SUSTAINABLE TEXTILES

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Abstract

Textile and fashion products are manufactured, distributed, sold and used worldwide, so the textile and fashion industry have a major impact on the environment. Environmental issues are playing an increasingly important role. The analysis of sustainability in this context is therefore extremely important. The training material entitled “Sustainable textiles” is a compilation of scientific, technical, economical, and environmental data of the various processes (from different publications and reports) and presents different aspects of the sustainable development of textiles. It is structured in eight major sections:
1. Sustainability - concepts and definitions: where are presented general aspects about sustainability and in particular about the textile and fashion industry sustainability.
2. Textiles and fashion impacts: some general considerations regarding the impacts, the textile processes and their impact, Clean by Design, and several aspects about how textile and fashion industry could become green.
3. Eco fibres and textiles: focused on natural fibres, man-made fibres, innovations linked with eco-friendly fibres, biodegradable and sustainable fibres.
4. Environmental aspects of textile finishing: includes some general considerations and problems regarding dyeing, dyes, eco finishing and their impact on the environment.
5. Green chemistry and the textile industry: in this chapter are presented aspects about green chemistry, its principles, non-eco-friendly substances and green chemicals.
6. Tools in assessing the sustainability: the main tools presented are Sustainable Textile Production (STeP), The Higg Index, The sustainable apparel index, which are completed with some aspects regarding standard test methods used for sustainability and eco labels.
7. Life cycle analysis: with general aspects regarding the supply chain, Life Cycle Assessment (LCA) and techniques used in LCA.
8. The consumer and future challenges: the final considerations and aspects presented are linked with the consumers and their attitude regarding the sustainability, and future challenges regarding sustainable textiles.

1 SUSTAINABILITY – CONCEPTS AND DEFINITIONS

Environmental issues are playing an increasingly important role in the textile industry, both from the point of view of government regulation and consumer expectations.

Almost everywhere in the world and in all industries, the sustainability movement has been manifested. In this context, it has to be mentioned that the textile industry is one of the biggest polluters. Sustainable textiles have grown in popularity because of the moral consciousness that many people feel, among others. A number of fashion and design companies are shifting their unsustainable ways also [1].

1.1 About sustainability

Sustainability is a systemic concept, relating to the continuity of economic, social, institutional and environmental aspects of human society. It is intended to be a means of configuring civilization and human activity so that society, its members and its economies are able to meet their needs and express their greatest potential in the present, while preserving biodiversity and natural ecosystems, and planning and acting for the ability to maintain these ideals indefinitely. Sustainability affects every level of organization, from the local neighborhood to the entire planet.

Sustainability may be described as our responsibility to proceed in a way that will sustain life that will allow the next generations to live comfortably in a friendly, clean, and healthy world; that people [2]:

- take responsibility for life in all its forms as well as respect human work and aspirations;
- respect individual rights and community responsibilities;
- recognize social, environmental, economic, and political systems to be inter-dependent;
- weigh costs and benefits of decisions fully, including long-term costs and benefits to future generations;
- acknowledge that resources are finite and that there are limits to growth;
- assume control of their destinies;
- recognize that our ability to see the needs of the future is limited, and any attempt to define sustainability should remain as open and flexible as possible."

Sustainability is meeting the needs of all humans, being able to do so, on a finite planet, for generations to come while ensuring some degree of openness and flexibility to adapt to changing circumstances [3].
Sustainability is based on a simple principle: everything that we need for our survival and well-being depends, either directly or indirectly, on our natural environment. Sustainability creates and maintains the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic and other requirements of present and future generations. Sustainability is important to ensure that we have and will continue to have the water, materials and resources to protect both human health and our environment [4].

Sustainable development is the one that meets the needs of the present without compromising the ability of future generations to meet their own needs. [Page 8, World Commission on Environment and Development. Our Common Future. (Oxford, Great Britain: Oxford University Press, 1987; Frequently referred to as the Brundtland report after Gro Harlem Brundtland, Chairman of the Commission)].

"Sustainable Development is positive change which does not undermine the environmental or social systems on which we depend. It requires a coordinated approach to planning and policy making that involves public participation. Its success depends on widespread understanding of the critical relationship between people and their environment and the will to make necessary changes." [5]

"Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Companies aiming for sustainability need to perform not against a single, financial bottom line but against the triple bottom line." "Over time, human and social values change. Concepts that once seemed extraordinary (e.g. emancipating slaves, enfranchising women) are now taken for granted. New concepts (e.g. responsible consumerism, environmental justice, intra- and inter-generational equity) are now coming up the curve." [6]

The Sustainable development contains two key concepts:

- The essential needs of the world’s poor to which overriding priority should be given;
- The limitations imposed by the state of technology and social organization on the ability of the environment to meet present and future needs.

Sustainable development is a long term strategy including economic, social and environmental resources (materials). This goal means that:

- Society becomes aware of a common responsibility;
- Environmental protection becomes an integrated search for solutions;
- Industry itself takes the responsibility for preventing pollution.

Corporate Social Responsibility is the continuing commitment by business to behave ethically and contribute to economic development while improving the quality of life of the workforce and their families as well as of the local community and society at large [7].

Business sustainability is often defined as managing the triple bottom line, a process by which companies manage their financial, social and environmental risks, obligations and
opportunities. These three impacts are sometimes referred to as profits, people and planet. However, this approach relies on an accounting based perspective and does not fully capture the time element that is inherent within business sustainability. A more robust definition is that business sustainability represents resiliency over time – businesses that can survive shocks because they are strongly connected to healthy economic, social and environmental systems. These businesses create economic value and contribute to healthy ecosystems and strong communities. Business sustainability requires firms to adhere to the principles of sustainable development. There are a number of best practices that foster business sustainability and help organisations move along the path from laggards to leaders. These practices include [8]:

- **Stakeholder engagement**: Organisations can learn from customers, employees and their surrounding community. Engagement is not only about pushing out messages, but understanding opposition, finding common ground and involving stakeholders in joint decision-making.

- **Environmental management systems**: These systems provide the structures and processes that help embed environmental efficiency into a firm’s culture and mitigate risks. The most widely recognized standard worldwide is ISO 14001, but numerous other industry-specific and country-specific standards exist.

- **Reporting and disclosure**: Measurement and control are at the heart of instituting sustainable practices. Organisations can not only collect and collate the information; they can also be entirely transparent with outsiders. The Global Reporting Initiative is one of many examples of well-recognised reporting standards.

- **Life cycle analysis**: Those organisations wanting to take a large leap forward should systematically analyse the environmental and social impact of the products they use and produce through life cycle analysis, which measure more accurately the impacts.

**Sustainable businesses** [9]:

- Replace nationally and internationally produced items with products created locally and regionally.
- Take responsibility for the effects they have on the natural world.
- Do not require exotic sources of capital in order to develop and grow.
- Engage in production processes that are human, worthy, dignified, and intrinsically satisfying.
- Create objects of durability and long-term utility whose ultimate use or disposition will not be harmful to future generations.
- Change consumers to customers through education.

The increasing importance of sustainability, as the concept for doing business worldwide, demands the commitment of producers to deliver a sustainable product. Companies worldwide have to be consistently committed to minimising the environmental impact of their products and processes by [10]:

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[8] Stakeholder engagement
[9] Sustainable businesses
[10] Minimising environmental impact
- maximising efficiencies in the use of resources (raw materials, energy and water),
- continuous reduction of waste, and optimal utilisation of unavoidable waste,
- further reducing emissions,
- being innovative and by the development of products and applications with an enhanced sustainability profile,
- respecting and going beyond the high standards of work safety and social conduct.

The term **sustainable industries** appeared in 1990 in a story about a Japanese group reforesting a tropical forest to help create sustainable industries for the local population (Dietrich, B., "Our Troubled Earth – Japan", *The Seattle Times*. November 13, 1990, page F-2.). Soon after, a study entitled “Jobs in a Sustainable Economy” by Michael Renner of the Worldwatch Institute was published, using the term sustainable industries (1991). The main reason: non-polluting, environmentally sustainable industries tend to be intrinsically more labour intensive and less resource intensive than traditional processes. Among the features of sustainable industry are energy efficiency, resource conservation to meet the needs of future generations, safe and skill-enhancing working conditions, low waste production processes, and the use of safe and environmentally compatible materials. Some of the benefits however would be offset by higher prices (due to labor costs) and a theoretically larger population needed to perform the same amount of work, increasing the agricultural and other loads on the system [11].

For industrial development to be sustainable, it must address important issues at the macro level, such as: **economic efficiency** (innovation, prosperity and productivity), **social equity** (poverty, community, health and wellness, human rights) and **environmental accountability** (climate change, land use, biodiversity).

**Sustainable manufacturing** is defined as the creation of manufactured products that use processes that:
- are non-polluting;
- conserve energy and natural resources;
- are economically sound and safe for employees, communities and consumers.

**Sustainable practice** means that:
- commitment extends beyond the company and customers;
- community and environment are important as well. [12]

**Sustainable Production** is the creation of goods and services using processes and systems that are [13]: non-polluting; conserving of energy and natural resources; economically efficient; safe and healthful for workers, communities, and consumers; socially and creatively rewarding for all working people.

Sustainability means tangible actions and concrete facts, such as (figure 1) [14]:

The main Principles of Sustainable Production are [15]:

√ Products and services are:
  - safe and ecologically sound throughout their life cycle;
  - as appropriate, designed to be durable, repairable, readily recycled, compostable, or easily biodegradable;
  - produced and packaged using the minimal amount of material and energy possible.

√ Processes are designed and operated such that:
  - wastes and ecologically incompatible byproducts are reduced, eliminated or recycled on-site;
  - chemical substances or physical agents and conditions that present hazards to human health or the environment are eliminated;
  - energy and materials are conserved, and the forms of energy and materials used are most appropriate for the desired ends;
  - work spaces are designed to minimize or eliminate chemical, ergonomic and physical hazard.
Workers are valued and:

- their work is organized to conserve and enhance their efficiency and creativity;
- their security and well-being is a priority;
- they are encouraged and helped to continuously develop of their talents and capacities;
- their input to and participation in the decision making process is openly accepted.

