European Journal of Social Sciences Studies
ISSN: 2501-8590
ISSN-L: 2501-8590
Available on-line at: www.oapub.org/soc

DOI: 10.46827/ejsss.v10i3.1785 Volume 10 | Issue 3 | 2024

ENVIRONMENTAL IMPACT OF THE LIFE CYCLE OF TEXTILES AND MITIGATION OPTIONS: ONLINE INFORMATIVE AND EDUCATIONAL RESOURCES[i]

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Abstract:
In recent decades, the consumption of textile products has grown very quickly, with huge amounts of low-cost garments prematurely discarded because they were perceived as out of style. Fast fashion is based on low-cost garments, which result, for instance, from low-wages prevalent in most producing countries and poor environmental practices. At the same time, governmental subsidies keep artificially depressed the international cotton price. Durable and easily repairable garments, with carefully selected colours and styles, can avoid producing items that are quickly disposed of because they are worn out or perceived as out-of-fashion. The Aral Sea has largely dried up, and the whole area is polluted. This is a consequence of the massive expansion of cotton production, which requires a lot of water and pesticides. Conversely, growing hemp or flax for fibres implies much lower water and agrochemical requirements. Washing synthetic clothes implies the shedding of fibres into the wastewater. An estimated 35% of the microplastics entering the ocean come from petroleum-based garments. Low-shed textiles are already available on the market and are expected to maintain integrity and shape longer thanks to reduced material loss. Natural fibres, not treated with synthetic dyes and/or chemical finishes, are expected to degrade faster than microplastics. Both synthetic and natural fibres can be recycled; conversely, blended fibres are often landfilled because their recycling is difficult. Contamination from, e.g. flame retardants, elastane and water repellents is also a problem. Regulating the content of chemicals in the new textiles is the first instrument to prevent hazardous substances from ending up in recycled products. Documents presented hereafter discuss techniques and ongoing research on recycling polyethylene terephthalate fibres. The design for recycling, discussed in some quoted papers, is aimed at creating products that at end-of-life are easy to disassemble and recycle. An environmental policy transfers the financial responsibility of the end-of-life management

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of products from the taxpayer to the producer and to the consumer, which is expected to stimulate the circular economy.

Keywords: online educational resources, fast fashion, Aral Sea catastrophe, hemp, durable garments, reuse, design for recycling

Riassunto:
Negli ultimi decenni il consumo di prodotti tessili è cresciuto molto rapidamente, con grandi quantità di vestiti a basso costo gettati prematuramente poiché percepiti come fuori moda. La "fast fashion" è basata sul basso costo conseguente, ad esempio, alle basse retribuzioni prevalenti in molti paesi produttori ed a pratiche ambientali poco rispettose dell'ambiente. In certi casi, sussidi governativi mantengono artificialmente basso il prezzo internazionale del cotone. Vestiti durevoli e facilmente riparabili, con stile e colori scelti accuratamente, possono essere utilizzati più a lungo senza essere gettati prematuramente poiché percepiti come fuori moda. Il lago di Aral è in gran parte prosciugato e l'intera area è inquinata, a causa della grande espansione della produzione di cotone che ivi sta continuando a richiedere enormi quantità di acqua e pesticidi. Produrre fibre dalle piante di canapa o di lino implicherebbe un uso assai più ridotto di acqua e prodotti chimici. Il lavaggio dei prodotti tessili implica una perdita di fibre con le acque di scarico. E' stimato che il 35% delle microplastiche che entrano nei mari proviene da capi d'abbigliamento sintetici. Esistono sul mercato prodotti tessili che rilasciano poche fibre; si suppone che, grazie ad una ridotta perdita di materiale, questi tessuti mantengano più a lungo forma ed integrità. Le fibre naturali, purché non trattate con coloranti sintetici e/o altri prodotti chimici, si degradano più rapidamente delle microplastiche. Sia le fibre naturali che quelle sintetiche possono essere riciclate, mentre è difficile riciclare quelle miste. Anche la contaminazione da, ad es.: ritardanti di fiamma, elastan, o idrorepellenti è indesiderata. Regolamentare il contenuto di sostanze chimiche ammesso nei nuovi prodotti è fondamentale per non averle poi nei tessuti riciclati. L'articolo presenta documenti riguardanti tecniche e ricerche sul riciclaggio di fibre di polietilene tereftalato. Il "design for recycling" è volto a creare prodotti che a fine vita sono facili da disassemblare e riciclare. Una strategia volta a stimolare l'economia circolare, consiste nel trasferire la responsabilità finanziaria della gestione dei prodotti arrivati a fine vita, dai contribuenti a produttori e consumatori.

