

# R principles for circular economy in the textile industry – a mini-review

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## ABSTRACT

*Textiles are used by humans for many purposes, from clothing to technical applications such as geotextiles, agrotextiles, or medical textiles. However, in addition to their importance, textiles are also responsible for various types of environmental pollution along the entire textile chain, from production, transport and trade to daily use to their end-of-life. Here we provide a brief overview of current approaches to establishing R principles in the textile industry in order to transform the recent linear structures into a circular economy and show in which areas there is a particular need for research and action.*

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## 1 Introduction

Textiles are indispensable to our lives. People need clothing as a protection from cold or heat as well as from ultraviolet irradiation [1,2], but textile fabrics are also used in medicine [3], in various technical applications [4-7] and in other areas of human life. On the other hand, textiles can cause skin irritations and other health problems, either directly through toxic dyes and other harmful chemicals used in their production [8,9] or indirectly by environmental pollution during the production, transport, and washing of textiles, as well as through waste at the end of their life cycle [10-12].

One possibility to address the latter problem is to implement so-called R principles in the textile industry in order to overcome the traditional linear structures and transform it into a circular economy [13]. In the following, we define these principles and point out the main problems of non-circular principles in the textile chain, before giving a brief overview of the latest approaches to implementing R principles in the textile industry.

## 2 Circular economy and R principles

The circular economy is an alternative concept to the linear model of production / consumption / waste and aims at thinking in terms of life-cycle [14]. A circular economy, as proposed by the Ellen MacArthur Foundation [15], has not only been proven to be important for combating climate change [16], but also offers new business opportunities [17].

Cycles in the circular economy can be divided into technical and biological material cycles [18]. While many industries can be clearly assigned to the technical material cycle, textile materials can be assigned partly to the technical and partly to the biological cycle, so that both parts of the circular economy must be taken into account here.

For the technical cycle, mechanical and chemical textile recycling processes have been investigated with regard to the possibilities of reducing the environmental problems caused by fast fashion [19], of fiber waste recycling [20], recycling of clothing [21] or chemical dissolution of cellulose textiles [22]. Closed textile recycling loops can be established in the biological cycle using bio-based processes, as shown in Fig. 1 [23]; however, this approach has been little studied.