Communities related to any stage of the product lifecycle (from production of raw materials through manufacture, use and disposal of the final product) are respected and enhanced economically, socially, culturally and physically.

Continued economic viability does not depend on ever-increasing (i.e., unsustainable) consumption of materials and energy.

**Renewable resources** are [16]:

- A substance of economic value that can be replaced or replenished in the same amount.
- Some renewable resources have essentially an endless supply, such as solar energy, wind energy and geothermal pressure, while other resources are considered renewable even though some time or efforts must go into their renewal, such as wood, oxygen, leather and fish.
- Most precious metals are considered renewable as well; even though they are not naturally replaced, they can be recycled because they are not destroyed during their extraction and use.

### 1.2 The textile and fashion industry and the sustainability

The textile industry is one of the longest and most complex and complicated industrial chains of the manufacturing industry. It involves actors from agricultural, chemical fibers, dyes and chemical manufacturing, textile and apparel industry, retail and service sector, and waste treatment [16].

In recent years ecological issues have become more and more important especially in the textile and apparel industry, an industry not noted for eco-friendliness. Every textile item releases toxic substances that are harmful to the environment. The traditional textile industry consumes large amounts of natural resources and pollutes the environment because their production and processing involves Chemical Intensive Applications; therefore is a stringent need for green textiles. Controlling pollution is as vital as making a product free from the toxic effect during the production processes. The utilization of rayon for clothing has added to the fast depleting forests and opened the door to the development in natural sustainable fibres like organic cotton, hemp and bamboo fibres. Petroleum-based products are harmful to the environment. An integrated pollution control approach is needed in order to safeguard the environment from these negative effects. Fabrics made in eco-friendly way can substitute the products that are not sustainable. *Green textiles* refer to clothing and other accessories that are
designed to use organic and recycled materials, less packaging and more energy-efficient manufacturing. The reduction of the environmental impact throughout the life-cycle of a fabric item or the use of lower impact products can contribute to the improvement of the actual situation. There are four major environmental key factors associated with the production of textiles: water, energy, pollution, and use of non-renewable resources [17].

**Sustainable textiles**

Sustainable textiles mean that all materials and process, inputs and outputs, are healthy and safe for human and environment, in all phases of the product life cycle and all the energy, material and process inputs come from renewable or recycled sources. It can also mean that materials are capable of returning safely to either natural or industrial systems and all stages in the product life cycle could enhance social well being too. **Sustainable textiles** mean ways of achieving more sustainable materials and technologies as well as improving recycling in the industry. **Sustainability in textiles** refers to the use of resources without exhausting them [18].

The definition of Sustainable Textiles involves [18]:

- All materials and process inputs and outputs are safe for human and ecological health in all phases of the product life cycle.
- All energy, material and process inputs come from renewable or recycled sources.
- All materials are capable of returning safely to either natural systems or industrial systems.
- All stages in the product life cycle actively support the reuse or recycling of these materials at the highest possible level of quality.
- All product life cycle stages enhance social well being.

Sustainable fabrics and textiles are essentially produced with limited impact to the environment and community and can be categorized in the following ways [19]:

- **Organic**: A crop which is cultivated using organic agricultural principles such as bio fertilisers and organic manures. The crop is cultivated without pesticides, chemicals or synthetic fertilizers, for example: hemp, organic cotton, organic ramie/jute (linen). Organic wool can be included here if the sheep have been raised on ‘organic’ land and the finished yarn is produced and coloured with organic pigments.

- **Eco Textiles**: A textile product which is produced in a conscientious eco-friendly manner and processed under eco-friendly limits (defined by agencies like OEKOTEX, IFOAM etc.). Natural fibres such as organic cotton, hemp, jute and ramie are considered eco textiles based on the process of cultivation.

- **Recycled & biodegradable**: Natural and synthetic fibers and textiles which are biodegradable and/or can be broken down into pieces in order to produce more textiles or convert into fibres.
- **Textile Processes and Sustainability**: There are many processes which must be taken into consideration to produce sustainable fabrics and textiles including the cultivation, spinning, dying, printing and finishing processes. Essentially, the fewer chemicals, water, energy and effluent disposals are used in the processing of textiles, the better it is for the environment.

- **Buying and Producing Locally.**

**Sustainable fibers**

Many people consider that a ‘sustainable fibre’ is an organic fibre or a natural one. They will reject any man-made fibres on the ground that they damage the environment. But some man-made or synthetic fibres can be more sustainable than natural ones as they do not use as many resources as the ‘natural fibres’.

The debate over how sustainable natural fibres are is based in general on the water and energy consumption during the production of the fibres. Unless the fibres are organic, then harmful chemicals are often used which not only damage the environment, but are also responsible for thousands of deaths a year. The amount of energy used in turning the cellulose of plants (like cotton or ramie) into a fibre can be huge and very damaging if the energy source is non-renewable. The water consumption of growing natural fibres often leaves others without clean water, and can damage the surrounding soil, making it infertile. [19]

Key sustainability challenges in fibre production vary for different materials, so it is important to assess individual processes, resources consumed and impacts, such as:

- significant use of energy and non-renewable resources for synthetics;
- emissions to air and water from producing synthetic and cellulosic fibres;
- adverse impacts to water linked to natural fibre production.

Regarding *Man-Made Fibres (MMF)*, the MMF Industry in particular has a long history in the pursuit of initiatives which support sustainability. The responsible care programme has been adopted in many countries, and has been applied by man-made fibre producers, since 1992.

The consumption of energy, raw materials and all other resources, and also the emission of solid, liquid and gaseous waste determine the sustainability of man-made fibres, just like for any other product. We should not forget the in-use phase, in which substantial environmental savings can be made, as well as the disposal or recycling phase. Improving the sustainability of man-made fibres is the guiding principle to improve ecological, economical and social performance. [20]

**Sustainable design**

Fashion by its very nature is a consuming business and *eco, green, natural* clothing has been in trends for many years. However, all the hype about clean green textiles did leave the legacy of a genuine concern about the impact of textiles on the environment.
Designers can make a difference by:

- understanding the theoretical, technical and practical considerations of the entire production process of a product;
- asking questions;
- collaborating with technologists, scientists, growers, manufacturers and marketing departments;
- understanding the performance and aesthetic qualities that are high on the consumer agenda;
- understanding how the consumer will use the product.

[Adapted from Raath, J., 2000, Sustainable textile practices workshop, TEA Conference Leura]

**What is Eco-Design?**

Eco-Design is not only about dismissing the fundamental principles of design in the favour of environmental benefits. Positive environmental outcomes can be achieved during the design stages to ensure the best performance or result that can be delivered without compromising the form or function.

Textiles and fashion eco-design is not just about 'eco-material' selection; it is also about making decisions that will reduce the overall environmental impacts or improve efficiency of the product throughout its entire life. This also introduces the issue of "sustainable consumption" where textile materials are used in such a manner so as to reduce consumption and to make them more sustainable [21].

**Why Go Organic or Eco Friendly?**

The main important aspects in this context are:

- **Social responsibility**: Chemicals and pesticides invade drinking water and groundwater, polluting its fish and even reaching human consumption. Organic and eco fibers grow without any pesticides or chemical fertilizers.

- **Biodegradable**: Eco and organic fabric biodegrade naturally over time. Synthetic fibers eventually become waste and let off harmful toxins when they degrade.

- **Health**: Many people are allergic or dislike wearing synthetic textiles. Eco fabrics have the properties of the new synthetic breathable fibers with added softness and drape; they feel better against the skin.

- **Absorption**: Conventional clothing is worn next to the most porous organ, the skin, and its chemicals could reach the groundwater. Organic and ecofibers are natural and do not contain irritating chemicals. Many of them are also considered hypoallergenic and naturally antibacterial.
● **Popularity:** It is a natural evolution that organic and eco friendly fabrics will gain popularity. Eco and Organic fabrics once considered an alternative are now entering into the mainstream.

As environment protection appears to be obvious, there is a growing need for the textiles with natural material derived, recycle & reuse and minimize energy use. The goals of eco-textiles are sustainable use of resource, clean production and healthy products, but all of them need to be certificated by certification systems, such as GOTS, OE (for organic textiles), GRS (for recycled textiles), and MBDC System (for cradle to cradle products) [22].

Many companies are taking the initiative to invest in sustainable technologies. Many firms are realizing that it is important to their growth and their own sustainability to be green.

There are many sustainable contributions to be made in the textile industry before the clothes even reach the consumer. Competitive solutions could be found, from pretreatments to the finishing touches, which help manufacturers to meet the challenges of producing high-quality fabrics in a cost-efficient and environmentally friendly manner.

There are lots of initiatives under way to produce overall sustainable textile products and the efforts are taken by responsible important players in the market and along the textile value chain, including textile machinery manufacturers too.

There are developed cleaner and sustainable manufacturing processes in order to overcome the image of a so called “dirty” textile industry, polluting water and environment during the life cycle of a product and also presenting a threat to the health of the end customers. Some facts have to change and the efforts undertaken up to now are still insufficient to change the image of this industry. [16]

It is a constant need to create manufacturing networks in the European Union states to enhance process information exchange and best practice toward sustainable manufacture and growth in the textile sector. The sustainable growth in the textile production and consumption needs deep analyses in all the stages, as is suggested in figure 2 [23].

Sustainability issues in textiles require taking into account the influences emerging from outside the boundaries of the conventional textile industry. These ‘external’ influences - ranging from agricultural practices to international energy policies, passing through consumption patterns and levels of ecological notions of society - have a great influence on the sustainability of the sector as a whole. Ecological and social systems extend beyond the boundaries of companies and individual industries; therefore, in order to develop a more sustainable textile industry is needed a strong commitment with these issues at the level they correspond to and connect with other disciplines, industries, communities and international groups, beyond their own boundaries [24].
Figure 2: Example of complex analysis for sustainable development [23]
2 TEXTILES AND FASHION INDUSTRY IMPACTS

2.1 General considerations regarding the impacts

Environmental and social impacts of the textile and fashion industry are growing, but there are many ways that can not only reduce negative environmental impact, but also increase positive environmental and social benefits, mainly through informed choices of materials and intelligent design. Thinking critically about materials is just one option, which is not an isolated solution, but part of a chain of positive choices along the whole supply chain. Therefore there is a pressant need for fibre diversification and a growing availability of innovative fibres and fabrics.