Parole chiave: risorse educative online, fast fashion, catastrofe del Mar d'Aral, canapa, indumenti durevoli, riutilizzo, design per il riciclaggio

1. Aims of the teaching unit

The article is aimed at increasing awareness and knowledge of the environmental impacts of global textile production and related mitigation options.

2. Materials and methods

The article presents informative and educational resources that consist of text, images, graphs, animations and videos downloadable for free from the internet. These resources can be used by teachers using the method that is most appropriate. This article is exclusively based on the documents quoted in the paper.

3. Introduction

"Textile Glossary" may assist in reading technical and scientific papers quoted in the article (2), and a document may help the readers in selecting reliable documents on the web for a further in-depth study (6).

The world's consumption of major textile fibres is growing very quickly, with fashion trends frequently changing (1 figure 2.4). Fast Fashion is based on cheap garments. This may result from low-quality materials, unsafe working conditions, child and forced labour (1 figures 2.7 and 2.8), dangerous working conditions, hazardous processes, unsafe buildings, and poor environmental practices polluting rivers that people use for fishing, drinking and bathing (39).

According to "How do agricultural subsidies in wealthy countries harm low-income countries?", the subsidies that rich countries provide to domestic producers result in market distortions. *An artificially depressed international cotton price consequent upon such subsidies* prevents millions of African producers from getting a fair wage (49).

Low prices encourage over-consumption of garments, generally worn 7-8 times and then prematurely discarded because they are perceived as out of style and obsolete, *which generates large amounts of waste* (1).

EU consumers discard an estimated 11.3 kg/year of textiles per person. In 2017, the production of textiles purchased by EU households implied the use of 1,321 kg of primary raw materials per capita, not including water. Producing 1 kg of t-shirts requires about 3 kg of chemicals. Producing 1 tonne of textile implies the release of 15-35 tonnes of CO_2 eq. Textile dyeing and finishing cause an estimated 20% of global water pollution, which the producers are not required to pay for. Most of this material use takes place outside Europe (1).

A document of the European Environment Agency deals with the destruction of returned and unsold textiles, whose estimated quantity is between 264,000 – 594,000 tons/year, and analyses the causes of this avoidable adversity (4). *The wages prevalent in most producing countries are so low, that the risk of producing an excess of clothing is preferable to the risk of losing potential sales*. The growth of online sales implies increased shares of return rates and unsold clothing, which worsens the situation. Recently, EU policymakers decided to introduce a ban on this destruction.

A graph shows the global growth of clothing sales and the decline in the number of times an item is worn since 2000 (39 figure 1). Whereas, the graph in figure 14 shows the average number of times a new garment is worn in US, China, EU-28 and the World.

Wide differences in the consumption of textiles can be observed between European countries (32 Table 2 / 1 figure 2.9).

Many chemical substances used during textile manufacturing may unintentionally remain in the final products; whereas other chemicals, such as flame retardants, are designed to persist in the product (1).

Growing volumes of biocide-treated textiles are arriving on the market to give anti-odour properties, which raises concern about the development of antibiotic resistance (42 / 3> View widely used chemicals). In fact, *the slow release of biocides into the environment creates a selection pressure inhibiting growth and reproduction of wild bacteria, with the less vulnerable surviving and passing their resistance to next generations*. According to the document, unnecessary use of such chemicals should be avoided.

"Textiles come with a toxic footprint" provides information about some of the most common groups of chemical substances used in the textile industry (40).

"A Comprehensive Guide to Textile Process Laboratories: Risks, Hazards, Preservation Care, and Safety Protocol" is a review study on the hazards and risks of textile processing laboratories (43).

"Textile Guide" provides basic information on the production steps of the process from fibre to finished garment while also providing an overview of the chemicals involved in the environmental impacts (3).

Dyes, discharged in large amounts into the wastewater, may contain hazardous substances, e.g. lead and cadmium. Achieving flame retardant and water repellent properties may imply using hazardous chemicals (3> View widely used chemicals).

The document discusses available alternatives that provide fabrics with the required properties without use of hazardous chemical substances (3> View widely used chemicals / 3>How to start substituting chemicals / 3> Alternatives to hazardous chemicals).

The document describes the textile production steps, while mentioning the chemicals used in the related processes. *Man-made fibres* are created from cellulosic raw material heavily treated with chemicals. Whereas, *synthetic fibres* are created through the polymerisation of monomers sourced from oil (3> Production process).

