplier activities and procedures which make up the sourcing process) consists of **supplier selection and supplier assessment.** Selection refers to pre-qualification requirements, and assessment is the subsequent verification of the sustainable practices of suppliers (Winter and Lasch 2016). These steps are also referred to as supplier selection and monitoring (Moretto et al. 2018). Sustainable supplier selection criteria can concern ecological or social aspects (Turker and Altuntas 2014) and are the first step of adopting sustainability in purchasing decisions (de Brito et al. 2008) and therefore orientating the supply chain toward a more sustainable focus.

In their empirical study of the textile and garment industry, Winter and Lasch (2016) focus on three main ecological purchasing criteria:

- *End-of-pipe control (wastewater treatment system)*—concerned with fulfilling legal minimum requirements of waste water, e.g., using of wastewater and sewage plants, wastewater filtering and return systems and the disposal of wastewater sludge by suppliers (Winter and Lasch 2016, 187).
- *Use of environmentally friendly material*—ensured with the help of environmental standards like the European Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) regulations. For example, buyers can decide between recycled wool or virgin wool as a material and are thus considering environmental aspects in the purchasing process (Clancy et al. 2015).
- *Carbon and hazardous substance management*—requires fulfillment of legal requirements of treating chemicals and further toxic substances, e.g., by providing safety data sheets for chemicals, safe disposal and training on handling chemicals (Winter and Lasch 2016, 187).

These purchasing criteria link to the disclosure guidelines from the Global Reporting Initiative (GRI) G4, which includes materials used, water, energy, biodiversity, emissions, effluents and waste, products and services, compliance and transport (Global Reporting Initiative 2013).

Integrating social criteria into purchasing decisions can also draw on the variety of social indicators included in these guidelines and derived from international standards such as the International Labor Organization (ILO) Convention, United Nations (UN) Global Compact, Universal Declaration of Human Rights, sector-specific organizations and guidelines such as Oeko-Tex 100 Standard, Fair Wear Foundation and other initiatives such as the Ethical Trading Initiative (ETI) or the Business Social Compliance Initiative (BSCI). Criteria can be divided into labor practices and decent work (e.g., equal remuneration for men and women), human rights (e.g., no forced of compulsory labor), society (e.g., anti-corruption) and product responsibility (e.g., customer health and safety) (Global Reporting Initiative 2013). These can be further sorted by internal (health and safety, quality of workers' life and worker rights) and external (local community support, inclusion of marginalized workers and social safety for the community) social performance (Huq et al. 2016). Criteria are then transformed to a company's *code of conduct* (Turker and Altuntas 2014, 846) which suppliers are the requested to sign by buyers in order to guarantee the fulfillment of their standards (Caniato et al. 2012). However, the effects of such voluntary codes of conducts are disputed and do not necessarily guarantee decent factory conditions (Bartley and Egels-Zandén 2015). Instead, it is shown that codes of conduct have an uneven impact and that they may improve overall workers' rights conditions but not for specific individual-level rights (Egels-Zandén and Merk 2014; Egels-Zandén and Lindholm 2015). Another aspect is to consider when making purchasing decisions are the regions where fulfillment of social criteria is more likely (Hansen and Schaltegger 2013; Perry and Towers 2013).

The assessment of suppliers' practices for verification can be conducted in several ways. One option is to carry out a supplier preselection using self-reported data on sustainability aspects (e.g., implementation of environmental management systems). Other options include supplier ratings and rankings, overall performance assessments, required criteria catalogues, as well as audits (Günther 2008). Köksal et al. (2017) differentiate between audits (physical inspections often carried out by internal staff of the buyer conducted at the production site and documenting the status quo), external monitoring and certification, and third-party monitoring or independent monitoring involving appointing "accredited external organizations, including large accounting firms, professional service firms, quality testing firms, and small non-profit organization to monitor compliance with codes" (Köksal et al. 2017, 15). Third-party monitoring "is widely acknowledged to be more competent, credible and transparent than a buyer's own audit" (Huq et al. 2016, 22). Huq et al. (2016) also name external monitoring, which is done by multi-stakeholder initiatives and often according to the standards associated with the initiatives. Suppliers often use this method for obtaining recognized accreditation. However, research indicates that factory audits are seldom able to identify process rights violations (Egels-Zandén and Lindholm 2015) and improvements are only likely to be observed at factories that have undergone numerous audits (Lindholm et al. 2016).

(d) Practical Examples of Sustainable Purchasing Strategies

The German sports apparel producer Vaude, considered a high performer around sustainability issues, considers ecological (e.g., chemical and environmental management) and social criteria when choosing suppliers. Vaude's environmental policy includes a self-developed Manufacturing Restricted Substance List (MRSL) for suppliers, which bases and exceeds the Greenpeace Detox Commitment MRSL and fulfils the REACH regulation. Furthermore, the company introduced the Greenpeace Detox Commitment Waste Water Guideline as a standard for its suppliers in 2017, and the publication of wastewater test results (80% of material's volume (Vaude 2018a, 1) were introduced in 2018. Regarding sustainable materials, Vaude's material policy considers production conditions, such as using only Responsible Wool Standard certified wool (Vaude 2018a) and a significant share of used cotton certified by the Global Organic Textile Standard (GOTS). Vaude's social criteria are based on the International Labor Organization (ILO) and Fair Wear Foundation (FWF) Code of Labor Practices which is mandatory for all its essential suppliers and the company states to work on the integration of suppliers' information for more informed sourcing decision-making (Vaude 2018b).

Outdoor clothing company Patagonia also developed its social criteria for its supplier code of conduct from ILO standards and are referred to directly in its sustainability report (e.g., no child labor, no forced labor, no discrimination, no disciplinary and security practices, freedom of association, working hours, employment compensation, health and safety practices, employment conditions, local community support), while others are mentioned indirectly (employment contract and working permission, inclusion of marginalized workers, social safety for the community). Two criteria are not mentioned at all (housing conditions, home worker conditions); Winter and Lasch (2016) categorize these as being detailed and new criteria which should be included alongside existing sustainability criteria. Environmental criteria are included in a general point concerning monitoring, disclosing and minimizing energy and natural resource usage, emissions, discharges, carbon footprints and waste disposal. Moreover, the code of conduct includes not previously mentioned criteria such as subcontracting only with prior written approval, respecting animal welfare, quality standards and traceability of all levels of supply chain (Patagonia 2013).

The European sportswear manufacturer Adidas uses supplier assessments to ensure compliance with their set standards, and it reports against it in detail. Audits which are internal and external, unannounced and announced are conducted regularly at production locations in Asia, America and Europe, the Middle East and Africa (EMEA). These are based on a rating system with social and environmental KPIs and attached scores, which then can lead to trainings, warning letters or even contract terminations. In 2017, around 1000 audits (Adidas 2018, 95f.) at supplier factories, of which 409 were internal (in-house technical staff) and 606 external (third-party monitored commissioned by Adidas business entities and licensees) audits were conducted. These audits covered 48% of all active suppliers (neglecting factories in "low-risk" countries) and around 70% of "high-risk" locations in Asian countries. The results of social compliance assessments in 2017 show that around 50% of the assessed factories are at a medium, around 20% have a higher and around 30% a lower level of social compliance. The environmental KPIs are not reported in detail in the report. Besides internal and external audits by Adidas itself or appointed officers, four independent external factory assessments or remediation verification exercises were conducted by the Fair Labor Association (FLA), an NGO which promotes international and national labor laws in 2017. The annual report contains further results and details an action plan to improve factories' environmental and social compliance performance (Adidas 2018).

As can be seen from the above discussion of sustainable purchasing practices drawing on practical examples, the full spectrum of supplier selection (e.g., GOTS, ILO, Greenpeace Detox Commitment) and assessment (e.g., internal/external audits, scoring system based on social and environmental KPIs) are discussed in sustainability reports of leading firms in the garment industry.

(e) Collaboration

The second category of sustainable buyer practices is centered on **collaboration** (Beske & Seuring 2014). Recent literature in this field places greatest attention on trustful and long relationships between buyers and suppliers. Buyers choose trustworthy suppliers with priority as they are more likely to fulfill set (sustainability) criteria, even if they are not undergoing formal audits or inspections (Boström et al. 2012). As well as easier fulfillment of sustainability criteria, the positive economic effects of long and secure relationships are welcomed by buyers, for example due to the predictable fulfillment of delivery times, mutual trust on both sides as well as easier access and understanding between buyers and suppliers (Boström et al. 2012). Trust also facilitates information sharing and lowers costs and can also lead to (sustainable) innovations (Franco 2017) and higher agility along the supply chain (Perry and Towers 2013). Long-term relationships offer positive effects in contrast to short-term benefits (Turker and Altuntas 2014; Roloff et al. 2015; Huq et al. 2016). These positive effects for buyers might be "evidence of consistency and reliability" (Towers et al. 2013, 968) and to reduce the need for control (Börjeson et al. 2015).

Close collaboration is "essential to diminish the barriers to successful policy implementation within the highly competitive textile industry" (Oelze 2017, 11) and open dialogue with suppliers is a key practice for more sustainability (Stevenson and Cole 2018). Cooperative relationships are also focused on "analyzing and correcting root causes of social issues, joint problem solving, mentoring, coaching, learning, capacity building, positive incentives" (Köksal et al. 2017, 14). Other forms include providing training programs or supporting infrastructure improvements for suppliers. Training programs can for example include the topic of detecting and remediating unfair labor practices (Stevenson and Cole 2018). Another form of positive collaboration is decreasing profit margins and lead times and therefore supporting higher wages of factory workers and reducing overtime on the factory floor. Such fair negotiation practices are key for improving sustainability within the supply chain of the textile and garment industry (Köksal et al. 2017). Further, knowledge sharing with the suppliers and actors along the supply chain is an important aspect that contributes to successful collaboration (Moretto et al. 2018). This may include clear explanation of requirements and their underlying reasons between buyers and suppliers, as well as outlining the benefits of going beyond legal requirements, knowledge on substitutes and more (Börjeson et al. 2015). To facilitate knowledge sharing, experts may be involved (Börjeson et al. 2015) or corporate compliance teams may be formed in order to improve supplier communication, provide training and hands-on knowledge (Köksal et al. 2017). Finally, good personal communication plays an important role (Boström et al. 2012), as does the introduction of a reward systems for ethical behavior (Li et al. 2014). The sustainable buying practices discussed above are summarized in Fig. 5.1.

As a practical example, Vaude reports on a variety of sustainable buying measures such as a focus on trust-based, long-term relationships with suppliers, close collaboration, direct business connections and dialogue with manufacturers and material suppliers, as well as fair negotiation practices. According to Fair Wear Foundation inspections, high wage levels above statutory minimums are paid at Vaude's producers. Further, the company strives to build cooperative relationships offering supplier training programs and infrastructure support to aid the implementation and improve suppliers' sustainability performance (Vaude 2018b). Another example includes Adidas' worker empowerment program, which was initiated in 2012 in Indonesia and focuses on improving management–worker communication to supplement existing grievance systems. The scheme has since been extended to 69 factories in four countries (Adidas 2019). In addition, Adidas strives to build long-term partnerships and the company provides various trainings around workplace standards, health and safety, supplier self-assessment methods, etc., to its suppliers to raise overall performance (Adidas 2019). Patagonia regularly meets with its suppliers to receive updates and to share best practice in a dialogic manner (Patagonia 2019).

5.3 Implementation Gap for Sustainable Textile and Garment Procurement

Sustainable textile and garment procurement practices can be divided into collaboration and supplier selection and assessment as outlined above. However, the application of these practices may not reach full effectiveness given the "different interests and asymmetric information…such that one player cannot directly ensure that the other player is always acting in mutual best interests, particularly when activities that are useful to one player are costly to another, and where elements of what the other player does are costly to observe" (Gong et al. 2018, 155) which may give rise to implementation barriers as a result of lacking trust and transparency between buying and supplying firms, as well as high costs in rectifying misalignment and misunderstandings (Oelze 2017). Therefore, we will now explore the underlying dynamics, namely barriers and drivers, for sustainable purchasing decisions building on the established body of work on green procurement in municipalities (Günther and Scheibe 2006; Guenther et al. 2013). Köksal et al. (2017, 8) define barriers as "factors that hinder focal companies in the implementation, realization and achievement of sustainable supply chain management practices" and drivers as "factors that initiate and motivate focal companies in implementing sustainable supply chain management practices" (2017, 8). The successful implementation of strategic sustainability approaches depends on how a company can strengthen drivers and inhibit barriers (Macchion et al. 2018). The identified barriers for the textile industry are highlighted in Fig. 5.2:

On the individual buyer level, drivers for sustainable purchasing include the intrinsic motivation of individuals (Oelze and Habisch 2018), the integration of sustainability into corporate values and (strong) commitment of the (top) management (Caniato et al. 2012; Moretto et al. 2018), good knowledge on sustainability aspects so buyers can make well-informed decisions (Clancy et al. 2015), innovation capabilities of individuals yielding new markets, management systems, and performance outcomes considering sustainability (Huq et al. 2016), as well as open communication (Roloff et al. 2015). In contrast, communication problems such as insufficient or missing communication, as well as cultural differences and language

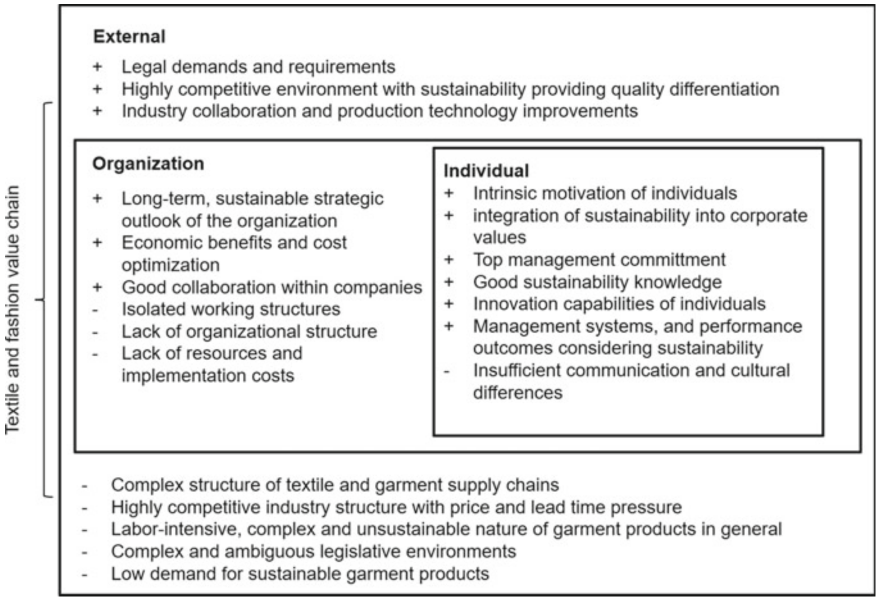

Fig. 5.2 Summary of the barriers (−) and drivers (+) to sustainability procurement practices in the textile and fashion value chain (*source* developed by the authors based on the literature discussed in this study)

problems are mentioned as barriers (Boström et al. 2012). Another barrier mentioned in the literature is the lack of intrinsic motivation of individuals (Oelze 2017).

At the organizational level, the main drivers for adoption of sustainable purchasing decisions are long-term, sustainable strategic outlook of the organization (Perry and Towers 2013), economic benefits and cost optimization (Caniato et al. 2012; Perry and Towers 2013; Li et al. 2014; Macchion et al. 2018), as well as good collaboration within companies (Oelze 2017). Organizational barriers to sustainable practices include isolated working structures (Boström et al. 2012), lack of organizational structure (Oelze 2017), additional coordination requirements (Seuring and Müller 2008), lack of resources due to a small company size (Oelze 2017), as well as implementation costs (Macchion et al. 2018).

The complex structure of textile and garment supply chains is one of the most pressing external barriers to more sustainable purchasing decisions (Perry and Towers 2013; Karaosman et al. 2016; Franco 2017). Further external barriers include the highly competitive industry structure with price and lead time pressure (Perry et al. 2015; Oelze 2017), as well as the labor-intensive, complex and unsustainable nature of garment products in general (Boström et al. 2012; Perry and Towers 2013). Complex and ambiguous legislative environments (Boström et al. 2012; Oelze 2017) which lack clear guidance (de Brito et al. 2008; Carrigan et al. 2013) are also said to hamper sustainable purchasing practices along the supply chain, and this is particularly the case in developing countries with weak governance (Karaosman et al. 2016).

5.4 Discussion and Propositions

In recent years, consumers are progressively demanding that the textile and garment industry in addressing the environmental and social issues prevalent in the sector (Gardetti and Torres 2013) and pressure on the industry mounting as a consequence of the Rana Plaza building collapse in 2013 (Reinecke and Donaghey 2015). This has resulted in the apparel brands and retailers at the top of the garment supply chain being increasingly seen as jointly responsible for the conditions in the factories of their suppliers and contractors (Anner et al. 2013). Consequently, there has been a renewed focus on risk management in global garment production networks, with lead firms and their buyers acting as "gatekeepers" which hold significant power over sustainability standards in the industry (Ven 2018). They have an important role to play in addressing these sustainability challenges and can effect change by adopting a focus on sustainable products sourced from responsible suppliers. From reviewing contemporary academic literature in this field, we can draw three main propositions which can be investigated further in future studies.

Proposition 1 Comprehensive and long-term collaborative approaches to procurement fosters sustainability outcomes.

While the sustainable procurement process includes a whole range of decision processes concerning processes ranging from product design to end of life, we find that the literature examining sustainability in the textile industry adopts a fragmented approach with studies focusing on these stages in situ, with the majority concentrated on buyer–supplier relationships from an operational perspective. These strategies build around supplier development programs which aim to build long lasting supply chain relationships (Perry et al. 2015; Köksal et al. 2017; Oelze 2017), utilizing supplier assessment and selection strategies in the procurement process to ensure suppliers comply with environmental and social standards (Winter and Lasch 2016; Moretto et al. 2018) set out in supplier codes of conduct (Turker and Altuntas 2014; Huq et al. 2016). Collaboration-based supply chain strategies focused on supplier development represent a departure from the traditional, transaction-based, short-term relationship supply chain management paradigm where lead firms search out alternative supplier in case of dissatisfaction instead of upgrading supplier capabilities. This recent development can be linked to the fast fashion supply chain model, which requires collaborative networks to allow for better supplier responsiveness. Increasing frequencies of fashion cycles, altering consumer demands and short product life cycles require high levels of agility to deal with reduced lead times, which can best be achieved via long-term relationship-based supply chain relationships (Perry and Wood 2018).

Proposition 2 Increased knowledge and training in procurement personnel increases pro-sustainable practices.

Intensified buyer training in relation to sustainable production and consumption would provide a necessary basis for better informed decision-making in the procurement process. Greater awareness of product lifecycles allows buyers to consider how the product will be used and can improve their decision-making in relation to durability, potential for repair and longevity of the product. In this case, buyers can select fabrics requiring less detergents and can be cleaned in cold water, reducing environmental impacts during usage phase. By conducing results from Life Cycle Analysis (LCA) covering environmental and social impacts from garment production and maintenance (Gibbon and Dey 2011; Kozlowski et al. 2012; Guenther et al. 2013), optimized decisions can be made during the design phase. Other tools such as Material Flow Cost Accounting (MCFA) can be used to calculate the full costs of waste and aid developing operational efficiencies (Schaltegger et al. 2012; Kasemset et al. 2015). The results from these assessment tools can be a useful tool for buyers when making procurement and purchasing decisions (Krozer 2008) and can be integrated with further Product Lifecycle Management (PLM) tools, minimum activity/component-based costing, and building price from costs up to help negotiate fairer prices. These managerial techniques can be combined with introducing targets and bonuses linked to responsible sourcing in order incentivize consideration of environmental and social criteria into purchasing decisions and subsequent supply chain management strategies.

Proposition 3 Realizing sustainable outcomes form procurement practices is reliant on consumer demand and legislative environments.

Many of the sustainable purchasing strategies such as voluntary codes of conducts and supplier audits have been shown to have significant limitations (Egels-Zandén and Merk 2014; Bartley and Egels-Zandén 2015; Egels-Zandén and Lindholm 2015; Lindholm et al. 2016). Further, our review of literature has also highlighted that there are manifold barriers to the adoption of more sustainable purchasing practices, which include but are not limited to the highly competitive industry structure with price and lead time pressure (Perry et al. 2015), cost of implementation and lack of resources (Oelze 2017; Macchion et al. 2018), ambiguous legislative environments (Boström et al. 2012; Oelze 2017), as well as the labor-intensive, complex and unsustainable nature of garment products in general (Boström et al. 2012; Perry and Towers 2013). Further, low demand for sustainable garment products is also stated as a barrier (Illge and Preuss 2012; Towers et al. 2013; Franco 2017).

Such consumer-driven conceptualization of garment demand is problematic, as lead firms play an important role in offering responsible products and creating demand for these products. Yet, textile and garment retailers and brands rarely tackle consumption issues, which are linked to the fast fashion business model (Lohmeyer and Schüßler 2018) as this would threaten the operational success which is built on selling large volumes of mass produced garments. However, this would be an integral step in tackling the significant wastage and unsustainable consumption of textiles and garments. However, a reduction in textile consumption could also mean job losses in producing countries, thus negatively impacting on workers there and creating a trade-off. Against the backdrop of the discussion of barriers toward implementation of adopting more sustainable purchasing at the lead firm level, we would like to highlight and draw attention to recommendations on how these barriers may be overcome. While reducing many of the barriers requires changes at the institutional level via an intensified focus on clear legislative and regulatory structures and governance mechanisms, we would like to limit our recommendations to the organizational and individual level to provide practical guidance for buyers at apparel brands and retailers.

5.5 Conclusions

Our review of the literature above demonstrates that there is a range of buying mechanisms and instruments that can be introduced to further sustainability in the textile value chain. It is highlighted that most studies adopt a fragmented, flash light approach to sustainable procurement, only focusing on certain stages of the procurement process. Such an isolated approach brings certain limitations with it as it lacks a comprehensive, systematic framework while also only focusing on operations without considering the strategic perspective examining the policy and control dimension. While the literature discussed in this section presents a good starting point, we see a potential for more systematic research on sustainable procurement in the textile industry building on comprehensive green procurement frameworks already applied in other contexts (Günther and Scheibe 2006; Guenther et al. 2013). Further, in this overview, we refer to the drivers and barriers for implementing ecological and social criteria into purchasing decisions as part of procurement and supply chain management strategies in the textile industry. However, it is important to note that there are numerous factors which influence procurement and supply chain decision-making in the industry, and therefore, a more comprehensive approach is required to draw concrete conclusions on how to develop an operationally and strategically successful supply chain management structure in the textile and garment industry.

There exists a large scope for future work in this field to take a systematic and holistic approach to examining the full extent of procurement processes in generating sustainable outcomes across the entire textile value chain. This section provides an overview of the key challenges facing the industry and future studies should address the extent to which long-term collaboration is more effective at creating efficient, responsive and sustainable textile value chains that minimize environmental and social impacts, or whether the existing business models can be adapted to value sustainable characteristics in the same way that cost, time and quality are currently valued. A second stream of work should focus on the knowledge capabilities and requirements for procurement managers in order to analyze and process the data required to comply with demands from auditors and external monitoring agencies, while a third stream of work should consider the wider institutional arena, taking into consideration consumer psychology toward sustainable consumption and the legislative environment which places pressure on procurement actors to move toward sustainability outcomes. Furthermore, we encourage future research to take a systematic approach toward the types of companies surveyed in terms of institutional environment, size (the experiences of SMEs compared to multinational companies are likely to differ markedly) and market type (i.e., mainstream or niche market) to fully understand how buying practices and procurement processes vary across a wide range of institutional and organizational contexts.

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Chapter 6
Sustainable Chemistry—Path and Goal for a More Sustainable Textile Sector

Lisa Keßler and Klaus Kümmerer

Abstract This chapter aims to portray the concepts of green chemistry (GC) and sustainable chemistry (SC) with regard to the textile sector and in response to the increasing challenges of the sector in terms of sustainability. It highlights potentials and pitfalls and offers concrete examples and practices of SC relevant for the textile industry. The textile sector is one of the most polluting industries in the world, contributing 20% to total industrial pollution of the water resources. In total, 5 billion kg of dyes, pigments and finishing chemicals are currently in use in the textile industry, adding up to more than 8000 different chemicals utilized for garment production. Moreover, extensive resource use (e.g., fossil fuels, processing chemicals, water etc.) in combination with unhealthy, exploitative working conditions pose a myriad of challenges involving all dimensions of sustainability. Once introduced into a process or product, chemicals and their products of unwanted side reactions and of incomplete mineralization in effluent treatment, so-called transformation products (TPs), are likely to remain a concern throughout the product's lifecycle and even beyond. For example, textiles at their life's end, so-called post-consumer textiles, still contain up to 90% of the chemicals that were initially introduced during manufacturing or finishing. This high amount of chemical residues on textiles (only partly washed out during laundry) is not only problematic in terms of resource use, but it is also an environmental threat. Residues are continuously released due to limitations in conventional wastewater treatment and form waste and dump sites affecting human health and well-being. The aforementioned sustainability issues arising during textile production, distribution, use and disposal are inextricably linked to societal and cultural systems. The complex, dynamic and highly intertwined nature of these

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sustainability challenges in the textile sector calls for both a focus on input prevention of chemicals and a strong normative premise of intentionally beneficial design of chemicals that are not harmful to the environment and human health. Sustainable chemistry has become an emerging concept in response to various sustainability challenges associated with the production, distribution, use and discharge of chemicals and products. It has been acknowledged by UNEP as an important cornerstone in achieving the Sustainable Development Goals (SDGs) and servers as a core concept within the Global Chemical Outlook II. Whilst green chemistry mainly addresses the synthesis of chemicals and some of their properties, SC reaches beyond the disciplinary boundaries of chemicals and their usage by a systems thinking approach. Being both a path and a goal, SC can act a beneficial umbrella concept for addressing the highly complex sustainability challenges regarding chemicals in the textile sector. Its specific potentials for the textile sector have not been studied hitherto and lie in its focus on input prevention, which influences not only production or wet processing of textiles, but the entire supply chain—including up- and downstream users—even beyond the product's end of life. Practiced of SC within the textile industry addresses spatial as well as temporal scales, flows and dynamics of chemicals, materials and products and hence addresses drivers of highly complex and currently unsustainable practices. Specific examples and practices of SC within the textile sector will be described in-depth such as new business models (e.g. chemical leasing).

Keywords Textile sector · Chemicals management · Green chemistry · Sustainable chemistry · Sustainability challenges

List of Acronyms

APEO(s)	Alkylphenol ethoxylate(s)
BAT(s)	Best available technique(s)
BFR(s)	Brominated flame retardant(s)
CEFIC	Conseil Européen des Fédérations de l'Industrie Chimique; European Chemical Industry Council
COD	Chemical Oxygen Demand
DWR(s)	Durable Water Repellent(s)
EPA	Environmental Protection Agency
GDCh	Gesellschaft Deutscher Chemiker
GHS	Globally Harmonized System of Classification, Labelling and Packaging of Chemicals
GPS	Global Product Strategy
HPV	High Production Volume (Chemicals Programme)
ICCM	International Conference on Chemicals Management
IED	Industrial Emissions Directive
IPPC	Integrated Pollution Prevention and Control
IUPAC	International Union of Pure and Applied Chemistry

IVU	Integrierte Vermeidung und Verminderung der Umweltverschmutzung (English: Integrated Pollution Prevention and Control, IPPC)
LCA	Lifecycle Assessment
LRI	Long-Range Research Initiative
MEA(s)	Multilateral Environmental Agreement(s)
MRSL(s)	Manufacturing Restricted Substance List(s)
NGO(s)	Non-Governmental Organisation(s)
NSF	National Science Foundation
OECD	Organisation for Economic Co-operation and Development
PFAS(s)	Per- and/or Polyfluoroalkyl Substance(s)
PVA	Polyvinylalcohol
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RSL(s)	Restricted Substance List(s)
SAICM	Strategic Approach to International Chemicals Management
SDGs	Sustainable Development Goals
SVOC(s)	Semi-Volatile Organic Compound(s)
TP(s)	Transformation Product(s)
USA	United States of America
UBA	German Environment Agency
UK	United Kingdom of Great Britain
UNCED	United Nations Conference on Environment and Development
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNSDS	United Nations Sustainable Development Summit
VOC(s)	Volatile Organic Compound(s)
WSSD	World Summit of Sustainable Development
ZDHC	Zero Discharge of Hazardous Chemicals

6.1 Introduction

The textile sector is growing and producing more and more articles. Along with that, volumes and diversity of substances used as building blocks, processing chemicals or for functionalisation of products are increasing. While this development has more than ever a global dimension, it leads to socio-economic development in the Global South and to huge sustainability challenges over different scales of space and time alike. The importance of chemicals for the textile sector and current chemical risk management approaches will be presented and discussed in this chapter including specific characteristics of the sector that constitute the current sustainability challenges associated with chemicals in textile production. A special focus will be placed on the concepts of Green and Sustainable Chemistry, which offer new perspectives for production, use and management of chemicals within the textile sector. The characteristics of Green Chemistry and Sustainable Chemistry as well as their respective specific potential for application in the field of textile chemicals will be described and highlighted. Last, but not least, different practices are presented to shed light on current efforts from the sector itself and academia aligning with the principles of Green Chemistry and Sustainable Chemistry in order to provide tangible examples on the one hand and entry points for further innovations on the other hand.

6.2 Use and Management of Chemicals Within the Textile Sector

In the following section, different types of chemicals used in the textile sector and their respective volumes will be described. Furthermore, a closer look will be taken on potential release and exposure routes concerning environmental compartments and human beings. Finally, past and current management actions will be presented.

6.2.1 Types and Volumes of Chemicals and Processes Involving Chemicals

The textile sector is one of the most polluting industries in the world, contributing 20% to total industrial pollution of water resources (Kant 2012). Whereas the Swedish Chemicals Agency compiled a non-exhaustive list of more than 1900 chemicals (KEMI—Swedish Chemicals Agency 2013), Scott (2015) states that more than 8000 different chemicals are used for today's garment production. Since some of the chemicals in use are considered confidential and, hence, remain unknown to the public, differing numbers may occur (KEMI—Swedish Chemicals Agency 2013). Nevertheless, it has been estimated that in total 5 billion kg of dyes, pigments and finishing chemicals are currently in use per year in the textile industry (Nimkar 2018). Among them are at least 165 substances which have been classified in the EU as hazardous to human health, for being either carcinogenic, mutagenic or toxic to the reproductive system, or for showing sensitising effects either onto the respiratory tract or the skin. Others have long-term adverse effects on the environment, e.g. the aquatic system (KEMI—Swedish Chemicals Agency 2013). In addition to the risk posed by those parent compounds products of incomplete degradation of chemicals, so-called transformation products (TPs), can be formed in common wastewater treatment processes, like UV irradiation, ozonation and clorination (Kümmerer et al. 2019; Leder et al. 2015).

Since textiles comprise a huge variety of different products, the chemical substances included in the article itself or its production processes and their respective impact vary accordingly, as do their individual properties (EEA—European Environmental Agengy 2014). This in turn impairs a proper risk assessment and handling along the supply chain—or even renders it impossible. The following factors identified in the Environmental Indicator Report (EEA—European Environmental Agengy 2014) may determine and influence the set of chemicals and their properties associated with a textile article and its production process:

- fibre type and chemical properties of the fibre(s) itself
- production method
- performance requirements of the product
- use-phase characteristics
- end-of-life treatment.

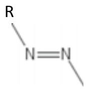
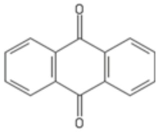
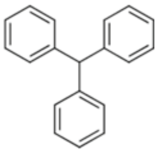
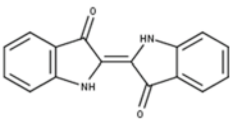
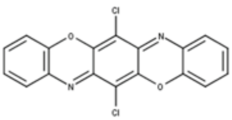
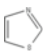
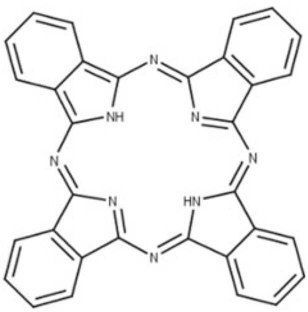
Starting with the fibre type, chemicals are involved from the very beginning of the textile supply chain. Petroleum-based man-made fibres require chemicals in fibre production and processing and finishing chemicals later on. Even natural fibres such as cotton require apart from enormous amounts of water for growing—additional chemicals such as pesticides and fertilisers during conventional fibre production. The majority of chemicals—both in terms of volumes and diversity—is used during wet processing. This phase involves different pre-treatment processes such as desizing, scouring, bleaching and mercerising, followed by dyeing or printing. Depending on performance requirements and desired use-phase characteristics, textile products finally undergo a finishing process, e.g. biocidal, anti-wrinkle or flame-retardant equipment.

Depending on the occurrence and combination of the aforementioned factors and the resulting wet processing steps, many different functional chemicals, auxiliaries and also unintended chemical substances, being present as impurities or degradation products, can either be part of a textile product or its respective production process including effluent and air treatment.

Functional substances mostly remain in the fabric or on top of the fabric's surface after the production process and comprise different functional classes of chemicals such as dyes and pigments (see Table 6.1), oil and water repellents, flame retardants, anti-creasing agents, anti-shrinking agents, plasticisers, biocidal substances, stabilisers, etc.

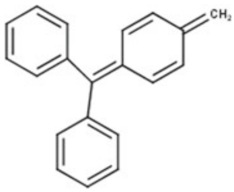
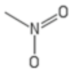
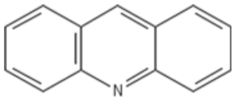
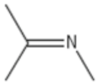
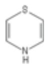
Auxiliaries are intended to only be present at a certain step in the production process where they exert their facilitating function. Organic solvents, surfactants, salts, softeners, acids and bases are used as auxiliary substances as well as biocides when used as preservatives during storage or transport of the textile products. Nevertheless, some auxiliaries can at the same time represent contaminations if their residues or their degradation products still occur in the final textile product (e.g. biocides used as preservatives or residues of processing chemicals since they remain on the fabric at least until the first laundry). Some reactive resins used for finishing treatments of textiles release formaldehyde or other volatile or semi-volatile organic compounds (VOCs/SVOCs) into the indoor air or directly onto the skin (Aldag et al. 2017; Piccinini et al. 2007). Azo dyes and pigments, for example, have been found to degrade into toxic arylamines (Le Marechal et al. 2012). The large diversity and quantity of chemicals, processes and their interconnectedness in textile manufacturing lead to an **individual chemical fingerprint** for each textile product. This makes it even more difficult to establish a proper risk assessment and to increase

Table 6.1 Examples of different functional groups of chemical classes of dyes used in textile manufacturing illustrating the high diversity within a single group of chemicals used (within each chemical class there are several different individual compounds)

Chemical class	Structural chemical formula	Method of application	Example
Azo		Direct, Reactive, Acid, Mordant, Disperse	Disperse Yellow 241
Anthraquinone		Reactive, Vat, Acid, Mordant, Disperse	Acid Blue 25
Triphenylmethane		Acid	Malachite Green
Indigo		Vat	Vat Blue 1 (Indigo)
(Di-)Oxazine		Direct, Reactive, Mordant, Basic	Pigment Violet 23
Thiazole		Direct	Indanthren Blue CLG
Phthalocyanine		Direct, Reactive	Pigment Green 7

(continued)

Table 6.1 (continued)

Chemical class	Structural chemical formula	Method of application	Example
Di-/Triarylmethane		Mordant, Basic	Methyl Violet 2B
Nitro		Disperse	Acid Orange 3
Acridine		Basic	Acridine Orange
Methine		Basic	Basic Yellow 11
Thiazine		Basic	Methylene Blue
Sulphuric	Different structures		Sulphur Red 6

sustainability of textiles. In combination with long and complex supply chains on a global level, this leads to a high level of uncertainty about the substances in textile articles and their respective concentration ranges (KEMI—Swedish Chemicals Agency 2014). Hence, once introduced into a process or product, chemicals or their transformation products are likely to remain a concern throughout the product's life cycle, and even beyond.

6.2.2 *Release of Chemicals into the Environment and Exposure Routes*

Possible release mechanisms and exposure routes along the textile supply chain are shown in Fig. 6.1. Unintended or intended release occurs at the production site into water and sediment, air or soil (sludge) or from the final product during storage, transport, distribution and use, and at the end of the products life after disposal by dissolution, desorption, volatilisation, incomplete degradation, etc. Potential release patterns of chemicals highly depend on their physico-chemical properties like

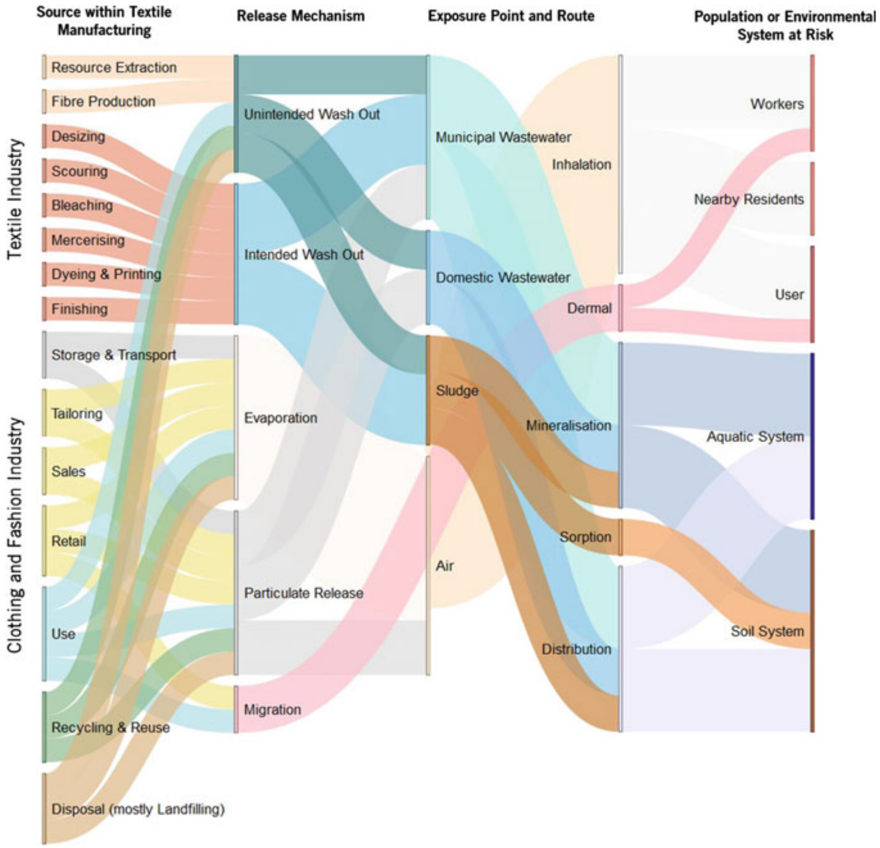


Fig. 6.1 Sources, release mechanisms, exposure points and routes and populations and environmental systems at risk along the textile supply chain regarding chemicals

vapour pressure, polarity, partition coefficients, e.g. *n*-Octanol/Water (P_{OW}), solubility, stability, etc. Therefore, release patterns and exposure routes are substance- and product-specific.

In the following section, three exemplary release patterns and subsequent exposure routes along the textile supply chain will be described in detail, even though other complex release patterns are also relevant for textile chemicals (see Fig. 6.1).

(a) Release from production processes or textile products during textile manufacturing

Release from textile production includes resource extraction, raw material production such as fibres and basic chemicals, and textile production itself. Direct release of untreated effluents or insufficient effluent treatment processes (either in-house or municipal) can create serious environmental and health-related risks by chemicals and their degradation products (Kümmerer et al. 2019, 2018). Since textile production mostly occurs in countries of the Global South, and hence in the absence or under conditions of insufficient enforcement of strict environmental legislations, measures for proper and effective effluent treatment are lacking (Busi et al. 2016; KEMI—Swedish Chemicals Agency 2014; Kümmerer and Clark 2016). Moreover, transformation products as the result of incomplete mineralisation of chemicals in effluent treatment can pose in some cases even greater risks than the parent compounds, e.g. *N*-nitrosodimethylamine (NDMA) formation by oxidative treatment (Kümmerer et al. 2019). Via the release of untreated or insufficiently treated wastewater into the aquatic environment, effluents containing potential micro-pollutants can reach the agricultural soil system and subsequently the food web either unintended or by water reuse practices (Kümmerer et al. 2018, 2019). While effluent treatment is currently in the focus of textile companies, the large amounts of sludge generated and the resulting air emissions are not yet (Nimkar 2018).

(b) Release from textile products during storage, transport, distribution and use

During storage of unpacked textile articles, particulate release of fibres containing chemicals and evaporation of volatile compounds may occur. Both dust and gaseous emissions pose a considerable exposure risk for people working in storage and packaging facilities. When transported and distributed to the consumer, additional (chemical) waste is created by using packaging material which contains chemicals itself, and contributes to environmental pollution due to resource extraction and production of plastic, paper and card board packaging. During retail, employees also have a considerable exposure risk due to evaporation, particulate release, and also dermal exposure of the hands, especially during unpacking and sorting of textile products (KEMI—Swedish Chemicals Agency 2014). Once textile articles are in use, fibres and containing chemicals are subject to unique conditions and stresses like exposure to sun light, abrasion, high temperatures, exposure to body warmth, sweat, and saliva, and exposure to water and detergents during laundry. Some textile articles, like clothes and bed linen, are used in close skin contact for many hours. Depending on different factors (e.g. type of material; properties and concentration of chemicals; skin characteristics), migration and penetration into the skin can occur (KEMI—Swedish Chemicals Agency 2014; Zhong et al. 2011).

(c) Release from textile products at the end-of-life during disposal

In the EU, only a small share of textiles at their life's end, so-called post-consumer textiles, is collected and sorted for reuse (8%) or recycling (10%), whereas 24.9% are incinerated (with or without energy recovery), and the largest part of 57.1% is ultimately disposed by landfilling (KEMI—Swedish Chemicals Agency 2014). This practice creates enormous amounts of solid textile waste, and is hence highly problematic in terms of resource and material use both from a fibre perspective and a chemical perspective, since chemical synthesis usually has a high energy and material demand. Moreover, 90% of the chemicals that were initially introduced during manufacturing are still present in post-consumer textiles (Nimkar 2018). Those residues can subsequently be released into soil and water bodies by leaching from waste and dump sites, and consequently threaten human health and well-being as well as the environment due to limitations in wastewater treatment and the often either non-biodegradable and/or persistent and/or bioaccumulative, and sometimes even toxic nature of follow-up products of those substances (Kümmerer 2017).

6.2.3 Chemical Risk Management in the Textile Sector as Important Sustainability Challenge

In order to prevent release or at least minimise exposure risks for the environment and human beings, sound chemicals management measures need to be applied at every step in the textile supply chain. Due to global dissipation of chemicals—both raw materials and functional chemicals, auxiliaries or contaminations within the textile product (see Fig. 6.2)—chemical risks are neither limited to the actual supply chain nor to distinct places and times, but exceed beyond the textile article's life and beyond production sites (e.g. resource extraction, production and manufacturing, consumption, waste).

Therefore, current attempts of managing chemical risks by governments or the industry itself operate on a global or at least European policy level (see Fig. 6.3). Recent years have witnessed a growing number of voluntary associations in the textile sector like ZDHC (Zero Discharge of Hazardous Chemicals, https://www.

Fig. 6.2 Global trade of textile products and subsequent dissipation of contained functional chemicals, auxiliaries and contaminations between the EU-27 and other world regions, 2012 (from EEA—European Environmental Agency 2014, p. 110)

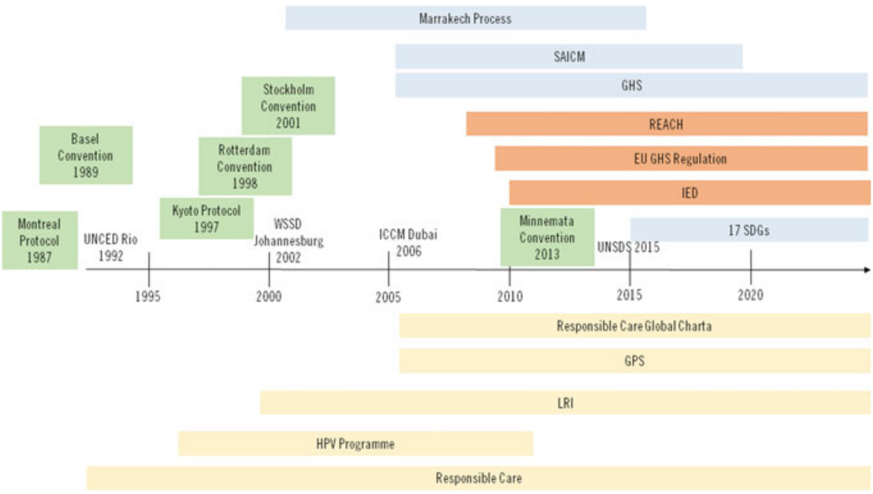


Fig. 6.3 Overview of different frameworks for chemicals management (green—MEAs; orange—regulations; blue—policy frameworks, processes or standards on international level; yellow—industry initiatives)

roadmaptozero.com/), Partnership for Sustainable Textiles (https://www.textilbuendnis.com/en/), use of RSLs/MRSLs (Restricted Substance List(s)/Manufacturing Restricted Substance List(s)) and the DETOX campaign of Greenpeace, etc., started off by different actors like companies, brands, NGOs or governments. The DETOX campaign, for example, focusses on the complete phase-out of eleven groups of chemicals (e.g. APEOs, PFASs, heavy metals, chlorophenols, BFRs) until 2020 rather than on compliance with threshold levels in wastewater or sludge.

6.3 Green Chemistry and Sustainable Chemistry

In the following part of the chapter, two concepts—Green Chemistry and Sustainable Chemistry—relevant for current sustainability challenges regarding chemicals in the textile industry, their origins and the relation between them will be introduced.

6.3.1 The Concept of Green Chemistry

In 1990, the U.S. Environmental Protection Agency (EPA) passed a law to reduce or prevent pollution at the source rather than treating and disposing unwanted toxic substances in industrial processes. With this so-called Pollution Prevention Act, the EPA—although being designed as a classical regulatory agency—created a national policy focusing no longer on conventional control approaches and end-of-pipe solutions but rather increasing interest of industry, government and public attention in pollution prevention and improved design in first place (Anastas and Warner 1998). Building on this legislation and other numerous efforts from regulatory bodies and academia (e.g. Richtlinie 96/61/EG 1996; OECD—Organisation for Economic Co-operation and Development 1998; Cathcart 1990), Paul Anastas and John Warner published in 1998 the following 12 principles of Green Chemistry as a summarising conceptual list to characterise a green chemical substance, product or process and to establish guidelines for the new research field.

The 12 Principles of Green Chemistry

1. Prevention
2. Atom Economy
3. Less Hazardous Chemical Syntheses
4. Designing Safer Chemicals
5. Safer Solvents and Auxiliaries
6. Design for Energy Efficiency
7. Use of Renewable Feedstocks
8. Reduce Derivatives
9. Catalysis
10. Design for Degradation
11. Real-time Analysis for Pollution Prevention
12. Inherently Safer Chemistry for Accident Prevention

(Anastas and Warner 1998).

A recent definition of Green Chemistry is provided by the EPA:

> Green chemistry is the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry applies across the life cycle of a chemical product, including its design, manufacture, use, and ultimate disposal. (https://www.epa.gov/greenchemistry/basics-green-chemistry)

Despite these seemingly straightforward 12 principles, it remains ambiguous how many of them need to be fulfilled in order to design a green product or process or if they are equally weighted (Kümmerer 2017). In case of the definition provided by the EPA, the characteristics of a substance classified as "hazardous" also leave room for interpretation—this might be a substance exerting acute and/or (sub-) chronic effects, being persistent and/or bioaccumulative or all together. Other than that, we argue that Green Chemistry does not sufficiently address aspects of why we use chemicals in the first place, how we could reduce substance, material and product flows and how rebound effects and entropic losses can be minimised. Addressing those fundamental questions do require a broader perspective on, e.g. competitive demands for resources and energy, alternative business models, economics and last, but not least, ethics. One telling example here is the enthusiasm about digitisation which often lacks a thorough consideration of the material basis. Not only the gadgets themselves are manufactured by using materials (e.g. non-renewable metals), but the enormous energy demand requires a material basis as well—even renewable energy technology (e.g. solar panels containing silicon).

6.3.2 From Green Chemistry to Sustainable Chemistry

In 1999, Hutzinger published an editorial in response to a controversial debate around the terms "Green Chemistry" versus "Sustainable Chemistry" within the Federation of European Chemical Societies, Division for Chemistry and the Environment. On the one hand, he affirmed the shared understanding that "dilution is not the solution to pollution, which led to the end-of-pipe mentality" (Hutzinger 1999, p. 123). On the other hand, he emphasised the different cultural-sociological factors that influence the meaning and connotation of terms—even in the scientific discourse held in English (Hutzinger 1999). While in the USA and UK, the term "green" received support both from funding bodies and scientific communities, organisations headed by German-speaking members at that time like IUPAC, OECD, CEFIC and GDCh were reluctant to adopt the term, as it elicited misleading political associations with the Green Party in Germany (Hutzinger 1999).

In addition to the more implicit cultural-sociological associations, Hutzinger (1999) clearly pointed out a fundamental difference between the two concepts: Whereas Sustainable Chemistry represents the "maintenance and continuation of an ecologically sound development" (Hutzinger 1999, p. 123), Green Chemistry covers the "design, manufacture, and use of chemicals and chemical processes that have little or no pollution potential or environmental risk" (Hutzinger 1999, p. 123). This early conceptual delimitation attributes the development of society within the ecological boundaries to Sustainable Chemistry, whereas Green Chemistry is already more confined to chemicals, products or processes themselves and their technical feasibility. Looking at current definition attempts and ongoing discussions within the community, this line of argumentation, provided by Hutzinger almost twenty years ago, is still one of the main distinctions between both concepts.

As early as in 1992, the UNCED emphasised in the Agenda 21 that research for substitution of toxic, persistent or bioaccumulative chemicals should be strengthened (Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit 1992). In response to the Johannesburg Plan of Implementation of the World Summit on Sustainable Development (WSSD) in 2002, the Strategic Approach to International Chemicals Management (SAICM) was agreed on in 2006 by the UNEP (United Nations Environment Programme) International Conference on Chemicals Management. SAICM aims "[…] to achieve, by 2020, that chemicals are used and produced in ways that lead to minimization of significant adverse effects on human health and the environment […]" (UN—United Nations 2002) and operates on a global policy level. Despite the early connection between Sustainable Chemistry and sustainable societal development drawn by Hutzinger (1999), the concept has not been an integral part of SAICM. However, in the continuation of these efforts—namely in the Sustainable Development Agenda 2030 with its 17 Sustainable Development Goals (SDGs)—the strong connection between Sustainable Chemistry and global development is clearly visible (Blum et al. 2017). Since Sustainable Chemistry has become an emerging concept in response to various sustainability challenges and is serving as a core concept within the Global Chemical Outlook II (UNEP—United Nations Environment Programme 2019), it is worth taking a closer look at the specific characteristics of the concept.

6.3.3 *The Concept of Sustainable Chemistry*

Whereas the U.S. EPA and many others still use Sustainable Chemistry as a synonym for Green Chemistry, various attempts have been undertaken to develop a common definition of Sustainable Chemistry (see also above, Hutzinger 1999).

In a collaborative effort, the OECD and the German Environment Agency (UBA) developed five general criteria for Sustainable Chemistry (UBA—German Federal Environment Agency 2009):

- Qualitative Development
- Quantitative Development
- Comprehensive Life Cycle Assessment
- Action Instead of Reaction
- Economic Innovation.

Currently, the OECD uses and presents the following definition originating from an OECD workshop in 1998 (OECD—Organisation for Economic Co-operation and Development 1998) which is in facat more related to Green Chemistry:

> Sustainable chemistry is a scientific concept that seeks to improve the efficiency with which natural resources are used to meet human needs for chemical products and services. Sustainable chemistry encompasses the design, manufacture and use of efficient, effective, safe and more environmentally benign chemical products and processes. (http://www.oecd.org/chemicalsafety/risk-management/sustainablechemistry.htm)

The OECD also considers Sustainable Chemistry as a process that stimulates **innovation** in products, processes and also practices for higher performance and value resulting in clear benefits for environment and society.

Kümmerer and Clark (2016) highlighted the **holistic nature** of Sustainable Chemistry encompassing all relevant "[…] aspects of a product related to sustainability, e.g. social and economic aspects related to the use of resources, the shareholders, the stakeholders and the consumers" (Kümmerer and Clark 2016, p. 47). Despite the various efforts in describing, the concept still evades definition—for good reason—as Kümmerer (2017) puts it:

> Chemistry is sustainable if it contributes in a sustainable manner to sustainability. A more precise definition of sustainable chemistry is not possible. […] It is not a new subdiscipline of chemistry, but a guiding principle. (Kümmerer 2017, p. 16421)

In 2017, Blum et al. published a conceptual paper summarising and integrating existing definitions and criteria and developing a shared understanding of Sustainable

Chemistry. They identified a "lack of direction and prioritization of the various activities" (Blum et al. 2017, p. 96) and in response provided a set of guiding principles and objectives:

- Design and Use of Benign Chemicals (referred to as benign by design (Haddad et al. 2015; Kümmerer 2007, 2012; Rieger et al. 2002)
- Development and Use of Alternative Solutions
- Reduction of Impact
- Conservation of Natural Resources
- Promotion of Reuse and Recycling
- Increase of Market Opportunities
- Application of Corporate Social Responsibility (Blum et al. 2017, p. 95).

Their understanding of Sustainable Chemistry is based on the OECD definition as well as on the 12 principles of Green Chemistry and on principles of chemicals management (e.g. operational safe use of chemicals) and is directed towards the SDGs:

> Sustainable chemistry is a holistic approach where the entire life cycle of chemical products and the related system of actors, institutions and culture is considered. This implicates that all stakeholders along the life cycle chain of chemicals have responsible roles. Besides health and environment, social conditions, research, science and economic aspects have to be considered and balanced within the capacity-limits of our planet. (Blum et al. 2017, p. 99)

The holistic approach and the involvement of different stakeholder groups offer a set of levers for implementation which are not limited to innovative ideas at substance or product level, but encompass new business models, responsible companies, resource recovery, reliable, accessible and transparent data, and demanding and enabling legislation (Blum et al. 2017). Moreover, efficient strategies for communication and co-learning in an interdisciplinary environment among the multiple actors, e.g. voluntary initiatives, NGOs, international organisations, consumers, etc., as well as education and capacity building help to facilitate the successful implementation of Sustainable Chemistry (Barra and González 2018; Blum et al. 2017).

6.4 Unlocking the Potential of Sustainable Chemistry for a More Sustainable Textile Sector

In this chapter, we set out from the understanding of Sustainable Chemistry provided by Blum et al. (2017), but want to add and highlight some key characteristics which not only help to distinguish the concept from Green Chemistry but constitute its enormous capacity for sustainability compared to green chemistry, also in the textile sector.

- Systems thinking approach
- Strong normative roots
- Input prevention

- Stakeholder focus.

After characterising specific sustainability challenges in managing chemical risks within the textile industry, the potential of Sustainable Chemistry in addressing those will be assessed using the aforementioned key characteristics.

The multiple complex, dynamic and highly intertwined sustainability challenges in the textile sector involve such broad and overarching issues like "climate change, chemical society, water shortage, and human rights" (Boström and Micheletti 2016, p. 367), which are all connected to the use of textile chemicals. Indeed, Boström (2015) describes the governance of chemical risks as "one of the key sustainability challenges that the textile sector has to tackle" (Boström 2015, p. 241) due to the "fragmented […] highly insufficient set of regulations and agreements" (Boström 2015, p. 241) both on a global and regional level. Managing and governing risks through legislative, regulatory or corporate efforts mainly raise the question how responsibility and accountability can be distributed effectively and in a democratically justifiable manner. By trying to allocate responsibility within the textile chain, one faces the aforementioned issues: **high uncertainty** and **lack of accessible data** on substances and composition of products or waste streams due to **individual chemical fingerprints** of textiles and processes—and in turn carbon and water footprints—**globalised and intertwined textile supply and demand chain**, **differing legislative and regulatory frameworks,** etc. Hence, risks and responsibilities are diffused, and none of the different actors within the supply chain nor the regulatory authorities seem to be capable of effective chemical risk management. An excellent illustration of the challenges in sound chemicals management is the varying degree of implementation coverage of the Globally Harmonized System of Classification and Labelling of Chemicals (GHS) as described by Persson et al. (2017). It has been shown that in 2017 a staggering number of 128 countries (66% of UN Member States) had not yet put GHS into national legislative practice due to a lack of financial and regulatory capacities and/or willingness (Persson et al. 2017). Among them are countries like India, Bangladesh, Pakistan and Nepal where textile production and the associated use of chemicals plays major role.

Additionally, even if all those challenges would be easily solved, no national government nor existing intergovernmental institution nor industry initiative has "sufficient jurisdictional and/or policy authority to comprehensively regulate the globalized supply and demand chain in clothing and textiles" (Boström and Micheletti 2016, p. 369).

In addition, those challenges are inextricably linked to **societal and cultural systems**. On the supply side, most companies in the textile sector are taking part in a race to the bottom regarding production costs, and hence outsource labour-intensive and hardly automatable textile manufacturing to developing countries or countries in transition (Boström and Micheletti 2016). Less expensive labour costs, lacking environmental regulation and/or respective enforcement of the latter allow for lower production costs and higher profit for companies—at least in the short-term—at the expenses of people's health and the environment outside of Europe (Boström and Micheletti 2016; Busi et al. 2016; Moore and Ausley 2004; UNEP—United

Nations Environment Programme 2017). For example, around 80% of textile products sold nowadays within the EU are imported from non-EU countries, especially from China (KEMI—Swedish Chemicals Agency 2014). Even products labelled as "Made in Europe" are seldom produced within the EU and according to EU labour rights and environmental standards, but instead only the assembly and mixing is carried out within the EU (KEMI—Swedish Chemicals Agency 2014). This raises the question of **environmental justice** and touches upon the social dimension of (global) sustainability:

> The world's poorest people routinely face the highest risk of exposure to toxic and hazardous chemicals, due to their occupations, living conditions, lack of knowledge about safe handling practices, limited access to sources of uncontaminated food and drinking water, and the fact that they often live in countries where regulatory, health, and education systems are weak. (UNDP—United Nations Development Programme 2012, p. 1)

On the demand side, on the other hand, extensive textile production and consumption are linked in the manner of "**fast fashion**" characterised by reduced periods of use through low product quality and low prices that do not reflect the true costs of the product anymore. Fast production cycles become accelerated by consumer's behaviour triggering feedback loops of adverse environmental effects. Large volumes of textiles of low quality, short periods of use, frequent replacement of textile articles by consumers, missing take-back systems and enormous amounts of waste represent considerable sustainability challenges in and of itself and contribute to both increasing volumes and diversity of related chemical substances and material flows (Niinimäki 2011).

Consequently, no single approach, either technological nor managerial, nor any discipline alone could offer satisfactory and sufficient answers to the pressing sustainability questions of the textile industry until now. Another driving force is the growing public awareness about the circumstances and impacts of garment production. The business model of the textile and fashion industry itself is threatened by NGOs releasing information and scandalising current practices, as it happened 2007 with the DETOX Campaign by Greenpeace. Hence, a holistic and innovative approach addressing all dimensions of sustainability is needed.

Although Sustainable Chemistry has been acknowledged by UNEP as an important cornerstone in achieving the Sustainable Development Goals (SDGs), the concept has nevertheless not yet reached all relevant fields like the textile sector (Blum et al. 2017). Since the chemical industry is a key partner for the textile manufacturing sector, almost all sustainability challenges of the textile industry are linked directly or indirectly to chemicals. Despite the abovementioned actions already taken, enhanced communication and integration along the whole supply chain is needed as well as education and cooperation across different sectors.

In the following sections, we will link the concept of Sustainable Chemistry and its key characteristics to the aforementioned sustainability challenges of the textile sector and explain how and why Sustainable Chemistry can act as a beneficial umbrella concept for addressing the highly complex sustainability challenges regarding chemicals in the textile sector.

6.4.1 Systems Thinking Approach

Regarding the highly intertwined sustainability challenges of the textile sector, it is argued that the so-called lock-ins keep us within our current unsustainable system of production and consumption. According to Unruh (2002), lock-in mechanisms, like dominant design, industry standards, routines, policies and social norms, values and behavioural habits reinforce the present situation and hinder transformation. Production and consumption are still mainly seen as separate, even opposite sides of the textile industry, even though they used to be interlinked at different scales (e.g. locally, personally) before industrialisation (Kaiser 2008). Blum et al. (2017) assign Sustainable Chemistry a key role in overcoming these different lock-ins by bringing along innovations at system level. In order to achieve transformation, Sustainable Chemistry reaches beyond disciplinary boundaries, for example in explicitly searching for non-chemical alternatives, and aims at considering all relevant solutions for a sustainability challenge within the chemical sector, but also other sectors where chemicals play an important role, like the textile industry. Moreover, Sustainable Chemistry does nothing less than asking for a new self-understanding of the chemical sector and its relation to society.

> Moreover, this encompasses system innovations which will lead to fundamental changes in both **social dimensions** (values, regulations, attitudes etc.) and **technical dimensions** (infrastructure, technology, tools, production processes etc.) and, very importantly, in the relations between them. (Blum et al. 2017, p. 95)

While mostly technological fixes are suggested to solve pressing sustainability issues (Ehrenfeld 2004), more scholars nowadays argue that changes in behaviour and practices rooting in changing values and mindsets are promising as well (Boström and Micheletti 2016). Looking at the textile industry and the functions, needs and desires it serves, consumption patterns, fashion business, societal and cultural norms are indeed important (yet largely unaddressed) drivers of current unsustainable practices in the sector; yet they are evading any technological fixes (Fletcher 2009). Sustainable Chemistry is more than a technological fix, but engages in system innovation by changing values and mindsets and recognises the role routines, consumption patterns and societal norms play within a complex and dynamic system. Moreover, while technological fixes and changes in behaviour are seen as short- to mid-term solutions, Sustainable Chemistry offers a long-term perspective not only by substituting hazardous compounds by benign ones (Kümmerer 2012, 2017).

Fletcher (2009) states that recent years have indeed witnessed a growing body of work dealing with sustainability challenges of the textile sector, but that it is all about “optimising parts of the textile production chain, […] improving discrete processes, separate life cycle phases or aspects of the supply chain” (Fletcher 2009, p. 369). Despite their disciplinary justification, rather disparate interventions have until now not been able to address sustainability challenges; sometimes, there is not even clear evidence if the intervention is beneficial or unfavourable concerning overall sustainability. For example, wastewater treatment of dye house effluent seeks to minimise pollution of adjacent water bodies. However, it does neither contribute to finding alternative solutions (e.g. benign chemicals, different processes) to fulfil the same function (e.g. colouring fabric) nor is it always beneficial or sustainable since huge amounts of contaminated sludge are generated and for some pollutants it just does not show any effects. Another example are efficiency improvements in wet processing, sometimes combined with recycling of certain chemical baths that reduce chemicals, water and energy use and often result in substantial time savings. Again, these supposed sustainability interventions seem successful only as long as one looks at the respective process or company. The yields of those efficiency improvements are usually put directly back into the production process resulting in increased productivity—hence, saved chemicals, water, energy and time can be used to produce more with fewer resources in shorter time. Moreover, the potential of (eco)-efficiency strategies is limited to the respective process or product and does not prove suitable for the complex sustainability challenges of the textile sector (Fletcher 2009). Nevertheless, those strategies are often enough first steps towards sustainability and pave the way for more fundamental change (Fletcher 2009). Another example from the area of policies and regulations is the European Commission's Integrated Pollution Prevention and Control (IPPC) regime that lists so-called BATs—"best available techniques"—for textile manufacturing, but lacks perspectives on system and life cycle innovation (Fletcher 2009). While incremental changes in processes or products are usually preferred by companies due to their relatively easy implementation into existing production cycles and the quickly felt benefits, Sustainable Chemistry searches for "long-term sustainable solutions" (Nimkar 2018, p. 16). Due to the inclusion of all life cycle stages, Sustainable Chemistry considers total material flows and seeks to avoid entropy transfers from one life cycle phase to another to prevent rebound effects and second-order problems (Kümmerer 2017). Offering different levers and means for intervention in the different (sub-) systems, it is not limited to technological approaches like benign molecular design, process improvements or enhanced synthesis routes. It does explicitly include levers for changing practices and values like better information and communication, data management, education, consulting and changing institutions (Blum et al. 2017; Boström and Micheletti 2016; Kümmerer 2017). Consequently, a wide range of actors have to be addressed but by that Sustainable Chemistry meets the needs of real-life complex supply and demand chains, which involve numerous stakeholders. Regarding the variety of levers, Westley et al. (2011, p. 762) emphasise that "promising social and technical innovations […] need to be […] connected to broad institutional resources and responses" if they ought to be successful and become common practice. In the case of Sustainable Chemistry, the importance of institutional change comes into play as acknowledgement by UNEP in the Global Chemical Outlook II (UNEP—United Nations Environment Programme 2019), and as the implementation of the International Sustainable Chemistry Collaborative Centre ISC_3 promoting and developing Sustainable Chemistry solutions worldwide (Elschami and Kümmerer 2018).

Ultimately, we need to deal with the problems of the textile sector at their respective levels (e.g. technological improvements, benign molecular design, etc.), and, at the same time, engage even more in systems thinking by reaching beyond boundaries of industries, disciplines and communities to account for drivers of unsustainability emerging outside (Fletcher 2009).

6.4.2 Strong Normative Roots

As shown before, risks and responsibilities are diffused in globalised, intertwined supply and demand chains and differing legislative and regulatory frameworks leaving actors uncapable of effective chemical risk management. This responsibility challenge needs both changing values and mindsets, a strong normative grounding and commitment to sustainability among all actors.

At the core of Sustainable Chemistry is chemistry as an objective natural science. That cannot be changed as chemicals react and behave accordingly to their inherent properties which are encoded in their molecular structure, i.e. the laws of chemistry and physics. However, where, how, when and why chemicals are manufactured and used is its normative basis. That is in the realm of culture, industry, society, politics and economy including Green Chemistry and Sustainable Chemistry. Regarding the textile sector, a short review of its history demonstrates this impressively. While Green Chemistry is rooted in environmental protection, Sustainable Chemistry is inherently connected to sustainability grounding its scientific endeavours on normativity. This normative part of chemistry opens up many opportunities for improvements but also responsibilities including better and in some cases also less use of chemical products in all sectors, including the textile sector.

Traditionally, the development of society within the ecological boundaries is attributed to Sustainable Chemistry rather than to Green Chemistry (Hutzinger 1999). Green Chemistry anchors itself in the normative premise of intentionally beneficial design of processes and chemicals which are not harmful for the environment and human health with one of its core principles—namely benign by design (Kümmerer 2007, 2017; Kümmerer et al. 2018). The principle benign by design has already shown its feasibility by successful redesign of chemicals and even pharmaceuticals where demands are very high concerning drug safety, effects and adverse drug reactions (Rastogi et al. 2015; Rieger et al. 2002; Leder at al. 2015; Haiß et al. 2016). Nevertheless, in accordance with the principles of Green Chemistry chemical warfare agents have been developed which of course cannot be called sustainable (Elschami and Kümmerer 2018). Therefore, strong normative roots and a holistic approach involving all dimensions of sustainability are necessary to achieve truly beneficial solutions for human beings now and in the future and for the environment.

6.4.3 Input Prevention

Another important key characteristic of Sustainable Chemistry is its focus on input prevention of chemicals reducing or even eliminating chemical risks from the beginning onwards (Haddad et al. 2015; Kümmerer et al. 2018). Regarding the textile industry, this principle does not only have great influence on wet processing of textiles, but on the entire supply chain, especially on the chemical burden of post-consumer textiles that nowadays contain up to 90% of the initially introduced chemicals (Nimkar 2018). Consequent input prevention of hazardous chemicals in the first place would make expensive and time-consuming control and risk management approaches at all later stages obsolete and would address global dissipation. Moreover, clear evidence suggests that in terms of economic performance of companies, pollution prevention is better than control approaches towards chemical risks (Alkaya and Demirer 2014; Nishitani et al. 2011; Zeng et al. 2010).

Considering possible benefits for companies, Walton et al. (1998) distinguish three attitudes towards environmental performance among companies—namely resistant, receptive and constructive. A resistant response towards environmental performance is characterised by sole legislative compliance rather than comprehensive implementation of policies (Fransson and Molander 2013). This management strategy often results in short-term end-of-pipe solutions, while the processes creating risks remain unchanged, e.g. wastewater treatment in the textile industry (Fransson and Molander 2013). Resistant adaptation cannot be an option for the textile sector when it comes to chemical use since it is predicted that "[i]f no action is taken, fashion brands will find themselves likely squeezed between falling average per-item prices, deeper discount levels, rising costs, and resource scarcity along the value chain" (Global Fashion Agenda and Boston Consulting Group 2017, p. 20). Moreover, rising pressure from stakeholders such as NGOs and customers will further aggravate the sustainability challenges of the textile industry (Börjeson and Boström 2018). Companies following the second "receptive" management type make incremental changes to their production processes which slightly exceed current policies, as they consider this strategy as more profitable (Fransson and Molander 2013). Companies responding in a so-called constructive way include environmental performance measures clearly exceeding legislation in their production planning right from the beginning (Walton et al. 1998) and aim at gaining advantages from being environmentally friendly at an economic and brand reputation level (Fransson and Molander 2013). The input prevention approach of Sustainable Chemistry represents one tangible way of a constructive response to environmental performance challenges of the textile industry, since it exceeds legislation, and even current MRSLs, and reveals economic advantages by saving money spent on expensive and time-consuming risk management procedures. Furthermore, it opens up possibilities for new business models that focus on the delivery of specific functions and services rather than sole provision of chemical products (Kümmerer 2017).

6.4.4 *Stakeholder Focus*

As mentioned before, the holistic approach of Sustainable Chemistry calls for engagement with a broad set of actors and stakeholders. This is especially relevant for the textile sector, whose supply chains are highly complex and intertwined. Sustainable Chemistry allocates responsible roles to all actors along the supply chain including "chemical industry, downstream users of substances and materials, manufacturers of products as well as consumers" (Blum et al. 2017, p. 99) and requires a cooperative mindset among them. Of particular importance for the textile sector is the design step where decisions are being made which influence heavily the amount and type of chemicals used for textile production, and subsequently composition of textile waste and possible recycling options. Materials, product requirements, colours and styles are chosen at this point and periods of use get pre-determined, all of which then determine the chemicals management challenges arising at later stages. Hence, designers need to be aware of their influence and about environmentally friendly materials and non-chemical alternatives. In collaboration of a wider stakeholder network including multiple perspectives and different forms of knowledge lies a great opportunity for so-called generative learning, which is about creating rather than adapting (Manring and Moore 2006). Again, Sustainable Chemistry with its distinct focus on all relevant stakeholder groups and its appreciation of interdisciplinary and undogmatic networks offers a highly suitable framework for the textile sector with its numerous professions and actors.

6.5 Examples and Practices of Sustainable Chemistry Within the Textile Sector

In this last part of the chapter, we want to present and discuss different examples and practices within the textile sector that already engage—to a varying degree—in Sustainable Chemistry. The examples and practice represent an own non-exhaustive compilation stemming from the literature (see Table 6.2). By presenting the following examples, we would like to stimulate a discussion within and between the communities of Sustainable Chemistry and textile research and industry. Finally, we would like to draw the readers' attention towards three selected examples and discuss them in depth.

First of all, how can examples and practices of Sustainable Chemistry be defined, if there is still no shared understanding? Since Sustainable Chemistry is "simultaneously both a path and a goal" (Kümmerer 2017, p. 16421), telling examples and practices point in the direction towards more sustainability in chemicals production, use, distribution and disposal and should not be assessed as if they would be a finite solution. Moreover, to avoid buzzwording, green washing and subsequently an arbitrariness of the term, every example has to be verified on a case-to-case basis ensuring that recent insights can be included to account for the uncertainty inherent in highly complex sustainability challenges. Practices of Sustainable Chemistry ideally

Table 6.2 Examples and practices of green and sustainable chemistry

Innovation approach		Example	Benefit	Source
Process optimisation	**Reduction** Energy/heat use	Microwave-enhanced dyeing Sonochemistry	Enhances the rate and selectivity of catalytic reactions	Centi and Perathoner (2009)
		White biotechnology (e.g. Novozyme)	Water and energy saving; eliminates use of harmful chemicals	Chatha et al. (2017), Shahid et al. (2016)
	Water use	**Nanocellulose-enhanced dyeing**	Reduction of water, salt and alkali consumption in cotton dyeing	Kim et al. (2017)
		Waterless dyeing (e.g. supercritical CO_2 dyeing; ColorZen; DyeCoo)	Eliminates the use of water, no effluent discharge	Kim et al. (2017), Nimkar (2018)
Change of feedstock	**Substitution**	Conventional cotton versus organic cotton	No herbicides or pesticides	Dawson (2012)
		PVA instead of starch for cotton sizing	No COD increase in wastewater; PVA is recoverable	Nimkar (2018)
		Non-fluorinated versus fluorinated DWRs	Avoidance of highly persistent PFAS	Schellenberger et al. (2018)
		White biotechnology (e.g. Novozyme)	Eliminates use of harmful chemicals	Chatha et al. (2017), Shahid et al. (2016)
		Clay-based products for oligomer reduction in polyester dyeing	No special treatment or handling after use	Nimkar (2018)
		Earth Colours (Archroma)	Dyes from bio-waste	Nimkar (2018)
	Recycling/Reuse	Regenerated cellulose fibres (e.g. Tencel)	Biodegradable cellulose fibre; closed loop production process for solvents	Dawson (2012)
	Bio-based	Natural dyes	Extracted from renewable sources; biodegradable	Bazzanella et al. (2017)
		Polylactic acid fibres	Produced from renewable carbohydrates by fermentation; biodegradable	Dawson (2012)
New business models		**Chemical leasing**	Minimisation of use of chemicals, reduction of costs and resource consumption	Kümmerer (2017)

(continued)

Table 6.2 (continued)

Innovation approach		Example	Benefit	Source
Alternative solutions		**Self-cleaning textiles**	Reduction of water, energy, detergent consumption	Busi et al. (2016)
Other	**Education, consulting and provision of specific knowledge**	Partnership for sustainable textiles	Trainings on Sustainable Chemical and Environmental Management in the Textile Sector in Asia	https://www.textilbuendnis.com/initiative-sustainable-chemical-and-environmental-management-in-the-textile-sector-in-asia/
	Data management	"Positive Chemicals" List		Nimkar (2018)
		Information flows in networks		Manring and Moore (2006)
	Digitisation	Digital printing—"drop on demand" technology	Eliminates use of harmful chemicals, no effluent load	Nimkar (2018)

address spatial as well as temporal scales, flows, and dynamics of chemicals, materials and products (Kümmerer 2017; Weiser et al. 2017), and hence address drivers of highly complex and currently unsustainable practices. The following examples comply to a varying extent with the definition by Blum et al. (2017) and the aforementioned key characteristics; hence, they should serve as a starting point for critical discussion.

6.5.1 New Business Models—Chemical Leasing

Chemical leasing is a good example for a practice of Sustainable Chemistry engaging in systems thinking and input prevention, as it represents a shift from a sales-oriented to a service-oriented business model. The profit here is not generated by the amount of chemicals sold, but by delivering a function. This function is only partly provided by the chemical itself, but also by communication, provision of specific knowledge about the correct use and application of the chemical, and by taking on full responsibility for the service that is needed by the customer. Hence, the supplier becomes a service provider focusing on the stakeholders within the supply chain and tailoring offers to specific needs of customers. Hereby, the use of chemicals is minimised, costs as well as resource consumption are reduced. This model can also be transferred to the textile sector if long-living clothes of high quality are sold together with specifics services such as free care and repair treatments and/or detailed instructions on how to prolong useful life of products.

6.5.2 Process Optimisation/Reduction—Nanocellulose-Enhanced Dyeing (Kim et al. 2017)

Kim et al. (2017) developed nanofibrillated cellulose fibres decreasing the amount of water, salt and alkali used in cotton dyeing by one order of magnitude, while still providing good dyeing performance. In addition to the reduction in water and chemicals consumption, the fibres are produced from an abundant, biodegradable and renewable material. Moreover, Kim et al. (2017) performed a LCA that revealed significantly lower environmental costs for this textile dyeing method. The authors have been awarded the 1st prize of the Green and Sustainable Chemistry Challenge in 2016 (https://www.elsevier.com/events/conferences/green-and-sustainable-chemistry-conference/about/green-and-sustainable-chemistry-challenge). This example represents the holistic approach, as it is not only concerned with a reduction of resource consumption, but also looks at biodegradability and renewability of the new method and takes the economic perspective into account.

6.5.3 Alternative Solutions—Self-cleaning Textiles Enhanced with Nano-Particles (Busi et al. 2016)

Busi et al. (2016) described the so-called self-cleaning textiles, which have a nanocrystalline TiO_2 photo-catalytic surface coating able to destroy organic material by solar irradiation. The performed LCA showed lower environmental impacts for water, energy and detergent consumption in the production and use phase of the garment (Busi et al. 2016). While highly functionalised textiles or composite materials, e.g. anti-wrinkling or antibacterial treatment with silver nano-particles, may show lower energy or water demand in the maintenance phase, they can have contradicting impacts when looking at the fate of the additional chemicals. In case of silver nano-particles, a valuable resource might be lost entirely due to high material dissipation. Moreover, the silver nano-particles in contact with skin-dwelling bacteria as well as the washed out nano-particles can contribute to the development of resistance in microorganisms within the human body, wastewater treatment plants or the environment (Panáček et al. 2018). Moreover, the reduced energy demand in the use phase can likely be shifted to another life cycle phase, e.g. resource extraction or recycling (Kümmerer 2017). Hence, leaching during home laundry, increased material dissipation (Kümmerer 2016; Kümmerer et al. 2018), and reduced or more difficult recyclability may be associated with the additional chemical load—even for thin layer coatings (Bazzanella et al. 2017). Last, but not least, synthetic nano-particles like TiO2 nano-particles, and their transformation products have been found in the aquatic environment possibly posing ecotoxicological risks (Kümmerer et al. 2011).

As mentioned before, the presented compilation is by no means exhaustive. The last example clearly highlights that “chemical innovations can cause trade-offs or contradicting impacts for different sustainability indicators” (Bazzanella et al. 2017, p. 23) and scales which makes it difficult to assess overall sustainability. Even the use of biomass feedstock remains rather inconclusive in terms of overall sustainability as there can be a potential competition with food supply, undesirable land use changes, and unwanted export of nutrients in soil (Bazzanella et al. 2017). In other words green is not necessarily more sustainable.

6.6 Summary and Conclusion

Finally, the sum of sustainability challenges of the textile sector associated with chemicals can be described as a wicked problem—due to its multi-level, complex and dynamic nature. On the one hand, it has been shown that current management and regulatory instruments hardly seem to be appropriate to govern global chemical risks arising from growing volumes and diversity of chemicals sufficiently, and, on the other hand, technological efforts like effluent treatment have as well proven to be merely end-of-pipe solutions with questionable success. This results in the urgent need for an innovative way of tackling chemical risks in global contexts building on use reduction and input prevention at first and a holistic approach with regard to all dimensions of sustainability, especially including social aspects. Innovative and integrative practices from the field of Green and Sustainable Chemistry applicable to major sustainability challenges of the textile sector need to be assessed on a case-to-case basis. Therefore, we plead for a systematic overview of examples and practices of Green and Sustainable Chemistry in the textile sector to identify areas of success but also gaps, and bundle efforts in tackling sustainability issues regarding chemicals. Moreover, the ongoing development of guiding principles (like the ones Blum et al. 2017 suggested) remains an important tool for mainstreaming and implementing Sustainable Chemistry and also to guide decisions makers in industry, politics and society.

In the light of the previously described potentials of Sustainable Chemistry for the textile sector, we argue that

(1) it is beneficial to join forces in tackling highly complex sustainability challenges,
(2) Sustainable Chemistry should finally come to the fore of stakeholders within the textile industry, and
(3) Sustainable Chemistry can act as an integrating umbrella concept for addressing challenges regarding chemicals in the textile sector.

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Chapter 7
Input-Oriented Chemicals Management Along the Textile Supply Chain

Thomas Schäfer and Maren Herter

Abstract In the textile supply chain—specifically in textile finishing—chemicals play a crucial role. The amount, kind and the processing conditions of chemicals bear considerable impact on environmental performance as well as occupational and consumer safety. For this reason, chemicals management should be focused upon as well as addressed commonly and in a coordinated manner. In the following, it is investigated to what extent input-oriented chemicals management illustrates a solution for the highly complex and seemingly impenetrable global textile supply chain. The relevant stakeholders—chemical suppliers, textile manufacturers and brands—are defined by means of their tasks and interrelation with each other within the supply chain. Further, instruments for chemicals management—that can reach from meeting legal requirements up to taking voluntary actions such as testing and a system-oriented approach—and their effectiveness will be explained. In specific, foundational elements of a system-oriented approach will be defined by ascribing responsibilities to stakeholders regarding the choice and application of textile chemicals. Thereby, a positive list of analyzed and assessed textile chemicals is introduced as an efficient tool. It will become clear that the concept of 'product stewardship' and its consequent implementation throughout the entire textile supply chain represents the key to an increasingly sustainable textile production. All players in the supply chain need to be willing to approach alternatives and to follow a chemicals management strategy, which goes hand in hand with 'chemicals *change* management' and induces companies to think one step further, rethink and foremost do not think short-term.

Keywords Chemicals management · Environmental performance · Occupational health and safety · Consumer safety · Input stream management · Toxicological assessment · Positive list of chemicals · Product stewardship · Preferred chemicals

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A practitioner's perspective

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7.1 What Does Chemicals Management Mean?

In 2002 on the World Summit on Sustainable Development in Johannesburg for the first time, the UN agreed upon the ‘2020 goal of chemicals management.’ The aim is to minimize the harmful impacts on human health and environment during handling of chemicals in all stages of the life cycle by 2020.

The definition of proper ‘chemicals management’ encompasses more than the adequate storage of chemicals and should go beyond the sole endeavor of creating a chemicals inventory list in textile finishing companies.

For an integrated chemicals management, all players along the textile supply chain are responsible and must act decisively in a common and coordinated approach. The aim is to minimize harmful impacts on human and environment during production and subsequent application of chemicals in appropriate time. Knowledge and transparency is crucial regarding type and volume of applied chemicals, contained impurities, application conditions and their potential impact on human and environment.

7.2 Textile’s Supply Chain

Due to the numerous processing steps (manufacturing of fibers, yarns, fabrics) and processing methods (dyeing, finishing, printing, coating, etc.), the supply chain of textiles can be defined as one of the most complex industrial value chains, where chemicals suppliers—next to raw material producer—can be considered as the very start. Specialty chemicals (e.g., dyestuffs and auxiliaries) as well as basic chemicals (e.g., sodium hydroxide and acetic acid) are involved. Since the apparel industry also processes a multitude of accessories such as metal zippers and plastic buttons, one further needs to consider, among others, metals and plastics processing. For this reason, the textile supply chain rather illustrates a supply ‘network,’ which is visualized in the following Fig. 7.1.

Irrespective of the production of synthetic fibers and the agricultural production of natural fibers, the supply chain level Tier 2 is certainly the most critical stage, when it comes to the subsequent application of chemicals. Consequently, Tier 2 is—or should—be well-informed and have adequate knowledge about the type and quantity of the used chemicals and their responsible management. In an ideal case, the chemical supplier supports the textile manufacturer for example concerning trace impurities below classification thresholds that are prescribed in a safety data sheet (SDS), but also via a technical data sheets (TDS) when it comes to recipe handling and optimized application conditions.

The brand, as owner of the final product for the market, can and must exert influence in various forms on the chemical management in a supply chain. Tier 2 or the chemical supplier is the most important contact. In Fig. 7.1, it becomes apparent that information exchange between brand and Tier 2 or the chemicals supplier is

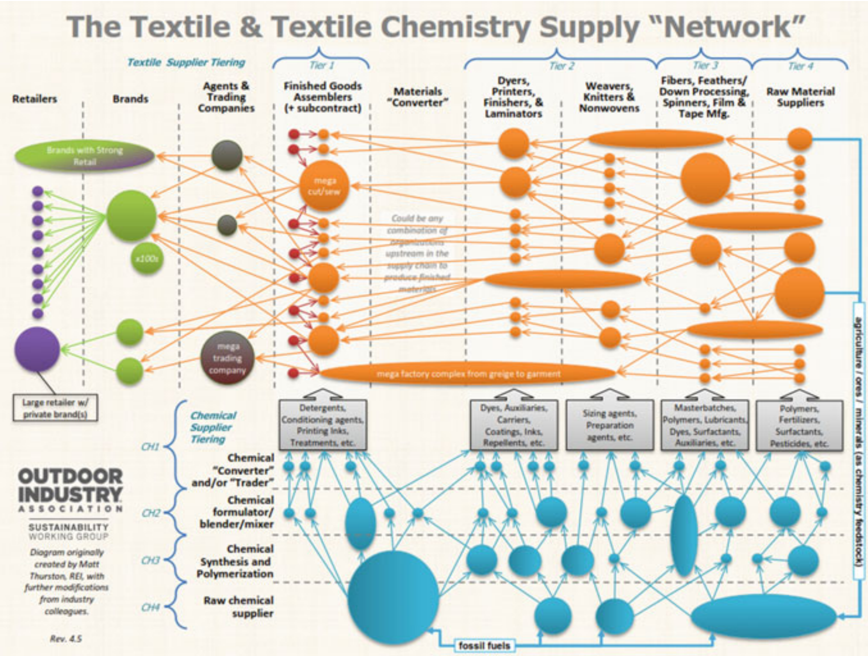

Fig. 7.1 The textile and textile chemistry supply "network", M. Thurston

certainly not simple. Most of the times other players are in between (e.g., agents, converters and trading companies) and deal with the brand, Tier 1 or even other Tiers. Having mostly only access to these respective in between players, brands face an essential obstacle for chemicals management along the entire textile chain.

7.3 Types and Quantity of Chemicals

Auxiliaries and colorants define as 'mixtures,' and for this reason, they differ from basic chemicals, also called 'commodities.' They are, among others, composed of effect-giving substances (also called 'active substance' such as a surfactant with washing effect or a colorant). Next to it, substances are included intentionally in mixtures, which are necessary for processing auxiliaries and colorants (e.g., water or an emulsifier, that emulsifies the active substance, etc.). The active substance might have affinity to the fiber and is to stay on the textile substrate (e.g., colorant, special after-treatment agent, finishing auxiliary) or illustrates merely a process auxiliary (as for instance a washing-, wetting- or a complexing/chelating agent). Figure 7.2 describes mixtures and their components: The intentional active substance and additive as well as the unintentionally contained impurities. An auxiliary or dyestuff consists of several intermediates, which again can represent mixtures. This makes

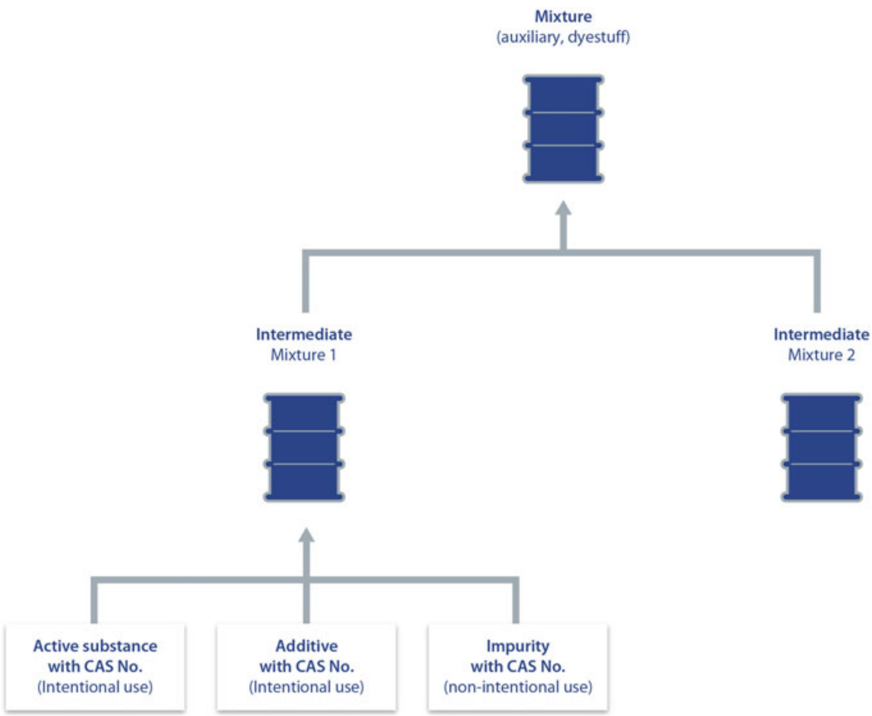

Fig. 7.2 Mixture and its components (Illustration by bluesign technologies)

traceability of impurities, even in the chemical production site, difficult, as an SDS serves as only source of information regarding the intermediates—if no other specifications are required. However, often an SDS lists a hazardous substance only from 1000 ppm onward and may contain insufficient information.

Since nowadays great focus is put on impurities, chemicals management's main task is perceived in minimizing impurities in auxiliaries and colorants (e.g., the possible contamination of disperse dyes with chlorinated benzene or toluene) as well as basic chemicals (e.g., heavy metals in sodium hydroxide) (Ecotextile News 2018). The consolidated European textile supply chain uses roughly 1500 basic chemical substances and 1500 specialty chemical substances, from which again around 15,000 mixtures (textile auxiliaries and dyestuffs) are produced (EnviroTex 2005).

Figure 7.3 illustrates the specific consumption [g/kg production volume (PV)] of auxiliaries, dyestuffs and basic chemicals for the production of woven synthetics during dyeing and finishing in 85 production sites.

Table 7.1 depicts average numbers for a traditional textile company that conducts pretreatment, dyeing and finishing. They serve a purely guiding purpose and even major variations are possible, as it already became clear in Fig. 7.3.

The consumption depends on the used textile substrates (polyester, cotton, etc.), the fabric type (woven or knitted) and the complexity of processes, but also on

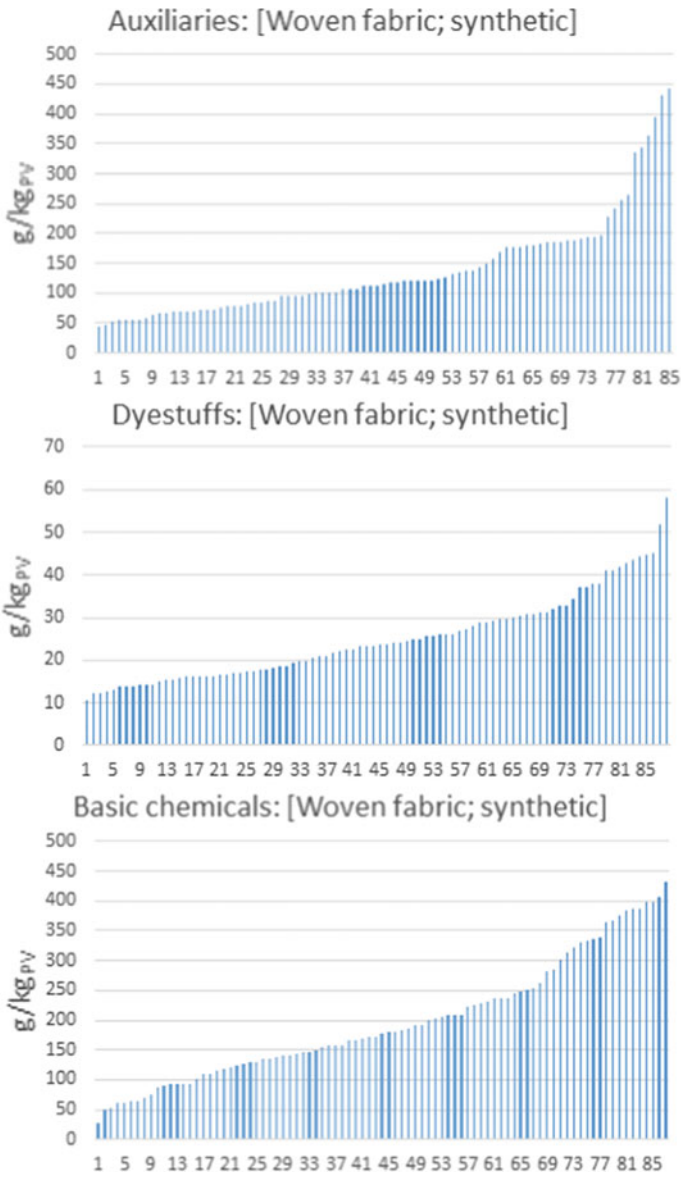

Fig. 7.3 Specific consumption of auxiliaries, dyestuffs and basic chemicals at 85 textile finishing mills (Illustration by bluesign technologies)

Table 7.1 Consumption and number of chemicals in textile finishing [2]

Chemical	Consumption (g/kg textile)	Number of chemical products
Auxiliaries	120	80
Dyestuffs	30	200
Basic chemicals	250	20

companies' performance regarding resource efficiency. When only one substrate-type is used, the number of applied chemicals can be significantly lower, specifically when it comes to colorants. According to the average values, a company, processing 5000 tons of textile annually, needs 2000 tons of chemicals per year.