Assessing the environmental impact or benefit of any fibre or material involves the assessment of numerous elements of the supply chain, from energy-efficient processes, chemical use and waste, to ethical labor and animal husbandry. To support such decisions, it is helpful to consider a combination of [25]:

- What criteria are the most important?
- What message is important for the brand?
- What values are important for the customer?
- Scientific fact – what are the proven benefits/downfalls of this fiber/fabric?

This includes fibre cultivation and processing, spinning, weaving, knitting, bleaching, dyeing and finishing, addressing the following main environmental principles:

✓ Water – the reduction of water use and wastage across the textiles supply chain.

✓ Waste – the utilization of identifiable waste streams for textile production and the reduction of waste creation throughout the textile supply chain.

✓ Energy – reducing the carbon impact across the supply chain.

✓ Biodiversity – the preservation and promotion of biodiversity, with an emphasis on diversification in textile fibres; it is moving away from a global dependence on raw materials that utilize unsustainable agricultural practices or result in the depletion of finite natural resources.

The textile processing major concerns are:
- Minimize pollution: air, water, land;
- Optimize resources: energy, water, chemicals;
- Workers safety;
- Consumer safety and satisfaction.

The textile value chain major ecological and social challenges are presented in table 1 [16]:

[Table 1]

[Table 1 content]
Table 1: The major ecological and social challenges (according to S. P. Abbas [16])

<table>
<thead>
<tr>
<th></th>
<th>Water</th>
<th>Effluent</th>
<th>Energy</th>
<th>Chemistry</th>
<th>Land</th>
<th>Society</th>
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</thead>
<tbody>
<tr>
<td>Cotton cultivation</td>
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<td>Spinning</td>
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<td>Weaving/knitting</td>
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<tr>
<td>Wet processing</td>
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<td></td>
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<tr>
<td>Garment making</td>
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Several authors and organisations have analysed the textiles and clothing industry impacts. Some of them are Slater (2000), Allwood et al. (2006), Fletcher (2008), Defra (2008), Ross (2009), Dickson et al. (2009) and Gwilt and Rissanen (2011). One specific study is Fashioning Sustainability: A Review of Sustainability Impacts of the Clothing Industry, which Stephanie Draper, Vicky Murray and Ilka Weissbrod conducted in 2007 for WWF, financed by Marks & Spencer. Figure 3 shows, schematically, environmental and social impacts of the textile, clothing and fashion industry [24].

Figure 3: Environmental and social impacts of the textile, clothing and fashion industry [24]
As the apparel industry is aware, the length of the supply chain (from the fibers, fabrics or other materials, all the way to the finished clothing) is quite long (figure 4) [97]. Because of the numerous processing steps involved in garment production, often conducted by different suppliers, the major environmental impacts of production usually occur before the Tier 1 (cut and sew) suppliers of brands and retailers.

![Diagram of materials to final disposal](source [97])

Textile and apparel production emits a large quantity of greenhouse gases (GHGs) in many phases of the product life cycle, from the growth of plants (like cotton) through textile manufacturing and dyeing, to consumers’ care. In order to find long-term solutions for these problems and provide better training for future industrial leaders, it is necessary to incorporate carbon footprint assessment into apparel design and merchandising. Therefore, the industry should be able to make more informed decisions in apparel design, production, sourcing, retailing, using, and reusing/recycling. However, due to the complexity of the apparel supply chain and lack of transparency in many phases of textile and apparel production, it is very difficult to assess the entire carbon footprint [26].

Textile and clothing is a labor-intensive industry. It has many working procedures which form flow processes. Each process has various influences on the environment and human health. The concrete effects are shown in figure 5 [96].
Among all the above factors, the environment influence includes exhaust fumes and waste water, materials pollutions, consumption of energy and water. Those harmful to human safety and health include excessive usage of pesticides and formaldehyde and other chemicals, noise pollution and air pollution in textile and clothing plants.

2.2 The textile processes and their impact

Regarding the sustainability issues in the textiles sector, the main focus is on social issues (such as child labour, working conditions and workers health and safety), but the environmental aspects in the production process are increasingly gaining attention. The main impacts can be summarised as follows (source TextileExchange):

- **Textile Environmental Impact:**
  - Water consumption: up to 600 L/kg;
  - Chemical consumption: 2000 different chemicals used daily;
  - Waste water discharge: salts, color, aquatic toxicity and so on.
√ Textile Energy Impact:
  • Energy consumption: electricity, dyeing, drying.

√ Textile Solid Waste Impact:
  • Solid waste:
    - manufacturing
    - post consumer
  • Air

√ Other important aspects are:
  - Textile waste occupies nearly 5% of all landfill space.
  - It takes 700 gallons of fresh water to make 1 cotton t-shirt.
  - In 2009, the world used 3 trillion gallons of fresh water to produce 132 billion pounds of fabric.
  - According to the World Bank: 20% of industrial fresh water pollution comes from textile treatment and dyeing.
  - 1 trillion kilowatt hours used every year by the global textile industry, representing 10% of the total global carbon impact.

Although environmental issues, like land use in the production of natural fibres (cotton, wool, bamboo), can also constitute an important environmental impact, these issues still receive limited attention in the European market. Environmental problems often occur in earlier stages of the supply chain (figure 6) [27], such as the primary fibre production through agricultural cultivation (natural and half-synthetic fibres) or chemical processing (synthetic fibres), the chemical pre-treatment or processing of fibres and the wet processing stage.

![Fibre production Chemical treatment/processing Spinning Knitting Weaving Wet processing CMI Buyer](image)

**Figure 6:** Schematic overview of the textile supply chain (source [27])

The main environmental issues are [27]:

a. Water use and pollution
b. Energy use
c. Chemical use

a. Water use and pollution

There are several ways to influence the water footprint of the product and its contribution to pollution; the main solutions and approaches are:
  - To be aware of the cotton water footprint of the product (and possibly adjust the design and the fabrics selection).
  - To consider non-cotton alternatives for the fabrics used.
To be aware of the impact of the wet-processing treatments on water use and pollution, when deciding on the look and feel of the product (e.g. colour, print, bleach, finishing); less treatment means less impact.

- To include suppliers in a dialogue on efficient water use and waste water treatment.
- To buy only from suppliers that offer (certified) fabric from water-efficient cultivation and textile mills.
- To consider performance on chemical use when selecting the suppliers. Hazardous chemicals may end up in waste water when irresponsibly used.

**b. Energy use and climate change**

Reducing the energy use within the supply chain will reduce costs and the negative impact on the environment; some examples are:

- To be aware of the energy consumption during the selection of fabrics and suppliers.
- To be aware of the energy consumption of the wet-processing treatments, when deciding on the look and feel of the product (e.g. colour, print, bleach, finishing); less treatment means less energy consumption.
- To define and implement a company energy strategy and action plan focusing on the company and the supply chains.
- To include the suppliers in a dialogue on efficient energy use and to provide them with information on energy saving measures.

**c. Chemicals**

Decisions taken in the design phase of the product impact have to take into consideration the chemical use the most. Examples of actions that can be taken are:

- To be aware of the chemicals necessary to meet the specific requirements (look, feel, colour, print) of the final product.
- To be aware of the use of chemicals when selecting fabrics and suppliers (certifications, specific requirements on the use of hazardous substances and/or information about the supplier’ management of chemical use).
- To look for suppliers that offer fabrics with specific chemicals claims that are relevant to the company and the buyer.
- To consider asking for alternatives for hazardous chemicals (e.g. natural dyes).
- To define a company strategy on restricted chemicals in the supply chain and further reduction of the risks of chemical use.
- To include suppliers in a dialogue on hazardous substances and the use of safe chemicals.

The textile processing industry is characterised not only by the large volume of water required but also by the variety of chemicals used for these processes. There is a long sequence of wet processing stages requiring inputs of water, chemical and energy and generating wastes at each stage. The other feature of this industry is the large variation in demand of type, pattern and colour combination of fabrics resulting into significant fluctuation in waste generation. Textile processing generates many waste streams, including liquid, gaseous and solid wastes.
some of which may be hazardous. The nature of the waste generated depends on the type of textile facility, the processes and technologies being operated, and the types of fibres and chemicals used. The overview on the amounts of waste generated within the textile processes are summarised in table 2 [28].