4. Cotton

Cotton farming accounts for 50% of all the pesticides used in developing countries. They are mostly applied by hand, with frequent poisoning of workers. To produce 1 kg of cotton lint, as much as 10,000 – 17,000 litres of water are required (7).

Cotton production utilises 2.4% of global arable land area and huge amounts of water, which may contribute to food deficits, especially in water-scarce areas (1).

According to "The sustainability of cotton: Consequences for man and environment", an estimated 4% of the world's total arable land is abandoned as a consequence of previous intensive cotton farming, with soil salinization being the main cause (7).

In Central Asia, the massive expansion of cotton production and related *huge irrigation water requirements did imply the withdrawal of large amounts of water from two major rivers flowing into the Aral Sea,* which caused a strong decline in water flow. Consequently, the Aral Sea, once the 4th largest lake in the world, underwent shrinking. At the same time, saline and polluted waters draining from the irrigated areas contributed to worsening water quality (8 / 9 video).

"The Aral Sea Catastrophe Explained" summarises the causes and consequences of intensive cotton farming for both the environment and people's health and the initiatives that are being taken to face a crisis involving five countries (23).

According to "What have we learned? A review of the literature on children's health and the environment in the Aral Sea area", the food grown in this area, as well as breast milk, are contaminated by chemicals. Here, the people are exposed to winds that raise polluted and salty dust from the dry lake bed (24).

Muynak, once an important fishing port and tourist resort, is now distant from the lake by more than 100 kilometres. The people had to face job losses and poverty, while the collapse of the sanitary system was intensifying the health burden (24).

In the US Southern States, where cotton is grown, the groundwater aquifers that supply irrigation water are heavily over-exploited, and problems in both quantity and quality are being experienced (16).

Residues of pesticides can be found in cotton fibres unless they are grown organically (3> View widely used chemicals).

Interestingly, organic cotton farming with an assured price premium improves the livelihoods of smallholder organic farms in central India (50).

5. Hemp

In Europe, hemp was traditionally used to produce textiles, rope and paper. Its production became illegal in the UK and USA as a consequence of its association with narcotics; nowadays, low narcotic varieties have been developed, which has allowed cultivation again in Europe (16 / 17).

Box 2 (16) shows the traditional method of textile production from hemp. "A Review of Hemp Fiber in Global Agriculture and the Textile Industry" provides text and images on history, machinery, global market share, utilisation and regulations in different areas (19).

Hemp, while providing 3 times more metric tons of fibre per hectare than cotton, implies lower agricultural costs (18 tables 8 - 10 - 11). Currently, there are no pesticides registered for hemp use in the US.

In the UK, the water requirements for hemp are met entirely by rainfall (16).

According to a document from the European Commission, among the environmental benefits, *hemp can store as much carbon dioxide as a young forest*. In addition, the dense vegetation of this plant limits soil erosion and water loss while being beneficial for biodiversity (20). The document also deals with the several uses of hemp.

"A critical evaluation of the use of hemp as a sustainable solution in garment making" compares the characteristics, e.g. tensile strength, abrasion resistance and breathability of hemp and cotton (33).

Cotton benefits from an already well-organised market, differently, for instance, from flax and hemp (17). The technology used for the industrial processing stages of hemp is less advanced than that of cotton because of a lack of innovation, but opportunities for technological improvements exist (18).

6. Animal fibres

The production of animal-based textiles, such as wool, is associated with extensive use of land and methane emissions (1).

Cashmere goats eat very close to the roots, and their hoofs damage the topsoil, which results in grazeland desertification (26).

Conversely, alpaca, thanks to both soft pads and way of grazing, respects the root system of the grass. The wool of this animal is considered more eco-friendly (21 / 25).

Most animal farming, however, has been negatively associated with ethical concerns (21).

7. Other fibres

The content of "Profiles of 15 of the world's major plant and animal fibres" is summarised by the title (10).

The Life Cycle Assessment (LCA) analyses and quantifies the potential impacts of a product from raw materials extraction to manufacturing (cradle to gate). Conversely, LCA may include transportation, retail sales, consumer use and end-of-life management (cradle-to-grave), in which case the entire life cycle of a product is covered (53).

Tables 1 and 2 (53) show, respectively, the environmental impacts both in the agricultural production of natural fibres and in the industrial production of polyester fibres. Tables 3 - 4 – 5 show the environmental impacts in, respectively, yarn preparation, spinning, weaving and dyeing processes. The available data do not cover all the fibres considered in the study. According to the authors of this 2023 paper, *lack of data is a consistent problem, and expanding the research in this direction might assist in transitioning into more sustainable fibres*.