7.4 How Chemicals Are Applied

The importance of chemicals management in the textile supply chain is not only derived from the type and quantity of the used chemicals (see Sect. 7.3), but also from their application. Except for some processes of finishing, printing and/or coating, all chemicals are supplied in water-based formulations and applied in continuous or batch machines. The machinery (dye unit, continuously working washing machines or foulards (impregnating units) with subsequent drying units, etc.) normally does not consist of 'closed' processes. Also, preparation stations for applied chemicals such as the 'dye kitchen' are not often fully automatized.

Two main consequences can follow from that: First, workers can be significantly exposed to chemicals at their workplace. Second, the waste water path as well as off-gas plays an essentially important role for the environmental performance of a textile production step. Except for colorants and few auxiliaries, with a fiber affinity, nearly all chemicals that are applied in pretreatment and dyeing processes as well as residuals from printing and finishing enter finally waste water. Thermal aggregates, which are often not equipped with off-gas cleaning and work in a range of temperature above 200 °C, can cause considerable off-gas pollution.

Ecological and workplace relevance becomes even more apparent regarding textile coating from solvent-based pastes, which are currently state-of-the-art in Asia. Here, *N,N*-dimethylformamide, which is classified as toxic for reproduction category 1B and other solvents are the choice. Production sites process often 500 tons or more of solvents per annum—and only in particular cases closed systems are installed.

7.5 Instruments for Chemicals Management

7.5.1 Globally Harmonized System (GHS)

The Globally Harmonized System (GHS) of Classification and Labeling of Chemicals of the United Nations is a worldwide uniform system for classifying chemicals as well as labeling both on packaging and in safety data sheets. Harmonizing the classification and the labeling of chemical substances and mixtures paves the way for a consistent and unequivocal communication of hazards. The EU Regulation 1272/2008 (CLP-Regulation) aligns the classification and labeling of chemicals according to GHS. GHS has not been introduced to all countries and classifications and labeling among several countries may differ. Also, not all hazard classes and categories of single countries, which had implemented GHS, have been taken over. GHS conformal safety data sheets represent a minimum requirement for responsible chemicals management, yet the complete and correct classification and labeling is often challenging.

7.5.2 Legal Requirements

In previous times, legislation regulated only a few harmful substances in textile products. Examples include among others:

- ‘Worldwide’ (Stockholm Convention)
  - POPs (persistent organic pollutants (e.g., PFOS)
- EU
  - Annex XVII REACh (e.g., some flame retardant, ‘Azoamine,’ PAH, tin-organic compounds, nonylphenol and nonylphenol ethoxylates, PFOA and PFOA-related substances)
- China
  - GB 18401 (e.g., formaldehyde, ‘Azoamine’)
- Turkey (Notification 29236), Japan (Act No. 112), Taiwan (CNS 15290), USA (CPSIA).

Yet, the number of textile relevant substances regulated by law and applied increases. An example thereof is the restriction of 33 carcinogenic, mutagenic and/or reprotoxic (CMR) substances of the category 1A and 1B for their use in clothing, footwear and other textile articles. In October 2018, the European Commission published Commission Regulation (EU) 2018/1513 which amended REACH Annex XVII by creating a new entry 72 in the Official Journal of the European Union (OJEU).

Another example is the adoption of *N,N*-Dimethylformamide, a typical solvent for the coating of textiles—in the Californian Proposition 65. Further, 350 substances are currently subject for the call of evidence for the preparation of an Annex XV restriction dossier according to Article 69 of REACH.

Alone these, three initiatives of authorities illustrate how dynamic legislation adoption can be in the field of chemicals management. Based on such undertakings, a crucial question arises: How can a textile producer or a textile trader ensure compliance with legally binding limit values? A safety data sheet alone, individual testing on textiles or textile chemicals, sheer conformity to restricted substances lists (RSLs) or manufacturing restricted substances lists (MRSLs) will neither be sufficient nor practical nor effective.

Input-oriented chemicals management represents a solution for the textile supply chain: It starts already at the chemicals manufacturer, with the result of a positive list of chemicals, which guarantees under proper use the statutory limit values. Indeed, not only a set of rules concerning consumer safety regulate chemicals management, but also national and subordinated environmental and workplace regulations exert either direct or indirect influence on chemicals management.

7.5.3 Restricted Substances List (RSL)

A reason for the existence of a Restricted Substances List (RSL) is surely the current deficit of statutory regulations when it comes to harmful substances in textiles. An RSL focuses on consumer safety and regulates the presence of certain chemical substances in articles (for example textiles, trims, leather) by defining concentration limits (e.g., mg substance per kg textile). Because the amount of a substance in an article depends often on the amount of applied substance during production, often an RSL indirectly regulates the use of substances in production.

Since most brands have their own RSL, a great number of different RSLs exists. This illustrates a great challenge concerning chemicals management: such a big number of RSLs cannot be handled in a responsible way by the supply chain and RSL management can turn into a paper tiger of bureaucracy (Patterson 2013).

Brands oblige their supply chain to confirm that the delivered products meet the RSL requirements. Principally, a confirmed or signed RSL qualifies as a legitimate minimum evidence and documentation for authorities. However, Fig. 7.1 demonstrates that often these confirmations—also called 'compliance declarations'—on the part of the suppliers are signed on Tier 1-level or even later (on a level between Tier 1 and the brand). Consequently, far too little information is available to assure RSL conformity in a credible way. It would be highly constructive when the supplier explains in a supplementary way by which means limit values are met and ensured permanently in the long-run (e.g., by establishing and maintaining an appropriate quality management system including a testing program and by input stream management regarding the used raw materials).

7.5.4 Manufacturing Restricted Substances List (MRSL)

A Manufacturing Restricted Substances List (MRSL) is a list of chemical substances that should not be intentionally used in facilities that process materials (e.g., textiles, trims). Typically, it defines concentration limits (often detection limits) for chemical substances in a mixture (e.g., mg substance per kg dyestuff or mg substance per kg textile auxiliary). The focus lies on environment as well as safety for workers and consumers.

One result of the Greenpeace Detox campaign in 2011 (Greenpeace 2011) is the first MRSL, being published in 2014. This MRSL focuses currently on the 'Greenpeace Detox' substances, respectively, substance groups with some supplements, e.g., a few glycols (ZDHC 2015).

It is to be welcomed that the MRSL approach has paved the way for the demand of an industry-wide input-oriented chemicals management that takes the finished textile and the applied chemicals into account.

The MRSL limit values refer to chemical products and are partly much lower than concentration values that are considered during creating a safety data sheet. Because of that, the user (e.g., the textile finisher) has no adequate mean to determine, whether the applied chemicals comply with MRSL limits. Only the chemical supplier can—by means of commensurate knowledge—provide information on MRSL listed substances and potential impurities in lower 'parts per million' range. An impurity management, that solely grounds on MRSL compliance, bears similar boundaries like the RSL. It should reach the chemical suppliers, but often only rare contact with the brand exists and, in most cases, chemical suppliers are unknown to the brand.

The choice of preferred auxiliaries and colorants depends not only on the ban of some substances. The first deficit of a chemicals management which is based purely on an MRSL approach is the missing environmental parameters (e.g., VOC content, biodegradability or aquatic toxicity) in chemicals assessment of a mixture. A second deficit is when a chemical supplier shall sign an MRSL but does not have sufficient knowledge. Only chemical suppliers with an appropriate product stewardship performance are able to answer an MRSL request in a reliable, complete and correct manner. A third deficit is that MRSL conformity does not automatically ensure that the environmental and OH&S prospects of the chemical production site are on an appropriate or even optimized level (Schäfer 2018).

7.5.5 Testing on Impurities

7.5.5.1 Products (textiles)

Random testing of textiles identifies single substances and can constitute an appropriate tool to prove the fulfillment of legal requirements and RSL conformity. Though it is often required by authorities, the significance of testing is small and cannot provide solution, as the reason for a 'pass' or 'fail' after testing is normally not known. Above, regular and intense testing can be costly.

7.5.5.2 Chemical Products

While only few years ago, impurity testing focused almost entirely on product testing (textiles, etc.), now increasingly more testing labs can identify chemical substances (impurities) in chemical products, though standardized procedures are lacking and not every lab result can guarantee the necessary solid evidence. Tests on specific single chemical substances or substance groups but also the so-called screenings are offered, which capture numerous substances semi-quantitatively and mostly via gas chromatography.

Some brands conduct testing on chemicals in their own responsibility and create an individual 'positive list,' which prescribe mandatory chemicals for their supply chain. Laboratories and labels conduct testings on textile auxiliaries and colorants, too. In case of successful testing (often based on few selected parameters), 'eco-certificates' for specific chemical products are granted for a given time. Yet, it is obvious that a testing for impurities on a sample, without knowing how a chemical product was produced (Were raw materials of equal purity used? How is this guaranteed? How is the quality management of the chemical supplier? Can consistent quality of supplied products be guaranteed? Is the safety data sheet significant and informative?) illustrates only a short-term statement with limited predictive value. Further, an impurity test of a chemical—equal with textiles—does not state anything about the environmental performance of a production site and a 'clean factory' approach is therefore not given.

7.5.6 NGO Campaigns

Campaigns with political background often provide a clear impetus specifically for big brand to take chemicals management within their supply chain into consideration. While they successfully refer to drawbacks and raise awareness in the public, it is up to the industry to develop and implement solutions.

7.5.7 System-Oriented Approach

A system-oriented approach consists of following components:

- Integration of all players (but foremost chemical supplier, textile manufacturer and brand), which expend effort to ensure the best possible traceability in the supply chain

- Requirements for environmental protection and OH&S as well as resource efficiency at all production sites (chemical suppliers, textile companies, etc.)
- Continuous optimization of the environmental performance and resource efficiency as well as worker and consumer safety and a continuous monitoring of the implementation of measures
- Focus on knowledge transfer and capacity building instead of plain ‘pass/fail’ audits
- Scientific methods that prioritize and assess chemicals and enable the derivation of limit values for critical substances in chemical products
- A chemical assessment of auxiliaries and dyes, based on an intelligent conjunction of hazard end-points and risk evaluation, which again considers ecological, OH&S as well as consumer safety aspects
- An input-oriented chemicals management system
- A positive list of preferred chemicals (e.g., textile auxiliaries and colorants).

7.6 Components of Good Chemicals Management

Good chemicals management is realized, when all relevant players in the textile supply chain fulfill their (product) responsibility and an appropriate information exchange between the players take place.

The pivotal task of input-orientated chemicals management is the integration of chemical suppliers. A first big milestone toward an effective chemicals management is achieved, when critical chemicals are not applied in textile finishing or—even better—assessed and chemicals of optimized qualities are applied. Figure 7.4 visualizes the input stream management approach with the three key players in the supply chain, where harmful substances are eliminated from the very beginning.

Further, it is essential that chemicals management is not only done on the paper (e.g., via RSL and MRSL conformity declarations), but also implemented demonstrably in the textile supply chain, which takes time and manpower. Necessary awareness, persuasion and the relevant knowledge are of equal importance. The following depicts a broadened concept of product stewardship for the individual players.

Fig. 7.4 Input-oriented approach for chemicals management according to bluesign technologies (Illustration by bluesign technologies)

7.6.1 Chemicals Supplier

The chemical supplier—in many cases, when there is an intermediate trader–the producer of auxiliaries and colorants must:

- take adequate precaution to minimize the environmental impacts on water, air and soil in the production site
- conduct the necessary organizational and technical measures to ensure workplace safety
- take the greatest possible effort to produce resource efficiently
- develop and manufacture products based on 'Best Available Technique' (BAT) to continuously increase and improve environmental protection and occupational health and safety at downstream use
  - Further, banned substances (e.g., Alkylphenol ethoxylates) through legal or voluntary initiatives must be not applied as active substance for products
  - This also foresees to maintain contamination with harmful substances in products on the lowest possible level
- label accurately and completely final products according to GHS
- provide recommendation for application by means of a technical data sheet (TDS).

The chemical supplier should take and permanently guarantee this responsibility. It is essential that the company installs a 'product stewardship management' paired with sufficient knowledge and experience based on the aim of continuously improving it. Often the question arises, whether new molecules are developed, like in the pharmaceutical industry. One can respond that revolutionary developments in this field have been falling short for the last years, due to the low average price of auxiliaries and dyes (5–50 USD/kg) and textile industry's outward move from Europe.

From Fig. 7.5, it becomes apparent that 'product stewardship' starts already at the purchase of raw materials and intermediate products (input-oriented chemicals management). The main tasks comprise the selection and assessment of suppliers, a certificate of analysis, specifications on impurity content, an impurity analysis of raw materials. In addition, knowledge and control of processes are prerequisites for consistent quality. When all modules of a product stewardship are introduced and developed, adequate know-how exists to create a basis for a successful chemicals management along the textile supply chain and to finally communicate the hazards.

7.6.2 Textile Finisher

Input-oriented chemicals management illustrates the preferred way for the textile finisher. By preventing hazardous substances to access the production site—due to either legislation or voluntary initiatives—one rectifies the problem at source. The

Fig. 7.5 Product stewardship at the chemical company according to bluesign technologies (Illustration by bluesign technologies)

textile finisher can save resources by using auxiliaries and colorants, whose applications consume less water and energy. With these chemicals, which are potentially less volatile or have a high degree of biological degradability, cleaning systems for waste water and off-gas can be made more efficient and cost-saving.

From a global perspective, it is right to state that the textile finishing industry is not able to conduct input stream management of chemicals on its own. Or differently said: it takes time and effort for the textile finisher to differentiate and identify complete and correct safety data sheets from sheets of low quality. Regular information flows from the chemicals supplier to the textile finisher are often missing. This lack, however, can be balanced out through referring to the so-called 'positive list' that comprises assessed auxiliaries and colorants, which were produced responsibly and whose impurity content and characteristics regarding occupational health and safety and environmental aspects were assessed and classified as recommendable by a third party.

Still, it is essential that the textile finisher, in the role as the chemical user, takes all necessary actions for environmental protection and OH&S to finally ensure a responsible application of the chemical. Despite the optimization of a chemical: a chemical remains a possibly hazardous substance, whose risks must be minimized.

The main tasks for a textile finisher are to:

- install, maintain and continuously improve an appropriate quality and environmental management system that includes chemicals management and chemicals change management
- define purchase conditions and to invest in trustful relationships with chemical suppliers
- select chemicals from a 'positive list'
- be aware of the best available techniques (BATs) and continuously improve resource efficiency.

At this point of the subsequent application, it becomes apparent that chemical management must often go hand in hand with 'chemicals change management.' The production site needs to install substitution measurements, for instance, when the applied chemical is supplied without an SDS or an inadequate one, when impurities are contained or when there are alternative products available with lower hazardous impact on humans and environment. Substitution requirements represent often the retarding factor, when looking closely on the global supply chain's chemicals management: old trade relations—mostly to local suppliers—would be at stake, costs and price increases could come up, which are barely communicable in the short-term, recipes for colorants must be revised, etc.

7.6.3 Brand

Only a few years ago, when the brand came into contact with the chemical supplier, only requirements concerning performance and effects were typically communicated.

Due to some well-known campaigns, chemical management has gained importance in brands' sustainability policy and in their environmental programs. Almost all production processes are outsourced, and the brand's main task is to manage the supply chain.

Core tasks for a brand are to:

- acquire sufficient knowledge on 'chemistry'
- set focus on the necessary chemicals for manufacturing a product next to material efficiency and 'life cycle' arguments, when weighing ecological aspects at product design and development
- achieve traceability in the supply chain (including Tier-2 and the chemical supplier) based on responsible selection of supplier with the prospect of long-time relationships (in order to avoid 'supply chain tourism')
- consider the aspect to what extent the supplier creates an appropriate chemicals management at the production site. In this regard, it is important to clarify whether adequate disposal companies as well as laboratories for waste water and off-gas analysis exist in the region of production
- ban specific chemicals completely (e.g., long-chain fluorotelomer chemistry)
- nominate auxiliaries and colorants. This means to prescribe chemical products. This can be done for instance by providing the textile finisher with a 'positive list' of assessed preferred chemicals
- implement an adequate RSL management and testing program.

The brand can accomplish these tasks by itself, within the framework of a consortium of brands and/or by joining a system that aims at the continuous improvement of input-oriented chemicals management, resource efficiency, environmental protection, occupational health and safety as well as consumer safety. It is undeniable that a holistic approach toward more sustainable actions is challenging and time-consuming. But simultaneously, it illustrates the only solution in the long-run.

7.7 Outlook

Upon reasonable ground, key players have been focusing on chemicals management along the global textile supply chain. The challenges of a complex global supply chain have been tried to overcome by means of several approaches. Approaches may differ from each other, but they must have one common denominator: the focus must lie on improving environmental performances in the production site and meeting safety standards for workers and consumers. Therefore, the inclusion of the chemical supplier is critically essential to ensure that input-oriented chemicals management starts at the earliest point in the supply chain. It remains to be hoped that based on a possibly common and aligned approach by the players, meaningful measures are developed and implemented. Next to improving knowledge and increasing the necessary awareness along the supply chain, it is crucial to continuously and successfully implement chemicals management in a step-by-step approach—with less focus on individual lighthouse projects and individual interests of single key players.

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Part III
Sustainable Production in the Textile and Fashion Value Chain

Introduction

The sustainable production of textiles generally comprises the four sub-processes of the textile chain: fibre production, fabric formation, finishing and confectioning. Apart from the subsequent use of textiles, fibre production and finishing processes have the greatest influence on ecological sustainability. Thread production and ready-made clothing require large human resources, which is why today's production is concentrated in the developing countries with the lowest labour costs in Asia, but also in Eastern Europe. A new wave of relocation to Africa is currently beginning, especially to Ethiopia. For example, the goal of the German Development Ministry is to prevent ecological and social grievances from arising on the ground in Ethiopia through educational work and cooperation.

In the ready-made clothing sector and fibre production, especially in large spinning mills, such as India, the focus concerning more sustainable production in the future will be on improving working conditions for workers, establishing trade union associations and complying with existing or future environmental regulations. In addition, the labour-intensive processes will have a lower labour requirement in the future due to the progressive developments in automation. Developing countries must adapt to this development at an early stage.

In new spinning mills, but also in weaving and knitting mills, highly automated production lines are being set up, which can only be operated by a fraction of the workforce due to increasing networking and sensory monitoring of the processes. Yet, automatic sewing machines that make human labour superfluous are also already being used in the ready-made clothing sector. An example is a highly automated bed linen production facility in Germany, which is able to win over the highly price-sensitive discounters as major customers. The advancing digitalization and online trade are currently fundamentally changing the production processes towards more individuality and greater adaptation to customer demands. New players in the apparel market, such as Amazon with its own brands, will accelerate this development and fundamentally change traditional supply chains, further reduce consumer prices and drive traditional brands out of the market.

In the printing sector, new business models will prevail, offering the smallest quantities worldwide and then bringing them together internally through digital networking in the production processes. Smaller quantities can be produced at competitive prices, for example the successful company Spoonflower. A further step is the digital transfer of customer design directly to the printing presses, allowing production on demand to be experienced. Increased transparency in the supply chain will also enable brands to influence production processes and means of production when all raw materials and additives are captured and made available digitally. Then sustainable best practice production processes and textile auxiliaries and additives can be defined from top to bottom.

With the many wet processes in textile production, the focus is on the treatment of wastewater, since the textile industry is responsible for about 20% of all polluted industrial wastewater in the world, this is one of the most important tasks in the new decade. The training of skilled workers and their training in sustainable production processes can make a further contribution to a gradual transition to more sustainable systems. Clean water is the basis of life for all living creatures. In Europe, renaturation was successful in many regions, and this can and must also be implemented in the current developing countries in the near future.

The present chapter Sustainable Production in the Textile and Fashion Value Chain, therefore, contains three articles with a strong focus on wastewater treatment; firstly, from a general perspective, secondly, related to a specific new implementation method and thirdly, related to one of the most common garments—jeans. Höhn's general, yet, comprehensive overview reflects his long practical experience in a dyestuffs company. He reports extensively on the various wastewater treatment processes by particularly focusing on the dyeing processes. The scientific article by Bagiran deals with the positive research results for the removal of pollutants and the reuse of treated water from the wastewater of a denim washing plant using pumice stones.

Chahboune spent many years working for Hess Natur in Asia in order to establish sustainable textile processes in the manufacturing countries in Asia. Her article is dedicated to one of the largest sectors of the clothing industry, the production of jeans. This area has undergone major changes in recent years. Sustainable and environmentally responsible practices have been developed and are increasingly applied throughout the life cycle of products, from the cradle to the end of their life.

Chapter 8
Textile Industry Effluent

Methods of Cleaning, Reuse, and Minimization of Textile Industry Effluent

Wolfgang Höhn

8.1 Introduction

The following text provides a systematic overview of the methods for prevention, minimization, reuse, and cleaning of sewage in the textile finishing industry. The focus of the paper lies on the cleaning of dyestuff sewage, which generally involves the treatment of wastewater of the textile pretreatment processes.

An attempt is made to summarize the current wastewater situation and the legal situation in Germany. According to the state of the art, a distinction is made between conventional (according to generally accepted rules of technology) and modern (state-of-the-art)methods as well as methods, which have been implemented in a pilot or even laboratory scale. (State of Science, e.g., DTNW, ITV).

Small- and medium-sized enterprises, indirect and direct discharging companies are involved.

The process or process combination, which is actually implemented in a specific individual case, depends on the respective operating and sewage situation. The specific technical, economic, ecological and legal aspects have to be taken into account and an individual, tailor-made solution has to be found.

The minimum requirement is the fulfillment of official wastewater provisions.

The ultimate target, namely wastewater cost minimization and even a positive payback, requires much more complex, ecologically and economically optimized solutions. In general, these only can be designed and implemented by appropriate wastewater specialists after detailed operational analysis.

A practitioner's perspective

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The main source of this research work is the text 3/94 UBA: Reduction of wastewater pollution in the textile industry (Schönberger 1994), which can be regarded undoubtedly as the most comprehensive monograph on the topic of textile wastewater.

8.2 Current Sewage Situation of the Textile Industry in Germany

8.2.1 General Information

In the old West and newly formed German states, the textile finishing industry is still the most abundant industrial sector prior to the chemical, the paper and the food industry. The annual consumption should be between 50 and 75 million m^3 of water now.

The predominant part is attributable to the textile refining industry and thereby especially to the areas of pretreatment and dyeing.

The sewage costs, which include fees for water, wastewater, costs for the depreciation and operation of sewage purification facilities, as well as costs for waste disposal and exhaust air purification, which however play a much smaller role, account for about 10% on average of the regional fluctuations of the wastewater fees. The tendency is increasing.

This explains Germany's position at the top of Europe and probably also the world's top, followed by the Netherlands in this field.

Thus, the necessity of optimizing the sewage situation by minimization, reuse, and cleaning is becoming even larger. Moreover, this is especially underlined by the fact that environmental legislation continues to get intensified: Not only the wastewater costs increase, also the values of the statutory wastewater limit decrease permanently. In this context, the new TEGEWA e. V., an association of manufacturers of textile, paper, leather and fur auxiliaries and paints, surfactants, complexing agents, antimicrobials, polymer flocculants, cosmetic raw materials, and textile auxiliaries, divides their members according to their relevance to water, into classes I (low water relevance) to III (highly water-relevant). The textile auxiliary manufacturers have to carry out this self-classification. Based on this, the users, i.e., the finishing companies, have to carry out a corresponding wastewater treatment or a corresponding textile auxiliary selection.In this context, there should be mentioned that in the recent time also internationally active private organizations such as ZDHC, Bluesign, GOTS and major textile trading companies, for example, Li and Fung, define more and more effluent relevant guidelines including limiting values for their members, which are usually even more restrictive than the government laws themselves.

8.2.2 German Legislation for Wastewater

Section 57 of the Water Resources Act provides the framework and is concretized as a legal ordinance in Annex 38 of the Waste Water Ordinance (AbwV 2018) for directly discharging textile companies as well as for municipal sewage treatment plants with wastewater of predominantly textile origin. In addition to certain prohibitions, bids and requirements, this contains limits for various sum and single parameters in wastewater. In particular, the color of the sewage is limited by three "spectral absorption coefficients (SAC)," also called transparent color numbers.

Based on this valid legal regulation, national laws dictate concrete emission standards as well as wastewater fees for the domestic textile companies now.

In the case of indirect discharging textile companies, these rules are not directly applicable. On the contrary, limits and charges are defined by the respective local authorities or local authorities in wastewater sanctions. On the basis of the so-called directives for indirect discharges by the respective German federal states, these are based primarily on the local effluent situation and the capacities of the respective municipal sewage treatment plant as well as the datasheet DWA-M 115 (DWA 2013), prepared by the German Association for Water Management, Wastewater And Waste (DWA), criteria or guidelines. In general, these limits are clearly higher than those in Annex 38.

8.2.3 Status Quo of Indirect and Direct Effluent Discharge in Germany

At the present time, there are still predominantly indirectly discharging textile finishing companies (about 95%) in the old West federal states and only a few direct dischargers. In the newly formed German federal states are already some more direct-opening textile companies.

A comprehensive multi-stage sewage treatment plant is needed for the direct discharge of the purified sewage into the receiving water because of the high requirements for the quality of the entire wastewater. This means investment and operating expenses, which is only feasible for either a large textile enterprise or a merger of several small- or medium-sized enterprises as a "wastewater community."

Thus, the indirect discharge into the public sewer system is actually the process of choice for most of the small and medium-sized enterprises. However, the requirements for indirectly discharged water will also increase and in the medium term a cleaning, which goes beyond sewage neutralization will also be required at most plants. At present, a relatively small number of indirectly discharging companies in Germany are carrying out such a wastewater treatment. In these cases, either the statutes make such operations necessary, or partial recycling is carried out, in a way that the sewage treatment is actually cost-saving.

8.2.4 Effluent Characteristics of the Textile Finishing Industry

Generally concerning characteristics of wastewater, there is the principle of individuality of every company with respect to its sewage. This diversification is due to the specific treatment substrates, process variants and chemicals used. Thus, no finishing or dyeing water is qualitatively or quantitatively comparable to that of another plant.

In addition, strong seasonal, daily and even hourly fluctuations in the quality and quantity of the water are observed. Nevertheless, some of the more likely occurring characteristics in sewage due to pretreatment and dyeing can be listed.

However, as described, these can be highly variable and also strongly time-dependent.

The methods described below for minimization, reuse and reaching the purification aim, even at a different extent, depend on these characteristics or on their reduction or removal. The objective is either the fulfillment of the respective direct or indirect discharge regulations or the reuse of the wastewater in the sense of further cost minimization.

Of course, the individually chosen method or method combination should not exceed the sewage problem of the customer too large as well as the corresponding official requirements and should be only as good as it is useful, ecologically and economically.

An extreme example would be a wastewater purification up to drinking water quality. This is superfluous as well as potentially "fatally uneconomical" for an indirectly discharging small-scale plant, which only has problems with the residual color.

On the other hand, a concept has to take into account possible future operational and legal developments, such as an expected increase in capacity or a probable exacerbation in the wastewater legislation.

Since operators are understandably often overburdened in assessing an individual wastewater concept according to these criteria, additional advice from third parties is recommended.

Possible contamination of pretreatment and dyeing sewage water are:

– <u>Colorfulness</u>
  Due to unreacted dye.
  It is detected spectral-analytically by the sum parameter spectral absorption coefficient (SAC). Residual color is the main problem of the sewage in the case of most indirectly discharging finishing plants for cellulosic textiles.

– <u>High COD or DOC value</u>
  Particularly resulting from sizes, preparations as well as some pretreatment and dyeing auxiliaries.

– Refractory and persistent substances
  Substances, which are difficult to be eliminated biologically, particularly those which have additionally a bioaccumulative potential.
  In particular: synthetic sizes based on PVA, CMC, polyester and certain polyacrylates, dyes, in particular, water-soluble ones, sequestrants based on EDTA, DTPA, certain phosphonates, acrylate protective colloids, anionic dispersants based on naphthalenesulfonates or lignin sulfonates, carrier substances, certain finishing agents.
  Refractory substances are critical in particular when they accumulate in the fatty tissue of the fish and thus enter the food chain finally.

– Wastewater toxiccompounds
  Low EC and LC values, CMR substances, endocrine substances.
  Except for heavy metal ions.
  E.g., refractory surfactants in higher concentrations, quaternary ammonium compounds from fastness improving agents, retarders and saponification catalysts, APEO-containing preparations, pretreatment and dyeing products as wastewater toxicmetabolites, aromatic hydrocarbons as dyeing accelerator substances.

– Heavy metal ions (Cu, Ni, Cr, Co, Zn)
  Mostly based on dyestuffs or reducing agents (Cr(III), Co (III)in case of 1:1 and 1:2 metal complex dyes and certain acid dyestuffs, Zn in case of certain basic dyes and in case of reducing agents of type Zn-hydoxymethylsulfinate, Cu, Ni ions for certain substantive, reactive and dispersion blue and turquoise dyes).
  Free bichromate like chromium (VI) or free chromium (III) originating from wooldyeing with mordant dyestuffs.

– Sulfur-containing reducing agents
  For example, sodium sulfite, sodium sulfide, hydrosulfite, also in its activated or stabilized form, thiourea dioxide.
  In these cases, toxic sulfite, severely toxic sulfide and sulfate, which is corrosive to concrete pipes, are generated.

– AOX
  In particular from the use of reactive and vat dyes, sodium chlorite, hypochlorite, organic chlorinating agents for the superwash finish of wool.

– High electrolyte content
  Mainly by Cel-finishing.
  Before neutralization more or less acidic or alkaline wastewater from wool dyeing or Cel pretreatment and dyeing.

– Organic and inorganic compounds
  Containing N- and P-eutrophic: Originating from dyestuff and textile auxiliaries/basic chemicals.

8.3 Overview of Measures for the Reduction of Wastewater Pollution

In addition to the fees for indirect and direct discharge, wastewater treatment represents an additional cost burden, which can be reduced by the so-called production-integrated measures like avoidance or minimization. By recycling of water and, if necessary, energy and the recovery of raw materials even a positive payback can be achieved as a result of resource conservation.

For the latter, partial flow treatment has to be preferred to mixed-water treatment and, if appropriate, cross-media approaches, e.g., detailed operating analyzes for the detection of the entire mass and energy flow of the plant, are advantageous.

Exemplary in this context is the Brinkhaus project in Germany, which will be discussed separately in this article.

The following priorities should always be given to wastewater reduction in favor of maximum cost savings:

1. Production-integrated measures: avoidance, minimization of wastewater.
2. Recycling or rather partial recycling of water, energy and raw materials as far as possible based on partial flow treatment and operational substance and energy stream analysis.
3. Purification of the remaining wastewater as an end-of-pipe process without recovery to meet the legal or statutory limit values.

The methods at 2 and 3 are similar or coupled.

In this context, a distinction has to be made between substances destroying measures and substances separating measures, as well as their synergetic combinations. Substance-destroying measures are better than material-separating methods from the ecological and economic point of view. You do not shift the disposal problem but reduce it de facto.

In substance-separating processes, more or fewer large quantities are produced, as a rule highly polluted waste. This has to be disposed of costly by drying, taking to a landfill or by additional substances destroying measures like combustion and wet oxidation. An application in agriculture, forestry or horticulture is only possible in exceptional cases, usually just for sewage sludge from mechanical or biological sewage treatment plants (see sewage sludge ordinance).

Despite the operational priority of measure 1—which is often forgotten–the methods of cleaning as a basis of the second and third measure are described very intensively within this publication.

8.4 Methods of Wastewater Treatment

8.4.1 Compensation Procedures

By means of balancing, collection, pH-buffering, detoxification or neutralization basin, a temperature of max. 35 °C, a pH range between 6 and 9 as well as an equalization of the mixed wastewater stream in terms of time and concentration are achieved. Anaerobic processes which can significantly increase the sulfide content as well as process-induced high amounts of sulfite, dithionite, sulfide are minimized or detoxified by recirculation, aeration or peroxide introduction. If this process is not possible or sufficient for the elimination of high sulfide amounts, sulfide precipitation with iron ions is usually carried out in the course of a flocculation process (see Sect. 8.4.2.1).

Compensation procedures, including sulfur detoxification, strictly speaking, are not part of the wastewater purification process, but are currently the only wastewater treatment measure in the most indirect discharging companies. In many places, they are still sufficient to comply with the municipal requirements for discharge into the public sewer system.

In the future, however, additional cleaning will become more and more necessary due to increasing environmental requirements.

8.4.2 Separating and Concentrating Processes

8.4.2.1 Precipitation and Flocculation

(See also Appendix 1–3).

The precipitation and flocculation of the wastewater ingredients are carried out by using iron (III) and/or aluminum salts (chlorides or sulfates) or polyaluminum chloride as coagulants (primary flocculants), together with lime milk or sodium hydroxide solution (NaOH).

Sometimes, the mere use of lime milkobtains satisfactory results.

The use of Fe (II) salts in the alkaline medium combines precipitation and flocculation with reductive wastewater treatment.

In addition to these flocculants as “classical” coagulants, new so-called “progressive” organic and inorganic alternatives have also become established in the meantime.

Modern inorganic alternatives are coagulants based on alkaline activated alumina and bentonites (Na-Al–Fe-Ca-silicates, see also Sect. 8.4.2.3) which can be used more efficiently and without additional alkalinity.

Modern organic alternatives are polycationic coagulants with lower molecular weight based on polyquaternary ammonium compounds and dicyandiamide-formaldehyde polycondensation products. These can be used alone or together with other coagulants or with flocculation aids.

If no combination with classical coagulants occurs, no additional alkali is required.

A significant increase in efficiency is possible in comparison to classical coagulants, especially when primary decolorization is concerned. In the latter case, polycationic coagulants have the advantage of a high specificity on the dye, i.e., other sewage freight is only subordinated.

The co-use of flocculation aids, the so-called secondary flocculants or just flocculants, based on organic, high-molecular-weight polymers have synergetic support in precipitation and flocculation, in particular in the case of the inorganic method. Examples for such polymers are polyacrylamides, as well as certain polyelectrolytes: polyacrylates, anionic and cationic acrylic copolymers.

Precipitation and flocculation are either conducted discontinuously in a flocculation tank or continuously as tube flocculation by means of the plant, whereby sedimentation phases are following the previous turbulent mixing phases.

The temperature for precipitation and flocculation should be as low as possible.

Separation of the solid phase after flocculation occurs by means of sedimentation and clearing or by pressure relaxation flotation. The flocculation sludge obtained is dewatered by means of chamber filter presses and disposed of as a special waste according to TA waste considering a key. Since the disposal costs have depended on the wet weight of the compact, effective dewatering and thus an already optimum sludge conditioning is particularly important during the precipitation process. Coagulants and flocculants are selected with regard to the optimum sludge conditioning which is substantially influenced by these chemicals as well.

In special waste disposal companies landfill, combustion or wet oxidation occurs. In the case of intended recycling of the water, either a deironing stage has to be connected downstream or else an Al salt has to be used as a flocculant. Cation surfactant coagulants should be avoided as far as possible in case of recycling purposes.

Precipitation or rather flocculation with subsequent phase separation is perhaps the oldest and most common method for dyestuff elimination. In fact, this standard process has a good average decolorization tendency. Furthermore, a large part of the emulsified, dispersed, colloidally dissolved and anion-active organic substance is eliminated. In addition, inorganic precipitants are eliminating phosphates and especially iron salts themselves are precipitating high amounts of sulfide ions (see Sect. 8.4.1).

The precipitation or rather a flocculation is relatively inexpensive from the investment and operation point of view. It is both useful for indirect dischargers to meet stringent pollution standards, in particular, residual color, as well as proven as the middle stage of combined wastewater treatment for direct discharge or recycling reasons.

The use of inorganic coagulants has also proved to be the so-called two-point precipitation within a conventional, municipal mechanical–biological-chemical combination treatment plant. The coagulants are metered into pre- or after clearing basins. In contrast to conventional precipitation or rather a flocculation, a cheaper sludge discharge is possible here according to sewage sludge ordinance.

Although the methods of precipitation and flocculation still satisfy the generally accepted rules of technology, in any case, more modern or advanced methods should always be considered from a holistic viewpoint, since even with optimization, a large quantity of precipitation sludge is produced which has to be—with the exception of two-point precipitation in biological sewage treatment plants—rather expensively disposed. Thus, this method is no longer quite contemporary for pure COD reduction.

On the other hand, it is still a very useful and efficient method for decolorization (indirect discharges) and polish steps (direct discharges). For reasons mentioned above, this is especially the case for the modern organic coagulants, which are more or less dye-selective and hence are not unnecessarily "consumed" by COD freight.

Due to the still dominant importance of the precipitation and flocculation for the cleaning of the textile wastewater, Annex 1 contains indicative formulations, which always has to be laboratory-tested and then practically adopted to the respective wastewater in individual cases.

Coagulants and flocculants are offered in powdered, suspended or dissolved form, as single or compound products by numerous manufacturers today. They form the most important group of the so-called wastewater purification chemicals.

8.4.2.2 Coarse Mechanical Filtration

The coarse mechanical filtration with sand, gravel, pumice, magna, etc. has no significance for wastewater clearing as such. Rather, it is only practiced as a polish step for the treatment of pre-purified wastewater in the area of recycling. In particular, suspended stuff, for example, resulting from previous precipitation, flocculation, sedimentation or flotation stage, are eliminated (see Sect. 8.5).

8.4.2.3 Adsorption Process

Adsorption of dissolved and undissolved, polar and nonpolar, organic and inorganic water ingredients to solid adsorbents in the fixed or fluidized-bed processes can be affected either by surface effects and/or via ion exchange.

Examples of primarily superficially active adsorbents:

- For predominantly nonpolar substances: activated carbon, brown coal coke, silica gel
- For predominantly polar substances: thermally activated aluminum oxides, superficially functionalized cellulose (CustoMem process, see Sect. 8.4.2.4), peat, wood, chitin, lignin, modified guaran, carbonized wool, etc.

Examples of primarily ion-exchange-active adsorbents:

Special Na–Al silicates (e.g., modified bentonites, see also Sect. 8.4.2.1), synthetic or modified native adsorbentresins on an organic basis with cationic or anionic groups, PA fibers, PA gels as well as the superficially functionalized cellulose.

Despite of the aquatic, chemical or thermal renderability of the most adsorbents and numerous published applications for highly contaminated and particularly colored effluents, the pure adsorption and ion exchange technology as well as the gravel filtration practically have been used hitherto only for the cleaning of very slightly contaminated rinsing waters and as a polish step for already pre-treated sewage. Therefore, it is, at least up to date, primarily of interest as the last stage for wastewater recycling, both for selective and universal purification.

The use of specially designed ion exchangers for decolorization or heavy metal removal has not been established yet, but further efforts are underway to achieve practical maturity.

Processes such as precipitation and flocculation (Sect. 8.4.2.1), sewage sludge adsorption and biofiltration are the subject of separate chapters since adsorption takes place only as a subordinate, system-immature side process. The use of specially designed ion exchangers for decoloring or heavy metal removal has not been established so far.

8.4.2.4 Membrane Separation

As a method according to the state of the art and of science, the filtrations can be designated by microporous membranes made of cellulose acetate, polyacrylonitrile, polyamide, polysulfone. With an increasing fineness of the membrane and thus with increasing energy consumption as well as increasing clogging speed, it has to be differentiated.

Microfiltration, ultrafiltration, nanofiltration, and reverse osmosis or electrodialysis.

The membranes are used in tube, plate, pillow, winding or capillary modules.

Microfiltration has no major significance in wastewater treatment.

*Ultrafiltration*removes large molecular weight compounds up to a molecular weight of 1000 u (g/mol). Therefore, it has gained practical importance in the recovery of indigo dyes.

The *nanofiltration* removes compounds up to 150 u molar mass, i.e., most dyestuffs, surface-active and non-surface-active textile auxiliaries except electrolytes, acids, and alkalis. Therefore, it is particularly interesting for the purification of dyestuff effluents, in particular strongly contaminated with dyes and/or surfactants. A reuse of the liquor in the pretreatment and dyeing process is immediately possible.

The *reverse osmosis or electrodialysis* also separates molecules well below 150 u of the permeate. Therefore, it is indicated where electrolyte, acid or lye have to be recovered as a polish step and water completely free from organic and inorganic contaminants is required, for example, in case of pronounced water scarcity.

Membrane filtration techniques for textile wastewater.

Membrane filtration for textile effluent				
Type of membrane filtration	Pressure	Volume stream per m^2 area	Limit of retention	Smallest retained particles
Microfiltration	1–4 bar	100–400 l/h	50,000–500 000 u 0.1–1 μ	Colloid and suspended particles, bacteria
Ultrafiltration	2–25 bar	20–200 l/h	5000–50,000 u 0.01–0.1 μ	Polymer dispersions, oils, sizes
Nanofiltration	25–40 bar	10–100 l/h	200–5000 u 1–10 nm	Low molecular organics (e.g., surfactants, dyes)
Hyperfiltration (Elektrodialysis, reverse osmosis)	40–80 bar	5–25 l/h	<150 u <1 nm	Salts consisting of one or several atoms

The recently in the UK developed CustoMem process is a special version of ultrafiltration. In this process, a membrane is used, which is simultaneously prepared as adsorbing biofilters (see Sect. 8.4.2.3). This consists of microbiologically protein-functionalized cellulose, which is able to heavy metal ions, every kind of dyes as well as polar low molecular organic substances besides the usual retentions of ultrafiltration (see table) by ad- or absorption.

8.4.2.5 Substance Separation via Inclusion Compounds

A state-of-the-art process, which has been hitherto practiced only in laboratory or pilot scale for selective separation of substances with possibilities for water reuse and recycling of valuable substances, uses special macrocyclic, regenerable ligands.

A polymer fixation and the use as a fixed-bed filling material in filter columns is intended.

In particular, the following compounds and processes are of interest.

Selective dye separation by means of *cucurbituril*: hitherto, a separation of direct, reactive, acid, dispersion dyes from highly contaminated baths is largely quantitatively possible by means of such compounds. Regeneration is feasible by oxidative, reductive treatments and acidic extraction processes.

Selective heavy metal ion separation by *azacron ethers*. Heavy metal recovery by acid regeneration is possible in this case.

Selective AOX separation by *calixarene or cyclization products from formaldehyde and chromotropic acid.*

8.4.2.6 Ion-pair Extraction

While the so-called direct extraction, as well as the adsorption, has virtually no significance for textile wastewater treatment, the indirect extraction process of the so-called ion-pair extraction (BASF) appears to be a very interesting, efficient process for the selective removal of sulfo group-containing dyes. In the meantime, the method has reached an approximate standard of practice now. Principle: A hydrophobic adduct of anionic dye and special quaternary amine migrates into the organic phase in weakly acidic water or hydrocarbon mixture, from which the dye is separated by addition of alkali and water. The organic phase and carrier substance are recovered.

Possibly, more of this relatively inexpensive process as well as of the inclusion compounds in the field of substance separation will be become known.

8.4.2.7 Evaporation and Freezing Procedures

Evaporation processes are currently used particularly in the purification of pretreatment effluents—which is the state of the art. The non-volatile impurities are separated from the aqueous phase plus volatile wastewater constituents like vapor, which is subsequently condensed. As with all material separation techniques, waste disposal has to be treated via landfill, combustion or wet oxidation.

In the evaporation processes, the so-called forced circulation or falling-stream, evaporators are used. The process is made economical by the so-called multi-stage evaporation and by using the heat energy of the vapor during its condensation. However, the investment costs of an evaporation plant are very high, so primarily the process is of interest for larger companies.

Freezing processes, which produce highly contaminated brine, are of low importance, except in those cases where water scarcity on the one hand and sufficient sunlight as a source of energy on the other are available, as in the Middle East.

8.4.2.8 Chemical and Mechanical Cleavage of Oil–Water Emulsions and Polymer Dispersions

Chemical cleavage:

Sometimes, an emulsion or dispersion cleavage can be effected by heat treatment (90 °C) and in the case of liquors with a high proportion of emulsified substances or polymers with the addition of salt and special auxiliaries (e.g., flocculants such as bentonite or cationic polymers). Afterward, the resulting oil or solid phase has to be separated by further separation techniques, for example, filtration or flotation. However, as a rule, such an emulsion or dispersion cleavage is difficult to be applied in case of higher amounts of emulsifier components. The process is of importance primarily for partial streams of finishing effluent.

Mechanical cleavage:

In the case of a high proportion of highly volatile solvents, for example, chlorinated hydrocarbons, a mechanical solvent desorption process can be carried out by means of blown-in air, so-called stripping. The importance is actually only given to those plants, where pretreatment and after-treatment in solvent plants are conducted.

8.4.2.9 Foaming Out of Surfactants

The method of foaming off surfactants by means of special devices and chemicals is a less difficult method for the pre-cleaning of highly surfactant-loaded partial streams. In this process, surfactants can be recovered simultaneously as valuable material.

8.4.3 Substance-Destroying Processes

8.4.3.1 Oxidative Methods

Aerobic biological methods

Aerobic biological purification processes have been the main stage of a municipal sewage treatment plant as well as most sewage treatment plants from direct dischargers for a long time. Here, mechanical processes like raking, sanding and sedimentation pretreatment basins are always placed in front of the aerobic biological stage, as well as chemical precipitation processes for the elimination of phosphate.

Aerobic biological processes are suited optimally for large quantities of relatively low polluted wastewater, e.g., mixed wastewater from a large textile finishing company or, even better, mixed wastewater from industrial and household wastewater. In the aerobic process, oxidative mineralization and adsorptive elimination of the wastewater freight are achieved by aerobic microorganisms. Therefore, there are actually substances-destroying and substance-separating processes occurring side by side.

An aerobic biological clarification stage is carried out either as an activated sludge basin containing a stirred and aerated sewage sludge mixture with a subsequent secondary sedimentation basin for sewage sludge removal or as trickling filter plant with lava or coke cascades covered with bacterial lawns or as reed biology or rather land treatment, respectively, wastewater dripping procedures.

The first method is predominant; the second is only used as a support for the activated sludge basin process at stress peaks; the third is no longer modern because of the successive earth contamination with refractory pollutants, especially dyes and heavy metals. In addition, its cleaning power is subjected to strong seasonal fluctuations.

In contrast to the aerobic coal-biological reactor processes, this is also called submerged pelvic biology. Aerobic biological nitrification and anaerobic biological denitrification stages are either downstream of or integrated into the activated sludge basin. In the basin, additional gassing with pure oxygen for simultaneous nitrification or Biolak-Wox processes with aerated and non-aerated zones besides each other for simultaneous nitrification or denitrification occur.

Nitrification or denitrification usually represents the most sensitive stage of an aerobic biological sewage treatment plant against wastewater toxins ("nitrification inhibitors").

In the meantime, the chemical phosphate elimination, which is also regularly followed, via iron, Al or Ca salts or bentonite has sometimes already been replaced by a biological phosphate elimination by means of special aerobic bacterial strains. The disadvantages of the chemical phosphate eliminations are electrolyte contribution and sewage sludge increase, which are not along with biological phosphate elimination. The main disadvantages of the mechanical and aerobiological sewage treatment plant are the non-removal of refractory compounds, including most soluble dyes as well as the matter of fact that partial separation of materials also takes place here. However, the sewage sludge discharge problem and its costs are generally not as large as for the waste from chapter "Separation and concentrating processes," because of the significantly reduced pollutant load. The sludge can often be used after dewatering and drying in agriculture and forestry as well as in horticulture according to sewage sludge ordinance.

Pressureless oxidation by means of chemicals and/or UV light

The oxidation potential of specific oxidizing agents, including that of UV light, used in sewage purification and thus also the decolorizing power with respect to dyes are clearly above those of the aerobic biological processes. However, adsorptive support is lacking at the same time.

In order of increasing oxidation power and discoloring effect, the following applications can be listed (from Fenton's reagent the processes are called AOP = advanced oxidation processes):

- Hydrogen peroxide in the alkaline medium
- Ozone
- Fenton's reagent: hydrogen peroxide + iron (III) ions in strongly acid medium ($pH < 3$)
- Hydrogen peroxide + UV light
- Ozone + UV light
- Vacuum UV and TiO_2-catalyzed UV photolysis (only at laboratory or pilot scale).

The oxidation is based on predominantly radical reactions and comprises almost all soluble azo dyes and most basic dyes, especially in the catalytic variants (starting from Fenton's reagent). However, the methods are not effective for decolorizing soluble and insoluble phthalocyanine, anthraquinone and sulfur dyes as well as insoluble azo dyes. On the other hand, the undissolved, insoluble dyes can be eliminated easily by material separation processes.

Furthermore, there is not only achieved partial mineralization and decolorization by chemical oxidation, but also sensitization of the not yet mineralized, but now at least polarized, disinfected and decontaminated components for downstream material separation or destruction processes. In particular, this applies to precipitation, flocculation and biological steps.

However, the absorbability is deteriorated.

Within the concept of combined sewage treatment, therefore, the oxidizing agent treatment has already an important position, either as a pretreatment stage, main stage or, in particular, ozonation, as a polish step with a disinfecting side effect.

However, the classical oxidation processes with chlorine, hypochlorite or chlorite have got a comparable effect due to the associated AOX problem but no longer any importance.

Wet oxidation process

Biocatalytic wet oxidation processes (biofilter processes)

This is actually a charcoal-activated special form of aerobic biological purification. Aerobic biology is based on activated charcoal or coke as a carrier substance. Therefore, in this case, we are speaking of carbon biology in contrast to conventional basin submerged biology. Activated carbon is blown with air at normal pressure or overpressure and room temperature in a reactor, the so-called biofilter, realized as fixed-bed technology for the Palmer-Nohl method and as fluidized-bed or mixed-bed technology for the Katox method. A tightly interlaced combination of activated carbon adsorption catalyzed air oxidation and intensified biological mineralization of the wastewater freight is carried out. However, as a rule, a subsequent substance separation stage is necessary in cases of direct discharge or recycling. In particular, there is the precipitation, flocculation and flotation stage (e.g., Katox F method), the adsorption stage (Katox A method) or, in the case of fixed-bed technology, a usually integrated ultrafiltration stage (pressure biology).In addition, carbon biology is even followed by submerged biology sometimes(e.g., Katox B method).

Even if the decolorizing power of the carbon biology is better than that of the conventional aerobic basin biology it is still significantly lower than that of other methods like anaerobic processes, wet oxidation, electro flotation. Although the process is still practiced by some of the large-scale textile finishing mills, it does not seem to have any perspectives for the future in case of dyed effluents due to the disadvantages mentioned above.

Wet oxidation (wet combustion)

In wet oxidation in the narrower sense, also described as wet combustion, almost all organic wastewater components are oxidized catalytically by means of air injection or hydrogen peroxide in a reactor at more or less high temperature and high pressure. Thereby, complete mineralization is occurring. In particular, also all persistent organic compounds and dyes contained in the wastewater are eliminated completely.

Especially, efficient and interesting is the wet oxidation for minor volume streams of medium and highly concentrated wastewater, i.e., for the treatment of concentrated partial flows.

It has to be distinguished between:

- High-pressure wet oxidation (compressed air, 50–150 bar, 200–300 °C, Cu catalysts)
- Low-pressure wet oxidation (3–20 bar, 120–200 °C); Variants: Loprox process: compressed air, iron (II) salts, chinon-forming organics; clear-finish process: hydrogen peroxide, iron (III) salts, lime milk or sodium hydroxide solution.

In particular, the slightly less intense low-pressure wet oxidation with its two embodiments has been found recently to have got major importance in the textile industry, owing to lower investment and operating expenditures, as the only necessary cleaning stage for wastewater in case of direct discharging and recycling. Some manufacturers already offer relatively inexpensive, so-called autothermic compact systems with the additional possibility of heat recovery.

In addition, the wet oxidation can also be used instead of incineration for the mineralization of waste from material-separating processes. The wet oxidation, as well as the higher sophisticated types of pressureless chemical oxidation processes, also belongs to the so-called advanced oxidation processes (AOP).

The wet oxidation should not be mixed up with the high-temperature combustion during the gas plasma oxidation process, which is atomizing the organic wastewater ingredients in special burners. However, the latter is generally uneconomic for textile wastewater. High-temperature combustion is only useful in case of small amounts of highly or extremely highly contaminated and highly toxic wastewater, as it is mainly the case in the chemical and pharmaceutical industry.

Electrochemical oxidation

Electrolysis with non-accessible vulnerable electrodes

This technology is also known as the electro-M method.

By the nascent gases oxygen and hydrogen arising at the electrodes, the wastewater is oxidatively and reductively degraded.

At the same time, a good decolorization, in particular of soluble azo, basic and phthalocyanine dyes, is achieved by the combination of oxidation and reduction.

In the so-called indirect method, the use of mediators, such as iron sulfate and triethanolamine, facilitates significantly these processes in comparison with the direct electrolysis which is free of auxiliaries at all.

Owing to the relatively high energy and chemical expenditure, the electrolysis with non-vulnerable electrodes, even the more efficient indirect method, has never gained any importance for textile sewage, although it has been considered for a longer time as a non-uninteresting sewage treatment method.

Electroflotation (electrolysis with accessible iron anodes).

This technology was developed by Klose in Germany.

At the anode nascent oxygen and at the cathode nascent hydrogen is formed, similar to the method described above.

However, catalytically active Fe (II) ions are created at the anode and alkaline pH value is established there. The latter one is finally causing the precipitation of iron (III) hydroxides, which additionally is flocculating the residual organic freight.

The resulting flocs are floated by the gases formed on the electrodes now and can be separated from the aqueous phase. Flocculation and/or flotation aids like collectors, foamers, regulators and insulators are supporting this process.

Thus, in this "klose process," a combination of oxidation, reduction, precipitation, flocculation and flotation is occurring side by side.

A formation of chlorine gas at the anode has to be avoided by special measures, which is in straight contrast to the AOX-problematic "Brinecell" method from the USA. There oxidizing active chlorine is even intended to be formed at the anode by addition of chloride salts.

The electroflotation process is an interesting but not yet widely practiced method for the sole purification of wastewater. In particular, it is interesting because the combination of several simultaneous effects is achieving an optimum purification and also—more or less color-independent—a significant decolorization success. The costs for the process themselves are nowadays already at an acceptable level.

The disadvantage compared with the usually more expensive wet oxidation, which also can be applied solely, is the matter of fact that discharged sludge is occurring, quite similar to the classical precipitation/flocculation (see Sect. 8.4.2.1).

Reductive procedures

Anaerobic biological procedures

In the case of anaerobic processes, the effluent in reactors is treated with anaerobic fermentation-active microorganisms under strict exclusion of air. Two stages are connected in sequence with their own bacterial strains, whose optimal milieu conditions have to be kept constant by regulation:

- Hydrolysis and acidification step (pH optimum 3.5–5.5, temperature 30–36 °C)
- Acetogen and methane phase (pH optimum 6.5–7.5, temperature 35–38 °C).

Apart from adsorption on sewage sludge, these processes result only in partial decomposition of organic freight. However, in particular aerobically not accessible components are cracked, hence a downstream aerobic biological process can be more effective by far.

It has to be emphasized especially that anaerobic processes, in addition to the adsorption of insoluble dyes, result in the decolorization of azo dyes and some basic dyes. Aerobic processes are not able to provide it at all. However, phthalocyanine dyes are not or hardly eliminated respectively discolored.

Further advantages of the anaerobic biodegradation processes are their high cleaning efficiency, the relatively low amount of sewage sludge as well as the use of methane in the sense of a positive energy balance.

Disadvantages, as already indicated, are the high sensitivity of the anaerobic biocenosis to milieu fluctuations and toxins, as well as the relatively large investment and operating costs.

Chemical reduction

By chemical reducing agents, there cannot be achieved a significant COD reduction. Their function in wastewater treatment is primarily the decolorization of azodyestuffs, many basic dyes, some anthraquinone, and some sulfur dyestuffs.

At least a partial decolorization in the case of non-azo dyes is usually possible by reduction agent, even in the case of phthalocyanine dyes. In addition, often a partial reduction, even without significant or sufficient decolorization effect, is causing a much better biological elimination of the dye in the downstream municipal sewage treatment plant.

Finally, some persistent organic compounds are cracked and sometimes heavy metal ions are converted into the elementary and hence easily eliminable metal state, mainly by sulfite-catalyzed sodium borohydride at pH 7.

While the very effective sulfur-based reducing agents, such as sodium dithionite or thiourea dioxide, do not appear to be useful in many cases because of their own environmental impact, the use of sulfur-free or sulfur-reduced, more environmentally friendly alternatives are increasingly preferred. First and foremost, they are comprising:

– Sodium borohydride + sodium bisulfite
– Hydroxyacetone
– Iron (II) salts in alkaline medium.

The latter ones are present as Fe (III) salts after the reductive use as coagulants for the organic sewage load (see Sect. 8.4.2.1). And thus, there is not only occurring decolorization but also COD reduction. On the other hand, in contrast to the other reducing agents, in this case, flocculation-specific problems are arising.

However, the lack of a significant reduction in COD is often an advantage of the other reducing agents, especially in the case of indirect discharging companies, since they can be used therefore exceptionally for decolorization without any consumption and loss for COD load.

The use of reducing agents for wastewater decolorization in indirect discharging companies is particularly advantageous in case of relatively high azo dye concentrations in wastewater (partial flow treatment), relatively high wastewater temperatures, relatively long dwelling time prior to discharge and a relatively high degree of dilution in the wastewater channel. Sufficient effect on the one hand and avoiding of any impairment of the downstream municipal biology, on the other hand, are then very likely.

The reduction agent concentrations necessary for medium to highly colored effluents are relatively low (per gram of dye: 1–3 g of reducing agent) under optimal conditions.

Electrochemical reduction

This is done simultaneously with oxidation in the electrochemical technologies described above.

8.4.4 Combined Wastewater Treatment Methods

8.4.4.1 System-Immanent Process Combinations

Many of the above-described individual substance-separating and destroying technologies cannot be carried out on their own, but inevitably require necessarily for their own effectiveness previous or subsequent, so-called system-immanent cleaning stages.It has not a real combined purification process (sewage treatment line) in the sense of this paper yet.

Examples of such system-immanent process combinations are for example the after clearing basins for sludge sedimentation after aerobic biological wastewater treatment, sewage sludge flotation or sedimentation processes after precipitation, flocculation or electroflotation to remove the precipitate or adsorption and precipitation processes after carbon biology.

All waste disposal methods, like filtration, drying, landfill, wet oxidation and combustion for sewage sludge of any origin are neither part of the system-immanent measures nor of the sewage treatment lines (see Sect. 8.4.4.2). These processes of drying, landfill, wet oxidation or incineration are carried out on a regular basis, not by municipal or company sewage treatment plants, but by external independent service companies for the purpose of eliminating waste.

8.4.4.2 Sewage Treatment Lines

For indirect discharges without recycling, sufficient wastewater treatment is usually already achieved by means of a single cleaning step. For the time being, in most of these cases, even a simple compensation process is sufficient (see Sect. 8.4.1).

However for direct feeding, municipal sewage treatment plants for textile sewage and, in particular, for at least partial wastewater recycling, to be carried out by indirect and direct feeders, usually, there is an adequate method combination necessary, which goes significantly beyond chapter "System-consistent process combination." Such a combination of processes should be planned very well since it has to be adapted exactly to the respective wastewater and to the intended use in terms of quality and quantity from the point of view of cost minimization (see Sect. 8.4.3).

A partial flow treatment instead of mixed-water treatment, which is usually not realizable in case of municipal sewage treatment plants, but in case of directly discharging plants, is particularly advantageous here. Such process combinations, so-called "cleaning lines," are combining compensation, separation and destruction processes, which are linked mainly serially and/or in a parallel manner, especially in the case of partial flow treatment or in order to minimize stress peaks.

Despite numerous different and—of course—very individual possibilities, a basic scheme can mostly be found for the process combination as typical cleaning line:

1. Compensation basin (for detoxification, neutralization, hydraulic compensation, sedimentation of suspended matters) in case of industrial cleaning or raking/sanding/ pre-settling basins in case of municipal cleaning.
2. Substance-destroying treatment (e.g., biology, chemical oxidation)
   Sometimes, there are placed substance separation processes prior to aerobic submerse biological processes, in particular, inorganic precipitation, flocculation or a biological phosphate elimination process because of better decolorization, sulfur detoxification, heavy metal separation, phosphate removal and elimination of refractory compounds. But a subsequent application of these material separation steps (see Sect. 8.3) is dominating and seems to be more favorable in most cases. Also, feasible and useful is a combination of several different substance-destroying treatments (e.g., aerobic biology—nitrification or denitrification-anaerobic biology or combination of carbon biology—submerse biology).
3. Separating treatment (for example precipitation/flocculation, sedimentation/pressure relaxation flotation, adsorption, membrane filtration, evaporation) with subsequent sludge discharge as a system-immanent measure (see "System-consistent process combination").

4a. One Part (0–100%) is discharged indirectly or directly into the effluent pipe or river (only in the exceptional case; here are polished steps acc. to 4b necessary).

4b. Part (complementary to 4a) further cleaning for recycling reasons with the means of one or several polish steps (e.g., via flocculation, ozonation, coarse filtration, adsorption/ion exchange, membrane filtration, softening, deironing, blending with fresh water, etc.).

In certain cases, particularly in case of partial flow treatment, however, a single treatment, which could be a system-immanent combination, for direct discharge or recycling for direct and indirect discharges, is sufficient.

These cases are mainly realized as electroflotation or wet oxidation equipment for wastewater decolorization or ultrafiltration units for the recycling of process water and size in case of pretreatment wastewater of woven fabric mills. These equipment are already available as compact units. However, in the case of the separation processes, e.g., size recycling, electroflotation, the expensive sludge discharge has to be considered only as an additional system-immanent step.

8.5 Methods for Wastewater Recycling, Recovery of Valuable Substances and Energy

8.5.1 General Information

The recycling, reuse or rather recovery of water, energy and valuable materials have an intermediate position between non-economic wastewater treatment as an end-of-pipe process and highly economic production-integrated effluent and waste prevention strategy.

In contrast to the pure end-of-pipe cleaning, recycling is already able to achieve the so-called payback situation.

We can differ between four categories of recycling, listed in order of decreasing expenditure, because of decreasing investment and operating costs, and thus in order of higher payback probability. At the same time, the fluid transition from a sewage treatment process to a production-integrated measure becomes evident:

1. Reconditioning of mixed wastewater,
2. Reconditioning of partial flow wastewater,
3. Reuse of only slightly contaminated final rinsing liquors,
4. Finishing using“standing baths.”

However, the process reliability and flexibility in the finishing process are reduced in the order of the methods 2–4 to the same extent and method 2 can mean a significantly higher investment expenditure compared to method 1, because of the establishment of an infrastructure for partial flow treatment.

Ultimately, the optimum recycling model has to be determined for the respective individual plant, whereby different processes are possible for different parts of the plant. Generally for the reuse of the recycled water according to the subsequently described processes, the following limit values have to be undercut in the finishing:

Color	Colorless
pH value	6.5–7.5
Inorganic components	450 mg/L spec. conductivity 70 microsiemens/cm
Cu ions	0.005 mg/L
Cr ions	0.1 mg/L
Fe ions	0.1 mg/L
Mn ions	0.05 mg/L
Al ions	0.2 mg/L
Silicate	1–10 mg/L
Sulfate	200 mg/L
Chloride	150 mg/L
Nitrite and nitrate	0
Suspending articles	0
Total hardness	5° dH (90 mg/L $CaCO_3$)
Carbonate hardness	2° dH (36 mg/L $CaCO_3$)
COD value	50 mg/L

8.5.2 Recycling of Mixed Wastewater

The recovering of mixed sewage is the most uneconomical method of cleaning and recycling due to the relatively high dilution and the extreme material diversity of wastewater freight. Mixed sewage is a mixture of the different partial streams in the case of a sewage treatment plant or a mixture of industrial wastewater and municipal wastewater in municipal sewage treatment plants.

Only in exceptional cases, recovery of heat energy is possible; however, the recycling of valuable substances is not feasible at all. Mixed wastewater recycling is placing the highest requirements on the cleaning plant with the highest investment and operating costs. Furthermore, only a relatively low recycling rate (max. 30–40%) is economical and usual, because the quality of the recycled water even has to be significantly better than that of the directly discharged water.

However, the recycling of mixed sewage is, at least economic for large companies respectively directly discharging plants, as in those cases as a rule a large cleaning facility is already available on the one hand and the establishment of an infrastructure for partial flow treatment (see "Reconditioning of partial flow wastewater") would mean an incomparably major effort than for indirectly discharging and small to medium-sized companies on the other hand. In fact recycling of mixed effluent is still for the time being the most widely practiced procedure from the four recycling methods presented.

The technical realization of mixed wastewater recycling is, in principle, set out in Sect. 8.4.4.2 and is comprising generally a multi-stage cleaning line, which is usually divided after a substance separating main step into a larger (<50%) direct discharge flow and a smaller recycling stream. Finally, as a rule, a waste stream is resulting from substance-separating techniques.

8.5.3 Recycling of Partial Wastewater

The purification and treatment of partial stream wastewater are much more efficient than mixed-water treatment, since generally highly, medium and low-contaminated partial streams with a defined composition are permitting a much more focused treatment. Heat and valuable material recoveries are generally feasible.

A higher recycling rate up to full recycling (50 to almost 100%) is possible.On the other hand, partial flow treatment requires a special infrastructure to be established within the plant, for example, extensive pipeline, buffer and treatment capacities. As a rule, this is cost-effective only for small to medium-sized companies, in particular, those with indirect discharge, especially in case they are still in the planning or development phase.

Currently, partial flow treatment is still carried out only in a few cases, although the tendency is increasing. The technical realization for partial flow treatment is, apart from additional equipment such as pipes, storage tanks, switches, special measuring and control technology within the plant similar to that for mixed wastewater treatment. However, single treatments like low-pressure wet oxidation) or at least shorter treatment lines than for mixed-water treatment are sufficient for the individual partial flows. See also Sect. 8.4.4.2.

The partial flow treatment can be variable, rigid or combined. At the variable treatment, concentration-controlled switches enable flexible partial flow treatment depending on the instantaneous sewage load, at the rigid treatment, there are defined department specific and hence substance specific partial streams, and at the combined treatment, there are department-specific partial flows, which are controlled and led by means of switch points.

The output results in one or more recycling streams (>50%), which do not necessarily have to be further processed, a smaller indirect or direct discharge stream and a small to very small waste stream. In most cases, there is also a heat recycling stream and sometimes a recycled valuables substance stream.

The most extreme and efficient version of the combined treatment would be the recycling immediately placed at the textile wet processing unit itself, a method that is far away from being state of art yet.

8.5.4 Reuse of Slightly Contaminated Wash Liquors (Bleaching Liquor Recycling)

The reuse of slightly loaded wash liquors, particularly final rinsing liquors, and peroxide bleaching liquors is principally partial flow recycling measures with or without appreciable cleaning or conditioning.

A cleaning system is not necessary. In addition, the infrastructure requirements are already significantly lower than in the chapter "Reconditioning of partial flow wastewater," but considerable investments have to be made for equipment accessories like measuring and control systems.

The recovery of heat in the countercurrent principle is implemented relatively easy here (e.g., CCR technique from Thies).

Whether a rinse liquor can be reused once only or even several times is depending on the specific application. Thus, the last rinsing liquor of a light to medium deep reactive dyeing can, for example, be reused successively as a second last rinsing liquor, soaping liquor, second and first rinse liquor, or—alternatively, it can be used only once as dyeing liquor. In the case of a deep reactive coloration, the possible applications of this so-called discontinuous countercurrent rinsing technique are sometimes more limited.

The disadvantages compared with the recovering processes are the lower flexibility and operational safety of the process and, in particular, the fact that this process covers only a small part of the wastewater ($\ll$50%).

The procedure is currently still in the trial and starter phase, but contrary to the chapter "Reconditioning of partial flow wastewater," it is likely that in the not so far future a broader commercial use will be found. Here, for example, the soaping and rising intense reactive dyeing will be aimed at.

At least a similar apparatus, process and measurement technology have already been established in the reuse of bleaching liquors, but this is not to be dealt with at this point.

8.5.5 Textile Wet Processing from Standing Baths

The reuse of baths of textile wet processing after re-activation with chemicals and/or dyes has become important and well proven in particular for the dyeing from standing bath. This is also a partial flow recycling without any cleaning effort or at least without a significant one. However, this is already nearly to be understood as a production-integrated measure, even more than the previously described method (see "Reuse of slightly contaminated wash liquor").

In contrast to the reuse of rinsing baths, no significant additional equipment such as storage tanks or pipelines is necessary here, apart from certain off- or in-situ measurement devices for the measurement of pH value, conductivity, residual color of the liquor, etc., since the liquor remains in the machine between the processes. The measuring techniques are sometimes inevitable for the determination of the necessary addition of dye and/or chemical for re-sharpening reasons, as far as empiricism is not sufficient as it is the case in the sulfur dyeing (see below).

The frequency of the reuse of the liquor depends on several parameters but in general, it should have an absolute upper limit at 5–7 reuses. Above this limit, operational safety is increasingly doubtful.

Apart from the lower investment and operating expenses, the same disadvantages are valid as in the case of "Reuse of slightly contaminated wash liquor," even in an enhanced form.

The dyeing from standing baths is already practiced successfully in the following cases:

- Dyeing cellulose fibers with sulfur and direct dyes
- Dyeing PA fibers, in particular carpets with dispersion, acid and 1: 2 metal complex dyestuffs
- Dyeing wool fibers with acid, 1: 1 and 1: 2 metal complex dyes
- Dyeing PES with dispersion dyes
- Dyeing PAN fibers with basic dyes
- Dyeing of aramid fibers with basic dyes.

Normally during dyeing from standing baths, almost complete bath exhaustion is attempted by appropriate temperature and/or pH control and/or electrolytic dosing. Depending on the degree of exhaustion, the effort ofthe above-mentioned measurement technology has to be lower or higher in order to evaluate the residual liquor and to calculate the replenishment additions of chemicals and dyes. An exception is the sulfur dyeing, as the classical dyeing from a standing bath. In this dyeing process, a certain color deviation is accepted, depending on the individual textile and dyestuff. Despite only moderate yield, this fact is reducing the effort of measuring and dyeing. Furthermore, in the case of sulfur dyeing, it is also advantageous in terms of disposition, that, as a rule, many batches are successively dyed in equal and deep nuances, for example, with hydron blue, hydrosol black or indocarbon.

However, the possibilities, occasionally published in the literature, of the reuse of medium to highly stressed reactive residue liquors for dyeing wool or polyamide after acidifying are very limited, less due to technical reasons, but more due to coloristic reasons.

8.6 Production-Integrated Measures for the Prevention and Minimization of Dyestuffs

The measures of avoidance and minimization of sewage generation, known as production-integrated measures, are the most cost-effective method of wastewater reduction in terms of quantity and in terms of quality. Especially with the inclusion of efficient partial stream cleaning, recycling methods and simultaneous cross-media measures, a production-integrated method with a near wastewater and waste-free operation, creating a maximum payback situation, can be achieved (see Brinkhaus project).

Such production-integrated measures, carried out in pretreatment, dyeing, printing, and finishing, are new recipes and products on the one hand and improved or rather new processes on the one hand. In the field of dyeing, these are for example:

(A) New recipes and products:

- Reactive dyes with an optimized degree of fixation or low salt demand (e.g., bifunctional ones)
- Dyes and auxiliaries, if possible, without ecologically harmful ingredients (traces in the ppm not relevant usually), as they are, e.g.,
  - Formaldehyde
  - AOX (mainly halogenated, low molecular weight C1–C12 compounds with >5% halogen)
  - AOX-producing inorganic compounds (sodium chlorite and hypochlorite)
  - APEO (alkyl phenol ethoxylates)
  - Nitrogen compounds
  - Phosphorus compounds, mainly phosphates
  - Sulfur-containing reducing agents
  - Heavy metal ions (e.g., Pb, As, Cd, Hg, Cr, Zn, Sn, Cu, Co, Ni, Sb-ions)
  - Non-bioeliminable (refractory, persistent) organic substances
  - CMT (cancerogenic, mutagenic, teratogenic) substances
  - Bioaccumulable substances (e.g., certain ethoxylates)

- Highly acute toxic or ecotoxic substances (with low LD or EC values)

- For applications where the latter item is not state of the art, there should be conducted at least a selection of those dyes chemicals which are still the best ones in terms of ecotoxicology as the following ones:
  - E.g., liquid dispersion of disperse, vat and sulfur dyes (containing fewer refractory dispersants than powder types)
  - Formaldehyde-free polyquaternary fastness improvers for Cel, SE and wool
  - Formaldehyde-free wool protecting agents
  - Carrier based on *N*-alkylphthalimide
  - Di-*n*-butyl phthalate-free diffusion accelerators or migrators for PES
  - N-pyridinium-free PAN migrators (base: trialkylbenzylammonium chloride/sulfate)
  - Alkyl quaternary cationic retarders or saponification accelerators

(B) New or rather improved dyeing processes:

- Dyeing from standing baths, flushing water recycling
- Low liquor ratio technology
- Improvement of dye fixation during pretreatment or dyeing
- Optimization of rinsing and soaping processes
- One bath combinations of pretreatment, dyeing and softening processes
- Substitution of improvement of highly environment-affecting dyeing processes
- Substitution of discontinuous by semi- or continuity processes with minimal system losses
- New dyeing systems with extremely low water volumes or totally without water (e.g., CO_2 dyeing).

Appendix

Practical Textile Wastewater Treatment Methods via Precipitation, Flocculation, and Reduction

1. *Conventional precipitation and flocculation (universal wastewater treatment)*: 1.0–4.0 g/L of aluminum sulfate, chloride or iron (III) sulfate or chloride as an inorganic coagulant. 0.1–0.2 g/L of a 1–2% solution of polyelectrolyte (as a so-called flocculation aid or flocculant) at pH 8 ± 1, adjusted by means of NaOH or $Ca(OH)_2$. Temperatures as low as possible (in any case less than 40 °C), thorough agitation (mixing). Then calm sedimentation with dwelling time 10 min until 1 day.

2. *Precipitation and flocculation with the inclusion of a cationic coagulant (universal wastewater treatment)*:
   0.2–1.0 g/L of aluminum sulfate, chloride or iron (III) sulfate or chloride as an inorganic coagulant. 0.1–0.2 g/L appr. 40% solution of polyquaternary ammonia compound as a so-called cationic organic coagulant. Only in exceptional cases 0.05–0.1 g/L of a 1–2% solution of a polyelectrolyte as flocculant at pH 8 ± 1 adjusted with NaOH or $Ca(OH)_2$. Temperatures as low as possible (in any case less than 40 °C) Thorough agitation (mixing), then calm sedimentation with dwelling time 10 min until 1 day.

3. *Precipitation with a cationic coagulant (in particular for* decolorization *and for general purification in the presence of anionic surfactants)*:
   0.01–2 g/L of an appr. 40% solution of a polyquaternary ammonia compound as cationic coagulant (appr. one gram of solution per gram of dye!), pH slightly neutral to slightly alkaline (7–8), salt content preferably less than 10 g/L, preferably low temperatures with at first thorough circulation (mixing) and then calm sedimentation with dwelling time of 10 min until 1 day.

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Chapter 9
Wastewater Treatment of a Denim Washing Plant by Using Waste Pumice Stones to Recycle Wastewater and Reuse

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Abstract In this study, the removal of pollutants from the wastewater of a denim washing plant by using the waste pumice stones and reuse of treated water were targeted. The trials were carried out through a continuous adsorption system. For this aim, the waste pumice stones were placed into an adsorption column, and the wastewater was allowed to pass through the column in different flow rates. The treated water was mixed with freshwater in certain ratios in order to be reused in laundry. The result of the studies revealed that the treated water has the potential to be used as denim washing input water.

Keywords Denim · Stone washing · Indigo · Pumice stone · Adsorption · Waste water · Waste water treatment

9.1 Introduction

In general, the textile industry consumes enormous amount of water and auxiliary chemicals primarily in the dyeing and finishing operations (Lin and Chen 1997; O'Neill et al. 1999; Veliev et al. 2006; Wambuguh 2009). Because the chemicals are not fixed on the fibre, they are removed during the washing and ending up in wastewater. About 12% of synthetic dyes used each year in the textile industry are lost, and 20% of these lost dyes released the environment through effluents. The effluent from denim industry containing 5–20% of the indigo dye used causes

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wastewater with colour, suspended solids (salts) and dissolved organics (O'Neill et al. 1999). Some of those contents cause main toxicity in the wastewater, effect the aesthetic look, harm the quality of receipt streams and could be toxic for the treatment processes. Discharged effluent containing dyestuffs decreases the light conductivity which is necessary for the life cycle of the primary photosynthesis producers that live in water. Therefore, it seriously damages ecosystems (Veliev et al. 2006).

Miscellaneous processes have been applied to remove the colloidal compounds and suspended solids to decrease the higher biological oxygen demand (BOD). However, there is no single treatment available to decompose the dyestuffs in the effluent. The main disadvantage of the existing processes is the high investment, operating and maintenance costs (Wambuguh 2009).

In contrast, the adsorption method is now becoming an appropriate method for treating the effluents and has been widely used in various industrial processes in separation and removal purposes, mostly in the removal of organic pollutants particularly in textile industry (Al-Qoda 2000; Zaharia and Suteu 2012). The well-known industrial adsorption processes are nano-filtration and reverse osmosis systems. Their biggest disadvantages are the high costs of the investments and periodical refreshment of the expensive adsorption materials (medium) (Bagiran 2018). Even though the contaminants are moved from liquid to solid medium, adsorption process is a very efficient solution to protect the environment due to the ability of capturing and keeping apart the treated effluent in small volumes. The contaminants which are loaded onto the adsorbents can be removed by using various methods like chemical and thermal treatments (Sabbas et al. 2003; Toraman and Topal 2003). Some opportunities exist to use up these materials like in house construction, public roads and buildings so that waste can be recycled (Sabbas et al. 2003; Sivrikaya et al. 2014).

Pumice is a very interesting adsorbent. It is a volcanic rock which has a porous structure resulting in having high porosity and large amorphous areas inside. It is mainly composed of SiO_2 with lower density (0.35–0.65 g/cm^3) in aggregate form. Thanks to high porosity/surface area of pumice, the use of various pumice types (natural, modified, etc.) to be used as an adsorbent to remove the inorganic and organic substances that pollute the wastewater is still under research (Akbal 2005; Veliev et al. 2006; Kitis et al. 2007; Samarghandi et al. 2012a, b; Derakhshan et al. 2013; Samarghandi et al. 2013; Sepehr et al. 2013; Çifçi and Meriç 2015; Heibati et al. 2015; Asadia et al. 2016; Kocadağıstan and Kocadağıstan 2016).

Denim is pure cotton or cotton blend twill fabric. Cotton can be blended with lycra, polyester, regenerated cellulose fibres, etc. Denim fabric consists of dyed and undyed yarn. Undyed weft yarn is nearly white in colour. In jeans manufacturing, warp yarns are dyed with indigo-based dyestuffs that enable to obtain dark blue colour on the fabric (Wambuguh 2009; Paul 2015). Nowadays, synthetic indigo has almost taken the place of natural indigo. On the other hand, non-indigo dyes like sulphur dyes are also alternative to indigo. Sulphur dyes are commonly used for bottoming and topping of indigo due to reduce the overall cost (Chavan 2015; Paul 2015). Manufacturing of denim fabric is generally similar to that of grey fabric. However, sizing process in denim manufacturing is different from conventional sizing. Warp yarns of denim fabric are dyed at the stage of sizing. Therefore, weaving has important effect on

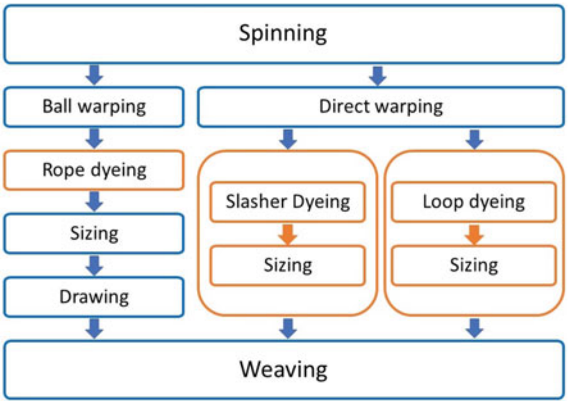

Fig. 9.1 Warp yarns dyeing methods in denim manufacturing (Illustration by S. Jonas)

the quality of the final garment (Paul 2015). Warp yarns are dyed continuously in three major methods. They are rope dyeing, slasher dyeing and loop dyeing (Fig. 9.1) (Meksi and Mhenni 2015).

In rope dyeing, 350–400 warp yarns make very thick cable of 10,000–15,000 m in length. Usually, 12–36 cables are first scoured and rinsed. Then, cables are dipped into a bath of leuco indigo. The wet pickup value is about 70–80%. After each dip, the cables are oxidized in air. At the end of the process, the cables are washed (Meksi and Mhenni 2015).

Instead of ball warping, direct warping is the stage of slasher dyeing. The warp yarns are in the form of sheet. It consists of about 4000 yarns. The sheet is first scoured and rinsed as in rope dyeing. Then, the sheet passes through the multi-dip/nip indigo dyeing section. The oxidation time is shorter than that of rope dyeing. The oxidation time takes at least 45 s. After dyeing, the sheet is washed and dried. The dyed sheet is dipped into size box, and the warp yarns pick up the required quantity of size solution (Meksi and Mhenni 2015).

Loop dyeing process is known as "Loopdye one for six". After pre-treatment process, the warp yarns are dyed in only a single bath with one squeezing unit. The yarns exit the dyeing bath. However, they do not move forward. Warp yarns are borne rear of the machine and come back to dyeing bath for another dye passage. Then, the dyed yarns are washed and dried. Sizing process follows drying directly (Meksi and Mhenni 2015).

Final stage is the weaving in the manufacturing of denim fabric. It is used for jeans, skirts, dresses, jackets, shorts, etc. Finishing of denim garments is very important for different look such as worn-out appearance. In order to get "the washed/aged look" on blue jeans, it is required to wash the raw garments in the wash baths that include pumice stones and/or various enzymes like cellulase and/or laccase so called "stonewashing". Following stonewashing, local or all over bleach steps are applied to obtain used look and faded colour that neutralization and many rinsing steps follow for ensuring to remove the leftovers of oxidative bleach agents (Wambuguh 2009).

Starting generally with the "stonewashing" process, the complete washing processes cause high amount of indigo to be removed from the denim fabrics into the discharged effluent. The effluent colour is highly visible even in very low concentrations for most dyestuffs, receiving complaints from an environmentally sensitive public and often failing to meet minimum requirements of the regulations valid for wastewater discharge (Wambuguh 2009). Effluent that contains indigo dyestuff is characterised by a certain amount of chemical oxygen demand (COD), organic and inorganic content, pH, suspended and dissolved solids and colour. Even though colour and COD are one of the main parameters monitored to meet wastewater discharge standards, some companies avoid treating the waste dyestuff present in the effluent due to extra operating cost (Wambuguh and Chianelli 2008).

9.2 The Washing Processes of Denim Garments and Their Basic Effects on Effluents

Finishing processes in textile industry are applied not only in yarn or fabric form but also in garment form. In denim washing processes, the treated materials so-called *jeans* are in garment form. Thanks to treating in garment form, denim washing processes are specialized to remove the indigo partially and create natural fade out effect on the garments. Denim washing processes consist of two separate sub processes: "*wet processes*" and "*dry processes*". The main denim wet processes are desizing, rinsing, stone washing, enzyme washing, local and/or complete bleaching and tinting. The main denim dry processes are scraping, tagging, oxidative agent spraying, 3D look application and resin application. The main pollutant of denim washing effluents is the denim wet processes (Bağıran 2011).

In desizing process, the stiffener chemicals which are applied onto warp yarns to protect the breakages during weaving are removed. The main sizing agents are starch, carboxylmethilcellulose (CMC) and polyvinylalcohol (PVA). These chemicals are difficult to degrade in effluent systems that cause higher COD and BOD (Bağıran 2011; Periyasamy et al. 2017; Periyasamy and Militky 2017).

In stone washing process, denim garments are treated with pumice stones in short liquor ratios to remove the indigo dyestuff on the garments so that natural fade out effect along seams and on the panels is obtained. In this process, high amount of surface indigo dyestuff is removed from the garments and dosed to the effluent. Because the indigo dyestuff is difficult to degrade, both the COD and BOD figures become too high that causes difficulty to clean the effluent effectively, and the colour degree of the effluent increases (Bağıran 2011; Amutha 2017; Periyasamy et al. 2017; Periyasamy and Militky 2017).

In enzyme washing processes, several types of enzymes like amylase, cellulase and laccase are used. Amylase is used in desizing processes to degrade starch molecules (Bağıran 2011). Cellulase is used in stone washing and biopolishing processes to remove fuzziness and create seam and panel abrasion on the garments (Sefer 2009;

Bağıran 2011; Periyasamy et al. 2017; Periyasamy and Militky 2017; Amutha 2017). Laccase is used to generate radical groups to catalyse the bleaching processes and remove indigo dyestuffs (Rodríguez-Couto 2012). As all the enzymes have abrasion effects on the garments, they cause to increase the pollution in the effluent in toxicity, COD, BOD and colour wise.

In bleach processes, oxidative agents like chlorine derivatives, hydrogen peroxide and potassium permanganate are widely used. Reductive agents are not preferred in denim bleaching due to low reaction speed. Bleach agents are used for fading the colour on denim garments to create wide variety of colour options. As the main bleach agents are oxidative, they are the main responsible chemicals to generate adsorbable organic halogen compounds (AOX) in the effluent (Sefer 2009; Bağıran 2011; Amutha 2017; Periyasamy et al. 2017; Periyasamy and Militky 2017).

In tinting process, denim garments are dyed mostly with direct dyestuffs. This process shall not be considered as a real dyeing process. Instead, it is for colour the garments in diverse shades. During tinting processes, salts are used to enhance the exhaustion, whereas they cause to increase the total suspended solid (TSS) figures. Direct dyestuffs and fixing agent do cause the effluent pollution in terms of colour, total dissolved solid (TDS) and TSS (Sefer 2009; Bağıran 2011; Amutha 2017; Periyasamy et al. 2017; Periyasamy and Militky 2017; Bağıran 2018).

9.3 The Characteristics of Denim Washing Effluents

Effluents are dirty wastewater and are supposed to be treated prior to discharging to the environment. Although they look dirty and contain suspended and dissolved solids which cause pollution in the water, more than 99% percent of the effluents are only water. The main issue is to treat the effluents by basic and/or special effluent treatment processes efficiently and discharge the properly cleaned water back to the environment (Eltem 2008).

The characteristics of denim washing effluents are categorized under three sub titles:

- Physical characteristics
- Chemical characteristics
- Biological characteristics

9.3.1 Physical Characteristics of Denim Washing Effluents

The most important physical characteristics of denim washing effluents are "*total suspended and dissolved solids, odour, temperature, density, colour and turbidity*".

9.3.1.1 Total Dissolved and Suspended Solids

The total solids in the effluents consist of suspended and dissolved solids. The total solid in the effluent, analytically, can be calculated by the remaining solids after heating and evaporating the effluent at 103–105 °C. The total solids effect turbidity and the proper delivery of dissolved oxygen in the water. They also effect the sludge amount that will be generated during effluent treatments. If the effluent has higher solid concentration, it consumes more oxygen to decompose the solid matters and causes to reduce the treatment efficiency with gas release with unpleasant odour (Eckenfelder 2000; Eltem 2008).

9.3.1.2 Odour

Odour in the effluents is mostly generated by the degradation of the organic compounds or by the chemicals added during denim washing processes. Besides, dissolved phenols and chlorophenols do cause the unpleasant odour, too. The most unpleasant odour from the effluent is caused by hydrogen sulphur which is generated by anaerobic microorganisms during the reduction reaction of sulphate to sulphite (Eltem 2008; Spellman 2009; Yerli 2011).

9.3.1.3 Temperature

The increase in the effluent temperature effect two main parameters: "*rapid oxygen exhaustion*" and "*fast breeding of microorganisms*".

Oxygen that provides to sustain the aerobic reactions in the effluents dissolves in cold/warm water rather than hot water. Moreover, the increase in the temperate boosts the biochemical reactions in the effluents which causes to consume the oxygen content in the effluents.

Furthermore, the increase in the effluent temperature will fast breed some microorganisms which they are supposed to be at lower concentrations to keep the balance (Eltem 2008; Spellman 2009; Yerli 2011).

9.3.1.4 Density

A certain density value is needed for proper flow of the effluents in the tanks and through the pipes. Density is linked with the content of the total solids in the effluent and the effluent temperature (Eltem 2008).

9.3.1.5 Colour

Normally, water is colourless. But the industrial waste contains colourful chemical substances which turn the effluent colour to diverse shades.

Furthermore, the increase in the effluent temperature will fast breed some microorganisms which they are supposed to be at lower concentrations to keep the effluent environment in balance (Eckenfelder 2000; Gönder 2004; Spellman 2009; Yerli 2011).

9.3.1.6 Turbidity

Turbidity, a measurable characteristic of the light permeability of water, is used for stating the quality of effluents based on included suspended and dissolved solids.

If the suspended and dissolved solid concentrations are high in the effluents, they cause to have lower light permeability which lessens photosynthesis reactions and to have less degradation of the chemical substances. Furthermore, the increase in the effluent temperature will fast breed some microorganisms which they are supposed to be at lower concentrations to keep the effluent environment in balance (Eckenfelder 2000; Eltem 2008; Spellman 2009; Yerli 2011).

9.3.2 Chemical Characteristics of Denim Washing Effluents

The most important chemical characteristics of denim washing effluents are "*organic substances and inorganic substances*".

9.3.2.1 Organic Substances

Organic substances contain carbon, hydrogen and oxygen atoms which sometimes have the combination of nitrogen and phosphor. A denim washing effluent contains proteins, carbohydrates, oils and synthetic organic substances. In mid-degree polluted effluents, approximately 75% of total suspended solids and approximately 40% of total separable solids have organic chemical structure (Eltem 2008).

Synthetic organic substances carry the most complex molecule structure that complicate the removal out of the effluent. They are the most polluting substances in the effluents. The most preferred types of them are "*surface-active substances*" which reduce the surface tension of the water, meaning that they reduce the free energy of the medium. Alkylbenzensulphonates (ABS) are widely used in surface-active substances which cause to have foaming on effluent surface thanks to their indecomposable structure (Eckenfelder 2000; Eltem 2008).

The amount of the organic substances in effluents is considered as the basic pollution measuring parameter in denim washing effluents. However, the composition of the organic substances in the effluents is so complex that it is impossible to define the concentration of each organic substance. To define the organic substance quantity in the effluent, two individual approaches have been set: "*biological oxygen demand* (*BOD*)" and "*chemical oxygen demand* (*COD*)" (Eckenfelder 2000; Eltem 2008; Yerli 2011).

9.3.2.2 Inorganic Substances

The inorganic substances of the effluent identify the water quality. The most common inorganic substances presented in the effluents are hydrogen, chlorine and ammonium anions, nitrogen, phosphor, sulphur and heavy metal ions.

Each inorganic substance mentioned has individual effect on effluent quality. Individually, they have the effects like determining the pH value, causing AOX and toxicity, acting as a nutrient for microorganisms and playing a role in vital reactions (Eckenfelder 2000; Eltem 2008; Spellman 2009; Yerli 2011).