<table>
<thead>
<tr>
<th>Process</th>
<th>Emission</th>
<th>Wastewater</th>
<th>Solid wastes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber preparation</td>
<td>Little or none</td>
<td>Little or none</td>
<td>Fiber waste and packaging waste</td>
</tr>
<tr>
<td>Yarn spinning</td>
<td>Little or none</td>
<td>Little or none</td>
<td>Packaging wastes; sized yarn; fiber waste; cleaning and processing waste</td>
</tr>
<tr>
<td>Slashing/sizing</td>
<td>VOCs</td>
<td>BOD; COD; metals</td>
<td>Fiber lint; yarn waste; packaging waste; cleaning waste, size unused starch-based sizes</td>
</tr>
<tr>
<td>Weaving</td>
<td>Little or none</td>
<td>Little or none</td>
<td>Packaging waste; yarn and fabric scraps; off-spec fabric; used oil</td>
</tr>
<tr>
<td>Knitting</td>
<td>Little or none</td>
<td>Little or none</td>
<td>Packaging waste; yarn and fabric scraps; off-spec fabric</td>
</tr>
<tr>
<td>Tufting</td>
<td>Little or none</td>
<td>Little or none</td>
<td>Packaging waste; yarn and fabric scraps; off-spec fabric</td>
</tr>
<tr>
<td>Desizing</td>
<td>VOCs from glycol ethers</td>
<td>BOD from sizes</td>
<td>Packaging waste; fiber lint; yarn waste; cleaning and maintenance materials</td>
</tr>
<tr>
<td></td>
<td>and scouring solvents</td>
<td>lubricants; biocides; anti-static compounds</td>
<td></td>
</tr>
<tr>
<td>Scouring</td>
<td>VOCs from glycol ethers</td>
<td>Disinfectants,</td>
<td>Little or none</td>
</tr>
<tr>
<td></td>
<td>and scouring solvents</td>
<td>insecticide residues; NaOH; detergents, oils; knitting lubricants; spin finishes; spent solvents</td>
<td></td>
</tr>
<tr>
<td>Bleaching</td>
<td>Little or none</td>
<td>H₂O₂, stabilisers; high pH</td>
<td>Little or none, even if little, the impact could be considerable</td>
</tr>
<tr>
<td>Singeing</td>
<td>Small amounts of exhaust gases</td>
<td>Little or none</td>
<td>Little or none</td>
</tr>
<tr>
<td>Mercerising</td>
<td>Little or none</td>
<td>High Ph; NaOH</td>
<td>Little or none</td>
</tr>
<tr>
<td>Heat setting</td>
<td>Volatilisation of spin finish</td>
<td>Little or none</td>
<td>Little or none</td>
</tr>
<tr>
<td></td>
<td>agents synthetic fiber manufacture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyeing</td>
<td>VOCs</td>
<td>Metals; salt; surfactants; organic processing assistants; cationic materials;</td>
<td>Little or none</td>
</tr>
<tr>
<td>Process</td>
<td>Emissions and Wastes</td>
<td>Emissions and Wastes</td>
<td>Wastes</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------</td>
<td>----------------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>Printing</td>
<td>Solvents, acetic acid drying and curing oven emissions; combustions; gases</td>
<td>Suspended solids; urea; solvents; colour; metals; heat; BOD; foam</td>
<td>Little or none</td>
</tr>
<tr>
<td>Finishing</td>
<td>VOCs; contaminants in purchased chemicals; formaldehyde vapours; combustion gases</td>
<td>COD; suspended solids; toxic materials; spent solvents</td>
<td>Fabric scraps and trimmings; packaging waste</td>
</tr>
</tbody>
</table>

The textile manufacturing process is characterised by the high consumption of resources like water, fuel and a variety of chemicals in a long process that generates a significant amount of waste. The common practices of low process efficiency result in substantial wastage of resources and a severe damage to the environment. The main environmental problems associated with textile industry are typically those associated with water pollution caused by the discharge of untreated effluents. Other environmental issues of equal importance are air emission, notably Volatile Organic Compounds (VOCs) and excessive noise or odour, as well as workspace safety.

**Air pollution**

Most processes performed in textile mills produce atmospheric emissions. Gaseous emissions have been identified as the second greatest pollution problem (after effluent quality) for the textile industry. Speculation concerning the amounts and types of air pollutants emitted from textile operations has been widespread but, generally, air emission data for textile manufacturing operations are not readily available. Air pollution is the most difficult type of pollution to sample, test, and quantify in an audit.

Air emissions can be classified according to the nature of their sources:

- **Point sources**: boilers, ovens, storage tanks;
- **Diffusive**: solvent-based, wastewater treatment, warehouses, spills.

Textile mills usually generate nitrogen and sulphur oxides from boilers. Other significant sources of air emissions in textile operations include resin finishing and drying operations, printing, dyeing, fabric preparation, and wastewater treatment plants. Hydrocarbons are emitted from drying ovens and from mineral oils in high-temperature drying/curing. These processes can emit formaldehyde, acids, softeners and other volatile compounds. Residues from fibre preparation sometimes emit pollutants during heat setting processes.

Carriers and solvents may be emitted during dyeing operations depending on the types of dyeing processes used and from wastewater treatment plant operations. Carriers used in batch dyeing of disperse dyes may lead to volatilisation of aqueous chemical emulsions during heat setting, drying or curing stages. Acetic acid and formaldehyde are two major emissions of...
concern in textiles. The major sources of air pollution in the textile industry are summarised in table 3 [28].

Table 3: Summary of the major sources of air pollution generated during textile manufacturing [28]

<table>
<thead>
<tr>
<th>Process</th>
<th>Sources</th>
<th>Pollutants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy production</td>
<td>Emissions from boiler</td>
<td>Particulates, nitrous oxides (Nox), sulphur dioxide (SO₂)</td>
</tr>
<tr>
<td>Coating, drying and curing</td>
<td>Emission from high temperature ovens</td>
<td>Volatile organic components (VOCs)</td>
</tr>
<tr>
<td>Cotton handling activities</td>
<td>Emissions from preparation, carding, combing, and fabrics manufacturing</td>
<td>Particulates</td>
</tr>
<tr>
<td>Sizing</td>
<td>Emissions from using sizing compounds (gums, PVA)</td>
<td>Nitrogen oxides, sulphur oxide, carbon monoxide</td>
</tr>
<tr>
<td>Bleaching</td>
<td>Emissions from using chlorine compound</td>
<td>Chlorine, chlorine dioxide</td>
</tr>
<tr>
<td>Dyeing</td>
<td>Disperse dyeing using carriers</td>
<td>Carriers H₂S</td>
</tr>
<tr>
<td></td>
<td>Sulphur dyeing; Aniline dyeing</td>
<td>Aniline vapors</td>
</tr>
<tr>
<td>Printing</td>
<td>Emission</td>
<td>Hydrocarbons, ammonia</td>
</tr>
<tr>
<td>Finishing</td>
<td>Resin finishing heat setting of synthetic fabrics</td>
<td>Formaldehyde carriers – low molecular weight Polymers – lubricating oils</td>
</tr>
<tr>
<td>Chemical storage</td>
<td>Emissions from storage tanks for commodity and chemicals</td>
<td>Volatile organic components (VOCs)</td>
</tr>
<tr>
<td>Wastewater treatment</td>
<td>Emissions from treatment tanks and vessels</td>
<td>Volatile organic components, toxic emissions</td>
</tr>
</tbody>
</table>

Water pollution

The textile industry uses high volumes of water throughout its operations, from the washing of fibres to bleaching, dyeing and washing of finished products. Approximately 200 litres of water are required to produce 1 kg of textiles, on average (table 4). The large volumes of wastewater generated also contain a wide variety of chemicals, used throughout processing. These can cause damage if not properly treated before being discharged into the environment. Wet processing creates the highest volume of wastewater of all the steps involved in textiles processing [28].

The aquatic toxicity of textile industry wastewater varies considerably among production facilities. The sources of aquatic toxicity can include salt, surfactants, ionic metals and their metal complexes, toxic organic chemicals, biocides and toxic anions. Most textile dyes have low aquatic toxicity. On the other hand, surfactants and related compounds, such as detergents, emulsifiers and dispersants are used in almost each textile process and can be an important contributor to effluent aquatic toxicity, BOD and foaming.
Table 4: Average water consumption for various types of fabrics [28]

<table>
<thead>
<tr>
<th>Processing subcategories</th>
<th>Water consumption (m³/tone fiber material)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
</tr>
<tr>
<td>Wool</td>
<td>111</td>
</tr>
<tr>
<td>Woven</td>
<td>5</td>
</tr>
<tr>
<td>Knit</td>
<td>20</td>
</tr>
<tr>
<td>Carpet</td>
<td>8.3</td>
</tr>
<tr>
<td>Stock/yarn</td>
<td>3.3</td>
</tr>
<tr>
<td>Nonwoven</td>
<td>2.5</td>
</tr>
<tr>
<td>Felted fabric finishing</td>
<td>33</td>
</tr>
</tbody>
</table>

Solid waste pollution

The main sources and types of solid waste in textile manufacturing are presented in table 5.

Table 5: Sources and types of solid waste in textile manufacturing [28]

<table>
<thead>
<tr>
<th>Source</th>
<th>Type of solid waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical operations of cotton and synthetics:</td>
<td>Fibers and yarns</td>
</tr>
<tr>
<td>- Yarn preparation</td>
<td>Fibers and yarns</td>
</tr>
<tr>
<td>- Knitting</td>
<td>Fibers, yarns and cloth scraps</td>
</tr>
<tr>
<td>- Weaving</td>
<td></td>
</tr>
<tr>
<td>Dyeing and finishing of woven fabrics:</td>
<td>Cloth scraps</td>
</tr>
<tr>
<td>- Sizing, desizing, mercerizing, beaching, washing and chemical finishing</td>
<td></td>
</tr>
<tr>
<td>- Mechanical finishing</td>
<td></td>
</tr>
<tr>
<td>- Dyeing and/or printing</td>
<td>Flock</td>
</tr>
<tr>
<td>- Dyeing and/or printing (applied finish)</td>
<td>Dye containers</td>
</tr>
<tr>
<td></td>
<td>Chemical containers</td>
</tr>
<tr>
<td>Dyeing and finishing of knitted fabrics</td>
<td>Cloth scraps, dye and chemical containers</td>
</tr>
<tr>
<td>Dyeing and finishing of carpets:</td>
<td>Yarns and sweepings</td>
</tr>
<tr>
<td>- Tufting</td>
<td>Selvage</td>
</tr>
<tr>
<td>- Selvage trim</td>
<td>Flock</td>
</tr>
<tr>
<td>- Fluff and shear</td>
<td>Dye and chemical containers</td>
</tr>
<tr>
<td>- Dyeing, printing and finishing</td>
<td></td>
</tr>
<tr>
<td>Dyeing and finishing of yarn and stock</td>
<td>Yarns, dye and chemical containers</td>
</tr>
<tr>
<td>Wool fabrication:</td>
<td>Dirt, wool, vegetable matter, waxes</td>
</tr>
<tr>
<td>- Wool scouring</td>
<td>Flocks, seams, fabric, fibers, dye and chemical containers</td>
</tr>
<tr>
<td>- Wool fabric dyeing and finishing</td>
<td></td>
</tr>
<tr>
<td>Packaging</td>
<td>Paper, cartons, plastic sheets, rope</td>
</tr>
<tr>
<td>Workshops</td>
<td>Scrap metal, oily rags</td>
</tr>
<tr>
<td>Domestic</td>
<td>Paper, sheets, general domestic wastes</td>
</tr>
<tr>
<td>Wastewater treatment</td>
<td>Fiber, wasted sludge and retained sludge</td>
</tr>
</tbody>
</table>
The primary residual wastes generated from the textile industry are non-hazardous. These include scraps of fabric and yarn, off-specification yarn, fabric and packaging waste. There are also wastes associated with the storage and production of yarns and textiles, such as chemical storage drums, cardboard reels for storing fabric and cones used to hold yarns for dyeing and knitting. Cutting room waste generates a high volume of fabric scraps, which can often be reduced by increasing fabric utilisation efficiency in cutting and sewing. Table 5 summarises solid wastes associated with various textile manufacturing processes [28].