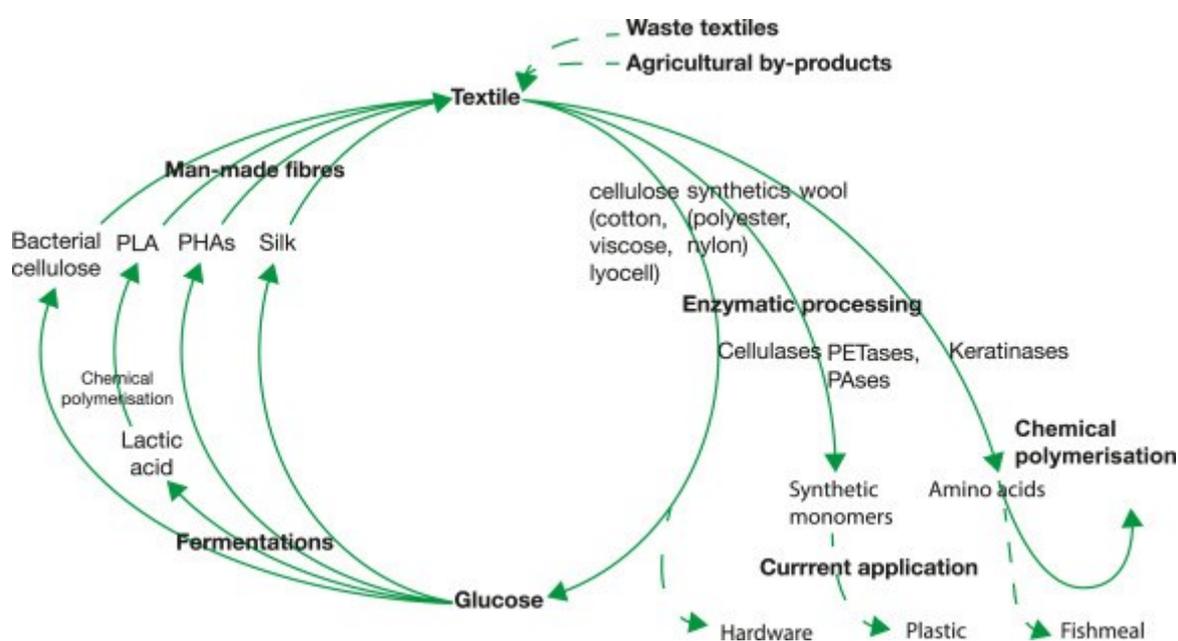


Fig. 1 Establishing a closed-loop bio-based process for cellulose-based textile recycling routes. From [23], originally published under a CC-BY license.

The so-called R principles include the ideas of reduce, reuse, recycle and recover, as discussed in the 4R framework [24]. They can also be extended to the 9R framework, which consists of refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover [25]. In both frameworks, the first principles are favorable compared to the latter [26] and should therefore be preferred to avoid downcycling as much as possible [27].

## 3 Disadvantages of traditional linear structures in the textile industry

In many industries, a comparison between linear and circular supply chains clearly shows the advantages of the latter [28]. In general, the circular economy can support economic, environmental and social aspects of sustainable development [29]. It is obvious that the motivation of companies and investors to implement circular economy concepts requires economic profitability [30].

Using the construction industry as an example, Nasir et al. emphasized the environmental benefits of circular economy principles, especially in the case of insulation materials, also mentioning the transport-intensive and thus carbon-emitting elements in the circular supply chain [31]. Walker et al. examined the advantages and disadvantages of a tax on plastic products in the context of a circular economy and showed that such a tax should only be used cautiously and in combination with other suitable

instruments to avoid undesirable side effects [32]. The problem of recycling composites was discussed by Korniejenko et al. focusing on tires, wind turbine blades and solar panels, showing that many technologies for separating multi-material composites still need to become more effective and economically justified or are not yet available [33]. For the manufacturing industry in general, Lieder and Rashid emphasized the importance of organizational development and the mindset of managers in terms of change management to move from linear to circular structures [34]. Furthermore, for small islands dependent on tourism, Schumann found that the shift to a circular tourism model could even have a positive impact on a larger shift to a circular economy [35].

In the textile and clothing industry, the negative environmental impacts of production and processes are well known [36,37]. Many research projects have therefore investigated the environmental impact of various aspects of the textile chain. According to studies, the main disadvantages of traditional linear structures in the textile industry include the large amount of textile waste that is not recycled or reused [12,38], as well as toxic dyes and other hazardous chemicals [39-41]. However, there are other environmental impacts of the textile industry, such as the depletion of water bodies, eutrophication of freshwater, the use of agricultural land or the reduction in the diversity of ecosystems and the availability of resources [42].

Numerous methods for integrating circular economy principles into the textile industry have been described in detail in the academic literature, with various strategies explored to achieve this goal (see Fig. 2). However, this discussion focuses specifically on the application and implementation of the 9R framework within the textile chain.

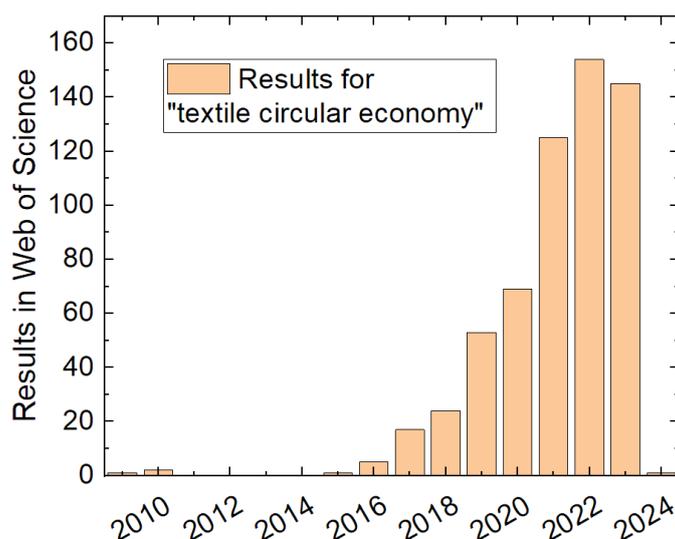


Fig. 2 Web of Science results for “textile circular economy”. Data received on Dec. 09, 2023.