9.3.3 Biological Characteristics of Denim Washing Effluents

Biological treatment activities in the effluents are as important as chemical treatment activities. In biological treatments, bacteria lead the reactions to degrade the unwanted substances such as organic and inorganic compounds. For effective biological treatments, the following parameters are needed to be considered:

- The type and the quantity of the bacteria in treatment areas and in the effluent.
- The optimal living conditions of the bacteria (Eltem 2008).

9.4 The Basic Effluent Treatment Processes

In denim washing plants, the main effluent treatment processes are performed in three individual steps: "*physical treatment, chemical treatment and biological treatment*".

9.4.1 Physical Effluent Treatments

Physical effluent treatments are the first step in the wastewater treatment. This step generally consists of screening to remove large floating objects, rags and other things that could damage plant equipment of the system. Additionally, grit removal is applied to take out the large gravel, stones and other mostly inorganic components.

Primary treatment consists of a sedimentation basin in which relatively heavy objects settle out and buoyant materials, such as plastic, as well as fats, greases and oil, float to the top. These are mostly organics at this stage, but there may be a few inorganics mixed in with them, as well (Hopcroft 2015).

9.4.2 Chemical Effluent Treatments

In this step, chemical reactions are benefitted to remove the pollutants from the effluents by using some special chemicals. The most important chemical treatment methods are "*chemical oxidation*", "*neutralization*", "*coagulation*" and "*flocculation*".

In chemical oxidation step, either the pollutants are provided to have harmless compound structures by increasing their oxidizing level or they are prepared for the next effluent treatment processes by the impact of oxidizing reactions. This process is used to remove colour, unpleasant odour, iron, manganese and organic substances from the effluent. Most common oxidizing agents used in this step are oxygen, ozone, chlorine anions and potassium permanganate (Eltem 2008).

In neutralization step, the pH figure of the effluent is set to the required value for bacteria activation during biological treatments, proper coagulation in the following chemical effluent processes and obtaining suitable discharge requirements after biological treatments. Acidic (citric acid, sulphuric acid) or basic (caustic soda, lime) chemical can be used to adjust the pH (Eckenfelder 2000; Eltem 2008).

In coagulation step, the individual colloidal substances in the effluents are prepared to form aggregates by adding some specific salts like aluminium sulphate and copperas. After the reaction, the colloidal substances tend to form the aggregates called flocs which will coagulate in the effluent.

In flocculation step, the coagulated colloidal substances attract each other to form the flocs by the impact of special chemicals called "polyelectrolytes". They form large aggregates, lose the ability to suspend in the effluent and sink in the effluent that helps form the effluent sludge (Eckenfelder 2000; Eltem 2008).

9.4.3 Biological Effluent Treatments

Biological wastewater treatment is often applied as a secondary treatment process, used to remove any material remaining after primary treatment. During the primary water treatment process, sediments or substances such as oil are removed from the wastewater, and then, the suspended and dissolved substances in the effluent left from the chemical effluent treatments are decomposed by bacteria, and they are converted to biological flocs, inorganic substances and gases.

There are three types of bacteria that perform the decomposing: "*aerobic, anaerobic and facultative*". Aerobic bacteria perform the reactions in the presence of oxygen as they need it to survive. In contrast to aerobic bacteria, anaerobic bacteria do not need oxygen in their life cycles and can decompose the organic substances in the lack of oxygen molecule. Facultative bacteria can both live in the mediums with or without oxygen molecules (Hopcroft 2015).

Aerobic wastewater treatment systems involve activated sludge process, oxidation ditches, trickling filters, lagoon-based treatments and aerobic digestion. During the treatment, aeration is applied to provide oxygen to the bacteria as they decompose organic substance in the wastewater.

In the case of anaerobic treatment, the organic residues are deteriorated by anaerobic bacteria in an oxygen-free environment.

9.5 Adsorption

Adsorption known to mankind for a very long time is increasingly used to perform desired bulk separation or purification purposes. Adsorption has two components an adsorbate that is the compounds attached to the solid surface and an adsorbent the solid itself. The heart of an adsorption process is usually a porous solid providing a very high surface area, and thus, a high adsorption capacity is achieved. However, the porous medium is usually associated with very small pores causing an increase in the resistance to the mass transfer. Understanding of the adsorptive capacity is within the domain of equilibria, and understanding of the diffusional resistance is within the domain of kinetics (Duong 1998).

The term *adsorption* is universally understood to mean the enrichment of one or more of the components in the interface between the bulk fluid (gas or liquid) and a solid surface. Because the adsorption process is accompanied by *absorption,* i.e. the penetration of the fluid into the solid phase in certain systems (e.g. some metals exposed to hydrogen, oxygen or water), the term *sorption* is also used to define the process. The term sorption is sometimes used to denote the uptake of a gas or liquid by a molecular sieve. The removal of the adsorbed substances from the surface is called as *desorption,* and the equilibrium is established when the adsorption and desorption rates are equal. The relation showing how the adsorbed amount changes with the equilibrium pressure, or concentration at constant temperature is known as the *adsorption isotherm* (Rouquerol et al. 1999).

Adsorbent to be used in a certain adsorption process is a critical variable because the success or failure of the process depends on how the solid performs in both equilibria and kinetics. A solid with good capacity but slow kinetics requiring too long time to reach the equilibrium is not an appropriate choice, since the slow kinetics means a high residence time in a column, hence a low throughput. On the other hand, a solid with fast kinetics but low capacity is not good either as a large amount of solid is required for a given throughput. Thus, a good adsorbent means a solid that provides good adsorption capacity as well as good kinetics. To satisfy these two requirements, the adsorbent must have a reasonably high surface area, reactive groups on the surface and relatively large pore network for the transport of molecules to the interior.

To satisfy the first requirement, the porous solid must have small pore size with a reasonable porosity. This suggests that a good solid must have a combination of two pore ranges: the micropore range and the macro pore range. The classification of pore size as recommended by IUPAC (Rouquerol et al. 1999) is often used to delineate the range of pore size:

Micropores $d < 2$ nm.
Mesopores $2 < d < 50$ nm.
Macropores $d > 50$ nm.

This classification is arbitrary and was developed based on the adsorption of nitrogen at its normal boiling point on a wide range of porous solids. The adsorbents such as activated carbon, zeolite, alumina and silica gel that are commonly used in industries do satisfy these two criteria (Duong 1998).

9.6 Pumice Stone

Pumice stone is a volcanic, light density rock which is formed following the volcanic eruptions. The stone has high porous structure thanks to the immediate cooling of lava by the impact of wind and cooler weather. The pore sizes and size of the pumice stone are variable. The pore sizes can be in nano, micro, meso and macro scale. The pores are generally not connected with each other, and they are covered by a glassy film layer (Sapçı and Üstün 2003).

Physically, pumice stones can have beige, dirty white and brown colour. Their density varies between 0.5–2 gr/cm^3. Their hardness varies between 5–6 in Mohs scale.

Chemically, the main component of pumice stones is "*sillicium mono oxide* (*SiO*)". The content of it varies between 45–80%. Thanks to the high content of sillicium, pumice stones both have a light density and good abrasion ability. The second main component is "*Di aluminium tri oxide* (Al_2O_3)". The content of it varies between 10–15%, and it provides good thermal resistance (Gündüz et al. 2001; Özkan and Tuncer 2001).

Due to the variable volcanic eruptions in the nature, pumice stones gain either acidic or basic characters based on their silica content. Acidic pumice stones have white or dirty white colour which are less in density and hardness compared to the basic pumice stones (Özkan and Tuncer 2001).

In denim garment stone washing processes, acidic pumice stones are preferable thanks to their lightweight structure which does not damage the garments and provide smooth abrasion effects along seams and on the garment panels.

9.7 Experimental

In this study, the removal of pollutants from the effluent of a denim washing plant by using the waste pumice stones used in stonewashing process was targeted. The reuse of the treated water in laundry was investigated. Thanks to their porous structures, the waste pumice stones should have a high adsorption capacity for the treatment of the effluent of a denim washing plant. The pollutants in the effluent of the denim plant were targeted to be removed through the adsorption, and the experimental studies were carried out in a pilot scale adsorption column installed at the exit of the biological effluent treatment unit of the industrial effluent treatment facility of the denim washing plant. The change in wastewater parameters like colour, COD, etc., determined by taking the samples at predetermined time intervals from the inlet and the outlet streams of the column. In addition to colour and COD, the parameters like TDS, turbidity, the amount of chloride anion, etc., were also measured.

The treated effluent was mixed with freshwater in 1:1 ratio for reusing purpose in denim washing processes determined as rinsing, stonewashing, stone bleaching and tinting. Two sets of garments were prepared, and the first set was washed with freshwater, whereas the second set was washed with the water mixture prepared. Following this, physical tests like crocking, tear/tensile strength, etc., and subjective evaluations like change in all over look were performed.

9.7.1 Materials

During the study, the waste pumice stones that were extracted from the denim washing plant were used as the adsorption material. The pumice stones were grinded into smaller sizes, and the size "*100–595* μm" was selected based on older studies as reference.

The effluent selected for the tests was taken from the exit of the biological treatment area.

For adsorption process, a special adsorption colon was manufactured with inlet and outlet points and pre-filtering area. The waste grinded pumice stones were placed into the adsorption colon.

A special pressure adjustable pump was used to pump the effluent to the inlet of the adsorption colon.

For effluent reuse tests, one type of denim fabric was used to form the denim garments. The fabric composition is 98% cotton + 2% elastane, and woven type is 3/1 right twill.

9.7.2 Method

During the study, the method was set to identify three main points as seen in the following:

1. The waste pumice stone adsorption of the effluent
2. Identifying the waste pumice stone characteristics
3. Reuse the recycled water in basic denim washing processes

In the first stage, the waste pumice stones were put into the adsorption colon. The effluent was pumped into the colon with constant temperature/pressure and specimens were taken at predetermined intervals. On specimens, the water quality parameters were tested.

In the second stage, on waste pumice stones after the adsorption, the material characteristics like scanning electron microscopy (SEM), energy dispersive X-ray (EDX) and Brunauer–Emmett–Teller (BET) analyses were investigated and parameters were tested.

In the third stage, the characteristics of the denim garments washed with the recycled water were investigated and parameters were tested.

9.7.3 Findings

9.7.3.1 The Waste Pumice Stone Adsorption of the Effluent

During the experimental that took two weeks in total, 55 treated effluent specimens were taken from the outlet of the adsorption colon. The change in the colour of the samples taken from inlet and exit of column are given in Fig. 9.2. As shown in

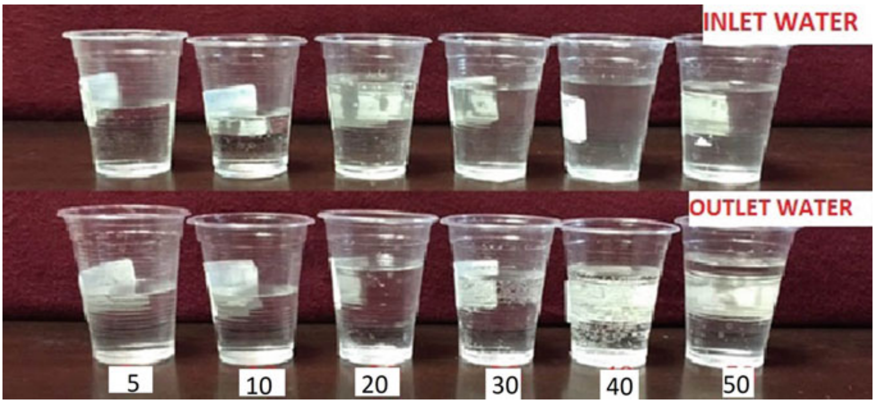

Fig. 9.2 The visuality of the change in the colour after adsorption (Author's own illustration)

the figure treated water is clearer than the untreated one. Fresh oxygen bubbles can clearly be observed.

In addition to visual observations, the samples were tested in terms of colour, and other water quality parameters. For colour wise, it has been observed that 59.09% of the effluent colour (in Pt–Co unit) has been removed after pumice stone adsorption.

COD wise, it has been observed that adsorption reduced the COD value by 25.88%. For total suspended solid wise, the reduction value is 46.66%. For turbidity wise, the reduction value is 79.15% and for AOX wise, the reduction value is 46.23%. All the results show that adsorption by waste pumice on denim washing effluent has reduced the pollution and colour drastically and prepared a suitable medium for reusing the wastewater in denim washing processes.

9.7.3.2 Identifying the Waste Pumice Stone Characteristics

The waste pumice stone that was used in the adsorption was subjected to SEM, BET and EDX tests to see how the adsorption affected the structure of the material adsorbent.

For the comparison purposes, three different samples (raw pumice stone, waste pumice stone used in stone washing and waste pumice stone used in both stone washing and in adsorption) were subjected to SEM analysis. The images magnified by 2500 × were given in Fig. 9.3.

A close examination of the figure revealed that the samples have almost the same surface morphologies with non-uniform sized pores. However, the pores on the surface of raw pumice stone have sharper edges in the entrance than the other samples. The edges of the pores are smoothed and become more open in waste pumice stone used in stonewashing. This structure forms an advantage for the adsorption of dye molecules because this makes easy the penetration of the molecule to the active sites. In the case of waste pumice stones used in stonewashing and adsorption, the

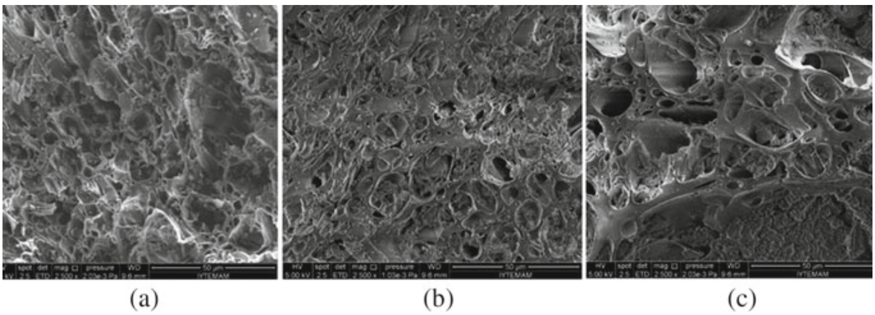

Fig. 9.3 SEM images of specimens: **a** shows raw pumice stone, **b** shows the waste pumice stone used in denim washing, and **c** shows the waste pumice stone used in stonewashing and adsorption (Author's own illustration)

surface seems to be more compact. This compactness will probably be the result of the filling of the pores with polluting materials.

The surface area and pore volumes of the pumice stones were determined by using the data obtained from adsorption isotherms. In Fig. 9.4, the adsorption isotherm of waste pumice stone used in denim washing and adsorption is given as an example.

When the figure is analysed, based on the guided graphics (Rouquerol et al. 1999), it is observed that the pumice stone used here has macro pores. The adsorption occurred on the surface of the stones and around the edges of the macro pores, and it continued both on single and multi-layers.

The surface area of the waste pumice used in denim washing and adsorption is calculated as 2.739 m^2/g, and the cumulative pore volume is calculated as 0.005910 cm^3/g. The surface area of the waste pumice used in only denim washing is calculated as 1.0806 m^2/g, and the cumulative pore volume is calculated as 0.002321 cm^3/g. Adsorption is a surface phenomenon, and therefore, the higher surface area means higher adsorbed amounts. However, the pore size plays

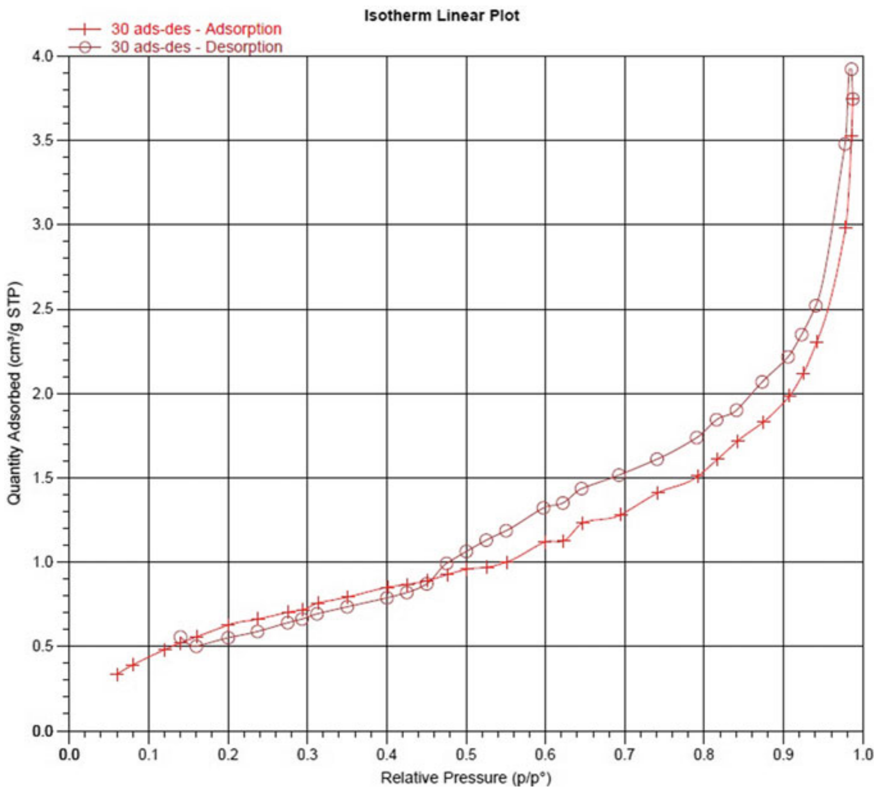

Fig. 9.4 Adsorption isotherm of waste pumice stones used in denim washing and adsorption (Author's own illustration)

an important role because if the pore size is less than the size of compounds to be adsorbed, adsorption does not occur.

In EDX analysis, the atom contents in the “waste pumice stone used in denim washing”, and “the waste pumice stone used in denim washing and adsorption” were calculated and compared to each other. Based on the results, it has been observed that the amount of carbon atoms has increased from 3.56 to 10.54% (in weight basis). The sulphur and chlorine atoms were observed at 0.05% and 0.36, respectively, whereas they were not observed in the pumice stone which was not used in adsorption. These increases proof that pumice stones have adsorbed the pollutants such as surface-active inorganic substances.

9.7.3.3 Reuse the Recycled Water in Basic Denim Washing Processes

After the adsorption, the treated water was mixed with freshwater in 1:1 ratio. The prepared water was used as input water in denim washing processes selected as rinse, stonewashing, chlorine bleaching and tinting. In order to get comparable results, another set of garments were washed with freshwater, and both results were compared.

The selected test parameters to compare the results are colour value, tear and tensile strength, crocking fastness and yellowing degree.

Colour wise, both specimens have very similar shades in all washing types according to objective and subjective evaluations. It has been observed that the garments washed with recycled water have slightly lighter shades. This could be due to the inclusion of chlorine and surface-active substances in recycled water which cannot be 100% removed.

Tear and tensile strength and crocking fastness wise, all specimens with all washes have close values to each other. No significant differences are noticed.

Yellowing degree wise, the garments washed with recycled water in rinsing have half degree less grade than the ones washed with the fresh water. Similar to lightness in the colour, this could be due to the chemical residues of chlorine and surface-active substance. In the other washing processes, all the yellowing values are the same.

9.8 Conclusion

In this study, the removal of pollutants from the textile effluent by waste pumice stone from a denim factory was studied. The results of COD and other parameters’ measurements indicated that the dyestuffs and other organic impurities were removed by adsorbent. It was observed that there were not significant changes on the garments that were washed in separate sets. The results show that the waste pumice stones can be used as adsorbents for the treatment of wastewater of a denim plant. It is recommended that the adsorption system of pumice stones can be used as a helping effluent treatment unit in addition to main treatment units, and through this way, an economic value can be added to the solid waste.

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Chapter 10
Greening the Blues—How Jeans Have Stood the Test of Time by Adapting Innovative, Forward-Thinking and Sustainable Production Practices

Marina Chahboune

Abstract The denim and jeans industry is a huge and powerful business segment that has proved over the past decade that it can take its responsibility and be a key driver for change for the apparel industry in general. The developments of substitutes for toxic chemicals and the invention of new, resource-saving technologies have lifted the possibility of sustainable practices to a new, never imagined level. This chapter is highlighting the best practices for applied sustainability, innovations and the latest developments in denim and jeans supply chains, from the choice of raw materials to utilization opportunities for used garments.

Keywords Sustainable jeans · Sustainable denim manufacturing · Environmentally friendly jeans production · Ecological footprint jeans · Lower impact denim · Eco-friendly jeans finishing · Jeans indigo dyeing

10.1 Introduction

Imagining a world without denim garments seems to be impossible nowadays: Blue jeans have reached global presence. Whenever Daniel Miller—author of the book *Global Denim*—went abroad, he started counting 100 random people who passed him on the street to see how many of them were wearing blue jeans. His survey resulted in the insight that "the majority of the people in the majority of the countries of the world are wearing blue jeans on any given day" (Miller and Woodward 2011). While jeans have become globally a favorite wardrobe staple and a constant in the trend-driven, ever-changing fashion world, the jeans trade itself has become an essential element of the apparel industry. Currently, the overall denim and jeans industry is valued at more than $57 billion with an expected growth rate of 6% by 2023, driven by higher consumer demand within emerging markets and the transformation from

A practitioner's perspective

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classical retail toward an e-commerce industry (Prescient and Strategic Intelligence 2018; Wang and Newbery 2018). These days, jeans are a lot more than simply a 100% cotton product: Blue jeans—commonly known as a durable, high-quality garment originally made from woven twill fabrics—have become a favorite wardrobe staple by constantly reinventing itself. Consumer demands on performance, style, fit, weight and design have changed the denim business completely, and denim has expanded its classic application area for trousers only to all parts of fashion such as casual and even athleisure wear.

Another key driver for change is an increasing awareness among consumers about the conventional jeans production's negative environmental impacts: "The denim industry has long been the subject of much sustainability scorn" (Styles 2018). Especially, facts such as the enormous water pollution and heavy usage of toxic chemicals are often cited by campaigners for pressurizing brands to finally integrate cleaner production methods (Styles 2018). In 2010, a Greenpeace report revealed the *dirty secret behind jeans* which has led to major efforts within the whole industry to mitigate its negative impacts. The report gave a critical insight into the unhuman working conditions and tremendous environmental pollution caused by jeans manufacturer in China's city Xintang—by that time known as the *Jeans capital of the world* with an annual production of over 260 million pairs of jeans (Greenpeace 2010). Life cycle assessments (LCAs), which are evaluating the environmental performance of products throughout the life cycle, have identified that over 60% of emissions actually occur within the production part of the supply chain (Levi Strauss and Co 2015). The main identified environmental hotspots are the raw material stage and the dyeing and finishing processes (Levi Strauss and Co 2015 and Ademe 2006). Especially, water has been recognized as an essential ingredient for these manufacturing stages, and the lack of access to sufficient water quantities would pose potential risks on ensuring future operations (Safaya et al. 2018). Nearly 20% of global waste water is produced by the fashion industry (United Nations 2018), 10% of global carbon emissions and 4% of the world's annual waste (Kerr and Landry 2017).

The United Nations Framework Convention on Climate Change (UNFCCC) report is addressing these alarming problems which are the Sustainable Development Goals with one of their central vision being to tackle two of the main negative effects of the current polluting production methods: waste and the excessive extraction of primary resources.

The United Nations Alliance for Sustainable Fashion was initiated to contribute to the achievement of the Sustainable Development Goals' targets (UN Fashion Alliance 2019).

The denim industry as one of the leading industries by production quantities within the apparel segment has understood its responsibility. The whole denim industry has seen a major shift in the past years attempting sustainable and ecologically responsible practices throughout the entire life cycle from cradle to the product's end of life by developing and adopting technologies and methods to lessen unnecessary negative environmental impacts without sacrificing trends and aesthetics.

Today, "no other garment represents the kind of forward-thinking innovation that the fashion industry needs as jeans" (Styles 2018). Disruptive technologies, new waterless dyeing and finishing methods, innovative fiber blends, product innovation and efficiency improvements have significantly reduced the former negative impact of denim and jeans production.

10.2 Fibers and Fabrics

Jeans traditionally made from pure cotton denim have a long history that can be tracked back as far as the seventeenth century. The most commonly used weaving technique for denim is the right-hand 3/1 twill made from an indigo-dyed warp and an undyed weft yarn, resulting in a blue fabric front side and a mainly whitish inside (Muthu 2017). The fabric surface shows the characteristic upward direction of the diagonal-lined twill running from lower left toward upper right. The denim fabric was originally developed to create durable, long-lasting workwear which resulted into the invention of the popular Levi Strauss jeans in 1873—a work pants that additionally convinced with copper rivets for strengthening the corners of the pockets (Balfour-Paul 2011). With the era of Hollywood in the 1930s, jeans saw its turning point shifting away from its former application toward becoming a global fashion item (Miller and Woodward 2011). While styles and fits started to change, the fabric remained as originally created. The invention of stretch fibers and fiber blends as well as new consumer demands for form-fitting styles, lighter fabric weights and technical performance has led to new and innovative fiber and fabric developments throughout the last decades that go beyond the traditional cotton twill known as denim. One of the early adopted key trends has been the incorporation of Elastane in the warp in small quantities about 2–4% within the total fiber composition to create body-flattering fits that give the wearer more agility and comfort compared to jeans formerly known fabric stiffness. That trend has changed the whole denim industry and culminated into fully stretch and super stretch fabrics that can even be applicated to active wear styles. By using elastomer spun in both warp and weft, developments have further led to bi-stretch denim for athleisure *jeans*. The latter has been a consequence of the lack of recovery of single-yarn stretch fabrics. Furthermore, fiber blends of cotton with polyester have gained widespread popularity to improve performance, providing great durability and abrasion resistance (Muthu 2017).

Cotton, known as a thirsty crop, is associated with excessive water use (Sandin and Peters 2018). In 2007, jeans *brand Levi Strauss & Co.* conducted the apparel industry's first-ever life cycle assessment (LCA) to analyze the entire life cycle impact of a pair of jeans including all stages of the life cycle from raw material extraction, materials processing, manufacture, transport, use, repair and maintenance, recycling and end of life (Laitala et al. 2018). The results uncovered that the greatest water and energy impact was in the areas of cotton cultivation and consumer care during the usage phase (Levi Strauss & Co 2015; Ademe 2006). The amount of required water for cotton varies greatly depending on cultivation region, rainfall, the origin of irrigation water and the type of irrigation technology (Ferrigno 2012).

Therefore, many brands started to integrate organically grown cotton or cotton from better agriculture practices and water management systems such as the *Better Cotton Initiative* (*BCI*) into their collection to lessen their impact on the environment. But shifting from the usage of conventional cotton to organic cotton alone will not be enough to tackle these future challenges.

With an estimated overall apparel consumption rising by 63%, from 62 million tons today to 102 million tons in 2030 and a growing world population toward an additional two billion people by 2050 and emerging markets, the industry will face an increasing demand for textile fibers, environmental pollution, shortage of resources and competition among industries on finite resources (Kerr and Landry 2017; Östlund et al. 2017) (Fig. 10.1).

The *Environmental Benchmark for fibers* developed by the former Dutch non-for-profit organization *Made-By* compares the environmental impact of the most commonly used fibers in the garment industry on parameters such as greenhouse gas emissions, human toxicity, eco-toxicity, energy and water consumption and land usage (Gardetti and Muthu 2017). Based on these parameters, each fiber is scored and classified from Class A to Class E. *Made-By* rates recycled cotton higher than organic cotton: Replacing 20% of cotton in denim fabrics with fibers from post-consumer sources can save up to 500 L per garment. Besides requiring less energy and water, as well as fewer chemicals than its virgin counterpart, recycled cotton also convinces with generating less greenhouse gas emissions during production (Chua 2018). The *Higg Materials Sustainability Index* (*MSI*) shows that the *Recover* yarns with recycled content of Spanish spinning mill *Hilaturas Ferre* make the "lowest-impact cotton yarns in the global market and generously outperform virgin equivalent yarns across all sustainability metrics" (Recover 2019). Unfortunately, the shredding process of pre- or post-consumer cotton waste is resulting in short-staple fibers which need to be blended with virgin, long-staple fibers in order to avoid low fabric quality outcomes. Besides the usage of recycled cotton, recycled polyester (rPET) derived from post-consumer waste such as plastic bottles has become common as well in the denim industry.

Making more informed raw material choices, such as blending cotton with low-impact fibers, can significantly reduce the jeans footprint. One of the latest fiber innovations which significantly improves the impact at the raw material stage by reducing the need to extract virgin raw materials is the *Lenzing Refibra*™ fiber—a new generation of TENCEL® fiber and the first cellulose fiber derived from post-industrial waste such as cotton scraps and wood, produced in the lyocell production process (Lenzing 2019). Well-known Italian denim weaving mill *Candiani* completely eliminated the usage of virgin materials for its *REGEN* denim series by adopting 50% *Refibra* blended with 50% pre-consumer recycled cotton in both its warp and weft. Furthermore, *Candiani* launched its *ReLAST* stretch denim line using a customized *Global Recycling Standard* (*GRS*) certified *Roica Eco-Smart* elastomer developed by Japanese mill *Asahi Kasei* (Candiani 2017).

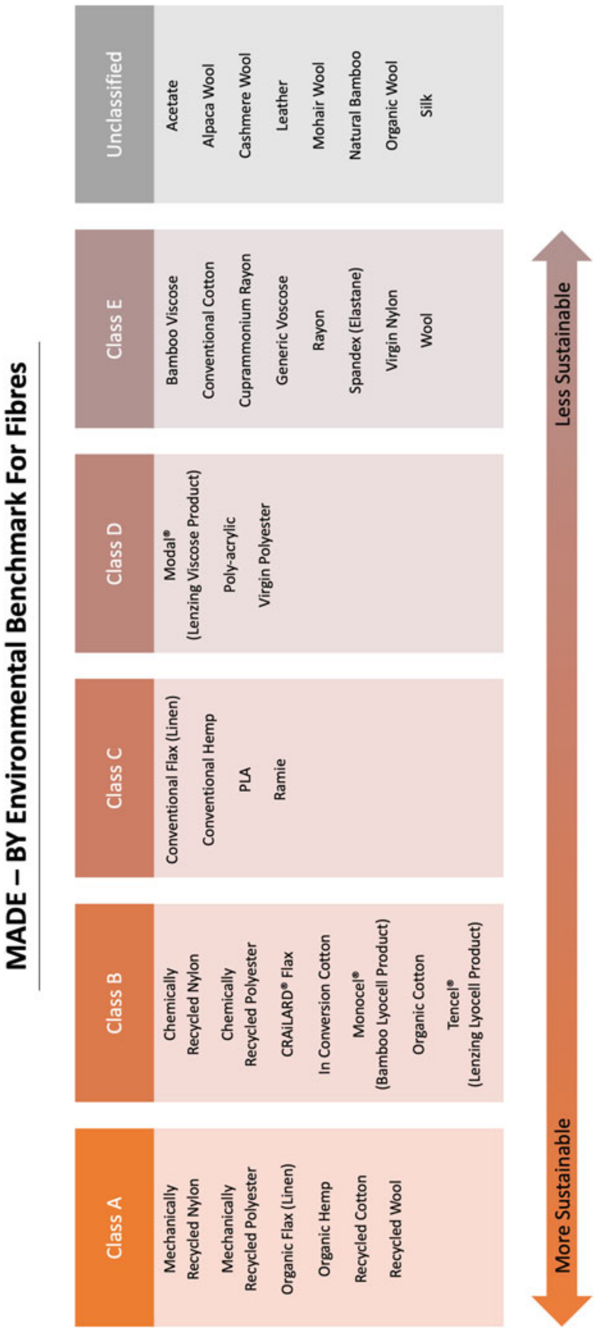

Fig. 10.1 Environmental benchmark for fibers by mMade-bBy (Illustration by D. Pircher)

10.3 Indigo Yarn Dyeing

The production step of yarn spinning is followed by dyeing, which for denim traditionally is a warp yarn dyeing process with indigo. The common procedure for it requires various preparation operations like prewetting, scouring and mercerizing to achieve a regular absorption of the dyestuff. Indigo itself is an insoluble vat dye which means that it cannot penetrate the cotton fiber until it is made soluble by the process of reduction. Reduction is basically a process where hydrogen is produced which opens up the indigo dye molecule allowing it to attach to a water molecule which carries the vat dye into the fiber (Mercer 2013). The common basic ingredients for the dyeing process are the indigo dyestuff, sodium hydroxide and hydrosulfite resulting in reactions that reduce indigo to the greenish-colored leuco-indigo, which can be applied to the yarns. This application process is continuously running alternately through the liquid dye bath and the so-called skyer to gradually oxidize. The air-oxidized yarns turn into the common indigo blue color again (Clariant 2012; Mercer 2013). The indigo blue color binds only to the surface and does not reach the core of the yarn which results into the subsequent characteristic jeans effect of color fading: As later, when the jeans is getting worn, the surface indigo slowly wears and washes off and the undyed white core appears (Velasquez 2017).

The whole dyeing process is very resource-intense, consuming up to several hundreds of liters of freshwater and energy. The significant amounts of chemicals and textile auxiliaries needed throughout the process are resulting in hazardous sludge and effluent that causes tremendous environmental pollution when released untreated into nature. The need to mitigate the negative impact of this traditional indigo dyeing process has been one of the key drivers toward more sustainable practices. Several leading denim manufacturers have developed competing, innovative new dyeing processes, and one can easily say that the process as applied today has changed remarkably.

Early attempts have been around an additional usage of sulfur dyes to achieve different cast of color shades while reducing costs. The sulfur dye can be applied to the yarns before the indigo application (sulfur bottom) or after (sulfur top) (Paul 2015). Chemical specialist *Archroma* has developed a range of low sulfur dyestuffs as well as the *Pad/ Sizing-Ox* dyeing process to reduce the consumption of water (Muthu 2017). *DyStar* in addition came up with its patented *Indigo Vat 40% solution*, achieving a significant reduction of the commonly needed amount of sodium hydrosulphite and water usage with this pre-reduced indigo liquid (DyStar 2019; Paul 2015). The latest experiments and developments are trying to not only reduce, but also to eliminate water consumption within the dyeing process nearly completely. Italian weaving mill *Candiani* is combining Kitotex with their in-house developed dyeing technology *Indigo Juice* to achieve a lower water footprint. While the usage of biodegradable Kitotex—a natural polymer derived from chitosan—replaces harmful pollutants and allows to cut down on water and chemicals and to operate at lower temperatures, Indigo Juice reduces the water, chemical and energy usage within the laundry process. During the dyeing process, the indigo is kept superficial on the yarn, therefore reducing the amount of water and energy needed to wash it down later in the jeans laundry process (Candiani 2017; Velasquez 2017).

Announced as breakthrough in the field of indigo dyeing is *IndigoZERO*™—a foam dye developed in the USA by the *Fiber and Biopolymer Research Institute of Texas Tech University* in collaboration with *Indigo Mill Designs*. This water-saving technique has been known for years but has only now been able to solve the former, hindering problematic indigo reaction with the air trapped inside the foam that had led to stop the dyestuff from penetrating the fiber, by replacing the oxygen with nitrogen (Mowbray 2018a, b). The whole process—from pre-reduced indigo production until the point where the yarns are ready for exposure to air for the oxidation—requires completely oxygen-free conditions. The technology works without a dye bath and without wastewater discharge, claiming to reduce water usage by up to 99% compared to the traditional indigo dyeing process, which results into production cost savings as well as significant savings of the precious resource water (Ethridge et al. 2018; Agarwal 2018). The first jeans collection made with foam dye is planned to hit the markets in 2019 by jeans brand *Wrangler* (Mowbray 2018a, b).

Another key innovation is *Smart-Indigo*™ developed by *Pure Denim* that is produced in an electrochemical process using indigo pigment, caustic soda, water and electricity only.

The enormes demand for water, energy and chemicals within the process of indigo yarn dyeing has led to an industry-wide effort in developing new and more efficient production methods. Stakeholders such as chemical and technology suppliers are coming up with a range of different, future-proof approaches to optimize the negative environmental footprint within the dyeing process by minimizing or even fully eliminating the usage of precious resources.

10.4 Finishing

There are two finishing steps within the jeans supply chain: the denim fabric finishing right after the weaving process that covers mainly mechanical treatments such as sanforizing, singeing or mercerizing and the garment finishing that is applied on the ready-made jeans mainly with chemical processes. Especially, the jeans finishing treatments that are needed, to give the jeans its worn-out look, used-effects like whiskers and other trendy appearances, often require toxic chemicals which are applied in wet processes. If done in the conventional way, the treatments applied within the finishing process often present potential health risks for workers, the environment through untreated effluent as well as later consumers wearing the treated jeans. In the conventional method, the indigo dyestuff gets bleached down from the jeans surface with the help of strong oxidative bleaching agents such as sodium hypochlorite (NaOCl) and potassium permanganate ($KMnO_4$). The amount of indigo removed from the denim is directly related to the amount of bleach added, the water temperature and the treatment processing time (Clariant 2012). Enormous water consumption, chemical usage and severe environmental pollution are the results.

Stonewash is a much-used method to achieve used looks, because of its ability to create varying degrees of abrasion in areas such as waistband, pockets, seams and body (Clariant 2012). For this process, pumice stones are added to the tumbler as abradants during garment washing. The degree of color fading depends on various factors such as the garment-to-stone ratio, washing time as well as machine load. There are many limitations and drawbacks associated with stonewashing, especially when it comes to wear and tear and damage to the washing tumblers and garments. In order to remove the pumice stones and their washed-off, sandy, dust particles from the garments and machines, several times of washing are required for proper cleansing. Furthermore, the quality of the abrasion process is difficult to control. One alternative that never really prevailed is synthetic stone made of abrasive material such as silicate or rubber. Their durability is much higher and therefore can be repeatedly applied. Alternatively, the stonewash process can be replaced by using enzyme-based washing technology. This would also help to conserve water, time and energy. Cellulase enzymes are natural proteins which are used in denim garment processing to create a stonewash-like look without actually using stones or at least by reducing the use of them. Unlike stonewash, cellulase acts primarily on removing the indigo from the fabric surface creating a clean and neat appearance without causing damage to the fibers (Damhus et al. 2013). Simple process handling, the obtaining of more reproducible effects and the minimization of softeners are additional advantages. For enzyme wash being a sustainable choice, the usage of genetically modified organism (GMO)—free enzymes—is advised. The finishing process in general undergoes a variety of rinsing—and tumble-drying steps in between the manual, mechanical or chemical treatments. The treatments are often harmful, labor intense, bearing potential risks in terms of human and environmental toxicity and consuming high amounts of water, which thereafter is also subject to contamination from the chemicals used during processing. Since water is known to become an increasingly scarce resource, especially replacing old washing tumblers with new, more efficient ones with better garment-to-liquid ratio and less water consumption have become standard for finishing laundries working with international brands. Leading suppliers involved within this production step have started to come up with more sustainable solutions and technologies for improved environmental performance (Roos 2016). One of the pioneers in this field is Spanish finishing technology manufacturer *Jeanologia* who has revolutionized formerly used finishing methods with the invention of several disruptive technologies such as laser, e-flow and ozone bleaching. The laser technology is an automated, digital tool to achieve effects on the garments and fabrics. It is a computer-controlled process, which enables the creation of patterns and used-effects which are otherwise created manually through hand scrubbing (Express Textile 2003). This ecologically and economically feasible technique achieves local abrasion and fabric breaks, used look effect, whiskers with excellent reproducibility and higher productivity. *Jeanologia's* most advanced laser machines like the *Twin Pro* are enabling more productivity, efficiency and an improvement of design management for large-scale productions of jeans. The machines are equipped with two laser heads working on both legs at the same time to increase production capacity for big quantities. The machines require very little maintenance and cleaning. The companies *G2* machine, is said to be the latest and most efficient technology for ozone bleaching. Supported by a generator, the machine takes oxygen (O_2) from the atmosphere and transforms it into ozone (O_3), liberating the particles inside the tumbler to produce results such as the elimination of indigo dye excess from the former dyeing process or the reproduction of the bleaching effects (Jeanologia 2019). Since ozone is toxic in higher concentrations, a closed system has to be secured at any time. At the end of the process, the ozone is breaking down again into pure oxygen. All of this is accomplished in a zero-discharge process without water or chemicals needed, therefore resulting in considerable resource, and cost savings after the investments on the machines are turned back. While the ozone technology has been a huge success, it took the industry a bit longer until they realized the huge potential of laser and even longer to integrate *Jeanologia's* nano-bubble technology *E-flow* into their processes. *E-flow* "breaks up" the surface of the garment, achieving soft hand feel and controlling shrinkage while using only minimal amounts of water. Oxygen is introduced into an electro-flow reactor and exposed to an electromechanical shock creating nano-bubbles and a flow of wet air to transfer chemicals onto the garments, such as pigments, coatings or softeners (Khalil 2016).

Jeans finishing is highly labor intense, and since the scandals of sandblasting went public, it is associated with unhuman and unhealthy working conditions, hazards and risks. While most of the new technology inventions focus on environmental and economic benefits, their automation has also resulted into factories being able to provide safer and healthier work environments that prevent accidents or even replacing labor with robotics for harmful production steps. Most chemical and mechanical treatments come with advantages as well as disadvantages, depending on how they are used and for which purposes. Bleaching down a dark blue denim garment to light blue with ozone makes little sense in terms of sustainability, since this process would require a good amount of energy. In this case, it would be preferable to produce a light blue denim fabric from the beginning to avoid excessive washing and bleaching. Sandblasting is a very good example for the industry having failed to set up proper standards and safety instructions. This treatment is based on blasting an abrasive material in granular, powdered or other form at very high speed and pressure onto the parts of the garment surface to achieve abrasion (Chandran et al. 2010). It is a purely mechanical process, not using any chemicals, nor water. But due to misusage and lack of workers' safety precautions, thousands of factory workers worldwide have fallen sick from the inhalation of the fine sand particles with an incurable lung disease, called silicosis, which leads to the disrepute of this treatment method that is prohibited today. It is necessary to evaluate each technology or processing method intensively and individually. On the outcome of this, individual safety arrangements, regulations and application areas can be defined to make this important production step safer in terms of human and environmental toxicology.

10.5 User Phase and End-of-Life Solutions

Jeans are of great popularity and besides t-shirts the most widely worn garment globally. With the current vast amounts of production quantities, it is necessary to find suitable ways to extend the product's life cycle and end-of-life solutions in order to avoid masses of waste.

The user phase is impacting the product footprint of jeans enormously and therefore offers a great opportunity to reduce its credentials: The biggest part of carbon emissions occurs during this phase as well as it contributes by a wide margin to water consumption. Clothing maintenance consists of repeated actions such as laundering and drying that contribute to high use of water, energy and chemicals. The longer the garment is used, the more important this phase will be for the overall environmental impact of the garment (Roos 2016). To handle the garments with better care during this phase can reduce the impact significantly (Ademe 2006). Washing a jeans every 10 times worn instead of every two times reduces energy, climate impact and water consumption by up to 80% as well as drying the garments on a washing line instead of using a tumble dryer (Levi Strauss and Co 2015). A washing machine cycle will use the same amount of energy regardless of whether it runs on full load or empty; therefore, it is preferable to always wash with full capacity. Furthermore, a washing machine uses electricity mainly for heating the water, which means energy can be easily conserved by washing with low temperatures (Black 2013). A case study done by ecologist Rachel McQueen from the *Canadian University Alberta* in 2011 proofed that it does not make a difference from a hygienic point of view, if one wears a pair of jeans unwashed for two weeks or a full year daily (Knowles 2016). McQueen took bacterial counts from a pair of jeans, which one of her students had worn for 15 months without washing. The result: The bacteria load on the jeans was surprisingly harmless and only comprised normal skin bacteria. McQueen discovered that bacteria growth was virtually the same from the jeans after 15 months with no washing, compared to two weeks after being washed (Cotter 2011; Knowles 2016). So far, adopting a sustainable user's behavior at the utilization and disposal phase was under the full responsibility of the consumer himself. Brands had very little chance to influence at this stage, besides advising on a suitable washing care behavior. Only recently, denim brands started to pay attention to the garment disposal phase, to include this stage within their operations and to promote sustainable practices that involve the consumer. With new developments for fiber sorting and recycling technologies, denim post-consumer waste has become an attractive input for the raw material stage. Jeans brands start initiating take-back systems at their point of sales (POS) for used garments to not lose this valuable resource to landfill that can then be either turned into second-hand items, upcycled into new products or used for fiber recycling. Swedish brand *Nudie Jeans* as pioneer in this field already offers a wide range of denims in their collection containing partly recycled fibers content from post-consumer waste. Denim garments which they receive back from their costumers that are still in good, wearable conditions are washed and if needed repaired just to make their way back into sales as second-hand denims (Nudie Jeans Co 2019). The trend to include a certain percentage of recycled content into the fabric composition has already been adopted by some of the big players in the industry such as Swedish fast-fashion retailer *H&M*. Dutch brand *Mud Jeans* has built his whole business model around circularity right from the beginning, making sure that the majority of their jeans are returned for further usage after the consumer does not need them any longer. The brand offers a wide range of denims for leasing. After leasing their jeans for a period of 12 months, the consumer can decide to either switch to a new pair or to keep them until they are worn out. The jeans taken back are shredded into new fiber input, and the brand claims that at this point, their collections already contain up to 40% of post-consumer recycled cotton per jeans (Mud Jeans 2019). Fashion retailer *C&A* has taken the idea of circular economy to its highest level by developing a cradle-to-cradle solution: In partnership with *Fashion for Good,* they developed the first-ever Cradle to Cradle (C2C) Certified Gold-level jeans, by including the strict environmental requirements of the certification, which evaluates garments for human and environmental health, recyclability or biodegradability, energy and water requirements as well as social fairness. The development phase has taken more than a year and has covered all aspects along the supply chain such as material health, material reutilization, renewable energy and carbon management, water stewardship and social fairness (Fashion for Good 2018). The key challenge identified throughout the project for creating Cradle to Cradle Certified jeans is the complexity of the network of partners involved as well as the still limited availability of components and chemicals. (Fashion for Good 2018).

Much of the impact from clothing arises during production and processing. Extending the life of clothing through more durable design, and enabling reuse, repair and recycling, helps to reduce this impact, as production from virgin raw materials has a higher environmental burden than reuse or repair (Gray 2017).

10.6 Forecast and Future Trends

The denim and jeans industry is a huge and powerful business segment that has proved over the past decade that it can take its responsibility and be a key driver for change for the apparel industry in general. The developments of substitutes for toxic chemicals and the invention of new, resource-saving technologies have lifted the possibility of sustainable practices to a new, never imagined level. Combining innovative solutions throughout the entire supply chain, the prospect of water-free denim production, which *Jeanologia* estimates for 2025, could become a reality. By integrating tracking systems to obtain full transparency along all production steps, material compositions and process chemicals could be better identified for the ease of fiber recycling or other suitable end-of-life solutions on an industrial scale. Inventions such as DNA molecular tagging are already under way today and would provide the industry with an effective tool to authenticate denim. Brands and their suppliers are realizing socioeconomic benefits that can immensely change the way we produce and consume jeans. Industry leaders in terms of production quantities and sustainability—such as Vietnam-based garment and finishing mill *Saitex*, who has set the benchmark and is claimed to be the *world's cleanest denim laundry*—are already today convincing with a LEED-certified production facility that recycles 98% of its water, relies on alternative energy sources and repurposes its by-products. Workforce, especially in high-risk process steps such as the application of chemicals, will be replaced by robotics, while companies are introducing fully automatic sewing lines and creative software systems for digitizing the process of designing jeans, to optimize efficiency and the challenge of increasing labor costs. Jeans have stood the test of time and with its ability to constantly reinvent itself and with its speed in adopting sustainable practices have the potential to lead the fashion industry into a new era of clothes manufacturing on all levels.

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Part IV
Sustainable End-of-Life Concepts and Strategies in the Textile and Fashion Industry

Introduction

Every year, humanity loses billions of tons of topsoil through the dumping of waste. This waste of resources and the associated pollution are largely due to current irresponsible industrial practices, business ethics and household consumption patterns. The textile and clothing industry, which accounts for a substantial share of total industrial production, must accept its share in the degeneration of habitats and the destruction of ecosystems. However, the differences worldwide are very high.

Basically, there are several types of recycling and different end-of-life concepts. Moreover, these approaches involve differences concerning sustainability impacts, economic feasibility and effectiveness. Exemplarily, with regard to sustainability aspects, we speak of material, raw material or chemical and energetic recycling in descending order.

At present, the transition to the circular economy, i.e. the transformation of the textile chain into a textile cycle, is the main objective. With "closed loop", the same product is returned to the textile chain, i.e. material recycling is achieved. The term "open loop" is used when the process is designed to disintegrate the product into its constituent parts, thus enabling raw material recycling of the constituent parts.

The task of industry and research must be to develop, evaluate and implement new sustainable and product-specific recycling concepts. Established processes have to be questioned, and, above all, the idea of a cycle has to be implemented during the design process. It will be the task of politicians to draw attention to the importance of textile recycling. Legal incentives are needed to promote the implementation of sustainable concepts and to provide incentives for a changeover through sustainable public procurement. The consumers' task is to question disposable habits and to use reused textiles.

The particular challenges for the conversion of the industry to a truly circular one are new mechanical sorting processes for mixed fibres, easy separability of non-textile parts, avoiding damage to recycled material and improving the economics of recycling processes compared to raw material.

Currently, however, in most countries, particularly in developing and emerging economies, textiles are being landfilled. In Germany, for example, there are efficient and established systems for the collection, sorting and recycling of textile waste, but here too not all textiles end up in a recycling cycle. A large part of the collected textiles is returned to the trade as second-hand goods. At the same time, only a small part remains in the European countries, the larger part floods the markets in Africa with cheap goods. This, in turn, destroys the local textile industries as well as local cultural peculiarities and traditions such as clothing habits or textile production techniques.

Mechanical recycling of old textiles remains tear fibres are obtained from the remaining old textiles, which are used almost exclusively in nonwovens for insulation, upholstery and automotive textiles. High-quality applications have so far been niche solutions, for example, the Otto spinning mill produces a 100% CO yarn, 25% of which consists of recycled cotton. Recovertex from Spain blends recycled fibres with coloured polyester fibres. By an intelligent colour adjustment of these PES fibres, it is possible to offer recycled yarns in constant colour qualities. The fibre welding process—as already described in Chapter 1 in this book—also offers an interesting starting point for the use of old fibres for new textiles. In the future, the aim must be not only to convert used fibres into low-quality products, but also to create equivalent or higher-quality products from resources. Against this background, the recycling sector has the potential to have a significant impact on the ability of the textile industry to achieve circularity. However, it remains a challenge, both technologically, logistically and socially. Those challenges are also covered by the following three contributions in this chapter.

Gloy et al. describe the recycling process in their article and give an overview of established technologies. The study by Turnball et al. offers a qualitative assessment of the current post-consumer waste models, the recycling streams and the challenges associated therewith. In the third article, Ahmed describes the way in which consumer engagement takes place in various phases of the textile value chain and presents approaches to how consumer behaviour can sustainably change the value chains.

Chapter 11
Textile Waste Management and Processing

Yves-Simon Gloy, Bernd Gulich, and Marcel Hofmann

Abstract The production of reclaimed fibers from used textiles and their processing into textile products has been an effective recycling solution for centuries and thus one of the oldest material cycles in the world. It has arisen historically from the scarcity of naturally occurring vegetable and animal fiber, the economy and the relative lack of need of people. The aim has always been to recover the fibers contained in unneeded textile structures as gently as possible as a raw material for new products.

Keywords Textile recycling · Carbon fibers · Nonwovens · Textile waste management · Textile waste processing

11.1 Introduction

The production of reclaimed fibers from used textiles and their processing into textile products has been an effective recycling solution for centuries and thus one of the oldest material cycles in the world. It has arisen historically from the scarcity of naturally occurring vegetable and animal fiber, the economy and the relative lack of need of people. The aim has always been to recover the fibers contained in unneeded textile structures as gently as possible as a raw material for new products.

As early as 105 AD, rags used to make paper in ancient China. The textile material cycle began to develop with the use of simple mechanical methods of recovering longer and isolated fibers in the fifteenth/sixteenth century. Because the purpose of textile recycling has steadily increased over the centuries for other reasons, the process of fiber recovery has developed further. Even if the invention of synthetic fibers seems to be an overabundance, textile recycling, as an essential foundation

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of sustainability, must be up-to-date and subject to constant development. Textile recycling should and must be understood as a link in textile value chains.

Textile waste as a raw material of textile recycling is today differentiated into production waste and used textiles. Although a well-developed collection system exists for used textiles, in Germany alone, more than 300,000 tonnes are still in the trash. Production waste with an estimated annual volume of 285,000 tonnes undergoes a process of change in connection with the structural change in the German textile industry and its orientation toward technical textiles (Korolkow 2015). The use of high-performance materials and the use of non-textile components make their treatment and recycling increasingly complex. The chapter exemplifies the recycling of carbon fibers. The amount of waste will increase continuously, not least as a result of China's ban on imports of textile waste. In response increases in textile recycling capacity through more effective technology and new technological solutions are required.

The main process for the recycling of textile waste is the mechanical treatment of reclaimed fibers. Although this process has sufficient potential in terms of performance and qualitative result, it quickly reaches its limits in production waste from the manufacture of technical textiles, e.g., in the processing of complex material compositions and heavily coated textiles.

The five-stage waste hierarchy of the EU Waste Framework Directive 2008/98/EC of 19.11.2008 represents a clear ranking in the handling of waste. Recycling is also the central component of this hierarchy in the textile industry and is the key to the circular economy (Gulich 2016).

11.2 Presentation of the Initial Situation

Nowadays, some material flows have been established for textiles in Germany (see Fig. 11.1). Textile waste is produced either during production or after use of the textiles. This waste can be used for energy or recycled textile. An important process step in this case is the tearing, which brings the textile waste into a necessary form for further processing.

Table 11.1 shows the amount of clothing collected in Germany and its subsequent use. Thus, the amount of clothing collected increased from 477,000 to 1,010,000 tons from 1975 to 2013. There is also a clear increase in the reuse of clothing from 30 to 54%. In return, the amount of discarded clothing dropped from 32 to 2%. Furthermore, when looking at the collected old clothes and home textiles, it can be seen that the quantity returned from 2007 to 2013 has risen from 112,600 to 135,000 tons. In the same period, the recycling rate increased from 60 to 74% (Gulich 2016).

Other sources report about 15 billion garments, of which owners in Germany separate annually. According to GfK SE, Nuremberg, Germany, spent EUR 43.5 billion on clothing in 2015, which corresponds to around 25 million pieces (Dillemuth 2006).

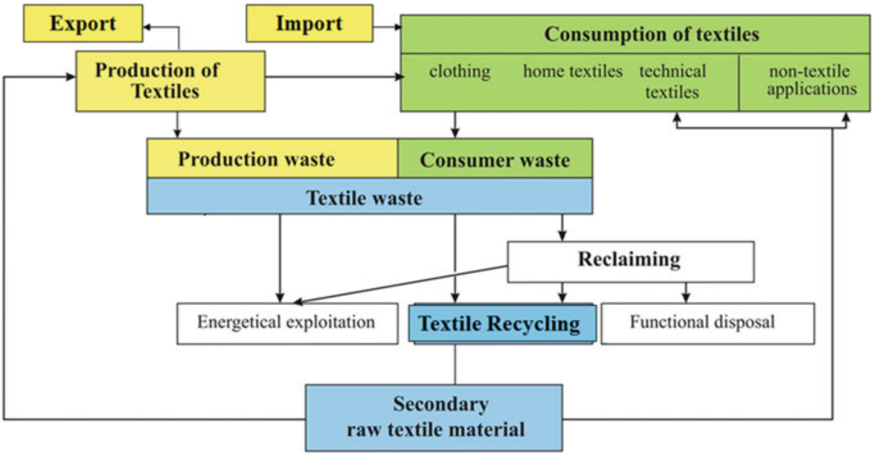


Fig. 11.1 Material flows of textile waste in Germany (Gulich 2016)

Table 11.1 Collected clothing and its use in Germany (Gulich 2016)

Year	Collection in ktons	Amount in %				
		Reuse as clothing	Recycling		Cleaning cloths	Disposal
1975	477	30	18		20	32
1990	520	45	19		16	20
1995	615	48	22		17.5	12.5
2000	620	50	21		17	12
2007	750	43	21	10	16	10
2013	1010	54	23		21	2

The companies of the German textile and clothing industry with 118,000 employees and a turnover of EUR 28.7 billion in 2016 make a considerable contribution to the domestic availability of textiles. But these companies also generate around 285,000 tons of production waste. Table 11.2 shows the volumes and recovery routes for production waste.

11.3 Textile Recycling

Efficient systems for collecting, sorting and recycling used textiles from industry and households have been around for a long time in medium-sized industry in Germany.

One way of recycling textile waste locally is to return it to the company's own material cycle (reuse) of a textile factory, for example, in spinning mills. The recycling of waste through recycling and reuse is carried out by various specialized

Table 11.2 Production waste of the German textile and clothing industry (Statistik 2018)

Textile	3.2 tons/a worker	78,800 workers	252 ktons
Clothing	0.85 tons/a worker	39,200 workers	33 ktons
Sum		11,800 workers	285 ktons
Thereof reused as:			
Cleaning rags			60 ktons
Recycling			60 ktons
Refuse-derived fuel			114 ktons
Disposal			51 ktons

disposal companies. Non-recyclable textile waste is used as fed public incinerators (thermal/energetic transformation). Their waste is finally disposed of in landfills. Old clothes not collected by collection are disposed of as part of domestic waste incineration (energy use). The collection of used textiles and worn clothes is mainly organized by private companies or charities such as the Red Cross or the Samaritan organization of workers. It is distinguished between street collection and container collection.

After collecting the old textiles, the old textiles go through the process chain. After unloading, transport to usually manual sorting stations takes place. The textiles sorted out for the production of reclaimed fibers are pressed into bales for further transport or intermediate storage. After being processed by cutting and tearing, the reclaimed fibers are pressed into bales. Subsequently, the reclaimed fibers are processed in nonwoven production process routes (Fig. 11.2).

The following procedure results in detail. First of all, the unloading and feeding of the used textiles in process chain take place. The unloading and feeding systems are distinguished between

- Manual unloading in cages/lattice boxes
- Manual unloading on a conveyor belt.

An example is shown in Fig. 11.3.

In the feed systems, one differentiates:

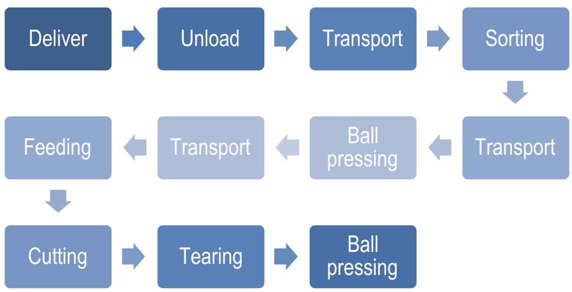


Fig. 11.2 Process chain for the treatment of used textiles (own illustrations of authors)

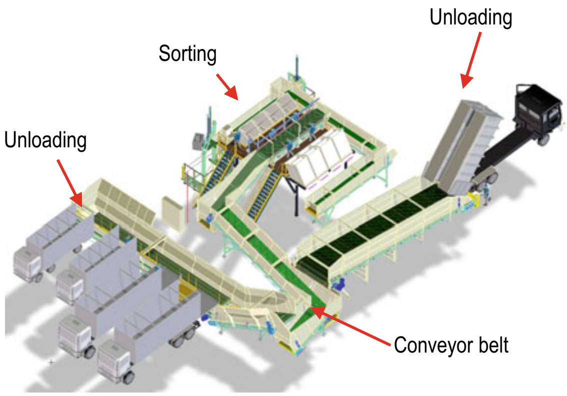


Fig. 11.3 Discharge systems for waste textile sorting plants (Valvan Baling Systems 2019)

- Ball opening system
- Manual unloading on the conveyor belt
- Robot feed system (Valvan Baling Systems 2019).

The used textiles are then brought to the sorting systems. Sorting is usually done manually. The basic sorting systems are described below. For production requirements of more than 15 tons per shift, a box sorting system is often used, see Fig. 11.4. A sorting station consists of up to 25 boxes, to each of which appropriate sorting criteria can be assigned. The shafts are emptied separately downward. The content is weighted and transported accordingly. The shaft arrangement minimizes throwing distances, ensures an ergonomic working area and increases the efficiency of sorting. This can reduce the cost and effort of sorting (Valvan Baling Systems 2019).

For production requirements up to a maximum of 20 tons/shift and a limited number of categories, belt sorting systems are often used. A belt sorting system

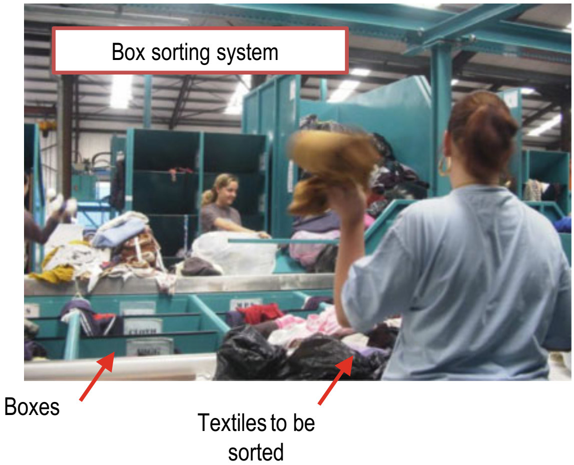


Fig. 11.4 Box sorting system of Valvan Baling Systems NV, Menen, Belgium (Valvan Baling Systems 2019)

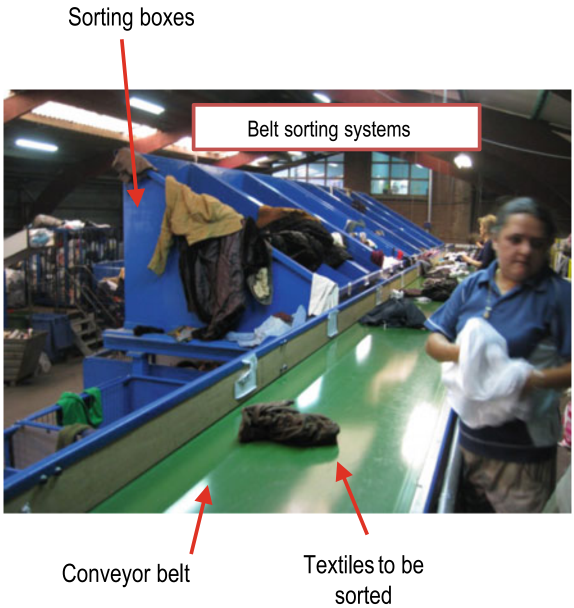


Fig. 11.5 Belt sorting systems from Valvan Baling Systems NV, Menen, Belgium (Valvan Baling Systems 2019)

consists of a feeding system, a first sorting line (see Fig. 11.5) and a second sorting line (Valvan Baling Systems 2019).

Another variant for sorting is a voice-controlled belt release system with an unlimited number of sorting criteria. A speech sorting system is a system in which each sorter has a microphone and defines with its voice the category of a sorted item. The sorted article is transported and stored on a long conveyor belt, and the control system blows the article by means of compressed air pulse at the predetermined position in a collecting container. The great advantage is that the number of sorted articles is virtually unlimited and limited only by what a sorter can detect and by the number of sumps. The language software is adapted to each language and dialect (Valvan Baling Systems 2019).

The possibility of automatic sorting is provided by the Fibersort technology of Valvan Baling Systems NV, Menen, Belgium (see Fig. 11.6). Fibersort is a technology that automatically sorts large amounts of textile waste into fiber composition using near-infrared spectroscopy. Near-infrared spectroscopy is a physical analysis technique and, like other vibrational spectroscopy, is based on excitation of molecular vibrations by (near) infrared electromagnetic radiation. As a prerequisite for flawless operation, the component to be awarded must be at least 60% in the mixture.

The next step in the processing of textile waste is to cut the textiles. First, the machine is fed by means of a charging system. After removal of the bale on the loading platform, the straps and the outer packaging of the bale are removed manually. Then, the bale is raised and dumped into the hopper. The loading platform returns to the waiting position, while the lower packaging is held by an automatic device. Trigger rods transport the clippings with an alternating and controllable shaking movement

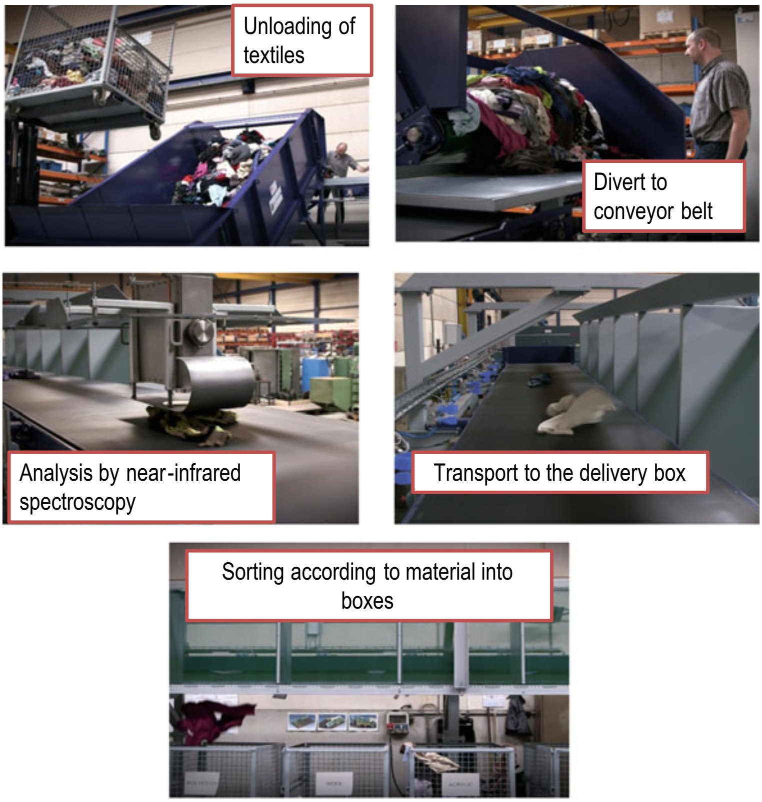


Fig. 11.6 Principle of Fibersort technology of Valvan Baling Systems NV, Menen, Belgium (Valvan Baling Systems 2019)

in an outlet channel. A horizontally arranged vibrating knife at the outlet channel limits the material thickness during feeding for the subsequent cutting processes (PIERRET INDUSTRIES 2019).

The robot from Pierret Industries s.p.r.l., Corbion, Belgium, is an automatic loading system with little operating effort, a separate hydraulic unit which makes the system freely positional and a throughput of 800 kg/h, see Fig. 11.7 (PIERRET INDUSTRIES 2019).

Fig. 11.7 Loading system robot of Pierret Industries s.p.r.l., Corbion, Belgium (PIERRET INDUSTRIES 2019)

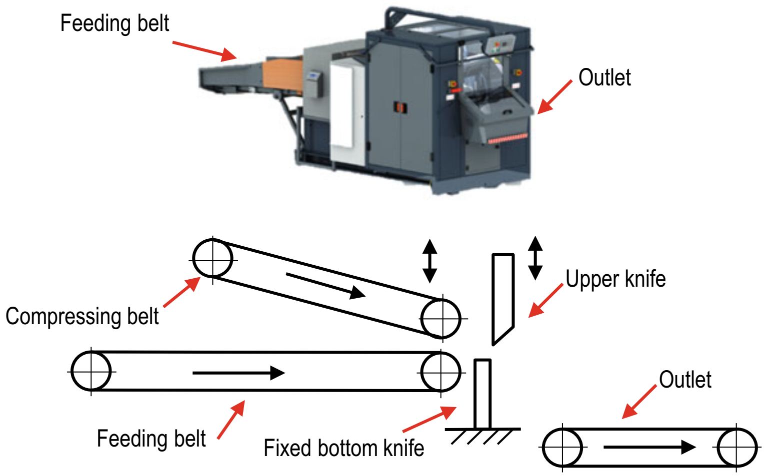


Fig. 11.8 Cutting machine CG60N from Pierret Industries s.p.r.l., Corbion, Belgium (top) and drop knife principle (below) (PIERRET INDUSTRIES 2019)

In the further processing, the cutting of the textiles has prevailed with the help of knife cutting machines. The textiles are transported by means of a feed belt to the cutting device. Tapes or rollers ensure that the textiles are conveyed non-positively and compressed on the support surface before they are fed to the knives. The cut between the moving carbide knife and the fixed knife ensures a clean, precise and easy cut. A typical installation is the CT60N from Pierret Industries s.p.r.l., Corbion, Belgium (see Fig. 11.8). The machine shows the following features:

- Cutting width of 600 mm
- Compacted material thickness of max. 180 mm
- Maximum cut material thickness (material feed) of approx. 500 mm
- Cutting speed of 200 cuts/min
- Cutting length range from 10 to 180 mm
- Production output can reach more than 10 tons/h
- Cutting machine is driven by four encapsulated three-phase motors with housing cooling, protection class IP55 (PIERRET INDUSTRIES 2019).

For uniform internal forces at high flow rates, (at least) two cutting machines arranged at right angles to one another are inserted. In the second step, the preparation for the tear fibers starts.

The operating principle of the tearing machine is that coarsely pre-shredded materials are fed through a transporting and at the same time clamping-acting feeder system to a drum rotating at high circumferential speed, the tearing drum. The pin or tooth-shaped tearing clothing arranged on the tearing drum enters the structure which is clamped on one side by the drawing-in system and tears the structure under the action of a tensile stress. This structure resolution can only occur as long as the material is in the clamped state. Therefore, for most textile structures, the passage of several consecutive breaking units is necessary.

The feed system on tearing machines can consist of two rotating rollers (roller infeed) or of the combination of a rotating roller with a rigid trough. Today, more frequently occurring trough feed can be reacted by the shape of the trough edge on the properties of the submitted material. In addition, the distance between the material clamping point and the area of action of the tear elements is reduced, which is advantageous for complete structural resolution, especially in the course of multi-stage preparation operations.

From the trajectory of the material to be ripped around the spool, it is possible to separate out the remaining and unresolved material components, the so-called spikes, due to their higher mass downward. Depending on the type of material and material structure and the quality objective of the ripping process, the separated material stream collected with appropriate technical means can be submitted to the process again (possibly after a corresponding intermediate treatment) or discarded (Fig. 11.9).

The state of the art in modern drawing machine construction offers working widths of up to 2000 mm and, in the case of tearing systems with a plurality of tearing drums arranged in series, permits throughput rates of a maximum of 1000 kg per meter working width.

Single- and double-drum machines are mainly suitable for processing a narrow range with constant product or structural properties and low quantity. Such machines are often found as part of internal circulation systems, especially in nonwoven manufacturing plants. The usual working widths of 500–1000 mm allow material-dependent throughput rates of 100–450 kg/h. Tear systems in recycling companies usually have at least three drums and a maximum of six drums with working widths of 1000 mm, 1500 mm or 2000 mm.

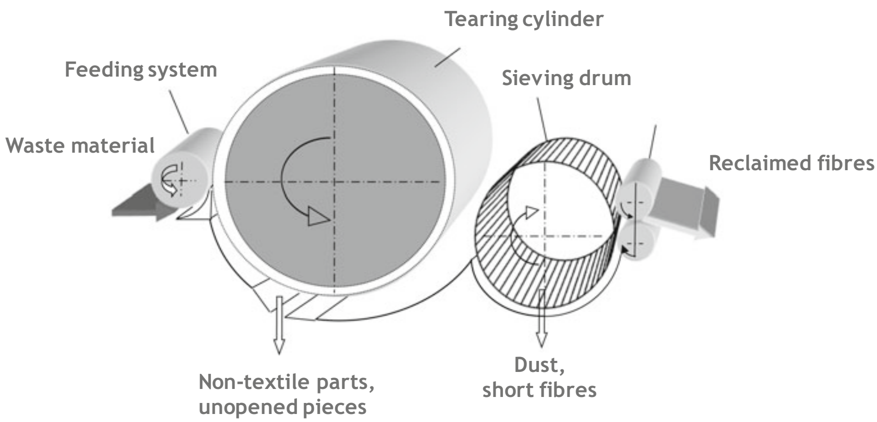


Fig. 11.9 Principle of the tearing process (own illustrations of authors)

The material transfer between the arranged in series tear drums is usually done by screening drums. This is to be achieved by the operating principle of a capacitor from the trajectory, and it is a fiber mat or a fiber skin for the individual tear-open units. As a general rule, in the case of a number of zippers, the increasing surface area of the fiber must be taken into account by the number and fineness of the tearing elements attached to the tufting. In order to ensure an accurate transport or insertion safety and a retaining force at the material clamping point, the structure-dependent design of the feed roller surface is also required. After passage of the last tearing drum in the system train, the material is directly sucked off and transported downstream equipment for post-treatment and packaging.

The production of tear fiber from used clothing requires a higher level of mechanical engineering and technological effort compared with the processing of production waste. One to two passages for coarse dissolution by means of special tearing drums with robust machine elements before the actual tearing process serve the structural disruption for separating the foreign parts from the textile material contained. It is expedient to carry out the intermediate treatment of the neps that have separated out on the pre- and fine tearing line by means of cleaning and a separate ripping process and to return this material to the current process. Characteristic of modern systems for the treatment of old clothes is also the material management via various separating units. This can be done several times during the reprocessing process—adapted to the respective status of the structure resolution (Fig. 11.10).

As a result of the tearing, reclaimed fibers are present, which are usually a mixture of so-called pits, unopened pieces, fibers of different lengths, thread remnants and fiber dust or short fibers, see Fig. 11.11 (Gulich 2016).

The production of nonwovens is today the common way to process large quantities of tearing fibers. Nonwovens made of or with tearing fibers find a variety of applications in the field of technical textiles. The following main areas of application for such nonwovens can be mentioned.

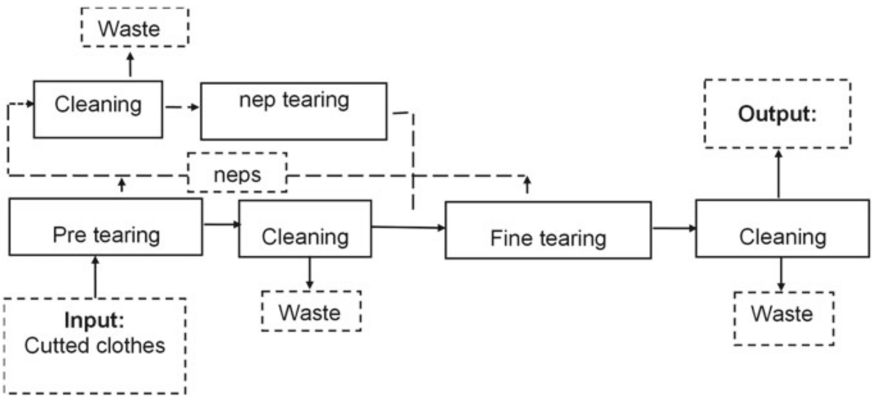


Fig. 11.10 Scheme of a tear line for the processing of used clothes (own illustrations of authors)

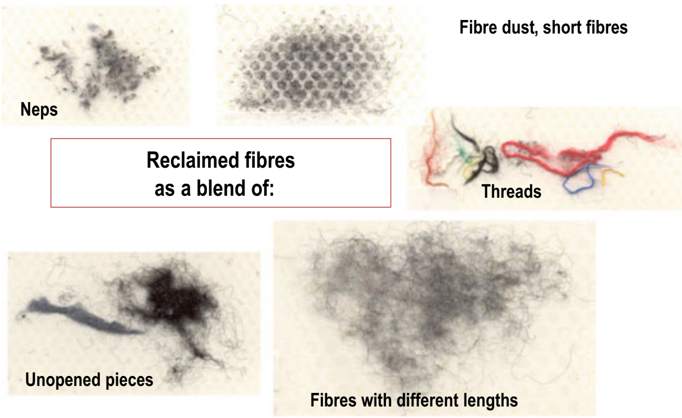


Fig. 11.11 Typical components of tearing fibers (Gulich 2016)

- Automotive textiles, installation in concealed area
- Spring core covers in upholstered furniture
- Insulation nonwovens (temperature, mechanical vibrations)
- Clothing interlinings
- Cleaning wipes
- Packaging material
- Disposable blankets for civil protection
- Erosion protection mats (made of predominantly decomposable tear fibers).

The usage idea for tearing fibers is based on a sufficient performance profile and an interesting price level for many applications. When manufacturing functional textiles for technical purposes, there are even opportunities to use cheaper secondary fibers if primary fibers cannot be used for cost reasons. Product-adapted reclaimed fiber properties can be achieved through targeted material selection and product-related tear technologies.

The production of nonwoven fabric from tearing fibers generally requires systems engineering with robust working elements and a material dissolution which is sufficient depending on the intended product application. Tear fibers can be processed into carded fabrics using the carding process and various aerodynamic processes (Fuchs et al. 2012).

The web forming processes place different demands on the quality of the tear fibers to be processed (Table 11.3).

11.3.1 *Web Formation by the Carding Process*

In the carding process, fiber flocks—in the processing of tearing fibers also yarn pieces to a limited extent—are dissolved down to the individual fiber and formed

Table 11.3 Minimum requirements for tear fiber quality depending on the web forming process (Böttcher et al. 1995)

Web forming principle	Tear fiber quality		
	Average fiber length (mm)	Short fiber content	Resolution
Aerodynamic	5 bis 30	Low to medium	Medium
Carding	15 bis 50	Low	High

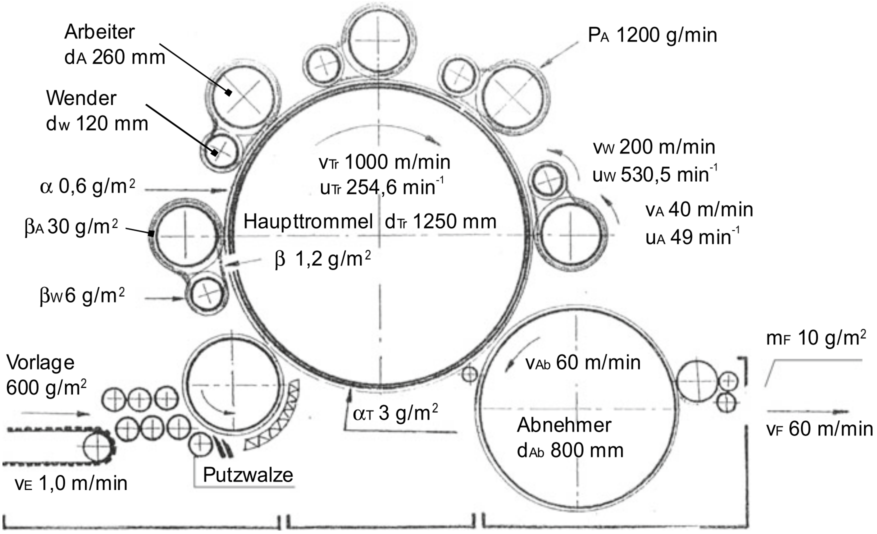


Fig. 11.12 Representation of the material flow and the speed conditions during carding (Fuchs et al. 2012)

into a coherent web in a parallel position or random orientation. In further processing, the formation of a nonwoven fabric from several web layers and its solidification into a nonwoven fabric takes place (Fig. 11.12).

In order to form a nonwoven fabric with a corresponding surface mass from the fibrous web formed by carding, so-called nonwoven layers are used. The most frequently used construction method is shown in Fig. 11.13. The web is characterized by a multiple overlapping of the carded fleece and simultaneous cross-draw.

11.3.2 Aerodynamic Web Formation

With web forming systems based on the aerodynamic principle, almost all conventional synthetic and natural fiber materials can be processed. A particularly broad field of application for such system technology opens up because of the comparatively low

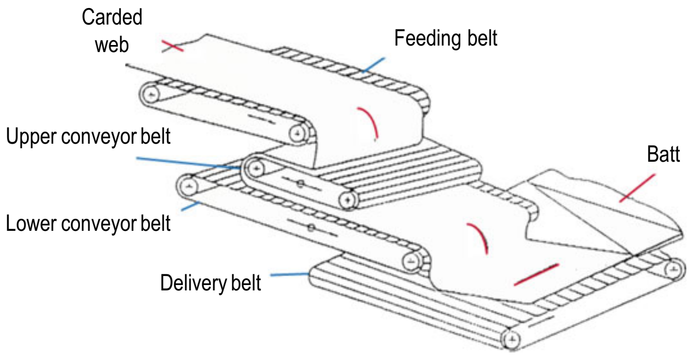


Fig. 11.13 Principle of web formation with horizontal cross-lapper (own illustrations of authors)

demands on the degree of fiber opening for the secondary fibers produced by tearing. In addition, the low stress of the fiber material in the shortened opening process of aerodynamic nonwovens allows the processing of coarse, delicate or brittle fibers such as vegetable fibers or glass fibers. The production of aerodynamically shaped random nonwovens is a productive technology variant for fabrics in the technical textiles product area.

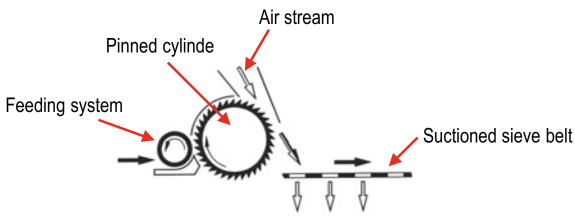
The basic principle of all aerodynamic nonwoven forming processes is that the fiber material opened by a fiber opening device of varying degrees is transferred to an air stream. With this airflow, the fiber material reaches a sucked-in and continuously moving screen surface (drum or belt-shaped). Here, a nonwoven fabric is formed, whereby the randomized fiber arrangement typical for the process arises in a three-dimensional manner (Fig. 11.14).

Significant advantages of aerodynamic web formation compared to the conventional web forming principles (carding and cross-lapper) are:

- Homogeneous distribution in terms of structural strength
- More favorable ratios of nonwoven surface mass and plant productivity
- High working widths with comparatively low effort
- Lower investment and operating costs.

The web consolidation can be carried out with different physical or chemical processes. Typical representatives of the tear fiber nonwovens are needled nonwovens and thermally bonded bulky nonwovens (using appropriate binder fibers).

Fig. 11.14 Principle of aerodynamic web formation (Fuchs et al. 2012)



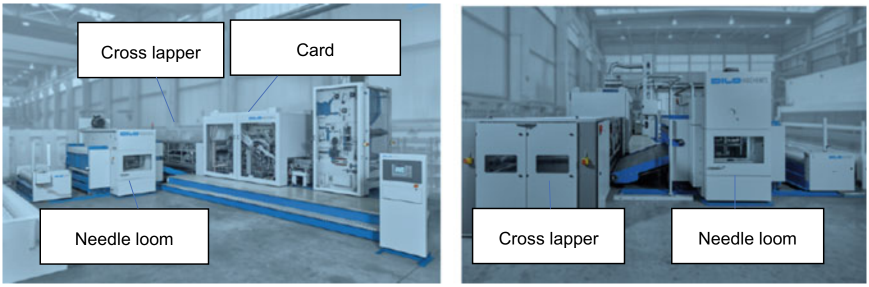


Fig. 11.15 Needlepunched nonwoven compact line from Dilo Machines GmbH, Eberbach (Dilo Machines GmbH 2019)

When needling, the batt presented to the machine is pierced by means of a plurality of felting needles. The barbs of the needles fill with fibers and orient them as fiber bundle in the cross section of the nonwoven. Along with this, the entanglement of the individual fibers with each other and the compaction of the batt into a nonwoven and the formation of the strength properties take place. The solidified consolidated web is transformed to a nonwoven web.

The company Dilo Machines GmbH, Eberbach a needlepunched nonwoven compact line for universal applications (see Fig. 11.15). The line consists of the Compact Card KC 11 24 SD with AlphaFeed K11 and a working width of 1.10 m. Then, the cross-legged LAK 11/22 and the needle machine DILO DI-LOOM OD-II with a width of 2.20 m are used (Dilo Machines GmbH 2019).

1. Recycling of carbon fiber waste
2. Recycling of carbon fiber waste.

Due to the excellent mechanical properties combined with the low density, carbon fibers are mainly used in the composite sector. Carbon fiber filaments can be processed directly as roving or either by using a variety of textile manufacturing technologies to build up textile semi-finished products (e.g., woven fabrics, non-crimp fabrics). These semi-finished textile products are subsequently processed into carbon fiber-reinforced plastics (CFRP) by embedding them in a matrix system. In recent years, carbon fiber has made its way especially into the aviation and automotive industry and has meanwhile achieved significant importance (Passreiter 2013).

Carbon fiber waste arises in various application areas both as cutoff waste of semi-finished textile products and in the processing of returned CFRP structures (e.g., end-of-life components) (see Fig. 11.16). Frequently, foreign materials in the form of films, papers or other valuable materials are included.

Especially, the production of complex-shaped components, which may be provided with large cutouts, shows the disadvantages of the use of textile semi-finished products. The waste rate of semi-finished products is in this case with 30–50% comparatively high (Rüger and Fröhlich 2011).

For the majority of the currently occurring carbon fiber waste, incineration is still state of the art. In 2015 18,000 tonnes of carbon fiber waste produced worldwide,

Fig. 11.16 Cutoff waste delivered to Saxon Textile Research Institute (STFI) (left) and CFK Valley Stade Recycling GmbH (right) (Rademacker 2017)

only 1600 tonnes were recycled by incineration or landfilling materials (with a value of several hundred million euros) which were destroyed (Bakewell 2016).

Despite the comparatively high technical risk involved in the processing of electrically conductive fibers, nonwovens have outstanding potential for economical use of recycled carbon fibers in new products, thus offering a solution to the recycling question. It is known that up to 100% rCF nonwovens can be produced by both the carding and the airlay process (Erth 2008; Köver and Riedel 2012). In addition the technically most sophisticated approach of processing 100% rCF, so-called hybrid nonwovens, forms another interesting product group. These nonwovens consist of fiber blends having at least two different blend components, in addition to rCF, other reinforcing fibers (e.g., glass, aramid or natural fibers) and/or thermoplastic fibers (e.g., polypropylene, polyamide or co-polymers) are possible.

Research work in recent years and the first application examples in the automotive sector, e.g., roof structures and seat shells in the i3 of BMW AG, Munich, Germany, show the potential of rCF nonwovens (Knof 2014).

Leading research partner in the field of nonwoven fabric production from rCF is STFI e.V., which has been working on the processing of carbon fibers by carding since 2005. The main focus of the work carried out is the processing of dry waste to reclaimed fibers and the subsequent web formation. In addition to the production of carded and airlay nonwovens and the subsequent entanglement via different processes (stitch bonding, needle punching, thermal bonding and hydroentanglement). The STFI also carried out extensive investigations in the production of carded slivers and yarns of up to 100% rCF (Gulich and Hofmann 2014). These investigations show the technical feasibility as well as the economic and sustainable meaningfulness of the treatment of carbon fiber waste and the subsequent web formation. Figure 11.17 shows the nonwoven line installed at STFI for the processing of dry carbon fiber waste and production of nonwovens by means of carding and airlay process with a working width of 1.0 m.

In addition, further research work in this field is known. The laboratory-scale investigations carried out at the Institute of Textile Technology (ITA) at RWTH Aachen University included the production of carbon fiber nonwovens using airlay and their combination with carbon fiber papers (Lütke et al. 2017). Investigations at the Institute of Textile Machinery and Textile High Performance Materials (ITM) at

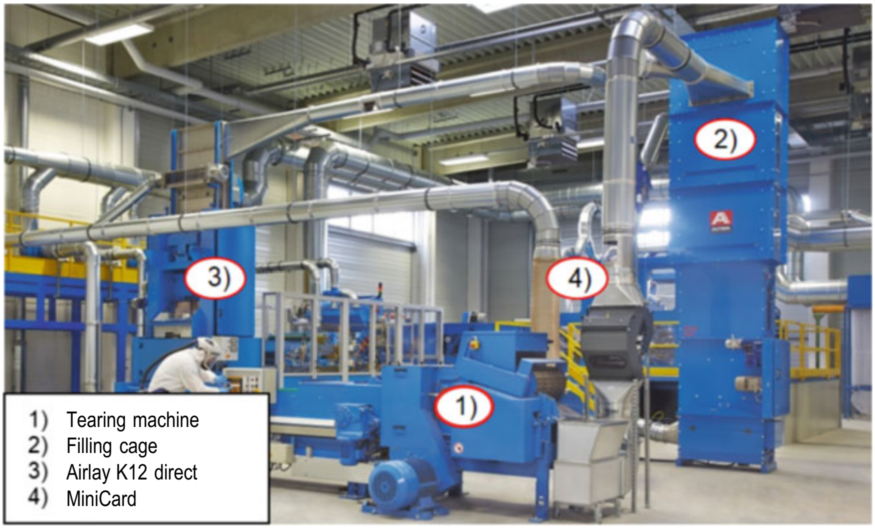


Fig. 11.17 Nonwoven line in the center for textile lightweight engineering at the STFI e.V. (own illustrations of authors)

the Dresden University of Technology have shown that rCF can be processed into a web, which is then converted into yarn structures by subsequent spinning processes (Hengstermann et al. 2015). The focus of this work is the processing of rCF in modified spinning processes. At STFI, it was also possible to show the successful production of various hybrid nonwovens and their further processing into organo sheets (Gulich and Hofmann 2015). In this case, fiber blends with fractions of rCF in the range of 10 to 90% were processed into carded nonwovens and then formed by molding processes (use of a flat-bed laminating machine or continuous compression molding system) to organo sheet.

Work carried out by the Institute for Textile and Plastic Research e.V. (TITK) in cooperation with SGL ACF GmbH & Co. KG underlines the positive processing properties of rCF nonwovens mentioned above. In combination with thermoplastic matrix systems (e.g., PA6, PP or PBT), it was possible to produce organic sheets which were shaped by means of compression molding in a further step (Reussmann et al. 2014).

In addition to the above-mentioned institutes, the ITA gGmbH, Augsburg, Germany, will also carry out research work in the area of carbon fiber nonwovens on a compact line established in 2016. Their research focuses on the processing of rCF mixed with thermoplastic matrix systems (ITA Augsburg gGmbH 2019).

In particular, industrial implementation of nonwoven production by means of rCF carding is also known, which ensures a short-term transfer of the research results to industry (Gulich and Hofmann 2015; Stevenson 2017; Cleff 2015).

11.4 Research on Textile Recycling

Numerous national and international research projects are investigating how textile recycling can be improved. In the process, new materials or combinations of materials, processes and processes as well as logistics and business models relating to textile recycling are examined. Following, selected projects will be presented.

The EU Trash2Cash project is investigating pulp separation from fiber blends, solution and molecular disassembly and the spinning of new fibers. Regeneration of cellulose is considered to obtain IONCELL F (CL) fibers. Further, the repolymerization is studied to obtain recycled polyester fibers (r-PET) and melt blending processes for the production of mixed PET pellets (Trash-2-Cash 2019).

The RESYNTEX project considers the value chain from the collection to the textile raw material. The aim is to increase the effectiveness and quantity of collections, to find new methods for the high-quality reuse of textile waste as well as an accompanying life cycle analysis (LCA) and life cycle costing (LCC) (RESYNTEX).

The EcoSing project will help technicians and industrial designers reduce the environmental impact throughout the product life cycle, including the use of raw materials and natural resources, manufacturing, packaging, transportation, disposal and recycling. In addition, it is appropriate to offer training courses for European environmentalists who add skills and competences related to environmental aspects (ECOSIGN).

The overall objective of the EcoMeTex project (ecodesign methodology for recyclable textile coverings used in the European construction and transport industry) was to develop a tailor-made ecodesign method to optimize the design of textile covers in terms of eco-efficiency and cost-effectiveness, see Fig. 11.18. The work involved an analysis of the entire life cycle, identification of significant environmental and economic impacts and thus potential for improvement, ensuring high product quality and high product safety (EcoMeTex 2015).

The innovative methodology faces the challenge of solving the paradox of textile clothing:

- On the one hand, the bonding of the multilayers must be solid and high-quality raw materials are used in various combinations to ensure long-lasting products.
- On the other hand, the multilayers must be easy to disassemble for recycling, but disassembly procedures to facilitate material recycling are not yet part of the product design process. Concepts that focus on technologies for recycling state-of-the-art textile coverings have failed due to complex mechanical or chemical separation processes and, consequently, their high cost and low eco-efficiency.