Cleaner production is an attractive approach to tackle environmental problems associated with industrial production and poor material efficiency [28].

Textile and clothing manufacturers are encouraged to re-examine the whole life cycle of their products with the aim to minimize environmental degradation at every stage, from manufacturing to disposal. They have to pay special attention in the selection of dyes and ensure the products are low in formaldehyde and free from pesticides and heavy metals. The reason behind those environmental requirements in textile and garment are as follows (table 6) [17]:

<table>
<thead>
<tr>
<th>General Parameters and Restrictions</th>
<th>Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH Value</td>
<td>Human skin has a light acid coating which inhibits the development of many diseases, textiles in which the pH lies in the neutral (pH7) or slightly acid region (below 7) are friendly to the skin. Also, under extreme pH condition fabric will be damaged.</td>
</tr>
<tr>
<td>Formaldehyde Content</td>
<td>Easy care finishing incorporates artificial resin containing formaldehyde which is intended to prevent shrinkage and to give the product a crease-resistant, smooth dry and soil release finish. However, resin finished fabric may retain chlorine resulting in fishy odour, fabric damage and skin irritations. Formaldehyde is found in clothing in a latent form as resin and also as free formaldehyde (split off from resin by high temperature, pH or oxidants). Formaldehyde has a strong irritant effect on the mucous membrane and may cause inflammation of the human respiratory tract. It can also give rise to inflammation of the skin. Formaldehyde is one of the most significant allergy causing agents and is probably also cancer inducing.</td>
</tr>
<tr>
<td>Heavy Metal Residues</td>
<td>Heavy metals are constituents of dyes. They can also be found in natural fibres because plants can absorb them through the soil or the air. Once absorbed by human, heavy metals tend to accumulate in the liver, kidney, bones heart and brain. The effect on health can be tremendous when certain level of accumulation is reached in affecting organs, e.g. mercury will affect the nervous system. The condition is particularly serious to children because of their higher absorption of the heavy metals.</td>
</tr>
<tr>
<td>Pesticides Residues</td>
<td>Pesticides are used in cotton cultivation for combating insects and also as moth protection during storage. They are rated from slightly to strongly toxic for humans. Sometimes they are very easily assimilated through the skin. Lindan is a possible assumed to be cancer inducing.</td>
</tr>
<tr>
<td><strong>General Parameters and Restrictions</strong></td>
<td><strong>Reasons</strong></td>
</tr>
<tr>
<td>----------------------------------------</td>
<td>-------------</td>
</tr>
<tr>
<td>Pentachlorophenol (PCP) &amp; 2,3,5,6-Tetrachlorophenol (TeCP)</td>
<td>To prevent mould spots (caused by fungi) chorinated phenols are applied directly on textiles and leather mainly in the third world countries. Both PCP and TeCP are very toxic and regarded as cancer inducing substances.</td>
</tr>
<tr>
<td>Azo Dyestuffs Azostuffs which can be reductively separated in arylamine of the MAK Groups III A1 and III A2 should not be used</td>
<td>This is the name of the group of synthetic dyestuffs based on nitrogen and which are often used for textiles. Separation products of certain Azo dyestuffs are regarded as cancer inducing and allergic. If a person has once been sensitized, other products which is containing Azo dyestuffs will lead to allergic reactions.</td>
</tr>
<tr>
<td>Chlorinated Organic Carriers</td>
<td>Commonly used as antistatic agent and flame retarding agent. It is very toxic which can cause pigmentation to skin, gastrointestinal disturbance and cancer.</td>
</tr>
<tr>
<td>Notes on Color Fastness</td>
<td>Wetting, sweating or rubbing may cause colour migration of garments. Those dye pigments released are easily absorbed by human through skin are especially harmful to babies. Particular attention should be paid to colour fastness of baby wears.</td>
</tr>
<tr>
<td>Notes on the smell of Mildew, Heavy Naptha, Fish, Aromas or Anti odor Finishes</td>
<td>The presence of this smell means that too much residual chemicals are left in the textiles. There exhibits a possibility that it is hazardous to human health.</td>
</tr>
<tr>
<td>Release of Nickel European Parliament and Council Directive 94/27/EC with three European Testing standards</td>
<td>The presence of nickel in certain objects coming into direct and prolonged skin contact may cause sensitization of humans to nickel and may lead to allergic reactions. The use of nickel in such objects is thus limited. Such objects include rivet buttons, tighteners, rivets, zippers and metal marks, when these are used in garments.</td>
</tr>
<tr>
<td>Organitin Compound (TBT and DBT)</td>
<td>Tributyltin (TBT) are organotin compounds used for anti-microbial finishing. High concentrations are considered toxic. These substances can be taken up via the skin and affects, depending on the dosage, out nervous system. In textile industry organotin compounds have been used for preventing the bacterial degradation of sweat and the corresponding unpleasant odour of socks, shoes and sport clothes. Dibutyltin (DBT) are also organotin compounds with various applications, such as an intermediate for stabilizers of polyvinyle chloride, a catalyst for electro deposition paints, a catalyst for various types of polyurethanes and a catalyst for esterification.</td>
</tr>
<tr>
<td>Dry cleaning using Ozone Depelting chemicals (ODCs)</td>
<td>Dry cleaning is often not justified and it obliges to dry clean the fabric even through a normal wash would suffice. In the dry cleaning process, CFC (freons= ozone killers) are used which are very hostile to the environment. CFCs are not degradable in the air layers closest to earth. They move to the stratosphere after tens of years and contribute to the decline of the ozone layer (hence leading to the green house effect).</td>
</tr>
<tr>
<td>Limit the use of &quot;Brighteners&quot;</td>
<td>Visual brighteners are not only used for white washing that is to look beautifully brilliant white. Pastel toned clothes are also finished with such substances to give them “added brilliance”. Visual brighteners transform invisible UV light in not visible blue light. To the human eye, a white eighth a light blue tinge appears especially white. These substances can give rise to allergies and skin disease.</td>
</tr>
</tbody>
</table>
### General Parameters and Restrictions

<table>
<thead>
<tr>
<th></th>
<th>Reasons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limit the use of &quot;Softening agents&quot;</td>
<td>Textiles feel hard to the tough after the finishing process, so softening agents are added to give the fibres a soft and flexible surface. Softeners are known to be allergens and burden the water consumption in industry as well as in home.</td>
</tr>
<tr>
<td>Merchandise should be produced in an environmentally compatible manner.</td>
<td>The products should be made from recycled material. Environmentally kind raw materials should be used in the production. Energy consumption should be reduced in production. The product should be recycled easily when no longer needed. A low pollution disposal is required when the products no longer needed.</td>
</tr>
<tr>
<td>Limit the use of Packaging</td>
<td>The more packaging materials we use, the higher the chance we have to dispose them.</td>
</tr>
<tr>
<td>The packaging should be easily disposed.</td>
<td>Many blister packs and boxes are made of polyvinylechloride (PVC) plastic. In burning of one kilo of PVC, 582 grams of hydrochloric acid are emitted into the environment (causing acid rain)</td>
</tr>
<tr>
<td>Plastic packaging materials should be declared</td>
<td>The declaration directly on the plastic itself is the determining factor for recognition and collection of the various plastics.</td>
</tr>
<tr>
<td>Phthalates in PVC</td>
<td>Phthalates are the most common plasticizers used to soften PVC. Softened PVC is very useful due to its greater flexibility and workability. However, some studies showed that the softened PVC when analyzed under stimulated conditions might release phthalates in quantities which were considered to cause potential hazardous effect on young children especially for those under the age of three.</td>
</tr>
<tr>
<td>Flame Retardant</td>
<td>Flame Retardant is usually added in textile material to improve its flame resistance. Some common ones are 2, 3 dibromoprophyl phosphate, Polybrominated biphenyls (PBB) and Poly borminated diphenylether (PBDE). However, prolonged exposure to the high dosage of flame retardant will have considerable effect such as impair or immune system, hypothyroidism, memory loss and joint stiffness</td>
</tr>
<tr>
<td>Biocides</td>
<td>Biocides are usually organotin compounds or quaternary ammonium compounds. Most of them are toxic in nature. They are used as antifungal or antibacterial agent.</td>
</tr>
<tr>
<td>Allergic Dyes/Carcinogenic Dyes</td>
<td>Some dyestuffs used in textile industry are classified as allergic dyes/carcinogenic dyes. Prolonged exposure to them may lead to allergic reaction or even cancer inducing. In the meantime, 19 kinds of dyestuffs are classified as allergic dyes while 7 kinds of dyestuffs are classified as carcinogenic dyes according to Oko-Tex Standard 100</td>
</tr>
</tbody>
</table>

Additional important informations, in this context, are [29]:

- Conventionally grown cotton accounts for more than 25% of worldwide insecticide use and 10% of the pesticides. One pound of chemical fertilisers and pesticides is needed to grow the three pounds of cotton necessary to make a T-shirt or a pair of jeans. Farm workers working in conventionally grown cotton fields suffer from an abundance of toxic exposures and related health problems. Pesticides used in cotton cultivation can cause acute poisonings and chronic illness to farm workers worldwide. Acute respiratory symptoms and other health
effects in communities surrounding cotton farms are also correlated with the high usage of defoliation chemicals.