"A systematic review of the life cycle inventory of clothing" provides data from the literature on GHG emissions, energy usage, and water use for different fibres (47 table 5).

Table 1 of "Comparative Life Cycle Assessment of Cotton and Other Natural Fibers for Textile Applications" shows the cumulative energy demand for the production of 1 kg of fibres (cultivation) and 1 kg of textile (yarn). Table 2 shows the schematic results of all impact categories evaluated for the production of textiles (17). In both tables, we can observe much higher values for cotton than for jute and kenaf. The document discusses other less impacting alternatives to cotton, such as hemp and jute.

A document of the Council of Fashion Designers of America contains two videos on linen production, respectively on an industrial and on a small scale (13).

The processing stage aimed at separating flax fibres from the stem of the plant can imply the use of harmful chemicals and water pollution. As an alternative, the "dew retting" can be practiced; *this latter process takes longer but does not imply using water and chemicals, and even energy requirements are lower* (13).

According to "Not all bamboo is created equal", while requiring few pesticides, this plant exhibits beneficial effects on soil and contributes to decarbonising the atmosphere. Fabric can be produced from bamboo utilising an *eco-friendly process, which is costly and labour-intensive, but saves large amounts of energy and chemicals* (30).

"The European market potential for sustainable materials" (21) deals with initiatives of several brands aimed towards sustainable productions. Orange fibre is an innovative fabric made from orange skins that results from the production of juice. *Fabrics also can be produced from, e.g. fruit waste, pineapple leaves and cactus* (21), *algae, bacteria, rinds, leaves, and other agricultural waste* (11).

8. Impacts of fibres processing

"Fiber Selection: Understanding the impact of different fibers is the first step in designing environmentally responsible apparel" outlines some differences between natural and synthetic, organic and conventional, and recycled and virgin fibres. To produce a garment, a fibre undergoes several processes, e.g. knitting, dying, and finishing, with each of them implying negative environmental impacts. The table compares the impacts observed in the diverse processing stages of several fibres (27).

The environmental impact relative to fabric production is largely determined by the management of the dyehouse (28). Preparing, dying and finishing a fabric may require large amounts of water, energy and a lot of chemicals. Selecting safer substitutes to the hazardous chemicals used in the production of conventional textiles is essential, as well as a proper treatment of wastewater. Worldwide, typically, the colour of half of the fabric dyed comes out wrong, which may require the process to be corrected or redone. The table compares the environmental impacts of dyeing cotton, polyester, viscose and wool.

"Advancements in Sustainable Natural Dyes for Textile Applications: A Review" discusses the main advantages, disadvantages and innovative technologies in the adoption of natural dyes (58). *Innovative processes employ agro-industrial waste and by-products as natural sources of dyes, which avoids the use of land competing with food production*. At the same time, new technologies reduce the consumption of water, energy and chemicals, as compared to traditional methods. The review also discusses limitations and difficulties encountered in the adoption of natural dyes on an industrial scale.

In some cases, textile dying can be avoided, for instance, by using naturally coloured cotton varieties (29).

"La viscosa Como se hace el rayón" shows, the production cycle, from felling trees to the fabric (64 video with English subtitles).

Producing fabrics, such as rayon and viscose, implies cutting down 70 million tons of trees every year; this quantity is growing and is expected to speed up deforestation (11).

A video shows a method developed by researchers to produce high-quality textiles. The method utilises textile waste and *forest residues, instead of felling trees,* which implies a significantly lower environmental impact (65).

A video shows that large amounts of forest residues left on the soil can make wildfires more intense and difficult to control (66). Removing a part of these forest residues to produce textiles implies the beneficial effect of easier wildfire control.

9. Impact of textiles during and after the use of the product

Washing synthetic clothes results in the shedding of fibres into the wastewater. At the same time, fibres filtered out at the wastewater treatment plants remain commingled with other waste, with this sludge used as a fertiliser. *In all cases, such microplastics may enter the food chain* (11 / 12 / 15 / 1).

According to a 2017 report of the International Union for Conservation of Nature, an estimated 35% of the microplastics entering the ocean come from synthetic textiles, while 28% originate from the abrasion of tyres (12 figure 4). Large amounts of these textile fibres have been observed in both open water and marine sediments; they are generally constituted by polyester, polyethylene, acrylic and elastane.

A document deals with the invisible microfibre pollution and consequences of the lack of biodegradability, which implies adverse health effects, e.g. *toxicity and mortality in zooplankton, gut blockages and nutritional deficiency in fish. Respiratory complications, endocrine disruption and cancer have been observed in humans* (15 page 12).