The feasibility of the re-design concepts is demonstrated by the production of prototypes of eco-textiles for floor coverings. The work is completed by describing the methodology in a code of conduct that is implemented in a custom, practical and intuitive software tool. The environmental communication of the results obtained is based on LCA results in EN 15804 format. These environmental product declarations

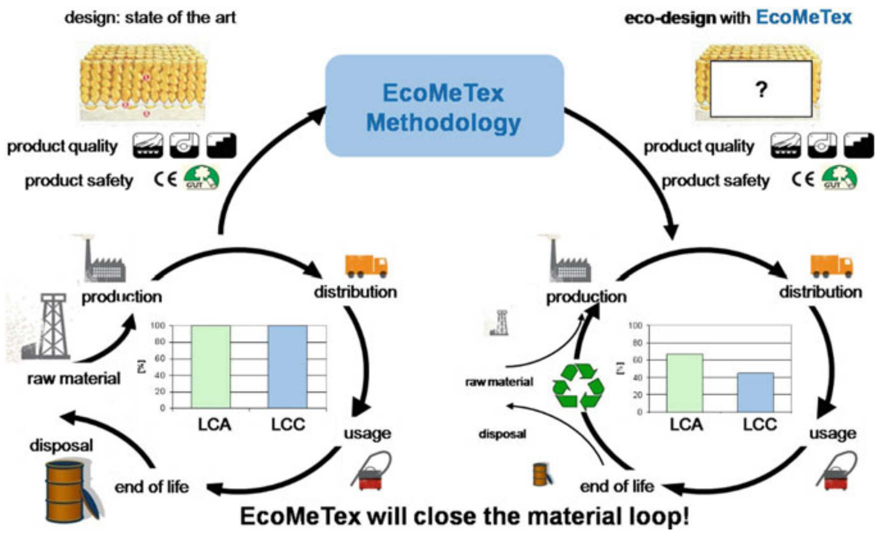


Fig. 11.18 Objective of the project EcoMeTex (Gloy and Schröter 2015)

(EPDs) are already widely used in the EU construction sector and contain data for architects and planners in a standardized format. The transferability of the ecodesign method for textile floor coverings to other sectors is analyzed using the example of luggage covers for automotive applications that represent the transport sector.

To achieve these goals, three basic strategies were selected:

- Mono-material batch
- Interface approach
- Material reduction (EcoMeTex 2015).

Numerous other research projects are carried out at the STFI e.V. in Chemnitz. In 2019, for example, it was possible to successfully launch a ZIM network on the subject of textile recycling, where one topic is the recycling of smart textiles. Together with the TU Chemnitz, the City of Chemnitz and the Gherzi Group, the Sustainable Textile School was established in 2017/2018. At the Sustainable Textile School, students and professionals will continue to be made aware of this issue with the help of experts. The goal is to build a global platform for textile engineering (Sustainable Textile School 2018). Ongoing work at the STFI aims to establish a competence center for the recycling and sustainability of textiles both at the Chemnitz site and nationwide.

11.5 Summary and Outlook

For textile waste, there are efficient and established systems for collection, sorting and recycling in Germany. For further use, the fiber production is the traditional treatment method. This textile waste can be processed economically to tear fibers. The tearing fibers thus obtained are used almost exclusively in nonwovens for insulation, upholstery and automotive textiles. Higher-quality applications are niche solutions so far.

The structural changes in the textile industry in many countries from the production of clothing to technical textiles are progressing. As a result, textile waste will continue to change with regard to the composition of materials, the composition of textiles, the quality of surfaces (finishes and coatings) and the use of electronic components in smart textiles.

The goal of future textile recycling research activities should be to increase the purity of the materials while minimizing mechanical, optical and structural damage to the material. Textiles should be designed so that they can be separated according to type. Innovative methods can facilitate the separation. In addition, innovative products with recycled textiles can be found, which can compete on the market. The decisive factor here is that the expenses for processing textile waste and its further processing can also be in economic competition with raw materials.

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Chapter 12
Achieving a Circular Textiles Economy Facilitated by Innovative Technology

An Analysis of Present and Future End-of-Life Solutions in Textile Recycling

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Abstract The textile industry, while remaining a growing sector in response to population increase and social change, has been identified as a significant consumer of finite natural resources and a large producer of waste. This linear economic model that allows for the consumption of resources with no measures in place for a product's end of life other than disposal is not sustainable, and changes to this model are being driven by society pressure and legislative measures, while being facilitated by technological innovation. While new solutions are emerging, logistical structures are not yet fully in place to facilitate this industrial progression and the question remains 'which new innovations in recycling technology can help to facilitate a new textile circular economy?'. The concept for this study was formed around the principal of finding solutions to the linear consumption of the planet's resources and the part played by the textile industry. This chapter offers a qualitative evaluation of the current post-consumer waste models, recycling streams, and the associated challenges, while providing an evaluation of new innovations in recycling technologies and a discussion around the viability of the integration of new technologies into the current economic models.

A practitioner's perspective

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Keywords Textiles · Recycling · Upcycling · Chemical recycling · Polyester · rPET · Circular-economy · Waste · Sustainability · End-of-life

12.1 Introduction

The world's resources are finite, and they are coming under increasing pressure year on year. The textile industry has been identified as a significant consumer of these resources, and the growth of this sector in particular is accelerating increasingly quickly, driven by social change and population increase amongst others. The linear economic model that allows for the consumption of resources with no measures in place for a product's 'end of life' other than disposal is not sustainable. Industry is beginning to take this issue seriously, driven by societal change, scientific advances, and legislative pressure, and new solutions are being developed and employed from many different directions. One of the main tests facing the textile industry is progressing from a linear economic model towards a circular economy and further more developing the technology and systems to achieve this. This study aims to outline these challenges, so as to enable better understanding of them and discuss the innovations that are being developed to address them.

This will be done through a review of raw material consumption and processing. The current end-of-life practices will then be identified, and new innovations that support closing the loop and creating a circular economy in terms of textile 'end-of-life' processing will be discussed in detail. Finally, the implications and application of these finding for brands in industry will be outlined, so as to offer new potential directions for achieving circularity in the future.

12.2 Methodology and Concept

The concepts for this study were formed around the principal of finding solutions to the linear consumption of the planet's resources and the part played by the textile industry. The focus was given to polyester, cotton, and polyamide because it was noted that establishing an effective solution to the reprocessing of these three fibres would deal with 80% of textile consumption as it currently stands. It was thought that providing a complete overview of the properties and technologies associated with the recycling of these three fibres would help further understanding of the barriers that exist in textile recycling, so as to help drive innovation in the field that will ultimately improve textile circularity. The studies and technologies that are referenced in this section were chosen based on their developmental status and acceptance by the wider market.

The study was undertaken using relevant methods including the literature reviews of reports relevant to the field, academic publications, and books. Qualitative research in the form of interviews and correspondence was also undertaken.

12.3 Material Flow

Interactions with textiles are often unconscious, but they are a fundamental part of everyday life, and the design, production, and distribution make up a substantial sector of the global economy. In 2017, global fibre production of textiles accounted for 105.3 million tonnes (Textile Exchange 2018), with production of fibres for fashion alone representing more than 50% of the overall amount (Ellen MacArthur Foundation 2017) (Table 12.1; Fig. 12.1).

Production of fibres increased almost fourfold over the last 40 years (Textile Exchange 2018), increasing from some 25 million tonnes in 1975 to more than 100 million tonnes in 2017, reporting a Compound Annual Growth Rate (CAGR) of some 3.5% in the same period (Fig. 12.2).

The production of chemical fibres (particularly polyester) has, and continue to increase rapidly over the shown time period, as opposed to cotton which remained fairly static (Textile Exchange 2018).

In the future, it is expected that the overall production of fibres for textile and fashion, for the period 2017–2025, will increase to over 130 million tonnes by 2025 (Yang Qui 2014), with a CAGR of around 3.6%. During this period, chemical fibres are predicted to continue growing at a faster pace with respect to the reference market, with a CAGR of some 4.8%, and reaching an overall production of approximately 100 million tonnes.

According to estimates, polyester should increase its leadership position and production could reach 85 million tonnes for textiles (Yang Qui 2014), increasing its importance both as the most used chemical fibre, from slightly less than 80% in 2017 to almost 90% in 2025.

Due to this predicted sizeable market for chemical fibres, and in particular polyester, it is clear that polyester is set to become even more prominent in the future. For this reason, it is important to determine where this material originates and how it will be treated post-consumption.

Table 12.1 Global production of fibres in 2017 by type

Fibre	2017 Production (Million tonnes)
Polyester	53.7
Polyamide (nylon)	5.7
Other synthetic	6
Cotton	25.8
Other plant based	5.8
Animal based (wool, down, silk, leather)	1.5
Viscose	5.36

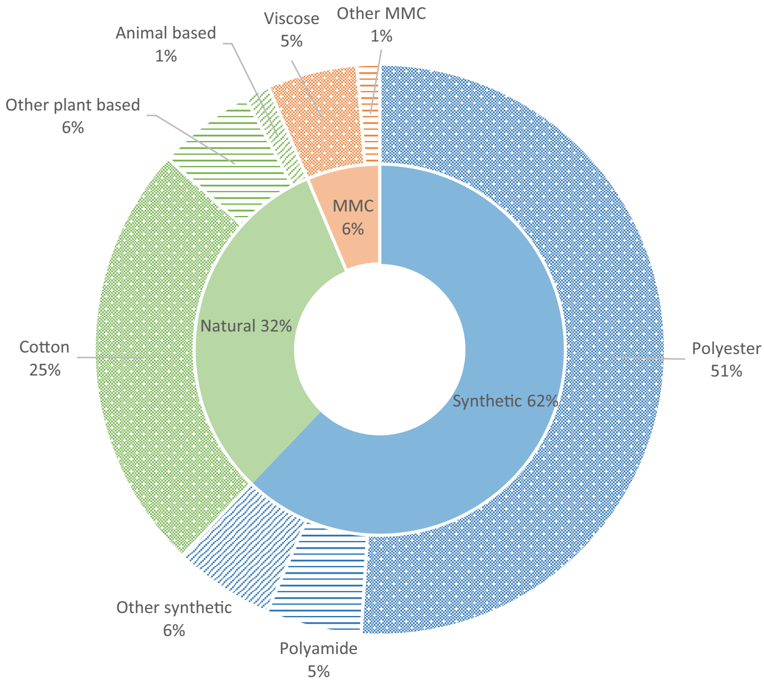

Fig. 12.1 Fibre types as percentage of overall global fibre production (illustration by the authors)

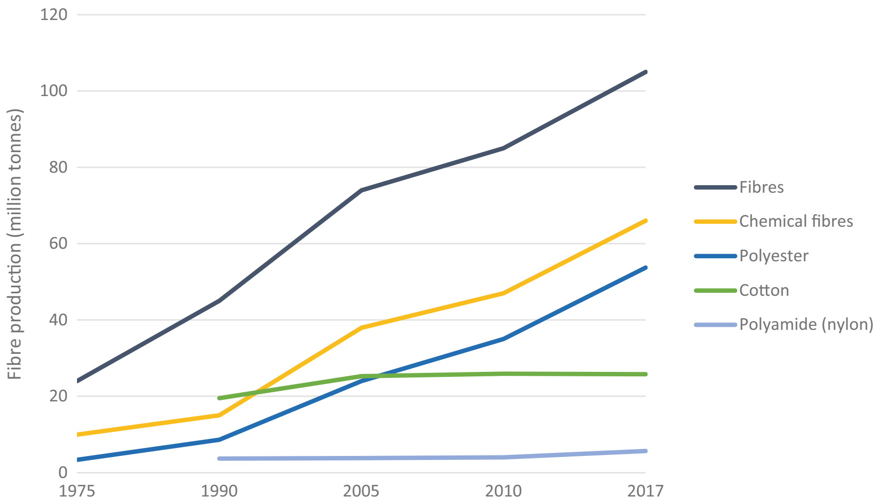

Fig. 12.2 Global fibre production from 1975 (million tonnes) (illustration by the authors)

12.3.1 Virgin and Recycled Polyester Reviewed

The growth in the consumption of polyester illustrates clearly the challenges faced by the textile and clothing industries. However, one of the key redemptive properties of polyester is the ability to repeatedly recycle and reuse it (Textile Exchange 2018).

The term 'polyester' refers to the polymer polyethylene terephthalate (PET). It is a material which is used in large volumes in textiles and clothing, in the production of common drinks bottles, as well as many other applications in the film and packaging industries. It is a synthetic polymer made of either purified terephthalic acid (PTA) or dimethyl ester dimethyl terephthalate (DMT), and monoethylene glycol (MEG). PTA is obtained by paraxylene, derived from refining crude oil, while MEG is obtained through the cracking process of ethane or propane, derived by natural gas.

Virgin polyester is that which is made from processing of natural resources that have not been previously used in any other product; this describes the majority of consumed polyester. The production of virgin polyester necessitates the use of non-renewable fossil fuel resources in large amounts (Ellen MacArthur Foundation 2017). The overall production of polyester, for fibres, which are the largest usage, as well as packaging and film, amounted to some 86 million tonnes in 2017 (Healy 2017), and almost 90% is coming from use of new resources (National Geographic 2018). About 98–99% of the current production of virgin polyester is coming from PTA and MEG, while the remaining percentage is obtained from DMT and MEG. The latter was the prevailing production technique in the past but was abandoned in recent years, due to the production of methanol as a by-product of the process, and its lower economic efficiency.

Given the current usage of non-renewable resources to produce polyester, and the forecasted consumption in the future, it is clear that alternative sourcing strategies, as well as improved post-consumption management, have to be found.

Currently, just over 10% of polyester produced comes from recycling processes (Textile Exchange 2018). The technology known as 'mechanical recycling' takes PET bottles and generates recycled polyester. Post-consumer PET bottles are collected and brought to a recycling facility where they are stripped of caps and labels (Plastic Insight 2019). The bottles are then cut in small pieces (flakes) and washed thoroughly to ensure no residues remain. The clean flakes are then melted, filtered, and formed into small pellets of high-grade recycled PET. The pellets are then melted again and extruded through spinnerets to make strands of yarn to produce polyester textile, or melted and processed in file or chips for packaging applications.

In 2017, the overall production of recycled polyester (rPET) compared with virgin polyester (vPET) was estimated in the region of 10 million tonnes (National Geographic 2018). From this, about 70%, or 7 million tonnes were used in the production of fibres for textiles and fashion (Textile Exchange 2018), this breaks down into 6 million tonnes used in the production of fibres for general purpose textiles, and 1 million tonnes being consumed by the clothing industry (Ellen MacArthur Foundation 2017). The remaining 3 million tonnes of rPET produced were returned to the packaging industry, mainly for the production of thermoforming sheet (also known

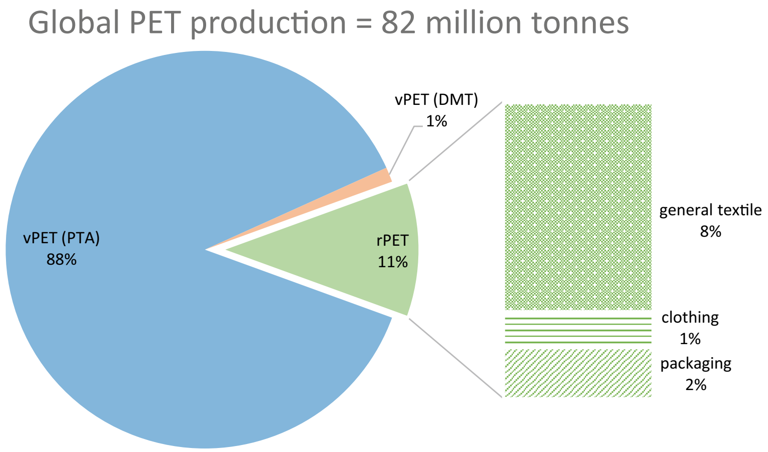

Fig. 12.3 Recycled polyester in the textile domain currently represents about 9% of the overall consumption, and around 1% is used for the clothing industry (illustration by the authors)

as thermoforms or PET trays) and blow-moulding packaging, both for food or non-food contact. Most of the rPET is converted into filament and staple in China, and due to a 2018 ban on importing different plastic wastes to China (Plastic Recycling Update 2018), recycled polyester production is expected to decrease in 2019 and the prices for recycled polyester have already been increasing as a result of the ban (Fig. 12.3).

12.4 Challenges in Recycling Polyester

As a fibre, polyester has a distinct and highly advantageous attribute, it can be recycled (Plastic Insight 2019), and the technology to achieve this is notably further forward compared to the recycling of other textile fibres (Textile Exchange 2018). This property has been acknowledged already, but it should be considered carefully now in more detail as it is key to achieving circularity in textiles. The ability to recycle polyester both mechanically and chemically and the readily available feedstock in the form of PET drinks bottles are key drivers in the success of establishing textile fibre recycling to the position it is currently.

The acceptance of rPET by the wider market has enabled further research and technological developments to occur and critically allowed for the establishment of a market for recycled fibres in general (Fletcher 2008). Fletcher notes that project using rPET from companies such as Patagonia have all helped make sustainability feel achievable and helped establish the market and drive it forward, through identification of new design and business opportunities. The Ellen MacArthur Report into ‘A new Textile Economy’ (Ellen MacArthur Foundation 2017) identifies brands such as Fjällräven, Paramo, Houdini, and Vaude that have chosen fabrics and trims constructed of a 100% polyester for the precise reason that they may be recycled more readily.

The acceptance of recycled polyester has been facilitated by factors such as having a 75% lower carbon footprint than virgin polyester and 90% lower than Nylon (Waste2Wear 2019). Its carbon footprint is also 50% lower than organic cotton. This marks recycled polyester out as a fibre that has a notably low environmental impact, with a growing market acceptance and with the potential to align well with increasing pressure from legislators and brands committed to a sustainable circular economy.

While production of polyester from recycled sources is definitely a virtuous practice, currently, this is not enough to move towards more sustainable textile and fashion value chains (Textile Exchange 2018). While it is clearly beneficial on the supply side (less use of natural resources), sourcing from recycled sources has no impact on the textile end-of-life side (Ellen MacArthur Foundation 2017).

Furthermore, there can be a number of challenges during supply and production of rPET which can further complicate the process. These issues can be demonstrated in the following case study, which describes the experiences of two rPET producers and the challenges they encountered.

Italian company Sinterama produces polyester textiles from rPET and includes a fibre called 'New Life', comprised of 100% recycled material (Sinterama 2019). Sinterama products are used mainly in the automotive industry, accounting for around 50% of the overall volume, followed by the home textile and furniture market and the clothing industry, with a share in volume of 30% and 15%, respectively. The company ambitiously attempted to source all of its PET bottles locally.

Dutch company Waste2Wear® is involved in the production of fabrics using 100% recycled polyester yarn or blended with natural fibres (Waste2Wear 2019). Their PET feedstock comes from ocean waste, as well as PET bottles, and they offer a range of recycled fabrics and products as well as focusing on consumer education.

Despite the challenges, both companies were able to overcome these issues courtesy of improved technical solutions and an established supplying chain. Today, Sinterama offers recycled polyester of comparable quality to vPET, with a full range of colours, and consistent properties, while Waste2Wear offers a range of successful fabrics and products.

The challenges that Sinterama and Waste2Wear encountered during the process of developing recycled PET including some of the considerations to overcome these issues are discussed below. All information was gained during direct interviews with the respective companies (Masson and Garza 2018; Piana 2018).

- **Logistics—Sourcing of feedstock—quality**
  - Feedstock (post-consumer PET bottles) must have a very high degree of purity in order to reduce impurities or contamination which lead to difficulties producing a continuous thread.

  - To overcome these issues, both companies reported the need to become extremely involved in their supply chains, including high-level feedstock selection.

- **Logistics—Sourcing of feedstock—colour**
  - Feedstock should ideally be transparent to guarantee consistency during colouration processes of the resultant material. vPET is completely clear and transparent in colour and can be dyed using Pantone standards while rPET is not, and therefore, regular colour standards are not appropriate.
  - This requires new colour standards based upon different feedstocks. Through rigorous research and development, Waste2Wear® developed a library to ensure that that colour standards could be achieved constantly (Masson and Garza 2018)

- **Logistics—Supply chain management**
  - The management of different sources of feedstock, virgin and recycled effectively requires the management of bigger volumes of inventory, two separate supply chains, increased investment in working capital, logistical issue resolution, and separate management of small production lots. This was especially problematic when recycled materials were initially introduced to the market, as material volumes were generally too low to justify an increase in effort.

- **Logistics—Lack of appropriate infrastructure**
  - In many countries, the waste management systems are not developed enough and there is an inefficiency and scarcity of recycling facilities and proper waste management options. This prevents plastic waste from entering the recycling value chain, and it simply enters the environment. This can be due to a lack of interest and funds from both local authorities and governments.

- **Yarn properties—Yarn strength**
  - Initially, thread produced from rPET had more filament breaking points and it was difficult to produce continuous filament fibres. This was not a problem when the yarn was intended for the production of nonwoven fabrics (used as thermal insulation or in construction applications), or for polyester staple, but was a significant issue when producing continuous filament, especially smaller yarn diameters.
  - This required improved technical solutions and extensive research and development. High twisting and high-level feedstock selection are a solution as well as the use of technical finishes in some fibre blends to improve strength.

- **Yarn properties—Colouration**
  - There are limitations in relation to printing. Some prints require the base to be optical white; however, this is not an option with rPET fabric.

 – Waste2Wear® recognized that pre-bleaching might achieve this, but the high environmental impact of the process meant it was not an option for them (Masson and Garza 2018).

- **Yarn properties—Melting point**
 – The melting point of rPET compared to vPET is slightly lower. This can be a problem for heat printing or other heat-dependent processes.
- **Consumer—Lack of awareness**
 – Consumer awareness of the plastic content in their own garments varies significantly, and many are not aware that rPET is an option, as such the question of buying recycled materials is not even considered.
 – However, plastic pollution awareness is gaining momentum and mind-sets are changing, and due to new and global attention, the demand is growing enormously. The sentiment towards recycled polyester is changing, and millennials are more likely to make sustainable choices and pay a slightly higher price. This means that there is a clear trend for young generations to choose a recycled product with a story than a traditional cheaper one with a negative environmental impact.
- **Consumer—Market and consumer acceptance**
 – The initial perception of recycled material was that it was a lower quality product, obtained from waste, and often customers expected a reduced price. Education and culture are also important factors. In many societies, recycled items are still associated with 'old and dirty' goods. There is a fear of safety and health hazards, or concern for other negative side effects or the possibility of dangerous chemical contents.
 – This prejudice is diminishing, largely due the commitment of sustainable brands and the education of consumers; recycled content can be seen as a benefit in some consumers' categories.
 – Only increasing education can change this, but the textile industry must move forward to become more transparent and bring the right information to the consumers so they are able to make more sustainable choices.
- **Cost**
 – The high costs of waste collection and treatment can result in recycled material being higher than virgin material, especially during periods of deflated oil prices. Brands and consumers are not willing to pay higher prices for recycled material over virgin product.
 – The commitment of brands and consumers is crucial to increase the acceptance of recycled material so that volumes can increase to the point where the value chain of recycled material would spread fixed costs and have comparable costs to the one of virgin material.

- **Legislation**
  - There is a lack of comprehensive regulations based upon clearly defined standards for recycled materials in many countries. This is preventing the transport (using reverse logistics) of recycled feedstock into countries which already have systems in place.
  - Governments must put in place new rules to make sure the international trading of compliant and certified feedstock is not obstructed, while understanding and preventing the risks of improper waste management.
  - More efficient systems with proper governmental support would reduce the costs associated with the recycling process, thus reducing the prices of rPET feedstock which would eventually reflect on the market prices of recycled polyester products.
- **Plastic pollution**
  - Concerns regarding microfibres released into the ocean have been raised, and it has been suggested that the textile industry is a major contributor to the issue of plastic entering the ocean (Ellen Macarthur Foundation 2016), with emission streams occurring during production and during the consumer wear and laundering phases.
  - It is still not clear if microfibres are coming more from virgin or from recycled textile, as there are contradictory studies and a common and accepted basis for the analysis is still missing.

12.5 Current Situation of Post-consumer Garment Collection and Recycling

This section aims to set out the current position of the industry that recycles garments when they come to their perceived end of use. By reviewing the processes and systems used in the collection and recycling of post-consumer garments, it is hoped that this may help further the understandings of the challenges faced and inspire innovation in this sector.

12.5.1 Classifying Waste

Textile waste can be broken down into three distinct streams, all of which differ in source and stage of the garment life cycle, content, and as such, available management options.

- **Post-producer waste**
  - Waste arising at the industrial stage of fabric and apparel manufacturers, e.g. off cuts, end of fabric rolls, production samples, etc.

  - Small amounts are being recycled mechanically, and the remaining amounts are going to incineration or landfill (Domina and Koch 1997; Sule and Bardhan 2001).

- **Pre-consumer waste**
  - Waste arising at the retailer level, e.g. overstocks, overruns, surplus goods, damaged and liquidated product, returns, etc.
  - The reusable portion of pre-consumer waste consists of clothing articles which are new or lightly damaged. These products are sold to traders or donated to charities which also sell to traders and utilize the funds for charitable projects.
  - The damaged products are given to incineration or landfilled, which is around 25% of total pre-consumer waste (Domina et al. 1997; Hawley 2006a, b, 2009, 2011).

- **Post-consumer waste**
  - Waste arising as a result of the consumer from articles that have been used and worn.
  - These are products that are discarded either because they are worn-out, damaged, outgrown, or simply outdated (out of fashion) (Chavan 2014). This accounts for the majority of all textile waste generated (Domina et al. 1997; Hawley 2006b, 2009).

The collection of post-producer and pre-consumer waste is less complicated since the volumes are consolidated at the manufacturing plant or retail shop level. In addition, the composition and the exact properties of the waste are already known to the owner.

In this section, we will focus only on post-consumer waste, as it is the most relevant in terms of volume and the most complicated in terms of collection, sorting, and recycling.

12.5.2 Managing Post-consumer Waste

Globally, it is estimated that only around 20% of post-consumer garments are collected for reuse or recycling through a variety of systems (World Economic Forum 2014). A recent study states that the rate of collection varies immensely among the countries in EU28 as well as in countries worldwide. Germany has a rate of collection of discarded garments of 75%, while in Finland, the collection rate is 35%, and in the US and China, the rates are around 10%. Many countries in Asia and Africa do not have a collection infrastructure at all, which is particularly relevant as these countries receive exports of collected clothes from higher-income countries, thus only slowing down the speed at which they will end up in landfill (Gwozdz et al. 2017) and not avoiding it.

Assuming reused clothes also end up either in landfill or get incinerated in the long-run, only a small fraction is actually recycled back into fibre. This suggests that high-quality recycling options and the flow of garment circulations can offer opportunities for creating value.

12.5.3 From Consumer to Recycle/Reuse: Current Models

There are a number of stages that textiles must undergo the following disposal by the consumer, to eventually be reused or recycled. Figure 12.4 identifies these stages and demonstrates the respective pathways followed by textiles at 'end of life' that are alternatives to disposal in landfill.

12.5.3.1 Collection

The collection process is the first step in giving unwanted textiles the opportunity for a second life. Collection is performed via several different approaches depending on the country legislative requirements and the market value of the collected goods. Historically, collection was based merely on charity donations and textile bank collections; however, due to the increasing economic value of textile, waste the collection methods have become more innovative. These include the following collection methods:

Fig. 12.4 Overview of the current post-consumer processes (illustration by the authors)

- **Residential waste system**: Many consumers throw clothing waste into their household waste bin. This is collected by their local council or waste management company and sorted at local facilities. Textile fractions are separated and processed separately; however, most of the textiles are contaminated with soil and other debris and thus have limited value (Morley et al. 2006; Hayley 2009).
- **Local authority collection**: These schemes are led by a city or a public institution who install collection points (banks) and then sell the collected product to a textile waste processor. This is becoming more popular as more and more local authorities have discovered the sale of used clothing and textile waste as easy additional financial income.
- **Charity collections**: Charitable organizations install collection banks or points (e.g. charity shop, recycling centres) where consumers donate unwanted textile waste. The charity organizations take out a minimal fraction of the donated goods that can be resold or can be given to their constituents in need. The leftover is then sold on the used clothing market.
- **Donations to a charity shop**: Unwanted textile garments and shoes are donated to a charity shop. The goods are initially offered for sale in the shop. After a specified time, all garments that are unsold are packed together and sold to a sorting facility (Hawley 2006b; Morley et al. 2006; Ekstrom et al. 2016).
- **Commercial collections**: Metal collection boxes are placed at the roadside by a commercial collector. Used clothing is deposited into the banks, which is then collected and brought to a consolidation warehouse, and the goods then are transported to a sorting facility (Sinha and Sissamayake 2009; Meginnis 2012).
- **Cash4Clothes collections**: Textile and apparel waste is brought to a collection shop where the goods are inspected and a price is estimated based on the value of reuse quality. After paying out cash on the spot, the goods are sent to a sorting facility.
- **Door2Door collections** (also called household collection schemes): After distribution of flyers informing the residents when and where to put their unwanted clothing and shoes, donations are collected and brought to a warehouse; from there, the goods are transported to a sorting facility.
- **Take-back collection**: In the last decade, a new textile waste collection scheme has grown in occurrence; used clothing and shoes are collection at the point of sale, by means of a take-back system for retailers or brands for their products at their stores. This concept practises the concept of Extended Producer Responsibility by manufacturers and retail brands (Schroder et al. 2013; Ekstrom and Salomonson 2014).
- **Direct collection via Internet in partnership with a parcel service provider**: The consumer registers online for collection of a box or bag of textile and shoe waste. A parcel transportation company collects the box or bag of used clothing and brings it to a consolidation point from where it is sent to the sorting facility. The logistics behind this concept is similar to the Door2Door collection scheme (PACK MEE 2013).

12.5.3.2 Sale to Sorter

Regardless of the method of collection, all collected textiles are sold to a sorter or processor of textile waste. The collection scheme and the geographic collection area are important factors that often influence the quality of the collected textile waste and thus the onward market value.

12.5.3.3 Sorting Process

Sorting techniques are mainly focused on the rewear potential of clothing waste, as it is the most economically valuable and forms the basis of the used clothing processors business model.

The sorting process of textile waste consists of 'number of touches', meaning how often one item gets touched and evaluated during the process. Usually, there are two to three touches depending on the sorting system.

After the arrival of the collected textile waste at the sorting facility, the first process is the unloading of the goods, during which easy detectable fractions, such as shoes, blankets, pillows, and electronic waste, are extracted.

The pre-sorting is the first touch by the sorting personnel, and the main aim during this process is to separate the used clothing waste into clothing type categories or 'groups' as well as to further extract contaminants such as household garbage, electronic waste, and paper.

After the pre-sorting, each group goes to a unit that is specially trained to process that group in the 'fine-sorting' process. Here, the clothing is further classified according its quality and saleability for export to developing countries. Not only the clothing's physical shape, but also fashion trends and branding are taken into consideration when sorting the wearable part.

12.5.3.4 Fates of Rewearable Articles

Around 61% of sorted textiles are 'high-end' or 'middle-end' and are suitable for rewear. These garments generate 96% of the total value, being sold to developing countries as second-hand clothing.

'High-end' defines the clothing which is in a very good shape and represents around 13% (Thompson et al. 2012). These garments are mostly sold to countries of Eastern Europe; countries of CIS, Balkan, and some of the Countries in the near East.

'Middle-end' defines the clothing which is seemingly worn and accounts for 48%. These garments are sold to developing countries such as Africa and Latin and South America.

12.5.3.5 Fates of Non-wearable Waste

The remaining 40% is non-wearable, and while representing a substantial amount of the total volume of collected textiles, this remaining ‘low-end’ volume waste generates only around 3–4% of the value. The primary reason for the low value is the lack of profitable markets in recycling. However, this accounts for a sizeable volume, and with further innovations and developments in closed-loop recycling technologies, this could be the basis for secondary raw material, and hence, its value could increase.

All non-wearable articles, depending on the fibre properties and potential of material recovery based on available technology are; downcycled into wipers, recycled into fibres, or are treated as waste and either incinerated or sent to landfill.

Articles that are made of absorbent fibres such as cotton fabric are repurposed as wipers. Similarly, textile products with oleophilic properties are used as wipers in heavy industry for oily spills. These items are pressed by the sorter and shipped to a cutting facility, where the pieces of clothing are cut into pieces of cloth.

Many textile articles are made from materials that are suitable for pulling or re-opening back into a fibrous form (Wang 2006). These fibres can then be:

- **recycled** for reuse in the textile industry in the production of new textile yarns and fabric (which can be characterized as closed-loop recycling)
- **downcycled** into a lower value product and used in a number of applications including:
  - construction into nonwoven textiles and used as insulation material in the automotive industry, construction industry, stuffing, carpet underlay, roofing felt, and low-end blankets
  - in the production of paper
  - as concrete and soil reinforcement.

For both recycling and downcycling streams, the fabric is broken down back into fibre through a series of mechanical processes. Following cutting of the garments into smaller pieces, an opening machine which is equipped with toothed cylinders tears the fabric and comb yarns and fibres out of the pieces. As the material proceeds through the different sections of the opening machine, the teeth on the cylinders become more numerous and finer. In this way also, fibres can be combed out of the yarns. In general, a good result can be obtained when the input of textile waste is quite homogeneous in terms of structure. That is why the recycling of jeans is relatively popular.

At every section of the opening machine, air is blown through the textile mass in order to remove dust and very fine and short fibres. In each of the sections of the opening machine, there is an option to remove heavier parts (pieces of fabric, but also non-textile parts like buttons and zippers, etc.). The textile parts are fed again in the machine (by air suction), and so, nearly all the textile can be processed into fibres.

12.5.4 Evaluation of the Current System

One of the limitations of the current system is that though hugely inefficient, most textile sorting is carried out by hand, meaning that someone must touch and visually inspect every item. Traditionally, textile sorting has been done manually because of the complex sorting criteria that exist. In the last 10–15 years, the sorters have tried to automate these processes, in particularly transportation within the sorting plant. The reason for a push towards automation is to increase productivity and lower costs. The Dutch machine manufacturer 'Valvan' is the leader in selling automated transportation lines for used clothing sorting lines. However, the past developments have shown that currently, no computerized clothing sorting does and can exist, since the multi-dimensional and creative thinking of a person in a sorting process cannot be replicated, i.e. a computerized system cannot perform extraction of good, very good, and average wearable piece of clothing for reuse.

Large challenges also exist because of the gap between the traditional sorting systems (which centre on sorting by garment type and detecting the valuable wearable part of the textile waste) and the need for material-type oriented textile sorting. A switch to material-type sorting could enable the extraction of used clothing consisting of a certain fibre type which is essential in order to reach closed-loop recycling system and could be covered by an automated sorting process, removing the laborious hand sorting process and opening up more avenues for recycling.

Finally, the current system is still very open loop and does not align with ambitious circular economy principles and practices. Even the rewearable articles will eventually become non-wearable waste, and the likelihood is that this will occur in countries where a proper waste management system is not in place, and so, these items will be landfilled or incinerated. The proportion which is used as wipers or downcycled will also be landfilled or incinerated after one use. It is thus extremely important to find closed-loop solutions to maximize the potential of textile waste and to try to generate additional economic value from the materials.

12.6 Future Innovations—Closing the Loop for the Textile and Fashion Industry

Recycling operators ensure the sustainable management of waste resources (new textile production, plastic synthesis etc.). But their operations are complex, require very specific waste material (sometimes only red cotton or specific mix of polyesters, granulation) which are free from all externalities (button, zippers etc.) and in sufficient quantity. These operations are referred to "prepare for recycling". This obliges the brands and retailers to ensure the material composition and cleanliness of the textile waste before delivering it to the recycling operators. For brands to implement this is too expensive and inefficient. The existing textile waste processors, such as big sorters, jobbers and/or charitable organisations cannot help to overcome these challenges. They either focused merely on second hand or discount stock trade or cannot process large volumes. As things are today, brands, retailers and recycling operators are held back in the process of a circular development with three needs to be tackled: i) the waste volume consolidation (ensuring enough quantity of waste textile in the same place); ii) the technical know-how to ensure adequate feedstock to recycling operators and; iii) the need for cost efficient prepare for recycling infrastructures to guarantee sufficient specific raw material feedstocks to recycling operators. The ability of this industry to evolve from a linear economic model to a circular version, whereby textiles are reused or recycled as opposed to destroyed, is underway, and the processes currently used to achieve this have been outlined in the previous section. However, it has been established that the system has short comings and is nowhere near as evolved as it will need to become in order to achieve full circularity. The requirement for innovation is significant, and new drivers are likely to be required for change to expedite the process; these will now be discussed in more detail.

12.6.1 New Targets for Post-consumer Textile Waste Collection in Europe

Textiles and clothing are a fundamental part of everyday life and an important sector in the global economy. It is hard to imagine a world without textiles. Unfortunately, the current system for producing, distributing, and using clothing operates in an almost completely linear way (Ellen MacArthur Foundation 2017). Less than 1% of material used to produce clothing is recycled into new clothing (Wicker 2016), representing a loss of more than USD 100 billion worth of materials each year (Global TEX Associates Ltd. 2016).

In fact, the current scientific literature seems to have difficulties even to state a more or less accurate occurrence of textile waste not only globally, across the EU, but also on a national level. The main reasons are the poor quality and quantity of available data (Thompson et al. 2012). Comprehensive, detailed, and reliable data for textile waste generation, collection, and management in Europe is not readily available from central data sources such as Eurostat, which only provides some production waste date which is only a small fraction of the much larger post-use waste category.

Globally, the USD 1.3 trillion clothing industry employs more than 300 million people along the value chain. Clothing represents more than 60% of the total textiles used and is expected to remain the largest application. Within such an economic context, it is clear that a potentially huge positive impact exists for a larger adoption of textile recycling. The recent 'Pulse of the fashion industry' report estimated that the overall benefit to the world economy could be about EUR 160 billion (USD 192 billion) in 2030 if the fashion industry were to address the environmental and societal fallout of the current status quo (Global Fashion Agenda and Boston Consulting Group 2017).

As the negative effects of a linear value chain appear more and more evident, there is a growing case for radically improving recycling to allow the industry to capture the value of the materials in clothes that can no longer be used. Increasing recycling represents an opportunity for the industry to capture some of the value in more than USD 100 billion worth of materials lost from the system every year, as well as to reduce the negative impacts of their disposal (Ellen MacArthur Foundation 2016).

Nevertheless, there is still a large percentage of textile waste going to landfill and not to recyclers. Primary reasons being the lack of highly profitable textile recycling business models and the lack of information on consumer level, who are still throwing their textile waste into household waste bin. Across the industry, only 13% of the total material input is in some way recycled after clothing use. Most of this recycling consists of cascading to other industries and use in lower-value applications, for example, insulation material, wiping cloths, and mattress stuffing—all of which are currently difficult to recapture and therefore likely constitute the final use (Watson and Palm 2016).

In Europe, the 2008 Waste Framework Directive (EUR-Lex Access to European Law 2008) sets the overarching legislative framework to sustain the increase of textile recycling. It defines the main concepts linked to waste management, including the ‘polluter pays principle’ (ensuring that the costs of preventing, controlling, and cleaning up pollution are reflected in the cost of goods), the ‘waste hierarchy’ (a priority order set among waste prevention and management options), and the ‘end-of-waste status’ (i.e. when waste ceases to be waste after recovery). The Directive sets binding targets to be achieved by 2020: preparing for reuse and recycling of 50% of certain waste materials from households and similar sources and preparing for reuse, recycling, and other recovery of 70% of construction and demolition waste (EUR-Lex Access to European Law 2008).

The European Clothing Action Plan (ECAP 2019) has the overall aim of reducing clothing waste across Europe and embedding a circular economy approach into Europeans’ provision, access to and consumption of clothing. However, these policies are only at the beginning and need to move further towards an extended producer responsibility regulation (EPR).

12.6.2 New Approaches to Improve Recyclability—From Eco-design to Innovative Collection Schemes

Tackling the existing recyclability issue of textile waste requires clearly a multi-dimensional approach, whose major sustaining elements reside in the improvement of eco-design, waste collection, and recycling technologies.

Currently, many terms are used in the eco-design area. Such terms as design for environment (DfE), green design and sustainable design or just eco-design have a slightly different meaning (Brezet and Hemel 1998; Fuad-Luke 2002; Simon et al. 1998):

- **Eco-design** is a design process that considers the environmental impact associated with a product throughout its entire life from raw materials through production and use to the end of its life. Eco-design aims to reduce environmental impact and seeks, at the same time, to improve the aesthetic and functional aspects of the product. It also includes the consideration of social and ethical needs.
- **Design for environment** (DfE) is the analysis of the environmental, health, and safety issues relevant to the entire life of the product. The idea is to reduce resource depletion and waste during the manufacture, use and disposal or reuse of the product. DfE is a synonym for eco-design, but it can also refer to certain environmental benefits of a product, such as 'Design for recycling' or 'Design for Disassembly'. In this case, DfE is a sub-concept of eco-design.
- **Sustainable product design** is a design philosophy and practice in which products contribute to social and economic well-being, have negligible impacts on the environment, and can be produced from a sustainable resource base. This is the widest concept of eco-terms.

If considered from an overall environmental footprint perspective, the eco-design area aims to improve the energy efficiency and resource effectiveness (closing the material loop) of textile products by implementing various strategies, such as dematerialization or multi-functionality. In fact, from a marketing perspective, the current Eco-design Directive set by the European Union (EU) can be extended to cover design, in terms of both scope and markets covered (from energy-related products to all products and services).

These products are focused towards limited usage of energy, reduced CO_2 emissions, minimized negative environmental impact through energy focus (De Groene Zaak and Ethica 2015), considering the fact that the product design and development play a significant role in determining the environmental impact of textiles (accounting for nearly 80% of the total) during various life cycle stages (Norden 2015). Such eco-design principles include not only the choice of the material but also the functionality of the product throughout the life cycle (affecting the environment in terms of water and energy consumption). In practice, many forerunner companies have started working beyond eco-design by embracing circular design principles, aimed to go beyond reducing the negative environmental impacts and succeed in creating a positive regenerative impact.

At the opposite end of the textile value chain, but strictly linked also to design of products, is another of the key current issues hindering the widespread acceptance of recycling: collection. In fact, the collection process is the first step in giving unwanted shoes and clothes the opportunity for a second life. Closed-loop recycling starts here, and there are several different approaches, depending on the country legislative requirements and the market value of the collected goods, since the cost of collection differs with each scheme.

The gathering and repossession of textile waste material are the key issues for the textile industry globally. In the past, the collection was based merely on charity donations and textile bank collections. Due to the increased economic value of textile waste, the collection methods have become more innovative (Schröder et al. 2013; SOEX 2018).

Obviously, both eco-design (at the beginning of the textile value chain) and collection (at its end) are but preparatory steps to the core step for re-evaluation of waste, that is, recycling. In the following sub-sections, an overview will be provided about innovative technologies by different types of fibres to be recycled.

12.7 Innovation in Recycling Technologies: How Fibre Types Affects the 'Take-Make-Dispose' Linear Approach

As already stated several times in the previous sections, textile recycling and clothing recycling are potentially beneficial activities from environmental, social, and economic points of view, as opposed to landfilling or being used for energy. In fact, the primary source of raw material for synthetic polymers is petroleum, and even for renewable natural fibres such as cotton, the production requires energy and chemicals that are based on non-renewable resources.

Typically, technologies for reprocessing are categorized as either primary, secondary, tertiary, or quaternary. They are undertaken as follows:

- Primary approaches involve recycling industrial scrap.
- Secondary recycling involves mechanical processing of a post-consumer product.
- Tertiary recycling involves processes such as pyrolysis and hydrolysis, which convert the plastic wastes into basic chemicals, monomers, or fuels.
- Quaternary recycling refers to burning the fibrous solid waste and utilizing the heat generated.

All these approaches currently exist for fibre recycling (Wang 2006), but the most interesting ones for real value saving in the textile chain are still in the initial stages of their industrial development.

If we look at the current worldwide picture, no clothing-to-clothing recycling operations exist at really large scale (Ellen MacArthur Foundation 2017). In fact, while textile recycling has been in operation for at least 250 years (Fletcher 2014), recycling technologies still have significant limitations. Most of the fibrous waste is composed of natural and synthetic polymeric materials such as cotton, wool, silk, polyester, polyamide, and polypropylene. Frequently, different types of polymers and other materials are integrated to form an article, such as blended textiles, carpet, conveyer belts, composites, to name a few. This clearly means that no single solution can solve the recyclability issue for textile, while a correct 'merging' and large-scale adoption of multiple technologies can be the only feasible path.

Polycondensates, which include polyesters, polyamides and polyurethanes, are well-suited for depolymerization (Aguado et al. 2011). The group of polycondensates more often used in the textile industry are polyesters, polyamides (nylon), and polyurethanes (Lycra or Spandex). All these polymers share the property that their polymerization is a condensation reaction, i.e. the formation of the chemical bond holding together two fragments is accompanied by the release of a small molecule, often water but also solvent. These bonds are typically ester bonds in polyesters, carbamate or urethane in polyurethanes, and amide bonds in polyamides. Condensation reactions are reversible; in particular conditions, these bonds can be broken exactly where they were formed and 'add back' the small molecule to return to the starting material. After breaking the polymer, the monomers are separated from the contaminants such as other materials, colourants, or additives in general. The recovered monomers are then suitable to produce new polymer via a new polymerization reaction. The cycle depolymerization/repolymerization can be potentially repeated indefinitely.

For most of the major fibres used in the existing production, several different approaches are currently being investigated for effective recycling and this chapter cannot be exhaustive in examining all of them. On the contrary, the aim is to provide an overview of the most promising ones, while highlighting the corresponding opportunities.

12.7.1 Polyester: Emerging Chemical Recycling Technologies

PET is a significant material in the global economy and makes up about 18% of global polymer production. Approximately, 65–70% of the PET produced is used for textile applications, the recycling of which is much more challenging (with respect to packaging products) using traditional mechanical recycling technologies. This is due to the complexity of textile products, which often contain a blend of fibre types as well as an assortment of chemicals used for backings, surface treatments, dyes, and pigments. As a result, PET textiles are often 'downcycled' into lower-value products or end up in landfills or incinerators.

The 'closed-loop' recycling approach is to recover the raw material that was used to produce a polymer product and then reprocess it into the same product of equivalent quality as that from virgin material. However, it must be realized that manufacturing polymer products require not only raw material (e.g. petroleum) but also energy for the production process. The combination of the two parts (raw material and energy for conversion) represents the energy content of a material. For many polymers, the energy equivalent for raw material is relatively low compared with energy required for conversion (McCrum et al. 1997). The recycling process itself involves not only pollution but also energy, which can be quite significant even for single polymers but especially for polymers that are integrated with other materials.

For these reasons, in the past, chemical recycling technologies for PET have struggled to become commercially viable, obviously also because of their higher capital and operating costs relative to mechanical recycling, lack of enough feedstock volumes to achieve economies of scale, and low prices for virgin materials, creating a weak market for recycled monomers or other outputs from chemical recycling facilities.

Fortunately, the last few years have seen the strong (and parallel) emergence of new chemical recycling technologies (DEMETO 2017; Carbios 2016) coming to the market at various stages of development and having the potential to disrupt the material economy for PET textiles.

As polyester is the highest volume polycondensate on the market, it is not surprising that depolymerization of this polymer has received significant attention from the industry. Polyester can be depolymerized using different kinds of reactions, with chemical catalysts or via enzymatic reactions, and several processes have been proposed in an industrial context, while most are still at laboratory level or pilot plant.

The major players working on chemical recycling of this type of material can be distinguished referring to the groups outlined in Fig. 12.5.

- Glycolysis:

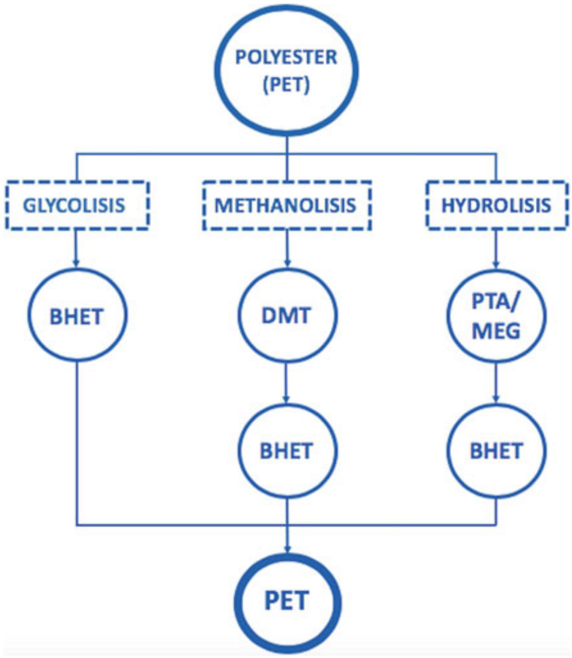

Fig. 12.5 'Paths' that can be followed to depolymerize/repolymerize PET/polyester (illustration by the authors)

  – Ioniqua (NL). Based on the usage of a so-called Ioniq Liquid (containing ferromagnetic nanoparticles), Ionica proposes the usage of a standard glycolysis reaction, where contaminants are eliminated during purification thanks to the properties of this unique solution and the application of magnetic fields. With a 3–4 h reaction time and a target feedstock cleanliness higher than 95%, the company is finalizing the construction of the demonstration plant and aims to reach commercial stage by 2020 with a 200 ktons/year productivity.

- Hydrolysis:

  – Carbios (FR). Established in 2011 as French public company, Carbios approach to PET depolymerization is quite peculiar, since they implement an enzymatic hydrolysis, where genetically engineered microorganisms produce enzymes that degrade PET. Their process is characterized by a pre-treatment of the polymer, while the enzymes can be used for more than one cycle before needing substitution. With a target 93–97% purification of the monomers, they plan to have the first demonstration plant (2–10 tons/day) ready by 2021.
  – Gr3n (CH)—DEMETO. Based on the patent of the Swiss company gr3n and engineering through the support of the Horizon 2020 programme, the DEMETO process implements hydrolysis of PET in basic conditions, but with the usage of microwave radiation as accelerant of the depolymerization process, the purification process then integrates a Chlor-Alkali unit to fully recover internally the NaOH and HCl flows needed. Aiming at virgin-grade purity of monomers and with a strong robustness to feedstock contaminants, the DEMETO demonstration plant (60 kg/h) will go online in Q4 2019.

- Methanolysis:

  – Loop Industries (US). Purchasing a patent from Prof. Hatem Essaddam in October 2014, this American company implements a process where the polymer is swelled using a chlorinated solvent before undergoing a typical depolymerization process; originally, they used water as reactant (hydrolysis) but only recently moved to Methanolysis (Loop Industries Inc. 2018). A demonstration plant (100 kg/h productivity) was installed in 2016, while the first commercial plant is expected for Q2 2020.

12.7.2 Polyamide: Existing Examples

Polyamides (PAs) are widely used in many engineering applications due to their very interesting mechanical properties and ease of processing, as they allow the injection of thick components with complex geometries (Naveau et al. 2011). As reported in the literature, PA6 is an important engineering material which exhibits excellent mechanical properties, chemical resistance, wear resistance, dimensional stability, low friction, etc. (Laredo et al. 2003). For these reasons, it is one of the most often used engineering fibres, due to its good mechanical (strength, hardness, toughness, damping) and tribological (sliding, wearing resistance) properties (Kohan 1995). Hence, it has found various applications in industrial and domestic sectors, such as transport, aviation, sealing, and coating.

PA6 fibres are tough, possessing high tensile strength, as well as elasticity and lustre. These are wrinkle proof and highly resistant to abrasion and chemicals such as acids and alkalis. The fibres can absorb up to 2.4% of water, although this lowers tensile strength.

Reusing and recycling PA6 from waste can be achieved in different ways, including: (i) depolymerization of PA6 chains into their monomers or oligomers (Moran 1994; Sifniades et al. 1997), (ii) extraction and separation of polymeric components without significant degradation (Subramanian 1995; Stefandl 1998), and (iii) melt compounding of the waste stream with additives and modifiers (Kotlair and Fountain 1997; Young et al. 1999).

Unfortunately, the same properties that make it so useful in products are also causing large environmental consequences. In fact, nylon does not break down easily and accounts for about 10% of the debris in the ocean. According to the World Society for the Protection of Animals, more than 600,000 tons of fishing gear is dumped into oceans every year, including nylon nets. Fishermen often discard the nets because the alternative is paying someone to dispose of them properly.

Nylon is not just found in fishing nets. It is also in clothing, carpets, and packaging. It was first introduced at the New York World's Fair in 1939 in the form of women's tights, but the fibre really took off after Second World War. Before 1945, fibres like cotton and wool dominated the apparel market; however, post-war synthetic fibres like nylon had risen to around 25% of the market share due to applications in military supplies such as parachutes, ropes, tents, and uniforms.

Contamination is another concern. Unlike metals and glass, which are melted at high temperatures, nylon is melted at lower temperatures, meaning some contaminants—non-recyclable materials and microbes or bacteria—can survive. Therefore, all nylon waste must be cleaned thoroughly before the recycling process.

When looking at industrial solutions to recycle effectively this synthetic fibre, one company name stands clearly and at large distance: Aquafil, already leading manufacturer of Nylon, and its ECONYL® product. In 2007, they began developing a machine that can churn through most kinds of nylons, producing new threads ready to be repurposed. The commissioning of ECONYL® back in 2012 marked the activation of a 'closed cycle' that recovers products made from polyamide-6, which have reached the end of their life and can be regenerated into a more sustainable raw material without compromising the quality of the end products.

In terms of life cycle environmental footprint, a filament of ECONYL® generates 50% less greenhouse gas emissions than an equivalent petrochemical filament (for every 10,000 tons of raw materials recycled into ECONYL®, 70,000 barrels of crude oil are saved, and 57,000 tons of CO_2 emissions are avoided compared to traditional production methods), guaranteeing on the other hand the same exact technical and functional characteristics. In fact, ECONYL® is a form of nylon that is made entirely from waste products. It is made from a range of post-consumer waste including abandoned fishing nets, carpets and rigid textiles and aims to be a green alternative to the original product which is made from a derivative of oil.

To produce ECONYL®, waste products such as reclaimed fishing nets are first taken to pre-treatment facilities where they are sorted and shredded into pieces small enough to be put through the ECONYL process. The shredded material is then moved to a regeneration plant where they are put into huge chemical reactors that, through a process of de and repolymerization, break down the components of the material and regenerate the PA6. The final product is then processed into yarn.

12.7.3 Cotton: Existing Examples

Cotton is by far the world's most popular natural fibre, and much of it is used for clothing. No doubt, it would be ideal if all those cotton clothes could simply be recycled into new garments when their time was up. It would keep millions of tons of waste out of landfills and allow the fashion industry to use far less virgin material, in turn cutting use of water, pesticides, and chemicals for dyeing, for an on overall much reduced environmental footprint.

Unfortunately, recycling cotton clothes are not simple. To create a new piece of clothing from old clothes, the old ones first must be shredded and turned back into raw material. However, the shredding process tends to lower the cotton's quality because it shortens the staple length of the fibres. Staple length plays an important role in determining the strength and softness of cotton threads. The longer the staple, the better these characteristics, which is why cotton varieties with extra-long staple lengths, such as Supima, are highly valued—and why fashion brands currently find it difficult to use any large amount of recycled cotton in their products.

For cotton, recycled fibres and yarns made from post-consumer sources are already available in the market. However, examples of these fibres in retail are more the exception than the rule, with most coming from recycled denim at places like Asos, Mud Jeans, Blueloop, Lindex, and H&M Group. In fact, looking at the quantitative figures obtained by the FIBRESORT project (Interreg 2018), Circle Economy has found that upward of 15% of all collected post-consumers textile is recyclable grade, mono-material, with more than 80% cotton, which is suitable for mechanical recycling into new textiles. With global collected volumes of more than 12 million tons per year, this suggests there are sufficient quantities of feedstock available.

From a technological point of view, recycled cotton may have its limitations and challenges, and there are certainly still challenges around quality and chemical safety that must be addressed, but the potential these fibres have for lessening fashion's impact on the environment is worth taking note of. In fact, Textile Exchange (Textile Exchange 2017) has been able to compile an extensive list of relevant companies that are trying to propose their approach as the most adequate for cotton recycling:

- Evrnu. Their approach is based upon the purification of cotton garment waste, converting it to a pulp to then extrude it for the creation of premium textiles. In fact, this process is conceived to create fibres with a wide range of properties and shapes. Overall, the objective of this American company is regenerating cotton waste to create high-level, renewable fibre for apparel, home, and industrial applications, by using chemical post-consumer cotton recycling. The technology is currently at pre-commercial stage, with prototype garments produced.

- Re:newcell. Born and supported in Sweden, this company has a textile recycling technology that can transform a large quantity of the cellulosic part of fabrics into high-quality recycled dissolving pulp; the strength of this approach is that it does not use harmful and environmentally impacting chemicals. Overall, the re:newcell pulp can be fed into the commercial textile production chain, and it has reached operational stage since 2017.
- Recover®. The approach of this Spanish company is based on mechanical recycling, used to produce cotton yarns from post-consumer textile waste; their mission is to help facilitate closed-loop manufacture and a zero-waste industry. Recover® is known for offering the finest gauges, consistent quality, and precise colour control. Recover® cotton is blended into accurate colours lot to lot without any dyestuffs applied to cotton fibre. Recently published LCAs indicate significant water, energy, chemical, and CO_2 savings.
- Refibra™ Tencel. To drive circular economy solutions in the textile industry, Lenzing (Austria) proposes a new lyocell fibre that combines cotton waste in addition to wood pulp to be recycled using Lenzing's pioneering closed-loop production on a commercial scale.
- Worn Again. As a UK-based innovation company, Worn Again has developed a solvent-based recycling technology for separating and recapturing polyester (PET) and cotton from textiles and plastic bottles. The process can separate out dyes, contaminants, and other polymers to produce virgin-equivalent polyester and cellulosic raw materials that are comparable in quality and aim to compete in price with virgin resources. The process can take in pure and blended polyester and cotton textiles (with up to 20% other fibres and contaminants), which means over 75% of all non-rewearable textiles, collected by the end of use collection industry, are suitable as feedstock.

12.8 Brand Perspectives

While we have seen that a number of promising textile recycling methods exist, it is important to consider if and how these have been taken perceived by the textile and clothing industries.

The outdoor industry is a significant user of polyester, with a high percentage of outer layer garments such as jackets and trousers being made from 100% polyester or polyester blends. It is also the dominant fibre used in base and insulation layers, footwear, and accessories such as gloves and hats and is also used as insulating fills in jackets and sleeping bags.

The fibre is used so widely as it possesses a number of performance characteristics that are perfectly suited to outdoor applications and are not readily available from other fibres, namely its lightweight characteristics, with a very favourable strength to weight ratio and natural hydrophobic properties which can be exploited to perform a variety of favourable functions, including quick drying, moisture management, and resistance to ultraviolet radiation. It is also noted for its dimensional stability and easy-care properties (Horrocks and Annand 2000) compared to fibres such as polypropylene which proffer a lower moisture regain, but with a comparably low melting point of 165 °C making laundering more challenging. The low moisture absorbency also makes it an excellent conduit for chemical treatments and finishes (Hallet and Johnston 2014).

However, despite these favourable characteristics, polyester's dependence on natural resources for virgin product production, its inability to biodegrade, and a lack of suitable end of life options are quickly turning what can be a highly suitable functional fibre, into an enemy of the planet. This has led to companies who have high consumption of polyester, such as those in the sporting goods sector and more specifically the outdoor clothing market, having to modify the way they consume PET. The life cycle of a garment is complex, and companies are tackling this challenge at different points of the life cycle, depending on their company's resources and vision. Leaders in this field, such as Vaude and Bergans, are taking the term sustainability and writing it into the core of their manufacturing strategy, from design to fabric choice (Vaude 2018; Bergans of Norway 2018), through to the method of transport into store and how the garments are processes at their end of life. Other brands are making changes at select juncture within their production process, and this included fabric selection and choosing to manufacture using recycled PET.

The climbing and lifestyle brand Patagonia were early adopters of rPET (Patagonia 2019). Their close collaboration with Malden Mills in the early developments of fleece fabric, coupled with their strong environmental policies, positions them well to be a lead-user of fleece in the first instance followed by rPET fibres. Fleece fabric has been a main stay of Patagonia's range since Melinda Chouinard sourced a pile fabric originally intended for toilet seat covers from Malden Mills in 1976 to make test garments from. However, by as early as 1993, Patagonia was taking used PET soda bottles and recycling them for use in their fleece products (Chouinard 2005). Between 1993 and 2003, they diverted eighty million soda bottles from landfill. Patagonia states that on average, it takes twenty-five soda bottles to produce enough rPET yarn to form the fabric for one of their Synchilla fleece garments. Today, recycled PET can be found in their base layers, board shorts, shell fabrics, and fleeces. The feed stocks of rPET have also expanded further to include not only soda bottles, but also their own garment waste and unusable manufacturing waste[64].

The range of companies now using rPET has also expanded significantly. The outdoor industry is a notable user of rPET, and the brands choosing to include it in their ranges are expanding steadily. A growing proportion is also promising to eliminate virgin PET from their ranges all together. Norwegian brand Norrøna currently uses 58% recycled PET, and by 2020, it has pledged to be using 100% rPET (Norrøna 2019). By the market season of 2025, Mammut has targets in place to manufacture apparel, packs, sleeping bags and harnesses using 95% recycled PET, while their footwear range has a target of using 75% rPET (Hollenstein 2018). Vaude points to 90% of their Green Shape Core Collections being produced using either recycled, natural, or biobased fibres (Vaude 2018). Haglofs emphasises a season-by-season increase in the use of rPET in their range. Many of their shell garments utilise rPET, and their insulation materials use post-consumer recycled fill. Similarly, Bergans is increasing their use of rPET in fleece, shell, t-shirts, and insulation pieces (Bergans of Norway 2018).

One of the main barriers to using rPET is cited by a number of companies including Haglofs and Norrøna as relating to the lack of consistent good-quality recycled PET and its supply (Haglöfs 2019; Boren 2018). Outdoor clothing is inextricably linked with the performance and durability of its products, and if they do not achieve those standards, then this has both business and sustainability implication. Norrøna makes the critical point that in terms of sustainability, it is of greater significance that a product has a long life than is made of recycled fibre. If a product is dis-guarded early in its life cycle because the quality of the materials is impaired, then this achieves little for the environment in the long term. However, Norrøna states that 'closing the circle' by recycling the materials they use is their main long-term goal (Boren 2018).

It is therefore seen that improvements in recycling technology and supply have ultimately aided increased adoption rate of recycled PET. Mammut is very clear on this point, stating that 'We are now finding recycled materials that meet our high requirements with regard to quality, performance, functionality and durability' (Hollenstein 2018).

However, it is not only the outdoor industry that is taking drastic steps to increase their rPET usage. Fashion retailer H&M Group is also approaching this challenge head on. At H&M Group, they believe that an industry-wide shift from a linear to a circular business model is the only solution (H&M Group 2017). In a linear model, too many resources go to waste after the products end of life, while in a circular one, resources stay in use for as long as possible before being regenerated into new products and materials, resulting in a reduction in waste and negative impacts. They are approaching this ambition holistically by building circularity into every stage of their value chain, including the products they design and make, the materials and processes they use, and how their customers care for and dispose of our products. To make the business model truly circular, they are also working to use 100% renewable energy in their own operations and to achieve a climate positive value chain.

One specific area where they are heavily engaged is the development of technologies needed to make the recycling of materials into new products fully scalable. They do this in various ways, such as direct investments and participation in research projects. These technologies will be the key to success, and there are many interesting projects for various materials ongoing that we look forward to being industrialized and made available on a commercial scale in the coming years (H&M Group 2017).

12.9 Discussion and Conclusion

There is no doubt that the recycling sector has the potential to make a significant impact on the ability of the textile industry to achieve circularity. However, it remains a challenging arena, both technologically, logistically, and socially.

It is suggested that the textile waste collection industry will need to expand considerably if various innovative models identified are to become economically viable. More participants will be required, and the current operators will need to face competition if the sector is to develop. The requirements for improved sorting techniques are identified throughout this chapter, and a move away from inefficient sorting methods, primarily based on manual sorting, will almost certainly be required.

The answer to the question of whether or not new innovations in textile recycling will contribute to a circular textile economy is almost certainly yes; however, this study has established that is only part of the required changes required and the further changes will be necessary in the sourcing habits of brands, textile producers, and consumers. It is certain that engagement from all along the current supply chain will be needed to drive real change. It is possible that innovation will be required not only in technology, but also in social domains. Changing consumer behaviour is likely to form a major part in the ability of the textile economy to achieve circularity.

Through this chapter, it is hoped that outlining the progress that has been made will provide both greater understanding and inspire innovation in the future. It is recognized that much of this research has originated in Europe and as such, only addresses part of the issue, but while it may have a skewed vantage point of a European perspective, this still offers the opportunity to affect change that can be disseminated throughout the supply chain, which today is certainly a global affair. It is also noted that the sources of a proportion of the industry-related data came directly from the companies themselves and those who are already involved in such projects and as such will come from a defined view.

This study offers an insight into the challenges that are faced by this sector, but it also identifies areas where real change can potentially be made. Suggested considerations for future innovation include advances in technologies that address areas of fibre use other than polyester, cotton, and nylon. New technology in fibre sorting is seen as an area where a significant amount of progress could be made. Similarly, advancement in the development in new materials could supersede many of the challenges that currently require circumnavigating with the reprocessing current fibre types. All of which have the potential to drive significant change.

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Chapter 13
Consumer Engagement and Roles for Sustainable Textiles

Minhaz Uddin Ahmed

Abstract The purposes of this research are to understand the manner of consumer engagement in different phases of textile value chain, to examine if the traditional manner of engagement is detrimental to the sustainability of environment, and to identify those consumer choices that can uphold sustainable textiles. In this qualitative study, the current literature about the consumers' involvements and roles in the textile value chain has been explored. This paper finds that consumers primarily involve in three stages of the textile value chain namely pre-consumption buying decision, in-consumption product care, and post-consumption disposal habits. The study reveals that, in general, the habit of overconsumption, and, in particular, the overconsumption of cheap, low-quality, non-durable fast fashion products distress the environmental sustainability. During consumption, certain ways of washing, drying, and pressing, and after consumption, indiscriminate throwing away of clothing are the other practices that cause depletion of resources and mounting landfills. This research presents the benefits of buying slow fashion products, sustainable ways of product care, and virtuous practices of reuse and recycling. Findings of this study may play a role in promoting sustainable textiles by developing consumer awareness and knowledge.

Keywords Sustainable environment · Consumer behavior · Fast fashion · Overconsumption · Durable textiles · Product care · Product life span · Reuse · Recycling

13.1 Introduction

In 2017, global textile production totaled US$ 746.1 billion, an increase of 4.5% from the previous year (Lu 2018). In the same year, apparels production, the largest application of textiles, amounted to US$ 872.3 billion, whereas global sales of clothing by fashion retailers were a staggering US$ 1391.2 billion (Lu 2018). Historically,

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both the production and consumption of textile commodities have never ceased to grow (Lu 2018). To feed such a gigantic industry, massive amount of resources is required. For instance, textile industry in India, occupying 5.67% of the global market share, consumes 425 million gallons of water per day (Statista 2018). To put this into perspective, just one kilogram of cotton production needs between 5,000 and 10,000 gallons of water. On the other hand, to produce 100 T-shirts, it takes 70,000 gallons of water, 22 lb of fertilizers, 1 lb of pesticides, and 120 lb of fossil fuels (Wallander 2011).

Water, land, fossil fuels, and hundreds of chemicals are to mention just some of the resources that are consumed by the textile sector on a massive scale. However, the enormous pressure on non-renewable resources is not the only adverse effect on the environment caused by textiles. A report by Ellen MacArthur Foundation (2017) reveals that textile industry causes a total of 1.2 billion metric tons of greenhouse gas emission annually that exceeds the combined yearly emission of international flights and maritime shipping. The report also suggests that an annual 500,000 metric tons of plastic microfibers from nylon, acrylic, and polyester enter into the ocean that accounts for 20% of industrial water contamination worldwide (Ellen MacArthur Foundation 2017).

Consumption of resources like water and energy is not just limited to the production phase of textile value chain. Massive amount of water and energy is also required in the use phase of consumers for washing, drying, and pressing. In addition, consumption phase also marks large environmental footprint owing to the release of carbon dioxide, wastewater, waterborne effluents, and microplastics (EPA Victoria 2010). Consumers deteriorate the environmental sustainability further by dumping the landfill with used textiles many of which have never been used or used only once or twice (Laitala 2014). These perfectly reusable or recyclable textiles, occupying more than 5% space in the landfill, are disposed of as solid waste either to be incinerated or to be left out there for hundreds of years to decay (World Wear Project 2019).

Consumption phase occupies an important place in the textile value chain for its potential to influence preceding and subsequent phases. Consumers, with their tastes and preferences, may influence the types of produce retailers and producers prepare for the market. Consumers may also have the option to be eco-friendly by making responsible choices in post-consumption disposal. Therefore, this research seeks the answer to the question of what choices consumers should make at different phases of the consumption namely the pre-consumption buying decision, the manner of product care, and the post-consumption disposal that may improve the sustainability of environment. This qualitative research explores the existing literature on environmental effect of the textile and clothing industry, sustainable ways of consumption and product care, and application of reuse and recycling in textiles. The purpose of this study is to introduce consumers of textiles and clothing with environmental deterioration due to overconsumption, harmful practices of product care, and eco-friendly ways of disposals. The study also aims to improve consumers' awareness and knowledge about reuse and recycling of textiles and how these practices can enhance environmental sustainability.

The remainder of this paper is organized according to the order of consumers' engagement in the textile value chain. Section two identifies the reasons that cause the tendency of overconsumption and how the habit of overconsumption creates a vicious cycle that threatens sustainability. Section three discusses how consumption of durable textiles and clothing can enhance sustainability. Both the sections two and three belong to the pre-consumption choices and buying decisions of consumers that may affect sustainability. Section four discloses the extent of energy and resource consumption during product care activities namely washing, drying, and pressing. Section four also evaluates alternative ways of product care that could economize the consumption of energy and resources. Section five examines the link between the life span of textile products and the practice of disposal. This section also highlights the possible engagements of consumers in prolonging the life span of a product to minimize the level of disposal. Section six talks about different aspects of reuse, an eco-friendly option for disposed clothing. In doing so, the section indicates the benefits, mechanisms, organizational roles, and challenges of reuse. Section seven analyzes recycling, another sustainable treatment of disposed textiles and clothing. This section presents contemporary recycling technologies, collection and sorting techniques for recyclable clothing, and ways to promote recycling in the society.

13.2 Overconsumption

Although clothing is regarded as one of the primary needs of humans in the modern society, the consumption of clothing goes beyond the basic purposes of protection, warmth, and modesty. We also buy clothes for reasons like complying with customs and rituals, presenting ourselves as attractive and desirable, or meeting functional requirements to perform jobs of certain professions. However, we also spend on clothing for reasons whose rationality is hard to comprehend. A recent survey, commissioned by Greenpeace (2017), exposes that, in developed and emerging economies, consumers buy more clothing items than they need. Today, an average consumer buys 60% more clothing than he used to buy 15 years ago (McKinsey 2016). In China, around 40% consumers are identified as excessive shoppers who buy as frequently as once a week or more purely out of compulsion. High-income women in their twenties and thirties are the most vulnerable group among the heavy shoppers. Most of the excessive shoppers report that they buy not really for fulfilling a basic need. They buy because they feel that more items of latest trend in their possessions can make them recognized, confident, and happy. Greenpeace (2017) reveals that brand new clothes with hangtags stay untouched in the closet for years. Many view shopping as leisure activity and engage in shopping for shopping's sake only. Many consumers are addicted for shopping, while others adopt shopping as a means for changing a bad mood (Elliott 1994). Still many see shopping as a means to show off one's wealth or strengthen one's self-esteem (Elliott 1994).

The rise of social media and its merger with e-commerce, among other reasons, have escalated the habit of overconsumption (Greenpeace 2017). In their social media accounts, consumers enjoy browsing fashion blogs, and posts of friends and celebrities. While it is already hard to resist the peer pressure and celebrity endorsement, ease and convenience of online shops and payment apps have made people very susceptible to overconsumption. There are even instances where people buys clothes or other merchandise online for no reason other than enjoying the excitement and novelty offered by the new world of technology (Fibre2Fashion 2018). Moreover, bargains, sales promotions, special discounts on shopping festivals, and free delivery are also causing shopping binge.

However, the survey (Greenpeace 2017) finds that the excitement of binge shopping is immediately followed by emotional hangover. Compulsive shoppers, within a day after shopping, feel remorse and shame. Instead of feeling happy, they feel bored and empty and realize that they have been duped by sellers and advertisers. They even tend to hide their purchases from family members to escape blames for wasting money.

The situation aggravates when retailers engage in a fierce battle to trick consumers in buying even more. They manipulate consumers' behavior, cash in on their shopping craze, and rope them into participating shopping deals that are too lucrative to refuse (Fletcher 2014). Eye-catchy advertisements with glamorous models, along with campaigns and activities to promote sales, never stop. Consumers' carts never leave the shops without overabundant goods as a result of pushy and aggressive sales tactics (Zboja et al. 2016). Moreover, various social media, to tap on this new shopping craze, are integrating shopping and payment functions in their platforms (Greenpeace 2017).

Therefore, the practice of overconsumption deteriorates the sustainability of textile industry by overstressing several phases of its value chain namely cultivation and production of raw materials, processing and manufacturing of textile products, transportation and logistics, product care, and disposal (Pookulangara and Shephard 2013; Perry 2018). Fast changing trends in fashion industry, fashion obsolescence, inferior quality, cheap price, pushy sales tactics, self-indulgence in shopping, overconsumption, and overproduction are all interconnected in creating a vicious cycle that deteriorates sustainability of textiles (Elliott 1994; Bhardwaj and Fairhurst 2010; Joy et al. 2012).

13.3 Durable Textiles

Durable textile products do not easily lose their strength, dimension, and appearance under stressful application such as tension, abrasion, friction, and wear (Annis 2012). Durability of textiles depends on fiber characteristics, yarn and fabric geometry, structure, and finishing treatments (Petrulis 2012). Due to having longer lifespan, durable textiles may lessen the frequency of product replacement which, in turn, minimizes the recurrence of shopping and the level of consumption. Therefore, durability should be a desirable quality in clothing and textiles.

Textile science has already advanced sufficiently to offer durable textiles that have both household and commercial applications. The followings enlist the types of fibers, the structure of yarns, the design, structure, and qualities of fabrics that make the end product durable:

- Polymer, polyamide, and acrylic fiber made textiles show higher abrasion resistance than rayon and viscose. Polyamide also has better flexural strength than other fibers such as cellulose acetate (Hicks and Scroggie 1948).
- Yarns with uniform diameter, identical twist, and homogenous blending produce durable fabrics (Petrulis 2012).
- Yarns with higher number of twists have great abrasion resistance capacity (Hicks and Scroggie 1948).
- Air-jet and rotor spun yarns show better abrasion and pilling resistance than ring-card spun yarns (Hunter 2009).
- Denser, tighter, and compact fabrics have higher abrasion resistance and lower propensity to pilling (Tait 1945).
- Fabrics of straight yarns are more durable and abrasion resistant than fabrics of crimped yarns (Backer and Tanenhaus 1951).
- Interlock fabric structure also has higher abrasion resistance and better pilling performance than jersey fabrics (Akaydin and Can 2010).
- Triaxial fabrics have better sheer resistance than biaxial ones (Scardino and Ko 1981).

13.4 Product Care Practices

Generally, the life cycle of a textile product has five major phases namely production of raw materials, processing of the raw materials into a textile product, shipping and transportation to the shopping outlet, use phase by consumers, and disposal. In 2009, a comprehensive study on the resource consumption and the environmental impact linked with the use phase of a garment's life cycle was conducted by Environment Protection Authority (EPA) Victoria (2010) and City West Water in Australia. The study shows that, at the use phase, the impact on the environment due to water consumption, energy consumption, greenhouse gas emission, and fossil fuel depletion is the highest. The study also finds that the total water consumption within the use phase of a cloth is linked with a number of phases of its life cycle such as manufacturing of detergent, manufacturing of detergent packaging, manufacturing of washing machine, and, of course, the use of washing machine for the actual wash.

EPA Victoria (2010) estimates that, to have one kilogram of clean dry clothes, 30.4 L of water is required of which 91.1% water consumption is attributed to a cold wash at 20 °C in the washing machine. In the report, investigation on the energy consumption at the use phase reveals that, alongside 27.9 L of water, 1506 kJ of energy is used for washing that reaches to a whopping 10,788 kJ in case of using an electric drying (Table 13.1).

Table 13.1 Impact of product care on the environment

Scenario	Impact category					
	Water use (L)	Energy use (kilojoules)	Global warming (kg CO_2)	Eutrophication (g PO_4)	Fossil fuels depletion (kilojoules Surplus)	Mineral depletion (kilojoules Surplus)
Washing machine *without* dryer	27.9	1506	0.15	0.04	96	0.0
Washing machine *with* dryer	29.1	10,788	1.17	0.19	649	0.3

The use of dryer, among the other phases, causes 75% of the total energy consumption, whereas detergent manufacturing, dryer manufacturing, washing machine manufacturing, and operation of washing machine are also attributable to substantial use of energy. The consumption of energy at the washing machine jumps to even higher level when warm water is used for washing. The study also discloses that, for the same base unit of one kg dry clothes, a total of 1.17 kg carbon dioxide is released into the air, 0.19 g of phosphates, along with other solid waste and waterborne effluents, go to the water body, and 649 kJ worth of fossil fuel depletes from the stock.

Therefore, to curb the exorbitant consumption of energy and to mitigate the adverse consequences on the environment, a lot must be done. Many solutions will result from technological innovation that are yet to be developed, while some solutions are already within our reach that only require our awareness and change in attitude. Here are some ideas that can play important roles in mitigating the environmental impact of textiles at the use phase:

- If we can replace the practice of laundering at the household level with laundering at community and commercial level, then significant achievement is possible in economizing the frequency of washing, number of washing machine, and the required amount of detergent, water, and energy (Tritex 2018).
- When there is no alternative for household laundering, at least full capacity of the washing machine should be utilized by filling the machine with adequate amount of washable clothes.
- Warm water wash should be avoided as much as possible. Instructions in the product care label and instruction manual of washing machine may describe cases when warm water application is not necessary (Allwood et al. 2006).
- Innovations in washing machine technology can offer the full benefits and outcome of washing with warm water by using only cold water (Fletcher 2014).
- Technological development can also produce better detergents and other washing agents that eliminate the necessity to use warm water for washing. In addition, concentrated detergents that use fewer chemicals and biodegradable detergents

without any harmful effect on water should replace existing detergents that are not friendly to the environment (Fletcher 2014).

- Innovations in fiber, yarn, and fabric properties that provide stain resistance to the textile products without compromising other desirable qualities should be explored (Fletcher 2014).
- Garments that are designed with stain and odor prone detachable parts like cuffs and collar can play an important role in minimizing the frequency of washing. When only a few parts of a garment are dirty and need only a little amount of water for cleaning, washing the entire garment can be avoided to save water consumption (Fletcher 2014).
- Avoiding the practice of tumble drying can cut down energy consumption at the use phase by 80%. Therefore, drying clothes simply in the open air can mark a great achievement in the direction of sustainable textiles (EPA Victoria 2010).
- Innovations in the wet processing and treatment can develop fabric properties like crease-resistance and wrinkle freeness that can eliminate the use of pressing altogether.

A closer look at the need for cleanliness reveals that cleanliness is not always related with hygiene, but, most often, it is associated with cultural values (Catton 2007). Society perceives lack of cleanliness as a representation of insensitivity, ignorance, and laziness which, in turn, symbolizes manual labor, poverty, and repugnance (Tomes 1997). Therefore, wearing clean, smooth, and new clothes serves the purpose of improving one's social desirability and status. However, our current practice of product care at the use phase is damaging to the ecology, and among all phases in the life cycle of a textile item, the use phase causes the highest impact on the environment due to water use, energy use, global warming potential, and fossil fuel depletion. If a change in cultural value could be made at this level where perception of cleanliness dissociates itself with the demonstration of social status and only associates with hygienic requirements, then society would make a leap forward in the direction of sustainability.

13.5 Product Life Span

International Fair Claims Guide for Consumer Textiles Products, developed by Federal Bureau of Consumer Affairs (2015), Dry cleaning Institute of Australia Ltd, International Fabricare Institute, and other organizations, for the purpose of claim settlements involving damaged textile products, estimates the life expectancy of various textile products. The implication of life expectancy is that during the period of the normal life of a textile product, it would provide the desired serviceability. For example, according to the guide, the serviceability of a woolen trouser for men should last for four years whereas the useful life of a cotton blend shirt should not expire before three years. Although 'the life expectancy chart' provided by the guide may not be taken on an absolute basis as there are multitude of factors (e.g., properties and qualities of the raw materials, wet processing treatments, frequency and intensity of laundering, and other product care methods, weather, etc.) that cause variability in the life span of a textile article, the guide helps a rational perception about how long textile commodities can be used before disposal.

The life span of textile products matters because longer life span means less necessity for replacement that, in turn, reduces the environmental impact causing from production, transportation, and disposal (Cooper et al. 2010). Researchers have found that gender, age group, cause of disposal, construction of the product, and the method of acquisition affect the life span of a textile product (Laitala and Klepp 2015). According to the findings, women dispose of their clothing faster than men do. Garments for teenagers have the shortest life time. Clothing for children is thrown away much earlier than adult's due to the obvious reason of the fast change of size and fit. Socks, stockings, and other intimate garments have the shortest life span among all. Again, there is an array of reasons why we throw away our clothes. When we find a better replacement with improved utility, we stop using our current product. When our product fails due to wear and tear, or stain and other damages, we no longer use it and dispose it off. Change in fashion or boredom with the old style also induces us to buy new clothes (Sego 2010). At times, we clear up our closet for nothing other than freeing up space in the storage (Domina and Koch 2002).

In the USA, an average person throws away 31 kg of clothes per year. In the UK, thrown away clothes amount 18 kg per year, and in Germany, it is 23 kg (Textile Intelligence 2009). Clothing sales have been ever increasing in a parallel fashion with increase in global GDP. However, clothing utilization is not increasing hand in hand with clothing sales. On the contrary, the more people buy clothes, the less they use (Ellen MacArthur Foundation 2017). Study on the underutilization of textile products reveals that 9% of the garments have never been used after purchase and 19% of the garments were used only once or twice (Laitala 2014). Studies also show that unused garments stay inactive in the wardrobes for long time before the owner finally decides to throw them away to clear up the space (Cluver 2008; Smith 2013). In fact, 40% of clothes that are thrown away in the dust bin can perfectly be reused (Morley et al. 2009). Throwing away underutilized clothes cause an annual loss of more than USD 500 billion globally (Ellen MacArthur Foundation 2017). Therefore, there are scopes for changing consumers' behavior so that they can get the full utility of a textile product by prolonging the period of consumption until the end of its lifespan.

Regarding the choice of a particular disposal method, textile consumers exhibit different approaches. Disposal methods of textile products influence the sustainability of environment. According to Waste Framework Directive (European Commission and the Council 2008), the most preferable approach for textile disposal is to delay the disposal or, in other words, to keep using the product as long as possible. The next desirable option is to reuse the product after cleaning, sorting, and repairing. If the disposed product is not suitable for reuse, recycling the waste into a new product is the third alternative. Throwing away the waste to the landfill or incineration are the least desirable options for disposal (DEFRA 2011).

13.6 Reuse

Reuse of clothing and textiles refers to the use of an already used product again by new consumer after the first user discontinues its consumption. The new consumer may acquire the used or second-hand product by means of purchase, gift, or donation. Waste Framework Directive (European Commission and the Council 2008) and the European Union Circular Economy Package (Bourguignon 2016) identify reuse of clothing and textiles as a preferable option to optimize product lifespan. Reuse can yield substantial contribution to the environmental sustainability by reducing tons of textile waste in the landfill. Costs of disposal minimize too as a direct result of reuse. Moreover, extending product longevity through reuse may lower the current volume of production and thus save energy, raw materials, and other resources, and, most importantly, reduce the emissions of greenhouse gases to cut down carbon footprint (EPA Victoria 2010). Besides, consumers can also save money by buying reusable products which are often sold at cheaper price. Finally, reusable clothing can be handcrafted to improve its appeal and value (Fletcher 2014). Organizations like TRAID and Junky Styling are experimenting the restyling and reconstructing the second-hand garments for a value enhanced transformation (Klymkiw 2017).

Instead of dumping reusable garments and other household textile items in the garbage can, consumers may give these away to the charity and second-hand stores or deposit into the collection bins. Collection bins in the neighborhood can be managed by charity organizations, nonprofit organizations, schools, community groups, and local government authorities (Ekstrom and Salomonson 2014). These organizations can also maintain virtual system of collection through their Web sites where people post the list of their reusable materials to be collected from their homes. The items thus collected are assorted in different categories based on the intended use, market segment, and quality. Many charity organizations and retailers are forming cooperation to boost up collections. For example, the charity firm named Myrorna's has made an alliance with the clothing retailer Lindex to encourage customers to hand in unwanted clothes in exchange of discount vouchers usable at the retailer's store (Ekstrom and Salomonson 2014). Charities can also facilitate the export of reusable garments. In Sweden, Denmark, and Finland, more than half of the collected textiles by charities are exported (Tojo et al. 2012). Second-hand garments have already gained a sizable market and demand in the low-income countries through donations and exportation. In Uganda, second-hand garments occupy 81% market share of clothing (TradeMark East Africa 2016).

Apart from charity organizations, various interest groups and governments can also stimulate the practice of reusing textiles. These organizations can work together to initiate public awareness campaigns on environmental damage due to throwing away textiles in the landfill. Educational programs in schools, electronic media, and social media can play significant role to popularize reuse of textiles (Prothero et al. 2011). Financial incentives offered to consumers for depositing textiles in the retailers' stores can also accelerate clothing reuse. Besides, convenient locations and availability of collection bins should be ensured to increase the practice of reusing textiles. Consumers often cite that collection bins are not conveniently located in the residential neighborhood (Ekstrom and Salomonson 2014).

However, the practice of reusing clothing and textiles has to deal with certain challenges. For instance, donations and exportations of reusable garments may suppress the growth of indigenous textile industries in the developing countries since locals find the cheap second-hand imports preferable to domestic products (Cline 2012). The cheap price of fast fashion products is another issue that questions the economic feasibility of reuse because the overall cost of collecting, sorting, distributing, and reselling reusable garments is, at times, higher than producing brand new clothes (Fletcher 2014). Besides, the reuse of second-hand products is neither popular nor acceptable to many wealthy consumers as this may not deem fashionable and posh. Since second hands can negatively affect the sales of 'new arrivals' at the display outlets, fast fashion retailers may not show much interest to promote textiles reuse.

13.7 Recycling

Recycling of textiles refers to collecting, processing, and converting textile wastes into new feedstock such as fabric, yarn, fiber, or constituent materials (e.g., polymer and monomer). About 87% of material used for clothing ends up in the landfill after consumption though this could be recycled into new products for earning more than USD 100 billion annually (Ellen MacArthur Foundation 2017). Therefore, recycling can enhance sustainability by reducing textile wastes in the landfills and incinerators, decreasing the consumption of non-renewable resources, lessening emission of greenhouse gases, and minimizing different types of pollutions that occur in the textile value chain.

After consumption ends, people view a textile item as a waste and dispose it of along with other household garbage. A change in consumers' perception of disposable textiles may bring about the practice of recycling on a large scale. The discontinuation of the use of a textile item does not mean that there is no more utility of that item. In quest of why consumers do not dispose of textiles for recycling, researchers have found that unawareness of recycling as an option for disposal and lack of knowledge about the methods of recycling are the important factors (Koch and Domina 1997; Koukouvinos 2012). Studies also found that even when the option of recycling is known, the textile users dispose of a recyclable article to the waste bin as it is convenient (Shim 1995; Koch ad Domina 2001; Ha-Brookshire and Hodges 2009; Morgan and Birtwistle 2009). Therefore, awareness and knowledge about recycling may make the consumers view a disposable textile article as an important source of feedstock for the fashion and textile industry. Consumers with environmental consciousness and knowledge tend to choose sustainable discarding options like reuse and recycle even when these options are not as convenient as throwing away.

Proper collection of recyclable materials is a precondition for efficient recycling. Used clothes from the household can be collected in various ways. Instead of throwing away the redundant garments into the garbage container where textiles can be stained and mixed up with various types of household waste, the garments can be placed in a bag and put at a designated place on the curbside. Containers for recyclable garments should be available in the vicinity. When recycling bins or stations are not around or the collection system for textile wastes is not well structured, consumers choose not to recycle. Easy access, availability, site mapping of collection bins, and nationwide network for collection system may influence improved disposal practice. Table 13.2 compares the advantages and disadvantages of various methods of collection system (Ellen MacArthur Foundation 2017). British Heart Foundation has an arrangement of picking up recyclable clothes directly from home though it has a narrow scope due to work intensiveness. Clothing brand Patagonia encourages its customers to mail back extra clothes to the store. H&M, Zara, and Marks and Spencer provide incentives to customers to return the unwanted clothes to the drop-off box in the store. Finally, along with reusable clothes, people can also drop off their disposable clothes to charity shops.

Accurate identification of materials and sorting into exact categories are also prerequisites for recycling efficiency. Sorting and recovery are difficult for blend fibers where non-degradable polymers are mixed with biodegradable cellulose-based natural fibers. Separation of various types of garments accessories (i.e., button, zipper, labels, interlining, elastic, etc., most of which are often non-biodegradable) also makes the recycling complex. Due to the difficulties in sorting and recovery, quality

Table 13.2 Clothing Collection Methods

Collection type	Advantages	Disadvantages	Examples
Municipal waste collection	Suitable for large scales	Textiles mixed and stained with dirt	Most countries
Curbside collection	Potential for large scale	Users need to separate out collectible clothing	Some municipalities in the USA, UK, and China
Home pickup	Convenient for users	High labor and transportation costs	British Heart Foundation
Neighborhood recycle containers	Convenience depends on location and size of the containers	High operating and maintenance costs	Red Cross, TEXAID
Brand mail back	Cash-back, discount coupons	Users have to mail items	Patagonia, Eileen Fisher
Retailer drop-off	Cash-back, discount coupons	Users have to remember to take items along	H&M, Zara
Charity shop Drop-off	Convenience depends on the location of shops	Users have to bring items to a shop	Oxfam, Red Cross, British Heart Foundation

and attractiveness become poor in recycled product. That is why garments with material homogeneity in both fabric and accessories have better recycling outputs. Non-blend long staple fibers and white textiles are easy to re-dye and increase recycling speed and efficiency (Palme et al. 2014).

At present, optical sorting technology and spectroscopic technology are used to detect ingredients of textiles for proper assortment (Ahmad 2004). Valvaan Baling Systems have applied spectroscopic technology to develop FIBERSORT for sorting large volumes of garments by fiber composition (Fischera and Pascucci 2017). Application of RFID technology is under research to identify composing materials of a product (Abdoli 2009). However, further innovation is necessary to advance tracing, identification, and assortment of textiles according to the fiber characteristics, yarn structures, and colors.