- Children are at greater risk for pesticide-related health problems than adults. Millions of children receive up to 35% of their estimated lifetime dose of some carcinogenic pesticides by age five through food, contaminated drinking water, household use, and pesticide drift.

- The rate of people experiencing health problems, such as rashes, allergies, respiratory problems and mental difficulties, due to chemical sensitivities has been growing alarmingly. Many people diagnosed with Multiple Chemical Sensitivities find organic clothing to be essential in reducing their exposure to the vast array of toxic chemicals that we are unknowingly exposed to every day.

The production, manufacturing, transportation and use of textiles for fashion and interior furnishing applications uses dyes, solvents, yarns (both natural and synthetic fibres), paper patterns and machinery. The main impacts arise from material selection and use, manufacturing processes, the dyes used to print fabrics and the ethical issues around the human labour used to produce garments. Different fibres, for instance, have different impacts on the environment (table 7). MADE-BY, a European NGO with a mission to make the sustainable fashion a common practice, published a study in which the environmental impact of the production of several fibres is benchmarked. The table below summarizes the results of the study. The fibres under Class A are believed to be the most environmentally friendly. This classification is not only based on water use, but also on energy use, land use, the use of non renewable resources and the use of hazardous chemicals [30].

<table>
<thead>
<tr>
<th>CLASS A</th>
<th>CLASS B</th>
<th>CLASS C</th>
<th>CLASS D</th>
<th>CLASS E</th>
<th>UNCLASSIFIED</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recycled cotton</td>
<td>TENCEL® (Lenzing Lyocell Product)</td>
<td>Conventional Hemp</td>
<td>Virgin Polyester</td>
<td>Conventional Cotton</td>
<td>Silk</td>
</tr>
<tr>
<td>Mechanically Recycled Nylon</td>
<td>Organic Cotton</td>
<td>Ramie</td>
<td>Poly-acrilic</td>
<td>Virgin Nylon</td>
<td>Organic Wool</td>
</tr>
<tr>
<td>Mechanically Recycled Polyester</td>
<td>Chemically Recycled Polyester</td>
<td>PLA</td>
<td>Modal® (Lenzing Viscose Product)</td>
<td>Spandex (Elasthane)</td>
<td>Leather</td>
</tr>
<tr>
<td>Recycled Wool</td>
<td>In Conversion Cotton</td>
<td>Conventional Flax (Linen)</td>
<td>Bamboo Viscose</td>
<td>Natural Bamboo</td>
<td></td>
</tr>
<tr>
<td>Organic Hemp</td>
<td>Chemically Recycled Nylon</td>
<td></td>
<td>Wool</td>
<td>Acetate</td>
<td></td>
</tr>
<tr>
<td>Organic Flax (Linen)</td>
<td>CRAiLAR® Flax</td>
<td>Generic Viscose</td>
<td>Cashmere Wool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monocel® (Bamboo Lyocell Product)</td>
<td>Cuprammonium Rayon</td>
<td>Alpaca Wool</td>
<td>Rayon</td>
<td>Mohair Wool</td>
<td></td>
</tr>
</tbody>
</table>

Table 7: Different fibres impacts on the environment [30]

More Sustainable | Less Sustainable

---
Some parts of the textiles and fashion industry have focused on the use of organic natural fibres and incorporating recycled fabrics or deconstructed garments into products. These can be useful strategies in reducing environmental impacts, although a life-cycle perspective can reveal other issues that also need to be addressed. Therefore, a systematic approach needs to be applied to the whole system: materials, manufacturing, inks and dyes, transportantion, use guidlines and instructions.

*Wider Ethical Issues*

The fashion industry is often criticised for the use of unethical labour practices, particularly in the production of garments and footwear. In recent years there has been a rise in consumer labels that promote ‘ethical’ fashion, such as the ‘no sweat’, ‘fair trade’ or ‘sweatshop free’ brands. These have been strong and successful communication tools for consumers, and are investigated as options for the products [31].

Design for environment (DfE) "provides a unique opportunity to make critical interventions early in the product development process and eliminate, avoid or reduce downstream environmental impacts." A step in environmental design is an analysis of environmental impacts. One of the most useful tools for this is life-cycle assessment (LCA), which is a technique for assessing the environmental impacts associated with a product or service (Lewis et al, 2001: 31).

To understand the environmental impact of textiles it is needed to examine their complete life-cycle, which includes growing and processing the fibre, manufacturing the yarn, manufacturing the fabric, dyeing and finishing, cutting and making the final product, maintaining the product during use and disposal or recycling (Lewis et al, 2001: 130) [32].

With the eco-fashion industry still in its infancy, the main responsibility belongs to clothes manufacturers and fashion designers, who need to start using sustainable materials and processes. The fashion world tries to growth constantly in the field of eco-friendly clothing and accessories. Many European and Asian companies are adopting some sustainable approaches. Thus, the fashion industry is targeting on the organic clothing rather the synthetic or fibre cloths that put a huge pressure on the nature.

In this great step it is not only the fashion world involvement, but also people who have to take such initiatives, namely the consumers. For this it is needed to recycle the cloths and make them use in the reversible manner. This will increase the life of the textile products.

“Making the land free from the chemicals is the best way to have and eco-friendly fashion world. However, another step is that to stop the use of the synthetic and chemical coating apparels like fashionable jackets and closets.” Most textile products are mass-produced in many countries where the company’s line is manufactured and imposes fair labour practices.
2.3 How can textile and fashion industry go green

The use of organic fabrics is not the only way the fashion industry could go "green" and protect the future of the planet and its natural resources. Companies have to be also more ethical and use fair trade and fair labour; this is the "ethical and environmental awareness". This means that companies are paying the fair price, creating fair employment opportunities, developing safe work environments for the workers that they receive their materials from. In addition, they are "engaging in environmentally sustainable practices, making sure that product quality is maintained, honouring cultural identity as a stimulus for product development and production practices, offering business and technical expertise and opportunities for worker advancement, contributing to community development, building long-term trade relationships, and being open to public accountability." [29]

In this context, both recycling fashion and organic clothing can contribute to an eco sustainable development [29]:

a. Recycling

“Recyclin refers to textiles that have been discarded by consumers, retailers or charitable organisations, which have undergone a discriminating process of sorting, grading and separation into waste-free products suitable for reuse.” Designers give recycled clothing and organic fabrics new life as fashionable dresses, skirts, jackets, pants and so on, that correspond to and attract the consumer. [29]

Certain initiatives had to be taken by the fashion world and by the consumers as well. It is a certain need to recycle the cloths and use them in a reversible manner. This will increase the life of the cloths and eliminates the pressure on the farmlands to grow huge amount of cotton using chemicals, for instance. [29]

b. Organic

Textiles, to qualify as being organic, should be made from natural sources, such as plants or animals, collected or organic manufactured. Dyes used on organic clothing should be either plant/mineral derived or environmentally low impact dyes. No heavy metals or other harmful chemicals should be used in the dyeing process. An ethically and environmentally aware approach should be extended to all the aspects of the organic clothing industry. [29]

Sustainable processing of textiles

There is a need for eco-friendly wet processing as a sustainable and beneficial method. Different sustainable practices have been implemented by various textile industries such as: eco- friendly bleaching; peroxide bleaching; eco-friendly dyeing and printing; low impact dyes; natural dyes; azo free dyes; phthalates free printing. There are also a variety of materials considered "environmentally-friendly" for many reasons, such as [29]:
The renewability of the product. Renewable resources are items that can be replenished in a relatively short amount of time.

- The ecological footprint of the resource - how much land (usually measured in acres) it takes to bring one of the individuals (plants or animals) to full growth and support it.

- The third thing to consider in determining the eco-friendliness of a particular product is how many chemicals it requires to grow/process it to make it ready for market.

### 2.4 Clean by Design

Clean by Design is an innovative program that uses the buying power of multinational corporations as a lever to reduce the environmental impacts of their suppliers abroad. Clean by Design focuses on improving process efficiency to reduce waste and emissions and improve the environment (figure 7) [55]:

![Figure 7: The main impact areas of the apparel industry (adapted after “Clean by Design” [55])](image)

Clean by Design promotes just these kinds of opportunities to increase efficiency (in energy, water, and chemical usage) and thereby reduce the environmental footprint while saving the factory money. The main impact areas are:
Raw Materials

The choice of raw materials for clothing has large impacts on the environment. Natural fibers like cotton are often assumed to be a more environmentally responsible choice, but cotton is notorious for its intensive use of water and pesticides. The same is true for "natural" dyes, which can rely on the harvest of millions of insects or plant bark to achieve different colors. These dyes often require the use of supplementary chemicals that contain toxic metals. Fiber choice also drives consumer-care requirements, which can indirectly impact the consumption of water, energy and toxic chemicals.

Manufacturing

Textile dyeing and finishing mills are particularly high-volume and high-impact producers of water pollution and carbon dioxide emissions. Designers, retailers and brands can reduce the footprint of their global supply chain by encouraging or requiring mills to adopt these improvements and reward those that do so with more business.

Transportation

The apparel industry is a global enterprise, where raw materials, manufacturers and retailers are in most cases on opposite sides of the globe. Each designer and retailer must choose among container ships, railroads, trucks and airplanes to transport the garments from factory to market. Each mode of transportation involves different levels of environment pollution and affects different populations and ecosystems around the world. There are many choices a retailer can make to decrease the impact of global transport and to help protect the public health.

Consumer Care

The way a consumer cleans and cares the purchased garments can have a large impact on water and energy use. Clothes that are frequently laundered or dry-cleaned have a big environmental impact. Washing in cold water and minimizing dry cleaning (even so-called "organic dry cleaning") can reduce the negative impacts substantially.