## 4 R principles in the textile industry

Since the R principles in the textile industry within the 4R or 9R framework [43-45] are only rarely discussed, we will address the 9 different principles of the 9R framework separately here.

### 4.1 R0 – Refuse

The R0 principle of rejecting one product means replacing it with another, i.e. making the production of a product redundant. In relation to the textile industry, this could mean creating “slower” fashion with fewer collections per year or even producing “timeless” designs that can be worn for as long as the garments are physically intact [46]. The idea of refusing to buy textiles is hardly discussed in the literature [47]; the less restrictive approach of at least refusing ecologically unfavorable clothing is also not often mentioned [48,49]. In contrast, the slow fashion approach – which includes new business models that prioritize quality over quantity – is discussed more frequently in the literature and is integrated into the textile industry to a small extent [50-52].

## 4.2 R1 – Rethink

Rethinking means extending the use phase of a textile product, e.g. by making it more efficient through a multifunctional design or by changing its shape. It can also mean that a textile product is no longer owned but rented, as is already the case in the workwear sector [46].

R1 is found more frequently in the literature than R0 [53]. Todeschini et al. cited “the inability to rethink the design phase” as one of the problems in the transition of the textile industry to a circular economy [54]. The same observation was recently made by Chen et al [55]. Some authors also state that companies need to rethink and innovate their business models, taking into account environmental and social aspects in addition to the necessary benefits for their customers [56,57]. Valencia et al. extend the process of rethinking to policy, value chains, territory, management, business models and corporate social responsibility (CSR) [58].

On the technical side, a rethinking of the raw materials used in the production of textiles has been encouraged, e.g. by using materials from renewable resources, recycled materials or revitalized materials [59,60]. To this end, food waste or textile waste has been analyzed for potential reuse [60,61]. On the other hand, bacterial cellulose or other bio-based materials that require only small amounts of water and energy for production have been proposed [62-64].

## 4.3 R2 – Reduce

A reduction of the use of resources can be achieved by increasing efficiency in production and use, e.g. by avoiding waste and using recycled and bio-based materials instead of virgin materials [55,65]. On the other hand, returned products and other losses during production and in stores must be taken into account [46]. In addition to solid waste, environmental aspects such as air emissions, wastewater, the consumption of harmful materials and environmental accidents as well as economic aspects such as the cost of material procurement, energy, fees and fines for waste and environmental accidents should also be reduced [66,67]. Finally, the user can reduce unnecessary washing and drying and thus reduce the consumption of energy, water and chemicals [46].

The reduction of textile waste is frequently mentioned in the literature [68]. This could be achieved by wearing clothes for longer and by effectively recycling and reusing textile waste as a raw material for new textiles [69]. This approach is often linked to green chemistry, which also aims to reduce pollutants and waste as well as energy costs in production for environmental and economic reasons [61]. In general, many of the principles of the 9R framework are interlinked, so product and manufacturing process redesign has also been proposed as a way to reduce waste [66].

On the other hand, vehicle emissions caused by the transport of textiles should be reduced through optimized planning and cleaner urban freight transport [70]. This aspect can also be addressed by producing clothing locally and reducing the negative impact of international supply chains [71].

It should be mentioned that the so-called “circular economy rebound” (CER) can occur if only the material resource flows are considered and the economic and market forces are neglected, e.g. lower prices due to lower material or energy consumption could lead to an increase in demand, which would eventually lead to higher material or energy consumption [72].