Potential solutions aimed at reducing the microplastic release from synthetic textiles exist, including a *reduction in purchasing synthetic products*. Other solutions include: a design of textiles aimed at reducing the shedding of fibres, a filtering device in the washing machines, pre-wash textiles to reduce the heavy microplastic losses occurring during the first wash, and water infrastructure with a better treatment efficiency (12 page 29).

On page 18 (15), a section provides an overview of the several opportunities available for policymakers, industry and investors to contribute to reducing microfibre pollution, *which includes regulating textile shedding rates*.

On the market, low-shed textiles are already available; these latter, thanks to reduced material loss, are expected to maintain integrity and shape for longer. Shedding rates can be reduced by up to 80-90% thanks to changes in the design and manufacture of textiles and garments. *Despite environmental and health concerns associated with microfibre pollution, the release of microfibres is still largely unregulated* (15).

"Microplastics from textiles: towards a circular economy for textiles in Europe" provides more information and links on the subject (61).

"Plastic microfibre pollution: how important is clothes' laundering?" reviews the current information on the subject and potential control methods. Microfibres are also released into the air as a consequence of wearing, brushing and mechanical drying of textiles. *The French government has recently approved a law aimed at reducing the microplastic release from washing machines by 2025* (14).

Natural fibres, *not treated with synthetic dyes or chemical finishes,* usually degrade faster than petroleum-based synthetic fibres. The biodegradability of fibres is not the focus of this article; however, a quoted document (59) may constitute a starting point for a more in-depth study. *Science-based policies aimed at regulating and minimising the environmental impact of textile waste are crucial*.

Between 1992 and 2010, the consumption of synthetic fibres grew from 16 to 42 million tons (12).

A graph (51 page 40) shows the impacts, global and by country, of a reduced wash temperature, and air drying instead of tumble drying. *Elimination of tumble drying and ironing, combined with lower wash temperature, may result in a halved climate impact of the product*.

"Laundry treatments at high and low temperatures" is a document of a UK governmental website that provides information aimed at ensuring cleaning and disinfection of infected linen. This may apply to hospitals or anywhere the care of the sick is undertaken (54).

10. Efforts of some brands and associations towards sustainability

Some brands support regenerative farmers. Regenerative agriculture is aimed at the conservation and rehabilitation of agricultural soils, with enhancement of the ecosystem services: improved water cycle, biodiversity, soil health and resilience to climate change (21). Regenerative agriculture contributes to atmospheric CO_2 sequestration, which applies in particular to organic hemp.

The website of a brand provides information aimed at sustainability. From here, the link to lifecycle responsibility includes a *care programme that deals with, e.g. garment care and storage, preserving colour and repair* (22).

"The European market potential for sustainable materials" (21) discusses the purchasing behaviour of consumers. In some countries, a lack of trust in fashion companies and their sustainability claims prevents consumers from buying sustainable products. In other cases, eco-consciousness is not yet prevalent in the population, or price is an obstacle to more responsible consumption.

Ecolabels may enable consumers to select products, e.g. made by sustainably sourced materials, durable, and with restricted use of hazardous chemicals (1 from page 30).

An educational document outlines some techniques that may improve the sustainability of the fashion industry; for instance, utilising the fabric that usually would remain on the cutting room floor to create new garments (11). Decisions made during the design stage of clothing are important for sustainability. For instance, *garments that incorporate pleats that can stretch are likely to be utilised longer by growing kids*.

A Dutch company utilises supercritical CO_2 to dissolve the dye used for colouring fabrics; the process does not use water and hence does not produce wastewater. In addition, since the dyed fabric is dry at the end of the process, no drying is required, while most of the CO_2 is then recaptured and reused (11 / 58).

"Putting the brakes on fast fashion" is a document of the UN Environment Programme. It deals with some entrepreneurs who are already designing the fashion of the future, for instance, collecting and turning ocean plastic into shoes, bags and clothing (52).

According to "Circular economy: From abandoned fishing nets to sustainable clothing", a project encouraged Basque fishers and local people to collect abandoned fishing nets. This material has been recycled in manufacturing new clothing while reducing oil consumption and limiting CO_2 emissions (69). A video shows the collection of old nets from the sea. An acoustic scanner may assist in identifying objects, thus making underwater cleaning operations more efficient and less costly (69> Euronews Ocean).

The abandoned nets are very dangerous for marine organisms that continue to remain trapped there. The nets degrade very slowly, with the resulting material contributing to microplastic pollution (69> Euronews Ocean / 70).