Traditionally, recycling was limited to shredding waste garments into shorter staple length fibers for producing only inferior products such as mattress stuffing, insulation materials, and rags. Currently, recycling technologies generate virgin quality fibers by recycling plastic polymer (e.g., polyester and polyamide) based textile waste. Chemical polymer recycling and mechanical polymer recycling are the two widely employed recycling processes. Chemical polymer recycling is suitable when the textiles are made of blend fibers such as polyester and cotton. In this process, polyester, a plastic polymer, and cotton, a cellulose polymer, are both dissolved in the appropriate chemicals. Later, these are extracted separately for treatments in the next phases. In chemical polymer recycling, virgin quality fibers can be produced (Palme et al. 2014). Mechanical polymer recycling, on the other hand, does not generate virgin quality fibers, nor does it remove dyes from the recyclable materials. Technology also exists for depolymerization of plastic polymers to extract monomers that can subsequently be used as feedstock for fresh quality polymer fibers (Achilias et al. 2012). A number of textile companies have successfully applied the various recycling technologies to produce raw materials. Their achievements in generating recycled products are presented in Table 13.3 (Leonas 2017). Auafil and Tenjin have employed depolymerization technique in manufacturing recycled products. Tenjin

Table 13.3 Recycled Products

Manufacturer	Product name	Material	Source
Unifi	Repreve®	Recycled polyester	Plastic bottles; industrial waste; fabric scraps
Tenjin	Ecocircle®	Recycled polyester	Consumer waste; Industrial waste
Aquafil	Econyl®	Recycled nylon	Post-consumer waste; fishing nets; old carpet
Martex fiber	ECO2Cotton®	Recycled cotton	Offcuts in garments industry
Evrnu	Evrnu	Recycled cotton	Cotton garment waste
Speedo	Powerflex Eco®	Recycled nylon	Fabric scraps; offcuts; fishing nets; old carpets
Hanes	EcoSmart®	Recycled cotton	Industrial wastes

has produced a recycled polyester material called Ecocircle® that retains the qualities of virgin fibers. Martex Fiber, Evrnu, and Hanes recycled cotton-based industrial and garment wastes such as fabric scraps and offcuts to produce recycled cotton fiber that is used in fleece apparel, socks, and t-shirts. Aquafil and Speedo utilized thrown away old carpets and fishing nets to generate recycled nylon fiber.

Along with changing the perception of textiles waste and disposal behavior, consumers can also promote sustainability by showing interests in buying and using products made with recycled materials. Increasing demand for recycled clothing may begin a virtuous cycle by encouraging recyclers and producers for innovation and further investment. Since government has the capacity of big volume purchase, large-scale orders, and consumption, it can promote the industry of recycling by increasing the public procurement of recycled textile products. A notable example in this regard is the Dutch Enterprise Agency, a government agency operating under the auspices of the Ministry of Economic Affairs and Climate Policy, which promotes the use of recycled fibers in workwear (Ellen MacArthur Foundation 2017).

13.8 Conclusion

Every year, 7 million people die due to the causes related with air pollution and another 3.6 million due to water pollution around the world (WHO). Every year, we lose 24 billion tons of top soil due to dumping 2.12 billion tons of waste (All Recycling Facts 2014). Every day, 2 million tons of sewage, industrial, and agricultural waste are discharged into the world's water bodies (UN WWAP 2003). Such pollution and human costs, along with fast depletion of resources, are attributable to current industrial practices, business ethics, and household consumption manner. Textile and clothing industry, holding a significant part in the entire industrial output, has to accept its share in the degeneration of habitat and ecosystem. At every phase of its value chain, textile and clothing sector destabilizes the environmental sustainability one way or another. Fast fashion, due to the mass production of trend-driven low cost products, causes the textile and clothing industry to devote massive amount of resources to supply its needs. Besides, to sustain its demand, fast fashion has to control the consumers to buy more and throw away fast. That is why, for the sake of sustainability, it is crucial to promote slow fashion that focuses on good quality durable products that are produced with recyclable materials and in environmentally and ethically conscious working conditions. The traditional linear economic system fails to account for growing shortage of resources, increasing pollution, and mounting landfills. Such economic system should be replaced by circular economic model that aims to optimize the utilization of resources by closing the energy and material loops through durable design, reuse, and recycling. Again, open loop recycling where the recycling of the material eventually discontinues and does not prevent the generation of waste in the landfill should be improved to closed-loop recycling. Closed-loop recycling is more inclined to sustainability where a product can have multiple life cycles through continuous recycling until the product is reduced to the basic elements that return to the environment without any harm.

This study underscores the roles of consumers and how consumers can engage in the appropriate phases in the textile value chain to promote sustainability. Since there are adverse consequences of self-indulgence in shopping and overconsumption, people may think about practicing conservatism and minimalist principles. Instead of indiscriminate buying of cheap and low-quality products, consumers may use durable textiles until the end of the life span of the product. At the use phase, consumers can advance sustainability by adopting eco-friendly product care practices such as washing clothes with cold water and drying in the open air. This research particularly focuses on the disposal practices at the end of the consumption. Instead of wholesale throwing away into the garbage, consumers can deposit or donate their used clothing in the designated places to facilitate efficient reuse or recycling. They may also show interest in consuming reusable products and products made with recycled materials. Thus, as an important stakeholder in the textile value chain, consumers can unleash their power to influence other stakeholders namely producers and retailers to innovate and develop effective technologies that result in sustainable environment. A number of top fashion retailers (H&M, Zara, C&A and many others) have pledged to adopt recycling as their main business practice. H&M aims to use only recycled or sustainably procured materials for their products by 2030. C&A has also committed to use at least two-third of the input materials from the sustainable sources. Policy makers can also introduce appropriate laws to promote sustainability. For example, charging consumers for discarding clothing in the garbage bin or banning textiles from the landfill and incinerators can drastically change the current disposal habit.

This study could be comprehensive if more data were available about the consumption and disposal practices in developing and underdeveloped economies. The study had to rely heavily on the facts and evidences in North America and European Union due to their having rich literature on the subject. Also, this study does not include the quantitative information on the frequency and extent of over-shopping and overconsumption, variation in overconsumption, disposal, and product care behavior among different regions and demographic segments. Further studies may fulfill these gaps.

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Part V
Sustainable Business Models and Communication Strategies

Introduction

Business models are a crucial element of competitive markets and a necessary condition for the profitability and persistence of companies as well as for the overall stability of ecosystem functions. Business models are strongly related to a company's value proposition, creation and delivery to the customer. Combining strategic and tactical considerations while aiming at large scale and entrepreneurial profit generation, there are massive areas of tension between value capturing and value creation. In addition, integrating sustainability concerns within a business model, complexity and conflicts increase. Including environmental and social values in the business model conceptualization makes a huge shift from a one-dimensional alignment to a multi-criteria-oriented sustainable value creation in a more holistic and balanced way. A sustainable value reflects the triple bottom line of sustainability, balancing environmental, economic and social issues. It should be measurable as well. At the same time, in the literature there are multiple types and conceptualizations of business models. In addition, there is no clear understanding concerning the wording. There are differences discussed referring to sustainability business models, sustainable business models and business models towards sustainability. However, beside conceptual variety concerning capturing business model and sustainability business models, more important seems is the integration of all three sustainability strategies *sufficiency*, *consistency* and *efficiency* while developing and establishing business models. Only a smart combination of all three sustainability strategies might cause a change in current production and consumption patterns.

Consequently, developing and implementing business models for sustainability require a holistic perspective and integrated thinking, particularly addressing interrelated sustainability objectives in global textile supply and value chains. From today's standpoint, this often implies a reconfiguration of management and business aspects. Furthermore, participation, interaction and communication between all stakeholders become essential. An effective and proper communication is always aligned with the company's specific activities, objectives and competencies. Entrepreneurial communication and marketing activities should be in line with the triple bottom line approach of sustainability and enhance transparency and honesty. Although in the literature, substantial deficits regarding the definitional, theoretical and conceptual foundations as well as the implementation of sustainability business models are identified, there are wide-ranging applications in practice stimulating interdisciplinary matters as well as meeting the main cultural, socio-economic and technological challenges of future market development.

In the textile industry, multiple drivers of sustainability business models were identified like technological ones, such as innovative fibres based on renewable raw materials, greening of manufacturing processes and the implementation of circular economy concepts. Social drivers comprise an increase of consumer awareness regarding own responsibilities of fashion production and consumptions as well as recycling. Moreover, the role of innovations needs to be rethought deeply. The main question here is how much innovation is necessary for human and how much innovation is capable for the earth's ecosystem? Other drivers stress diverse strategies for upcycling, recycling, fair trade, CSR and lowsumerism. Current research emphasizes the impact on different elements and components of business models when changing business models towards sustainability, like partner selection, customer relationship, inter-firm collaborations and value proposition or joint investments in circular textile flows. A reorientation towards sustainability often causes innovative solutions for dealing with pressure on capital and promoting a collaborative mindset among stakeholders. Responsible, transparent and sincere communication gains of importance. Innovative business models for sustainability comprise mass and niche markets accentuating the heterogeneity of segments and the diversity of the textile industry.

This chapter comprises three contributions from different angles. The first scientific article by Morris et al. is about labels in the textile and fashion industry. The authors write about the awareness and information strategies, such as sustainability labelling, stating these strategies are a crucial step in promoting sustainable consumption through improved information provision which may facilitate an institutionalized shift towards embedding sustainability criteria into consumer decision-making processes. Tamborrini et al. and Basset present practical perspectives on datafication processes emerging new opportunities of sustainable value creation, thereby fostering corporate social and ecological responsibilities, as well as on circular business innovations to foster sustainability. The contribution by Tamborrini et al. focuses on a data systemic and communicative approach in the global fashion industry proposing an information flow strategy based on data and information processing technologies. Bassett proposes in her article circular business models by generating new value including sharing, product life extension, resource recovery, circular supplies and product as a service.

Chapter 14
Labels in the Textile and Fashion Industry: Communicating Sustainability to Effect Sustainable Consumption

Jonathan Morris, Lisa Koep, and Matthias Damert

Abstract The textile and fashion industry is associated with numerous ethical problems such as poor labour conditions, low wages, long hours and unsafe working conditions, as well as a range of negative environmental impacts. A key challenge is to reconcile the behavioural impacts across the value chain, from producers and manufacturers to consumers. Achieving real change requires organizational shifts across multiple levels of the textile and fashion value chain, away from focusing on the focal firm but across the entire value chain, as well as overcoming the information and knowledge deficits held by consumers and professionals alike. Awareness and information strategies such as sustainability labelling are a crucial step in promoting sustainable consumption through improved information provision which may facilitate an institutionalized shift towards embedding sustainability criteria into consumer decision-making processes.

Keywords Sustainability labelling · Textile and fashion industry · Consumption · Transparency · Sustainable consumption

14.1 Introduction

The textile and fashion industry is associated with numerous environmental and social problems such as poor labour conditions, low wages, long hours and unsafe working

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Submission to Chapter 5: Behavioral and Societal Aspects in the Textile and Fashion Value Chain.

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conditions (Pedersen and Gwozdz 2014). These challenges are exacerbated given that the textile industry is a major employment provider for workers in developing countries where there are lower requirements environmental and social standards (Boström and Micheletti 2016). Reforming the sector in this context is difficult, since the presence of these industries is crucial for the prosperity of the local and national economies, creating a path dependency for affected countries.

A major characteristic of the textile and fashion industry is that it is a 'buyer-driven chain' with retailers and brands concentrated in Western Europe, Japan, and North America driving the market, determining where to produce, what to produce, and what prices to demand (Balasubramanian and Soman 2018). Due to vertical disintegration, retailers and lead firms rarely own the production process and as a result recording the environmental and social impacts which occur along the value chain is complex and challenging. This presents additional challenges for collecting, generating, and providing this information to consumers and also greatly reduces the ability of buying firms to measure, monitor, and manage the sustainability performance of their suppliers (Börjeson and Boström 2018). The concept of labelling is therefore important to provide transparent information on the environmental and social performance of textile products and turning them into a quality characteristic with the aim of increasing demand for products with higher sustainability performance (Hartlieb and Jones 2009). Labelling therefore can be seen as a mechanism to correct market failure of over-consumption of goods with poor environmental and social standards in the production process.

For a labelling approach to work, there needs to be demonstrable competitive advantages for companies who undertake such efforts to tackle these challenges and accurately report on them (Pedersen and Neergaard 2006) and give incentive for them to participate in these mostly voluntary schemes. Such benefits may include improving their reputation and company image and therefore increasing sales and higher economic performance (Plewnia and Guenther 2017; Guenther et al. 2018) to companies which offer sustainable products in order to meet the criteria required to display such labels (Thøgersen 2002).

Therefore, the logic of labelling is rooted in the idea that greater focus should be placed on the information provision for the consumer to make better informed, socially and environmentally responsible consumption decisions, which in turn place pressure on brands to incorporate these sustainability criteria into their sourcing and supply chain management strategies (Hartlieb and Jones 2009; Mol 2015). These top-level demands may help to facilitate a change in accepted practices across the entire value chain. Labelling alone will not solve sustainability challenges, but if implemented successfully, it can lead to an institutional shift in the industry and move beyond confining focus on sustainability activities and certification on the actions of individual firms (Hartmann and Moeller 2014). For a successful development of a sustainable textile label, the focus should also be placed on how information is collected throughout the entire value chain in order to increase transparency (Mol 2015) and provide comprehensive information to consumers, overcoming knowledge deficits held by them regarding the 'best quality' products according to sustainability criteria (Christensen and Murphy 2004; Cerri et al. 2018). The role for a labelling system in textile value chains can therefore be aimed at changing attitudes and perceptions of end-consumers through provision of credible and robust information (Janßen and Langen 2017). Such labelling schemes should be designed to meet the aim of embedding and extending sustainability practices across the entire industry and throughout the multiple tiers and levels within the industrial value chain via greater disclosure and transparency. However, there are multiple approaches towards labelling of textile products, and different label schemes may be better suited to different market conditions (e.g. niche or mass market products).

This chapter addresses how shifts towards sustainable consumption in the textile industry can be achieved via labelling, the barriers that can hinder labelling schemes from shifting demand towards sustainable products, and how the process of information collection to design labels filters through towards diverse stakeholders involved in the textile value chain and instigates a bottom-up shift towards sustainable production processes. The following section moves on to outline how labelling schemes may be applied to the textile and fashion sector by drawing upon existing theoretical approaches. In the next section, the current landscape of sustainability labels is presented. Subsequently, the forces at play within the textile industry and why labelling is a crucial mechanism for promoting sustainable consumption is discussed based on empirical evidence regarding the effects of labelling on consumer behaviour. Finally, conclusions and future directions for research and practice are presented.

14.2 Theoretical Approaches and Rationale for Implementing Labelling Schemes

Information asymmetry is the key theoretical driver behind implementing labelling schemes and is rooted in the idea that consumers are responsible for making sustainable consumption decisions which consider wide social and environmental criteria (Pedersen and Neergaard 2006; Belz and Bilharz 2007). This is based on the assumption that labels act as exogenous stimuli, creating signals in markets that allow consumers to act on these positive impulses (Pedersen and Neergaard 2006). Pedersen and Neergaard (2006) discuss how ‘a consumer may perceive a product labelled with a pine tree or water droplet as an environmentally sound product’ and conclude that it is not sufficient to focus on functional aspects of a label. Instead, labelling can be successful if it evokes an emotional response. The question of whether consumers use information in sustainability labels when purchasing clothing is much studied and conflicting consumer preferences with regards to purchasing decisions is a barrier which requires further examination. Even if consumers are willing to engage in sustainable consumption, other factors remain which influence purchasing behaviour such as quality, consumer taste, and price of goods (Liu et al. 2016). Belz (2001) states that consumers usually decide in accordance to their individual benefit maximization which is generally conflicting with the characteristics of sustainable consumption behaviour. Yet there may also exist a gap between the beliefs and attitudes held on the one hand by consumers and their actual consumption of sustainable products. This can be seen as a limiting factor of sustainability labels (Horne 2009; Grunert et al. 2014; Plank and Teichmann 2018; Testa et al. 2018). Information economics theory is based upon three qualities: search, experience, and credence. Search qualities are where consumers can readily inspect before to purchase (e.g. price). Experience qualities are those which can be evaluated post consumption such as taste or functionality (Nelson 1974; Brach et al. 2018). Lastly, credence attributes are those which consumers cannot readily evaluate prior or post purchase due to a lack of expertise or high costs to obtain sufficient information (Darby and Karni 1973; Brach et al. 2018). Markets with high information asymmetry and imperfect information are characterized by producers having greater knowledge about their products than consumers. For the textile industry, this creates problems for customers when attempting to evaluate sustainability credence criteria with regards to superior performance that are related to fair trade, child labour, cruelty free manufacturing (Brach et al. 2018).

Therefore, labelling schemes should be designed to simplify the complex environmental and social impacts across product life cycles so that they can be easily expressed into indicators that present the sustainability information to the consumer and address the asymmetrical information and low levels of consumer knowledge that can lead to market failures (Brach et al. 2018; Cerri et al. 2018). This type of approach has been applied to the food industry with some success, with certain products certified as organic or as fair trade (Jaffee and Howard 2010) and is increasingly being applied to quantifying environmental impacts of food production to address the challenges of consumers to 'compute the overall impact of their consumption' (Bougherara et al. 2005, 6), for example, through the calculation of the carbon footprint. In this context, labelling can be viewed as part of the practices associated with corporate responsibility and communication. Most organizations embracing corporate responsibility communicate their actions to some extent in order to leverage the benefits and the reasons for undertaking these activities are plentiful. Communication about corporate responsibility is thought to create and increase legitimacy for the organization (Du and Vieira 2012; Seele and Lock 2015), strengthen credibility (Schlegelmilch and Pollach 2005), develop and maintain stakeholder relationships (O'Riordan and Fairbrass 2008, 2014), help organizations develop a competitive advantage point, and build the organization's reputation (Schwaiger 2004; Eisenegger and Schranz 2011), which in many cases translates into financial benefits and further unique selling points for their firms, such as attracting and retaining employees and generating positive consumer perception. Technological developments such as digitalization (Capriotti 2014) and globalization (Ihlen et al. 2014) have enabled organizations to demonstrate transparency with regard to their actions and impact, due to increased stakeholder expectations with regard to corporate responsibility (Scherer and Palazzo 2009, 2011). Overall, there is now greater pressure placed on organizations to interact and communicate with their stakeholders and with improved access to digital data and Internet-based platforms, it should be simpler for companies to collect, process, and disseminate the information required to circulate their sustainability performance via labelling. For the textile industry, a pertinent example is the increasing trend to disclose corporate responsibility in the textile industry which is linked to the collapse of the Rana Plaza factory in Bangladesh, which killed more than 1000 workers. This acted as a key event in mobilizing stakeholders to act on health and safety initiatives in low wage textile economies (Lohmeyer and Schüßler 2018). As a result, a range of public and private governance initiatives have emerged, such as the Bangladesh Accord and Alliance aimed at improving health and safety standards, the German Partnership for Sustainable Textiles, as well as the UK Modern Slavery Act 2015. These developments have resulted in a greater need to inform and communicate sustainability credentials of garments in the form of labels.

However, labels on their own may not be enough to drive sustainable consumption patterns (e.g. Horne 2009), and there are several suggestions which could be used to overcome the most popular barriers to adoption and effectiveness. For example, Cho (2015) recommends that sustainability labels should clearly state in what way consumers can benefit of sustainable consumption, such as regarding health or safety. In this way, consumers with low sustainability motivation could become interested in sustainable products. There are also suggestions for greater strength in governmental institutions (e.g. Horne 2009; Annunziata et al. 2011) where formalized policies should support the development of clear and reliable labels, taking into consideration the trust consumers have in labels. Further, there is evidence of the need for further institutional shifts towards acceptance and usage of labels, drawing on ideas of institutional theory (Scott 2008; Clegg 2010). For example, labelling can become embedded in the textile and fashion industry through coercive action of external agencies and regulation, but also as a part of normative action where labelling becomes established as best-practice throughout the value chain, and through mimetic mechanisms as smaller companies copy labelling due to a belief of the added-value to product lines that labelling can create.

There are a number of approaches linked to the purpose of labelling and the underlying measuring, monitoring, and marketing of sustainability activities and the necessary information provision which arise from interactions of diverse stakeholders across the industry. These activities are crucial in order to reach those responsible for sustainability performance in textile firms, as well as providing credible information and best practices for the diffusion of institutional practices across the multiple levels in the textile value chain. In order to explore and synthesize these concepts in the context of textile and fashion industries, and how labelling links to sustainable consumption in the textile industry, we surveyed academic literature and existent labelling schemes drawing on databases such as web of science, Scopus, Google scholar, with keywords of variants of ‘label’, ‘labelling’ alongside ‘sustainability’, ‘value chain’, and industrial key words including ‘clothing’, ‘textile’, ‘garment’, and ‘fashion’. The idea of the search was to be exploratory and free-flowing. As a result, strict parameters associated with systematic reviews were not applied.

14.3 Overview of Textile and Fashion Labelling Schemes

The first sustainability labels arose in the early 1990s and were predominantly initiated by international organizations and social movements (Koszewska 2011). Specific to the textile and fashion industry, it is estimated that there are currently about 120 standardized sustainability labels issued by over 100 certification bodies worldwide (Schaus 2016). Online platforms, such as the German website *Siegelklarheit* (translated as 'labelling clarity'), have been created (https://www.siegelklarheit.de/home#textilien) to help consumers navigate the labelling landscape. The ones that are most important in terms of adoption rates and potential are shown in Table 14.1.

In general, sustainability labels can be differentiated by asking the following questions, as illustrated in Fig. 14.1

- Which sustainability topics are covered?
- What is the scope of the label?
- Who issued the labelling scheme?
- How does the certification process look like and who is responsible for certification and monitoring?

The first distinction in sustainability labelling can be made according to the topics covered. Environmental or eco-labels certify compliance with certain environmental protection requirements, such as organic cotton farming (e.g. Global Organic Textile

Table 14.1 Overview of popular sustainability labels in the textile industry (based on Schaus Schaus 2016)

Name of the standard	Logo	Topics covered	Scope	Adoption rate
Oeko-Tex	OEKO-TEX® CONFIDENCE IN TEXTILES MADE IN GREEN	Health and safety	Textile products at all stages of production	~9.500 companies
Global Organic Textile Standard (GOTS)	GLOBAL ORGANIC TEXTILE STANDARD · GOTS ·	Environmental and social sustainability	Textile products	~3.085 companies
Fair Wear Foundation	FAIR WEAR FOUNDATION	Social sustainability	European garment companies	~80 companies
FairTrade	FAIRTRADE TEXTILE PRODUCTION™	Social sustainability	Textile products	~35 companies

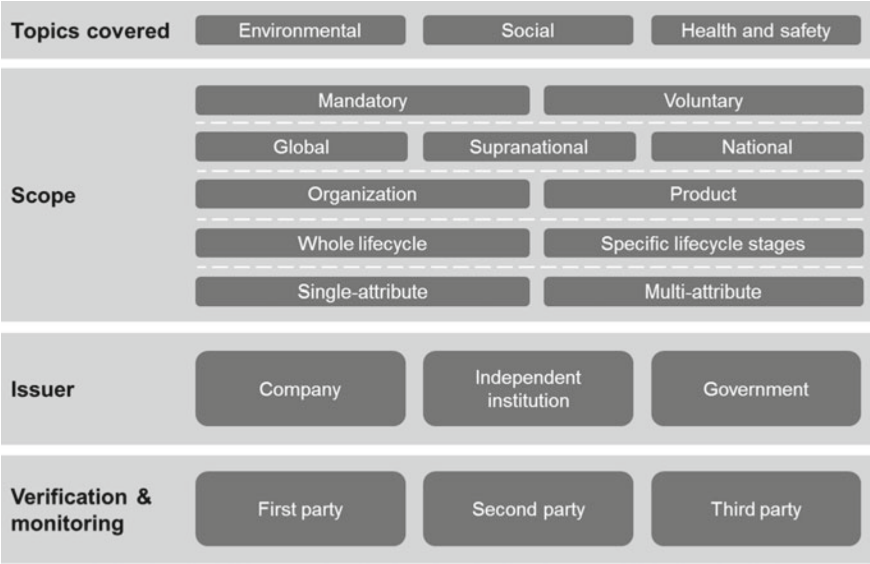

Fig. 14.1 Classification of sustainability labels (own illustration)

Standard) and zero discharge of hazardous substances (e.g. ZDHC or Greenpeace's DETOX campaign). Social labels (e.g. FairTrade) testify adherence to standards related to social sustainability issues such as human rights, labour conditions, fair wages, animal welfare, etc., and were mostly designed to provide consumers in developed countries with information about production conditions in developing countries. Eco-labels were the first to be established, and as a result, social labels are still fewer in number, have lower adoption rates, and may be less well understood (Koszewska 2011). In the textile industry, another popular type of label addresses health and safety concerns to help consumers identify products that are harmless for human health (e.g. Oeko-Tex[1]). Only few labels cover several dimensions of sustainability, such as the recently introduced 'Green Button'. The label was created by the German Government in conjunction with the Partnership for Sustainable Textiles and is a voluntary, product-based approach to provide consumers with an all-encompassing sustainability label covering both social and environmental aspects. It aims to simplify and legitimize the information provided to consumers. Regardless of the topics covered by a label, its certification can be based on single category (e.g. a single environmental impact) or multi-attribute standards where several categories of impacts are considered (Golden 2010).

A second criterion for grouping sustainability labels is the scope that is covered by the label. For example, some labels address sustainability issues in certain stages in the value chain, such as in the production stage or during disposal (e.g. bluesign),

[1]Öko-Tex is the world's leading eco label for textiles and has granted 20,000 certificates to millions of textile products (Oeko-Tex 2018).

whilst others cover the whole life cycle of products (e.g. Cradle-to-Cradle, MADE IN GREEN by Oeko-Tex). A distinction can also be made between standards for products (e.g. Nordic Swan) and standards for organizations (e.g. EMAS, Fair Wear Foundation, Clean Clothes Campaign). Moreover, a sustainability label can be of global (e.g. Better Cotton Initiative), supranational (e.g. EU Ecolabel) or national applicability (e.g. Blue Angel, Germany).

There are different institutions that have developed and are implementing sustainability labels, including governments, industry associations, companies and non-governmental organizations. Standards vary with regard to the underlying governance arrangements (who sets and who monitors the standard?) and the organizational structure of the certification body, such as profit versus non-profit, public–private partnerships and industry initiatives (Lambin and Thorlakson 2018). Due to the absence of binding legislation, most sustainability standards in the textile industry remain voluntary. However, third-party verification is necessary in most cases to obtain certification. There are attempts to formalize labelling schemes within standardized national frameworks. For example, Cho et al. (2018) discuss labelling within the context of France, where the Grenelle II environmental laws set out the right for consumers to be provided with information about the environmental performance of products at the point of sale, compared to the United States where product sustainability labelling is emerging through a voluntary perspective. Under the current voluntary system, companies are legally free to disclose the sustainability criteria which they feel to be most important. Whilst in the example of the Grenelle II laws, these laws only apply to companies with more than 500 employees, and the scheme does not set out penalties for non-compliance. Therefore, the implementation of labelling schemes remains voluntary.

To support the creation of transparent and credible labelling frameworks, the International Organization for Standardization (ISO—see 2006, 2016, 2018) has defined three types of voluntary environmental labels which organizations can strive for:

- Type I: Labels relying on third-party verification (ISO 14024)
- Type II: Informative self-declaration by companies or industries (ISO 14021)
- Type III: Quantified information labelling based upon independent verification using pre-set indices (ISO 14025).

Apart from the above-mentioned characteristics, organizations that want to participate in sustainability labelling and consumers that want to assess the trustworthiness of labels should also consider the following aspects (Moore and Wentz 2009; Golden 2010; Lambin and Thorlakson 2018):

- The rigour of the certification process (Are companies required to conform to a standard or just show improvement in practices towards a goal? How ambitious are the standards and which practices do they cover? Do standards become higher over time? Is verification of compliance the responsibility of a first, second, or third party?);
- Time to and duration of certification;

- The transparency of the certification process and the possibility of stakeholder engagement, and
- Financing (licensing, application, membership fees).

The above overview of labels in the textile industry demonstrates the fragmented labelling landscape in the sector despite common frameworks that attempt to guide label development. In the following section, we discuss how these labelling schemes impact garment consumption decisions.

14.4 Impacts of Labels—Empirical Evidence in the Textile and Fashion Industry

Successful labels are those which provide transparent, easily understandable information to consumers (Ma et al. 2017), based on third-party certifications and endorsed by via official and regulated organizations (Hyllegard et al. 2012). The theoretical perspective of labelling is rooted in the idea that the information provided can influence consumption patterns of consumers by activating internal drivers such as identity construction (Niinimäki 2010), as well as external drivers such as social pressures which are dependent on the level of individual ethical awareness (Freestone and McGoldrick 2008). Therefore, the impact of labelling should lead a shift towards increased consumer sustainability preference when faced with tradeoffs between price, quality, purchase convenience, style, and social and environmental considerations (Solomon and Rabolt 2004). However, the impact of additional sustainability information may be limited and does not always translate into sustainable consumption choices (Joergens 2006). Firstly, consumers are often unwilling to pay higher prices for sustainably produced items (Roberts 1996; Nakano 2007) or to accept unattractive designs or materials (Carrigan and Attalla 2001), and lack of durability (Jacobs et al. 2018). So although consumer attitudes towards clothing items have developed favourably in the past years, the market share of sustainably produced clothing is still lagging behind, highlighting an attitude-behaviour gap around clothing consumption (Solomon and Rabolt 2004; Jacobs et al. 2018). More general consumption studies highlight that one of the limitations of sustainability labels lies in the fact that they are simply providing information without involving consumers in the process (Horne 2009) and therefore diminishing the potential impacts labelling could have.

In the textile and fashion industry, sustainability labels seem to be only effective in guiding decision-making when consumer is not facing a compromise on quality (Carrigan and Attalla 2001). Despite the many ambivalent studies regarding the impact of sustainability labels on clothing consumption, there is merit in labelling due its focus on providing greater transparency and visibility (Boström and Klintman 2008). For example, several studies show that the influence of sustainability labels on consumers' textile garment purchase decisions may be on the increase (Hustvedt and Bernard 2008; Hiscox and Smyth 2011) and that those consumers motivated by sustainability are willing to pay more for sustainably produced garments which are labelled (Prasad et al. 2004; Hustvedt and Bernard 2010), highlighting the presence of a niche market.

However, the research on the effectiveness of labels in the textile industry is not so clear-cut. Dickson (2001) empirically analysed consumer preference towards a clothing label guaranteeing certain working conditions and found that only a small percentage of consumers to be influenced by the label. Yet the same study also identified that such a label which covers social values, for example, that guarantees certain working conditions, is rated more positively when making purchasing decisions rather than labels based on environmental certification. Phau and Ong (2007) found from an Australian study that acceptance of sustainability labels by consumers may have increased, and observe how shoppers now respond more positively to direct environmental performance messages for products when purchasing clothing compared to messages around corporate donations for environmental causes which may be viewed cynically as brand image management. In a European context, Pedersen and Neergaard (2006) reported on textile eco-labelling schemes in Nordic countries such as the EU Ecolabel, noting that consumers did not pay much attention to environmental impacts and instead focusing primarily on price and garment quality.

What these studies reveal is that labels do not always lead to changes in consumer preferences (Pedersen and Neergaard 2006). Reasons for this are related to the influence of consumer trust in the organizations from which the labels originate (Gertz 2005). For example, Gertz (2005) found that the highest levels of distrust were found regarding labels developed by retailers. In certain cases, sustainability labels may contain misleading information or information that is not easily understood by the consumer (Gallastegui 2002; Horne 2009) and lead to scepticism and distrust by consumers (Goworek et al. 2018). Other barriers towards label success relates to schemes which overwhelm consumers and lead to increased consumer confusion. This can be as a result of the high number of labels and their wide diversity (Langer et al. 2008; Bernard et al. 2015) and the lack of standardization across labelling criteria (Aspers 2008) which can reduce the ability for consumers to understand the criteria which underpin the labelling mechanisms (Pedersen and Neergaard 2006). At an organizational level, the development of 'own-brand' labelling can lead to a lack of objectivity regarding the criteria and certification process and open retailers to accusations of 'greenwashing'. The overall result of this is to reduce the credibility of labelling schemes in general (Thøgersen 2002; Rousseau 2015). As Nikolaou and Tsalis (2018, 106) state:

> Consumers are inundated with products which not only have labels with different emphasis, but also have a number of different certifications. Another significant question focuses on the influence of the number of labels on the purchasing decisions of consumers. In other words, how consumers behave when they have to choose a product from a bunch of products which have the same quality and use but they have different number of certification and labels (e.g. ISO 14001, EMAS, European Flower, Energy Star, ISO 26000, and FairTrade)

It is suggested that labels may encourage institutional shifts towards greater corporate responsibility disclosure and increased product labelling (Crifo and Mottis 2016; Chelli et al. 2018) but that there is a need to address consumer scepticism in labelling to fully realize their effectiveness (Cho et al. 2018) and that successful labelling schemes labels require that claims on environmental and social responsibility of products are substantiated through third-party auditors and independent certifications (D'Souza et al. 2007).

Goswami (2008) describes how Indian companies are rolling out environmentally friendly textiles not only for exports but also for domestic consumption in order to attain standards required for labelling schemes. Staying with the Indian context, manufacturers such as Alok Industries Ltd. have decided to increase its output of organic cotton from 5% in 2007–2008 to 15% in 2008–2009 in order to supply brands who wish to gain environmental certification (Mehta 2018). Interestingly, in survey analyses, Greenbiz.com (2005) found that as many as 71% of online consumers in India are willing to pay more for socially responsible products, which is significantly more than their counterparts in developed nations like UK, where the corresponding percentage is just 47%, indicating that cultural factors as much as informational can explain the impacts that sustainability labelling has on consumption patterns. In the context of the textile industry, willingness to pay (WTP), cultural background, and educational attainment were found to be strong identifiers as to whether sustainability labelling influenced consumption patterns. This draws in ideas of cognitive dissonance and the desire for individuals to seek out information which confirms their pre-existing held views regarding sustainability (Schlaile et al. 2018).

Given the perceptions of sustainability impacts from clothing production and the influence that consumer choices can make, there remains difficult challenges in relating purchasing decisions to wider environmental and societal impacts arising through the production process (Goswami 2008).

Sustainability labels may help to assure customers about making pro-sustainability choices and help respond to increased transparency and informational demands based on clear information and effective communication strategies. Such communication measures would help to bridge different cultural and ethical perceptions and empower consumers to believe that their actions have an impact on sustainability performance of industries, consequently tackling global challenges such as environmental destruction (Schlaile et al. 2018). Sustainability labelling may enable producers to charge a higher premium for certified products, consistent with a study from the UNCTAD on German consumers (UNCTAD 1999) noting that around 5–15% of German consumers may pay a slightly higher price for sustainable clothing. Another 50% of Germans would buy these products if assessing their sustainability credentials was made easier through clear labelling and if items were not more expensive than alternatives. However, as a challenge for sustainability in the fashion industry, 40% of German consumers stated that they would never use eco-friendliness as a criterion in their purchasing decision. This percentage of German consumers who would consider sustainability criteria in their purchasing decision was significantly lower than the percentage of Indian consumers who would consider criteria into their purchasing decisions, which may reflect the proximity of Indian consumers to the effects of unsustainability in the textile and fashion industry (Goswami 2008). Price is not the only consideration as sustainable clothing must also be accessible and cannot be underestimated as a driving factor for sustainable consumption in the industry. As Goswami (2008, 442) states, ethical consumers are 'calling for fashionable ethical products to be available on the High Street so that they are convenient and easy to access, thus suggesting a potential way forward for ethical manufacturers to avoid becoming a niche product and instead becoming more mainstream'. Therefore, whilst labelling alone will not solve the sustainability challenges within the textile and fashion industries, it can help to stimulate demand for products where consumers can accurately assess sustainable credentials if supported by wider availability of sustainable products.

14.5 Discussion and Conclusion

To tackle the environmental and social sustainability challenges faced by the textile industry, information deficits need to be addressed to aid greater uptake of sustainable purchasing decisions. In order to comply with requirements from buying firms and consumers, textile and fashion garment producing firms are required to provide transparent information on their sustainability performance. Labelling schemes help to address these requirements and can also be used as evidence for supplier sustainability assessment as well as for marketing purposes. Our review of the labelling literature with focus on the textile and fashion industry highlights the variety of common and diverging characteristics of contemporary labelling schemes and the need to address the asymmetric nature of information between different tiers of the value chain. It becomes evident that the variation in the scope and topics covered impacts on the way in which consumers judge the trustworthiness of labelling schemes. The effect of labelling on consumption behaviour is therefore conditional on these factors but also on the sustainability-related beliefs held by consumers when making their consumption decisions. Brach et al. (2018) suggest that labels are a mechanism for correcting market imperfections, our review demonstrates that in reality, only a small number of consumers are actively influenced by labelling, which becomes weaker in strength the further consumers are located from where the externalities are felt (Dickson 2001; Goswami 2008).

The overarching aim of this chapter was to address the questions of how a shift towards more sustainable consumption in the textile industry can be achieved through labelling. Our findings suggest that labelling schemes can serve as a marketing strategy to boost demand for products by indicating quality criteria. By contrast, we also see that labelling does not address the access for products with higher sustainability, which remains limited in some regions.

Secondly, the chapter contextualizes how this shift towards sustainable consumption can be achieved in practice by exploring the barriers which can hinder the successful adoption of labelling schemes. Consumer confidence in labels is an important factor in ensuring the success of sustainability labels at a societal level. However, consumers are facing a range of challenges when trying to assess credentials and focus of sustainability labels (Nikolaou and Tsalis 2018). Whilst Websites such as www.siegelklarheit.de aim to help consumers to better understand labels, more clarity regarding credibility of labels is needed. In order to strengthen consumer confidence, there should be renewed focus on labels providing credible and robust information (Janßen and Langen 2017), underpinned by labelling frameworks such as those offered by the International Organization for Standardization (ISO—see 2006, 2016, 2018) to help consumers navigate better the various certifications that exist and to counteract the credibility challenges of labels due to the rise in own-brand labels (Thøgersen 2002; Rousseau 2015). Further, the different and sometimes conflicting foci of labels should be harmonized to facilitate easier decision-making. The 'Green Button' issued by the German government could be a promising sustainability label combining both environmental and social at the product level. Consumers should have the right to easily access credible and clear sustainability-related information for garments in order to make informed decisions.

Thirdly, the chapter discusses the context of label design and the barriers towards efficient information provision. Here, we see that a widespread roll-out of sustainability labelling can utilize the information collection processes as a push towards considering sustainability characteristics and the criteria that consumers and purchasers utilize to make consumption decisions, which over time has the potential to develop into an institutional shift that leads towards greater sustainability across the entire textile value chain. However, the experiences from German consumers in the late 1990s show that this can be a slow process and challenges strongly held beliefs and cognitive dissonances held by consumers, as well as purchasing managers. What becomes evident is that sustainability trends in the textile industry cannot be achieved in isolation without providing some criteria for labelling as a reliable and institutionally accepted measure of the sustainability credentials of textile retailers and their wider textile value chains. Strengthening the accepted structure of what should comprise a labelling scheme is critical to overcome scepticisms and to foster widespread adoption of labelling. This would help to position labelling schemes as key influencing factors for consumer and procurement manager decision-making processes. Government backed schemes on mandatory standards on textile sustainability may help speed up this shift but would require international agreements due to imports from areas where standards are not legally enforced. Further research in this field should focus on answering questions regarding the developments in the industry to move towards the standardization of labelling schemes. Research should address how the information collection and dissemination processes lead to institutional shifts in the textile industry and efforts should be focused on engaging with producers and consumers to identify how these shifts diffuse in both directions across the value chain.

This would help to position labelling schemes as key influencing factors for consumer and procurement manager decision-making processes. Government backed schemes on mandatory standards on textile sustainability may help speed up this shift but would require international agreements due to imports from areas where standards are not legally enforced. Further research in this field should focus on answering questions regarding the developments in the industry to move towards the standardization of labelling schemes. Research should address how the information collection and dissemination processes lead to institutional shifts in the textile industry and efforts should be focused on engaging with producers and consumers to identify how these shifts diffuse in both directions across the value chain.

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Chapter 15
Enhancing Fashion Sustainability Through a Data Systemic Approach

Paolo Marco Tamborrini, Cristina Marino, and Chiara Lorenza Remondino

Abstract Today everyday life is characterized by the interaction with an ever-increasing flow of digital data. The research aims to analyze the fashion industry as a data-driven enterprise in which the correlation of data characterized by greater information power and higher quality gives the chance to make a more informed deci-sion making that lead to undertaking better and more sustainable actions in all the value chain. Data, in this focus, could have the power of increasing the efficiency of the system and reducing its impact at the same time, creating a new model that is not only able to improve environmental, economic and social sustainability but also communicative, enabling a more human-centered products and services designing. This research highlights the importance of giving an integrated and holistic perspective through a data systemic approach to deal with a complex and fragmented sustainable problem, proposing an information flow strategy that makes accessible information improving transparency and traceability. This paper presents several case studies that show how data-oriented projects can contribute some benefits to a fashion system that has environmental sustainability as its priority, but also that the lack of correlation of all these strategies is not yet able to generate and lead to a systemic change.

Keywords Fashion industry · Big data · Sustainability · Systemic innovation design

15.1 Introduction

Today, everyday life is characterised by the interaction with an ever-increasing flow of digital data.

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The fashion system is not new at all to the use of these assets to increase, sales, customer segmentation and consequently its environmental impact.

Harmful to the customer, detrimental to the worker, corrupting to society, polluting to the environment, fashion today embodies one of the most significant failures of the industrial age in term of sustainability. However, the fashion industry is also characterised by complexity, intricate interdependence and a high fragmented supply chain, while the current sustainability strategies lack a systemic and integrated vision.

The increase in population, the demand and the consequent increase in consumption have led to the inevitable involvement in this sector of the technological component in every aspect of the supply chain with the final goal of accelerating production processes and offering unified garments for the mass market (Fletcher 2008). This addition has inevitably caused repercussions and considerable impacts on tailoring production, with the consequent subtraction of the quality of materials and of the product itself.

The current processes of digitalisation of the fashion system include, still not wholly, datafication processes capable of going beyond what is commercialised, allowing to explore patterns of consumer behaviour and unexplored sustainability practices.

Starting from data analysis and exploration, from a design-oriented perspective, this contribution shows how in industries, brands, territories and consumers, a big data-oriented culture can be useful to design new products, services and process throwing the bases for an innovative and sustainable fashion industry (Viktor and Kenneth 2013).

The research aims to analyse the fashion industry as a data-driven enterprise in which the correlation of data characterised by greater information power and higher quality gives the chance to make a more informed decision-making that lead to undertaking better and more sustainable actions in all the value chain.

Data, in this focus, could have the power of increasing the efficiency of the system and reducing its impact at the same time, creating a new model that is not only able to improve environmental, economic and social sustainability but also communicative, enabling a more human-centred products and services designing.

In this, the focus is to understand complex industrial systems and identify the opportunities to transform them into circular systems, where information in outputs becomes the inputs for a more conscious consumer and brand decision (Bistagnino 2011).

The objective of this research work is to explore convergence and divergence between the current fashion data model and a systemic one, able to enhance a sustainable development for fashion industry.

Because fashion generates annual revenues of $1 trillion, provides jobs for half a billion people and dresses us every day, we need to redefine the industry based on severe values. Develop real, structural and systemic solutions for the responsible use of resources and promote a better way of life for all so that we can make the difference between destruction and conservation of the planet. (Bistagnino 2017).

In order to generate a sustainable fashion system, the goal is to integrate all the information about consumer, product, and company usually not related and connected to each other, aware of each other with the surrounding environment. Data, in this regard, might provide to business the opportunities for designing the right product, in a relationship with the right system, to the right person.

The goal is to show that by integrating systems thinking and its methods, the systemic design brings human-centred design to complex, multi-stakeholder service systems.

This research highlights the importance of giving an integrated and holistic perspective through a data systemic approach to deal with complex and fragmented sustainable problem, proposing an information flow strategy that makes accessible information improving transparency and traceability.

This paper presents several case studies that show how data-oriented projects can contribute some benefits to a fashion system that has environmental sustainability as its priority, but also that the lack of correlation of all these strategies can not lead to a systemic change.

15.2 Case Study: Current Trend in Fashion Data

The fashion industry is experiencing today unprecedented change: from one side is contributing to the degradation of the world's biodiversity and undermining nature's ability to provide ecosystem services to society, from the other side has all the potentialities and the resources required to re-design our cultural paradigms from the current to a more hopeful and sustainable one.

However, if there is one thing that has grown in tandem with consumption in fashion, this is the information available in large and small companies able to better manage the complexity of a system so interconnected and rich in variables.

The ability to access millions of data from every sector proves that the latest expertise needs a keen awareness to bear on the world's most complex problems.

The data deluge is already starting to transform business, government, science and everyday life: telecommunications, financial services, retail, healthcare, media and communication are just some of the sectors most involved.

The rich information landscape available today is nourished by every sector that moves objects, which it sells to consumers, that uses machinery, that generates or uses content, that provides a service or that deals with money. For these reasons, the ability to collect, understand, give meaning and communicate information has become fundamental, with enormous consequences and relapse on how to operate and act, becoming a strategic reading of the reference context quantifying the sustainable and unsustainable aspects not only to individual level but above all collective.

Applications of data analysis strategies can be the most diverse, from organisational and strategic decisions within the development of new products and/or services for the consumer. (Banica and Hagiu 2016).

Linkedin, for example, thanks to accurate data analysis on the use of its Web service, has developed an extremely sophisticated recommendation system, sensing "people you may know", "groups that might interest you" and discovering "who has looked at your profile". Still, Netflix, a service for the distribution of movies, television series and other entertainment content, identifying and defining about 80,000 different micro-genres, has come to define the first custom TV, (Marr 2016).

In general, it can be inferred how the data in companies have not only changed technologies but above all processes, management and orientation of organisational culture.

Investigating and considering concepts like sustainability, transparency, traceability and awareness as a final goal, this article aims to investigate the technical, social and creative challenges useful for re-configuring the fashion industry from the use of data.

Big data are acquiring crucial and ever-increasing importance in the fashion world since the last decade. The essential experiments regulate trend forecasting, strategies for optimising supply chain management, analysis of customer attitude online and offline, customer preferences and the more forward-looking the definition of their pattern behaviour (Tham 2008). The fashion world today is subject to rapid, continuous and difficult to interpret changes. The client's needs move transversely from a customised style to the homologation that obliges millions of people to request the same types of garments with only small details of difference (Farley and Hill 2015).

Some, unfortunately still separate, case studies tell how to have new data categories available can be useful to create new services and make the shopping experience more inclusive of consumer needs, more profitable for the company and have a low impact on the environment. The methodological approach applied to the case studies to follow was exploratory through the use of bibliographic reviews and using data from individual Websites. The aim was to highlight as many case studies as possible to understand how the use of a data-oriented strategy could in some way increase or facilitate sustainability practices by connecting or increasing the amount of information circulating in the fashion system.

ASAP54, for example, is the most comprehensive dataset of fashion garments, and it can able to simplify the phases of a search for a specific outfit. Relying on the app's database, it is enough to photograph a dress, or a simple detail of a fantasy to trace the coincidence with a garment. The system that refers to images taken from catalogues can recognise the object being photographed, but if this is not available on the database, the app will provide a set of similar products. Finally, the system can redirect the user to the site where to buy online. This project that offers a research service has the potential to become a portal for shopping on many sites.

Another service able to create a profitable relationship between the management of information for the company and the consumer is Arket. Born with the mission of democratising quality through widely accessible, well-made, durable products, their design aims to be used and loved for a long time avoiding the need for ever-new garments (Arket Identity 2018). The Arket system is based on the Arket ID a unique nine-digit code given to and shown with each product. This system was created to make it easy for the customer to find and re-find product both in physical and digital stores. The code functions also as a tool to archive, record and preserve the company's product.

This system not only allows indexing the products and knowing the details but also makes the relationship between the user's research and the management of company information useful.

However, this useful project lacks a substantial contribution of transparency and traceability of the garments which, by making known the steps of the production of a garment would give the consumer greater ability to choose between their products.

In this sector, the Provenance case study seemed complete. In collaboration with Martine Jarlgaard, an English fashion producer, Provenance tracked the world's first garment with a unique ID holding location mapping, content and timestamps from every step of the production. The journey information was made accessible via the garment's smart label (Provenance 2017). This case demonstrates that a significant database could support blockchain implementation in fashion supply chains in order to enhance sustainable value.

Working with data in the fashion industry means to bring the intangibility of the experience of purchase and consumption to something tangible: Amazon does this through a gathering of photos collectable through its new device in order to compare outfits to find out which looks better. Among all the projects sought, this is one of the few that takes into account the consumer experience after the purchase and aiming to create a lasting relationship between the customer and his clothes improving the management of the outfits and the wardrobe. Echo Look is capable of handling the wardrobe automatically by integrating other sources of data like weather, occasion, season and more mixing territorial and personal data.

It is precisely on the personal experience, on the way we dress, but also on the way in which we present ourselves to the world, the Stitch Fix platform bases its business in a manner to change the entire shopping experience for the consumer.

Collecting data on the fundamental elements of what a customer prefers and condenses within an algorithm, Stitch Fix provide personalised advice for each of its customers (Stitch Fix 2018). This radically changes the shopping experience: in the traditional sales model, customers enter a store, look for available clothes and look for items that best fit their overall style.

With data-driven personalisation, however, machine learning systems and AI best understand customer psychology. The company, therefore, acts as an intermediary between the customer and the personal style of the consumer, focusing on different aspects of the shopping experience, that is the emotional value rather than focusing on a weak relationship based on the logic of trends and consumption. The consumer is then sent a box of pieces, and human input and his personal decision-making process become an integral part of the algorithm. Ultimately, the whole process is based on the idea that data-driven decisions are functional not only to their customers but also to the entire company similar to what happens in other companies Stitch Fix leverages data to automate internal and external processes.

However, the real strength of this vision is never to neglect the human factor in the entire system design process but instead to integrate it by making the whole process adaptive to this variable.

Another case where the contribution of the personal data is crucial is the Data Dress develop by Google in collaboration with Ivyrevel: The app stores the activities and the lifestyle of the user giving life to the perfect Ivyrevel outfit for the occasion (Coded Couture 2018). You only need to specify the type of event: business, party or gala.

Integrating user personality into the design process, the system creates a digitally tailored dress.

This quick round-up of case studies demonstrates a considerable lack of a scientific take into account data relating to clothing use and sustainability production impact. New technologies can offer a new value chain, one that through the collection and analysis of data allows players not only to engage potential customers or increase the number of sales, regardless of where they are and what they are doing but also to direct production to a sustainable path and style in line with user characteristics.

15.3 Influence of Big Data Technologies in Sustainable Fashion Supply Chain

Today, big data deluge is more than a trend or a fleeting fad, and this is demonstrated by the repackaging of many researchers in different academic or not fields in order to fit within the advent of new technology and to better understand the new scenario.

In many levels of interest, data could influence the entire supply chain, and for the fashion industry, it can become crucial. These new possibilities could have a considerable impact from the choice of raw materials to production, up to consumer awareness within the system. Starting from the early stages of production by knowing the preferences of the target client, it is possible to perform short-term forecasting and suit to ever-changing market trends, avoiding the significant risk of overproduction.

However, the use of big data remains limited without the appropriate technologies that support not only the collection but also the management and new production processes that could develop from such a considerable amount of data in continuous dynamism.

The following section presents some of the emerging technologies and some projects which, in improving and optimising the fashion supply chain, do not shirk environmental and social responsibilities and whose impacts are easily traceable.

First of all, the data analysis of customer preferences and options can be redirected to design and e-prototyping.

Being aware of the physical characteristics of consumers for the company is not new: Through sales data, companies can manage and optimise the flow of sizes in the warehouse (Loker 2008). Despite this, a 3D body scanning technology can offer the customer and company a new pool of data more precise and accurate through which get lower their environmental impact.

However, as Fashion-Tech journalist Lorraine Sanders says: “There are fascinating things that happen with the mapping of human bodies, and the attempt to create a predictable sizing through the use of big data could help many sectors—and almost certainly could help the fashion industry” (Sanders 2014).

The new body sizing and scanning technologies, the intelligent scales and all the wearables can create a significant data pool for this sector, and through these data, the companies can create garments perfectly adapted to the needs of their customers eliminating the modification conjectures.

Body scan data can reduce the flow of unsold and returned apparel due to poor fit and assist in building a more sustainable fashion system, providing speedy, consistent and accurate data that could redefine apparel sizing systems and customer preferences.

Custom-sized clothing by definition means that consumer is involved in the design and production process to make garments uniquely for them, based on their individual measurement, not only with one or more fitting and match but also with some decision about style and fabric.

The data resulting from a body scan can keep track of large-scale anthropometric studies giving to the research a measurable impact: from the particular in the guise of the consumer, to the general in the perspective of a territory or the global impact of a given collection. The use of body scan in the fashion industry can also support medical analysis and size can be used to explore related diseases.

Opening the research to increasingly interdisciplinary scenarios and an expanded concept of well-being and human-centred design.

The goal in both approaches is to reduce the flow in the sustainable fashion system by eliminating the production of the unsold garment in a specific territory and improve the customer engagement to.

In marketing phases, collecting consumer data allows a more user-centred design but is not the only advantage. Using data in a systemic way enable companies to fill the gap between the reality and the perception they have of their consumers by measuring, for example, the impact of their advertising campaigns, thus having a continuous feedback system of their users.

Based on finding from social media, blogs, emails preferred product for a specific customer and the effects of a promotion campaign, management can identify new product and services opportunities, optimise pricing and improve customer loyalty and satisfaction.

Sentiment analysis helps companies to analyse every aspect of customer demand through the collection of the responses (likes, shares, comments, re-tweet) to a specific product; thus, not only sales but also marketing and advertising become useful tools for a sustainability transition.

Interlacing this data with sales in a particular time or with the activities of definite influencer, it becomes possible to explore the driver of a target sector and determinate a pattern of behaviour.

When a company has feedback on his marketing activity, and awareness about his impact can invest more safely on customer experience and can sustainably improve their products and service.

Furthermore, the use of sentiment analysis to map consumer behaviour can be extended to areas of data collection that are still inaccessible to businesses.

All usage data of fashion products are currently not collected and conceal a huge potential in terms of sustainability and customer awareness within the system.

RFID technology is currently able to monitor the entire chain from production to sales, to enable an information flow strategy is essential to recognise the value of this technology also to enhance aspects such as the traceability and transparency of the system and not just the logistics aspects. An RFID system is able to capture an extensive amount of data in this context.

For example, when big data are integrated into a clothing company, refers to the connection of location with the flows of goods. By receiving information from a territory related to traffic congestions and safe routes, delays or customer complaints, the management can make the best decision regarding the shipment planning, product delivery, and the security of the transport activity. Nevertheless, mapping territorial resources and activity management can design an intelligent and environmental safe transport plan through visualisation and analysis of real-time data about the supply chain networks.

Therefore, is also crucial adopt information technology to monitoring the product and facilitate communication and information exchange among supply chain partners to satisfy customer needs, enhance operation efficiency and improve decision-making in the supply chain context. (Choi 2016).

Nevertheless, the real value of RFID technology is that unequivocal identification carried out in real time that allows you to handle the many variables that the fashion industry must manage.

Increase system transparency by increasing traceability of pattern of use puts fashion companies in a position to collaborate with their peers and external stakeholders on sustainability more productively.

Traceability becomes in this way a prerequisite for identifying and improving the environmental, social and ethical impact of fashion.

It is interesting to explore how to manage the data and understanding how to make use of it to improve sustainable decision-making.

Another aspect of experimentation through big data collected with RFID technology is, for example, the installation of a system that allows identifying the garments tested in the dressing room to better understand the movements and the selection criteria of fashion products.

The possibility of knowing which items are not purchased makes it possible to reason in a more systemic fashion on the processes of fashion, on the arrangement of goods in the store, but also on the design during production and on possible future developments of textile material.

Data that the RFID technology allows to generate are new both for fashion and, in particular, for retail. Learning to makes it a treasure, also and above all concerning environmental sustainability is one of the critical points of this research. A recent survey by the World Economic Forum reveals that 92.1% of business leaders believe that 10% of people will wear clothes connected to the Internet by 2025 (World Economic Forum 2015). It means that we will be able to generate data that can even go beyond the management of the production process, beyond the mapping of the products in the closet. In this scenario, we will be in a position to map, under the strict control of the privacy rules, the whole experience of use and consumption of fashion items.

The physical space that opens up the possibility of new scenarios through the use of big data is undoubtedly the retail: Here, data can collect the true essence that drives the decision to buy an item or not.

Retailers have long been studying how their customers make decisions about what goods and services to offer. It goes back as far as the Victorian shopkeeper who was the original one-to-one relationship manager working hard to understand customers' tastes and quirks.(Strong 2016).

Retail responsibility in the relationship with the consumer and his awareness of sustainability must, therefore, be tied up for obvious reasons: In this sense, the retail must assert its social impact.

In a data-driven fashion industry, a retailer has a direct connection with customers, so they are in the best position to know customer options and to want to know more: In an integrated big data system, retailers have full access to everything related to the product it sells and the person who buys it.

However, mapping customer inside the retail does not mean to create the perfect sales for the company, and the aim of a data-driven retail strategy has the ultimate goal of gender a closer relationship between consumer and product to lengthen the product lifecycle. The research aims above all to increase his awareness in order to improve the global consumer experience with the fashion product. The collection of wardrobe data, which currently do not represent a priority for fashion system, hides an unspeakable value concerning sustainability.

They could show to the consumer an overview that gives a snapshot of his current relationship with his clothes, with the aim to prevent "errors" and follow the garment cycle of use.

The role of design in this scenario rich of data changes radically. Big data are not there to offer a solution like an oracle, but to guide insight to the point of always putting the human in the centre of every kind of project related to the fashion industry, that as we say at the beginning of this article, has the most profound social nature.

15.4 Discussion and Final Considerations

The present exploratory work contributes to identify information gap and guidelines to develop an integrated strategy of data planning and collection.

Have been recognised three datasets dedicated, respectively, for consumer, product and company. The ongoing research, analysis, development and application carried out by this research present three main types of information are identified to be crucial to the efficient, economical and sustainable strategies on fashion system:

1. Customer information,
2. Product information and
3. The flow of information.

Customer information is important to replace human need over profit, product data could express and share awareness about the process behind, and last but not least, the structure of information flow can be a useful leverage point in the fashion system, if the information is delivered where it was not before, causing people to change behaviour (Meadows 2008a, b).

In the fashion industry, adding to or changing the flow of information between companies in a supply chain or between retailers, designers and consumers can create significant changes for little effort. Contrary to what happens with the sustainability strategies currently in use that are focused on symptoms and endorse methods that try to solve single problems not caring about existing relationships, systemic design approach can be an effective tool to restore the lack of information that concern the whole process and all actor.

This approach, which looks at the larger picture, focuses on the transition from a linear vision, where individual environmental issues are addressed, to a systemic approach, where an improvement of the individual components, if put in relation, corresponds to improvements for the whole industry.

Data can be involved with this innovative approach in the phases of fashion creation and at the same time can implement processes and applications in a more sustainable direction and themselves become tools and materials for design, being a fundamental component of the project and not just its objective This means that for quantitative input of information, it is possible through design and a circular approach to create sustainable value within the system. (Gaiardo et al. 2013). It should be noted that these indications associated with a systemic use of data through the fashion industry are currently lacking experimentation, but attempts have been made to visualise the data if they were available (Remondino et al. 2015).This work was part of our master thesis in Ecodesign at the Polytechnic of Turin, discussed on 22 December 2017. As a proposal for future research, there is no doubt that of prototyping and testing reactions to such visualisations before planning a structured collection of data. This can also be implemented by research on new technologies that can make the collection less manual as possible, and it is assumed that the data collected and displayed are effective especially at the stage of purchase and consumption where you can change the habits and behaviour of consumers.

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Chapter 16
Sustainable Fashion Through Circular Business Innovations: New Business Models Reduce Waste

Nicole Bassett

Abstract The business model of the apparel industry has contributed to harming people and the planet. A new opportunity to accelerate sustainability in the industry can occur with a shift toward circular business models. The linear economy relies on raw materials to generate financial value, thus driving down wages and cheaper practices to access raw materials in order to generate more revenue. Circular business models by contrast, generate value out of apparel and textiles by using them in new ways. This can include sharing, product life extension, resource recovery, circular supplies, and product as a service. Leaders in the circular space are creating these new business models, which are changing the way apparel is bought and sold, as well as increasing the sustainability of the apparel industry.

Keywords Circular business · Linear business · Product life extension · Sustainability

The research explored in this paper is a look at the economic system of the apparel industry and how that system impacts sustainability. This research is based on first-hand experience as a sustainability practitioner since 2004, working with companies and organizations such as Patagonia, prAna, and textile exchange, and currently as the co-founder of The Renewal Workshop—the leading provider of circular solutions for apparel and textile brands. The tactics to create a sustainable fashion industry started with a focus on the product itself, and the supply chain to deliver that product. Today there is an opportunity to look beyond product sustainability, at the system itself in which the fashion industry operates.

Fashion used to be sustainable. About 230 years ago, before the Industrial Revolution in the late 1700s, apparel and textiles were localized, made from only natural materials and at a pace that aligned with the natural resources of the planet. Since the Industrial Revolution, the apparel industry has created non-natural materials that

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A practitioner's perspective

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are no longer able to be absorbed into the natural environment; created supply chains that have exploited labor globally in a rush to drive down prices; and has grown the scale in which apparel is produced, creating harmful side effects of pollution and overproduction (Greenpeace n.d.).

The mid-1990s was the turning point for awareness of the real environmental and social impact of the apparel and footwear industry. Nike's press about its working conditions brought a spotlight on the supply chains and the people who actually made the products (New York Times 1997). This awareness brought about the understanding that the industry is completely reliant on people and the planet to sustain its ability to produce goods. The way in which apparel is made has received further exploration and scrutiny. The more transparent the supply chain gets, the more customers are demanding to know "who made my clothes" (Fashion Revolution n.d.). Campaigns, like Fashion Revolution, are driving continued attention to the subject. As customers learn about issues within apparel manufacturing, and their complicity in furthering harm or good depending on their choices, customer behaviors have begun to influence brands and suppliers to shift toward better supply chain practices. These shifts result in an increase in more ethical fashion, which ultimately benefits the industry.

Early advocates for sustainability aptly identified a need for the apparel industry to adopt a triple bottom line approach to business—People, Planet, Profits (Elkington 1999). For the past ten years, members of the apparel and textile industry have built tools to identify, measure, and change products and supply chains to adjust the environmental and social impacts of the industry; led by members of the Sustainable Apparel Coalition. The work done up until recently on the triple bottom line remained heavily focused on understanding the environmental and social impacts. The opportunity now exists to change the financial levers within the triple bottom line, to create as significant of benefits.

Currently, the business model of the industry is linear, where the only way to achieve financial growth is to make more clothes. The opportunity exists to shift to new business models where economic growth aligns with social and environmental sustainability. If the industry can adopt these new business models, an economy that integrates the environment, people, and financial value can emerge. Only with this integration will there be an industry that is inclusive and regenerative.

The tipping point for change is also being driven by a constraint on resources. The Industrial Revolution aided in the scale of manufacturing to the point where negative impact also comes from the volume of products that are created and consumed. According to Cruickshank (2017) currently, "Americans buy five times as much clothing as they did in 1980."

Accenture Strategy produced the report "Circular Advantage" in 2014, identifying the resource demand and supply imbalance. They show that based on the resources used to create the products of today, there will be a deficit of resources to achieve the projected business growth in the future(Accenture Strategy 2014). This imbalance will directly impact businesses as they plan to scale and their access to resources is not available.

The terms linear and circular entered economics in the mid-1960s as a reflection of open and closed material loops (Pearce and Turner 1989). The economy can be defined as the production and consumption of goods and services, which ultimately moves financial value around. Out of the Industrial Revolution, the global economy emerged as a linear model. What this means is that products are produced from raw materials (cotton, steel, plastic, etc.), businesses sell those goods, consumers buy those goods, use them, and at the end of their useful life, those products are often sent to landfill. A linear economy takes, makes, uses, and wastes.

Manufacturing before the Industrial Revolution was done at a small scale, and resources were highly valuable because the ability to extract them was only limited by machinery and technology. For example, if it took a person two days to cut down a tree, then it took a dozen people one month to strip the tree of bark and cut it into useful materials, the wood was highly valuable. Today, hundreds of trees can be cut in one day, loaded on trucks, and sent to sawmills, where they are stripped and planed into lumber in a matter of hours. Speed and access to raw materials have shifted our culture, society, and economy.

When products were more valuable, we managed them differently. Jars, clothing, and tools were attended to with care and used repeatedly until there was no more useful life in the product. Only then were products recycled into something new. The ability to recycle was easier because these items were made from a single material (cotton, wool, steel, wood, glass, etc.). For example, clothing was made of either wool or cotton, so it could be cut into smaller pieces, used as rags or even used to spin new yarns; and at the end of its life, that material could be composted.

Today, materials management is very different. Along with the speed of resource extraction, the Industrial Revolution brought about entirely new innovations in materials. Most notably, innovations in chemicals resulted in a multitude of cheaper, convenient products. The most widely used today are plastics. Toothbrushes, speakers, and packaging all contain these new materials that are not made from a single material, but new compounds that are not easily broken apart. These products now were not only made of less valuable materials, but a mix of materials that were never designed to be broken apart.

In the linear economy, we have a high number of products that were quickly extracted from raw materials, designed to be used once, and cannot be recycled. In the 1960s, the linear economy was starting to show its impact on the environment (Carson 1962). This impact inspired several various thought leaders to ask good questions about how we might do business differently.

16.1 The Opportunity is Circular

If the goal of an economy is to produce and consume goods and services to move financial value around, can it be done so in a way that does not cause harm to the planet and people on it? The idea of a circular economy emerged as a response to the awareness that the linear model does not work in a closed system, the earth being the closed system in which the economy relies on. In this circular economy, we must look at raw materials as valuable again; so valuable that once they are extracted, we build a system that uses them forever.

Best defined by the Ellen McArthur Foundation (2017), "The circular economy is restorative and regenerative by design. Relying on system-wide innovation, it aims to redefine products and services to design waste out, while minimizing negative impacts."

Similarly, a circular business is one that takes into consideration from inception where their products came from, and where they will go. In a circular business, there is no waste; there is only a positive impact on the planet and the people who make the product. A circular business works within a system to flow materials through at their highest value. And it is profitable. In fact, more profit can be made because the value is created throughout the lifetime of a product.

Circular businesses tied together to create an economy. In a circular economy, there are new ways of generating revenue. The World Business Council for Sustainable Development released a CEO Guide to the Circular Economy in 2017, focused on inspiring opportunities for the business community.

The World Business Council for Sustainable Development develops tools for CEO's, so that they can innovate their businesses inside the circular economy. As outlined in Fig. 16.1, there are five business models that apparel and textile companies can look to for inspiration as they shift away from the linear models they are reliant on now.

Circular Supplies—Use renewable energy, bio-based or fully recyclable input material to replace toxic and single-lifecycle inputs.

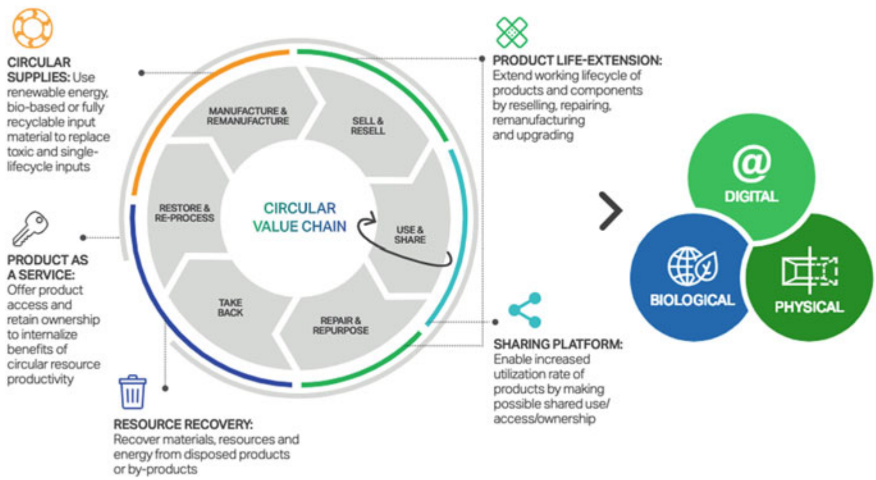

Fig. 16.1 World Business Council for Sustainable Development (2017) "CEO Guide to the Circular Economy"—Five business models and three disruptive technologies

Product as a Service—Offers product access and retain ownership to internalize benefits of circular resource productivity.

Resource Recovery—Recovers materials, resources, and energy from disposed products or by-products.

Product Life Extension—Extending the working lifecycle of products and components by reselling, repairing, remanufacturing, and upgrading.

Sharing Platform—Enables increased utilization rate of products by making possible shared use/access/ownership.

These circular business models are not just academic ideas, but real businesses in the early stages, testing the ideas of circular and demonstrating that financial growth can be integrated into social and environmental benefit.

The following are three case studies of companies that explore one of the WBCSD examples for circular business models. Each includes an overview of the business model, and how revenue is decoupled from resource use. This is allowing the business to address the resource availability and demand tension, and work within a closed system like the earth's ecosystem.

The Renewal Workshop—Product Life Extension.

Circular, at The Renewal Workshop, is a new framework for doing business. As experts in the apparel industry, The Renewal Workshop looked at how the industry makes and sells apparel in a way that does not lead to waste. The first step was to actively stop the linear economy in its tracks by taking the waste that was being created, and finding a new path for it to follow.

The Renewal Workshop (TRW) is the leading provider of circular solutions for apparel and textile brands, offering Apparel and Textile Renewal, Sales Channel Management for Renewed Products, Circular Mapping, Data Collection, and Textile Recycling R&D. The proprietary Renewal System takes unsellable apparel and textiles and turns them into Renewed Products, upcycled materials, or feedstock for recycling. The Renewal Workshop operates a zero-waste circular system that recovers the full value out of what has already been created as a way of serving customers, partners, and planet (Fig. 16.2).

The Renewal Workshop enables the next use for apparel and textile products. Items that cannot be resold by a brand because they were returned by consumers for being used or damaged, can go through the Renewal System, and then be sold as a certified Renewed item. The Renewal System organizes, cleans, repairs, and quality checks each piece, so its new owner can have the satisfaction of a quality product with a lower environmental impact. This model allows any apparel brand to collect back their products from customers and keeps it in use as Renewed Product or materials for recycling.

The Renewal Workshop works with twenty different apparel brands from the outdoor and fashion industry including companies such as prAna, The North Face, Indigenous, and Mara Hoffman. Through the partnership, these brands are extending the life of their products and are generating new revenue off their old products. By creating a new revenue model for these brands from products that already exist, this reduces the need to create new products to generate that same revenue.

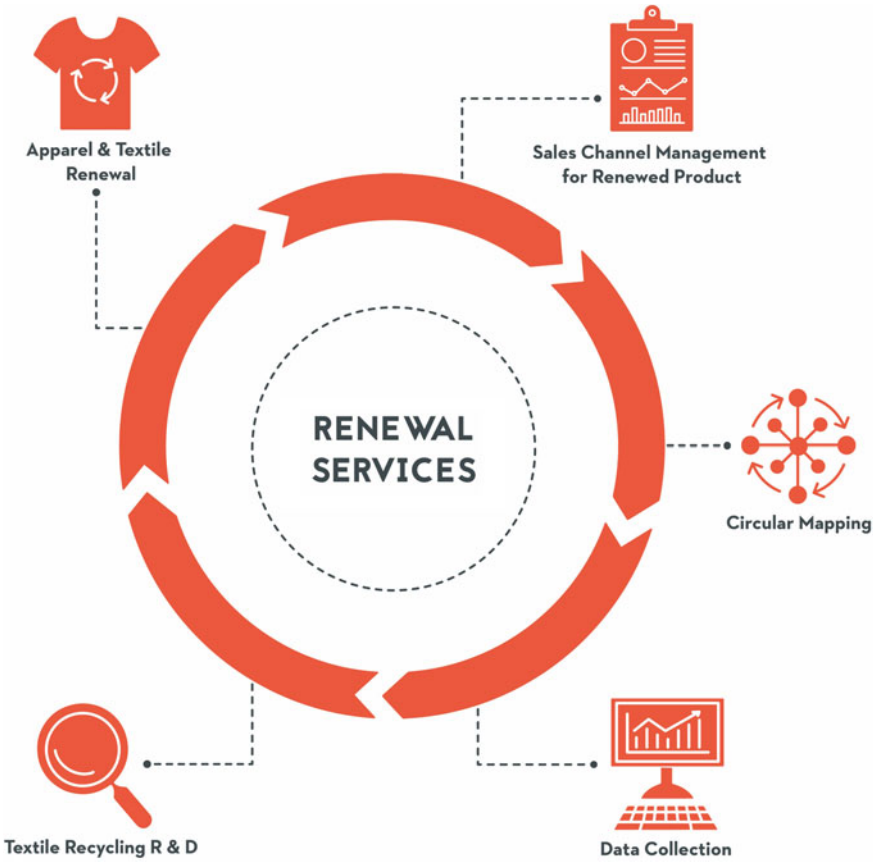

Fig. 16.2 Renewal Workshop Renewal Services (Illustration by the author)

The future economy will see value in every material used in the production and consumption of goods. Those products are able to generate value in the next use as well as become a new raw material for a new future product. A circular system does not create waste.

Silk Roll—Sharing Platform.

The sharing economy is probably best known for companies like Airbnb and ride shares like Lyft and Uber. The idea is to utilize products not in use, and create revenue from the sharing of the item. Sharing apparel has been done as an activity for generations—like giving to friends or organized clothing swaps. In 2013, apparel thrift and consignment companies started emerging online. Companies like Thredup, The RealReal, Vestiaire get useable products out of people's closets and back into use. These companies generate their revenue from the sale of the used items.

Silk Roll started in 2015 with the intention of providing a sharing platform where the customer is given points for their clothing, and those points can be used to access other clothes. It is an exchange where the customer can rotate their clothes from the available inventory. They leverage the digital currency and trade to build value in their business. Revenue for Silk Roll comes from a service fee on each order that is made by a customer.

The ability to create a business on the behavior of sharing is a unique concept that will increase the utilization of products already in use. The behavior of buying and owning products will shift as companies like Silk Roll provide an alternative to customers who do not want to own products. Using a digital currency of points shifts the customer from a financial transaction to a sharing exchange. The mindset of exchange shifts toward the circular mindset where products are part of a larger system of use. Silk Roll brings that experience to apparel by providing a Web site, and a selection experience in a way that feels high end, despite the fact that the product itself has had multiple owners. Sharing platforms increase the use of existing products, providing an alternative to buying new products, thus reducing the environmental impact of creating new clothing.

For Days—Circular Supplies.

For Days was founded in 2018 on the principles of closed loop. The founders spent time identifying the whole system from the beginning—how products would be made, used, and then sent to their responsible next use. The company offers a service to customers for basics that are worn often and not likely to have a second owner, such as basic t-shirts and tank tops. The customer buys a membership and can then swap out their shirts at any point, paying a swapping fee. The products are 100% organic cotton and designed so that they are easily recyclable. This model allows the company to maintain "ownership" over the product while it is in use by the customer. When the customer is done with the product, too stained or damaged for further wearing, it is then recycled down into fibers, and those fibers are spun with virgin cotton for future products.

For Days embodies the circular supplies by using a bio-based raw material and by designing their products with recyclability in mind.

There is a new revolution in sustainability occurring in the apparel industry right now. As more examples of circular business models move to the mainstream, the foundation for how the industry makes, uses, and manages its resources will be driven by not only environmental and social benefit, but be reinforced and sustained by new economic models.

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Part VI
Behavioral and Societal Aspects in the Textile and Fashion Value Chain

Introduction

Already during the industrial revolution in Europe, the textile industry played a major role in social and behavioural changes. For the rural population, a further source of income was generated in the large textile factories, which led to strong population growth, especially in the cities. By using machines, the working population in the factories had to adapt to the cycle times of the machines. Thus, daily routines adjusted to seasonal requirements changed and led to the well-structured ones to which we are all subject today. Even then, the oversupply of human labour was exploited by a few capitalised members of society who owned the assets to make profits on the products produced. These developments are now taking place almost unchanged in developing countries. The fact that Bangladesh today has the largest increase in wealth in the world is illustrated by this repetition of history.

At the same time, workers started to join together to form trade unions to demand their rights and to participate in the sparkling profits of the textile export economy. Witnessed also nowadays, this is even strengthened and supported by European role models of labour unions and globally operating NGOs. The almost worldwide availability of information and knowledge via the Internet, the use of smartphones and further aspects are accelerating these developments.

In addition, especially in developing countries, new career prospects are also emerging for many women in the textile industry. As an example, through the easier accessibility of information and knowledge, new possibilities for self-realization arise through the educational offers, but also through the sole getting-to-know of strong female personalities, who become their role models and give them the strength to break out of ancestral systems.

Last but not least, safety and health aspects are playing an increasingly important role in the changes taking place in developing countries. Only the knowledge of the various safety standards that have been built up over decades in industrialised countries and their implementation in their own companies has been leading to a significant improvement in working conditions and a reduction in accidents. The factory inspections carried out under the Bangladesh Accord on Fire and Building

Safety launched in the aftermath of the Rana Plaza factory collapse in Dhaka in 2013 are just few examples of such changes.

In the following chapter, three different focal points from this topic area will be examined. Thereby, particular attention is given to two of the world's largest garment manufacturing countries, India and Bangladesh. In his contribution, Rathinamoorthy analyses the knowledge of consumers in India about the "Slow Fashion" concept. In particular, he discusses the obstacles and challenges for a far-reaching implementation of slow fashion.

In their contribution, Siddique et al. describe the developments in Bangladesh, including the personal perception of university professors who teach textiles in the country. The training and further education of personnel for industrial production with skills and competences as well as increasing the awareness of future middle management of sustainability issues will also play a decisive role for the future of the country's textile industry.

Beyer and Arnold examine in their contribution how discussions on circular approaches and business models for social sustainability in the textile industry developed in parallel in theory and practice between 2008 and 2017. Using the practical example of the fast fashion retail brand H&M, an attempt will also be made to illustrate the changes in corporate communications concerning sustainability efforts following the devastating collapse of the Rana Plaza factory in Bangladesh.

Chapter 17
Slow Fashion—Mindset and Acceptability Among Indian College Students of Tamil Nadu

R. Rathinamoorthy

Abstract The most popular and dominant paradigm in the fashion and apparel industry is the fast fashion system, which ultimately motivates the customers to consume more than they need. The fast fashion and cheap quality products encourage the customers to dispose of their apparel products more often than usually, and so it increases the amount of solid waste in the environment. With regard to sustainable apparel production and utilization, many initiatives and strategies were developed and adopted in society by various governments and private organizations around the world. One of the sustainable concepts, which is very customer-oriented, yet least explored is the "slow fashion" concept. The concept of slow fashion has different versions of definitions for designers of apparel products, for manufacturers, for retailers, and for consumers. The main objective of the research is to analyse the consumers' knowledge about the slow fashion concept, their perspective on the fast and slow fashion designs and apparels. Various barriers and challenges concerning the implementation of slow fashion in a large-scale level are discussed. In this study, a survey among the centennials, also known as "Gen Z" consumers about their environmental awareness, clothing purchase and disposal behaviours along with the slow fashion concepts was conducted. The results of the study revealed that consumers do not have enough knowledge about the environmental impact of the apparel products. The preference of fast fashion products mainly is based on their behaviour like the latest trend, personal lifestyle and fashion knowledge. The results further indicated that the centennials are more concerned about the environmental issues, and they are ready to follow the slow fashion apparels if it is properly offered. All the results were analysed with regard to the implementation possibilities of slow fashion practices among the consumers.

Keywords Sustainability · Fast fashion · Slow fashion · Consumer knowledge · Acceptability · Implementation barriers

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17.1 Introduction

The major driving factor for the world's fashion industry is fast fashion. As the name suggests, the idea of fast fashion is a fast response. It is converting the luxury fashion from fashion shows across the world to a mass market in a shorter time than the past decade. Previously, the conversion from the design to apparel has taken approximately six months to one year. Also, the brands were selling two or three seasons in a year. However, as the fast fashion trend emerged, it changed the industry totally. The concept is defined as low-cost clothing collections, which are imitations of the current luxury fashion clothing items being in trend (Fletcher 2008). The fast fashion system motivates faster production and encourages higher disposability. This system pushes the consumers to buy more than they need. As a result, the average consumption of textiles and apparels per capita increases, and at the same time, the utilization percentage per article reduces in an exponential way. A research report mentioned that clothing consumption increased by 15% in 2017 compared to the previous year (Circular Fibers Initiative analysis 2016). They also mentioned this increment noted in all the nations invariable of their economic nature. The overall consumption of apparels in 2017 was calculated as 842.7 billion USD with an incremental rate of 5.5% compared to the previous year. In 2021, the apparel market value will increase to 1004.6 billion USD with a growth rate of 19.2% (Ganit Singh 2018). Fast fashion is one of the major factors for the over-consumption of apparels, which motivates customers to prefer clothing by following fast-changing trends. Hence, the fast fashion sometimes is known as "throwaway fashion" (Bhardwaj and Fairhurst 2010). The main drawbacks of fast fashion are:

- the concept does not bother about the quality of the products
- the concept encourages quickly disposable (short life) products
- the concept focuses on cheaper raw materials
- the concept does not bother about how it is manufactured (environmental pollution).

The main advantage of the fast fashion system is low cost, fresh design, and quick response time from the luxury fashion to the mass market. The major issue with the fashion industry is that they are working in the "linear economy" model, the most accepted version of the economic model since the Industrial Revolution. The linear economy model is generally termed as "take–make–dispose of" strategy. The hunger for the raw material is very high in this kind of economic model. As the fashion industry is stuck with this model, the pollution of the environment caused by the textile and fashion industry increases multifold every year. Higher utilization of resources is the major flaw of the linear model without bothering about nature and their reproducibility. According to the literature, the material scarcity is already evident in the market in terms of volatile markets and raw material prices (Bocken et al. 2016; Towards Circular Economy 2014; Resource Revolution 2011).

In contrast, Kate Fletcher, one of the leading socialist, coined the word "slow fashion" pointing at the fact that the consumption of fashion products increased multifold due to too frequent and volume buying. A report mentioned that people are buying one third more garments than they did four years ago (Allwood et al. 2006). The term slow fashion is defined as "something durable, made from recycled or organic materials" (Holt 2009a). In 2006, Sharon Astyk wrote an article on "slow clothing" in an online magazine, where she pointed out the impacts of cheap quality cloths on the environment and questioned the fashion industry about its exploitation of the environment and poor people. She suggested to increase awareness and to reduce clothing purchase by using high-quality products with long life (Sharon Astyk 2006). Other researchers mentioned that slow fashion is a term which is used to identify the solution for changing the fashion product based on a sustainable way. This includes the design, production, consumption, use and encourages reuse of products. It further addresses the ethical way of doing manufacturing at every stage of the product's life cycle (Clark 2008).

Additionally, in her book on "*Sustainable Fashion & Textiles: Design Journeys*", Kate Fletcher mentioned that the problem is the "speed". Initially, the fashion seasons were two and now they have become eight to twelve seasons (Fletcher 2008). These new collections make people buy more; but at the same time, Fletcher also did not fail to mention that we cannot give up fashion as it is our culture and identity. The author also mentioned that we obviously need fashion in our culture and society, but we also do need it to be sustainable. This is where the author sees the potential of the slow fashion concept. She mentioned that it is the time for "slow fashion" in society and for considering the true cost of choosing quantity over quality. Clark (2008) mentioned that the real motive of slow fashion is not slowing down the apparel or fashion supply chain but creating sustainable practices in each step of manufacturing from the planning and designing to the consumer education. He also lists three attributes as components of slow fashion like (1) considering local resources for the production, (2) transparent system for production, and (3) long-life products. Other literature differs in their approach towards the concept of slow fashion. Johansson referred to it as "farmer's market approach" to clothing (Cataldi et al. 2013). Watson and Yan mentioned that the slow fashion suggested being the opposite of fast fashion, however; it does not have any formal definition. They had mentioned that it is often a stigma, given to retailers who produce long-lasting clothing that is typically not in response to quickly changing fashion trends. Zoica Matei had been identified as slow fashion stores, and they are incorporating concepts of green, recycled, and fair trade into their trans-seasonal clothing (Kristin 2018; Cordero 2008).

As an effect of the slower production cycle, the coexistence of environment and society in a healthier way increases and so it allows time for the environment to regenerate by itself (Clark 2008). However, few authors defined slow fashion as the direct opposite to fast fashion (Holt 2009b). Cline (2012) mentioned the inherent nature of the slow fashion, as it is produced exclusively in small batches based on requirements; it reduces the consumption of resources. In the slow fashion system, it is possible for designers to invite consumers to the design process, which satisfies their needs for creativity and identity (Watson and Yan 2013). However, the existing practices in the fashion industries are more time-oriented instead of being quality-oriented. Hence, the impacts of the fast consumption and sustainability issues related to them are discussed in the next section.

17.2 Fashion and Sustainability

Fashion and sustainability are both extremes that cannot be united in a short span of time. The textile and fashion industry pollutes the environment in all aspects like air, water and solid waste. So achieving sustainable production in the sector is the most complicated issue as ever known. Sustainability is a process of maintaining a balance in fashion production, which includes resource utilization, directions of investments and technological developments. Changes should be well balanced and enhance the current and future potential to meet human needs and aspiration.

The word sustainable clothing or apparel represents the clothing or apparels which are manufactured by any or all of the sustainable concepts like a societal response, environmental aspects and fair trade manufacturing (Goworek et al. 2012). Natural Resources Defence Council (NRDC) report that the apparel industry pollutes the air and water significantly every year, along with solid wastes and has the largest carbon footprint globally. The 20% of the world's pollution is generated by the fibre-to-fabric conversion part of the textile manufacturing activity. The report further stresses the relevance of the entire supply chain instead of single operations for polluting the earth (Henze 2018).

The textile and fashion industry contributes to 10% of the world's greenhouse gas emissions, which is more than that of both the aviation and shipping industries combined in the world. Cotton is the majorly consumed fibre in the textile and apparel industry due to its quality characteristics. Research estimated that cotton used in a pair of jeans requires more than 2700 L of water (Siegle 2011). As a living example, the Aral Sea in central Asia, the world's fourth-largest lake, has nearly disappeared due to the water reduction from the main rivers (which feed the lake), like Amu Darya and Syr Darya. They were utilized for 5 million acres of farmland in the Ferghana Valley (Micklin and Aladin 2008). The Aral Sea disaster is known as "one of the planet's worst environmental disasters" (Daily Telegraph 2010). Further, it is also noted that 24% of insecticides, and 11% of pesticides used in the world is for cotton cultivation (Drew and Yehounme 2017).

Next to water, the industry also consumes the earth's non-renewable resources like oil. The major resource consumption in the textile industry incurred in synthetic fibre production, fertilizers to grow cotton and chemicals to produce, dye, and finish fibres and textiles. It is approximately 98 million tonnes in total per year, including oil (Ellen MacArthur Foundation 2017). Next, the industry also pollutes the ocean with microplastics. This has become a recent hot issue due to the potential negative impacts associated with aqua and human life. Previous research mentioned that around half a million tonnes of plastic microfibres are released annually from clothing during washing. The rationale for the shedding is the increased use of synthetic fibres like polyesters and nylon (O'Connor 2014). The environmental impact of a garment is mainly calculated based on its carbon footprint. This impact on the environment of any apparel is depending on what raw material is used in that garment. Compared to cotton, synthetic fibre is used in fast fashion apparels due to the ease of production and cheap cost. Whereas cotton is known for its enormous water consumption, the synthetic fibres like polyester and nylon emit as twice as the amount of greenhouse gases per kilograms used. Approximately, 5.5 kg of greenhouse gas is emitted from a polyester shirt; whereas in case of cotton, it is 2.1 kg. It is also mentioned that about 706 billion kg of greenhouse gases released from polyester textile production per year equal to 185 coal-fired power plants' annual emission (Drew and Yehounme 2017). In October 2018, a documentary titled "Fashion's Dirty Secrets" was released by BBC investigating and reporting that it is one of the top five most polluting industries on the planet (Planet aid 2018).

In summing up, as the fast fashion trend increases, the end-users are not bothered about the environmental impact of the clothing material and increase their quantum of purchase drastically. This pushes the supply chain to deliver more output than in the earlier process. This is like an endless loop, creating pollution in society. Research by Circular Fibres Initiative mentioned that there is a reduction of 36% in an average apparel usage by an individual in the last 15 years (Circular Fibres Initiative analysis 2016). A value of 460 billion USD worth clothing materials was thrown away earlier than that they might have been used. Moreover, few apparels were disposed of after just ten wears (Trade Association Textile Recycling 2016). Collectively, all these information indicate that the emerging fast fashion trend has drastically increased the quantity of purchase and disposal and is playing a vital role in the environmental impact.

17.3 Slow Fashion

As an alternative to the fast fashion concept, a new term "slow fashion" is now becoming the attention of researchers. The ideology behind the concept is producing sustainable clothing without causing any pollution. This sustainability can be achieved in all the stages of production, from the design concept to the end-user (customer). The fundamental concept of the slow fashion is inspired by the "slow food movement" founded by Carlo Petrini in Italy in 1986. According to the literature, slow fashion is all about designing, producing, consuming and living better. The main factor in the slow fashion concept is quality. Further, it is not the opposite of fast fashion; instead, it is a different approach where the designers, manufacturers and consumers are well aware of their actions and concerned about their environmental impact. Due to the technological advancements, individual customers are updated to the current trends in the market. As a result, they are motivated to update their wardrobe for every season. To achieve customer satisfaction in the fashion world, short lead-time and rapid production became the standard mantra. This is the major cause of all the issues. When the requirements increase, the manufacturers increase the production with low price or the same price, so the manufacturing firms prefer cheap raw material and compromise quality aspects of the product. Hence, the fast fashion end product's lifetime is shorter compared to the quality products (Byun and Sternquist 2008). As the fast fashion concept is majorly driven by the consumer requirements, the "slow fashion" philosophy intents to educate the consumers of the product. This was clearly mentioned in the article by Fletcher as, it is not the process of slowing down the speed of the fashion cycle; but instead, it is a socially conscious act, which makes the consumers understand the needs of quality over the quantity. Further, it also encourages consumers to buy high-quality products so that the life of the usage can be increased significantly.

Fletcher also mentioned in her book that the slow fashion concept should be incorporated in all stages of product development: From the ideology to design, design to product, production methods, the way it is transported, the way it is consumed and disposed of. At every life stage of any product, consumers or manufacturers should mind about their environmental impact and social sustainability (Fletcher 2008). In general, slow fashion makes the customers be aware of their clothing based on their local culture and that it is produced from locally available resources. This ultimately makes the supply chain transparent and reduces the number of intermediate producers. This makes the people to work along or to interact with each other (designer, manufacturer and consumer). When the product is manufactured locally with local resources and workers, it ensures community development and diversity. This local manufacturing reduces the transportation costs and their subsequent environmental impact and so there are fewer carbon footprints on each product. By shortening the supply chain, the slow fashion concept encourages social and environmental sustainability (Jung and Jin 2016).

The literature mentioned that functionality, authenticity, equity, localism and exclusivity are the attributes of the slow fashion process as shown in Fig. 17.1 (Jung and Jin 2014; Pookulangara and Shephard 2013). It is assumed that these attributes are the major driving factors, which shape the slow fashion concept. In the five attributes mentioned, equity represents fair trade, fair compensation and a fair working environment in the manufacturing. This attribute details the transparency of information to the customers and their awareness of it (Clark 2008). Authenticity refers to consumer's tendency towards the originality of the products like sustainable production methods, original craftsmanship over the machine-oriented fast production system. Functionality is the third attribute of slow fashion, which is related to maximizing the utility of the fashion product (Cataldi et al. 2013). The next attribute is localism. It specifically stresses the factors like the production of products with local resources, such as skilled artisans, local factories, or locally produced raw materials. Another important attribute is exclusivity that opposes the ready-made mass production. It emphasizes uniqueness through exclusively available fashion items, so it increases the value and emotional attachment to the product. These factors will result in a longer usage of the fashion product.

Fig. 17.1 Different attributes of slow fashion (authors own illustration)

Many other literatures mentioned that to take the "slow fashion" concept into action, it is necessary to educate the consumers regarding the material and technology side of the product (Gonzalez 2015; Goworek et al. 2013; Gargi and Ha-Brookshire 2011). The second major issue with the slow fashion product is the cost. The process compels the apparel manufacturers to make efforts to introduce and include environmentally friendly, ethical and sustainable practices into the concepts, product designs, manufacturing methods. The process of manufacturing slow fashion products also insists on quality production, craftsmanship and skilled operators in the manufacturing (Pookulangara and Shephard 2013; Gam and Banning 2011). For instance, the designers are encouraged to consider the "cradle-to-cradle" approach, so that the design phase itself can define the usefulness of the product at any stage of its life cycle. Moreover, the designers can also predetermine the life of the product along with how it can be discarded or how that can be re-used (Gam et al. 2009). In manufacturing, the companies use sustainable raw materials like naturally grown fibres and naturally dyed materials; for instance, the cost of the material will be much higher than the synthetic fibres. The factories also adapt fair wage policies to the workers, which make them pay the correct amount of wages. Further, as the expected quantity of sales per season is smaller, the slow fashion retailers cannot order a bulk quantity like a fast fashion retailer, henceforth the cost of transportation or shipping increases marginally per garment. Along with these factors, the eco-friendly tags, packing materials, printing inks, etc., add more cost to the product.