3 ECO FIBERS AND TEXTILES

The eco-problems in textile industry occur during some production processes and are carried forward right to the finished product. In the production process, like bleaching and dyeing, the subsequent fabric makes a toxin that swells into our ecosystem. Therefore there is a huge need of eco textiles. Green textiles, as it was stated befire, refer to clothing and other accessories that are designed to use organic and recycled material.

Eco textiles are fabrics created with the goal of making a system which can be supported indefinitely in terms of environmental and social impact they might have, including carbon footprint, throughout the total life span: the growth, harvest, manufacture, transport, post
purchase use and disposal. Designers have the responsibility to work towards sustainability, even before the product life cycle begins, in line with the Sustainable Design philosophy. There are many factors when considering the sustainability of a material: the renewability and source of a fibre, the process of how a raw fibre is turned into a textile, the working conditions of the people producing the materials and their total carbon footprint. In this context it is needed a holistic approach to eco textiles selection that takes into account the impact of the fabric and also its look and feel [33].

Organic and eco textiles cover a wide range of natural and recycled fibers. Certified Organic textiles are grown in controlled settings with no pesticides, herbicides or synthetic fertilizers and are certified by an international governing body such as Control Union, IMO (Institute for Market ecology) or One-Cert. The term “eco textiles” refers to a select group of textiles that have a reduced carbon, energy and pollution impact. Generally, eco friendly fabrics are produced from crops that do not require pesticides or chemicals to be grown, use less water and energy to be produced and processed and create less waste during production, processing and at the end of their useful lives. Sustainable textiles can also refer to manmade fabrics produced from renewable sources such as bamboo or wood [34].

**Fibers** - Fibres are classified in 2 groups: natural fibres and man-made fibres (MMF) [20].

**Natural fibres** are fibres made by nature. Typical examples are cotton and wool, which are mainly used in textile clothing.

**Man-made fibres (MMF)** are fibres made by man. MMF can be organic or inorganic. Organic MMF can be made from natural materials like wood, or are made from synthetic polymers.

### 3.1 Natural fibres

Natural fibres will play a key role in:

- the emerging “green” economy based on energy efficiency,
- the use of renewable feed stocks in polymer products, industrial processes that reduce carbon emissions and recyclable materials that minimize waste.

Natural fibres are a renewable resource *par excellence*; they have been renewed by nature and human ingenuity for millennia. They are also carbon neutral: they absorb the same amount of carbon dioxide they produce. During processing, they generate mainly organic wastes and leave residues that can be used to generate electricity or make ecological housing material. at, They are 100% biodegradable at the end of their life cycle.

Processing of some natural fibres can lead to high levels of water pollutants, but they consist mostly of biodegradable compounds, in contrast to the persistent chemicals, including heavy metals, released in the effluent from synthetic fibre processing.
More recent studies have shown that producing one tone of polypropylene – widely used in packaging, containers and cordage – emits into the atmosphere more than 3 tons of carbon dioxide, the main greenhouse gas responsible for global warming. In contrast, jute absorbs around 2.4 tons of carbon per ton of dry fibre.

Natural fibres really excel in the disposal stage of their life cycle. Natural fibres decay through the action of fungi and bacteria because they absorb water. Natural fibre products can be composted to improve soil structure, or incinerated with no emission of pollutants. By contrast, synthetics confront the society with a range of disposal problems. They release heavy metals and other additives into soil and groundwater. Recycling requires costly separation and incineration produces pollutants; for example, in the case of high-density polyethylene, 3 tons of carbon dioxide are released for every tone of burnt material. Left in the environment, synthetic fibres contribute, for example, to the estimated 640 000 tons of abandoned fishing nets and gear in the world’s oceans. [35]

There are many natural fibres which can be considered as eco-friendly, such as [36]:

**Organic Cotton** - The best textile for casualwear and the most popular textile product in the world is cotton. It is the most valuable non-food agricultural product, but due to the history of unethical labor practices, extremely hazardous chemical inputs and devastating water misuse, it has been labeled as the world's “dirtiest” crop.

Organic cotton is much more environmentally-friendly than the traditional variety as it uses no pesticides, herbicides, or insecticides during the growing cycle. Even more promising is the new cotton that is grown in the tradition of the Aztecs, a coloured cotton with long enough fibres to be spun into thread, naturally grown in shades of green and brown. It has the added benefit of not fading in colour and it gets more vibrant with the first few types of washing. [36]

**Organic linen** – is the linen that is made from flax fibre. It could also refer to the linen made from other organically grown plant fibres.

**Bamboo fibre** - fast-growing without water, pesticides or fertilizers, bamboo textiles have a huge potential as a sustainable textile, not to mention the softness and kind-to-skin properties that make them feel amazing. Bamboo clothing can be breathable, naturally anti-bacterial and hypoallergenic. It’s one of earth’s most sustainable resources, but as a textile there is a difference between the sustainability of bamboo as a crop, and the sustainability of the way it is processed.

It is a common fact that bamboo can thrive naturally without using any pesticide. It is seldom eaten by pests or infected by pathogen. Scientists found that bamboo owns a unique anti-bacteria and bacteriostasis bio-agent named "bamboo Kun". This substance is combined with bamboo cellulose molecular tightly all along during the process of being produced into bamboo fibre. Bamboo fibre fabric still possesses excellent function of anti-bacteria, bacteriostasis, even after fifty times of washing. Its test result shows over 70% death rate after
bacteria being incubated on bamboo fibre fabric. Bamboo fibre's natural anti-bacteria function differs greatly from that of chemical antimicrobial. Bamboo fibre main properties are as following:

- naturally anti-bacterial;
- green and biodegradable;
- breathable and cool.

**Hemp** - is one of the most environmentally friendly and versatile natural textile plants on Earth, and one of the first textile plants in human history. Hemp is incredibly strong, requires no herbicides as it grows so fast that weeds can't compete. It requires no pesticides as it is unpalatable to insects, and needs very little water to grow. It is UV protective and anti-bacterial. Unfortunately, it has been overtaken by cotton which is softer.

By far, the crop with the most potential for eco-friendly textile use is hemp. The ecological footprint of hemp is considerably smaller than that of most other plants considered for their fibres. Hemp plants grow very quickly and densely which makes it difficult for weeds to take hold, eliminating the need for herbicides and artificial fertilisers. It requires no irrigation as it thrives on the amount of water in the average rainfall, and it is highly pest-resistant.

Hemp has naturally long fibres which makes it suitable for spinning with a minimum of processing. Those fibres are also long-lasting. Hemp fabrics come in a variety of weights and textures. It can be used for rope, bags, clothes, hats, insulation, and plasterboard, almost anything. The first American flag was made from hemp, and Levi Strauss made his first pair of jeans from Hemp too.

**Jute** - Similar to hemp, jute is a type of vegetable fibre used for thousands of years, with outstanding potential for the future.

**Ramie** - Ramie fibres are one of the strongest natural fibres. Ramie can be up to 8 times stronger than cotton, and is even stronger when wet.

**Alpaca** - Alpaca sheep don't require insecticides to be injected into their fleece, don't need to be treated with antibiotics, and don't eat very much. Alpaca wool is also long-lasting. [36]

### 3.2 Man-made fibres

Man-made fibres account for 68% of fibres used worldwide, and 75% of those processed in Europe. The World production was around 53 million tonnes in 2010 and the European production was 3.8 million tonnes. Their principal end-use is in clothing, carpets, household textiles and a wide range of technical products: tyres, conveyor belts, fillings for sleeping bags and cold-weather clothing, filters for improving the quality of air and water in the environment, fire-resistant materials, reinforcement in composites used for advanced aircraft production, and many more. Fibres are precisely engineered to give the right combination of qualities required for the end-use in question: appearance, handle, strength, durability, stretch, stability, warmth, protection, easy care, breathability, moisture absorption and value for...
money, for example. In many cases, they are used in blends with natural fibres such as cotton and wool. Man-made fibres come in two main forms:

- continuous filament, used for weaving, knitting or carpet production;
- staple, discontinuous lengths of fibre which can be spun into yarn or incorporated in unspun uses such as fillings or nonwovens.

Man-made fibres are classified into three classes: those made from natural polymers, those made from synthetic polymers and those made from inorganic materials.

**Fibres from Natural Polymers:** The most common natural polymer fibre is viscose, which is made from the polymer cellulose obtained mostly from farmed trees. Other cellulose-based fibres are Lyocell, Modal, Acetate and Triacetate. Less common natural polymer fibres are made from rubber, alginic acid and regenerated protein.

**Fibres from Synthetic Polymers:** There are very many synthetic fibres, for example organic fibres based on petrochemicals. The most common are polyester, polyamide (often called nylon), acrylic and modacrylic, polypropylene, the segmented polyurethanes which are elastic fibres known as elastanes (or spandex in the USA), and speciality high-tenacity fibres such as the high performance aramids and UHMwPE (Ultra High Molecular weight PolyEthylene).

**Fibres from Inorganic Materials:** The inorganic man-made fibres are fibres made from materials such as glass, metal, carbon or ceramic. These fibres are very often used to reinforce plastics to form composites.

**Renewable Raw material**

Most of the man-made fibres (MMF) are made out of synthetic polymers where the feedstock is oil-based. However, some MMF are also based on renewable resources. Viscose, Lyocell and Modal are typical and important MMF which are based on wood as the renewable resource. Cellulose is the world’s most important biopolymer by far. About half of the global biomass consists of cellulose, being an amazing unique biopolymer. Wood is converted into pulp, and pulp into fibres. The pulp and fibre industry is part of the natural carbon cycle.

A small but growing proportion of man-made fibres production, in this context of sustainability, is based on innovative raw material sources such as corn or vegetable oil. Typical examples are PLA fibres, and the use of bio-propanediol (PDO) out of corn, as a substitute for the oil-based PDO, for the polymerization of PTT polyester.