A video shows the recovery of nets in the sea. The industrial processing includes reproducing the monomer, which is then re-polymerised to produce textiles. According to Mr. G. Bonazzi, CEO of Aquafil, the process produces a first-grade material that can be recycled an unlimited number of times (70).

Table 7 (71) of "Abandoned, lost or otherwise discarded fishing gear" summarises the environmental, economic and social costs they imply. Again, according to the FAO document, besides the fish lost from the fishery because they are trapped in abandoned nets and the unnecessary suffering of the fish, the nets may also imply navigation hazards (71 figures 16 and 8).

11. Circular economy, textile repair and reuse

Better working conditions in the textile industry may result in higher product prices. This contributes to preventing the over-consumption and over-production that generate huge amounts of products that end up as waste. Selecting locally produced items may result in reduced worldwide shipping and the creation of local jobs (1).

In a circular economy, the designer, through a careful selection of colours and style, can avoid the production of items that are quickly disposed of because they are perceived as out-of-fashion. The use phase of products can be prolonged thanks to resistant materials that are free of harmful chemicals, and designed so that the parts are easily disassembled to allow repair, component reuse, or recycling (1).

There is a growing interest in service-based businesses where the customer pays to use a product instead of buying it. This implies that *the producer is incentivised to select materials and product designs that make the product durable, easy to maintain, and to repair*. The potential for subsequent reuse is also important in view of the conservation of the value; ease of recycling and delayed disposal are also important (1). Particularly attractive is the rental of garments that are used for short periods, such as pregnancy's and children's clothes.

According to a UK study, leasing clothes may prolong their potential life. This is already occurring for clothes used for both work and specific short-term purposes (51).

12. Supporting repair and reuse

In Paris, there are shops called "Les Recycleries"; here, used articles that people do not need any more while still having a value are collected, repaired and resold (32 Box 19). The municipality partially supports these shops that employ long-term unemployed and disadvantaged groups. Besides this social function, in 2016, they collected 2,665 tons of articles, thus diverting most of them from landfill, incineration and recycling; in meanwhile, the City of Paris saves 200 Euro/ton on municipal waste collection and incineration.

Sometimes, the consumer has no interest in clothes repair because it is more expensive than the replacement of the item. As a support policy, *Sweden has reduced the taxation on repair services to make them more competitive*. Practical courses may help people learn sewing and mending, while awareness campaigns aimed at promoting longer use of items could also play an important role (1).

A promising option aimed at improving the competitiveness of second-hand stores consists of providing them with a space at a low cost. The implementation of *reduced taxation on second-hand sales might stimulate businesses based on reuse* (19).

In the Netherlands and Flanders, regions/municipalities partially subsidise collection and sorting, which provides environmental benefits, while employing and training socially marginalised people (31).

"Repair your clothes or other textile items yourself or drop by the Repair Café!" this is a proposal of Repair Café, that we can find in many countries (55> Repair Café in your area). From this website a link helps people to start their own Repair Café.

Reused clothes laundered many times may contain fewer chemicals, thus being preferable from a health point of view (1 page 32).

13. Textile recycling and reuse

From the environmental point of view, textile reuse is much more advantageous than recycling, while also offering opportunities for low-skilled employment (1).

"LCA-based assessment of the management of European used textiles" compares water and energy uses in producing new and reused t-shirts and the different environmental impacts of reuse and recycling (44 graphs).

The transport is the only important contributor to the overall environmental impact for reused t-shirts, with sorting accounting for only 5%, while water use is minimal. In producing new t-shirts, the amount of energy used is so high that transport is the smallest contributor to the environmental impact. In addition, a lot of water is used in this latter process (44). Table 19 compares CO_2 emissions and water use for both new and reused t-shirts. Producing durable garments, besides resulting in a longer first-use phase, favours the reusability of the item.

In Europe a small percentage of second-hand clothing is purchased, and a large share of it is exported in Africa and Asia for reuse or recycling. In Uganda, this percentage is 81%. *But, in Sub-Saharan countries, an oversupply of used clothing combined with cheap clothing imports from Asia, had been associated with the decline of the local textile industry*. For this reason, several African countries announced their intention to stop importing used clothing from the US and Europe. From 2025, the member states of Europe will be obliged to collect textiles separately, which implies the need to find suitable outlets for large and growing volumes of textiles, for instance, by recycling (1 / 31 / 51).