All these requirements make the manufacturers spend more on every product they produce, and so the increased cost is an unavoidable issue with the slow fashion or sustainable apparel products (Benson 2017).

The other most important problem associated with this sustainable or slow fashion product is trust among the customers about the authenticity of the product. Sometimes the customers are even ready to pay more for the product, which is more sustainable; however, they have doubts regarding the originality. The customers are not sure about whether they are paying for authentic products or not. This is because of the increased negative publicity of leading retailers like Zara, regarding the poor working conditions of their factories and culture of their employees (Perry 2012). This is due to the lack of a clear mechanism to authenticate the originality of the sustainable product or brands in the market. As a consequence, customers think twice before spending more money.

In summing up, the slow fashion system is an alternative way or approach, which includes more consumer-oriented attributes. As it relates to the product, and economic and social sustainability altogether, practicing slow fashion in the society requires more knowledge for the end-user or customer. Major attributes listed by the literature are very consumer-oriented; however, the consumers either lack the know-how about those attributes or they do not even know them. Addressing this gap between the academic literature and the consumers' knowledge level is the major objective of this research work. Hence, this study aims to analyse the consumers' knowledge level about slow fashion, their basic purchase motivations and their overall attitude towards the acceptability of slow fashion.

17.4 Methodology

17.4.1 Survey Methods and Geographical Location

The study focused on Gen Z customers because they never knew the world without unlimited digital access. They are more of tech-savvy, and they are mentioned as mobile natives by a Google survey (Woo 2018). They spend more time "online" than any other generation (Woo 2018). This makes them think differently and adapt to trends in a faster manner. They update their wardrobe more frequently and consume more resources, as they are available (Park 2015). A total of 200 undergraduate students from 22 different majors participated in this qualitative analysis. The participants are able to speak and understand English and the local language Tamil. All the participants were undergone for a small direct interview to evaluate their fashion conscious and knowledge on environmental problems in general. Based on their habits like purchase motive, frequency and adaptation to the latest trends in the market, 152 participants were selected for the qualitative study. The survey was conducted for different discipline students at a different time (April 2018–June 2018) based on their availability. At each time, a minimum of 15–20 participants was included. The session lasted for 30–45 min, the participants were briefed about the concept of slow fashion and the questionnaire was provided to them to evaluate their acceptability of the concept. The qualitative analysis method was selected due to the different lifestyle and background of the participants. As the research is focused on the evaluation of some specific criteria related to the slow fashion concept, the survey method is selected.

The survey aimed to collect the combined attitude of the respondents towards their behaviour concerning clothing purchase, use and disposal attitude. The survey was conducted in leading engineering institutions in Coimbatore (11.0168° N, 76.9558° E), Tamil Nadu, India. The questions presented in the survey were grouped under four broad categories based on the previous literature as follows:

1. Environmental concern analysis (Kim and Damhorst 1998; Roberts and Bacon 1997);
2. Purchasing behaviour analysis (Fletcher 2017, 2008; Clark 2008);
3. Apparel product disposal analysis (Fletcher 2017, 2008; Clark 2008); and
4. Slow fashion acceptability analysis (Gam 2011, Ka-Leung et al. 2013).

The questionnaire was distributed and collected in both methods offline and online. In case of the online analysis, the online survey platform Google forms were used to collect information and analysis.

17.4.1.1 Environmental Concern Analysis

In this section, the consumers' knowledge and their concern towards the environment during their purchase time were analysed by three questions.

1. Do you know about the environmental pollution caused by every garment produced?
2. Will you consider environmental impact before purchasing?
3. Do you know about the environmental impact of fast fashion in production and disposal?

17.4.1.2 Purchasing Behaviour Analysis

To evaluate the purchase behaviour pattern of the Gen Z consumers, the following questions were included into the survey. The questions are:

1. What is your major motivating factor for the purchase of new apparel?
2. How often do you purchase a new garment?
3. How much do you spend on clothing every year?
4. Which is the important factor in your purchase decision?

17.4.1.3 Apparel Product Disposal Analysis

To measure the factors which motivated the disposal of apparel products, the following questions were incorporated in the survey and the results were analysed.

1. How frequent do you dispose of your clothing?
2. Which is the main factor that motivates the disposal of the garments?
3. Which category of garment type will you dispose of very often?

17.4.1.4 Slow Fashion Acceptability Analysis

Based on their knowledge about the environment as well as disposal and purchase behaviour, the consumers' opinion about the slow fashion concept and its acceptability for the individual customer is requested with the following questions.

1. Have you been aware of the slow fashion concept before this survey?
2. Which of the following do you think will increase the lifetime of the apparel: increasing the quality, using a garment in multiple ways, repairing the old garment, reuse the second-hand garment, donating to others?
3. The "slow fashion" concept reduces the quantity of purchase and increases the quality of the product. Will you go with this concept?
4. How much can you spend extra for the quality and durability of the slow fashion product?
5. These are the key elements of slow fashion garments: locally manufactured, multifunctional, buy on requirements, knowledge about the product. State your position against each element.
6. In general, your attitude towards buying slow fashion apparel is …?

17.4.2 Details of the Respondents

A total number of 152 participants participated in this survey with a gender distribution of 67.8% female and 32.2% male. As the survey was planned to conduct among the "Gen Z" consumers, the majority of the participants were undergraduate students within the age limit of 18–24. Among the respondents, 76.3% are within the targeted age group of 14–18. The details of the respondents are provided in Table 17.1.

Table 17.1 Personal information of the respondents

Criteria	Frequency	Per cent	Cumulative Per cent
Student	116	76.31	76.31
Professional	29	19.07	95.38
Others (Employers, entrepreneurs, etc.)	7	4.62	100
Total	152	100	

17.5 Results and Discussion

17.5.1 Environmental Concern Analysis

The first section of this analysis evaluates the consumers' mindset towards the environmental impact of apparel products. The respondents' awareness of the pollution caused by fashion products is provided in Table 17.2.

From the results, it can be noted that only 25% of the respondents ($N = 38$) were already aware of the environmental impacts. Around 25.65% of the respondents ($N = 39$) mention that they know about the issues, they have selected 4 in a 5-point Likert scale rating. 75 respondents (49.34%) selected either 3 or less than three ratings in the Likert scale, meaning that they either do not know or know very little about the environmental impacts created by the apparel production. The respondents were also asked about their preference of products based on their environmental impact in the manufacturing stage. The results are provided in Table 17.3.

If we consider the rating of 4 and 5 meaning that respondents consider the impact of environmental issues before buying, out of 152 respondents, a sum of 38 respondents (25%) mentioned that they are considering the environmental impact before purchase. 32.89% mentioned either they are not worried about it (3 = neutral) or they do not purchase. Only 25% of the customers mentioned that they will consider the impact of production in the manufacturing stage during the purchase.

For the question about the environmental impacts of fast fashion in production and their disposal activity, the responses showed that out of the total participants, 52% of the respondents mentioned that they are aware of the environmental issues caused by the fast fashion product. Based on the question numbers 1 and 3, half of the population in the survey has the knowledge about environmental impacts

Table 17.2 Respondents' awareness about pollution caused by fashion product

Scale	Respondent number
1. Strongly disagree	15
2. Disagree	14
3. Neutral	46
4. Agree	39
5. Strongly agree	38

Table 17.3 Respondents' consideration of environmental issues before buying process

Scale	Respondent number
1. Strongly disagree	35
2. Disagree	29
3. Neutral	50
4. Agree	19
5. Strongly agree	19

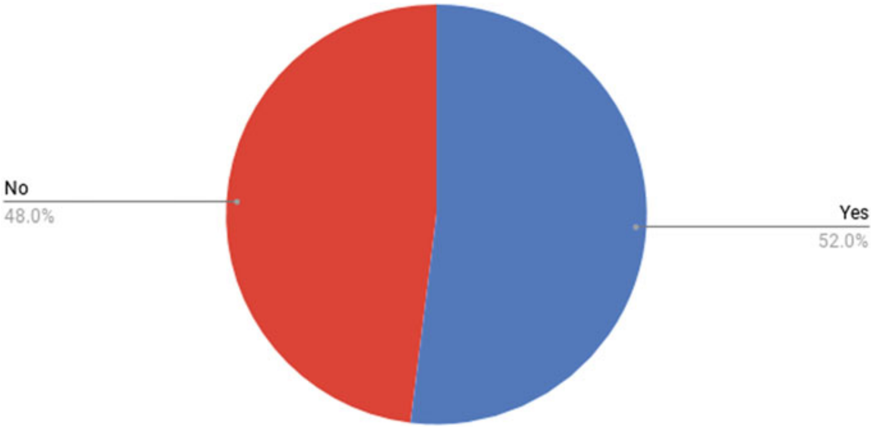

Fig. 17.2 Awareness of environmental impacts in production and disposal (authors own illustration)

caused by apparel products (49.99%) and fast fashion system (52%). However, it can also be noted that in contrary to that result, the majority of the respondents (75.64%) mentioned that they do not consider environmental impacts before buying (Fig. 17.2).

From the above analysis, we can derive the conclusion that the respondents' knowledge level with respect to the environmental impacts has increased; but when it comes to purchasing, they are not ready to consider the impacts of the product before purchase.

17.5.2 Purchasing Behaviour Analysis

To analyse the respondents' motivation for the purchase, they were asked to rate their preferences among several options. The results are shown in Fig. 17.3.

A great number of the respondents mentioned ($N = 60$, 39.47%) that the motivation for purchase is the change concerning trend and fashion. The second most preferred option is personal behaviour. Around 38 respondents (25%) preferred the option of personal behaviour. The result also clearly represented that the purchase motivation among the young Gen Z consumers is less affected by the various discount sales and prices. They either feel to update their wardrobe when the new season and styles are introduced into the market or it has become their personal behaviour.

The next question was framed to measure the frequency of the purchase by the Gen Z consumers. The result mentioned that out of the total 152 participants, 53 participants, 1/3 of the respondents (34.86%) stated that they will purchase every month as the new collection comes into the stores. Next to that, 51 respondents (33.55%) mentioned that they purchase once every six months (Fig. 17.4).

With respect to costs, among the total of 152 respondents, 67 respondents mentioned that they are ready to spend less than 10,000 INR (125 Euros) per year.

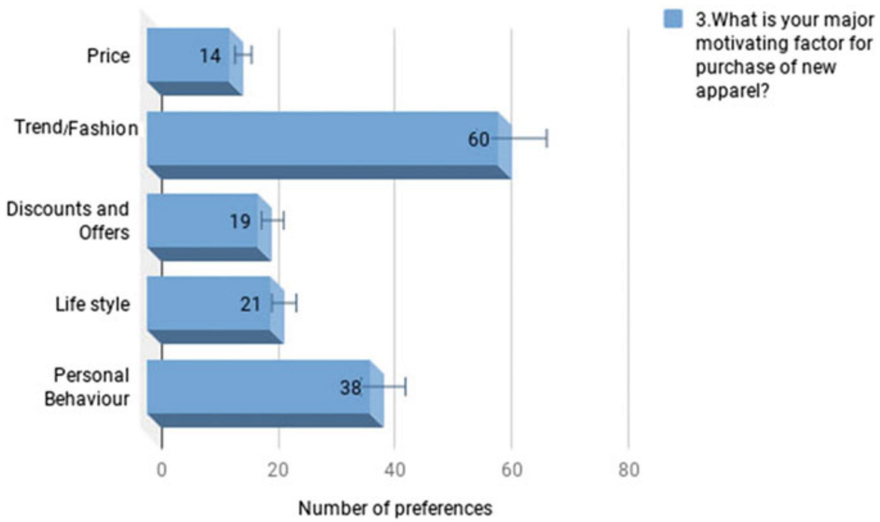

Fig. 17.3 Respondents' preference on motivating factor for purchasing (authors own illustration)

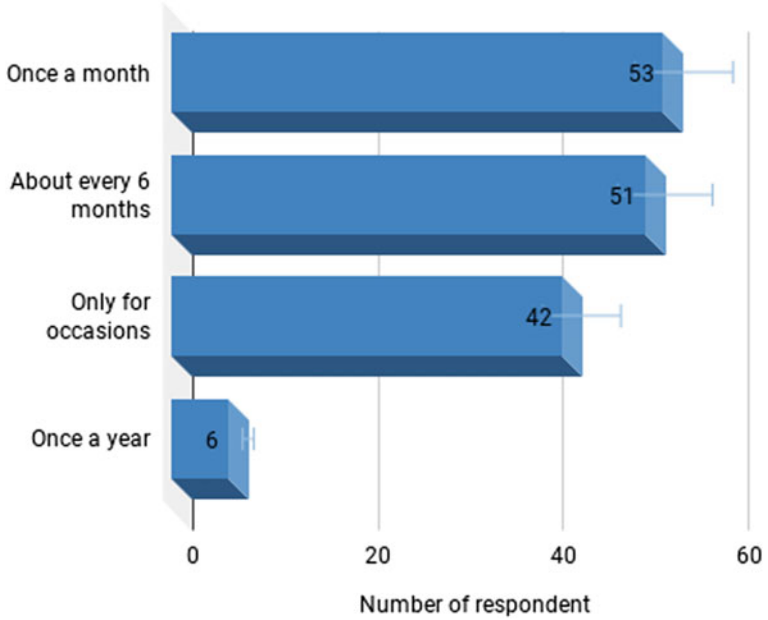

Fig. 17.4 Respondents' preference on the frequency of purchase (authors own illustration)

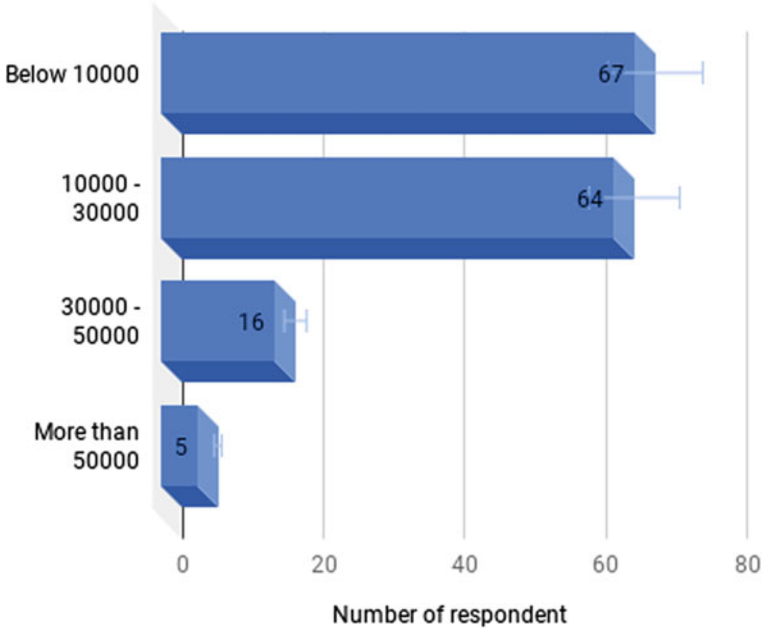

Fig. 17.5 Respondents' average spending on fashion in INR (authors own illustration)

However, 64 respondents stated that they usually spend from 10,000 INR to 30,000 INR (125–375 Euros) per annum on clothing purchase (Fig. 17.5).

Even though 52% of the respondents accepted their responsibility towards the environmental impact in the previous section, in the purchase behaviour analysis no correlation between the two results was found. In this analysis, the results revealed that respondents motivated by new fashion/trend changes in the market are ready to spend from 10,000 to 30,000 INR (125–375 Euros) per annum for fashion products alone. It is also interpreted that the lifestyle and cultural impact along with higher family income might be the reason for their response. Due to the changes, they prefer to buy brand new clothing every month. To confirm that information, the respondents were asked to mention the major factor influencing their purchase decision. It was expected that consumers will prefer requirement as their major choice. However, from the analysis, it has been revealed that a large number of respondents (47.36%, $N = 72$) preferred lifestyle and culture as their major influencing factor on purchase. The second most preferred option is personal identity with 39.47% respondents preferences ($N = 60$). The personal need or requirement is preferred as the third option with 69 participants (45.39%). With respect to the values and ethics, most of the respondents (31.57%, $N = 48$) mentioned neural as their preference, they neither denied nor agreed on 'values and ethics' influence on their purchase decision. The respondents also referred that they are not influence by friends suggestions (61.18%, $N = 93$) and advertisement (61.84%, $N = 94$).

17.5.3 Apparel Product Disposal Analysis

The respondents' disposal behaviour was analysed based on the responses of the above-mentioned questions. For the question about frequency, a majority of the respondents mentioned ($N = 102$; 67.10%) that they use to dispose of their clothes once in a year (Fig. 17.6).

However, it is asked about the factors that motivate a garment disposal, among the given choice, a large number of consumers preferred either fit ($N = 81$) or colour fading ($N = 75$) as a major reason over other options. More details are provided in Table 17.4.

The next question is posted among the respondents to identify the most disposed adult's garment. The respondents were asked to select between night, casual, formal, and intimate wear. The results of the analysis are provided in Table 17.5.

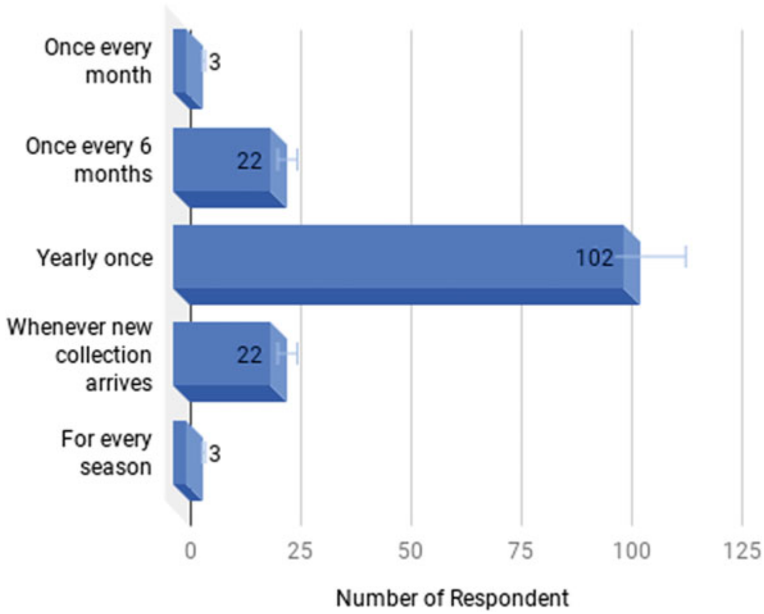

Fig. 17.6 Respondents' average disposal time of fashion products (authors own illustration)

Table 17.4 Analysis of disposal factor

Factor	Number of respondents
Fit	81
Out of fashion	52
Out of season	49
Colour fad	75

Table 17.5 Analysis of more frequently disposed garments

Garment type	Number of respondents
Nightwear	41
Casual wear	47
Formal wear	52
Intimate wear	48

From the results, it can be noted that a lot of respondents mentioned intimate wear is disposed of higher than the other three categories (31.57%). The second most preferred option is casual wear (30.92%). In both the other types, formal and nightwear, the customer neither accepts nor denied about their frequent disposal as the major responses were noted as "neutral" in the respective Likert scale rating.

17.5.4 Slow Fashion Acceptability Analysis

The last section of the survey focuses on the evaluation of the participant's attitude towards the slow fashion concept and its acceptability. About 64.5% of the respondents participating in the survey acknowledged that they were not aware of the slow fashion concept before the survey process. Very few (35.5%) of the respondents mentioned that they have either read or heard about it (Fig. 17.7).

Based on an explanation of the slow fashion concept against the fast fashion trend in the market, the respondents' acceptability of the slow fashion product if such products are available in the market was asked in the second question. For that question, 140 respondents (91.10%) mentioned that they would definitely purchase

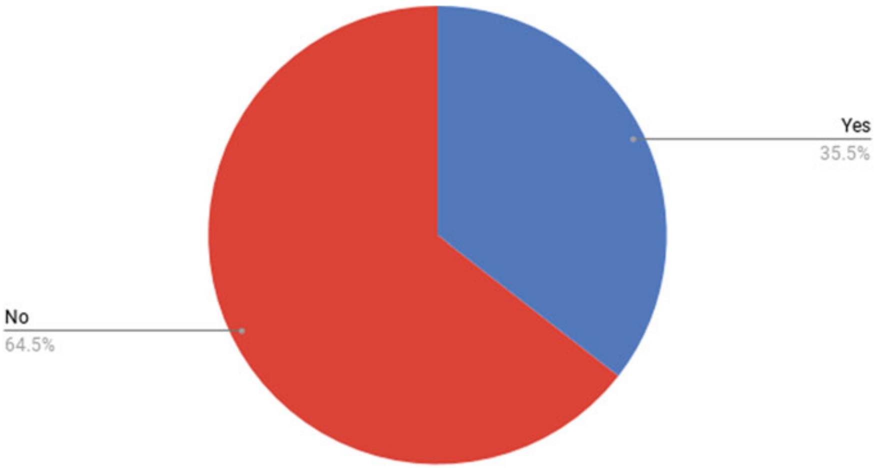

Fig. 17.7 Awareness of slow fashion concept before this research (authors own illustration)

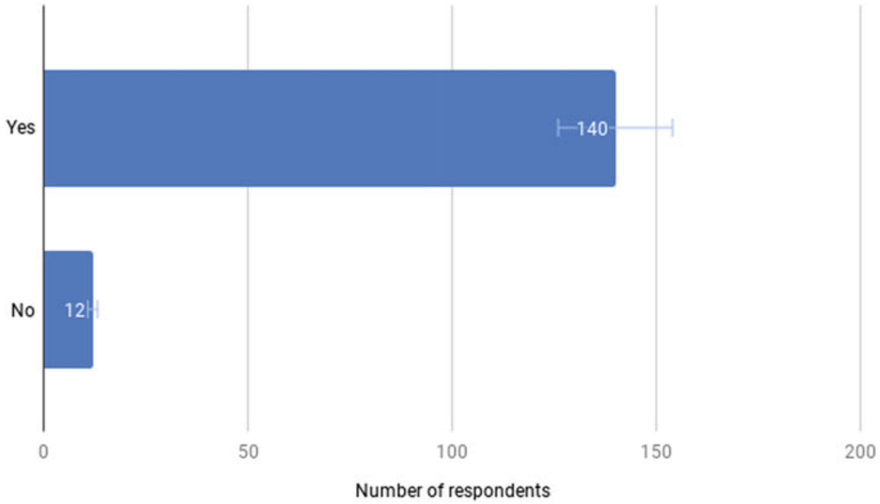

Fig. 17.8 Respondent's acceptability of the slow fashion concept (authors own illustration)

and accept quality product over the fast fashion product with a longer life. Only 7.89% of the respondents (12 respondents) mentioned that they do not prefer the product over fast fashion (Fig. 17.8).

From the two questions it can be clearly seen that initially, the respondents were not aware of the slow fashion concept. However, explaining the concept as "by increasing the raw material quality and product quality, one can extend the longevity of the product", respondents agreed towards the impact of fast fashion and 140 out of 152 respondents mentioned that they love to purchase a quality product if offered. Only a few respondents ($N = 12$) denied the slow fashion concept. Hence, to increase the lifetime of the product, the respondents were asked to rate different factors like: increasing the quality, using a garment in multiple ways, repairing the old garment reuse the second-hand garment and donating to others. The respondents' major choice for product longevity is "to increase the quality of the product". Out of the total number of respondents, 69 respondents selected the rating option 5. The second most preferred option by customer is "to donate to others". Next to this, 'to use in multiple ways' was preferred by 47 respondents. However, the other two options, namely "repairing" and "reusing", the garments are not preferred by the respondents. After being further discussed with a few of the respondents, they have mentioned that the quality and cleanliness of the second-hand products are the major doubts they have about these garments. Next to this, they did not find a proper brand or quality assured outlets to access such products. In the case of repairing process, the respondents mentioned that sometimes they were not aware of the method or they dispose of it and go for a new product due to the cost associated with the repairing work. Few also mentioned that they consider this as their economic status so they did not prefer that option.

Furthermore, when the respondents were asked, how much they can spend extra for the quality product compared to the existing fast fashion product in the market, the majority of the customers ($N = 73$) preferred to say that they can afford approximately up to an increase of 25% in the product cost as extra if the product is durable and has a long lifetime (Fig. 17.9). In the next question, the respondents were introduced to elements of the slow fashion concept like local manufacturing, multifunctional, purchase on requirements and knowledge about the products. The majority of the respondents preferred the "buy on requirement" option. The next preferred option is "multifunctional", followed by "product knowledge". After all, in consolidation, the respondents were asked to rate their preference and purchase attitude towards the slow fashion product from 1 to 5. The majority of the respondents selected Likert scale ratio of 5 ($N = 60$) and rating 4 ($N = 55$).

Hence, based on the results, it is confirmed that the consumers have a positive attitude towards slow fashion garments. They were unaware of the slow fashion concept; but after the explanation, they preferred to spend more money and also to choose products incorporating slow fashion elements compared to the normal products.

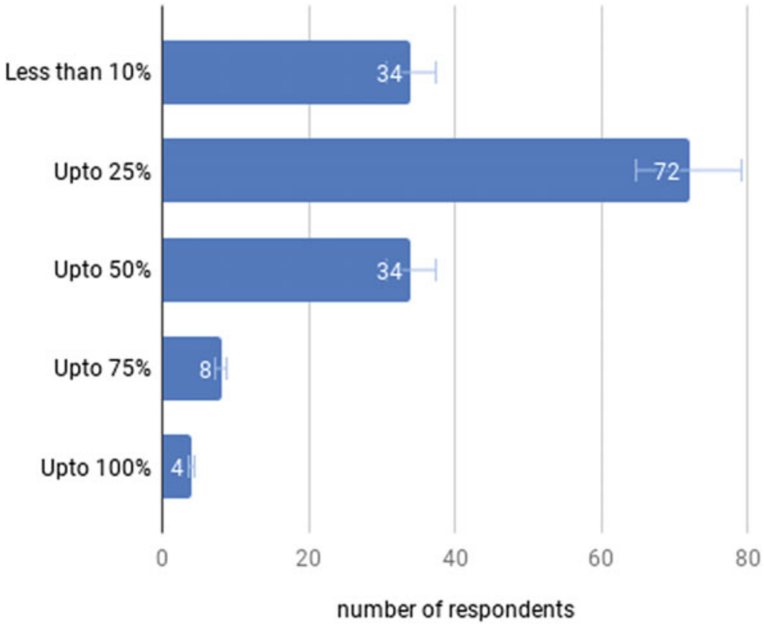

Fig. 17.9 Respondent's interest in spending extra money for slow fashion products (authors own illustration)

17.6 Summary of the Analysis

The key findings of the research work are summarized in this section.

- The findings of the research revealed that the respondents were aware of the environmental impacts of the fashion or apparel product. However, when it comes to purchasing decisions, the majority of the respondents mentioned that they never considered the product's environmental impacts before buying.
- Regarding the purchase behaviour, the majority of the respondents mentioned that their purchase majorly depends upon the current trend and fashion in the market. They had also said that they approximately purchase once every month, and they use to spend around 10,000 INR (125 Euros) per annum. The purchase decision is mainly based on their lifestyle and culture adapted. The requirements or need comes as a second factor.
- With respect to the disposal, respondents mentioned that they dispose of most frequently the intimate apparels compared to other items. The disposal of fashion apparels is mainly due to the colour fading and the fit issue. The respondents mentioned that they will clear and dispose of their wardrobe once in a year. Disposal is not a pivotal issue at all.
- The respondents positioned themselves in line with the slow fashion concept; however, they had not been aware of the concept before the survey. About the acceptability of the slow fashion, the respondents were ready to accept the slow fashion. They had also mentioned that they are ready to spend up to 25% higher costs for the product. Further, the results identified the respondents' choice for the increased life of the product is quality.

17.6.1 Challenges and Barriers in the Implementation of the Slow Fashion Concept

In general, the clothing consumption practice is a complex problem for any individual (Lundblad and Davies 2016), reinforced by attributes like personal satisfaction, identity, societal acceptance and distinction (Joy et al. 2012) (Fig. 17.10).

- **Individuals' Knowledge Level**

From the research results, it can be clearly understood that even educated individuals in society were not aware of environmental impacts regarding apparel products. Either a lack of awareness or not considering the sustainability issues at the individual level is one of the main barriers (Sheila and Oppenheim 2008; Williams and Dair 2007). After it being explained, the majority of respondents accepted to go with slow fashion articles over fast fashion or cheap quality products. Hence, educating the customers towards the slow fashion concept will be the major challenge for governmental bodies and other organizations. However, in recent times, it has been noted that there are some mind shifts among the consumers towards organic, eco-

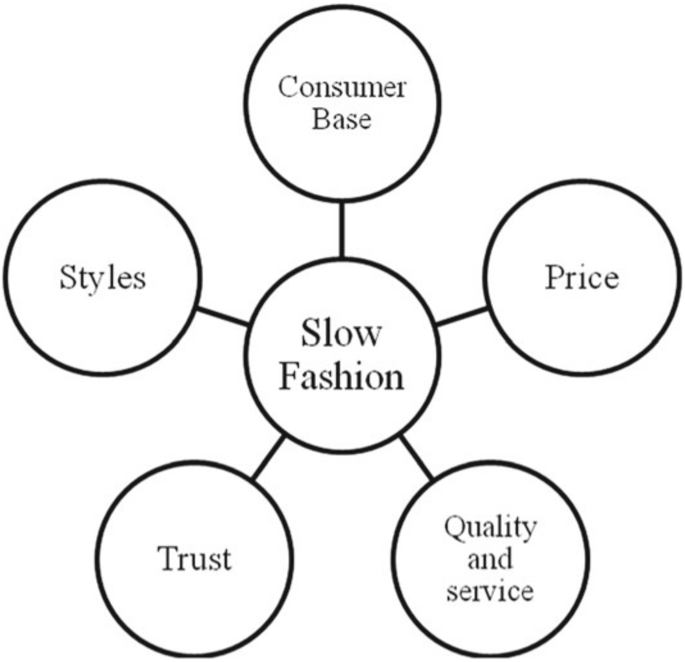

Fig. 17.10 Barriers in the implementation of slow fashion (authors own illustration)

and sustainable apparel products. This shows consumers' awareness has increased considerably over these times (Štefko and Steffek 2018). Even though the attitude of the customers towards sustainability is positive, research yet observed a major gap in consumers' purchase behaviour (Prothero et al. 2011).

- **Price**

The price is the next major barrier in the implementation of slow fashion. Even though the mindset of the consumers has changed, the economic options of the individual customer are different. When the same product is cheaper available than the slow fashion product, it is sometimes hard to convince the customer. Previous research has already mentioned that the purchase behaviour of the consumers is not affected by unethical business policies or corporate practices (Hyunsook et al. 2013; Carrigan and Attalla 2001). Blake (1999) and Young et al. (2010) mentioned that the economical constrain is a further important barrier which prevents the customers from sustainable behaviour. Also, the products that are named as sustainable are often perceived as more expensive. This is found to be a major restrictive factor for the commercialization (Williams and Dair 2007; John 2005). Further, if the requirements of a middle-class economic person's desire to get value for the money are considered, it will override all the other factors. Eckhardt et al. (2010) mentioned that when one is too poor to worry about ethical issues, it is difficult to expect from that individual to spend money on a sustainable product.

- **Quality, Service and Trust**

Quality and service of the product and trust are interrelated issues. One of the important factors to develop a successful slow fashion product is quality. The educated consumers are ready to pay extra money for the slow fashion product; but at the same time, they are having little confidence about the quality of the product. When the consumers doubt about the authenticity of the product, ultimately they are not ready to buy the product. Moreover, if a factory operates sustainably and in an eco-friendly manner, there will be a restriction in wasting raw material and using synthetic material in designing and manufacturing. This will lead to a reduced design option for the customer. The customized productions over mass production, the usage of natural and organic materials over synthetic products as well as fair and ethical manufacturing practices incorporate barriers in style options and increase costs in implementing the slow fashion concept. Consumers' trust comes from their mindset. The prejudice of the customers towards the aesthetic and quality aspects of the sustainable garment is not good. Often, sustainable clothing is associated with a stereotypical image of anti-fashion due to the usage of natural dyes and eco-friendly processing methods (Moon et al. 2015). The reason for the limited amount of trust might also be due to the confusing and inadequate logos and labelling, such as the use of the terms "organic" and "better cotton". Missing transparent information often leads to uncertainty and a lack of trust (Iris and Verbeke 2006). Unreliability on sustainable brands and products along with negative inferences about their functional performance is also reasons for the lack of trust among the consumers (Luchs et al. 2010). The customers' distrust has also been initiated by negative advertisements as well as ambiguous and contradictory messages from manufacturers regarding the social and environmental consequences of purchases (Young et al. 2010).

- **Product Accessibility**

It is also noted that even the availability of sustainable fashion products is one of the major barriers for an individual customer in the market place (Ryan Partnership Chicago 2012). The interview conducted by Moon et al. (2015), revealed that limited knowledge about the product among the customer, supply sources of sustainable products in the market, economic issues like the premium price of the sustainable product and the design style available with the sustainable apparels are the major barriers of a sustainable apparel product. Unavailability of the required infrastructure, accessibility and affordability of slow fashion or sustainable products often make the customers choose an alternative option. Thus, the customers encounter difficulties in their day-to-day activities (Kersty 2004). As a consequence, consumers start to ignore the environmental impacts of that product and they take no action (Daiane and Fischer 2013).

- **Standards and Norms**

Standardization of the product quality is another big problem in the fashion industry. The fashion industry is often compared with the food industry, but it does not have any governing bodies like in the food industry. Around the globe, no third-party certification is available concerning sustainable products, neither for manufacturers nor for retailers. Alternative approaches proposed by the slow fashion system are not commonly accepted. Major alternative practices proposed by the slow fashion system are reusing, recycling, second-hand clothing, rental services or leasing the apparels, leaving actors like sellers and consumers with many practical difficulties. However, from the perspective of costs, these options are viable for the consumers. Lifestyle and social trends are other important factors which decide about the acceptability of the slow fashion concept. The dynamic nature of fashion is highly correlated with the lifestyle and social trends of every individual (Cholachatpinyo, Padgett and Croker 2002).

- **Aesthetic Appearance**

Literature has mentioned that the consumers often consider the sustainable products being unattractive and not up to the trend (Power and Mont 2010). It is noted that aesthetic is one of the major constraints for the consumers in the case of sustainable or eco-fashion products (Joy et al. 2014). The previous study evaluated the consumer behaviour against the sustainable product and results revealed that the style and compatibility to the current trend are the major barriers for sustainable apparels. However, no one from the manufacturing side, from designers to retailers, is aware of this factor (Niinimäki 2010). Due to its limited colours and styles, consumers misunderstood the sustainable products being either associated with environmental movements or luxury type of material (Cheng 2017; Wagner et al. 2017).

17.7 Practical Implications of the Research

The aim of the current research is to analyse the consumers' knowledge level on the environmental impacts of textiles and apparels and to understand their purchase behaviour with respect to the Gen Z customers. The study also determined the respondents' interest in the acceptability of the slow fashion concept over the existing fast fashion system. Accordingly, the major finding of the research is that the consumers are not aware of the environmental impacts and pollution caused by the current textile and apparel production system. Only 25% of the respondents already had some idea about the pollution-related issues prior to the survey. These findings are the benchmark for the Indian scenario, where the sustainability-related awareness is in an infant stage. Unlike other studies (Crommentuijn-Marsh et al. 2010; Harris et al. 2015), the uniqueness of the current study is that the respondents are Gen Z customers who are going to be the future of the country. The second implication of the study is the details concerning apparel buying and disposal behaviour of young customers. The research revealed that most of the Gen Z consumers preferred to stay on trend, so they frequently purchase the apparels whenever the trend changes. Lower knowledge level about the pollution or impacts of the apparel product on the environment and more frequent purchase behaviour represent consumers' lack of awareness. This implication provides scope for future studies in the area. The third implication of the current study concerns consumer acceptability level of a slow fashion product. The respondents were able to realize the importance and responsibility in their purchase process. They have mentioned that they are even ready to spend extra money on products. This is one of the important findings of this research. A large number of the respondents mentioned that they would definitely buy the slow fashion product if offered. Although the current research falls short in the survey area and sample size, the major outcome of the study is that the young consumers are ready to adopt sustainable methods in their purchase process if educated properly.

From the above-mentioned points, it can be clearly seen that the present study had addressed the fundamental difficulties in adapting to the new fashion concept called slow fashion. The implications for future research can be listed as follows:

1. The major finding of the study represents the lack of awareness among the customers. Hence, a proper model should be developed and implemented in the society to educate consumers.
2. This study reflects the interest of young customers in accepting the slow fashion products. Hence, it provides the opportunity for future research in the area of cost reduction, especially offering possibilities and ways of making sustainable low-cost slow fashion products comparable to existing fast fashion products.
3. The research also points out that there is no proper mechanism in the market for approving or regulating sustainable products as an authenticated product. Hence, it provides scope for conducting further research in this field to develop a proper mechanism to be realized in the society. This will improve the customers' trust in sustainable products and increase their purchase intentions.

17.8 Conclusions and Limitations of the Study

The results of the research revealed that the respondents of the research are highly interested in the slow fashion concept. However, at the same time, their current purchase behaviour and knowledge about the environmental impacts of apparel products are not up to the expected level. The major influencing factor for the purchase is their lifestyle and culture. In addition, most of the responses mentioned that they buy clothing once a month. The main reason for the disposal is the poor quality of the product. Even though the attitude of the consumer towards the slow fashion product is positive as expected, it is noted that respondents were not aware of the concept initially. As mentioned in the literature, the concept is more consumers' knowledge-oriented. Hence, to implement the slow fashion concept in densely populated countries like India, it is highly necessary to improve consumers' knowledge about impacts of fast fashion products through different modes of education. Unless the consumer knows the consequences, it is very difficult to reduce the impacts of fast fashion products on the environment, society and individuals. However, the following points are considered as limitations of the study and, thus, prevent the generalization of its results.

1. The survey was conducted among 152 respondents in the city Coimbatore in Tamil Nadu, India. As the study mainly focused on college students and the age group of 18–35, the respondents' income range was not considered in this research. Grouping the respondents according to their earning capacity, gender, education status and the above-mentioned age limit may also lead to differences in the conclusions.
2. Only a small number of questions were included in this survey. This procedure was used in order to increase the interest of the respondents in answering this survey. No feedbacks and open-ended questions were provided for the respondents regarding issues such as sustainable clothing purchase and utilization.
3. The results obtained from the study are reflected against the author's perspective on the slow fashion concept. Hence, the research findings may not be a definite solution for the problem addressed.

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Chapter 18
Sustainable Development in Textile and Ready-Made Garment Sectors in Bangladesh and Innovation for Poor Population in Asia

Abu Bakr Siddique, Hosne Ara Begum, and Dominic Berndt

Abstract Sustainability is an area which is gathering more and more attention in nowadays society. But a standardized definition of sustainability and how to quantify it is still a work in progress. Especially, the textile industry has drawn major negative headlines in the past regarding working conditions in the least developed countries, pollution and wasteful usage of resources. Bangladesh stands as one of these countries where the true cost of the consumer behaviour of the industrial nations is paid by the workers in the textile factories. Several steps have been made in the field of textile technologies to lower the burden for the environment and workers. Actions took place to improve the working conditions and safety of the textile workers but there is still a long way to go that the workers benefit from the rising textile industry in Bangladesh.

Keywords Natural fibres · Textile chain · Environmental and socio-economical sustainability

18.1 Introduction

While the textile industry is not being known to be economical with its resources, there is also a large proportion of unnecessary waste produced each year. Economic prosperity, seasonal and fast fashion encourage the quick replacement of garments. The consequence of a "throwaway society" is that manufacturers will more and more

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develop high quantities of clothing with a low durability which is going to produce more waste from both the manufacturing and household sectors (Bhattacharjee 2019).

The world is facing challenges in economic, social and environmental areas that require the need for a sustainable development. Inequality within countries like India and Bangladesh has been rising. At the same time, unsustainable consumption and production patterns have become common but at a huge environmental, economic and social costs (United Nations 2013).

Especially Bangladesh has been affected by unsustainable development of the textile industry of the past decades. The country is known to be one of the least developed countries (LCD) in the world; therefore, labour is cheap, laws for the protection of nature and workers are weak or rather none existing. Because of the catastrophes of Tazreena fashion fire and the Rana Plaza collapse which took 1200 lives in Bangladesh, most parts of the world were made aware of Bangladesh's drawback and the consequences of our consumption behaviour.

18.2 Sustainability, State of the Art

One of today's biggest questions remains, what is sustainability? Where does it start? Where does it end? And what needs to be included to call a product, a process chain or lifecycle sustainable?

To our current knowledge, sustainability is a lifestyle where everyone's footprint from an environmental and economical point of view does not exceed the factors inherent to the system. That means, for example, using nature fibre plants but in a manner that has nothing to do with the conventional cotton cultivation where great amounts of water, fertilizer and pesticides are needed. The ultimate goal should be to use regional grown fibre plants, natural finishing and natural dyes. However, the most sustainable fibres are useless if not processed properly. Therefore, textile technology requirements regarding effectiveness and efficiency are high and demand a constant development. Desirable would be a textile product made out of regional textile fibres and a local textile chain.

The reality looks much different. Millions of small, medium and large textile fabricators in every region of the world forming the textile and apparel chain and all have the pressure to hold down costs, innovate products and deliver on tight deadlines (International Finance Corporation 2019). Many of these manufacturers are in countries where laws over fire and building safety, labour conditions and pollution controls are weak such as Bangladesh. Additionally, the major textile companies do not tend to establish a regional textile chain. They rather look after the greatest possible savings even if it means to pay for transportation and take advantage of people in need. A good example is Bangladesh who stands as an LCD with low wages and therefore serves primary as ready-made garment industry. But at the same time, Bangladesh is not known for its textile fibre production as shown in Fig. 18.1. So, it has to import great amounts of textile fibres.

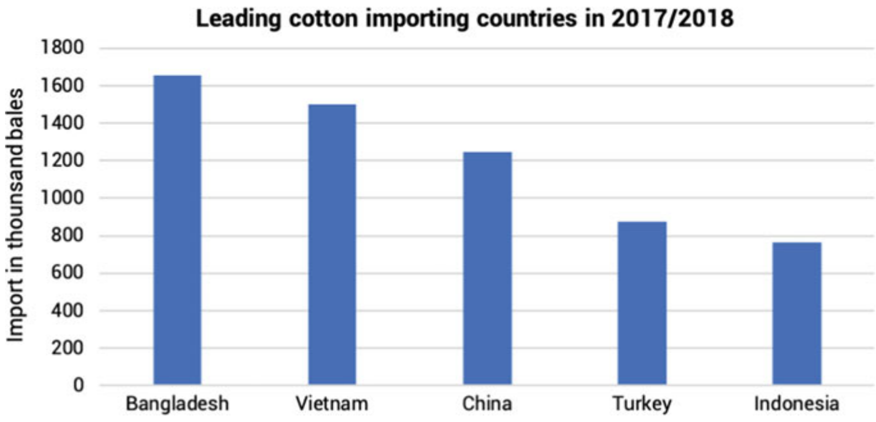

Fig. 18.1 Amount of cotton import (own illustration by authors, Data source: US Department of Agriculture 2019)

To accomplish sustainability is very challenging tasks for poor population groups in Asia and less developed countries. Because sustainability comes along with a price, sustainability is for people who can afford it. It is a lifestyle. Therefore, in the last decade, it has been tremendous developed in LDC countries, especially in Bangladesh. But bottom of the pyramid shape is being increased due to unequal wealth distribution (Lopez-Acevedo and Robertson 2016). However, a simple rise of the wages does not solve the issue when it directly affects the price of the garment. If the garment does not meet the price set by the textile entrepreneur, they will move on to a country who can fulfil their demands. As a result, millions of Bangladeshis would lose their jobs and the country itself would lose majority of its export receipts. So being sustainable is something Bangladesh simply cannot afford at the moment.

18.3 Sustainability in Textile Materials and Technologies

18.3.1 Textile Fibres

Textile products are made out of fibres. They are the key which determine processing technology, application area, lifetime and sustainability. Apparel, home furnishing and industrial are the three main categories that classify the application of the fibres. Their future application also determines their service life, from short term (rapid disposable) to medium term (slow disposable) use such as apparel, carpet, automotive interior (Siddique and Begum 2013). Therefore, the management of waste has become a demanding problem. The overall guiding principle, agreed by everyone, to protect the environment is to “reduce, reuse, repair or recycle” and actual disposal of waste should be a last resort (Muthu and Gardetti 2016). In this context, this chapter

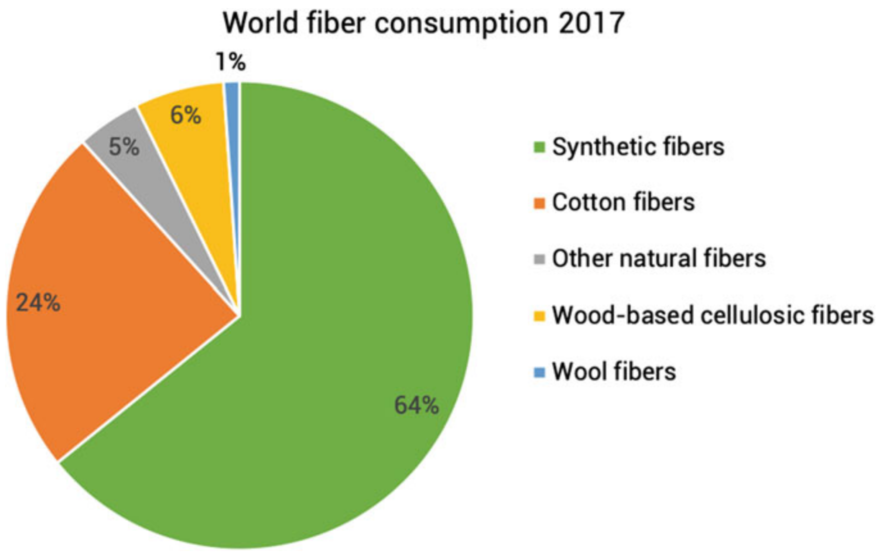

Fig. 18.2 Share of fibre groups in world fibre consumption in 2017 (own illustration by authors, Data source: Lenzing Aktiengesellschaft 2017)

presents the various issues related to the sustainability of some common natural plant fibres, namely cotton, hemp, flax and jute and some renewable fibres like banana, sisal, hemp, pineapple, coir, areca and their processing technologies (Begnum et al. 2019). The present market scenario of different textile fibres are presented (Fig. 18.2).

To understand which fibre groups have a better sustainability feature, it is important to take growing/production conditions and used technologies into account. Natural, synthetic and regenerated fibres have different advantages and disadvantages regarding their sustainability potential. The polyester fibre is the most consumed fibre type, and it requires far less water when comparing to cotton growth. But because fossil fuels are required, and the production is more energy-intensive synthetic fibres which have a greater contributing to global warming as a result of harmful greenhouse gas emission (Palamutcu 2017). Cotton is a natural fibre and has so far become synonymous with green, clean and even sustainable in comparison with synthetic fibres. However, it is not entirely acceptable. The cotton growing process requires a lot of pesticides and insecticides which cause a high load of toxic pollution. Another important disadvantage is the great amount of irrigation water (Palamutcu 2017). Concerning to overcome such environmental influences, organic cotton use is flourishing where intensive chemical use is abandoned. It only uses environmentally low-impact methods and materials. Some of commonly known programs are Better Cotton Initiative (BCI), cleaner cotton and natural coloured cotton but it is nevertheless water-intensive. Another sustainable type of fibres is regenerated fibres. Those biodegradable fibre types are introduced to the textile market favouring their natural raw material backgrounds. They are produced from renewable cellulosic plants such

Table 18.1. Global natural fibre production (Siddique and Begum 2012)

Fibre	M.tonnes	Main producer countries
Cotton	26.00	China, USA, India, Pakistan
Jute	2.50	Bangladesh, India
Wool	2.20	Australia, China, New Zealand
Flax	0.50	China, France, Belgium, Belarus
Kenaf	0.45	China, India, Thailand
Coir	0.45	India, Sri Lanka
Sisal	0.30	Brazil, China, Tanzania, Kenya
Ramie	0.15	China
Hemp	0.10	China
Abaca	0.10	Philippines, Ecuador
Silk	0.10	China, India
Kapok	0.03	Indonesia
Henequen	0.03	Mexico

as beech trees, pine trees and bamboo. The lyocell fibre is the most environmentally friendly fibre among the regenerated fibre because it does not need many chemicals and whitening agents. The energy and water consumption can be decreased due to shorter washing machine cycles (Muthu and Gardetti 2016). And still, cotton is by far the most produced natural fibre in the world as shown in Table 18.1.

The primary criteria for the selection of other fibres are:

- usable in the textile industry (convertibility into textiles).
- easy availability of these fibres/plants around the world in fairly abundant quantity and therefore are relatively easier to exploit for commercial purpose, e.g. banana, pineapple, hemp.
- High growth potential, e.g. sisal, hemp.

In summary, natural plant fibres are usually considered more environmentally friendly than synthetic fibres for several reasons such as the growth of plants results in the sequestration of CO_2 from the atmosphere. Moreover, at the end of their lifecycle, natural plant fibres and their products tend to be biodegradable (Barth and Carus, 2015). Cotton, flax, hemp, jute, sisal, banana, coir, bamboo and others offer several benefits with respect to synthetic fibres such as biodegradability, eco-friendly, made out of renewable resources and better physiological properties. Growing natural plants consumes less energy than the production of synthetic polymers and fibres (Barth and Carus 2015). However, it has been reported that the processing of synthetic fibres to a manufactures textile has a lower impact on the environment than cotton fibres (Muthu and Gardetti 2016). This makes it even more obvious how important efficient textile technologies for natural fibre processing are.

18.3.2 Processing Technologies

Textile manufacturing technologies cause some high amount of environmental load on the nature as a result of their energy consumption, wastewater discharge and other types of waste accumulation. All manufacturing operations and technologies create harmful influences on the nature; however, most of the processes are indispensable processes that are conventionally accepted. There is no possibility of zero impact, or entirely erasing of the environmental load, left behind by a textile product. One possible way to reduce the environmental load is to technology improvement, appropriate technology selection and efficient technology management. Current technological developments offer several opportunities to take action of new production technology routes and models to build sustainable textile technology environment.

Yarn manufacturing is the second main processing stage of a conventional textile item. Technological improvements have been focused on high production speed, less waste, high efficiency and less labour while the manufacturing principles stayed the same. Ring-spinning machinery and its technological improvements have only focused on production speed and yarn quality. OE-rotor spinning, friction spinning and air-jet spinning are new generation of spinning machineries where high-speed yarn production and lower manufacturing costs have become possible. With the air-jet technology, having a productivity level about 20 times is higher compared to the ring-spinning technology (Knick and Biermann 2019). Furthermore, it offers the air-jet spinning technology lower manufacturing cost for cotton yarn in comparison with ring spun yarn since the energy, labour and auxiliary material costs are lower (Knick and Biermann 2019). Besides high-speed production, new spinning machineries require shorter pre-spinning and post-spinning processes and machineries. The results are lower energy costs, less required space, less waste, higher dye absorption, less size and therefore less wastewater. All the aforementioned facts suggest better sustainability features of spinning technology.

The next step in the textile chain is the manufacturing of textile surfaces where different methods and technologies are used. Weaving, knitting, braiding, nonwoven, tufting and felting are commonly used processes. Weaving technology is one of the most frequently used techniques including weaving preparatory and weaving machines. Knitting is the other common surface producing technique where they are less manufacturing stages than at the weaving process. Braiding technology is used for the technical textile production where sustainability feature is also getting more important. Nonwoven, tufting and felting processes are the shortest way among all of textile surface manufacturing techniques without the yarn manufacturing phase. They start directly from the fibre. The environmental load of manufacturing machineries that are used for the nonwoven, tufted and felted surface productions is quite low comparing to the weaving and knitting.

Especially, the pre-weaving process requires a lot of additional resources. The sizing process consumes a large amount of sizing materials and chemicals which are discharged with water at a later stage and account for 40–50% of the total wastewater

Table. 18.2 Energy consumption in million INR (Sharma 2014)

	Fuel	Electricity	Total
Weaving	4467	24,848	29,315
Knitting	4059	11,709	15,858

release of the plant. For the weaving process itself are different weft insertion mechanism for shuttle-less looms used which are further classified into projectile, rapier, water-jet and air-jet looms. Air-jet looms can be considered as the newest weft insertion technology. Because of their high productivity and better control features, they are becoming more and more popular in textile industry. The advantages compared to other weft insertion technologies are the production rate of 1100 weft insertion per minute and the possibility to process a wide range of yarns types and fibre materials (Grassi et al. 2016). The disadvantage is the great energy consumption due to compressed air usage. This becomes even more unfavourable in countries where energy cost represents a great fraction of the manufacturing costs. The second commonly used textile surface manufacturing technique that has been practiced for the thousand years is knitting. The process is split into the two principle technologies of weft and warp knitting. The machinery consumes mostly electric energy in their driving systems and control systems. In comparison with the weaving and its pre-weaving process, the energy consumption and the attached environmental load of the knitting process are low (Palamutcu 2017). As shown in Table 18.2 where the energy consumption of knitting and weaving processes are compared, it can be safely assumed that the knitting process has better sustainability features.

Seamless knitting technology is a new technology. It was first introduced in 1995 since then it has become popular in different groups of clothing products such as underwear and sport clothing. Seamless knitting products require minimal or no cutting and sewing. Therefore, the amount of post-knitting labour is reduced to a minimum. Furthermore, this innovative technology provides more comfort and better fit to the consumer by eliminating seams. This knitting process itself has a higher energy consumption and greater environmental load compared to the traditional knitting technology due to less productivity. But the advantages of a product manufactured by the seamless knitting technology in comparison with the conventional process are (Palamutcu 2017):

- saving labour
- less manufacturing times
- less manufacturing cost
- lower environmental load
- lowest possible level of waste disposal
- reduced need of fibre and yarn

18.3.3 Dying, Finishing and Manufacturing

The next stage in the textile chain is wet processing on textile products which are a pre-treatment of fabrics before the process of dyeing, printing or finishing. All stages of wet processing require high amount of energy and water. As a result of high energy and water consumption (100–150 L/kg), wastewater and emission loads of the processes are also high in the traditional textile wet-processing plants. In the world, about 28 billion kilos annually of textile materials are being processed in water as solvent medium (Palamutcu 2017).

The focus of new technologies is reducing energy consumption, eliminating process water, wastewater and decreasing chemical's usage or substitutes it with natural alternatives. One emerging process for dyeing is the supercritical dyeing technology, where supercritical carbon dioxide is used as dyeing medium. The process is performed in a high-pressure vessel. Carbon dioxide exists as a supercritical fluid at temperatures at about 31 °C and pressures above 72 bar (Hasanbeigi 2010). Another new technology is ultrasonic-assisted wet-processing which is developed as an alternative method to conventional high-temperature processing technologies. The equipment is installed directly into the existing machines. It offers improved performance in fabric preparation and dyeing without impairing the properties of the processed materials. Other advantages include energy savings due to reduced processing temperatures, time and lower consumption of auxiliary chemicals (Palamutcu 2017). A third alternative finishing process is the foam coating technology. The technology uses air instead of water to dilute the chemical which is later applied to the textile. With the foam coating technology, up to 80% of water consumption and 60–65% of energy use can be saved depending on the type of finishing treatment which is used. Additionally, emission gases are minimized (Palamutcu 2017). Other, more sustainable finishing processes are air dye method that is developed in California by Colorep and plasma treatment which is mainly used for desizing, dye uptake, printing ink adhesion and final finishing treatments such as softening, hydrophilization, easy care and anti-shrinkage (Palamutcu 2017).

The substitution of the conventional printing technologies which requires about 50–100 L of water per linear metre is the digital printing technology which uses 1 L of water per linear metre. The digital printing technology not only saves a lot of water but also 50% energy and CO_2 reduction of 90% (Palamutcu 2017). Another option for a more sustainable dying process is the use of natural dyes in the wet processing technologies. The natural dyes themselves are very well known and have again become popular with the increasing awareness of the society for sustainable products. Textile brands all over the world have started to prepare natural dyed and printed collections to showcase their sensitivity to the nature (Palamutcu 2017). Research and commercialization of the natural dyes have increased in the last decade. Some natural dyestuffs have already become commonly used which are indigo, madder, cochineal, weld and cutch. A wide application of natural dyes in the market can make the finishing process more sustainable by eliminating expensive chemical auxiliary consumption and decreasing the environmental load of dyeing chemicals (Palamutcu 2017). Enzyme formulations develop the improved application methods, reduce the technical risks, maximize economic and environment benefits.

Garment manufacturing or ultimate product manufacturing phase of textile manufacturing steps involves with cutting, sewing, ironing and packaging processes in conventional textiles. Cutting process is mostly completed via electric engine drive cutting systems where low level of energy is consumed. The key factor for cutting process is to cause the lowest possible cut waste during the cutting of the fabric. It has been reported that approximately 15% of textiles intended for clothing ends up on the cutting room floor. Sewing process involves different types of sewing machineries where a reasonable amount of electric energy is consumed. Continuous cleaning, oiling and maintenance of electric engines and other appliances of the sewing machinery will help to manage the energy consumption on the sewing machineries but is also time-consuming. Ironing process is the highest energy-consuming process in the garment manufacturing. Steam production and heating of iron are maintained using electric energy. Packaging materials and label tags of the manufactured garments have the highest level of environmental harm. All of the package material and label tags directly send to the wastelands right after reaching to their last destination at the consumer closed. Amount of package and label material, their type and their biodegradation time are influential parameters. Types of used package materials are paper, synthetic materials or any other material (Siddique and Begum 2013; Xiong and Li 2010).

Textile industry itself is not a very energy-intensive industry; in general, great amount of textile mills worldwide makes them a factor that cannot be ignored. With that in mind, even a relatively small percentage of reduction in energy consumption within the textile chain results in a huge amount of global energy saving.

18.4 Sustainability from a Social Point of View

The RMG sector is the most important factor of the Bangladesh economy and the nation's development. RMG exports totalled between 2017 and 2018 US$ 28 billion which is over 80% of the nation's export earnings. The textile industry is employing around 4 million workers and an estimated 55–60% of whom are women. Even more important is the fact that the growth of RMG sector has created a group of entrepreneurs which led to a strong private sector (International Labour Organization 2016). There has been a study carried out which shows that Bangladesh is the top country with the rise of the riches being 17.3% of compound annual growth rate from 2012–2017 (Wealth-X 2018). However, nothing is said about the wealth distribution and it is expected that only fraction goes to the benefit of the workers. A more detailed look into the minimum wage should clarify the financial situation of the worker.

The first wage board was formed in 1984. Its task was to set a minimum wage for the sector's workers. A minimum wage is set by the government and represents the legal framework so an employer is not allowed to pay below the set wage. This happened long after the Bangladeshi entrepreneurs ventured into the territory of apparel business. Since then the minimum wage increased steadily from Tk560 in 1984 up to Tk5300 in 2013 and with the latest rise in 2018 being Tk8000. However, the workers demand was Tk16000. This led to dissatisfaction among RMG workers which the government now promised to solve (Ovi 2019).

As it is described, a wage increase is one possibility to let the workers take a stake in the economic revival. But the remaining question is how much more value does a worker possesses after the raise of the minimum wage in comparison with 2013. Back in 2013 the minimum wage was Tk5300 and rose up to Tk8000 in 2018. That means a salary increase of 51% on paper. However, over the 5-year period from 2013 to 2017, the inflation rate was about 6.5% on average which left the worker with a real wage of Tk4051 in 2017. So, even after the raise of Tk2700 in 2018, the real wage is only TK6487. Considering that the minimum wage board only meets every 5 years, and the average inflation rate is supposed to be around 6.5% p. a. By 2021, the workers stand where they were in 2013. Figure 18.3 visualizes the aforementioned.

With the wages being one part of the social sustainability, another aspect that needs to be accounted for is the health and safety of the workers. The disaster of the Tazreena fashion fire and the Rana Plaza collapse has clarified the need for higher standards of worker safety. Over the years, public and private stakeholders have been brought together to promote economic, environmental and social sustainability for the textile industry (Lopez-Acevedo and Robertson 2016). But, it is not only the aforementioned catastrophes that caused so many deaths. It is also the environmental pollution that is threatening human health and economic growth of Bangladesh, where air pollution is mostly affecting the health of urban children. Bangladesh could avoid 10,000 deaths

Fig. 18.3 Comparison of minimum wage and real wage (own illustration by authors, Data source: Ovi 2019; WorldData.info 2019)

and save between 200 and 500 million dollars a year if the air pollution in the four major cities is reduced to the acceptable limit (International Finance Corporation 2019).

The reality looks much different:

- “Only 17 of 72 apparel and footwear companies within the Bangladesh garment industry have agreed to implement a transparency pledge regarding worker conditions”. (Westerman 2017)
- “85% of the workers in the Bangladesh garment industry are women. Most workers within the industry work 12 to 14 h a day, which is way more than the legal limits in place for the industry”. (War on Want 2011)
- 60% of the workers within the garment industry are unable to meet their production target. The target is that each worker produces 20 shirts per hour. (Maher 2010)
- “The textile-clothing industry in Bangladesh has become a 100% export industry, with no finished products from the industry being sold to the local market”. (Masum 2016).
- “Parents have to send their children of to smaller villages to live with their grandparents in order to have a better start in life”. (Ross and Morgan 2015)

The true challenge is whatsoever to find a solution that puts all the mentioned shortfalls behind. Wages can be increased, buildings can be secured, working time can be reduced but who is willing to pay for it? What if Bangladesh tightens its laws and protect its people? Are the clothing companies stay in Bangladesh once all the advantages of an LCD country are gone? If they do not stay there and move to another country many people, especially women are going to lose their job. The result would be the loss of one income per family putting them again at risk to survive.

18.5 Changes Are upon Us

There is an increasing awareness among the industrial countries since the catastrophe of Rana Plaza regarding the social set of problems within the textile industry. Western companies and labour unions have signed together with Bangladesh the Bangladesh Accord which task is to increase the factory safety. The Bangladeshi government itself tries a lot to protect its own people. International cooperation between universities has been established with the purpose of a bilateral knowledge transfer. Many actions have started but there is still even more to do.

Several initiatives have started after the Rana Plaza collapse in 2013 with one of them being the already mentioned Bangladesh Accord on fire and building safety. It was founded by over 190 western clothing brands in cooperation with Bangladesh for duration of 5 years. A few results of the Accord are listed below (Gallagher 2019):

- 1688 of the approximately 4600 factories are covered by the Accord
- 1601 factories have been initially inspected
- 116 are not allowed to do business with the cooperating brands

- 131 have been shut down
- 142 were relocated
- 668 of 1311 cases with insufficient alarm and fire detection are still unsolved

To cut things short, many activities have taken place but only 100 out of 1688 RMG factories have passed all of the required criteria by the Accord. As of now there are still many debates whether the Accord will be continued or not.

Another key area which is drawing major attention is education. Not only on an academic base but also within a textile factory and the employees connected to the textile industry such as labour inspectorate and fire service. Once Bangladesh government's aim was to give every person of Bangladesh Primary Education. But day by day, this thinking is changing. Bangladesh government is also thinking about higher study for education sector. Higher education is considered a very significant area for any country's social, political and economic development. Higher education in Bangladesh is in a state of flux while responding to the challenges of globalization in a local way. Over the last years, there has been an excessive growth of new private universities which mostly concentrate around lager cities. To meet the increasing demand, public universities are also being allowed to open profitable part-time or evening programs (Islam 2016). The main goal is to keep the students in Bangladesh to be able to fill the vacancies of leading positions in the textile industry with the own people rather than employing foreign specialists. But there is still a long way to go since the education system itself has a need for major improvement. It has been reported that a disconnection between the needs of the market and the courses offered by higher education leads to high rate of unemployed graduates (Islam 2016). Even more recently it is documented that the lack of high-quality education is the result of two specific reasons (Islam 2016):

- Not enough graduates with specialized skills or the higher education sector
- Skilled graduates still missing sufficient abilities in the English language, computer, communication and problem-solving

Another reason is that only discipline-specific knowledge development gets preference and promoted and aspects like teaching and learning strategies are overlooked. Even though universities have made great investments in modernizing their institutes, teachers are disinclined to work with newer strategies in teaching and learning, and therefore, many opportunities are still under-utilized (Islam 2016). In contrast, countries like Germany have a better higher education system. They have better opportunities of new inventions and the latest technologies. That is one reason why the university staff has a better prerequisite for high-quality research. In the Bangladeshi education system, one big gap is that the learning system in universities is mostly theory-based education. It has happen due to lack of technological opportunities, lack of research opportunities, lack of funding, lack of proper knowledge, etc. Therefore, cooperation between Bangladeshi und German universities has started to establish a bilateral knowledge transfer. That includes scholarships to study in one another's country, research opportunities and funds acquisition from donor agencies. The final aim is that the Bangladeshi are able to make their own decisions regarding a sustainable development because the best decisions are those which came from within a country itself.

To point out a what-if: If the higher education of learning in Bangladesh does not act with a serious urgency, they would be on the wrong side of the swiftly widening knowledge and technology gap (Islam 2016).

After major catastrophes, it was clear that the labour inspectorate required a complete reconditioning if it was to be effective. As a result, the Department of Inspections of Factories and Establishments (DIFE) undergoes a major overhaul by the Government of Bangladesh (International Labour Organization 2016). This includes a rise in employees, budget and an agreement for labour inspection strategy and road map. Additionally, an inspection checklist as well as more effective information management systems are being developed (International Labour Organization 2016). As part of its reform efforts, DIFE has implemented a number of training programs for its inspectors. These include a recently concluded 40-day foundational training course helping 160 labour inspectors gain the skills needed to boost working conditions and worker safety in Bangladesh. These will significantly strengthen the systems which form the foundation upon which DIFE operates. To operate effectively, basic equipment such as motorcycles, office and inspection equipment is being granted to the DIFE. There have also steps been made towards better transparency by setting up a public database and web site where inspection reports can be accessed (International Labour Organization 2016).

In the last five years, safety has improved at larger factories that have direct relationships with Western retailers and are under the supervision of two initiatives. But workers at the smaller factories that have domestic contracts and those that are subcontracted and get the overflow work from other factories are still in peril. Those factories are under the responsibility of the Bangladeshi government, which has not done as thorough a job of inspecting or pushing for remediation and still has hundreds of factories to inspect (Epatko 2018). The main reason for the slow process is being the costs. A participation of many companies, the Bangladesh government and other international organizations have been proposed which would mean that no one alone needs to stand for the costs. But as it can be imagined retailers do not have the motivation to help factories that are not one of their suppliers. This leaves many textile factories in the invidious of the situation of losing their contracts because they do not fulfil the safety requirements and do not have any leverage towards the retailers to support them financially for better working and safety conditions (Epatko 2018).

18.6 Conclusion

It is undeniable that every piece of clothes leaves a footprint on society and environment. They question is, how great is the footprint and what can we do to reduce it? First of all, there has to be an unmistakable and widely excepted definition of sustainability and how to quantify it. This needs to be done along the entire textile chain starting with our consumer behaviour all the way to the recycling process. At the same time, it is important to view both, the technological and socio-economic aspects and to let them develop together in a manner that both parties benefit from each other. It is not productive to deny the access to better technologies to ease the workload of the workers nor should not the machinery dictate the working speed.

Achieving sustainable development will require global actions to deliver for further economic, social and environmental progress; requiring growth and employment for sustainable development will need to take special care of the needs of the poorest and most vulnerable countries like Bangladesh and India. Researchers are working to reduce the inequality of the development among the rich and poor peoples in a sustainable manner (United Nations 2013).

Therefore, the following aspects should be the main goals:

- Sustainable textile materials and processing development, which are economical, environment friendly and socially accepted and positively impactful.
- Creating a common platform with digitalization for buyer, consumers and manufacturer to deal the sustainability challenges and implement the systems in global.
- Looking for product diversification recycled product and its process through sustainability.
- Increase human resource capacity, skilled manpower, good working environment for male and female in the textile and RMG industry.
- Sustainable textile industries develop to reduce inequality between rich and poor peoples in Asia.

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Chapter 19
Circular Approaches and Business Model Innovations for Social Sustainability in the Textile Industry

Katja Beyer and Marlen Gabriele Arnold

Abstract The global textile industry typically is seen to have a negative image due to ethically questionable working and sourcing conditions in mainly Asian located low-cost production countries. The *Rana Plaza* building collapse in Dhaka, Bangladesh, on April 24, 2013, the *DETOX* campaign of *Greenpeace*, and the promotion of circular economy concepts by NGOs and scientists affected particularly companies such as *H&M* but not just exclusively. These aspects supported a change in corporate strategies toward more transparent communication and dissemination of statements and reports on corporate sustainability activities or strengthening commitment and involvement in multi-stakeholder initiatives to enhance social and environmental sustainability in sourcing and production countries. However, circular approaches focus mostly on economic and environmental sustainability, thereby neglecting the social dimension of sustainability and systemic change particularly necessary in the textile industry. In fact, limited understanding exists with regard to the following questions: *Which topics and patterns concerning circular concepts and social sustainability or corporate responsibility have been considered in the global textile industry? In what way do academic viewpoints and corporate activities differ?* We explore how discussions around circular approaches and business models for social sustainability in the textile industry have been evolving concurrently between 2008 and 2017 both in theory and in practice. The research employs a systematic software-based qualitative literature analysis in the context of the textile industry, thereby also exploring the illustrative practical example of the fast fashion retailer *H&M*. Our findings reveal that circular business models in the textile industry are becoming of increasing relevance, thus contributing to a sustainable development. However, particularly social aspects are underrepresented in scholarly publications on circular economy, yet promoted by textile companies. We conclude by highlighting implications and suggesting avenues for further research.

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19.1 Introduction

The collapse of the *Rana Plaza* building on April 24, 2013, in Bangladesh, accommodating five garment manufacturers, amongst others, probably has become the epitome in collective memory for a global textile industry that pursues profit maximization from value creation abroad at the expense of social and environmental sustainability (Fischer 2018; Huq et al. 2014; Boiral et al. 2017; Comyns and Franklin-Johnson 2018; Egels-Zandén 2016; Arretz and Meyer 2018; Weisert 2018). Next to systemic shortcomings in low-cost production countries such as poor infrastructure (Baumann-Pauly et al. 2018) and limited public regulation (Egels-Zandén 2016), the literature also points to structural deficits such as mismanagement regarding supplier oversight (Paik et al. 2017) and little subcontractor accountability (Taplin 2014) among textile companies. Further causes include a priority of profitability and export-led economic growth at the expense of enforcing worker safety laws and labor abuses especially in production countries as well as a detachment of primarily Western-based fashion retailers from production locations and a general neglect of social responsibility (Paik et al. 2017). In addition to this, likewise the dominating fast fashion business model, the concentration of the fashion retail sector and Western consumers' willingness to consume fast fashion items (Taplin 2014; Caro and Martínez-de-Albéniz 2014) are seen to have been decisively contributing to a profound crisis of the global textile industry (Paik et al. 2017).

The need to foster transparency, explicit communication and governance of operations in textile supply chains and throughout manufacturing processes also pushed the implementation of social sustainability (Fifka 2018; Turker and Altuntas 2014; Henninger et al. 2016). According to the *UN Global Compact* "social sustainability is about identifying and managing business impacts, both positive and negative, on people" (UN Global Compact 2019). Rising pressure for (social) compliance (Sinkovics et al. 2016) has been forcing fast fashion retailers to newly develop or align their CSR policies (Caro and Martínez-de-Albéniz 2014). Increasing demands for socially responsible business operations and inducing systemic changes also extend altering prevailing production and consumption patterns in the textile industry (Hirscher et al. 2018; Austgulen 2016). Yet, such profound changes are likely to require more radical, non-technological innovations as highlighted in recent research by Bidmon and Knab (2018).

In this context of uncertainty and risk, business model innovations are seen to be highly valuable (Rauter et al. 2017) since they provide alternative ways to the creation and capturing of value by challenging the dominant regime logic (Bidmon and Knab 2018). In doing so, business model innovations facilitate corporate transformation and renewal in order to sustain organizational performance and competitive advantage (Zott et al. 2011) as well as to drive transitions (Bidmon and Knab 2018). This more or less firm-centered view is extended by business model innovations for sustainability which also emphasize a societal impact of value creation, capturing and delivery, thereby taking into account the interests of multiple stakeholders (Dentchev et al. 2018; Tolkamp et al. 2018; Ritala et al. 2018) and fostering systemic change (Koistinen et al. 2018).

"The idea of a sustainable development stresses the creation of resilient ecological, social and economic systems by respecting the natural and given limits of ecological viability and capacity" (Arnold 2018: 582). One way of enhancing business model innovations for sustainability is enhanced by the concept of the so-called circular economy (Lüdeke-Freund et al. 2018; Antikainen and Valkokari 2016; Nußholz 2017). At the core of the concept lies the idea of designing an economy that is restorative and regenerative based on closed loop flows of materials and energy (Heyes et al. 2018; Geissdoerfer et al. 2017). Closely linked to this is an alternative treatment of waste, namely by promoting the minimization and avoidance of waste as well as its use as a valued secondary resource (Geissdoerfer et al. 2018; Moreau et al. 2017; De Angelis et al. 2018). The concept has been boasted by increased attention both in academia and practice particularly over the last decade (Geissdoerfer et al. 2017, de Mattos et al. 2018) driven by the growing and rapid depletion of natural resources around the globe (Moreau et al. 2017).

We investigate which themes and topics have been included in circular economy and business model innovations for sustainability in the textile industry over time, thereby particularly focusing on social aspects. We believe that paying special attention to social sustainability and (corporate) social responsibility is essential given frequent media reports on the global textile's industry morally and ethically questionable business practices such as, among others, child and forced labor, excessive working hours or low wages (Köksal et al. 2017). Moreover, studies on the integration of social sustainability-related aspects such as, and also including, impacts on social equity and future generations, in the circular economy and business model innovations are largely absent (Kirchherr et al. 2017, de Mattos et al. 2018).

To work toward addressing this research need, the study employs a two-pillar conceptual framework and uses the illustrative example of *H&M*. In doing so, we analyze corporate sustainability reports by means of automatic content analysis in order to derive "verbal patterns" on themes and concepts that are pivotal to *H&M*'s understanding of circularity. Though there are several studies on circular economy-related approaches and strategies in the textile industry (e.g., Stål and Corvellec 2018, Bocken et al. 2017, Fischer and Pascucci 2017), to the best of our knowledge, business model transformation toward circular business models in the textile industry has not been explored using the procedure of finding "verbal patterns" in corporate communications. The aim of this research is to improve our understanding of evolving dominant themes and subjects in circular business models and strategies in the textile industry over time in general and as reported by *H&M* in particular. From this objective and in order to fill in the research gap, we seek to address the following two central research questions:

- **RQ 1:** Which topics and patterns concerning circular economy-related concepts and approaches have been reflected in the global textile industry?
- **RQ 2:** Which topics and patterns concerning social sustainability and corporate responsibility have been considered in circular economy approaches and circular business models in the global textile industry?

The remainder of the paper is structured as follows: This introduction comprises of the rationale and objectives of our research. In the next section, an overview of the literature on research streams relevant to our paper, namely "circular economy," "business model innovations for sustainability," and "circular business models" is presented. This is followed by a detailed description of the conceptual framework as well as the material and methods used in this study. We then summarize and discuss the findings of our content analysis and the real-life business example. The last section is devoted to a summary of conclusions, including implications for theory, practice, and further research.

19.2 Theoretical and Conceptual Background

The following section reviews relevant literature streams that are pivotal to addressing our two research questions. We begin with highlighting main aspects characterizing the concept of circular economy before recent theoretical discussions on sustainable and circular business models are presented. As the amount of publications has increased considerably in recent years (Kirchherr et al. 2017), we decided to focus on reviewing randomly selected papers published in peer-reviewed academic journals from 2016 onwards in this section. Thus, this theoretical and conceptual background makes no claim to being complete.

19.2.1 Key Characteristics of a Circular Economy

The concept of a circular industrial system and its underlying ideas are not new (Moreau et al. 2017; De Angelis et al. 2018). First attempts in outlining the characteristics of the concept date back until 1966 (Geissdoerfer et al. 2017). Yet, the term "circular economy" itself was introduced into the academic discussion just by 1990 (Prieto-Sandoval et al. 2018, Geissdoerfer et al. 2018, de Mattos et al. 2018). It took roughly another two decades until the concept received broader attention among both practitioners as well as the scientific community (Manninen et al. 2018; Geissdoerfer et al. 2017) to accelerate transition toward sustainability at multiple levels (Ghisellini et al. 2016; Lüdeke-Freund et al. 2018).

The concept fosters opportunities for a fundamentally rethinking of the current logic of economic activity, thereby opposing the prepondering linear "make-take-dispose" business model (Nußholz 2018; Ranta et al. 2018a; De Angelis et al. 2018).

The extensive use of natural resources with devastating impacts on the environment (Moreau et al. 2017; De Angelis et al. 2018) and physical limits (Tura et al. 2019) of contemporary production and consumption patterns are seen to be the major reasons for the concept's current prominence. Structural and socio-economic changes are further broadening the need of alternative ways to design a viable economy (De Angelis et al. 2018).

Many different schools of thoughts and approaches, disciplines, emerging fields, and semi-scientific concepts loosely have been contributing to the development of the current understanding of a circular economy (Korhonen et al. 2018b; Geissdoerfer et al. 2018). These ideas and concepts stem from various different disciplines such as industrial ecology, production economics, engineering, operations research, design, management, and corporate sustainability (Lahti et al. 2018; Prieto-Sandoval et al. 2018; De Angelis et al. 2018; Geissdoerfer et al. 2018), amongst others, and on the main shared idea of closed loops (Geissdoerfer et al. 2017). Despite these diverse theoretical foundations, the concept itself has been largely developed and promoted by practitioners from the fields of policy, business, and consultancies (Korhonen et al. 2018b; Lahti et al. 2018; Kirchherr et al. 2017) only recently (De Angelis et al. 2018). Though the concept is considered to facilitate implementing the vague concept of sustainable development (Kirchherr et al. 2017), it is not entirely uncontroversial. Moreover, research also acknowledges that real-life successful implementation of the concept in companies remains limited (Tura et al. 2019, de Mattos et al. 2018).

The concept promotes value and wealth creation which is decoupled from the consumption of finite natural resources (Hopkinson et al. 2018). Thereby, the concept fosters economic growth, environmental resilience, and the transition toward an ecological economy (Lahti et al. 2018; Oghazi & Mostaghel 2018; Prieto-Sandoval et al. 2018). For this to become implemented, eco-innovations, different models for designing closed loops, systemic and institutional changes as well as a long-term perspective are required (Prieto-Sandoval et al. 2018; Merli et al. 2018; Tura et al. 2019; Levänen et al. 2018; Lüdeke-Freund et al. 2018; de Mattos et al. 2018). Figure 19.1 summarizes main themes and ideas underlining the concept of circular economy as discussed in recent literature, particularly in the field of sustainability management.

The literature has pointed to several drivers as well as challenges of implementing the circular economy (Tura et al. 2019; Hopkinson et al. 2018; Ranta et al. 2018b; Ghisellini et al. 2016). Exemplarily, research has emphasized the need of particular sector-specific approaches (Heyes et al. 2018) as well as companies' ability to adjust to transforming institutional frameworks (Levänen et al. 2018) as potential challenges for the circular economy. Next, similar to the concept of sustainable development, the concept has recently been criticized for its blurriness given the various different understandings and approaches that exist both in theory as well as in practice (Kirchherr et al. 2017; Tunn et al. 2018; Korhonen et al. 2018a). Thus, further exploring the concept theoretically as well as conceptually becomes necessary (Kirchherr et al. 2017).

Interestingly, given the practitioner-led development of the concept, several authors claim an overall piece, despite a recently growing amount of scientific

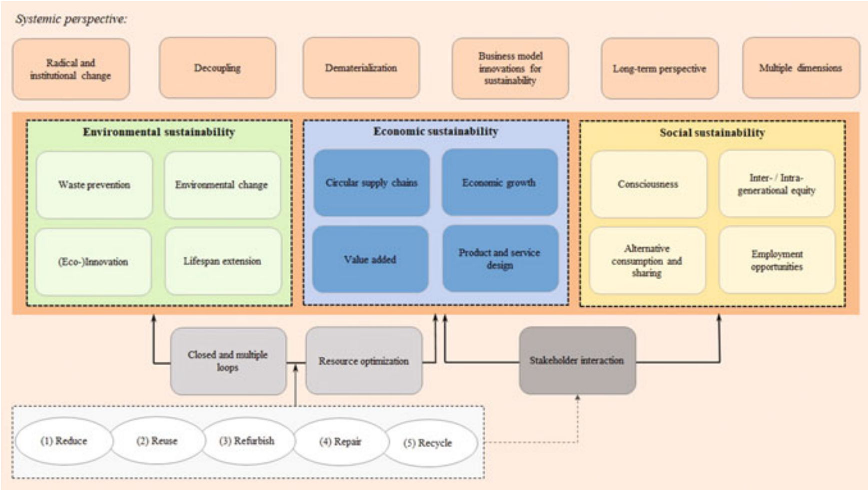


Fig. 19.1 Schematic representation of frequently occurring themes and ideas underlying the concept of circular economy in sustainability management research [*as emphasized by the authors* (Synthesis and visualization as stressed by the authors; Selection of themes and ideas based on Geissdoerfer et al. 2017, 2018; Yang et al. 2018; Ranta et al. 2018a; Manninen et al. 2018; Lahti et al. 2018; Hopkinson et al. 2018; Ghisellini et al. 2016; Heyes et al. 2018; de Mattos et al. 2018; Korhonen et al. 2018a, 2018b; Merli et al. 2018; Lüdeke-Freund et al. 2018; Bocken et al. 2016, 2018)]

research on the topic particularly in the fields of management, organization, and strategy (e.g., Hopkinson et al. 2018, Lahti et al. 2018, Merli et al. 2018, Urbinati et al. 2017). Korhonen et al. 2018b stress a significant lack of empirically rigorous research particularly with the link between the concepts of circular economy and sustainability or sustainable development. Perhaps one of the few notable exceptions to this claim is the study by Geissdoerfer et al. (2017). The authors compare the two concepts of sustainability and circular economy. In their view both concepts share features such as intra- and intergenerational commitment and the integration of non-economic aspects into further development. Further similarities include the substantial importance of private business for implementing both concepts and business model innovations in order to facilitate industry transformation (Geissdoerfer et al. 2018; Bocken et al. 2017; Lahti et al. 2018). Despite these similarities, however, the authors also identify certain differences between the concepts in terms of objectives, motivations, and rationales as well as the sustainability impacts. Exemplarily, sustainability should benefit all stakeholders alongside the three core dimensions environment, economy, and society at large (e.g., Arnold 2017) by aligning objectives and commitments between stakeholders. In contrast, the circular economy focuses on economic actors that drive generating benefits for the economy and environment such as competitive advantages and less resource depletion. Thus, offering benefits for society is not a major concern and at best occurs via secondary effects in the circular economy (Geissdoerfer et al. 2017; Ranta et al. 2018a;

Manninen et al. 2018). However, social awareness is a key element for facilitating the implementation of the circular economy (Lieder and Rashid 2016). Moreau et al. (2017) criticize this neglect of primarily addressing also social dimensions in contemporary circular economy approaches. They argue that—next to institutional conditions—also elements from the social and solidarity economy have to be included to develop the circular economy on a large scale. This may include employment-related aspects such as "increasing labor-intensive activities while raising the quality and diversity of human work involved in remanufacturing" (Moreau et al. 2017: 504). Social potentials of the circular economy also rest on a deeper change of prevailing social values in the economy. Fostering approaches stemming from the sharing economy are also seen to promote values such as a "sense of community, cooperation and participation" (Korhonen et al. 2018b: 40) as well as avoiding a culture of ownership and consumerism (Korhonen et al. 2018b).

19.2.2 The Importance of Sustainable and Circular Business Models

As mentioned above, companies and business model innovations for sustainability are of central importance to facilitate the transition toward a circular economy (Manninen et al. 2018). Several studies have recently focused on business model innovations that embed sustainable and circular strategies (e.g., Urbinati et al. 2017; Antikainen and Valkokari 2016; Nußholz 2017; Lewandowski 2016; Bocken et al. 2017). Sustainable business model innovation explicitly focuses on *all* three dimensions of sustainability, thereby also including significant positive impacts on the society. This also extends to a fundamental rethinking of the companies' conventional approaches concerning the proposition, creation, delivery, and capturing of value (Bocken et al. 2017) as well as to radical systemic changes (Nußholz et al. 2017, 2018). Such business model transformations additionally mean resolving trade-offs and conflicts based on different primarily financially-oriented values and objectives among stakeholders (Bocken et al. 2017; Lüdeke-Freund et al. 2018). At the same time, overcoming such dilemmas provides chances for learning, improvement, and development (Bocken et al. 2017).

In light of this, scholars have increasingly explored the concept of circular business models (e.g., Tunn et al. 2018; Sumter et al. 2018; Oghazi and Mostaghel 2018). As this research field is just progressing, only few definitions of circular business models exist (Nußholz 2017). According to the literature, circular business models are a specific type of sustainable business models (Lüdeke-Freund et al. 2018; Geissdoerfer et al. 2018) that foster the implementation of sustainable development by incorporating the principles and ideas of the circular economy into the *whole* value chain and by pro-actively balancing the interests of multiple stakeholder as well as fostering a long-term perspective of business operations. Based on closed, slow, and narrow loops to maximize the value of resources, materials, components, products and labor over time, circular business models allow for profit creation on the basis of reducing, reusing, and recycling while improving environmental sustainability (Manninen et al. 2018; Geissdoerfer et al. 2018; Lahti el al. 2018; Nußholz 2018). This also might involve value creation by extending business activities and developing alternative financial models (Manninen et al. 2018) or by creating alternative product and service designs and reliance on information technology (de Mattos et al. 2018). Implementing circular business models further requires innovations regarding logistics and supply chains based on a close collaboration with partners and experts in fields such as secondary materials (Lüdeke-Freund et al. 2018).

With regard to the benefits of circular business, recent research highlights the likely emergence of new or the enlargement of already existing markets and cost savings, as well as reductions in the consumption of raw materials and natural resources. From a societal viewpoint, they are seen to bring about benefits particularly for customers such as different behavioral and consumption patterns as well as extended usage experiences (Lüdeke-Freund et al. 2018). An increased sharing and reusing of resources are also intensifying interactions (Oghazi and Mostaghel 2018).

Although an explicit consideration of social sustainability in circular business models in contemporary literature is mostly neglected, as shown also in Fig. 19.1, a few studies focusing on the comparative features of circular business models also singularly point to incorporating social aspects (e.g., Geissdoerfer et al. 2018). Moreover, the study by Geissdoerfer et al. (2018) emphasizes the sustainability dimension "Protection of future generations," which explicitly asks for considering systemic changes and long-term collaborations when meeting future social challenges.

Further criticism also claimed a lack of arguments on the rationale and degree toward adopting circular strategies from a corporate perspective as well as the omission of contingency factors and little context-sensitivity in current research on circular business models (Urbinati et al. 2017; Lüdeke-Freund et al. 2018). This is seen to be critical in light of a high degree of uncertainty and risk in the environment for companies fostering the implementation of circular business models (Lahti et al. 2018; Bocken et al. 2017). The prevailing discussion of circular business models on either micro- or meso-level neglects a macro-level perspective on characteristics and impacts of such strategies. This is spurred, among others, by a missing determination of the roles of stakeholders at the macro-level, such as NGOs and governments (Lüdeke-Freund et al. 2018).

19.3 Research Method

Acquiring a deeper understanding of circular economy approaches in business models of the textile industry as well as their social sustainability and corporate responsibility-related aspects, the research design and process rests upon a multiple-pillar structure. This framework embeds both a theoretical as well as a practical perspective. Figure 19.2 summarizes the overall conceptual and methodological

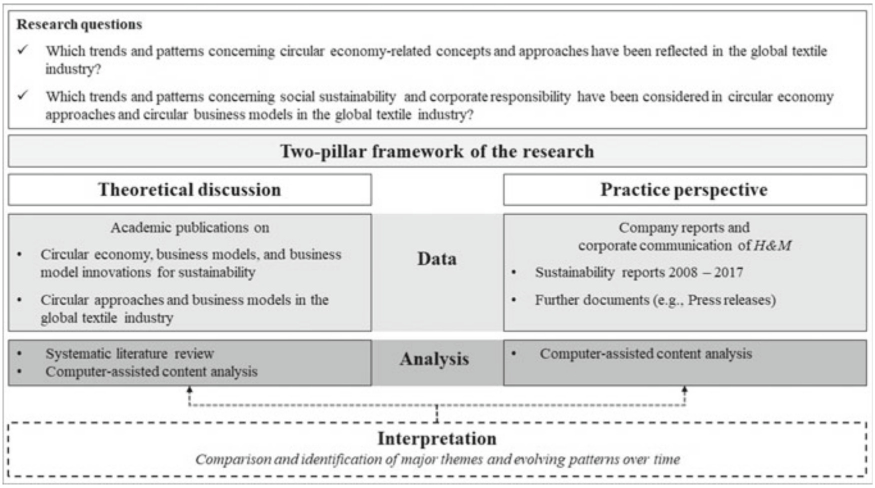


Fig. 19.2 Analytical framework of the research design and process (*authors' own illustration*)

framework of the present research, thereby highlighting materials as well as methods and approaches used. Each of the study's pillars is described more in detail in the following section.

19.4 First Pillar of the Study: Systematic Software-Based Literature Analysis for Exploring Theoretical Concept and Network Cloud Visualizations

In a first step, we employed a systematic literature review (e.g., Saidani et al. 2019; Quarshie et al. 2016) constituting the basis for our systematic software-based qualitative literature analysis. In general terms, a literature review aims at rigorously identifying, selecting, and assessing the existing body of knowledge on a specific topic in a systematic, transparent, and reproducible manner (Ansari and Kant 2017; Merli et al. 2018). In line with previous research (e.g., Homrich et al. 2018; Gerritsen-van Leeuwenkamp et al. 2017; Schallehn et al. 2019; Camacho-Otero et al. 2018), our systematic literature review includes the following steps: (1) Material collection including database selection, sampling procedure, determining criteria for inclusion and exclusion as well as the search of relevant articles; (2) Data analysis based on a computer-assisted content-analysis software tool; and (3) Presentation of results. Figure 19.3 presents the procedure of the systematic literature review adopted in this study in detail.