## 4.4 R3 – Reuse

While principles R0-R2 belong to the general strategy “smarter product use and manufacturing”, R3 is the first part of the strategy “extending the life of products and their parts” [25]. In the textile industry, reuse refers to used but still intact textiles that are either donated or resold to other people [46]. Although reuse is frequently discussed and practiced, a recent study considers it an under-researched circular economy principle, not only in the textile industry [73].

Reuse is one way to reduce the production of new textiles [74]. It applies to “slow fashion” or “long-lasting fashion”, which is made from durable materials and designed to last, as opposed to fast fashion,

which is usually recycled rather than reused [75]. According to the Thred-Up 2019 Resale Report, reuse is one of the fastest growing parts of the fashion market [76]. Nevertheless, the share of reused solid textile waste (8%) in Europe is still lower than the share of recycled waste (10%), while both shares are far below the share of solid textile waste sent to landfill (57%) [77]. A report by the European Parliament even assumes that only 1% of textiles are reused [78].

On the other hand, there are already approaches based on design aspects to improve reuse and inspire future designers through the creative potential of reuse [79-81]. Furthermore, the members of the Waste Framework Directive have agreed to establish separate collection and treatment of textiles to improve preparation for reuse and recycling from 2025 [82-84], so the proportion of reused textiles should be increased in the near future.

#### **4.5 R4 – Repair**

Repairing textiles and clothing allows them to be used for longer. This step includes the repair of buttons or zippers, but also of seams or even the textile structure itself. While the former can often be done by consumers themselves, the latter often requires repair sewing, but can also be supported by patches or other means that allow for effortless repair [46].

Repairing is discussed more frequently in the literature than the previous steps and is actively carried out by consumers and businesses. Potential challenges for consumers include the lack of time and repair skills and the relatively high cost of some repair methods compared to buying a new, cheap textile [85-87]. Some studies have found a positive association between clothing repair and concern for climate change [86,88], while other studies have found that even people interested in reducing their environmental footprint do not repair their clothing [85,87].

Community repairs - e.g. in the form of repair cafés - can help to raise awareness that repairing is an important part of the circular economy, support people who do not know how to repair textiles and add a social component to the purely material-related repair process [89,90]. On the other hand, the repair industry faces challenges such as low profitability of repair work and insufficient access to skilled personnel, as well as the low quality of new products, which often make repairs inefficient and unattractive to consumers [91]. Both challenges – improving the quality of the original product and improving consumer knowledge about repairs – must be overcome in the future in order to improve the possibilities for repairing textiles.

#### **4.6 R5 – Refurbish**

In the textile sector, refurbishing is a method of overcoming fashion dictates and boredom with long-worn clothing, as well as simple problems resulting from changes in body measurements that cause garments to no longer fit a person. Refurbishing can therefore mean refitting, but also redesigning, e.g. by adding new features or changing the color of a textile to bring it back in line with current fashion [46].

Refurbishment can be carried out by a consumer or a company, especially if the textile products are leased rather than purchased [92]. Manufacturers can refurbish products to the same standards as the original products and return them to customers [93]. However, such leasing models suffer from the limited leasing fees possible for products with high resale value on the second-hand market, so that an established second-hand market, such as for baby and children's clothing, can reduce the economic potential and thus the advantage of a leasing model for manufacturers [94].

The environmental impact of refurbishing was investigated for an event tent and a beach flag, both textiles that are generally only used once, and was between 45 and 88% [95]. However, this is a special case. For frequently purchased clothing, various challenges must be overcome before remanufacturing is possible, such as the technical necessity of sorting the textiles despite low economic viability and the low social acceptance of mandatory return and refund schemes [96]. These obstacles to refurbishment – as well as to reuse and recycling – must be overcome in order to achieve a greater circularity in the textile industry.