A Swedish study has estimated the consequences that a significant increase in the collection of used textiles in Europe may imply and what measures are necessary to maintain an economically attractive business for the market actors (31). The study is based on trade statistics and on interviews with actors involved in the collection, sorting and wholesale of used textiles. According to the interviews, *European textile exports cannot continue in large amounts, and we need to reduce their consumption through more sharing, greater reuse, and less fast fashion*.

"Used Textile Collection in European Cities" deals with successful approaches to the collection of used textiles, which may inspire other city municipalities and actors to adopt and further develop these approaches. For instance, *placing containers in schools and nurseries has proved strategically effective because, besides the educational value, there is a quick turnover and a high value of children's clothing for reuse* (32 / 46).

Textiles not collected separately become municipal solid waste (1). Better sorting of the used garments intended for export is important to avoid exporting items that will not be reused in the recipient countries, thus ending up as waste after long and useless transportation (44).

Table 2.1 (1) shows recycling processes for major fibres/textiles. As shown in figure 2.9, a broad variability exists as for the percentage of textiles collected separately in the European countries.

According to "Why Fashion Needs to Be More Sustainable", less than 1% of clothing is recycled into new clothes. *The fibres are constituted by polymers that, as a consequence of wearing and washing, become too short to create a new strong fabric* (11).

A video shows a Pakistani factory where virgin cotton is mixed with up to 30% of used cotton from old jeans to recreate new pairs. In fact, recycled fibres are too short and need to be mixed with virgin cotton (62).

According to "Could the recycled yarns substitute for the virgin cotton yarns: a comparative LCA", cotton recycling may relieve resource and environmental problems, as summarised in figure 6 (48).

A video from the Italian Recycled Textile Association shows the mechanical wool recycling process (73).

"How is a recycled wool fabric made?" is a document of a textile company (72). Wool, is a durable and an easily recyclable fibre. In this company, wool recycling does not imply use of dyes and other chemicals. The sorting process of post-consumer garments and production scraps implies, inter alia, dividing the material by colour and composition. Thanks to this part of the process, the colour of the recycled wool can be created by simply mixing different shades of wool fibres, and without the use of dyes and chemicals.

14. Production and recycling processes of synthetic fibres

Polyester production consumes 70 million barrels of oil annually (11).

"How It`s Made Polyester" shows the production process of polyester cloth from plastic bottles (63 video).

According to "Polyethylene terephthalate (PET) recycling: A review", mechanical recycling is the most common method used. PET products are shredded into small pieces, cleaned, melted down, and then molded into new products, including fibres (35). This is a cost-effective and energy-efficient method but the quality of the resulting material is suboptimal, with some contaminants that persist despite decontamination processes.

Conversely, chemical recycling implies breaking down the long chain of PET molecules into its individual monomers. After de-polymerisation, the contaminants are removed, then the product is re-polymerised and formed again. This process results in a high-quality recycled PET, with properties similar to those of the virgin product, that can be used even in demanding applications. The potential for chemical recycling is significant despite some *challenges that need to be overcome, such as the development of more efficient and cost-effective industrial processes* (35).

Bio-recycling is a novel technique that uses enzymes to de-polymerise PET products and may result in high-quality monomers. After decontamination, these latter are re-polymerised, which results in a new polymer whose properties are similar to those of the virgin PET. Bio-recycling may overcome some limitations of mechanical and chemical recycling; *this method needs further research and optimisation, however, in order to become commercially viable* (35).

"Techno-economic, life-cycle, and socioeconomic impact analysis of enzymatic recycling of poly(ethylene terephthalate)" deals with process modeling of the enzymatic de-polymerisation for PET recycling (68). According to the study, the process may achieve cost parity, while substantially reducing energy use and greenhouse gas emissions relative to virgin polyester production.

"Patagonia's Common Threads Garment Recycling Program: A Detailed Analysis" is a study carried out by a private company. In Japan, the company collects worn-out garments from local customers, that will be broken down to make recycled polyester fibres. *When locally collected polyester is used, only 11,962 MJ are necessary* (38 table at page 8).

The experiment also evaluated the use of garments collected in the US and then shipped to Japan for recycling. In this case, due to increased energy costs consequent to the transcontinental shipment, 17,733 MJ were necessary (38). Conversely, when fossil fuels are used, as much as 72,422 MJ are necessary to produce one metric ton of the precursor chemical of polyethylene terephthalate.

15. Textile contamination and recycling

"Poly (ethylene terephthalate) recycling for high value-added textiles" discusses, inter alia, the problems encountered when post-consumer PET is recycled, *with contamination playing a major role* (36). Contamination cannot be admitted for technical reasons; therefore, it should be minimised. Paper, glue, and dyes used for colouring bottles may cause undesirable effects. Contamination may also occur when PET bottles are used to store chemical products.