(1) *Material collection*

As highlighted by Ansari and Kant (2017), material collection is of prime importance in a systematic literature review. For our review, we chose the following databases

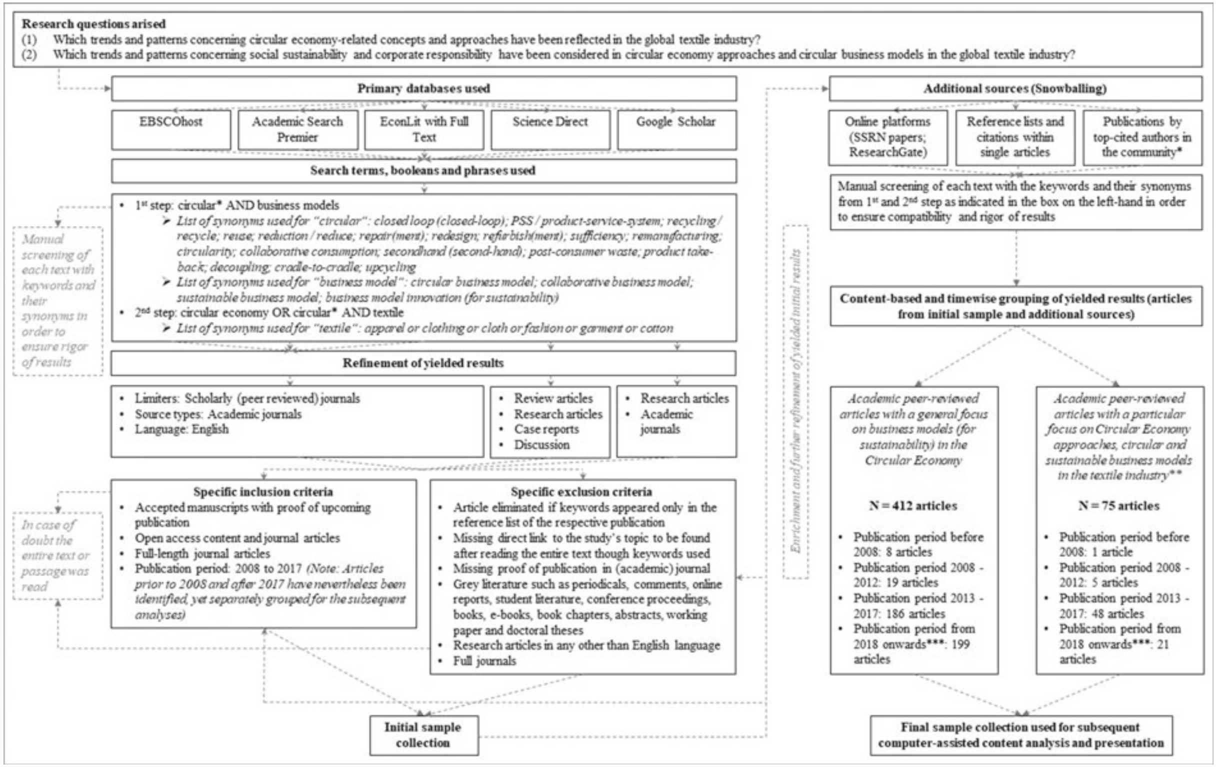


Fig. 19.3 Procedure of the systematic literature review employed in this study (*author's own illustration*)

for an initial search: *EBSCOhost*, *Academic Search Premier*, *EconLit with Full Text*, *Science Direct,* and *Google Scholar*. The keywords used for collecting relevant material in those databases related to the research areas of circular economy, business models, business model innovations for sustainability, corporate social responsibility and the global textile and apparel industry (see Fig. 19.3).

In order to have a quite broad and comprehensive final material collection for the subsequent content analysis, we also implemented further article search strategies such as "snowballing"—a technique which has been frequently used in social research (Neutzling et al. 2018) and also been deployed in previous literature reviews (e.g., Gerritsen-van Leeuwenkamp et al. 2017) or research particularly on the circular economy (e.g., Tukker 2015). As can be depicted from Fig. 19.3, we established several criteria for inclusion and exclusion of articles in the final sample (Ansari and Kant 2017; Quarshie et al. 2016; Rajeev et al. 2017) in order to refine and further sort the collected material. Furthermore, several "must-criteria" were established to assess a study's relevance. Exemplarily, in order to be included in the final sample, *all* publications must contain the keyword "business model" (or any of its synonyms as shown in Fig. 19.3)—if this was not the case, the article was directly eliminated from the search result list.

For the purpose of our research, namely our two research questions, we classified the yielded results of collected research articles according to their content and their publication date into two groups. The first group included 412 peer-reviewed, full-length journal articles on business models (for sustainability), and strategies in the circular economy. The second group of peer-reviewed, full-length journal articles compiled of 75 publications focusing on circular economy approaches, circular and sustainable business models in the global textile and apparel industry. In every group, several subsets of time frames were formed according to our chronological analysis (see Fig. 19.3).

We acknowledge several limitations related to the systematic compilation of literature in the present research. As Tukker (2015) comments the final sample of research articles collected "is inevitably the result of choices which are, to some extent, arbitrary" (Tukker 2015: 78). The first choice in our study concerns the databases and search engines selected as well as the keywords applied. Perhaps different research results may be obtained when referring to databases from other research disciplines or databases that provide more access to full-length content as well as including other types of publications (e.g., books). Additionally, applying further keywords such as "resource efficiency," "sharing economy," or "jeans" amongst others, may have changed the final search results. Yet, we believe that our approach of including several snowballing techniques of collecting material counteracted the risk of omitting potentially relevant research.

(2) *Data analysis*

In deviation from conventional systematic literature reviews and given the limitations of particularly manual coding such as human subjectivity and inter-coder reliability (e.g., Young et al. 2015; Bryman 2015; Zawacki-Richter and Naidu 2016), we employed a useful alternative based on a computer-assisted software tool to conduct a content analysis (Harwood et al. 2015). In doing so, we used the text-mining and data-visualization tool *Leximancer*™ (version 4.50). This software is increasingly acknowledged across disciplines (Harwood et al. 2015) and has also already been employed in previous research on sustainability-related topics (e.g., Ranängen and Lindman 2017). With particular regard to previous research on the textile and apparel industry, the software tool has been used in order to explore themes relating to sustainable supply chain management (Kim and Kim 2017).

Based on a Bayesian machine-learning technique (Bigi et al. 2016) *Leximancer*™ features an automatic lexicographical analysis to inductively and iteratively identify main concepts and themes from the data (Harwood et al. 2015; Cheng et al. 2018; Gautami Fernando et al. 2014). This analysis is based on a statistical examination of the frequency, (co-)occurrences, and interrelations of words (Young et al. 2015; Angus et al. 2013). In the sense of this software tool, concepts are "collections of words that generally travel and occur together throughout all the literature" (Cheng et al. 2018: 772). *Leximancer*™ allows two types of analysis, namely (1) thematic or conceptual analysis focusing on identifying core concepts as well as (2) semantic or relational analysis examining links between all concepts (Zawacki-Richter et al. 2017; Thomas and Maddux 2009; Bigi et al. 2016). Both types of analysis were also used in our procedure.

At the end of the analysis, clusters of similar concepts occurring in close proximity (Zawacki-Richter et al. 2017) are visualized in a two-dimensional map (Harwood et al. 2015; Thomas and Maddux 2009; Zawacki-Richter and Naidu 2016). Next to concepts, these maps also include themes which are "clusters of frequently co-occurring concepts" (Buzova et al. 2016: 1056) and "summarized into circles" (Harwood et al. 2015: 1033). The most prominent concept in a cluster of concepts also serves as the name for the respective theme (Zawacki-Richter et al. 2017; Harwood et al. 2015). The map also represents the semantic relationships between concepts and themes based on their relative position within a theme. Semantic relations are stronger (weaker), the closer (the farer) concepts are related (Buzova et al. 2016). At the same time, closer proximity and overlaps among themes on the map indicate a closer relationship in the underlying textual documents (Bigi et al. 2016).

When applying the software, we used its interactive features (Thomas and Maddux 2009; Young et al. 2015; Harwood et al. 2015). We manually adapted coding processes and customized the subsequent visualization according to our research objectives. Despite the benefits of the software such as transparency and reliability, *Leximancer*™ also imposes several challenges regarding interpretation of findings (Zawacki-Richter et al. 2017).

(3) *Presentation of results*

Figure 19.4 shows the annual distribution of publications in peer-reviewed scientific journals for the two groups of articles, namely business models and strategies in the circular economy as well as circular approaches and business models in the textile industry. As can be seen, there has been a sharp increase in publications for both groups in recent years. Exemplarily, until 2014, only 57 publications on business models and strategies in the circular economy were to be found. In contrast, the

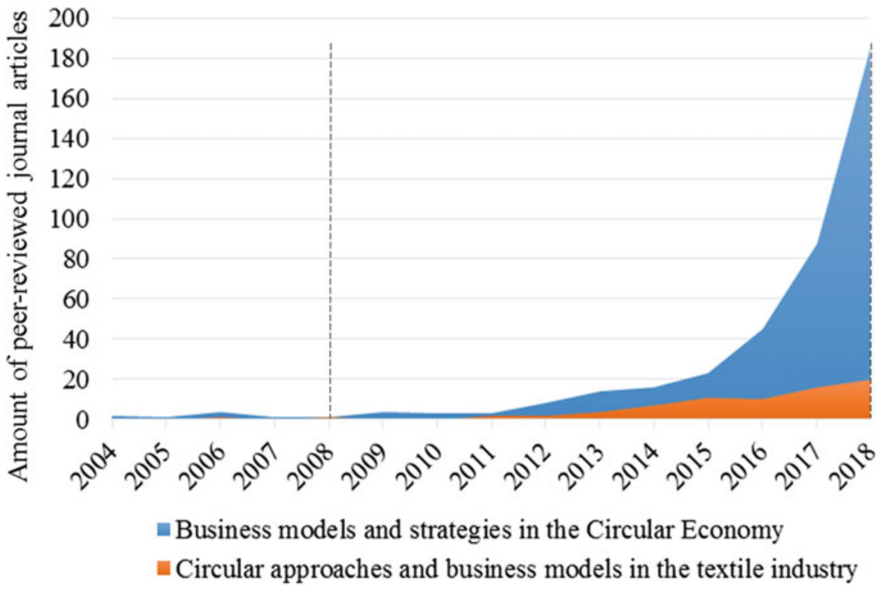


Fig. 19.4 Annual distribution of publications on circular approaches and business models

amount of publications has almost doubled annually between 2015 and 2018. For the second group of articles focusing on circular approaches and business models in the textile industry, a much lower number of publications was gathered, both in absolute as well as in relative terms. Only 75 articles between 2006 and 2018 were identified.

The findings from the interpretation of the concept maps generated during the *Leximancer*™-based content analysis are presented in the Results section of the paper. In line with the illustrative example of *H&M* and being able to draw conclusions based on a comparative analysis, the total period between 2008 and 2017 was chosen for the following reasons: At the time this research was drawn up, the latest *H&M* Sustainability Report presented on the company's website was from 2017. So, using 2017 as reference year, we stepped 10 years back and split the whole period into two sub-periods (2008–2012 and 2013–2017). A 5-year period was deemed reasonable to observe changing strategies, perspectives, expressions, and interpretations of theory, concepts, and practices.

19.5 Second Pillar of the Study: The Illustrative Example of a Fashion Retailer for Reflecting Practical Insights

The second pillar of our research focuses on the Swedish company *H&M*. In particular, we analyze the Sustainability Reports of *H&M* published between 2008 and 2017 in terms of their circular economy-related concepts and themes. We did so since we strive at comparing the findings from this real-life example with theoretical perspectives on circular approaches, strategies, and business models in the textile industry in order to identify major themes and evolving patterns over time. In the next section, we initially introduce the company and describe the selection criteria for this particular practical example.

(1) *The illustrative example of H&M at a glance*

H&M was founded in Sweden in 1947 and sells clothes and cosmetics globally. In 2017, the company employed 171,000 people around the world (H&M 2017), thereby spanning a huge network with suppliers in developing and emerging countries (Svensson 2009). We chose this particular company because of the following five reasons:

(1) As the world's second largest fashion retailer, *H&M* also operates in Bangladesh;
(2) The company has a much disputed and adverse reputation in the media and broader public. On the one hand, the company has repeatedly been mentioned in reports of NGOs and other organizations that criticize the working and production conditions in low-cost countries such as Bangladesh. Further, corporate communication scandals such as racist advertisements have raised massive public outrage against *H&M* forcing the company to take action (Fortin 2018). On the other hand, *H&M* is an established company around the globe concerning the proliferation of a culture of consumerism and the fast-fashion business model;
(3) The company has been repeatedly awarded with prizes for social sustainability reporting, increasing transparency and ethical business operations (e.g., H&M 2013b); and
(4) *H&M* has already been in the focus of previous scientific studies. In a brief literature search, we found 25 full-length peer-reviewed English journal articles published between 2002 and 2018 that are either investigating *H&M* as a single case study (e.g., Åhlström 2010; Shen 2014; Giertz-Mårtenson 2012) or including the fashion retailer in a larger set of empirical cases from a comparative viewpoint (e.g., Stål and Jansson 2017; Garcia-Torres et al. 2017; Illge and Preuss 2012).
(5) However, the final decisive selection argument was motivated by the announcement of the company to become 100% circular and renewable by 2030 (H&M 2018).

Reflecting a unique case (Bryman 2015) given the assumingly entire transformation of a deeply entrenched fast-fashion business model toward a sustainable, circular business model raised our attention and reinforced our interest in investigating the sustainability efforts of that particular firm.

(2) Material collection

For the purpose of our study, we collected the Sustainability Reports published by *H&M* between 2008 and 2017. This procedure yielded in 5 reports published between 2013 and 2017. In order to be methodologically consistent, the same amount of reports was collected up to 2013. So, reports prior to 2008 were excluded from the analysis. The final set included 10 reports, which all are publicly available on the Sustainability Report website of *H&M* (https://sustainability.hm.com) and published in English language. The Sustainability Reports all primarily publish information on social and environmental activities pursued by *H&M*. It should be noted that *H&M* provides quite comprehensively information on the company's sustainability objectives, strategies and actions on its corporate website. We loosely collected further sustainability-related information such as press releases and corporate statements (e.g., interviews with the Head of Sustainability at *H&M*) in order to include it in the Discussion section of our paper. Yet, against the background of our conceptual framework, these documents were not included in the subsequent automatic content analysis.

(3) Data analysis

Similar to the data analysis phase concerning the systematic software-based qualitative literature review in the first pillar of our research, we employed the automatic text analysis program *Leximancer*™ for a primarily qualitative content analysis to further explore the Sustainability Reports of *H&M*. Basically, we again relied on the default settings of the software tool. Yet, where considered necessary and useful, we adapted the settings and technical operations (e.g., forming of merged concepts in case of singular and plural words). Against the background of our research questions and methodological approach, we run the software in several rounds. This procedure is similar to previous research using the software tool (e.g., Zawacki-Richter et al. 2017). Specifically, we first conducted an analysis of the entire data set involving all 10 Sustainability Reports by *H&M*. In a second step, we divided the overall publication period of reports into two groups of which each subset comprised five years (2008–2012; 2013–2017). In this step, we run a separate analysis for each of the two groups. The results of this data analysis and interpretation of the concept maps are presented in the Results section below.

19.6 Results and Discussion

In light of our two research questions and the systematic software-based qualitative literature analysis as described above, this section presents the results of the *Leximancer*™-based content analyses. Given the comprehensiveness of our content analysis, this section highlights mainly a synthesis of findings within and across the two subgroups 2008–2012 and 2013–2017. Based on this comparison, several central propositions are derived and presented below.

(1) *Content analysis of literature on circular approaches and business models in general*

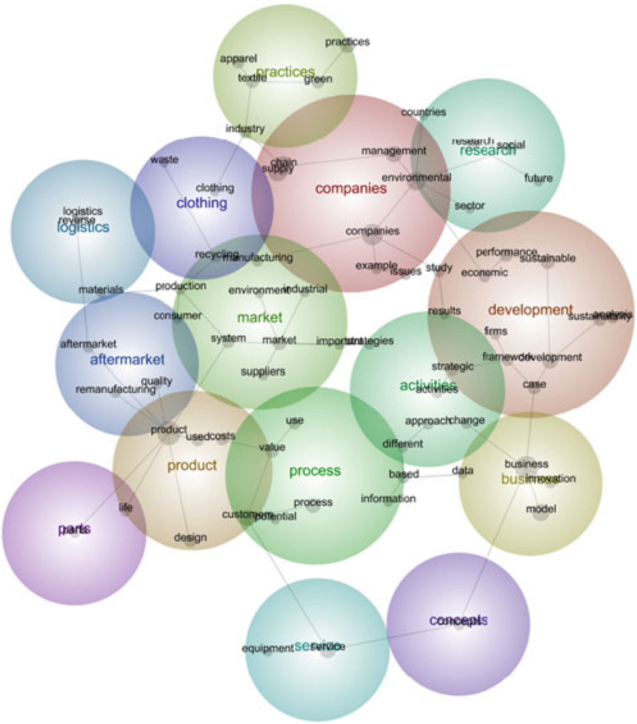
The results of the content analysis of research on circular approaches and business models in general mainly indicate a shift from primarily business and economic-related aspects explored between 2008 and 2012 to the investigation of environmental and scientific-related themes between 2013 and 2017. This can be seen in the first two Fig. 19.5a and b.

This development includes a deeper academic-based investigation of aspects that relate to alternative ways of value creation including also non-economic values and by fostering research on the concepts of closed loops and a circular economy. In

a

Concept map of software-based qualitative literature analysis for the period 2008-12

(General focus on circular economy approaches)



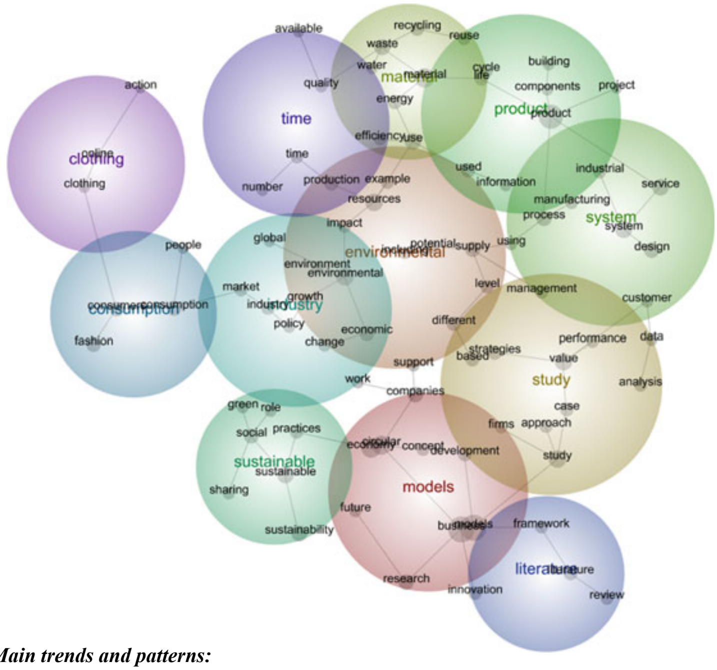
Main trends and patterns:

- the concept map includes 15 thematic regions
- thematic regions of large size are "companies" and "development"
- the thematic region "development" includes 12 different concepts; among them "strategic", "performance" and "firms" as well as "sustainable" and "sustainability" or "study" and results"
- not all of the themes are linked or have overlaps as can be seen regarding the concepts "service" and "concepts"
- although most of the thematic regions are overlapping, these intersections are not of a large size

Fig. 19.5 Content analysis on circular economy approaches and business models in general (*Details see* Fig. 19.3, *100 % visible concepts and 33 % theme size*)

b **Concept map of software-based qualitative literature analysis for the period 2013-17**

(General focus on circular economy approaches)



Main trends and patterns:

- the concept map includes 12 thematic regions
- thematic regions of large size are "environmental" and "study"
- the thematic region "environmental" includes 13 different concepts; among them "resources", "impact" and "environmental" as well as "supply " or "production", "growth" and "economic"
- there is a thematic region "models" presented where 10 concepts are included; among them "future", "research", "business", "models", "circular" and "economy"
- within the theme the concepts "business" and "models" as well as "circular" and "economy" are characterized by an intersection each of a large size and they are both linked to the concept "innovation" in the thematic region "literature" by a concept path
- the thematic region "models" also provides overlaps with two other thematic regions, namely "sustainable" and "study"
- all of the themes on the concept map are linked or have overlaps and often these overlaps are of a large size

Fig. 19.5 (continued)

this respect, the shift in the second-time frame also mirrors aspects that genuinely relate to the social dimension. Exemplarily, results from the analysis highlight the relevance of issues such as sharing within published research after 2013. In fact, these concepts may be seen as important enablers or drivers regarding the consideration of a social dimension of a circular economy as well as the overall transition toward sustainability and sustainable development.

Further, a rising interest in business model innovations among researchers can be retraced. This is complementary to our findings in Fig. 19.4 above showing a growing interest in the topics of circular economy and circular business models among scholars since 2013. The overall amount of research has sharply increased in particular since 2016. Moreover, as can be seen in Fig. 19.5b, in the period from 2013 to 2017, a higher density and more overlaps in research topics covered can be asserted from the automatic content analysis of publications generated by *Leximancer*™. These interrelations can be attributed to an increase in interdisciplinary research. At the same time, this finding might provide evidence for the growing complexity and recognized dependency of aspects relating to characteristics, potentials, and challenges of circular approaches and strategies.

(2) *Content analysis of literature on circular approaches and business models in the textile industry*

Considering the results of the content analysis of literature on circular approaches and business models particularly in the textile industry we find that—similar to the general focus of research on circular approaches and business models—research has also been gaining an increasing importance and relevance in the period 2013–2017. This finding is visually illustrated on the concept map in Fig. 19.6b. Moreover, the finding of an increasingly growing number of publications on circular approaches and strategies in the textile industry becomes supported by Fig. 19.4. Furthermore, as depicted in the graphical map in Fig. 19.6b, findings provide evidence for a more differentiated perspective on the textile industry. The growing number of emerging research topics in the second time period is emphasizing this observation. Exemplarily, issues regarding innovation have become of major concern to researchers.

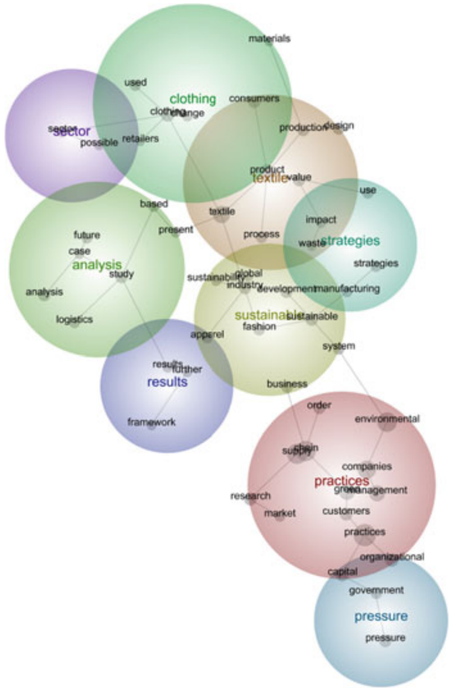
Quite astonishingly, as shown in Fig. 19.6a, in the first period of analysis, research articles have focused on practices in the textile industry highlighting supply chains, companies, management, and customers. In contrast to this, the *Leximancer*™-based content analysis provides visual evidence that these practices have been related to other issues in the second time period. Exemplarily, practices are related solely to approaches which imply changes in fashion while at the same time are connected to aspects of sustainability, thereby likely reflecting much-needed transitions.

Whereas in the period between 2008 and 2012, scholarly publications have pointed to pressures, organizational, and government-related aspects in their research, from 2013 to 2017 such thematic foci or similar critical issues (e.g., standards) cannot be retraced from the graphical map presented in Fig. 19.6a. However, in contrast to this finding, issues that are reflecting a contemporary "*zeitgeist*" in the textile industry have been evolving in scholarly publications between 2013 and 2017. As illustrated in Fig. 19.6b, these include aspects of the circular economy such as recycling and slow fashion.

Against the background of our two research questions, we also find a central role of aspects relating to the concept of slow fashion, thereby pointing to a holistic and central character of the concept by linking core activities and major stakeholders alongside the sustainable textile value chain. Exemplarily, the role of designers, consumers, and consumption can be highlighted, thereby addressing key features concerning the implementation of the circular economy in the textile industry that

a **Concept map of software-based qualitative literature analysis for the period 2008-12**

(Specific focus on textile industry)



Main trends and patterns:

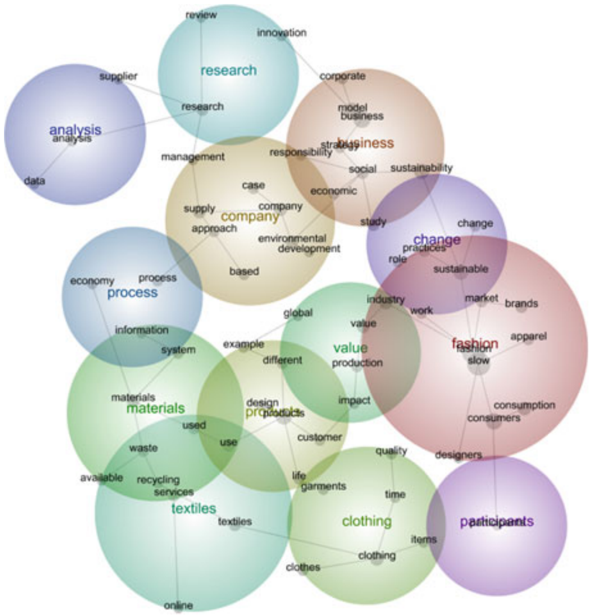
- the concept map includes 9 thematic regions
- thematic region of the largest size is "clothing"
- the thematic region "clothing" includes 6 different concepts; among them "materials", "consumers" and "retailers" as well as "change"
- the thematic region "clothing" also presents the largest overlap on the concept map with the thematic region "textile"
- another big thematic region is "practices" including 13 different concepts such as "customers", "order", "companies", "management", "organizational", "capital" but also "environmental" and "research"
- the concept map provides a thematic region "pressure" that shows the concepts "pressure", "capital", and "government" and that is overlapping with the thematic region "practices"
- these two thematic regions are not linked directly with the other themes on the concept map
- all the other themes on the concept map are linked or have overlaps and some of these overlaps are of a relatively large size

Fig. 19.6 Content analysis on circular approaches and business models in the textile industry (*Details see* Fig. 19.3*, 100 % visible concepts and 33 % theme size*)

b

Concept map of software-based qualitative literature analysis for the period 2013-17

(Specific focus on textile industry)



Main trends and patterns:

- the concept map includes 13 thematic regions and the thematic region of the largest size is “fashion”
- the thematic region “clothing” includes 12 different concepts; among them “consumers”, “designers”, “markets” ,“industry” and “work” as well as “sustainable”, “slow” and “fashion”
- these two concepts “slow” and “fashion” are presented with a large overlap
- the thematic region “clothing” also presents large overlaps on the concept map with the thematic regions “value” and “change”
- another big thematic region is “textiles” including 8 different concepts such as “waste”, ”recycling”, “services” and “used” and providing a large overlap with the thematic region “materials”
- the concept map provides a thematic region “business” that shows concepts such as “corporate”, “social” and “responsibility” and that is overlapping with the thematic regions “change” and “company”
- on the concept map themes can be found that have not been presented previously, among them –next to the two thematic regions “change” and “company”– also “value” and “participants”
- the thematic region “analysis” does not have any direct intersections with other themes; it is just linked by concept paths
- all the other themes on the concept map are linked or have overlaps and some of these overlaps are of a relatively large size; the concept map shows a close relationship between these themes and concepts

Fig. 19.6 (continued)

is a particular research interest since 2013. We also find that in the five years from 2008 to 2012, no such aspects like corporate responsibility were displayed. These issues have become important in the second period of analysis. In line with this, social sustainability is presented as part of business activities in scholarly research on circular approaches and business models in the textile industry.

(3) *Content analysis of Sustainability Reports published by H&M*

Figure 19.7a and b highlight major results from the content analysis of Sustainability Reports published by *H&M*. As shown, an increased role of supply chain management can be asserted in the period from 2013 until 2017. This finding is in line with the concept of a circular economy since the adoption of circular corporate practices also extends to the implementation of, among others, a circular supply chain. The shift toward more circularity also can be proved by an increasing role of recycling of material and aspects relating to use such as materials and energy. This is particularly emphasized in the concept map mirroring the time horizon up to 2013. At the same time, findings from our analysis of Sustainability Reports published by *H&M* prior to 2013 predominantly focus on economic, environmental, and natural resource-related critical topics that have been promoted by the company. These primarily relate to raw materials (e.g., water) as well as their inclusion into production processes (e.g., chemical treatments).

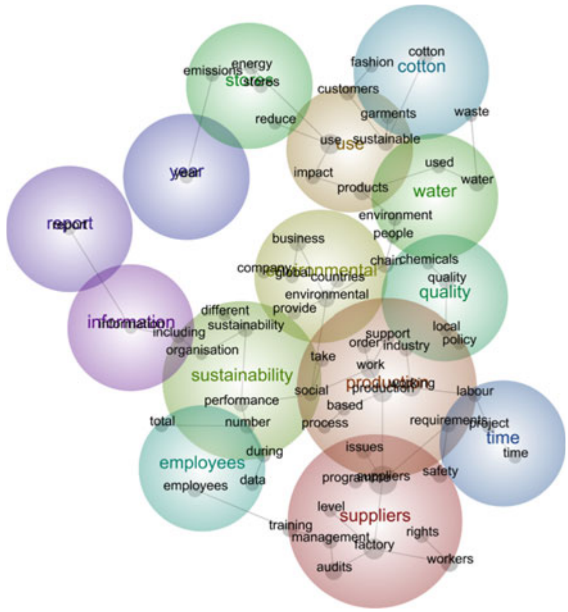
Moreover, in the second time frame, new aspects such as policies and fair working conditions have been much stronger emphasized in the Sustainability Reports (see Fig. 19.7b). This involves issues such as the improvement of workers' rights. As shown in Fig. 19.7a, such or similar topics have not been in the focus prior to 2013. Next to this, also aspects relating to the training and development of workers and the management of the company have gained prominence in the reports of *H&M*. Furthermore, from 2013 to 2017, the company obviously pays more attention to issues concerning the improvement of standards and systems in close relationship with its suppliers.

To sum up, the greater consideration of aspects relating to the social dimension of sustainability in Sustainability Reports published by *H&M* after 2013 is one major finding of our comparative analysis. In so doing, it also clearly contrasts with the results from the content analysis of the academic publications. Comparing the listed themes in Fig. 19.1 with the analyzed *Leximancer*™ maps, it is obvious that there is a great overlapping of the topics and themes of environmental and economic sustainability. In the context of social sustainability, holistic issues, like consciousness and equity, are not found at all. This is in line with the absence of most systemic items presented in Fig. 19.1.

Moreover, at the industry level, many different steps have been taken toward increasing multi-stakeholder dialogues and toward promoting social and environmental sustainability of corporate actions and strategies in the global textile industry. Exemplarily, several collective initiatives addressing standards for fire and building safety at production sites have been formed to increase workplace safety (Baumann-Pauly et al. 2018). Furthermore, NPOs such as "*Fashion Revolution*" were founded that strive to raise awareness on textile supply chain transparency

Concept map of software-based qualitative analysis for Sustainability Reports 2008-12

a *(Focus on H&M)*



Main trends and patterns:

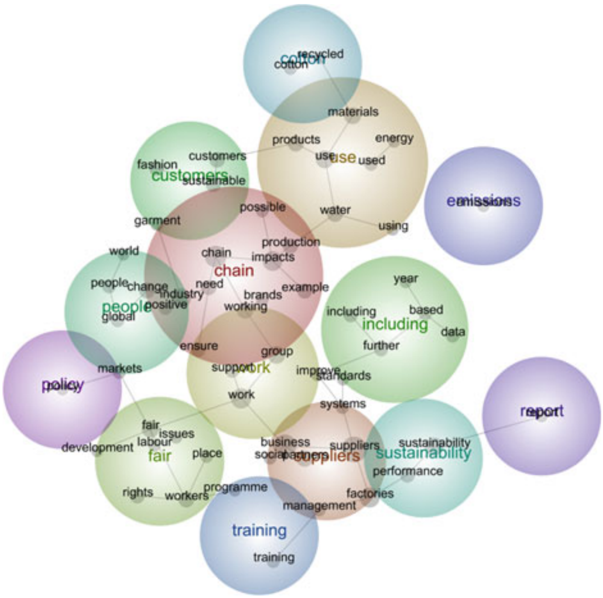
- the concept map includes 14 thematic regions
- thematic region of the largest size is "production"
- the thematic region "production" includes 16 different concepts; among them "order", "requirements", "suppliers", "industry" and "process" as well as "labour", "social" and "local" and "policy"
- the thematic region "production" also presents large overlaps on the concept map with five other thematic regions such as "sustainability", "environmental" and "quality"
- another big thematic region is "suppliers" including 11 different concepts such as "factory", "management" and "audits" but also "rights", "workers" and "safety"
- the concept map provides thematic regions referring to natural resources such as "cotton" and "water" or "sustainability"
- all thematic regions on the concept map are linked or have overlaps

Fig. 19.7 Content analysis of Sustainability Reports of *H&M* (*Details see* Fig. 19.2*, 100 % visible concepts and 33 % theme size*)

with their campaigns targeting at mainly Western consumers (Cornelius 2018). In single-industrialized countries, several multi-stakeholder initiatives were established such as the "*Partnership for Sustainable Textiles*" in Germany (Schützeneder and Bracker 2018) highlighting growing collaborative, knowledge, and information sharing efforts in the textile industry. At the same time, new initiatives such as the slow fashion movement evolved. Opposing the predominant business model of fast

Concept map of software-based qualitative analysis for Sustainability Reports 2013-17

b *(Focus on H&M)*



Main trends and patterns:

- the concept map includes 14 thematic regions
- thematic region of the largest size is "chain"
- the thematic region "chain" includes 14 different concepts; among them "industry", "brands", and "working" as well as "impacts", "change" and "ensure"
- the thematic region "chain" also presents large overlaps on the concept map with four other thematic regions such as "customers", "people" and "work"
- on the concept map themes can be found that have not been presented previously, among them "people", "policy", "fair" and "training"
- the thematic region "fair" includes 7 concepts such as "fair", "rights", "workers" and "development"
- two thematic regions are not directly linked with other themes on the concept map: these are "emissions" and "report"; they also include only one concept each
- all the other thematic regions on the concept map are linked or have overlaps

Fig. 19.7 (continued)

fashion, retailers in the slow fashion domain "often provide customized service and have deep supplier and client relationships" (Overdiek 2018: 69). However, stakeholder engagement and network building, initiated in practice, are not reflected as core patterns by the *Leximancer*™ analysis—they neither play a pivotal role in the map in Fig. 19.6b nor in Fig. 19.7b. This fact can be interpreted differently. On the one hand, circular economy is in its infancy, so, stakeholder engagement has not yet reached an important level. There is a time lack in theory—so practical initiatives have time advances before science pays attention and includes such initiatives in their investigations. On the other hand, concerning the Sustainability Reports of *H&M*, it is far more difficult to interpret. It seems *H&M* either does not communicate prominently about such engagement in their reports or the initiatives do not play a decisive role.

Previous literature has also discussed the issue of risks from the corporate perspective of textile companies. A higher level of multiple risks has been associated with sourcing and production in low-cost countries particularly for fashion retailers. These exposures also included financial and reputational damage given increased public awareness and media coverage (Jacobs and Singhal 2017). Furthermore, the moral obligations and social legitimacy of companies have been questioned among stakeholders, thereby nurturing the already existing credibility gap of CSR reporting (Lock and Seele 2016). Consequently, there has been an increasing need among textile companies to adopt improved risk management strategies (Köksal et al. 2017). However, direct linkages to risk management or an increase with dealing with risks are neither recognizable in the maps of Fig. 19.6b nor Fig. 19.7b. Even in the circular economy papers, risks and risk management do not seem to play a crucial role. There are no themes or patterns given. It seems that risk management is embedded more indirectly, but not communicated directly by the companies. This is also in line with previous research on the concept of circular economy.

Scholarly publications have repeatedly emphasized that the concept's focus is on economic prosperity and ecological advantages rather than societal benefits (Geissdoerfer et al. 2017; De Angelis et al. 2018; Kirchherr et al. 2017; Lieder and Rashid 2016). Nevertheless, several companies in the textile industry have started to develop strategies for adopting it. On June 20, 2013, the world's second largest fast fashion retailer *H&M* announced its participation in the global networking program *"The Circular Economy"* to foster transitions toward a circular economy (H&M 2013a). Less than five years later, on April 4, 2017, the company announced its entire strategy turnaround including the central vision to become 100% circular and renewable by 2030 (H&M 2018). The particularly telling example of *H&M* reflects the ongoing dynamics in the global textile industry, particularly with regard to promoting economic and environmental sustainability. However, the question arises whether these ambitious goals show a "real and true" business model transformation and whether this also involves fostering the social dimension of sustainability and corporate responsibility.

In line with this, Brooks et al. (2017) criticize current advocates and their campaigns on implementing circular approaches in the textile industry such as the ideas and initiatives of the famous, often-cited *"Ellen MacArthur Foundation,"* amongst others. While generally recognizing the industry's accelerating efforts to transform, the authors argue that "challenging commercial interests, questioning high-tempo fast fashion models of production and consumption, or proposing alternative models of social relations that constrain the opportunities for market growth and profit accumulation" (Brooks et al. 2017: 493) are not addressed by proponents of circular economy approaches. In fact, in their research, the authors even go further stating that closed-loop recycling of textiles is particularly appealing for large retailers such as *H&M* since "it can enhance a rapid rhythm of purchase and disposal" (Brooks et al. 2017: 494). Based on the criticism expressed by Brooks et al.

(2017), the generally little consideration of social aspects in the concept of circular economy (Moreau et al. 2017) and our findings, it seems that social issues still do not play an important role in the business models in the textile industry provided for mass markets. They apparently are not the principal focus for large, Western-based fashion retailers' strategic decision-making to spur transitions toward sustainability including alternative production and consumption patterns.

To summarize, deeply rooted structural and systemic shortcomings of global textile value and supply chains as well as embedded business models have ultimately contributed to a crisis in the textile sector. New approaches regarding circular strategies and business model innovations for sustainability in companies in the global textile industry can be recognized in the second period from 2013 to 2017. Strategies and principles such as, among others, recycling are explored in terms of their potential value propositions, creation, delivery, and capture. Yet, there is a clear neglect in academic journal publications by large, concerning the examination of such new forms by explicitly focusing on social sustainability-related aspects. Scholarly interest in circular approaches, strategies and business models in the textile industry in order to facilitate change has been increasing over the last years. However, this rising prominence has included an only limited *theoretical* examination and consideration of social aspects for implementing circularity alongside textile value and supply chains. A more holistic but also fine-grained and differentiated consideration of social sustainability related aspects in *companies* of the textile industry as communicated in their sustainability reports has also been recognized, and might be strengthened by the GRI engagements, as well. Based on these findings, we offer the following propositions:

- **Proposition 1**: The issues of social sustainability are more related to a communication strategy than to business model concepts in textile mass markets.
- **Proposition 2**: Systemic themes are clearly underrepresented. The more systemic themes will be integrated in business model concepts and practices the more social sustainability will play a role in textile mass markets.
- **Proposition 3**: The integration of social topics is limited to a business level. In order to integrate multi-levels in textile business activities, clear incentives and global regulations are necessary. The more alternative consumption and production patterns are honored, the better groundbreaking and sustainable business models can occur and be embedded in textile mass markets.

19.7 Conclusion

Our results show different trajectories for scholarly research and practice in terms of circular approaches and their consideration of social aspects. Though circular business models in the textile industry are becoming of increasing relevance, particularly social aspects are underrepresented in scholarly publications. At the same time, companies are increasingly taking actions to meet social challenges—at least as evidenced in their sustainability reporting. Our findings reveal that each period and type of documents (e.g., theory-centered academic publications vs. corporate reports) investigated is characterized by a large amount of varying topics and issues. At the same time, our findings also reveal that companies report on social sustainability in their transition toward circular loops and circular business models openly, highlighting aspects such as fairness as well as improvement of standards. In contrast, among scholarly investigations aspects relating to corporate (social) responsibility in innovative and circular business models in the textile industry are largely underrepresented. Here, research seems to focus predominantly on the customer as well as on particular concepts such as slow fashion.

However, the results of the study can be challenged given its focus on written communication in the form of sustainability reports. Thus, finding major themes and concepts as verbally communicated by companies is one side of the coin, while examining the real-life implementation of circular strategies, business models and social sustainability is a different story. Hence, the question of a potentially one-sided social legitimacy-promotion of CSR- or greenwashing strategies by companies such as *H&M* remains. This becomes reinforced as circular business models are seen to be established in parallel with traditional models within one company (Tunn et al. 2018). From a managerial perspective, changes toward sustainability play a pivotal role and are ongoing. Companies should align their business models with sustainability. Integrating social issues and reprocessing to circular economy approaches is one possibility. However, the other and more transformative option is the alignment to systemic strategies, like decoupling, inter- and intra-generational equity, consciousness, long-term orientation, and cross-sectoral approaches. A main goal should be the development of business models not emphasizing innovations and fast fashion, but producing and promoting textiles of lasting value with humanly dignified working conditions and wages as well as a prevention of habitat-destroying procedures. This also includes alternative product design strategies based on aspects such as slow fashion, local production and customization which help to establish a system of new value creation for customers (Niinimäki and Hassi 2011). In line with this, a system's perspective on business model innovations for (social) sustainability also fosters value creation aimed at encouraging sufficiency and reduced consumption, amongst others, by means of informing and educating customers as well as reframing marketing and corporate economic goals (Bocken et al. 2014). Therefore, groundbreaking collaborative, circular-oriented or cradle-to-cradle-based business models are needed which should be based on fundamentally new personal, consumer, and firm mindsets as well as social norms.

Based on these limitations, further research has also explored issues relating to, among others, social aspects of circular business models and strategies in the textile industry as regards their effective implementation. This could also mean a stronger consideration of systemic issues and fundamental change in the transition toward circular business models and sustainable development. Concerning the methodological approach used and its limitations, further research may extend the present analysis by conducting a content analysis according to Mayring (2015) in order to prove the findings gathered by the software-based text analysis program *Leximancer*™. In addition, such findings also could deepen the explanation of similarities as well as differences between theory-based discussions and practice reports. Such investigation then should also take account for the form and degree of verbally communicated aspects relating to circular and sustainable business models in the textile industry as well as to the consideration of critical issues on social sustainability and corporate responsibility.

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Part VII
Sustainability and Systemic Approaches in the Global Textile and Fashion Industry

Introduction

In order to achieve truly sustainable solutions in the global textile industry systems thinking based on a balanced consideration of economic, ecological and social sustainability becomes crucial. A systemic approach includes, among others, the holistic consideration of interests, objectives and expectations of different as well as new players and stakeholders in global textile and fashion value chains. For this to happen, collaborations and partnerships in order to facilitate knowledge exchange and learning as well as the development and implementation of innovative business models, new products and processes are increasingly playing an important role. International cooperation among multiple stakeholders and the implementation of systems-driven approaches such as communication and networking platforms or policy frameworks facilitate global coordination and sharing of information, expertise and experience. Further, collaboration of companies with stakeholders such as suppliers or NGOs might allow systemic change by increasing supply chain visibility or reducing barriers and risks. These developments are to encourage primarily alternative ways and forms of shared and sustainable value creation.

Further, systemic approaches in the global textile industry include multiple-level challenges such as national and regional specifics of textile production and consumption patterns as well as the development of internationally harmonized regulations, norms and standards within and across different sub-sectors of the textile industry. Meeting these mutually reinforcing challenges also implies changes to the industry's prevailing complex global structure and the primacy of economic and business pressures such as lead times, quantity and costs. The idea of circularity based on sustainable designs fostering product longevity and lifetimes as well as closed-loop supply chains, among others, might induce such systemic changes. In this regard, advancing recovery and processing technologies, offering more robust materials, product-service systems and reducing replacement purchases as well as innovative communication and marketing strategies of companies by labeling circular practices offer various starting points for fostering sustainability across different levels.

A systemic view on the global textile and fashion industry also extends to company-specific issues in increasing the level of sustainability in their business operations. It includes aspects such as acknowledging the role of global reporting tools and compliance declarations, comprehensively considering social and environmental management and performance systems, changing production practices as well as properly realizing opportunities stemming from growing digitization and technology transfer in order to foster sustainability on a systemic level. Further, assuming social responsibility and a central commitment to sustainable and ethical values and changes in attitudes are essential for implementing mechanisms for shared and sustainable value creation. Changes in power structures between firms along textile supply and value chains as well as sustainable investments in local communities are to be imperative for systemic change in the globally interlinked textile industry. This also includes the consideration of true prices for apparel reflecting its economic, environmental and social costs.

Next to this, consumer-specific issues can play a largely supporting role in fostering sustainability in the textile industry from a systems perspective. Increasing awareness and consciousness, proactive involvement in clothing design as well as fundamentally altering needs and purchasing, use and disposal behavior are crucially important to limit excessive consumption and contributing to devastating environmental impacts including waste generation and climate change, among others.

This final chapter includes four contributions employing primarily practical perspectives on sustainability and systemic changes in the global textile and fashion industry based on best practice and case examples. The first two articles in this chapter by Hall and Boiten as well as Kumar et al. focus on circularity in the global textile and fashion industry, thereby highlighting the importance of innovative technologies and multiple stakeholder engagement, among others. Ravasio calls for a widespread implementation of fair and ethical leadership in textile companies in order to restore the industry's reputation. The chapter ends by the contribution of Schumann et al. who address the role of digitization as a likely key driver for enhancing sustainability in global textile value chains and business models.

Chapter 20
Circular Textiles: Building Business Case Scenarios Through Stakeholder Dialogue

Nicholas Hall and Valérie Julie Boiten

Abstract The circular economy represents a significant market opportunity for innovative technologies concerned with the recycling and valorisation of textile waste. In order to render our textile production and consumption systems more sustainable, we need to develop new technologies but also new business models that valorise the growing fractions of lower-quality textile waste, thus diverting textile materials from landfill and incineration. This chapter draws on the EU H2020-project Resyntex, which has developed chemical recycling technologies capable of accepting mixed textile fibres to produce marketable chemical feedstocks. Premised on the principle of an 'industrial symbiosis', this technology processes waste fibres into secondary raw materials to be used in the construction, transport and packaging industries. To identify the possible routes to commercialisation for this textile recycling technology, a strategic investment decision-making (SID) perspective was adopted, assessing a wide range of interrelated market, financial and stakeholder perspectives. The engagement of stakeholders throughout the value chain played a crucial role in designing new concepts of industrial symbiosis and demonstrating possible revenue streams that could emerge from valorising textile waste. The outcomes of the research can be used to make effective strategic decisions around which products and processes are feasible and commercially viable at industrial scale, in a circular economy system for waste textile fibres.

Keywords Circular economy · Stakeholder engagement · Scenario planning · Sustainable textiles

20.1 Introduction

Low-grade textile waste streams have rapidly increased in recent years, driven by low-cost models of fashion business generating unprecedented increases in textile

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consumption (WRAP 2015). It is estimated that merely 15–25% of overall available textile waste in Europe is collected separately, entering potential reuse or recycling routes (Zamani et al. 2014). Most commonly, this fraction of textile waste is of higher quality and can be resold into reuse markets (for garments), or recycled into applications such as wiping rags and insulation material. The lower grade textile waste, however, is generally landfilled or incinerated. Often mixed in municipal or industrial waste streams, the amount of non-valorised textile waste in the EU is estimated at 9.35 million tonnes per annum (Bell et al. 2016). Unsurprisingly, therefore, stepping up recycling efforts has widely been identified as a potential solution to limit the textile and fashion industry's environmental impacts (Schmidt et al. 2016; Hvass 2016; Zamani et al. 2014).

With circular economy thinking gaining momentum and consumers becoming more aware of the polluting impacts of textile production (Pinkstone 2017), we can be sure to expect increased pressure to divert growing piles of textile waste from landfill and incineration. Indeed, the EU's circular economy package stipulates that member states will be required to set up, by 1 January 2025, separate collections of textiles from households (European Parliament 2018). This will most certainly affect how textile collection and processing schemes operate across the European continent. The key problem is that higher collection rates are likely to go in parallel with an increased share of the lower-quality textile waste fraction (Ljungkvist et al. 2018; Textiles Division BIR 2018), while the recycling industry remains dominated by a logic of reuse of garments and mechanical recycling of natural monomaterials (cotton)—routes that are essentially only suitable for high-quality waste.

Transitioning to a more circular system will therefore necessitate the scaling up of sorting capacity and, in turn, to increase the demand for new technologies that can recycle textile materials in large volumes, recovering valuable resources efficiently. It is of crucial importance to determine and develop markets for the growing amounts of low-grade textiles collected and processed, valorising the outputs of recovered materials so that their recycling is worthwhile and can attract investment—ultimately establishing a Europe-wide infrastructure for the recycling and reuse of textile waste.

20.2 Resyntex: From Textile Waste to Secondary Resources in the Circular Economy

The circular economy represents a significant market opportunity for innovative technologies concerned with the recycling and valorisation of textile waste (Ellen McArthur Foundation 2016). Where discarded materials are transformed into secondary resources, new opportunities arise for industries to collaborate and construct value chains that represent 'industrial symbiosis', an interdependent recycling and production system that rely on waste as resource (Talmon-Gross and Miedzinski 2016). New collaborations are required to provide access to the range of expertise required to generate realistic solutions (Lacy and Rutqvist 2015). Indeed, through collaborative networks and co-creation, sharing the risks entailed in developing sustainable technologies, firms can navigate the complexities of building resilient infrastructure for long-term sustainable production and consumption.

A key example of such collaboration for textile circularity is the EU Horizon2020-funded project Resyntex, which has developed innovative chemical recycling technologies capable of accepting mixed textile fibres to produce marketable chemical feedstocks. The textile fibres are chemically recycled in intermediate products that have applications in sectors as varied as packaging, construction and automotive production. The Resyntex technology offers a synergistic chemical and biotechnological approach, including stages of pre-treatment (e.g. decontamination and discoloration) and advanced sorting by fibre type (Fig. 20.1).

The Resyntex project has been carried out by a set of project partners that represent the envisioned value chain, including the textile industry, collectors and sorters of textile waste, R&D partners that separate, purify and chemically reprocess textile fibres, as well as the chemical industry who are the gatekeepers of potential markets for the feedstocks that the recycling process generates. Figure 20.2 illustrates the basic value chain.

Three years into the project, the technical viability of the process is confirmed, yet commercialisation is challenging. It is possible to define in detail what costs are involved in generating the feedstocks from recycled textiles as an industrial operation, and to scale these according to the availabilities of textile fibres within present

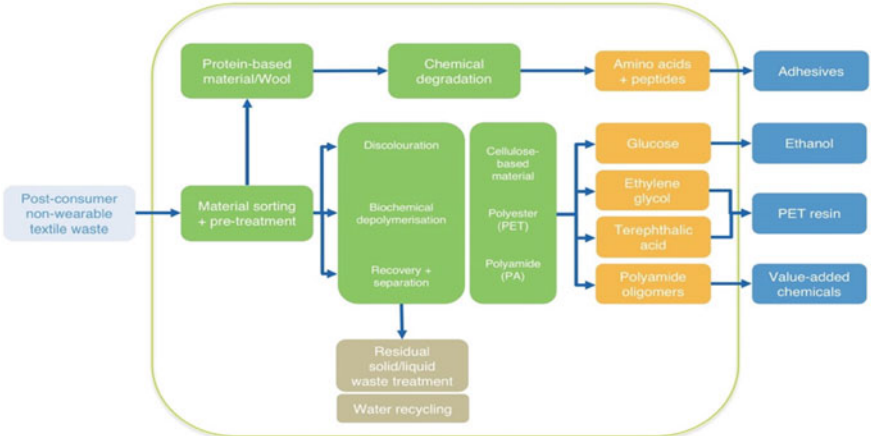


Fig. 20.1 Resyntex chemical recycling process (Authors)

Fig. 20.2 Basic Resyntex value chain (Authors)

waste streams. The challenge, however, lies in determining suitable markets for the feedstocks—vital in ensuring that textile recycling becomes a profitable enterprise.

Today, the prices of feedstock commodities are generally low, as a result of long-established economies of scale that are based on stocks of virgin raw material. In simple terms, the commercialisation of Resyntex recycling technology requires there to be a feasible market for the outputs it is producing. The use of recycled resources (contained in textile fibres) remains more expensive to date than the conventional extraction of raw materials. This is a crucial dilemma affecting the introduction of sustainable technologies, and our very ability to reduce our reliance on a linear take–make–dispose economy.

Therefore, to make the case for a commercialisation of the Resyntex recycling technology, the market potential for valorising low-grade textile waste must be fully achieved, and this by demonstrating that the recycling network can compete with the linear system it wishes to replace, at a comparative industrial scale. The benefits, advantages and challenges around recycling can then be fairly compared, leading to the making of considered strategic investment decisions (SID).

20.3 Towards a Business Model for Fibre Recycling: Research Methodology

To identify Resyntex routes to commercialisation, a strategic investment decision-making (SID) perspective is adopted as a basis developing a framework that systematically evaluates Resyntex commercial and develops appropriate business models. SID is based on two contextual practices: a] the use of capital budgeting techniques or financial appraisal and b] strategic considerations. Depending on the market orientation of the venture, there can be a focus on one or both forms of contextual practice. Carr et al. (2010) propose a four-state model that categorises the market orientation of firms as a way of examining the balance between financial and strategic considerations needed for SID making (Fig. 20.3).

Figure 20.3 defines the four market orientations as market creators, value creators, refocusers and restructurers. The position of each category in the quadrant defines the emphasis or balance between strategic (*Y*-axis) or financial considerations (*X*-axis). The Resyntex recycling technology sits in two categories: market creators and refocusers. This is partially because the project plans to introduce a new technology that valorises textile waste (market creation) and partially because it plans to refocus the (linear) market towards recycling textiles into useful resources using industrial symbiosis. Given Resyntex' positioning within the categories, we adopted a balanced approach with financial and strategic considerations being of equal importance as determinants for SID making.

The Resyntex textile recycling technology can be defined as an 'advanced manufacturing technology' (AMT), as a 'manufacturing system that improves performance

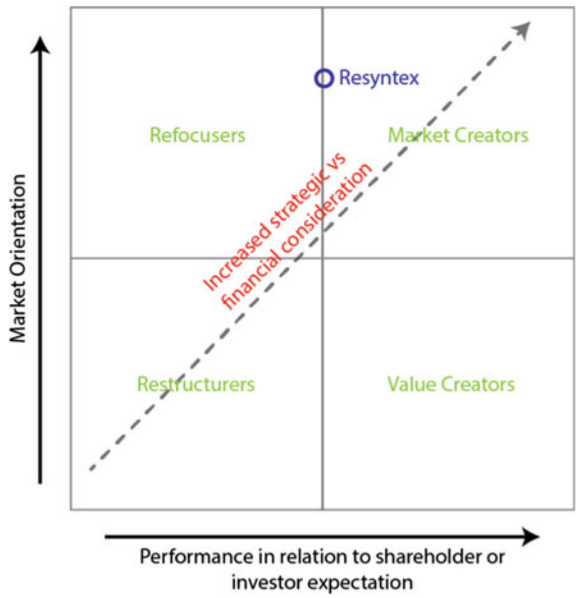


Fig. 20.3 Four-state model of market orientation and SID considerations (Adapted from Carr et al. 2010)

through innovative application of technology, processes and methods within production' (Small and Chen 1995). The relevant literature specifically categorises sustainable processes and technologies within production as AMT (Jayal et al. 2010). For new sustainable production technologies, a number of challenges arise when evaluating strategic and financial considerations, as suggested by the AMT literature (Table 20.1):

Table 20.1 Challenges of evaluating advanced manufacturing technology (AMT) (Adapted from Chan et al. 2001; Jayal et al. 2010)

Strategic	Financial
Lack of established methods/frameworks for appraising benefits of new textile recycling technology at industrial scale	Often involves considerable investment and extended payback period that increases risk
Insufficient levels of confidence in the technology (as it is currently and early-stage technology)	Unclear financial environment (cost/benefit and potential market poorly defined)
Pioneering: Lack of previous implementation examples from which to learn in order to mitigate risk	Difficult to measure or quantify performance potential
Potential of emergent or unexpected application or benefit of the technology in practice currently unrecognised	

Chan et al. (2001) go on to suggest that the challenges of evaluating AMT require a balanced or 'hybrid' approach to SID, because of the need to explore the uncertainties defined above (Table 20.1). This calls for a more thorough exercise of deriving benefits and risks, as the interrelationships between drivers, outcomes and implications (and their variability) are critical. The results of the hybrid approach provide more detailed justifications for SI making by evaluating a wider range of perspectives (Jayal et al. 2010) than just financial appraisal. Jayal et al. (2010) also suggest that for sustainable technologies, the visualising of entire value chains is a necessary exercise.

In addressing the question of commercialising the Resyntex technology for textile recycling from an SID perspective, we needed to examine such a wide range of interrelated market, financial and stakeholder perspectives and to project their outcomes in a format that can be used for business planning at industrial scale.

Business scenario building was selected as the vehicle to do so.

> Business scenarios can effectively organise a variety of seemingly unrelated economic, technological, competitive, political and societal information's and translate it into a framework for judgment.

Business scenarios provide a framework for identifying and exploring combinations of strategic implications and using these to envision how new circular markets for recycled textiles may be constructed based around the introduction of a sustainable technology such as Resyntex. Three key research perspectives within this scenario building exercise were identified and are summarised in Fig. 20.4:

Research Perspectives:

1. **Historical**: Adoption and diffusion of technology is the process by which new technologies are adopted by individuals, businesses, societies and economies. The process of adoption and diffusion of new technologies and the likelihood of their acceptance or rejection lies in the identification and analysis of the key factors that influence the rate and patterns of adoption, in both technical and social contexts. Historical perspectives from relevant case studies within adoption and diffusion literature are evaluated against the case of Resyntex.
2. **Financial**: An in-depth cost assessment including life cycle assessment and life cycle costing of the new technology, its service structure, delivery model, capital and operational costs vs. potential revenue generation, using financial appraisal methods to generate industrial scale, long-term financial projections.
3. **Market**: An examination of the current market situation for textile recycling, its current market drivers from a waste collection behaviour (post-consumer waste) perspective and a waste processing and recycling industry perspective, that include an evaluation of the current market situation for the feedstocks generated through recycling.

The scenario building approach followed intuitive logics (IL), which has the following objectives:

- Enhancing the understanding of causal processes, connections and logical sequences in underlying events that can be applied in future contexts.

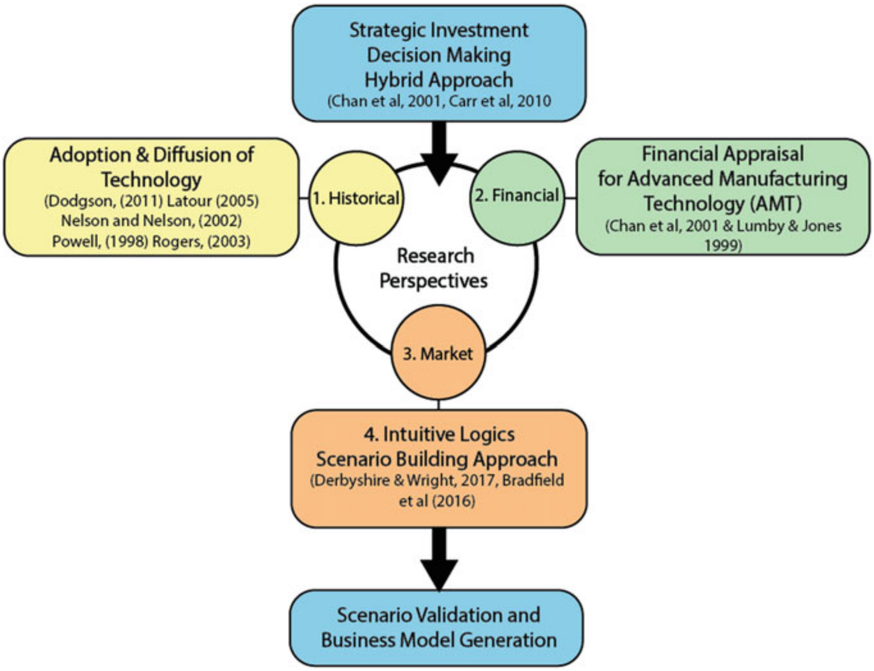


Fig. 20.4 Hybrid approach to building business scenarios for SID making for sustainable technologies. (Authors)

- Challenging conventional thinking to reframe perceptions and change mindsets in organisations.
- Improving strategic investment decision-making by presenting strategic, economic and analytic information as plausible future scenarios.

Bradfield et al. (2016) offer the following defined stages with an IL scenario building process (Table 20.2). It employs 'plausibility-based' approaches that are defined by expert participants in the scenario building process. Stage 1 is aimed at building strategic narratives by identifying forces that drive the outcomes of cause and effect relationships, including the historical, financial and market perspectives that determine market forces (Stage 2). Identified forces are clustered into sequences within scenarios by participants to consider how they influence 'unfolding chains of causation' (Bradfield et al. 2005) (Stages 3 and 4) with the objective of identifying 'critical uncertainties' (Stage 5). Critical uncertainties are the forces identified by the participants as having the highest-level impacts and being the least predicable in terms of cause and effect (Postma and Liebl 2005). Critical uncertainties are then used to form scenario matrix (Stage 6) that frames the final scenarios that examine strategic implications (Stage 7).

The combination of research within these perspectives generates *commercialisation pathways* that demonstrate initial concepts of how the sustainable technology

Table 20.2 Stages of the intuitive logics approach to scenario planning (Adapted from Bradfield et al. 2016)

Stage	Activity
Stage 1: Setting scenario agenda	Defining the issue of concern and process
Stage 2: Determining driving forces	Exploring a series of wide-ranging forces
Stage 3: Clustering driving forces	Clustering related forces and naming clusters
Stage 4: Defining cluster outcomes	Defining two extreme but plausible outcomes from the clusters
Stage 5: Impact/Uncertainty matrix	Ranking the clusters to determine critical uncertainties
Stage 6: Framing the scenarios	Use critical uncertainties to develop scenario matrix
Stage 7: Developing the scenarios	Develop scenario narratives and evaluate strategic implications

may be adopted. These pathways serve as starting points for experts and potential partner organisations to build value chains that organise the potential outcomes of multiple strategic perspectives into useful scenario narratives. The scenarios constructed can be validated by experts as to their plausibility and used to generate business models, allowing for considered and informed SID making around the commercialisation potential of a sustainable technology.

20.4 Engaging Stakeholders Across the Value Chain

In assessing the viability of the fibre recycling technology developed in Resyntex, our research takes a systemic approach to innovation (Arnold and Wade 2015), with an emphasis on identifying the *relations* between determinants of innovation within complex networks of interconnected processes, people and flows of material and information. In the end, the key to establishing a new value chain in which textile fibres can ‘circulate’ is the reconfiguration and alignment of the operations that facilitate it. Alliances and joint ventures between previously unconnected sectors, industries, organisations and actors are needed to rethink how waste is converted into resource. The emerging networks also form models of shared risks, where the challenges involved in developing sustainable production and consumption and demonstrating their feasibility can be reduced through collaborative approaches.

While the Resyntex consortium has been constructed in this manner, containing the required expertise and related organisations to actualise a circular textile economy, we required broader stakeholder inputs to explore multiple value chains for the cascading reuse of textile fibres. To this end, we have set up a *value chain dialogue* involving technology developers and industry stakeholders, bringing their expertise and perspectives more closely into the research undertaking. The value chain dialogue included the textile, waste management and chemical industries, as well as experts in textile recycling machinery and technology, aimed at building multi-stakeholder symbiosis.

The argument for engaging stakeholders in innovation and transition processes has been elaborated in a wide variety of disciplines, including innovation management (Blok et al. 2015, Widen et al. 2014, Ayuso et al. 2011) as well as innovation governance and policy (Owen et al. 2012; Foxon and Pearson 2008). Largely influenced by the triple helix model of innovation (Etzkowitz and Leydesdorff 1995), the recent thinking around innovation and knowledge production increasingly emphasises the relations and interactions between organisational spheres in the production, transfer and application of intellectual capital (Ranga and Etzkowitz 2013).

The stakeholder dialogue across the value chain (Fig. 20.1) was intended as a crucial component of the building of business scenarios geared towards the following key questions:

- How we might construct the innovation network and where the value/incentives might be for those actors and stakeholders within it.
- The enabling conditions required for the system to be commercially viable: market drivers as well as political, economic, technological, legislative and environmental factors and 'tipping points' of such drivers, for example, a shortage in raw cotton supply and a rapid increase in its cost resulting in demand for recycled alternatives.
- Challenges and barriers to enter the market of recycled feedstocks: competitiveness, quality, compatibility of products with existing systems, volumes of waste, pricing of commodities.

Closely aligned with the stakeholder integrated research approach (Gramberger et al. 2014), we designed and moderated a process whereby sectoral representatives collaboratively assess the viability of industrial symbiosis approaches for textile fibres, constructing solutions and identifying potential markets for the future recycled feedstock. The methodology underpinning the value chain dialogue consisted of the following steps:

1. Mapping the innovation ecosystem
2. Ensuring a fair representation, relevance and legitimacy in selecting individual stakeholders, using the Prospex-CQI approach
3. Designing an appropriate format and ensuring professional facilitation by a neutral moderator
4. Clustering identified forces and drivers from stakeholder outputs against market research, commercialisation pathways and financial appraisal results, to generate preliminary business scenarios.

20.4.1 Mapping the Stakeholder Innovation Ecosystem

For the purpose of matching recycled fibre supply and demand, the mapping of industry stakeholders (Mitchell et al. 1997) needed to travel beyond the 'usual suspects'. As a starting point, innovators and businesses from the five value chain stages (Fig. 20.1) were identified. Looking through the lens of ecosystemic innovation, however (Adner 2006), we also considered stakeholders and businesses that provide complementary technologies in the textile recycling process. These included, as an example, developers of automated sorting machinery, as well as developers of other chemical recycling technologies (such as depolymerisation by microwave technology) which can add value to the overall Resyntex case. The ecosystemic mapping helped to identify potential gaps in capabilities along the Resyntex value chain (such as sorting skills), which might have ripple effects on the industrial symbiosis. This helped to gain a more comprehensive understanding of the ecosystem in which an innovation such as Resyntex can materialise.

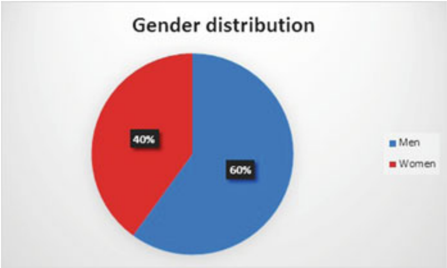
20.4.2 Ensuring a Fair Representation of Relevant Perspectives

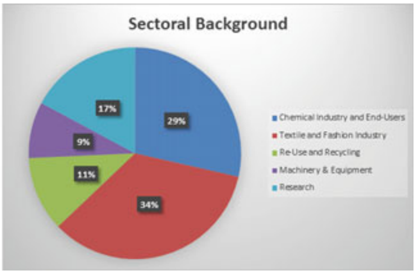
The Prospex-CQI method (Gramberger et al. 2014) was used to ensure a fair representation, relevance and legitimacy when collecting stakeholders' opinions. In essence, Prospex-CQI stands for:

- Criteria (C): Defining a set of criteria for stakeholder groups that are either affecting the set-up of a circularity system for textile fibres, being affected by it, or both.
- Quota (Q): Setting specific minimum quotas for all categories.
- Individuals (I): Identifying individuals that fit the categories, with the overall selection fitting the quotas set.

The criteria, also termed categories, were defined through a mapping of the Resyntex supply chain (see Fig. 20.2), from waste fibre to secondary raw materials. The criteria established included: the textiles and fashion industry, the chemical industry and other potential end-users of the recycled feedstock, the research community, the reuse and recycling sector as well as the recycling machinery and equipment industry.

The stakeholder mapping and identification were conducted with a set of complementary research methods. We conducted desk research, relying on sources such as a.o. the specialised press, sectoral association publications, yearly company reports and academic publications. We attended various conferences and conventions bringing together textile, chemical and waste management industries at a European and global level. In addition, we approached individual experts, researchers and sectoral representatives. Thanks to their practical insights, expert knowledge and the





Figs. 20.5 and 20.6 Gender distribution and sectoral representation in the value chain workshops (Authors)

stakeholder networks they are part of, we were able to identify additional stakeholder groups and individuals.

As a next step, for each of these stakeholder criteria a minimum quota was defined, agreeing that these quotas needed to be indicatively met in running the value chain dialogue. The aim of the stakeholder quotas is to reduce the biases and distortions that could derive from an over-representation of certain typologies of participants or sectors. The quotas therefore applied to the sectoral representation of stakeholders (see categories), but also to the balance of gender and geographical levels of activity (Figs. 20.5 and 20.6).

Finally, the research team selected and invited individual stakeholders, matching the categories and quotas set, and in view of their business, technological or market expertise that would enable the making of informed judgments on potential business scenarios for Resyntex. Importantly, the stakeholders invited to take part in the value chain dialogue were briefed beforehand on activities, expectations as well as purposes of the Resyntex research. They were offered reimbursement of their travel expenses for attending the workshops, funded as part of the Resyntex H2020 grant. The workshops took place in December 2017 (in France) and in March 2018 (in Ljubljana).

The following table summarises the areas of expertise used for participant selection (Table 20.3).

20.4.3 Design and Facilitation

The workshop design followed a Focus Group format (Krueger and Casey 2009), enabling a targeted, participatory process in which a diversity of viewpoints can be expressed. At the same time, the format enabled respect for commercial sensitivity, working in small groups and with prior confidentiality agreements.

Guided by a neutral facilitator, stakeholders engaged in a rich and lively conversation on the boundary conditions for the Resyntex circular supply chain transforming textile fibres into secondary resources to work in practise. The process relied on

Table 20.3 Expertise criteria for participants (Authors)

Expertise	Role/Expertise
Textiles and fashion industry	Material Development/Sustainability Coordinator
Chemical industry and end-users	Production Design Engineer/Production Planning/Production Process Manager/Quality Manager
Research community	Research Consultant/Research Associate/Market Research
Reuse and recycling sector	Business Development Manager/Director of operations
Recycling machinery and equipment	Technical director
Textile Sorting and Recycling	Technical Director/Process Manager

a creative forecasting approach (Byrne et al. 2010), whereby the implications of ideas, solutions and future trends were critically and collaboratively assessed, with entrepreneurial drive and imagination.

A multi-stakeholder dialogue brings together different strands of knowledge in a co-creative process. While the sorters and graders share insights and data on the textile streams, stakeholders from the packaging, automotive and furniture industries (as examples of industries potentially acquiring the recycled feedstock) openly reflect on quality requirements for outputs such as PET-resins (from polyester) or glucose juice (from cotton). This immediate and open exchange of information, in a select group of stakeholders, stimulated a hands-on, creative and collaborative identification of potential value chains for recycled textile fibres.

20.4.4 Clustering Identified Forces and Drivers from Stakeholder Outputs Against Market Research, Commercialisation Pathways and Financial Appraisal Results to Generate Preliminary Business Scenarios

The stakeholder's inputs were corroborated against market research to support workshop discussion with research and form evidence-based narratives that form scenarios. These can be evaluated against one another and used to make effective strategic decisions around which products and processes are feasible and commercially viable for the circular transition. Through value chain engagement and market analysis, it was possible to design new concepts of industrial symbiosis and to demonstrate the joint ventures and revenue streams that could emerge from valorising textile waste. These will be discussed in the following section.

20.5 Future Perspectives: Drivers, Forces and Uncertainties for Circular Textiles

The scenario narratives, developed with crucial inputs from stakeholders, provide detailed viewpoints from which to make informed strategic investment decisions (SID), by visualising potential routes to commercialisation for Resyntex technology. The process is summarised in the following diagram (Fig. 20.7):

The intuitive logics-methodology suggests to illustrate the outcomes of stakeholder engagement by building '**wild card**' (but plausible) scenario outcomes. These allow to visualise results so that they can be presented back to participants. This continues the process of broadening perspectives and encourages feedback on the value chains presented. Kosow and Gassner (2008) and Rounsevell and Metzger (2010) argue that wild card scenarios stimulate imaginative thinking 'beyond the axioms, norms and constraints of conventional wisdom', generating a more open and insightful dialogue between stakeholders in the scenario building process.

Following Voros' (2003) generic foresight process framework, we distinguish between five classes of **alternative futures**: potential, possible, probable and preferable, as shown in Fig. 20.8. Voros' (2003) diagram demonstrates the limits of possible

Fig. 20.7 Photographs from the value chain engagement (Authors)

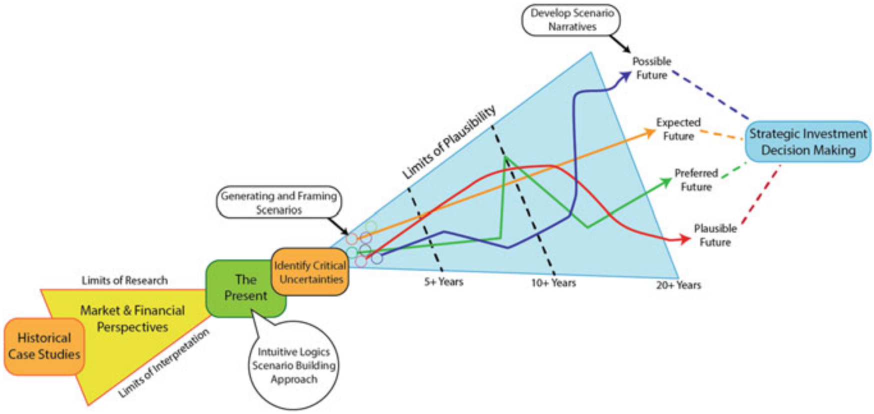


Fig. 20.8 Scenario building summary diagram (Authors)

futures on the fringes of the cone (defined by the generation of wild card clusters). The 'probable' clusters represent the clusters that participants judge the most likely. Preferable outcomes are scenarios that participant would favour, illustrating the potential for shaping of outcomes through actors' intentions within the system. This often results in the development of strategic objectives towards *making* a preferable future happen. Plausibility is defined as the group of scenarios that the participants judge as a range of likely (plausible) outcomes for the future. The wider the range of plausible futures, the higher the level of uncertainty (Voros 2003).

Once plausible futures and their drivers and forces are better defined, stakeholders together with the research team can systematically consider and rank the impact of key drivers, pinpointing 'critical uncertainties' defined as those forces that are the most unpredictable and have the highest impact or influence on the outcomes of the scenario. These are crucial to form a scenario matrix. Figure 20.9 illustrates a way of ranking impacts to build scenarios that examine cluster opposing strategic forces proposed by Gertler et al. (2016) (Fig. 20.10).

This approach includes a simple scoring mechanism for **ranking levels of impacts** by providing a score out of ten in two phases, one for ranking level of impact where $0 > 5$ is considered low, and $6 > 10$ is considered high, and then ranking their level of uncertainty using the same ranking levels to positions them on the matrix accordingly, allowing identification of critical uncertainties. The distribution on the matrix can be used to frame sets of scenarios matrix that use critical uncertainties as an axis (axis of uncertainty). Scenario construction then considers two positive or negative outcomes of each critical uncertainty, paired with a comparative that creates a four-quadrant matrix (Fig. 20.11), which was used during the value chain dialogue to help guide the process.

Throughout the Resyntex value chain dialogue, two key issues were highlighted that have a significant impact and high levels of uncertainty affecting strategic decision-making and have been used to create one exemplar scenario matrix:

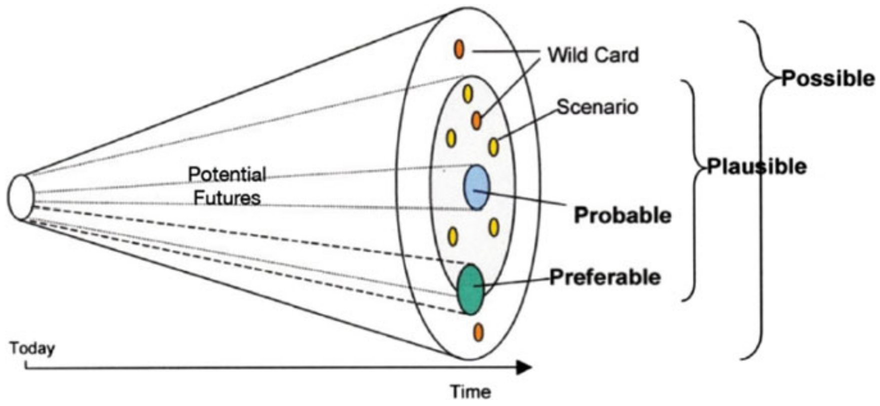


Fig. 20.9 Futures cone (Voros 2003)

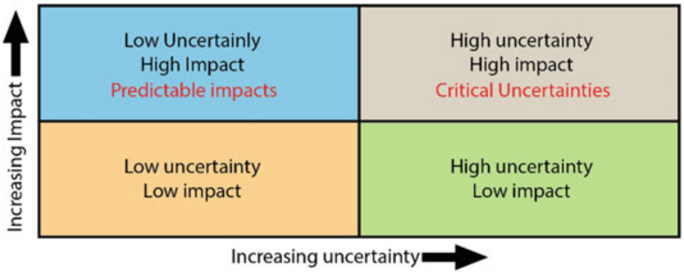


Fig. 20.10 Impact ranking matrix (Adapted from Gertler et al. 2016)

- *Axis of uncertainty one*: The success of Resyntex's optimisation focused on efficiency and cost-reduction of Resyntex processing, to reduce the cost of recycling low-grade textiles.
- *Axis of uncertainty two*: The availability and accessibility as well as the volumes of residual textile waste.

The chosen axes of uncertainty are used to cluster relevant drivers and forces extracted from the research under four scenario themes, one in each quadrant (Fig. 20.10). Together with stakeholders, we assessed the drivers and forces impacting on collection rate and volumes of textile waste, as well as the drivers and forces towards gaining access to waste streams useful source of waste for input into the Resyntex process.

Having ranked critical uncertainties, descriptors of the scenario matrix are defined to consider and frame the outcomes of each critical uncertainty and to select relevant combinations to form axes. During this process, scenarios can be constructed and themed or named. This process requires a level of decision-making, whereby the value chain stakeholders expressed their expert judgment on the critical

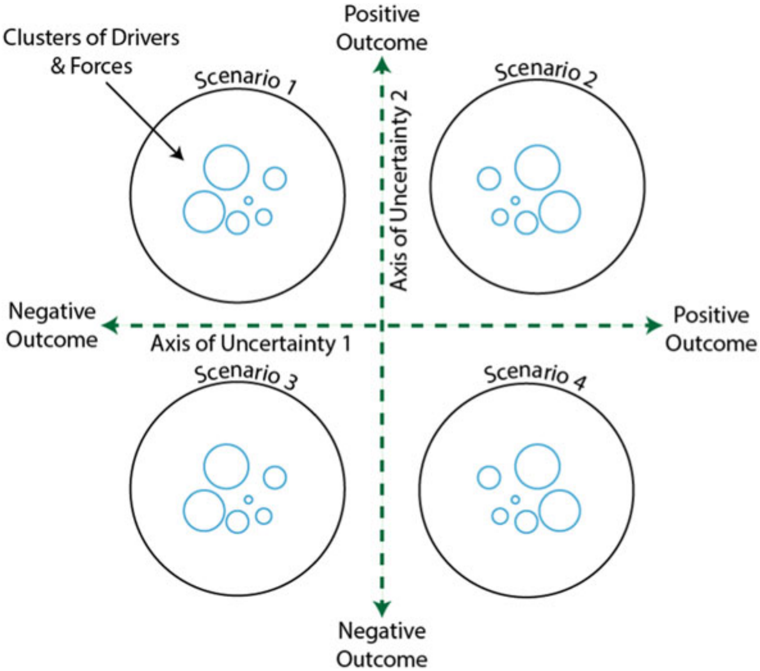


Fig. 20.11 Scenario framing using critical uncertainties to build axis (Author)

uncertainties presented (Postma and Liebl 2005). This generated different types of scenarios as defined by Voros (2003) future cone: plausible and possible (Fig. 20.9 and Table 20.4).

In a final step, strategic narratives describe the interactions and relationships of clustered forces within the scenarios. These narratives provide a storyline that summarises the complex interactions between forces and drivers and that shows the outcomes of the chosen critical uncertainties. The narratives thus allow for final comparison of the overall outcomes of the scenario building approach. As a result, the key business opportunities and challenges for the Resyntex recycling technology were visualised and summarised.

Table 20.4 Scenario categories

Plausible	Possible
Probable scenarios	Wildcard scenarios
Preferable scenarios	

20.6 Key Insights: A Stakeholder-Driven Development of a Circular Business Scenario

Figure 20.12 shows the four scenarios that the research produced. Table 20.5 shows a summary of two of the scenarios (1 and 2) to illustrate the building of scenarios through multi-stakeholder engagement and how constructing strategic narratives around different outcomes different critical uncertainties can explore a greater range of commercialisation pathways. The table shows the type of scenario, as defined by Voros (2003), key drivers that create the scenario theme, a brief articulation of the scenario narrative and strategic direction.

As described above, together with stakeholders, we particularly examined drivers and forcers impacting the availability of residual textile waste (vertical axis of uncertainty). This was important to highlight compatibility issues with the current textile recycling system, regarding the sorting of varied textile waste streams into suitable 'baskets' of material-sorted, decontaminated textiles that can feed into the Resyntex process.

The findings are summarised in three categories of available textile waste: post-consumer streams, controlled commercial streams and industrial streams. Table 20.6 summarises the drivers and forces impacting on the collection rate and volumes of textile waste. Table 20.7 examines the forces and drivers around gaining access to those waste streams that were judged by stakeholders as a useful source of supply for the Resyntex-type of recycling.

Fig. 20.12 Chosen axis of uncertainty and scenario examples visual summary (Author)

Table 20.5 Summary of two scenarios (Author)

Scenario name	Scenario type	Key drivers	Brief narrative	Strategic implication
1: Textile production waste recycling	Probable	Future changes in legislation regarding landfilling and incineration, treatment costs, waste sorting, GHG emissions reduction and low carbon recycling incentives may create favourable environment for Resyntex working with producers on a smaller, batch scale Resyntex manages to secure contracts with fashion manufacturers based on providing a recycling compliance service	Resyntex system of chemical feedstock production remains high-cost Batch volumes of residual textile waste become accessible through agreements with textile manufacturers	Resyntex re-positions itself as a specialist service to fashion and textile manufacturers that recycle large volumes of production waste. These services allow them to comply with new legislation based on extended producer responsibility (EPR)
2: Municipal Waste Contracting	Preferable	Through establishing supply contracts with public and private municipal waste contractors Resyntex is able to secure supply of high volumes of unsorted residual textile waste in exchange for diverting it from landfill or incineration on an industrial scale Investment in R&D focussed on process efficiency and/or technological innovations reduce processing costs significantly making Resyntex commercially viable	Resyntex system of chemical feedstock production becomes low cost A high volume of residual textile waste becomes accessible through agreements with public and private waste management services Clear commercialisation potential is demonstrated and capital investment constructs dedicated textile recycling facilities	In this scenario Resyntex investment in R&D towards developing more efficient textile recycling processes pays off, it is able to introduce a cost-effective alternative to landfill and incineration for residual textile waste on a large scale

(continued)

Table 20.5 (continued)

Scenario name	Scenario type	Key drivers	Brief narrative	Strategic implication
3: IPR & Spin-off Technology	Probable	Composition of waste textiles causes expensive sorting, decontamination and grinding requirements that require investment in automation to speed up pre-processing Capital investment in an industrial-scale plant is significant and extends the amount of time the operation may take to 'payback', representing considerable investment risk as a new to market technology	Resyntex has difficulty commercialising its recycling technology based on its original target markets. The complexity of Resyntex system; its cost, difficulties with supply, quality of product and volatility on the chemical feedstock market, limit investment. It seeks alternative income streams utilising valuable patents that generate additional R&D interest with a focus on technology spin-offs and licensing deals	Post-project completion Resyntex undertakes a knowledge and research review, with the specific aim of securing the protection of valuable IP. Using the IP, new open innovation research platforms are established to create a number of R&D projects that work on multiple applications for the commercialisation of Resyntex technology in specialist markets
4: Modularity Micro-cycle	Wildcard	The most commercially viable Resyntex process recycles wool and silk fibres is one of the least available streams of residual waste. Scaling up becomes a challenge Resyntex chemical reprocessing becomes a certified process for safely disposing uniforms and wins contracts with major airlines and public services. Secures supply consistent supply of pre-sorted materials	In this scenario, Resyntex R&D investment pays off and production costs are reduced, but in specific cases, not in all of the processes. Compounded by the issue of difficulties getting adequate supply of residual waste, Resyntex focuses on specialist services and locates itself in close proximity to private textile recycling organisations	Resyntex dilemma is that some of its processes are cost-effective while others, particularly to do with cellulosic and polyester recycling, are not. Resyntex is forced to consider a modular approach to developing its facilities, specifically focusing on commercially viable processes such as wool and silk recycling or value-added secure recycling of uniforms, on a much smaller scale than anticipated. The investment seeks to develop a range of Resyntex machinery of suitable size and cost to sell to sorters who can then recycle specific materials for themselves, under a licence and servicing agreement

Table 20.6 Summary of drivers and forces impacting on collection rate and volumes of textile waste (Author)

Post-consumer streams	Controlled commercial streams	Industrial streams
Consumer incentives to recycle (e.g. retailer takeback)	The sharing economy and collaborative consumption might complicate access to waste streams	Industry 4.0 and new business models for recycled materials in industrial use in Europe (opportunity)
Standards of living are changing globally (growing middle class)	Economic growth	Rise in demand of textile products
Fashion trends (highly transient)	Legislation on disposal	Production growth
China's ban on waste imports	Life expectancy (often short due to standards)	Circular economy: bringing textile production (partly) back to Europe
Extended Producer Responsibility		Developments in recycling technology and material reuse
Green public procurement		Lean production: optimisation means waste reduction, hence input reduction for Resyntex
Consumer awareness on the ecological burden of consumption and disposal		Sustainability strategies of big brands
Population growth (outside of Europe)		Demand for recycled/reclaimed fibres
Fiscal policy, e.g. carbon tax		
Resource price volatility		

Resyntex was widely considered by stakeholders to be an expensive process, with various costs related to collection, sorting, decontamination and processing that will likely outweigh the return on investment by the delivered feedstocks. Importantly, stakeholders voiced the concern that in order to attract investment and buy-in, Resyntex needs to investigate different commercialisation pathways than those that were identified at the onset of the technology research and development.

Indeed, in the process of building business scenarios, the diverse group of industry stakeholders which we convened identified numerous opportunities for industrial symbiosis around the Resyntex technology, which had not been previously considered. As an example, it was suggested that the cellulose inputs from cotton fibres can serve to produce added-value sugar platform chemicals, with a far wider range of applications than initially envisaged by the research team (e.g. cosmetics, coatings, pharmaceuticals). Other suggestions included the use of recycled synthetics in packaging applications through an approach of gradual blending. This would entail starting with a low percentage of recycled, textile waste sourced feedstock, which can

Table 20.7 Summary of drivers and forces towards gaining access to waste streams useful source of waste for input into the Resyntex process (Author)

Post-consumer streams	Controlled commercial streams	Industrial streams
Consumer-led sorting and segregation	Reverse logistics	More competition as more materials start flowing (B2B)
Logistics intricacies: transporting from source to sorting centres	Textile services contracts	Producers becoming capable to reuse their own waste
Ever-stricter anti-dumping legislation	Anti-dumping legislation	Waste will become a more valuable resource to companies
If you can get a change in mindset, so people would bring more to the containers—also the non-wearables	Disincentives (legal, fiscal) on landfill	Brand protection issues
Circular Economy package translated into national directives, with recycling quota of 65% and binding landfill targets	Lack of textile segregation and sorting in the waste stream	Companies are generally reluctant to grant access to their waste—needs full transparency and certified disposal
Competition	Waste management contracts	Guarantees and credible information on the environmental performance
Lower quality of the available textile materials in waste streams	Corporate social responsibility strategies and policies	
Partnerships and business models	Lack of knowledge on recycling routes for uniforms amongst companies and organisations	
Eco-design of textile products	Competition	
Fashion as a service and leasing models could gain some more traction		

be gradually increased while improving performance, purity and quality, and in alignment with growing regulatory pressure. Beyond the identified end-products, stakeholders were also keen to point towards regenerated textile fibres, more and more in demand by large-scale fashion retailers who are keen to improve their environmental footprint.

Next to offering a critical steer into commercialisation opportunities, the stakeholder dialogue also brought in valuable insights as to the boundary conditions and enabling environment for a textile recycling technology such as Resyntex to be (widely) adopted. This included the vital need to develop sorting capacity and optimise technology to make the collection, sorting and pre-treatment more economically viable and more capable of handling the growing complexity of blends, as well as the

Table 20.8 Summary of stakeholder-led analysis on an enabling condition for Resyntex: the sorting of textile on material basis (Author)

(1) Design for recycling	(2) Market demand for recycled fibres	(3) Sorting technology	(4) Regulation	(5) Business case
Fillings, components and trims that can be removed easily	Macro-economics: prices increase for virgin materials	Technological advances in material detection: RFID, automation, near infrared spectroscopy (NIR)	Ban on textiles being landfilled/incinerated	Demonstrated business case for sorters, including market development
Limited use of blends	Demand of regenerated material (consumer awareness)	RFID traceability on industry-wide level	Financial incentives for manual pre-sorting	Economies of scale: pooling the volumes
Monomaterials, including for seams and labels	Development of new and higher quality fibres	Availability of a fibre bank or database	Producer pays for recycling	
Dissolvable yarn for buttons and zippers			Tax break on sorting labour	
			Tax on textile products with mixed fibre content	

decline in the quality of clothing available in the textile waste stream. Stakeholders reflected on what it would take to change industry practices so that we can collect and sort low-grade textile waste by fibre type—this specific enabling condition is shown in Table 20.8.

20.7 Conclusions

The purpose of the preliminary business scenario examples is to start informing strategic decision-making by presenting the trajectories and strategic implications of different clusters, drivers and forces to show alternative futures for Resyntex. The futures generated are based on the outcomes of selected critical uncertainties, underpinned by findings from the research methodology as well as from stakeholder exchanges. The presented methodology can be used to construct further scenarios that demonstrate commercial opportunities, built and validated according to the research design. These can be used to make strategic recommendations and construct preliminary business models.

Based on the preliminary results in the project, the following strategic insights are offered that would make difference to Resyntex attractiveness for investment and commercialisation and need to be explored through further research:

1. **Reduce input costs**: Securing sources of residual textile waste input that can be pre-processed and transported efficiently at low cost.
2. **Process efficiency**: R&D investment in optimising Resyntex processes, by improving efficiency and yields, reducing energy, water and chemical inputs, lowering process costs.
3. **Process selection**: It may be that Resyntex chooses to focus R&D efforts on processes that have the most potential. Though the current financial appraisal models show poor results, processes such as the cellulosic fibre hydrolysis (towards PTA and glucose solution) show promise if efficiencies could be realised.
4. **Product selection**: The processes where value-added chemicals were produced are more likely to move towards profitability. It would be difficult for Resyntex to compete in large-scale markets where economies of scale have already been exploited, such as bio-ethanol.
5. **Specialist market**: Because of Resyntex potential scale, in may be that it focuses on specific markets and creates new synergies or networks within that. For example, specialist wool and silk recycling working with sustainable wool producers, suppliers and retailers could be possible.
6. **Technology spin-offs and IP exploitation**: Though original project concepts may not be possible, other market routes to exploitation may be found based on evaluating the scenarios and considering strategic direction. For example, discoloration of cellulosic fibres and their supply may be useful to firms like Lenzing™ as demand for textiles like Tencell® and other sustainable cotton alternatives increases.
7. **Industrial-scale costs**: Comprehensive costs of operation within the Resyntex value chain and more accurate appraisal of required capital investment for establishing Resyntex processing plants are needed to produce more accurate financial predictions.

The making of early yet significant decisions when bringing the Resyntex technology to a higher scale needs to be guided by strategic considerations that have benefited from active and critical contributions by a network of industry and market players. The involvement of these stakeholders has proven to be instrumental in assessing the future commercialisation potential of the Resyntex technology. Throughout the value chain dialogue, and across a diverse set of sectors and industries, a broad consensus emerged: while Resyntex demonstrates a strong technological performance, the recycling process is currently not set up for end-products that are commercially viable. In the transition from technology to market, strategic investment decisions (SID) will need to be made on the types of waste textiles (feedstock) and the range of end-products (outputs) to be targeted for the chemical recycling of textile waste. The business scenarios and value chain engagement have proven useful tools to prepare such crucial decision-making.

20.8 Limitations

This study is based on evidence specific to the 'Resyntex' project and the research activities therein. The methodology is presented on the basis that the principles of the ecosystem approach, stakeholder engagement workshops and resulting preliminary scenarios may have currency in other projects aimed at commercialising sustainable new technologies. Thus, the methods constitute a 'piloting' of combining mixed-mode research methods and evaluating initial results.