#### **4.7 R6 – Remanufacture**

In remanufacturing, new textile products are produced from industrial and/or consumer waste [46]. Remanufacturing is a greater challenge than conventional manufacturing due to the great variance of returned textiles in terms of quality and quantity [97]. Therefore, remanufacturing is less established in practice than, for example, recycling or repair, especially for low-value clothing [98].

To overcome this problem, it is important to design textiles for remanufacturing [99], which is why some authors proposed design methods to extend the life of a product through remanufacturing and other circular principles [100,101]. Nevertheless, only a few case studies of textile companies practicing remanufacturing as part of the circular economy can be found in the literature [102,103]. However, different researchers discussed chances and challenges of remanufacturing. Pal et al. mentioned process challenges that reduce the industrial scalability of fashion remanufacturing and suggested a lower process interdependence for larger-scale fashion remanufacturing [104]. Aravindan et al. investigated remanufacturing of woven carbon fiber industrial waste into fiber composites [105]. For the special case of e-textiles in which components are adhesively bonded, Hirman et al. suggested design methods for remanufacturing [106].

#### **4.8 R7 – Repurpose**

Repurposing can be applied to textile products by using raw materials from other industries to manufacture new textile products or by using textile waste and surplus textile material for new functions, thereby changing the application of a product [46]. Reuse has been defined as a potential solution to the problem that textiles collected for recycling are often exported to countries where there is no collection infrastructure [74].

Various textile and shoe companies have reported on the reuse of plastic bottles and leather scraps [107,108]. Pre-consumer waste could be converted into merchandising products for circular fashion [109]. But unwanted items could also be reused as a potential solution to the fast fashion problem, where overconsumption is followed by disposal [110,111].

#### **4.9 R8 – Recycle**

Principles R8 and R9 belong to the beneficial use of materials and can be used when the previous principles are not applicable [25]. The recycling of discarded textiles, i.e. pre-consumer or post-consumer waste, usually starts with sorting the textiles, followed by chemical, mechanical, thermal or mixed recycling processes. Recycling is easier for single-material textiles than for multi-material fabrics. Depending on the quality of the textile waste, the recycled fibers can be used to produce new fibers for apparel or for composites and other low-value products [46].

Recycling is one of the frequently used and studied principles to make the textile industry more circular [112]. Nevertheless, potential problems also arise here, e.g. from companies wanting to use the best available raw materials instead of recycled materials in order to maintain the quality of their products [66]. In most recycling processes, the quality of the final product is reduced compared to the original product from which the waste was obtained, so it is necessary to think about new models to improve the quality of recycled products instead of downgrading them during recycling [113].

#### **4.10 R9 – Recover**

Recovering textiles by incineration for energy recovery is the last option for recovering the value of used textiles, although it is not actually part of the concept of the circular economy [46]. Nevertheless, many textile materials are incinerated as a last alternative to disposal in landfills [92,114-116].

## 5 Conclusions

This mini-review provides an overview of the recent application of the 9R framework principles – refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle, and recover – in the textile industry. In particular R0 – refuse – is little discussed, although it is very valuable for the circular economy approach. On the other hand, R9 – recovery – is still very often used as the last alternative to landfill disposal of textile waste.

Our brief overview clearly shows the need to focus on the first, more valuable principles to establish a circular textile economy. In the apparel sector, a shift to “slow fashion” is essential, while technical textiles mostly require careful design that enables extended lifecycles and especially “smarter product use and manufacture”, e.g. through cradle-to-cradle approaches, to keep textiles in the circle as long as possible. Furthermore, by combining the technical with the biological cycle, incineration can be avoided, e.g. in case of no longer usable wool fabrics which could be given a second life as natural fertilizer.

## Author Contributions

A. K. Schnatmann: conceptualization, methodology, investigation, writing – review and editing; F. Schoden: conceptualization, methodology, investigation, writing – review and editing; A. Ehrmann: conceptualization, writing – original draft preparation; E. Schwenzfeier-Hellkamp: conceptualization, writing – original draft preparation, supervision. All authors have read and agreed to the published version of the manuscript.

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## Conflicts of Interest

The authors declare no conflict of interest.

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