"Recent advances in recycling technologies for waste textile fabrics: a review" deals with the recycling of textile blends. To achieve desirable properties, fibres are often blended, which compounds the recycling process and often results in textile waste being landfilled (37 table 2). For instance, elastane may impart elastic properties to textiles, and is commonly blended in small percentages with other fibres, *which makes recycling difficult or impossible*.

Chemical products, such as dyes, antimicrobial finishes, fabric softeners, and flame retardants, may remain in textile products up to end-of-life despite the launderings undergone. *Fast fashion items, may reach the end-of-life after just a few washing cycles, with certain chemicals not yet washed-off and a limited knowledge on their effect on the recycling processes* (37).

16. Extended Producer Responsibility (EPR)

EPR is an environmental policy where the responsibility of the producer includes the post-consumer stage of the product's life (5 / 1). The municipalities or the retailers make available collection points where the consumers discard end-of-life products (5).

According to the Polluter-Pays principle, the polluter should bear the expenses of preventing and controlling pollution to ensure environmental conservation (57 / 5). *EPR transfers the financial responsibility of the end-of-life management of the products from the* *taxpayer to the producer. The cost of disposal can be incorporated into the price of the product. In this way, the price represents the real cost of the product.*

EPR provides incentives to create products that, from the design stage, are aimed at reducing the life cycle impacts (57 / 5). *In particular, a reduced use of toxic and hazardous materials and an easier disassembly of the product increase the possibilities of reuse and recycling while allowing the producer to retain the maximum value of the materials.*

A document of the Organisation for Economic Co-operation and Development (56) has several links, including a video entitled "Extended Producer Responsibility and the Impact of Online Sales".

EPR can be voluntary or mandatory. A guidance manual for governments provides information and concepts (57).

According to a 2019 document (1), France is the only country that has implemented EPR policy for clothing, linen and shoes. The document also outlines some challenges that this country has encountered.

"Extended Producer Responsibility - An examination of its impact on innovation and greening products" considers EPR in industrial sectors other than textile (60). Thanks to EPR, some producers decided to eliminate some toxic substances from their products. *In fact, when toxic substances are eliminated at source, the cost of waste management, and not only the hazards for health and environment, are reduced*.

Some car manufacturers have created cooperation between vehicle dismantlers and designers, aimed at enabling the latter to learn about design for end-of-life (60).

17. Design for recycling

"Textile eco-design guidelines to improve recyclability" provides guidelines aimed at an easy repair or recycling of products (67).

Box 4.3 (1) shows a set of jeans redesign guidelines. *A garment should be easy to disassemble, for instance, without metal rivets and with any different material easy to disassemble*. A German outdoor company developed a simple and innovative approach aimed at improving the recyclability of garments. This company obtained from the suppliers that all the materials constituting the garment, including fabric, zips and labels, were made with 100% polyester. This *mono-material* product results in an easier and less costly recycling process (34 page 22). The recycled fabric, while not being of the required quality to be used again for apparel, was suitable, e.g. for creating seat covers and office furniture.

A document deals with a US university student competition, focusing on the design for easy disassembly and recycling of a jacket. Both wool and dyes used for the outer shell of the jacket were certified as safe for humans and the environment. The outer shell was sewed using cotton thread, and wooden buttons were used for this jacket so that all these materials could be composted together (41). The lining of the jacket was made of 100% polyester fabric, and its parts were also sewn using 100% polyester thread in order to provide the best conditions for easy recycling of this material. All the prototypes proved to be disassembled very easily and quickly.

According to "Gaining benefits from discarded textiles", the content of chemicals in post-consumer textiles is often unknown. At the sorting stage of used textiles, however, products known for the presence of hazardous chemicals are kept separate in order to minimise the risk of contamination. However, in some cases, hazardous chemicals found in dyes cannot be distinguished and separated (45).

According to a report of the Swedish Environmental Agency reviewed in the document (45), in some recycling processes all the substances present in the old product end up in the recycled product. The document provides a list of product types that could be unsuitable for recycling as a consequence of the chemicals they may contain.

However, regulating the content of chemicals in the new textiles is the first instrument aimed at preventing hazardous substances from ending up in the recycled textiles.

Conflict of Interest Statement

The author declares no conflicts of interest.

About the Author(s)

The author is a former middle school teacher and wrote about 75 educational papers starting 37 years ago. Areas of interest: Health Education, Environmental Education and Prevention of Natural Disasters. The author has a University Degree in Biology.

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