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Chapter 21
The Circular Apparel Innovation Factory

Testing a New Collaboration Model for the Textile & Fashion Industry in India

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Abstract India's textile and apparel industry is one of the world's largest and a major contributor to the global textile and apparel production. Pioneering industry players are driving the sector's transition towards less wasteful and more circular business practices. However, there is the recognition that a transition towards a circular textile and apparel industry in India requires a holistic and system-level approach that involves all actors across the textile and apparel value chain to collaborate, innovate and share knowledge and evidence on 'what works'. This chapter presents a practitioner's perspective and early efforts to create a new collaboration model and platform for action for the Indian textile and apparel industry through establishing the 'Circular Apparel Innovation Factory' (CAIF), an industry-led initiative established by Intellecap, The DOEN Foundation and Aditya Birla Fashion and Retail (ABFRL) with the mandate to build the capabilities and the ecosystem needed for a transition towards a circular textile and apparel industry in India. After an introduction that summarizes some of the sector's challenges and drivers towards circularity, the article presents CAIF as a case study for a collaboration model and provides examples of innovative collaboration projects that are aimed towards closing critical ecosystem gaps. The article concludes by calling out further areas for industry action and the need for industry iniatives such as CAIF.

Keywords Circular fashion · Supply chain innovation · Ecosystem building · Systems thinking · Sustainable business models · Indian textile · Sustainable fashion · Business model innovation · Collaboration · Circular innovation

A practitioner's perspective.

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21.1 The Need for a Transition Towards Circularity—Why India's Textile and Apparel Industry Requires a Shift

India's textile and apparel industry is one of the world's largest, and is a major contributor to global textile and apparel production. Its current estimated worth is over USD 150 billion, and it is expected to grow to over USD 220 billion by the close of 2021. The industry currently employs more than 45 million people—and hence is also the second largest employer in India—and it contributes to more than 15% of the country's export earnings, and to almost 7% of the country's industry output (India Brand Equity Foundation 2018). While the domestic textile industry is expected to grow to almost USD 220 billion by the close of 2021, estimates indicate the apparel market to expand to USD 59.3 billion by 2022 (Ibid) making it comparable to those of the United Kingdom and Germany.

While globally, the EU and USA have been recognized as the world's largest apparel markets on the consumer-side, countries like India and China have been considered to be manufacturing hubs. India is considered to also be one of the largest textile exporters in the world, and recent estimates suggest that it holds more than 5% of the global textile trade share—which is dominated by China and the EU (India Brand Equity Foundation 2018).

There are numerous trends that are shaping India's textile and apparel industry, leading to its positioning over the next few years as a leading manufacturing and consumption hub—globally. These trends and drivers also point to a need to rethink the way the industry works, while ensuring growth is accompanied by sustainability and efficiency in the long term. Some of these key trends and drivers that point to the need for a circular economy in the industry are listed below.

21.1.1 Driver 1: India is Transitioning from a Manufacturing to a Consumption Hub

Arguably, India is a formidable producer of textiles and apparel, yet recent trends in consumer demand, disposable income growth and purchasing decisions indicate that India is soon to be a major consumer market as well (Amed et al. 2018). A recent report indicates that the Indian middle class is growing at an annual rate of 19.4%, along with this—the report projects household incomes and purchasing power to increase for this segment—leading to the creation of a sizeable market of differentiated consumers over time (Ibid). In addition, 'conscious consumerism' is on the rise in India: According to a report by Myntra-Jabong,[1] India is expected to be the world's largest market for sustainable products by 2030 (Agarwal 2018; Kalia 2018). Consumer awareness has been especially rising among the youth, who currently

[1]Myntra-Jabong is an Indian conglomerate that accounts for a little over 1% of India's $100 billion + fashion & apparel industry.

form India's largest demographic category. Recent analyses have highlighted this consumer segment to be more inquisitive—the youth tend to make more conscious decisions and often look for informational labels on products about social and environmental impacts (Nielsen 2014). Another report also indicates that today's youth—while increasingly demanding 'sustainability' in their products (Nielsen 2018) are also predominantly influenced by the Internet and often turn to hold institutions publicly accountable of various avenues such as social media. Some segments of the youth are also willing to pay a premium for such 'conscious' products.

As the industry is witnessing the rise of this 'conscious consumerism' (Lad 2016), brands and manufacturers are beginning to focus on sustainability and increase their efforts towards it to match consumer demands. Given that close to a third of global, consumers are now incorporating 'responsible values' into their purchasing decisions (Amed et al. 2018), and that this awareness and yearning for accountability are only expected to grow further—India has big role to play in this shift as one of the world's largest manufacturers of textile and apparel.

21.1.2 Driver 2: International and Domestic Pioneers are Adopting Sustainable and Circular Business Practices

Although the numbers indicate a positive trend in terms of growth of the Indian apparel and fashion industry, the question of sustainability looms large on the sector. Given that the production of textiles results in the creation of 1.2 billion tonnes of greenhouse gases each year, the industry is the world's second largest polluter, and estimates indicate its contribution to global climate change is peaking at 8.1% (Quantis and CWF 2018; Ellen MacArthur Foundation 2017; Stand.earth 2018; Szokan 2016). The Indian textile and apparel sector is one of the most polluting and is scattered with multiple social inequities among other issues. To illustrate, India is currently the second largest producer of polyester and viscose globally, all non-recyclable, chemically dyed, and a major source of micro-plastics. 70% of garment factories in Delhi pay less than minimum wage; 1 in 7 female garment workers have been physically or sexually abused; these numbers illustrate the social impact of the sector (Fair Wear Foundation 2019). There is child labour in 40% of documented garment factories, and higher numbers in illegal factories (The Asia Foundation 2017). Women, who form a large portion of the textile and apparel industry in India, work and operate in the informal economy under poor working conditions, with low wages, high exploitation and non-compliant social and labour standards.

Alongside these environmental and social issues, current manufacturing processes have led to unchecked consumption of raw materials and inputs. In 2010, India's material demand was the third largest in the world, after China and the USA. Studies suggest the Indian textile industry alone is a major contributor to waste and pollution with nearly 5% of all landfill space being taken up by textile waste and 20% of all fresh water pollution being made by textile treatment and dyeing plants (Narayanan

2015). As a result, the government of India has come up with a number of policies to incentivize or penalize companies pushing them to comply with various environmental standards during consumption and disposal (Arora et al. 2018). One such example is the 2015 case of the Madras government shutting down a major hosiery cluster in Tirupur for not adhering to the Zero Liquid Discharge standards.

As a reaction to the increased pollution, the growing negative impact of manufacturing and changing regulations, international brands and manufacturers, like H&M, C&A, Patagonia, Stella McCartney, as well as large domestic conglomerates like Aditya Birla Fashion & Retail, Arvind Ltd., Reliance Industries Ltd., are making public commitments to sustainability and circularity and are joining initiatives such as the *Sustainable Apparel Coalition*, the *Global Fashion Agenda*, *Make Fashion Circular* and others and have started to mandate sustainable and circular production methods in India (Remy et al. 2016). Nudged by initiatives like the accelerator programs run by *Fashion for Good*, or the Organic Cotton Accelerator, the Dutch Fashion Action Plan, or the World Economic Forum's 'PACE' pioneering brands like H&M, Arvind Ltd., and C&A, Lenzing, and others, have started to embark on their circularity journey and are actively on the lookout for innovative solutions and collaboration models.

21.1.3 Driver 3: Innovation is Needed to Stay Competitive

A transition towards more circular industry practices is critical for India's apparel and textile industry in order to remain competitive, manage risks and make use of opportunities through innovation and 'self-disruption'. Reports note that by 2030, if fashion brands were to continue business as usual and not innovate to be sustainable or competitive as markets evolve, they would witness a significant decline in EBIT (earnings before interest and tax) margins of more than 3% (Lehmann et al. 2018). This would translate into a profit reduction of approximately EUR 45 billion for the industry (Ibid). India is increasingly witnessing the impacts of this stress due to resource constraints and an inability to match supply and demand.

In December 2017, India's apparel sector succumbed to the mounting pressures along with its inability to meet demand and supply conditions and saw a 3% decline in its Compounded Annual Growth Rate or CAGR compared to the corresponding period in 2016 (Tyagi 2018).

Global players in the textile and apparel space such as China and Vietnam are growing at rapid paces—matching or even surpassing that of India's—leaving the Indian market and its actors in a struggle to remain competitive and innovative while meeting sustainable requirements and mandates. At the same time, innovative businesses have started to propose better ways to run and transform the apparel industry's complex supply chain with offerings ranging from smart textiles, to alternative fibres and digital technologies to enhance resource and process productivity, offering an opportunity for new collaboration models and creating space for an emerging consciousness that will drive the industry to reconsider its current practices and adopt newer business models.

21.1.4 Driver 4: Digitization and Emerging Technologies Could Enable India to Leapfrog

India has the opportunity to leapfrog in the circular fashion agenda since it is currently at a stage where the industry is ready to adopt solutions and is actively looking for ways to do so. By gathering learnings and insights from other countries and models, India has the potential to improve and build upon the efforts of other markets such as those in the EU—Netherlands, Sweden, Germany, etc.

Over the years, and with a view to enable a circular economy, Europe has positioned itself as a hub for innovation and scalable business models for a circular economy to prosper across industries. These models have a strong focus on the consumption or consumer side. The company *MUD Jeans*, for instance, leverages an innovative new retail business model and works to ensure that materials are continuously kept in the loop; likewise *Sympany*, gives a new life to pre-loved garments and is considered to be one of the largest independent suppliers of second-hand clothing in the country with a booming supply and demand. Today, many European brands and manufacturers have started to establish their retail and supply networks with a circular focus and are now driving more process-based, and consumer-level innovations across the textile and apparel value chain.

India, however, has only recently embarked on its journey towards circularity, and it is for this reason that the country has the opportunity to leverage existing efforts to tackle consumer-level challenges and introduce new business models for circular fashion. India also has the added advantage of tackling production and process-level challenges simultaneously.

By adopting and creating more innovative business models as the first step, India has the potential to replicate the success of the e-commerce boom in the circular fashion space too. Digital technology has enabled the industry with the power of data, information and ways to interface physical resources more than ever before (Perzon et al. 2018). This technology infrastructure has given the industry and consumers new ways of communicating, improved processes and ensured maximum resource usage (Ibid). As a result, solutions like fashion as a service, renting or subscription based models are on the rise (Ibid). These models of shared or temporary ownership, prevent wastage and enable the monetization of underutilized clothing. Over time, this can have an impact on the need to buy new clothes thus impacting circularity.

In addition, investing in transparency and traceability has long been known as a key driver for circularity and ethical practices across the value chain. There now seems to be a compelling business case for retailers to improve their visibility from factory-to-retail, enabled by the operational advantages that emerging technologies bring. A

2017 report on retail trends and drivers highlights this shift, noting a high willingness to adopt Blockchain technologies and IoT solutions among global retail chains (Siddhanta 2018; Technologies 2017). A number of leading Indian clothing retailers such as Shoppers Stop, Future Group, Globus, Gini & Jony, Jack & Jones, Vero Moda and Only have recently signed agreements to implement IoT and Blockchain technology solutions at select outlets across India—signaling this potential industry level transformation.

21.2 India's Textile and Apparel Industry is Witnessing a Circular Makeover

21.2.1 Defining the Circular Transition for Indian Apparel

While the aforementioned trends point towards a sea change in the apparel industry in India, there is a pressing need to define the industry's circular transition. The scattered nature of the supply chain and the lack of a coherent understanding from stakeholders have stifled efforts to truly define India's circular fashion movement. It is known that mass fashion or fast fashion in India is cheap. Long-term consumption and production of fast fashion have led to the proliferation of certain consumption and production behaviours that are detrimental to the environment and society. In addition, the industry is currently caught between the struggle of meeting margins with increasing costs, while keeping costs low. Circular fashion presents an opportunity to shift the paradigm and bring in a new value proposition for the consumer, and the businesses—one that offers a better environment and has the long-term benefits of added economic value.

In defining circular fashion for India, three stages or iterations become evident across the supply chain or the lifecycle of a garment. The first is a pre-consumer-level manifestation of circularity that is across the manufacturing and retail value chain. The second is focused on the consumer—and how she or he chooses to purchase, use and discard the garment. The third and final manifestation is in the post-consumer phase focused on maximizing the value of the garment through recycling, upcycling, or transformation of the garment itself.

- Pre-consumer circularity: The focus for manufacturing traditionally in India has often been to employ a labour intensive, low-technology and low-price power manufacturing unit that is often focused on volumes and costs. When considering various aspects of circularity in the pre-consumer phase and defining essential practices for it, additional consideration must be made of the multiple informal economies that operate in the space as well. In India, especially, the collection and recycling of textile waste created during the manufacturing process have been the work of the informal sector. For instance, across manufacturing hubs, large informal markets exist for offcuts and end pieces of fabrics. These informal players purchase the ‘waste’ from manufacturers to reprocess into various other forms—sometimes including garments—such as fillers and alternative products like dust-cloths or industrial insulation/scrubbers. A local term for this kind of waste is ‘*chindi*’. While the informal economy does work to reprocess the waste fabric, their operations limit the value and scope of the waste itself and hinder the introduction of new business models in the textile to textile recycling space, in the use of alternative and recycled materials, and in the integration of a less waste-producing process.

- Consumer-level circularity: Indian society and culture have always had circular ideals, constantly striving to extend the value of objects such as garments by passing it down through generations, and in some cases, re-purposing the garment itself for various household uses. While this household level ‘second-hand’ economy is present in a majority of Indian households, a formal second-hand economy and market are needed to drive circularity across the industry at the consumer level. With the rise of new business models aimed at increasing the lifespan of apparel through repair, subscription-based retail, and other modes such as rental, consumer-level circularity is beginning to take shape in the Indian market as well. Models from other regions such as that of MUD Jeans from the Netherlands or Rent the Runway from the USA are being tweaked and replicated in various parts of India. Al-beit at small scales, the potential for scale is high given the rate at which consumer mindsets are shifting.
- Post-consumer circularity: The existence of a large waste management and collection market in India is testament to the vast potential for post-consumer circularity to prosper. While informal waste management markets do exist in the post-consumer phase, with small to medium organized efforts in sorting out waste at source or recovering waste from landfills, the opportunity for textile-to-textile recycling is ripe. Efforts such as this also require the formalization and organization of a large number of informal sector workers, which could provide the double benefit of bringing these informal players into a formal market segment and creating an organized post-consumer textile waste supply chain.

21.2.2 Laying the Foundations for Circular Fashion in India

Scattered across the value chain and across India’s vast textile and apparel industry are major and minor efforts that leverage new technologies, new business models and the principles of circular fashion into their operations. There is an increasing awareness among businesses in the industry of the harmful nature of unsustainable production methods and the ever increasing environmental and carbon footprint of the industry.

Efforts by the large brands and retailers such as Aditya Birla Fashion and Retail, and Reliance Industries Ltd.’s R|Élan to create new ecosystems and supply chains for sustainable fibres such as recycled polyester, and viscose fibres are underway. On the other hand, small and medium enterprises or SMEs are also partaking in the circular transition—with a heavy focus on recycled cotton, polyester and wool. There are new models emerging in both the B2B and B2C segments, wherein businesses are supplying to both international brands and local consumers.

While the recycling space is growing at a fast pace, the alternative materials supply chain is beginning to develop innovative solutions that are circular and could potentially contribute to make the agricultural sector and the textiles and apparel sector circular. For instance, organizations are beginning to work with agricultural waste and non-conventional fibre sources such as hemp, banana, coconut and nettle to offset the dependence on cotton and other resource intensive, environmentally unsustainable materials such as polyesters.

However, in India, numerous factors still prevent the large-scale adoption of circular fashion. Some of these are:

- The lack of awareness on the brand and the consumer side in terms of the opportunity of the transition,
- The major gaps in technology in terms of financing and a supply–demand mismatch,
- The lack of economies of scale due to a strong unwillingness to adopt and risk-averse behaviour,
- The lack of financing and investment is a barrier overall, leading to an inability to scale innovative business models, technologies for the production of alternative fibres, and create incentives to enable the transition to a circular apparel economy and lastly, in terms of 'closing the loop',
- The systems for collection, sorting and processing of waste at both the production and post-consumer stages are still underdeveloped—more so in the last mile.

The traditional nature of the apparel industry in India with an inclination to exports often also makes it resistant to change unless the change is driven externally by customers or by legislation.

In addition, buyers and manufacturers are not incentivized or willing to invest in transitioning to a circular economy. While on the one-hand manufacturers operate on low margins due to the costs and constraints placed upon them by buyers; on the other hand, buyers tend to operate with the ethos of profit maximization with the lowest possible cost due to the volumes and scales at which they operate. This 'chicken and egg' situation so to say, leads to inertia from buyers, brands and manufacturers in investing in new technologies and processes that could support their transition to circularity. The question of overcoming the lack of trust, willingness to invest and commit to circularity by the brands, buyers, or manufacturers remains. In this complex scenario with diverse stakeholders, each with their own drivers, incentives, structures and decision-making mechanisms, there is a need for a systems-level solution that can bring key stakeholders onto a single platform to deliberate and collaborate effectively. With market actors scattered across the country and operating at different levels, it is imperative that each stakeholder be engaged to build a robust circular supply chain and overcome the challenges of the industry at large.

21.3 The Circular Apparel Innovation Factory—A 'Systems Approach' to Build a Pathway to Circularity in India

21.3.1 A New Collaboration Model for the Indian Textile and Apparel Industry

The complex set of relationships and interconnectedness of challenges in the Indian apparel and textile industry calls for an industry-wide solution that enables systemic collaboration. Recognizing that a transition towards circular industry practices in the Indian apparel and textile sector requires a systems approach that facilitates new types of collaboration and unusual alliances, the Circular Apparel Innovation Factory was launched in 2018.

With the aim of creating collaboration and innovation infrastructure for the sector in India, the Circular Apparel Innovation Factory (CAIF) is testing a new collaboration models between corporates, brands, suppliers, manufacturers, start-ups, innovators and other actors from the apparel and textile ecosystem but also academic institutions, civil society organizations, NGOs and international agencies through a process that facilitates the co-creation of product, process or business model innovation. Spearheaded by Intellecap, an India-based consulting firm that focuses on mandates with a social impact, The DOEN Foundation, a Dutch foundation with the vision to work towards a circular economy through strengthening entrepreneurship, and Aditya Birla Fashion and Retail (ABFRL), one of India's largest multi-brand fashion and lifesstyle businesses, the intent is to make this initiative private-sector led and involve pioneering brands as anchor partners of the initiative. The intended outcome after an initial three-year period is to establish a model for pre-competitive collaboration between brands, producers and the larger apparel ecosystem that can generate circular solutions and to establish CAIF as a membership organization driving the circular apparel and textile agenda in India in the long-term.

21.3.2 Applying Anticipatory Approaches to 'Imagine the Future' and Identify Opportunities

System's thinking has recently gained increased attention to overcome complex challenges and bring complex systems on new pathways. While there are few practical tools available, anticipatory tools and methods are often used to explore new territories and identify opportunity areas. CAIF therefore applies approaches like design thinking, participatory and user-centric design to help organizations 'imagine the future' and identify innovation opportunities along the following four areas[2]:

[2]Digitization and emerging technologies as well as business model innovation cut across and are horizontal to these four areas.

1. Designing products with renewable inputs
2. Using inputs that are sustainable and not of concern
3. Increasing the usage of clothing through superior products, higher value and longer lifespan
4. Increasing the recycling of clothing through textile-to-textile recycling and material exchange.

In additon to the environmental goals, CAIF also aims to reduce the negative social impact of the sector, improving working conditons and increase social responsibility through inclusive circular business models. Overall, CAIF helps Indian value chain stakeholders build a common understanding of the problems and challenges, align in a vision for solutions and opportunities, build commitment to action through pilot and prototype interventions, and facilitate collaboration and new kind of alliances.

21.3.3 Facilitating Innovation and Co-creation Through a Four-Step Process

The Circular Apparel Innovation Factory aims to work as an innovation facilitator to help industry players, especially brands and producers, develop and test circular product, process and business model innovations. Aggregating a diverse set of stakeholders from the apparel and textile industry but also other fields that could provide solutions to bring the Indian industry on a circular pathway, the CAIF facilitates a four-step-innovation process:

- Identify and Scope solution providers, stakeholders, challenges and opportunities for a circular economy to prosper across the textile and apparel value chain
- Contextualize and Conceptualize ideas that can be scaled, that stakeholders are willing to adapt, collaborate on, implement and sustain
- Ideate, Prototype and Stress test ways in which brands and manufacturers can work together to transition and adopt circular product, process, or business model innovations
- Build industry capabilities as well as Disseminate and Scale learnings and processes across the industry through a variety of convenings, capacity building formats and an online platform (www.circularapparel.co).

Start-ups and innovators as critical pillars of the initiative

While start-ups and innovators from India and around the world have started to develop product, process and business model innovation that has potential to disrupt the fashion and apparel industry and move towards circularity, the discovery of those solution providers is a challenge: There is an information asymmetry between those who are looking for circular solutions, i.e. brands and producers and innovators and start-ups who are working on solutions. CAIF brings these innovators in the centre and creates visibility for them through different channels including, at the same time helping them to make their solutions scalable through targeted enterprise-focused capacity building. Through workshops and collaboration days, innovators and start-ups get a platform to showcase their solutions. The online portal www.circularapparel.co additionally helps the discovery.

An India-centric initiative with a global connect

While globally, private-sector and multi-stakeholder sustainability or circularity initiatives exist,[3] CAIF aims to complement those through creating an India-centric action-oriented platform that establishes evidence and case studies through making collaborations happen on the ground. While the focus of action is India, CAIF aims to bring innovations and solution providers from across the world to India. A first step has been made to pilot an 'innovation corridor' between India and the Netherlands and help the transfer of technologies and scaling of innovative solutions to the Indian market. The intention is to broaden the efforts across multiple European countries and establish a 'circular apparel innovation corridor' between Europe and India.

21.4 Driving Innovation Through Collaboration—Three Cases of Innovation for a Circular Economy

With the vision of acting as the 'collaboration infrastructure' for the sector in India, CAIF works on multiple levels to facilitate 'unusual alliances' and partnerships between different value chain stakeholders as well as other solution providers. Innovation in an industry such as the textile and apparel requires collaboration in experimenting with various collaboration models; CAIF has been able to spur innovations through co-creation and aims to build these out further. The following case examples illustrate the systemic approach, the initiative is adopting to enable innovation and collaboration.

21.4.1 Case Example 1: Fostering Collaboration Through Co-creation and Ideation Workshops

Achieving the transition to a circular economy in the apparel industry in India requires the creation, adoption and scaling of circular innovations across stakeholder segments of the value chain. However, three challenges currently hinder the industry to 'self-disrupt' and move towards circular innovations: First, the innovation landscape is highly fragmented, making the discovery very challenging. Second, solution providers from other sectors and domains exist that have valuable solutions to offer

[3] See for example: Sustainable Apparel Coalition (https://apparelcoalition.org/), Partnership for Sustainable Textiles (https://www.textilbuendnis.com/en/), Better Cotton Initiative (https://bettercotton.org).

to the apparel and textile industry; however, awareness levels among the industry on these solutions are low. Third, collaboration opportunities between innovators and brands and producers are limited, missing out on the potential to co-create solutions together.

To overcome these challenges, CAIF periodically runs co-creation and innovation workshops that bring value chain stakeholders and solution providers from diverse fields together to jointly develop ideas that can lead the sector towards circularity. The co-creation and ideation workshops mark the first stepping stone in a journey that CAIF facilitates to bring about circular product, process and business model innovation. Post the workshop, ideas and concepts that are co-created are validated through rapid research methods, prototyped and refined and finally prepared for launch. As an approach to fostering collaboration among key stakeholders and solutions providers, CAIF runs a range of workshops and convenings such as ideation & innovation workshops. One such ideation and innovation workshop was held in December, 2018. The workshop brought together more than 40 key stakeholders such as major brands, enterprises, innovators and enablers to discover and define issues in their value chains, ideate on ways to solve them, and co-create solutions that can be implemented as pilot programs to be scaled up.

Applying a three-step process based on design thinking methodologies, the workshop aimed to look at challenges to circularity as opportunity areas, and address gaps through ideation and high-level solutioning. The first step was to 'discover' key issues and challenges within individual supply chains, develop a joint understanding of the critical bottlenecks towards circularity among workshop participants and create a problem statement that would form the basis of the solutioning process. The next step was to 'ideate' on different ways in which the identified problem could be solved, and the third step was to 'co-create' a shared vision and solution through partnerships and collaborations that can be launched to create a circular apparel economy in India. Together, delegates surfaced key painpoints and opportunities for a circular apparel economy to prosper in India, these were:

- **The lack of a common understanding of circular apparel**: There is currently no common understanding of a circular apparel economy among stakeholders in India. The lack of this common understanding and definition is a major barrier to creating dialogue, standards and certifications for the industry
- **The existence of large knowledge and information asymmetries**: Knowledge and information asymmetries are pervasive across value chains on three key fronts. The first being the lack of information on innovations and solutions for brands, the second being the solution provider's inability to access interested brands and manufacturers and the third is the lack of an industry-wide body to create knowledge and circularity 'best practices' and share them with the community
- **There is a need for systems-level innovations**: Key stakeholders from the industry are keen to take action, however, the ecosystem is currently still in a nascent stage. There is an urgent need to call for innovations at the systems level to build a robust value chain with strong forward and backward linkages from the fibre and yarn to the post-consumer stages

- **Low consumer willingness to adopt and pay**: Consumers are unwilling to pay high prices for circular and sustainable textiles; this has led to manufacturers and brands becoming weary of transforming their business practices to become more circular—given the additional costs and the rise in product prices
- **Lack of access to risk-capital and finance**: While scale has been a major issue, an addition and important factor for key stakeholders that serves as both a barrier and an opportunity is lack of access to capital for innovations to scale, and brands/manufacturers to adopt existing solutions.

The workshop resulted in the creation of five high-level concepts that were all aiming to drive circularity on an ecosystem level, rather than on an organizational level: Ideas ranged from innovative incentive mechanisms that nudge the consumer to the development of India-level Circular Apparel Industry Principles as a common framework to guide the industry. All ideas showed that circularity as a concept is still nascent in India, and there is a need to create a level playing field for all stakeholders, foster a common understanding among all value chain players, and create the right incentive mechanisms for actors across the chain—including the consumer. The most promising concepts are currently being validated and over the next six months prototyped and brought to life.

21.4.2 Case Example 2: Building and Nurturing a Support Ecosystem for Circular Innovations Through an Enterprise Capacity Building Program

The Circular Change Makers, launched in collaboration between Intellecap's CAIF and IMG Reliance's *Circular Design Challenge*, an initiative by Lakmé Fashion Week, Fashion for Earth by R|Elan, and UN Environment, is a collaborative commitment that marks the beginning of India's turn to a more circular and sustainable fashion industry. The first Circular Change Makers Showcase in August 2019 was designed to make innovative and scalable circular fashion solutions across the value chain visible and facilitate strategic investments with brands, corporates and early stage investors.

The platform provides startups and innovators with the opportunity to present their solution, their business plan and in a pitch-like format, receive targeted capacity building, and put forth their 'ask' to a jury of esteemed and diverse investors, brands, corporates and professionals from the industry. Through the program, participants—startups, innovators and businesses—have the ability to connect with a range of strategic investors and stakeholders from different parts of the supply chain to seek collaborations on various aspects of product development, testing and distribution, as well as scaling through investments.

As India's first investor showcase focused on circular fashion, Circular Change Makers represents a starting point in India's adoption of circular fashion. The program is a call to enterprises across the value chain working with circular models, innovative alternative materials and recycling initiatives, but also aims at awareness raising at the side of the industry and the investor ecosystem. Through the platform the program creates, stakeholders have the ability to reach out to enterprises with proposals and ideas on how they can collaborate on different aspects of making fashion circular.

The effort is the result of a joint stewardship of major industry stakeholders across different parts of the ecosystem—all coming together to recognize, and award talent in the circular fashion space through a bundle of investment readiness and business support services received in the months before the showcase and partnreship facilitation post the showcase.

21.4.3 Case Example 3: Creating Transparency and Accelerating Partnerships and Innovation Through an Online Community

There is a need for industry infrastructure that enables brands and circular fashion innovators to navigate ways of working together that accounts for this business ambition.

Current platforms aiming to drive circular practices offer ways to benchmark individual organization's performance, measure the product or process impact on society, environment and the bottom-line, some even enable brands and innovators to discover each other. However, none of the existing platforms or tools helps in navigating through a successful and long-term partnership that aligns with business strategy. Recognizing this 'white space', CAIF has been working to create a platform (www.circularapparel.co) for brands, enterprises, innovators, investors and other enablers of the circular fashion agenda active in India to curate their collaboration experience.

Some of the key highlights of this platform are:

Emphasis on opportunity and sustainability

The platform enables innovators offering circular solutions to strengthen their business models and improve their ability to raise finance. It also helps these innovators to showcase their work, make it discoverable for the industry. An "Innovation Challenge" Feature of the platform allows enterprises and innovators to offer their solution to the industry or to articulate their own 'asks' to other industry players to solve industry challenges togetger.

Partnership acceleration

Usually forming a partnership between brands, solution providers and other players could take anywhere between 8 months and sometimes even 4 years. CAIF and its platform have developed a process that will be able to accelerate this process by striving for transparency, establishing priority and developing alignment with all key stakeholders. The platform's business model and success criteria rely on brokering these successful partnerships.

Collaborations

With this venture, CAIF and Intellecap are not only leveraging their own capabilities and past work but also some of the top industry players and plugging in existing tools. A large affiliate network with organizations like Fashion Revolution, Forum for the Future, IMG Reliance, Fashion for Good, Enviu, Textile Association of India, Centre for Responsible Business, World Resources Institute are involved in specific collaboration projects and ecosystem building.

21.5 The Way Ahead—Testing Collaborations and Scaling Innovations for a Circular Apparel Economy

Having launched only in July 2018, the Circular Apparel Innovation Factory is still a young industry initiative. However, the past months have validated the need for a systemic and industry-level innovation and co-creation platform. While a lot of encouraging activities are happening in India, it is critical to strengthen the circular innovation system through supporting interventions such as a platform to ease discovery of circular solutions, the strengthening of a pipeline of circular innovations, and the creation of the ecosystem for circular apparel in India through investment, knowledge exchange and convenings.

- Easing the discovery and adoption of circular solutions: Innovators with alternate solutions have taken up to four years to get the right partner and into a supply chain opportunity (Kotak 2019). Many solution providers, small or big, end up looking at markets or support programs overseas (Saravanan 2019). Very few who rely on the Indian market have seen success in the short run. To solve this, the Circular Apparel Innovation Factory is further strengthening its online platform www.circularapparel.co to give momentum to all brands and manufacturers in their search and adoption of innovations for their supply chain.
- Strengthening the pipeline for circular innovations: The Indian textile industry understands the need for innovations and doing things differently in the value chain. It has however been hard for brands and manufacturers to find innovations and integrate them into the supply chain. The only way to make this a reality for brands, big or small, seems to be by spending large amounts of time and resources into sourcing the right partners (Agarwal 2018; Vardhan 2019). This might be a possibility for some but is seen as a non-core business activity thus making it difficult for many to justify such investment in sourcing innovations. With the overwhelming response to the Circular Change Makers and other innovation challenges CAIF has been hosting, the Circular Apparel Innovation Factory

is strengthening its sourcing activities and creating a suite of services for enterprises and innovators ranging from capacity building and investor showcases to partnership programs with stakeholders in India.

- Building the circular apparel ecosystem in India: Through numerous interactions with industry stakeholders to validate the need for a platform such as the circular apparel innovation factory, it became evident that the 'circular fashion' ecosystem in India is still in early days. While there is growing awareness and intent from brands and consumers, the manufacturers, recyclers, innovators and other key enablers that are integral to truly creating a circular economy need greater capacities to cater to the needs of these conscious consumers and sustainable mandates from brands. Needless to say, the supply chain will fall into place as demand increases from consumers and brands alike; yet it remains that the linkages between actors within the supply chain and greater awareness need to be created. The Circular Apparel Innovation Factory is thus driving innovations and strengthening the ecosystem for circular fashion by creating a collaborative and robust supply chain for brands and manufacturers in India to be more circular. The first CAIF Conclave, hosted in November 2019, is a first step to physically convene the ecosystem on a regular basis and aimed to become an annual event to bring the stakeholders together to drive the agenda.

In that light, CAIF is leveraging its vast stakeholder network to engage in convenings that can foster dialogue, interaction and more informal avenues for collaboration among stakeholders. On the other hand, while knowledge and networks are built to foster this collaboration—capital needs to be channeled into the sector through investments and innovative financing. To be able to channel these investments and invest in supporting circular innovators, CAIF is piloting an 'investor circle' to promote and finance circular economy initiatives in India and engage global stakeholders in knowledge and innovation transfers in a contextual manner.

In testing these new collaborative models for a circular economy to prosper, CAIF aims to create a strong ecosystem of support through knowledge, networks and capital for stakeholders across the supply chain. The opportunity is ripe for innovation and collaboration. Now, more than ever, there is increased willingness from all stakeholders to engage in building a circular economy and a robust supply chain that overcomes the pervasive fragmentation of the chain itself—and only by building on this momentum and fostering collaboration will a circular apparel economy come to light in India.

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Chapter 22
Corporate Governance and Corporate Responsibility

The Importance of Values, Leadership, and Accountability, in Driving the Textile Industry Towards a Sustainable Future

Pamela Ravasio

Abstract When there is a problem in businesses, there are typically three different root causes that together, and interdependently, prepare the ground for the situation: lack of fairness or fair play; bad process; and bad leadership. On the flip side, to have good results, **all three** of these ingredients are needed. As a consequence, the questions discussed in this practitioner article are as follows: How could a governance and leadership approach look like that leads the textile industry towards a sustainable and successful future in a social and environmental context, and economic reality, so very different from the one we know right now? What are the ingredients? What are the processes? In order to do so, first the 'Fair Process Leadership' (FPL) model of governance is reviewed, and then its application to both, top-level strategic decisions in companies as well as to operational decisions such as supply chain partnerships is illustrated. In this way, this paper proposes a different, more conscious as well as conscientious, quality-oriented governance and decision practice, suitable to strategic challenges as well as operational key tasks of the textile industry.

22.1 Introduction

Decisions in companies, brands, and indeed any organization, are never based either on a single argument, or the consequence of a single person's 'way'. Rather, companies have, to an extent, their own personality. And it is for this very reason that companies—but of course also NGOs, not-for-profits, foundations, etc.—are considered 'legal persons', i.e. a legal entity with its own rights, duties, obligations, and responsibilities.

A practitioner's perspective

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A key question, one that is discussed both in academia, in business schools, but also the public at large is: a decision taken by an organization—is it largely independent from, or a necessary consequence of, the decision(s) that the individuals within the organization have taken? In environmental scandals, the question then would be: Who is (or: was) ethically, morally, and factually responsible for it? The organization as a whole, the senior management as a group, or individuals within? Or all three? And who should as a consequence be held accountable? And in what way?

The Rana Plaza disaster (factory collapse in Bangladesh on 24 April 2013) became such a reference point in the textile industry, because of the many known brands that had (knowingly or unknowingly) products made there—and because the brand names were found out under public scrutiny. A similar statement could be made for wastewater discharge in production countries such as China that became headlines thanks to a range of very vocal and media savvy civil society organizations.

Scandals and disasters are just the pinnacle: the sad result when corporate governance, procedures, processes, and decisions of different players aggregate and drive towards unhealthy extremes. The chain has to break sometime. But it needs to be remembered: ultimately 'the fish rots from the head down'.

When there is a problem in businesses, which is typically a symptom, there are three different root causes that together, and interdependently, prepare the ground for the situation (Van der Heyden 2016):

1. *Lack of fairness or fair play* [specifically at the top].
2. *Bad process* [throughout including at the top].
3. *Bad leadership* [at board and/or the C-suite level].

To have good results, a combination of *all three* is needed (and not just 1 or 2 out of the 3): hence, fair play, as well as great process, and also great leadership.

The questions, therefore, discussed in this practitioner article, are as follows:

- How would good governance and leadership look? One that leads the textile industry towards a sustainable, proper, and successful future in a social and environmental context, and economic reality, so very, very different from the one we know right now?
- What are the ingredients? What are the processes? And how can we ensure that group inertia and group dynamics follow the path towards 'doing the right thing' rather than just towards 'doing things rightly'?

In order to do so, first the 'Fair Process Leadership' (FPL) model of governance (Van der Heyden 2013) is reviewed, and then—via case examples—its application to both, top-level strategic decisions in companies in the textile industry, for example, in regard to business model innovation and also proactive risk management, as well as to operational key decisions such as supply chain partnerships, is illustrated.

In this way, a different, more conscious as well as conscientious, quality-oriented governance and decision practice, suitable to strategic challenges as well as operational key tasks of the textile industry, is proposed: applicable starting from material innovation and production processes, to consideration of strategic investment and partnerships with long-term impact.

22.2 An Introduction to Fair Process Leadership (FPL) Governance

Typical economic as well as management theory assumes that people are purely outcome driven. Or in other words, as long as the outcomes are 'good' and (subjectively) 'right/correct', they are happy and content. According to the 'Rational Choice Theory', (summarized in, e.g. [Levin and Milgrom 2004, or Goodwin et al. 2014] mechanisms through which corporate organizations intend to control and motivate employees, from the CEO down to the temporary intern, are reflected in incentives, bonus, and remuneration systems, as well as organizational structures.

Unfortunately, real life does not always work as theory expects it to, because in contrast to the above-outlined assumptions:

> People do care about outcomes, but […] they also care about the processes that produce those outcomes. They want to know that they had their say—that their point of view was considered even if it was rejected. Outcomes matter, but no more than the fairness of the processes that produce them. (Chan and Mauborgne 2013)

For the corporate context specifically, Kim and Mauborgne (1991) and Chan and Mauborgne (2013) could show in their research that:

> Managers who believed the company's processes were fair, displayed a high level of trust and commitment, which, in turn, engendered active cooperation. Conversely, when managers felt fair process was absent, they hoarded ideas and dragged their feet. (Chan and Mauborgne 2013)

22.2.1 Fair Process Leadership: What is It? and: How Does It Work?

Fair Process Leadership (FPL) (Woodward et al. 2016):

> […] is an integrative approach to leadership that emphasizes high levels of engagement and transparency with stakeholders, as well as objective evaluation of both outcomes and process. Research shows the presence of FPL generates trust, and leads to effective collaboration and collective commitment, both critical features for team and organizational performance.

More specifically, and in accordance with (Limberg and Van der Heyden 2007; Van der Heyden 2013; Woodward et al. 2016), the following five complementary characteristics must be present (i.e. validated) together by a (decision) process, at every step of the way, for it to be perceived and accepted as fair and equitable by people involved in and affected by the process:

- *Communication*—or the ability to give all a voice which they can exercise without fear of retaliation;
- *Clarity*—or transparency of behaviours, interactions, and exchanges by the actors of the process;

- *Consistency*—the uniformity in the treatment of actors, issues, and steps, including over time;
- *Changeability*—the possibility of 'correction' or changing actors' beliefs and also the possibility to change the chosen course as a function of new evidence;
- *Culture*—ethicality, or the commitment to aim to 'do the fair and ethically correct thing' not only superficially, but deeply and fundamentally.

In practice, Fair Process Leadership (FPL) is an approach of leading by asking questions, rather than by telling people what to do. FPL is based on a five-step approach that requires the leadership team as a whole, as well as its members individually, to be engaged in an open, transparent, and honest discussion (Van der Heyden et al. 2005; Wu et al. 2008):

The Five Stages of the 'Fair Leadership Process'

1. **Engage**—This is the time to reach out to the broad stakeholder base of interested, implicated, and impacted individuals and groups, to ask for contributions. It is in the '*Engage*' process where the questions for consideration and decision are being submitted: What are the issues at hand? The risks? The ethical dimension? The scope of stakeholder impact? What are the facts, the options, and possible outcomes?
2. **Explore**—This is where board (or more generally: team) competence and diversity are of key importance. A thorough examination of contrarian views is required to understand available scenarios, options, and consequences. Some of the proposals will be discarded while others may gain relevance. It is in the '*Explore*' process that confrontational debate amongst the 'pros' and the 'cons' of particular approaches is essential: What could go wrong if this decision is implemented? What are its risk factors? What are entirely unexpected influences that could severely impact, or fundamentally change, the efforts?
3. **Explain**—This is the time when a decision is reached, and subsequently, the rationale, train of thought for the decision, is to be explained. It is in the '*Explain*' process where the decision's consequences and implications are communicated to all parties, including—but not limited to—those that had contributed in stage 1. Doing a transparent, stringent, and clear job of explaining the decisions and its rationales is essential to create trust and acceptance amongst those implicated in and affected by the decision, as well as to create confidence into the leadership. It is important to note at this point that Fair Process is not a decision process driven by neither 'consensus' nor 'democracy in the workplace'. The goal instead is to give every idea a chance. The *merit and quality of the ideas*—and not consensus—is what drives the decision-making process.
4. **Execute**—The outcome of the 'Explain' process (above) is evaluated. There is still time to correct mistakes identified and improve on the existing proposal. It is from the '*Execute*' process onwards that all efforts are geared towards the full implementation of what has been decided.
5. **Evaluate**—The status quo of the 'Execute' process (above) is evaluated. This is about the future. This step is in part to ensure performance as intended, revisit

any outcomes generated, learn about the impacts of past decisions, and adapt. But it is also about revisiting questions of future approaches—strategically for the company, or even within operations—in the light of recent progress and experiences. It is in the '*Evaluate*' process that the organization as a whole can learn about its competences, including its ability to execute, and of the need to adapt decisions, structures, and people in view of the fundamental changes and challenges the company will experience over the course of the next few decades of this twenty-first century.

➔ ***Re-Engage****[Continue by going back to Number 1].*

22.3 Fair Process and Organizational Innovation Performance: Governance and the Importance of Values, Leadership, and Accountability

One question that arises is the link between 'Fair Process' and the economic and psychological (innovation) performance of an organization. In this regard, Limberg's (2008) results show a positive, strong, and linear relationship. One of the questions asked in the introduction is discussed both in academia [most recently in (Orts 2017)], in business schools, but also the public at large: a decision taken by an organization—is it largely independent from, or a necessary consequence of, the decision(s) that the individuals within the organization have taken?

This is particularly relevant when it comes to the leadership of organizations (i.e. the board and the C-suite), because we know that once that problems occur, bad leadership—including bad moral and ethical leadership—is one ingredient to that extent:

> We get so focused on making money that we sometimes overlook the value of collaboration and the spirit of making the world a better place for the future of our fashion industry. Scott Deitz, Vice-president public affairs, VF Corporation, in (Wright 2018)
>
> 'Make the numbers' is an over-riding force in many modern companies. But the more managers focus on what they achieve – 'results' – the less they worry about how they achieve it. (Limberg and Van der Heyden 2007)

In the context of this paper, and for the prosperous future of just about any industry currently imaginable, however, the 'How' is critical.

It is the difference between.

- the long-term view required to face, address, and (maybe) succeed in view of a radically changed economic, but also social and environmental, landscape that is about to emerge over the next few decades of this twenty-first century, and
- the by far dominant quarterly, and hence, extremely short-termed, reporting cycle of publicly listed, but also privately invested, companies.

With regards to the quality of the 'How', Sepinwall (2017) makes an important point by stating that corporations themselves have no capacity for emotion or responsiveness to moral reasoning—and therefore moral and ethical value judgements—and are consequently unable to experience guilt. Hence, as it makes sense only to blame those who can experience guilt, corporations do not qualify for moral agency. Instead, it is the individuals inside the corporation, who transmit their own personal values to the corporation at large, and not the corporation itself, who should take responsibility for actions taken in the name of a firm.

Sepinwall's (2017) insights translate to the following: For an organization itself, there is no difference between doing 'business as usual' in a 'responsible', or an 'irresponsible', way. The difference exists only for individuals, both within but also outside the organization. And this precisely is where the crux lies.

Because, Ultimately, It Is Individuals Within Organizations That Have To Take Decisions, Be Accountable, And Prioritize.

The fundamental and critical 'detail' though is that since any such decision taken by an individual is a translation of that specific person's values and morals into facts and actions: 'doing corporate responsibility' will invariably show to peers, and to the world at large, what those values and morals truly are. 'Doing corporate responsibility' fosters personal accountability within companies—both internal and external facing—like nothing else and indicates where the 'North' of the corresponding value compass lies.

This is why 'doing corporate responsibility' is at its core so controversial and deemed so 'very difficult, nigh impossible': in a world shaped over centuries by 'results' only, primarily expressed through organizational and balance sheet KPIs such as—to just name a critical few—turnover, EBITDA,[1] ROI,[2] gross/net/operating profit margin, COGS,[3] revenue growth rate, or cash conversion cycle, which unfortunately pay *zero* consideration on *How* these KPIs actually are being achieved (cf. quote by (Limberg and Van der Heyden 2007) above).

And depending on the dominating, hence acceptable, tenor across society, the manifestation of these values and morals may make an individual's life very easy—or very complicated. Today, differently to only a few decades ago, it is much more likely that the purely 'results' (KPI) driven value compass would be brutally exposed, and clashes with what communities, but also society at large, deem acceptable, because after all, it is about long-term prosperity of the social, environmental, and economic well-being of our species and its surroundings.

It is for that very reason that for many players in our economically driven world the 'Licence to Operate' (Nielsen 2013) is being questioned like it has never before.

[1]EBITDA: Earnings before interest, tax, depreciation, and amortization.

[2]ROI: Return on invest.

[3]COGS: Cost of goods sold.

22.3.1 Leadership: Values, Accountability, and Fair Process

To come back to the concept of 'Fair Process' and 'Leadership' introduced in the dedicated chapter above, and to underline the importance of what was discussed there: *Fair (and transparent) Process does not exist if the leaders are not fair and transparent and if Leadership fails to lead well, fairly, ethically, and with transparency and integrity.* Yet, a framework such as the Fair Process Leadership (FPL) model is set up to be able and remedy some of the worst failures of leadership through due process, although it will only partially be able to compensate for when leadership itself is mediocre at best, and not aligned with the fundamental morals and ethicality of fairness and corporate responsibility. However, at the very least:

> It is worth noting that if Fair Process is pursued when private agendas prevail and matter, it is quite likely to reveal their presence. (Van der Heyden and Huy 2008)

It brings us to the next set of questions:

- What are the leadership qualities and values that are required to succeed in this unique twenty-first-century landscape? and
- What are the accountability mechanisms that need to go with it?

22.3.1.1 Leadership Qualities and Values

The complexity—and beauty—of the Fair Leadership Process (FPL) approach is that the personal and professional qualities required to implement it successfully are multifaceted, and as a consequence, do not come 'intuitively' (or 'naturally') to any one person or group. Instead, it is an approach that benefits from a diverse skill set on the one hand, and a curious and 'continuous-learning' mindset on the other.

Maybe more importantly, and based both, on this authors experience, and on early indications in literature (e.g. Limberg and Van der Heyden 2007), the FPL approach also adds a third dimension to the traditional (hard) 'Business Skills' (Fig. 22.1, *Y*-Axis) and (soft) 'People Skills' (Fig. 22.1, *X*-Axis) universe required from leaders (e.g. Bachiochi et al. 2000; Scott et al. 2011), namely that of '*Values and Innovation Perspective*' (Fig. 22.1, *Z*-Axis).

For successful outcomes from FPL, the opinions, insights, and experiences considered in the process must be drawn in (ideally) equal proportions from around the whole landscape of leadership qualities depicted in Fig. 22.1, as the combinations are complementary and therefore, help to contribute, and scrutinize, proposed solution approaches.

22.3.1.2 The Values and Innovation Perspective: Considering 'The How'

The '*Values and Innovation Perspective*' (or: 'The How') illustrated in Fig. 22.1 is looking at '*How*' an organization achieves its goals, and therefore, specifically at two

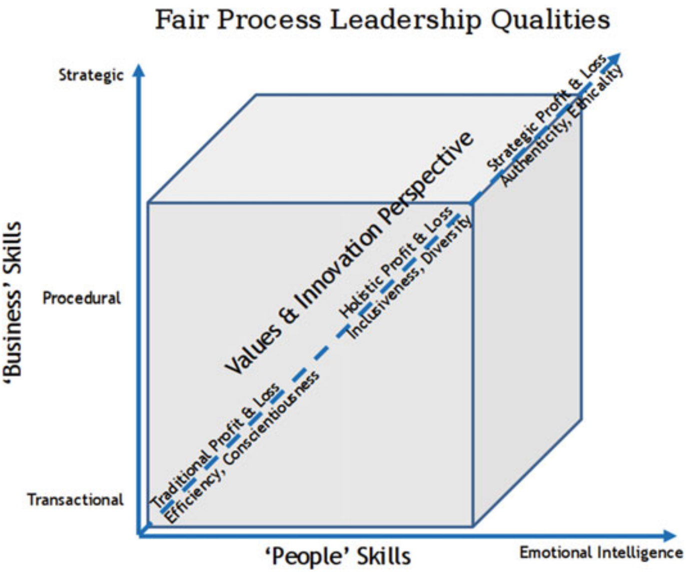

Fig. 22.1 Three dimensions of fair process leadership qualities: 'Business Skills' (or: 'hard' skills); 'People Skills' (or: 'soft' skills), and the 'Values and Innovation Perspective' (or: the 'How') *(Author's own illustration)*

of the Cs and two of the Es defined above ('*Communication*', '*Culture*'; '*Engage*', '*Explore*'). If these are taken seriously, they allow to learn about what is seen as acceptable in terms of ethicality and what is seen as infringement on the societal perception of what is considered acceptable.

The '*Values and Innovation Perspective'* at its core emphasizes, accepts, and indeed capitalizes, on the fact that an organization is embedded in an ecosystem outside of and beyond its organizational confines, which it affects and impacts through its decisions. Ideally, this perspective seeks to balance the performance for both the organization itself, as well as the system it is embedded in as a whole. It is a perspective that plays a critical role when it comes to an organization's *License to Operate* (Nielsen 2013).

22.3.1.3 Accountability: Ensuring that 'The How' Indeed Matters

Failures and problems in organizations arise, as mentioned in the introduction already, due to:

- *Lack of fairness or fair play* [specifically at the top].
- *Bad process* [throughout including at the top].
- *Bad leadership* [at board and/or the C-suite level].

This is without a shade of doubt the case when results drive an organization's behaviours strongly by accepting that 'the goal justifies all means', and as a consequence '*How*' this is being done largely stops being of relevance. Most scandals, to a larger or lesser extent, have their root in this 'laissez-faire' approach. This is why any accountability and evaluation mechanisms, taking these failures into consideration, also need to take a stark look specifically at '*How*' goals are being achieved. Transparency (entailed in '*Clarity*') plays the most significant role in this puzzle, more so as '*Clarity*' builds on the fundaments of '*Consistency*' (no preferential treatment given to any one single player) as well as '*Culture*' (ethicality, i.e. the *How* of goal attainment) in order to come up with true, meaningful, and widely accepted (or better: acceptable) results—and of course also consequences wherever appropriate. For boards, this means in a first step to ask, and insist, on the following questions:

- Why are we doing this business?
  - i.e. ensuring the awareness about a business' mission, vision, and its raison d'être.
- What is this business' role in this world, economically, and in society at large?
  - i.e. being explicit and public about the business' core values.
- Why are we 'doing business' exactly the way we do?
  - i.e. trying to understand '*The How*': What behaviour is in scope, or out of scope, for the organization as a whole, and the individuals within, to achieve corporate goals.

'*Clarity*' in the above three points allows for the translation of the insights into

- *Codes of ethics and conduct*, from the board and the C-suite through to the intern, that are based on the fundaments on which the business is built rather than 'just' on legal requirements.
- *Corporate procedures* that are built for purpose and that allow to contextualize the above-mentioned codes.
- *Talent management processes* (hiring, performance evaluation, incentives) that that are in line with the organizations' core values, as well as its 'place, aspirations, and responsibilities in the world'.
- *Business model innovation*: deep insights into systemic challenges and resulting innovation efforts that are required so that the business remains successful mid- to long term.
- *Risk early warning system*: deep insights into the risk perception inside the company, as well as the potential mismatch of the inside-out perspective against the outside-in perspective.

It goes without saying that the outcome from the above, as well as any required changes, must be concrete, quantifiable, measurable, tangible, as well as actionable.

22.4 Governance and the Textile Value Chain—The Long-Term View: Driving the Textile Industry Towards a Sustainable Future

In this chapter, Fair Process Leadership (FPL) is illustrated through two publicly acknowledged case examples from the textile/fashion industry. Each of the cases outlined hereafter illustrates a translation of selected FLP stages into corporate reality. It is relevant to mention that the FLP terminology is not explicitly used. Instead, their practice illustrates the innate need, the process, and the outcome, in a way that allowed to identify the presence of FPL (components). It is for this reason that, for the purpose of this paper, we have used publicly available resources and quotes.

The examples are as follows:

1. One VF—Towards a Corporate Purpose
   - FPL stages: Engage, Explore
   - Corporate area: Development of Corporate Values.
2. PVH in Ethiopia—Building the Supply Chain of the Future
   - FPL stages: Execute, Evaluate, Engage
   - Corporate area: Supply Chain/Sourcing Decision and Investment.

Case 1: One VF—Towards a Corporate Purpose

Background

VF Corporation (VF) is globally renowned and recognized for its business and operational discipline and how they think about driving value for shareholders. One of the key components for this latter is their focus on acquiring relatively small high-potential companies and grow them into successful globally recognized brands by leveraging any synergies and efficiencies that come from sharing resources across VF's brand portfolio.

Key data:

- FPL Process steps: Engage, Explore
- Company: VF Corporation.
  - Industry: Fashion and Apparel
  - Employees: 65'000+
  - Turnover: USD 13 billion (2018)
  - Number of owned brands: 25
  - Number of distribution markets: 170+
  - Number of manufacturing countries: 50+
  - Number of owned facilities: 17 (2017).

Need, Process, Outcome

The 'One VF' effort started when VF Corporation's new CEO Steve Rendle took office in 2017. The outcome was made public—in a low key manner, suitable to a company focused on delivering results—in early summer 2018. Luckily, the public appearances of company representatives allow to track fundamental learnings from the approach, as well as the thinking behind the process.

The Need:

> That's what was lacking for all these years, the definition of 'why'. [...] we weren't purpose-led in the past. (Smith 2018)
>
> The way we behave or misbehave matters matters from a business and social standpoint. (Wright 2018)

Engage process:

> The purpose statement was developed over the course of one year using a thoughtful approach that included input from more than 1'000 VF associates around the world, and external stakeholders and experts. (Imperative 2018)
>
> [...] The company looking at what customers demand from the outdoor and active lifestyle brands they choose to do business with. (Smith 2018)

Explore Process:

> What's that common thread that's helped VF grow over the last 119 years? (Smith 2018)
>
> [...] A second step was to help every associate gain clarity around their own personal purpose – and to link this personal purpose to the organizational one. (Imperative 2018)

The Outcome:

> [The purpose] [...] brings the 'why' to the 'how' and the 'what' of our strategy. (Smith 2018)
>
> [...] We made a commitment to put purpose on par with performance and to drive all of our decisions not as an 'either-or' but as an 'and.' (VF Corporation 2018)
>
> That means that sometimes we will lead movements, sometimes we will join movements, but we will be movement makers in ways that makes us more a purposeful and value created company. (Wright 2018)

While the 'One VF' has so far had good resonance with VF's staff base, as well as the wider stakeholder community, there is no doubt that this approach is still very fresh. It therefore remains to be seen—and proven—if the process going forward, and as it moves into the 'Explain' and 'Execute' phase, will indeed fulfil the expectations and deliver the added value, both for society at large as well as the shareholders.

Case 2: PVH in Ethiopia—Building the Supply Chain of the Future

Background

PVH Corporation is a conglomerate of brands that—not dissimilar to VF above—is first and foremost known through the brands it owns and the potential and reputation these have with the end consumer. It is unique in that, other than competing luxury fashion houses, their brands are less explicitly driven by the allure of a star designer's name, but rather through a very distinct brand identity.

Key data:

- FPL Process steps: *Execute, Evaluate, Explore*
- Company: PVH Corporation.
  - Industry: Fashion and Luxury
  - Employees: 36′000+
  - Turnover: USD 8.9 billion (2017)
  - Number of owned brands: 9 (+8 licensed)
  - Number of distribution markets: 100+
  - Number of manufacturing countries: 50+
  - Number of (co-)owned facilities: 1 (2018).

Need, Process, Outcome

The Need:

> This work includes the lengthy project plans to evolve our supply chain program that impacts over 2,400 factories. (PVH Corporation 2017)
>
> PVH wanted to have more control [again] over the location of its suppliers. (Mihretu and Llobet 2017)
>
> To have better oversight and enforcement, PVH moved to adopt a fully integrated vertical supply chain, including direct investment in one of the manufacturing facilities. (Mihretu and Llobet 2017)
>
> The development of a fully integrated vertical supply chain, in which a clothing brand owner, garment manufacturers, and a fabric mill work together under the same vision, is essential to make the textile and garment industry scalable and sustainable, according to PVH. (Mihretu and Llobet 2017)

Execute process:

> In line with our supply chain priorities, we recently restructured our relationship with Li & Fung Trading Limited. (PVH Corporation 2018)
>
> Producing in Ethiopia was also a game changer for PVH, allowing a significant shift in its business model. […] PVH is pioneering the world's first example of a fully vertically integrated, from ground to finished product, socially responsible supply chain in the textile industry. (Mihretu and Llobet 2017)
>
> HIP [Hawassa Industrial Park] was planned and designed as a world-class eco-industrial park focused on the textile and apparel industries. (Mihretu and Llobet 2017)

Evaluate process:

> A facilitating factor was PVH and the government of Ethiopia's shared commitment to the environment, safety, and sustainability. (Mihretu and Llobet 2017)
>
> Both PVH and the government of Ethiopia were open to learning and to accommodate each other's interests. […] A trusted relationship between the parties emerged. (Mihretu and Llobet 2017)

> Many hurdles remain before PVH's project can be declared a manufacturing center of excellence. These challenges, if not properly addressed, could prevent PVH from realizing its model as well as keep Ethiopia from becoming the manufacturing powerhouse of Africa. (Mihretu and Llobet 2017)

Engage Process:

> For their part, textile firms, both foreign and domestic, could also exercise a greater degree of responsibility and supply chain analysis to attempt to reduce the use of TIP [Trafficking in Persons] and forced labor in their product supply chains. Firms are also well-placed to ensure that they are paying workers adequate wages, regardless of whether a legal framework in Ethiopia obliges them to do so. (Verité 2017)

> But wages are better than in some other professions in Ethiopia […] while approximately 30% of the country's then population of 90 million lived below the poverty line in 2011.[…] On top of that is a concern about low productivity by employees unfamiliar with factory work. […] The recruits need training, but with inadequate housing and transport, he's worried about a high turnover of staff as the rapidly rising cost of living eats into pay packets. (Guardian 2017)

> Many workers [are] not interested in organizing collectively but demanding on an individual basis." (Somo 2018)

> Due to quality challenges, H&M has since 2014 not been able to use Ethiopian cotton, but our long-term aim is to engage in the development of a sustainable cotton industry in Ethiopia, taking into account both social and environmental issues associated with cotton. (Somo 2018)

> As a landlocked country, Ethiopia needs to assure investors timely connections to ports. Heavy reliance on the port of Djibouti poses significant risks. (Mihretu and Llobet 2017)

The Outcome:

> Apparel giant PVH Corp has received an Award for Corporate Excellence (ACE) from the US Secretary of State in recognition of its role as lead investor in the apparel manufacturing facility at Hawassa in Ethiopia. (Fana Broadcasting Corporation 2018)

> Brands that are confirmed to be producing in Ethiopia: Gap, PVH, H&M, Tchibo (Maasho 2017), as well as JCPenny and VF (Somo 2018)

PVH is a company in transition from a traditional shareholder-driven approach towards a more pronounced long-term value-driven approach. This is visible in the way it approaches its supply chain strategy, which—learning from existing risks and past challenges—is looking at where the next-generation opportunities and benefits lie. It is interesting to observe that by way of process, the result overlaps by and large with a prioritized CR approach.

22.5 Summary and Conclusion

The creation of a Fair Process in organizations and teams, leading to innovation performance improvement over time, as well as a strategic outlook capitalizing on stakeholder buy-in, requires more than the ambitions of a sole single leader. Fair

Process—not necessarily under this denomination—is the result of an organization's overall desire to practise and implement Fair Process behaviour. As a consequence, the entire team or organization needs to develop communication norms, routines, or processes, that encourage the consistent application of such an approach. When this occurs, genuinely and consistently, organizations and teams will notice an improvement in their work effectiveness, organizational culture—notably with regards to '*How*' business is done—and overall performance.

By being conscious about the '*How*' (as well the 'Why') of business as usual, boards, and executive teams will learn, in a structured manner, not only from current and past risks and mistakes, but they will also learn to include diverging opinions and outlooks to the mid- and long-term future and business environment. This again, as a consequence of good governance, opens the door to harnessing the skill set of all relevant players (shareholders, stakeholders, employees, etc.) so as to inform, generate, foster, and implement senior leadership decisions.

Lastly, but maybe not unimportantly, Fair Process Leadership is very much (only) common sense. It just so happens that it is not common practice.

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Chapter 23
Sustainability and Digitalization in the Global Textile Value Chain

Anton Schumann, Lorenz Wied, and Marcus Krahl

Abstract Communication that extends across an entire supply chain will lead to *reverse supply chains where supply and demand can meet* in real time. This yields previously unthinkable opportunities to react to worldwide demand in a precise and concrete manner. Demand should become predictable.

23.1 Introduction

Digitalization and sustainability are widely mentioned in association's announcements, institution, and industrial studies and consumer surveys as the two major trends changing the textile industry strongly within the next decade. Due to the enormous growth of the textile industry volume with their fields, techtex, hometex, and Fashion, the use of resources should change by regulation, consumer demands, and entrepreneurs in the next years to meet the SDGs of the UN. Digitalization will lead to transparency, faster and more efficient supply chains, and new business models where supply and demand can meet in real time. Digitalization can help sustainability, circularity, and efficiency to gain ground in the global textile industry. Such new business models can lead to more transparency and efficiency to decrease transfer costing and misuse of resources.

Online business platforms are leading to a change in consumer behaviour and in supplier business models around the world. Amazon, as the world's biggest marketplace and the future powerhouse player in textiles, will change the textile industry forever. In a post-brands age, Amazon and other digital business models/platforms

A practitioner's perspective

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will be able to control the B2B and B2C supply chains with data from around the world, and thus, establish a cost- and resource-efficient supply chain focusing 100% on predictable customer demands. Successful platform models will reduce transaction costs, and the efficiencies of an international supply chain will be optimally exploited. This will impact circular and sustainable business models within the textile chain.

The textile manufacturing industry is just beginning to embrace digital, sustainable, and circular business models, and these trends are already boosting one another. Digitalization will expand the opportunities of a sustainable global textile supply chain through transparency, real-time communication, and predicted demand. The real-time textile supply chain will cut out such inefficiencies as intermediaries, certifications, and wasting of resources and materials. It will lead to transparent supply chains for resource- and cost-efficient business models.

For the establishment of sustainable and circular business models in the textile industry, future textile professionals will understand and capitalize on all the opportunities of digitalization in order to save costs and resources.

23.2 The Development of the Textile Industry to the Present Day

To manage the risks and the options within the changes by sustainability, circular economy, and digitalization within the next decades of the textile industry, it is important to understand the developments of the past 200 years of the international textile industry. The global textile industry began with the industrial revolution in Europe in the middle of the eighteenth century. From manufactories and individual work done in homes, innovations such as the steam engine and the first automatic loom and spinning machines led to the development of industrial structures and factories in Central Europe and the UK by the mid-nineteenth century.

23.2.1 The Eighteenth Century

As the population grew sharply in the eighteenth century, the demand for textiles increased. Initially, distributors would buy raw material and send it out for processing by spinners and weavers, mainly from the rural underclasses. In most instances, the entire family had to work to make a living with such work. The distributor then sold the finished product. It was at this time that the first spinning machines and mechanical looms were developed. Production is shifted to large factories with numerous spinning machines and looms. What had once been labour-intensive manual work was now being done by machines. As a result, many weavers and spinners lost the basis of their subsistence and were compelled to work in the emerging factories as industrialization continued.

23.2.2 Transformation in the Nineteenth Century

Change was a constant in this industry: in the nineteenth century, British companies were competing against those in Germany. Cheap cotton and increasing mechanization displaced the linen and cotton processing industry in the areas bordering the Netherlands. The advent of steam-powered shipping in the Netherlands deprived canvas weavers of their market, and the much more efficient and cheaper, automated manufacture of textiles in England and Europe led to global manufacturing structures, especially in the overseas colonies, where foreign goods were cheaper and considered more attractive (Beckert 2014).

By contrast, some European countries gained a global dominance, especially in the manufacture of machinery for yarn and fabric production and in the chemical processes used in dyeing and finishing the textiles. Especially, Poland, Germany, and the UK were able to develop outstanding machines and processes to handle spinning, weaving, and knitting, resulting in products that were in high demand around the world. In addition, these machines and chemicals were also exported worldwide (Dattel 2010).

23.2.3 Boom in the Twentieth Century

After the Second World War, various areas of Europe developed into important centres for the clothing industry. Due to the scarcity of raw materials and the urgent need for products, these industries initially reworked old clothes and textiles. As Germany and the rest of Europe experienced an economic recovery in the decades after the war, the textile industry was able to develop into one of the most profitable and largest industries in Europe, a situation which lasted well into the 1970s. This also had a positive effect on suppliers of machinery and chemicals. In this period, Europe was a leader in machine and chemical innovations for textile production (Beckert 2014).

23.2.4 Global Changes in the Twenty-First Century

Since the 1990s, liberalized global trade in textiles and raw materials has resulted in a significant shift in the production capacity away from Europe. Nevertheless, the demand for textiles for the fashion, home textiles, and technical textiles sectors in Europe and America grew, resulting in a massive increase in production capacities in

Asia, Turkey, and South America. From 1990 to 2016, the global fashion and textile industry has more than doubled, as demand continues to rise in almost all parts of the world (Tran 2010).

After more than forty years of trade with import quotas, the textiles and clothing sector eventually became subject to the general rules of the World Trade Organization (WTO) from 1 January 2005. Protection of the textile and clothing sector has a long history. With the establishment of the WTO in 1995, the Agreement on Textiles and Clothing (ATC) was negotiated as a transitional regime to the full integration of textiles and clothing into the multilateral trading system. Four countries had been restricting their imports of textiles and clothing (Canada, the EU, Norway, and the USA). The integration took place in four steps over a ten-year period, ending on 31 December 2004.

Since the beginning of 2005, imports from previously restricted suppliers have increased sharply in the USA and the EU. Chinese imports have seen particularly strong increases, leading to the imposition of new limitations on the import of Chinese textiles and clothing in the USA and the EU. The legal basis for this new, selective quantitative restriction on Chinese exports can be found in the Report of the Working Party on the Accession of China, annexed to China's Protocol of Accession to the WTO (Tran 2010). China became the leading producer and exporter of textiles in the world by 2010 and expanded the volume by 15% on average every year (Statista 2019).

Digitalization will change the global textile industry within the next decades as in the line of the industrial revolutions before. Digitalization is defined as the integration of digital technology into everyday life. As business and working are a major part of everyday life for most people and consumers, it is probably the main thing to change. Being able to automate processes, measure the aspects of business that were previously unmeasurable and even cross reference and apply information from a wide variety of sources to provide insight into decision-making. Textile digitalization will reverse supply chains and will enable the business drivers to new supply chains and business models in the same way as the technological innovations like the automatic weaving loom or the synthetic dyestuff have done.

23.2.5 Digitalization Will Fundamentally Change the Traditional Textile Industry

Shortly after the turn of the millennium, when US retail guru, Paco Underhill, postulated that retail would change more over the following 10 years than in the past 100 years, and he was met with considerable scepticism. Underhill's predicted changes are now more evident (Underhill 2000).

By 2017, in the first year when companies with digital business models were named the top five most valuable companies in the world, digitalization was on everyone's mind.

Amazon and Alibaba have become the world's most powerful marketplaces and are planning a complete transformation of the textile industry. And it is not just international textile producers that are using the worldwide platform to target and supply their customers around the world. A weaver from China can now directly build a customer base in Europe via these platforms. The same is true in the opposite direction. Amazon is now also producing textile products for all areas of life under its own brands and selling them B2C and B2B around the world.

Companies with innovative, digitally based business models have and will not simply put pressure on others; they will replace them. The highly successful business models of the fast fashion companies H&M, Inditex, Benetton, GAP, UNIQLO, Primark, etc., initially pushed independent fashion retailers out of the market. Now, these industry leaders are under pressure themselves as they jostle for position in an increasingly competitive market. How can a company with more than 1000 bricks and mortar stores also do business online without massively reducing its store locations? Retailers who only do business online have advantages in this regard (Fischer 2010).

Digitalization will also make sustainability a hot topic as the textile industry continues to evolve. Sustainability in this context can best be understood as resource efficiency. Digital business processes, sensor technologies, monitoring, and communication with the customer will allow the global textile industry to produce and sell more effectively on target. Accordingly, a sustainable textile industry can develop on the basis of technology and engineering expertise (Black 2018).

The global fashion textile industry has doubled since 2000 leading to previously unthinkable ecological and social complaints around the world (Gwilt 2014). Environmental protection organizations and the media have been relentless in shedding light on this: The growth and massive social and ecological footprint (Sumner 2018) of the global textile industry means an extensive transformation of the industry towards digitalization and sustainability will have to take place over the next few years. Transparency and targeted, sustainable production can make this possible if consumers and policy-makers want to achieve similar goals. Eco-design is establishing itself as a trend in the industry and is changing consumer perceptions towards the conservation of resources in order to meet the needs of consumers around the world (Gwilt 2014).

23.3 Sustainability in the Textile Industry

Even today, in the midst of the Fourth Industrial Revolution, textiles are still made from warp and weft or knitted. This centuries-old method will continue into the future; the processes that have been practised for centuries are too efficient and developed. What will change is not only increasing efficiency but also transparency (Gwilt 2014) along the global and regional supply chain. Producers and intermediaries not only have to adapt to the market, but also to the regulations passed by the policy-makers and consumer organizations. Sustainability in what has become a massive global supply chain has long been a topic in the media, as the 2016 film by Andrew Morgan made clear. International quasi-governmental organizations such as the OECD and the World Economic Forum are increasingly tackling issues related to textile production and trade. Since the beginning of the twenty-first century, numerous organizations have begun addressing the task of environmental sustainability in the textile industry, an issue that has seen consistent growth in interest since the late 1990s. In 2011, Vivienne Westwood presented her collection in Paris with the slogan: *Dress up—Do it yourself!* This was a fashion line dedicated to sustainability, a mission that Westwood has since been promoting through extensive media engagement, rebranded: *Buy less, Choose well!* (Black 2018).

Since events such as Rana Plaza (2013) and the Greenpeace DETOX campaign of 2011 not only have business models like those of Hess Natur[1] and Patagonia[2] made their appearance. (Gwilt 2014) Not only are brands promoting their own ecological efforts towards resource-saving production in their marketing and communication, but the industry is also beginning to call for greater sustainability and resource efficiency by regulation, law, or certification processes (Cobbing and Vicaire 2017).

Textiles for clothing or living, which are sourced cheaply in low labour cost countries have had to prove that they are harmless for consumers in Europe since the 1980s. The OEKO-Tex® label (https://www.oeko-tex.com) has since become a seal certifying safe and clean textiles. However, this did not include the information on how and where these textiles were produced because such matters were not of interest to consumers and governments in Europe at the time. However, this changed at the end of the 2010 due to strong media activities of various organizations and the establishment of new NGOs alongside the existing textile associations. Since then, the number of global eco-labels in the textile industry has grown steadily (Big Room Inc 2019).

Sustainability has become established as a trend in the worldwide textile industry due to consumer demands, supplier/producers visions, regulations, and stewardship activities in the second decade of the twenty-first century. In the past few years, changes in the industry have largely been the result of changing legal regulations. One prominent example has been the switch from fluoride-containing, water-repellent treatment of outdoor items to treatments that are fluoride-free. The best-known fluoride-based treatment used to repel water has been Dupont's Teflon brand, which has been used in medicine and military since the 1970s. Teflon and other fluoride-containing textile treatments had come into wide use in the textile industry since the 1990s, thanks to the positive growth of the outdoor clothing industry.

Fluoride-based chemical agents are extremely stable and have extremely slow biodegradability. For this reason, the use of fluorinated C8 hydrocarbons has been under fire by the environmental authorities in some countries since the 1990s. In addition, since 2000, initiatives in various Northern European countries have targeted further measures to ban the use of fluorinated C6 and C4 chemicals. Since 2005,

[1] Cf. https://www.hessnatur.com/de/.

[2] Cf. https://www.patagonia.com/home/.

several environmental agencies have recommended restricting the use of fluorochemicals in the field of consumer textiles. As a result, several brands, including Haglöfs[3] and Patagonia, launched their first "ecological" water-repellent products in 2008 and began marketing them as sustainable and even "clean". By 2018, most restricted substances lists (RSL) and manufacturing restricted substance lists (MRSL) of major outdoor textiles distributors in Europe included bans on fluorinated water repellents in production and on the product.

Similar examples of changes in the use of chemicals in textiles include the use of halogens as flame retardants and the use of azo dyes. Through the recognition and implementation of legal regulations, which in some cases differ strongly between the producing countries and consumer countries, many large textile distributors in Europe have now adapted their regulations to those of the European Chemicals Agency (Vicaire 2017). In addition, retailers are now not just recommending specific production methods, but also prescribing them. See the ban on sandblasting jeans imposed by Marks and Spencers, ALDI and LIDL, for example. This change in the industry received positive marks in the 2018 Greenpeace Report. According to Greenpeace, the work in the years since the first DETOX Report of 2011 has paid off (Cobbing and Vicaire 2017) as more and more companies are using unique RSL and MRSL, and the regulations of manufacturing companies implement them in the LLCs (Greenpeace 2019).

Sustainability has not only started in the textile industry but has also been strongly implemented in the 2010s. It is now a standard practice for major international brands not only to prescribe the chemicals used in dyeing and finishing processes, but also to nominate the suppliers in some cases. The supply chain is becoming more and more transparent[4] and is being managed end-to-end to save costs and meet environmental standards.

The number of "sustainable" labels is growing worldwide. There is hardly a new designer or a new line from an existing fashion house that has not embraced sustainability in its strategy and products. In 2018, there were more than 6,000 blogs worldwide (Gould 2014; Black 2018) addressing organic textile production and sustainable design. The countermovement to fast fashion is developing positively and is making it possible for small producers, labels, designers, and retailers to be active internationally through the Internet (Edwards 2016). Sustainability is being used as a strategy and part of the business model that can grow a solid customer base. Eco-fashion has become a market niche that is growing, as fast fashion and the mass market struggle not only with organic production, but also with digitization. Both developments are changing business models as customers, and customer needs change.

[3]Cf. www.hagloefs.com.

[4]Cf. https://wwwen.ipe.org.cn—supply chain transparency regarding waste water streams and https://interactivemap.marksandspencer.com.

23.3.1 Sustainability has Found Its Place in the Textile Industry of 2019 and is Continuing to Evolve

This is not to say that sustainability has already been widely implemented in the textile industry. The global industry is still so focused on mass production and increasing efficiencies that there is little room for considering all the costs of production, including the impact on the environment and the societal impact. Discounters like Lidl[5], Aldi,[6] and Decathlon[7] have proactively managed sustainability in production in recent years. Not only have they introduced MRSLs and RSLs, but are also training and auditing their suppliers, which is causing a ripple effect in the industry. The large users of technical textiles in the automotive sector also began specifying chemicals or production processes to their supply chains in 2005. Global organizations such as the Sustainable Apparel Coalition SAC[8] and Zero Discharge of Hazardous Chemicals ZDHC[9] are helping the industry and all stakeholders across the supply chain to develop sustainably according to their respective MRSL and RSL regulations and legal requirements. And digital transparency is making it more difficult to go rogue.

But even if sustainability in the field of production has already been implemented to a large extent and will only continue in the coming years as producing countries such as India and China have also enacted laws and regulations that impede or prevent unsustainable production, the next challenge for the garment industry will be its own volume. As already mentioned, the textile industry has almost doubled in the last 10 years.

Clothing became a "*disposable item*" in the world of fast fashion (Gwilt 2014). Each year, major distributors such as H&M and Uniqlo bring tonnes of clothing to Europe and the USA which have a lifespan of four years or less. This results in massive mountains of waste. Trying to recycle the raw materials they contain remains a real challenge for the industry (Gwilt 2014). Fast fashion produces vast amounts of waste both in production and through rapid wear-and-tear, further depleting the resources of the environment. The industry needs to find a way to optimize the use of resources (Gwilt 2014).

Here, too, the industry has activated several solutions since 2017. Zalando accepts returns of used clothes and sells them. Uniqlo also takes back clothes and donates them. The EU is investing millions in a wide variety of projects for the recycling of textiles. Reuse and recycling are already major issues in the industry, and the coming years will see more companies, business models, and technology to reverse the cycle and extract raw material from textile waste (Gwilt 2014).

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[5]Cf. https://www.ecotextile.com/2017011222529/fashion-retail-news/lidl-publishes-textile-supplier-list.html and https://www.lidl.com.mt/en/CSR-textiles-and-shoes.htm.

[6]Cf. https://www.aldi-sued.de/de/sortiment/bekleidung/textil-leitfaden/.

[7]Cf. https://sustainability.decathlon.com.

[8]Cf. https://apparelcoalition.org.

[9]Cf. https://www.roadmaptozero.com.

23.3.2 Examples of Sustainable Business Models and Products in the Industry

Here are three examples of the continued and profound change and evolution in the industry towards sustainable production. The global textile industry is developing more efficient processes, using "clean" chemicals, producing and using new raw materials for a sustainable textile industry with at least some reuse and recycling.

23.3.3 Processes and Chemistry

The trend of sustainability in the textile industry has also led to new products and processes for wet processing of textiles. Dyes based on renewable raw materials are already being used by Archroma (2012) in a number of different brands around the world. These dyes are derived from natural raw materials, including shells and plants, and are used to dye native fibres. The aids for the dyeing process are also obtained from natural raw materials such as waxes and oils. As early as the 1990s, the industry began to deliver research showing the effectiveness of native process chemicals for the production of textiles. But oil-based commodities were still mostly cheaper and thus kept the upper hand on the market (Gwilt 2014).

All of the well-known international textile chemical companies are currently marketing processing aids based on natural raw materials or certified by GOTS (https://global-standard.org/de/), Bluesign (https://bluesign.com), etc.

Some processes for waterless dyeing of polyesters developed back in the 1980s are gaining in popularity due to the latest environmental regulations and the embrace of environmental responsibility by international corporations. Dyecoo has been developing and improving the technology used in waterless dyeing since 2017 with new investors from the IKEA and NIKE Foundation (https://www.dyecoo.com). This has led to the installation of new machines in Asia and, in future, also in Europe, where automotive textiles will be dyed waterless from 2020 onwards (Black 2018).

In addition to the dyeing processes, the latest denim production processes can reduce water consumption by as much as 60% (Archroma 2012, Black 2018).

23.3.4 Native Raw Materials

The tremendous growth in fashion and home textiles is constantly driving the search for new and innovative raw material sources for the textile industry. Cotton and polyester are widespread and have their pros and cons, which allow the market to search for new sources of raw materials that are of natural origin and have a lower eco-footprint. To date, the project has failed mostly due to the cheap prices of subsidized cotton and overcapacities in polyester production which make the price for any product very attractive.

But increased demand for alternative cellulosic raw materials is also making it possible to use waste products from the agricultural industry as raw materials for the textile industry. In addition to algae (https://www.alga-life.com), oranges (https://orangefiber.it/en/), and pineapple (https://www.ananas-anam.com), a wide variety of new sources for the production of yarns and non-wovens is finding use. The ongoing discussion on contamination by microplastics (Milburn 2018) in many areas of food and nature is also leading to reconsideration of choices of raw materials (Black 2018).

23.3.5 Textile Recycling

In addition to resale, composting, or incinerating used textiles to generate energy, new business models and technological approaches are currently developing new, valuable products from waste textiles as a form of "*upcycling*". Government bodies such as FEDEREC (Federec 2019) in France and the BVSE (BVSE 2019) in Germany (Gwilt 2014), private-sector organizations such as Kleiderkreisel,[10] and second-hand platforms such as UBU[11] are establishing themselves in the textile mass market, but are still clearly niche solutions for giving a second or even third life to textiles no longer needed by their original owners. Or they end up sorted and purified for further use as raw materials. Precursors such as the collection of clothes by charitable institutions and sending them to Africa, for example, have proven to be profitable business models since the 1980s. However, these "cheap" shipments have severely affected local textile production in Africa, Eastern Europe, and Central Asia (Black 2018). The volume of waste produced in throwaway economies now covers the demand in Africa and Eastern Europe so well that the organizations can no longer find buyers for their donated clothing. Meanwhile, large chains such as Uniqlo (Uniqlo 2019) are also seeking their own reuse systems within their supply chains and their business model (Gwilt 2014). It seems fast fashion has overheated after 15 years and is now seeking new ways and business models to promote its continued evolution and growth (Wahnbaeck and Roloff 2017).

A lead project is ECOALF, making new clothes from fishing nets and plastic wastes from the oceans in Spain and Indonesia. Adidas is using plastic waste from rivers to make shoes.

Technologically, recycling requires decisive changes in the mindset as well as in the structures of the textile industry. Textiles and textile-based raw material are available in bulk. But they are usually not sorted by material type, which is a basic prerequisite for quick and inexpensive recycling. The industry has been running at high speed in recent years, producing faster, cheaper, and more efficiently to meet all consumers' needs, and increasingly sophisticated fabric blends are being sold.

[10]Cf. www.kleiderkreisel.de.

[11]Cf. www.ubup.com.

The main problem in textile recycling remains the separation of the different fibre blends. For the reuse of textiles in production processes, the different raw materials have to be separated from each other, or else a new product needs to be found that does not require such sorting. Cleaning rags and insulation are the simplest products that allow for a reuse of textile waste, but these are clearly a "downcycling" of the materials, with the product features from the materials' first life completely obliterated. Textile recycling can only develop a serious position in the existing textile industry through positive business models.

Textile recycling will play an important role in the ecological and sustainable economy in the future. Due to the massive use of textiles in a variety of fields, it is crucial that the industry will find ways to extend the useful life and use recycled textiles to create value. It is crucial that business models develop that are able to compete against the still unrivalled prices for polyester and cotton yarn, as well as in the non-woven segment (Van Delden 2017). But there are already closed cycles for recycled cotton in China that can communicate the advantages of production and product features to customers in the supply chain. Tommy Hilfiger launched recycled cotton jeans in 2018 that proved able to compete with the subsidized prices of virgin cotton (https://dk.tommy.com/recycled-cotton-straight-fit-jeans).

It all begins with design. Recycling of post consumer waste would be much mire economic, when designers would use 100% material compositions. Separating fibres, sewing yarns, labels, rivets, zippers, and accessories is a manual or heavy chemical process. This leads to a disadvantage in price for the environment and generates unskilled work with super low wages. A precondition for meaningful recycling is clean textile engineering using fibres from the same type and composition to avoid cost and impact of separation by man or chemicals.

After more than 15 years of a movement towards sustainability in the textile industry (Black 2018), some initial successes can be noted. Nevertheless, fast fashion and globalization have tremendous momentum that will not change from one season to the next. It can clearly be seen, however, that private-sector and statutory regulations have led industry players to rethink and implement new sustainable, pro-recycling strategies. Technology and design provide product developers, designers, and buyers with more opportunities to develop and design the product more ecologically and to make the supply chain more transparent to management (Fung et al. 2017).

An increasing number of designers and labels are marketing "slow fashion" (Vernon 2019) and lead their suppliers to adopt sustainable and social production practices (Cobbing and Vicaire 2017). However, there has also been a clear change in the producing countries which, due to their outsized growth in the past 20 years, will need to change their industries in order to develop decent jobs and environmental conditions for their people and their workforce (Black 2018).

23.4 Digitalization in the Textile Industry

Almost 200 years ago, the First Industrial Revolution began with the steam engine and the mechanical loom. At that time, the driving forces were raw materials and industrial processing methods, while the Fourth Industrial Revolution is being driven by digitalization and accelerated online communication. The textile industry is also fundamentally changing with digital business models that are accelerating and making communication between producer and customer more efficient (Beckert 2014).

The following considers the opportunities digitalization is opening up for the textile industry based on three recognizable trends. The transparency demanded by movements towards sustainability and a social economy plays a role in all three.

Digital transformation will open up risks and options for workers, producers, suppliers, traders, and consumers of the global textile industry with faster and more efficient supply chains and business models.

23.4.1 Transparency Through Digital Business Models: Cutting Out Intermediaries

Numerous international studies have shown that it is the innovations in business models that deliver a higher potential for success than product and process innovations. At present, this connection is even becoming increasingly important in the textile industry as a result of ongoing digitalization and the trend towards sustainability.

Business models, to put it simply, are the way someone does business with someone else. The streams of data and transparency of supply chains have created new business models in the textile industry. These can provide customers with the information they need to take a "sustainable" purchase decision. Such business models also manage to bypass intermediaries in the global textile trade through direct communication, allowing control of margins and costs.[12] It can also be clearly seen that companies in supplier countries are making extensive use of the Internet to communicate directly with their customers. Why should one also let a brand be exploited by retailer markups if one can address the customer directly? *No markups* have become the credo of many companies in supplier countries such as Turkey, Indonesia, China, Bangladesh, and Germany.[13]

Platform systems and hybrid networks in the textile industry are creating new supply chains that were previously unthinkable. Parts of established supply chains are being skipped in order to put customers and producers into direct contact quickly and easily. Both B2B and B2C options are now available. Examples are companies

[12] Cf. https://www.sonofatailor.com/.

[13] Cf. https://www.grana.com.

like Spreadshirt,[14] Spoonflower,[15] Roostery,[16] etc. All three examples are united in the fact that they come into direct contact with end-users via the web and thus use the transparency in the supply chain to ensure both their economic success and sustainability. In addition, customers can act as their own designers, product developers, and suppliers and thus market their own sustainable and efficient production and supply chains (Fischer 2010).

23.4.2 Efficient Merchandise Management Through Digital Communication: Mass Customization

Thanks to networked ERP and logistics systems, supply chains in the textile industry are becoming ever faster and more transparent. The link with the POS allows producers and traders to react directly to products that are selling well (Ganesan). Suppliers and retailers are becoming supply chain managers. Directly at the point of sale, which can be online or off, the data is used to make decisions for the next production or product innovation. Customers no longer have to wait long for the product because the supply chains are networked and efficient thanks to ERP systems (Fischer 2010).

Not only in retail and wholesale are the efficiency and the accuracy of the results improved by real-time analysis of data. Data flows will increase efficiency also for production in global supply chains. Automotive quality assurance already operates in some areas with online-based systems, which, for example, allow colours to be approved in real time with system support. This saves time and prevents human errors. Systems such as colordigital.de optimize complex processes in global supply chains and, in some cases, can also automatically organize dyes, suppliers, and specifications in the cloud.

These fast communication structures make supply chains much more efficient and enable *on-demand* production. Ideally, products would only be produced on order. The efficient production for the consumer's specific need saves resources and does not produce waste for the landfill or the incineration plant. The right step to keeping as little capital as possible tied up in inventory and making optimal use of resources. Optimizing the use of resources is the most sustainable production (Black 2018).

[14]Cf. https://www.spreadshirt.de.

[15]Cf. https://www.spoonflower.com.

[16]Cf. https://www.roostery.com.

23.4.3 Transparency Through Digital Real-Time Communication

Digitalization will make global supply chains transparent. Customers will be able to find and buy the most economically and ecologically attractive product. Digitalization opens up options for transparently presenting the origin, ingredients, and production routes, in short, the entire journey of a product. And that will change the perception and the processes of the entire industry.

An increasing number of consumers around the world want to know which farmers grew the vegetables or grains they are eating, raised the livestock from which their meat came, and under what conditions their clothing was produced. There is a need for transparency coupled with ensuring trustworthiness, because buyers rely on the reputation of the organizations and labels providing the data.

Here, the digital linking of the individual stages of production in the small-scale textile chain can bring about a quantum leap, because information about the use of chemicals, materials, logistics data, and working conditions can be passed on digitally and checked.

Disruption through digitalization is evident in the provision of product and production-specific data. Major discount chains like H&M, Lidl, Aldi, or Marks and Spencer have put parts of their supply chains online. The Chinese platform IPE[17] already lists many Chinese and other companies on the supply chain. The site requires that they publish their latest wastewater reports there.

NGOs and organizations that strive for holistic quality assurance process this data and create the basis for transparency regarding ecological criteria.

The change in the textile industry in China, India, and Bangladesh, as well as in many other countries, will change not only with the purchasing contracts of Western companies, but also with local legislation. Europe has taken an exemplary role here with its REACH regulations.

23.5 Digitalization Promotes Sustainability in the Textile Industry

While digitalization does not contribute directly to sustainability, digitalization creates opportunities for sustainability from the fibres to the wardrobe, giving the client, designer, product developer, and buyer the opportunity to strive for sustainability in their products and their suppliers.

Digitalization will change the sustainability and resource efficiency in production to such an extent that supply chains and production processes will become more transparent and thus more sustainable through cloud-based communication systems. This will influence B2B and B2C buying behaviour (Chalmer et al. 2018).

[17] Cf. https://wwwen.ipe.org.cn.

Quality assurance is about to take a digital leap. In addition to reducing costs, saving time is on the agenda. Digital means real-time display on the monitors of those responsible so that they can approve deliveries, even on the other side of the planet. Blockchain can play an important role to introduce trust and reliability of value chains.

But putting the supply chain online is only a part of it. Up to now, high costs have been incurred in order to record and document company data down to the level of the individual product. What end consumers, NGOs, associations, and labels want is for the production conditions to be made visible. In addition, the ecological footprint: Which fibres, chemicals, and processes were used? How far has the piece travelled? Were renewable raw materials used and is the product recyclable? And being able to view it directly by scanning a QR code on the product label, as it is already the case in the food industry (Walter 2016).

23.6 Conclusion: Sustainability is too Important to Leave It to the Sustainability Department

Historically, the textile industry was the cornerstone of development for most countries. It remains the world's foremost industry with a vast impact on the socio-economic development of many countries. The global apparel and footwear industry was worth $1.7 trillion in 2017 and will continue to grow by 2% a year through 2022. If it was a country, it would be the world's eighth-largest economy after Italy.

Polluted rivers and damage to locals' health are putting the entire industry under massive pressure. Major achievements are already being made in dyeing and finishing processes. This was heavily driven by NGOs and the fear of governments, especially in China, that health damage could lead to unrest in society. Factories in China are shown on an online platform (https://wwwen.ipe.org.cn/). If they are not meeting wastewater requirements, they are shut down.

Digitalization will mean resource-saving production that will be more efficient than ever thanks to the possibilities of transparent communication. Rana Plaza has had an impact on consumer demand through pressure in the media and has initiated many campaigns that have the industry in the news. What is being shown is an industry that has grown tremendously, but has not always taken all of the costs into consideration (Chalmer et al. 2018).

Digital communication will also allow new technologies, business models, and products to reach consumers more quickly than they previously could in linear and multi-layered value chains. However, this also means that laws and regulations can be implemented more quickly in one market, and monitoring compliance with regulations will be much tighter than before.

According to the latest report of the Global Fashion Agenda and The Boston Consulting Group (GFA 2019), "sustainable management" and a strategy geared to sustainability lead to entrepreneurial success: as analysed in some of the largest companies in the European clothing industry. With digital tools and data, such a strategy will be much faster and more efficient than those in the 1990s thanks to audits and PDF documents.

Sustainability in the textile industry as well as in other industries is the job of engineers and designers developing a product under these premises with qualities that match its use. Sustainability will be the strategy of any entrepreneur who wants to create value in this new world. Sustainability is much more too important to leave it to the sustainability department (Chalmer et al. 2018).

This is why sustainability is too important to be left with the sustainability department. The hard decisions can only be made by the CEO, owner or top manager. It is a long-term responsibility towards people wearing non-harmful but comfortable and skin-friendly clothes and towards the environment to use resources wisely and reduce waste to the absolute minimum necessary. Last but not least, there is a huge societal responsibility to offer jobs that let people work in dignity and make enough money to have a decent life with their families. This is a complex topic as negotiations between buyers and factories are hard. But this is an old thing. What the industry needs are legal frameworks in producing countries, safety standards for buildings and workplaces and management skills and practices to cope with the huge challenge of the Fourth—The Digital—Industry Revolution.

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