**Eucalyptus Tencel** - Tencel Lyocell is produced exclusively from the wood pulp of Eucalyptus trees certified by the Forestry Stewardship Council (FSC), and the fibre carries the Pan-European Forest Council (PEFC) quality seal. Eucalyptus is woody and therefore needs energy input to convert it into a soft fibre suitable for clothing. The Eucalyptus is reduced down then reformed into a spin-able fibre. This is done in a process with similar principles as other semi-synthetic natural fibres, such as Viscous bamboo fabric. The process used to make
Eucalyptus Tencel is much more eco-friendly; it is simply the most environmentally friendly man made cellulose fibre available today.

**Non-renewable Raw Material**

Most of the man-made fibres (MMF), in product types and volume, are made out of synthetic polymers, the feedstock of which is oil-based. This non-renewable resource is, in view of sustainability, not the preferred resource compared to the renewable ones. This has to be considered in the context of other resources needed for the production of natural fibres, like land use and water use.

**Polymer Waste as Raw Material**

Waste is to be avoided at anytime, whether it is a waste of money or a waste of resources, but it is sometimes unavoidable despite all efforts made.

Man-Made Fibres (MMF) are committed to decrease the environmental impact by reducing the use of resources and reusing as much as possible polymer waste of whatever source, if technically and economically is viable. Polymer waste is more and more frequently used to spin man-made fibres. We have to consider process waste or factory waste which comes from the polymerisation process and the spinning process, and we have to consider polymer waste being Post-consumer Waste. Process waste is often sold, recycled into polymer chips and finally into short fibre. A typical example of a non-fibre, post-consumer waste recycling are the PET plastic bottles which are collected and recycled into polyester short fibre. [20, 36]

*Recycled PET*: Recycled polyester clothing is potentially an incredibly sustainable material due to its Cradle-to-cradle potential. This means a plastic bottle could be recycled to make an item of clothing, which could be recycled to make a plastic bottle, and so on, forever. The reality is that few facilities exist to do this, the transport distance between the user and the recycler is often massive and the suitability of recycled PET as a next-to-skin textile is not as soft or breathable as natural fabrics. C2C sustainability is a worthwhile concept and recycled PET must form part of the solution, certainly for details like buttons and zips and for garments that require a hard wearing finish that natural textiles cannot provide [37].

*Recycled polyester* - Polyester fibre is one of the most non-biodegradable polymers which create environmental problems. The legislation opens the door towards working over recycling of PET. The Wellman Inc is the world’s largest polyester recycler. It is a new generation of fibre that is most suitable for diversified products range such as backpacks and blankets, T-shirts, sportswear, soft luggage and socks.

*FORTREL EcoSpun* – is a fibre made from plastic containers. [29, 37]

### 3.3 Innovations linked with eco-friendly fibres

Some noticeable developments, in the context of sustainable textiles, are [36]:

---

**FUNTEX**
Soy silk - Soy silk is made from the by-products of the tofu-making process. The liquefied proteins are extruded into fibres which are then spun, and used like any other fibre (woven, knitted, etc). One can purchase skeins of soy silk yarn. The high protein content makes it receptive to natural dyes, so the colour palette is very wide.

Milk silk - Silk made from milk.

Corn fibre - It is created by extracting the starch and then sugars from corn, and processing them to make a fibre, which can be spun into a yarn or woven into fabric.

Apart from the eco-friendly fibres mentioned above, some other important ones are:

- Pineapple fibre;
- Banana leaf fibre;
- Black diamond fibre;
- PLA fibre;
- Lycra.

3.4 Biodegradable and sustainable fibres

More and more textile researchers, producers and manufacturers are looking to biodegradable and sustainable fibres as an effective way of reducing the impact textiles have on the environment. The emphasis in Biodegradable and sustainable fibres is on textiles that are beneficial by their biodegradation and come from sustainable sources [38].

New and exciting developments in fiber technology and their applications, exploring fields such as biomimetics, nanotechnology and biodegradability have been reported. Fibers will enter into more novel and unexpected applications as the 21st century progresses.

Natural polymers are both biodegradable and sustainable. But research is still on-going to develop new synthetic polymers/fibres derived from renewable sources. For a material to fulfil the ‘cradle to grave’ sustainability requirement, it must be both derived from a renewable source and be degradable (figure 8) [98].

The biodegradable polymers can be classified into three main categories [98]:

a) Natural polysaccharides and biopolymers; e.g. cellulose, alginate, wool, silk, chitin and soya bean protein:

Many natural polymers occur as fibres that are ready to be processed into yarns and fabrics, and which can ultimately be broken down by enzymes and metabolised in the ecosystem. Others such as Alginate, Chitin and Soya Bean Protein require processing to create useful fibres.

b) Synthetic polymers, particularly aliphatic polyesters e.g. poly(lactic acid), Poly(e-caprolactone):
Degradable synthetic polymers (i.e. those created catalytically from monomers) include poly(lactic acid) (PLA) derived from a renewable monomer and Poly(ε-caprolactone) (PCL) from a petroleum product.

c) Polyesters produced by microorganisms; e.g. poly(hydroxyalkanoate)s

![Figure 8: Degradable and sustainable polymers (source [98])](image)

“Polymers from renewable aliphatic esters e.g. poly(lactic acid): Poly(lactic acid) (PLA) is a linear aliphatic polyester derived from sugar or polysaccharide, a 100% renewable source, therefore sustainable and degradable. The monomer used to manufacture poly(lactic acid) is obtained from annually renewable crops (corn, sugarbeet, wheat) in the agricultural carbon cycle which uses energy from the sun to convert carbon dioxide and water into starch or other fermentable sugar, which is fermented to lactic acid.” [98]

“The mechanisms by which polymers/fibres degrade vary depending on the material. These degradation mechanisms include biodegradation, hydrolysis and photo degradation. Some materials degrade solely by one mechanism alone, while others degrade by a combination of mechanisms. The environment where the polymer/fibre is disposed has a great effect in the types of degradation that can occur. A ‘degradable’ material disposed in an inappropriate environment may not degrade at all.” [98]

“Hydrolytic degradation: Most heterochained polymers are susceptible to aqueous acid or base degradation referred to as hydrolysis. This susceptibility is due to a combination of the chemical reactivity of heteroatom sites and to the materials being at least wetted by the aqueous solution, allowing contact between the protons or hydroxyl ion to occur.” [98]
“Photo-degradability: Synthetic polymers can be degraded by the absorption of ultra-violet light. This applies also to natural polymers, but these tend to be more rapidly degraded biologically, by the attack of micro-organisms.” [98]

“Biodegradation: In the broadest sense, biodegradation is the biologically catalysed reduction in the size and complexity of a molecule (figure 9). This breakdown is carried out by microorganisms which, because they are living entities, require suitable conditions such as optimum pH and temperature in the composting process.” [98]

![Diagram](image)

**Figure 9**: Biodegradation (adapted after [98, 102])

4 ENVIRONMENTAL ASPECTS OF TEXTILE FINISHING

4.1 General considerations

The global textile industry discharges 40,000 – 50,000 tons of dyes into the water system and Europe discharges 200,000 tons of salt.

Over the last two decades the synthetic dye industry has developed thorough health, safety and environmental standards to reduce negative impacts. There are still companies making carcinogenic dyes or those laced with harsh chemicals.

The majority of garment production and fabric dying now takes place in developing countries. Often health and safety regulations are not well enforced, with workers not using protective
equipment or using banned products, which can be extremely damaging to health and wellbeing.

An alternative to chemical dyes is natural dyes (dye colours made from plant and animal sources). These may not be suited to large scale production, often requiring large amounts of water and chemical fixing agents. However they can be grown organically and are carbon neutral and their use brings great benefits at an artisanal level.

Fashion professionals can play an important role through their specification and monitoring of the use of dyes, making sure that their products are dyed in the most environmentally friendly way possible, without damage to workers health, or by using natural dyes where appropriate. Five classic natural dyestuffs are indigo, cutch, weld, madder and cochineal. These dyes can be used to make almost every colour. [40]

Textile dyes enhance our environment, bringing colour into our lives. The current ranges of dyes have been developed to withstand environmental effects, such as degradation by exposure to light and water. However, the industry involved with the application of dyes to textiles has a responsibility to ensure that potential harm to the environment, for example through residues in waste-streams, and to the consumer is minimized.

A number of chemicals that may be used in textile processes are worth mentioning for their potential negative effects on the environment and human health and are therefore regulated. Ecolabels are developed in order to easily identify the textiles that meet these requirements. Since the textile industry uses water as the principal medium for removing impurities, applying dyes and finishing agents, the main concern is therefore about the water discharged and the chemical load it carries. [41]

The textile dyeing and washing industry plays an important role in the economical growth as well as the environmental sectors and contributes significantly to the textile and clothing export trade. But the textile dyeing industries has been condemned as being one of the world's most offenders in terms of pollution. The assessment of the present situation of environmental impacts arises from such activities and several mitigation measures are needed. This was done by analyzing numerous data obtained from different laboratory test concerning a range of water quality parameters for instance. Important water quality parameters like pH, turbidity, TSS (total suspended solids), BOD, COD and presence of metals like copper, cadmium, mercury, arsenic, etc. could be measured by testing samples [42].

4.2 Dyes and their negative impact

Dyes cause a lot of problems in the environment, such as [43]:

- Dyes can have acute and/or chronic effects on exposed organisms, depending on the exposure time and dye concentration.
- The presence of very small quantities of dyes in water is highly visible due to their brilliance.

- The greatest environmental concern with dyes is their absorption and reflection of sunlight entering the water. Light absorption diminishes photosynthetic activity of algae and seriously influence on the food chain.

- Dyes can remain in the environment for an extended period of time, because of high thermal and photo stability. For instance, the half-life of hydrolysed Reactive Blue 19 is about 46 years at pH 7 and 25 °C.

- Many dyes and their breakdown products are carcinogenic, mutagenic and/or toxic to life. Dyes are mostly introduced into the environment through industrial effluents.

- There is strong evidence of their harmful effects. Cancers involving kidney, urinary bladder and liver of dye workers have been reported. Most of the dyes, used in the textile industry are known only by their trade name, while their chemical nature and biological hazards are not known. Mathur et al. studied the mutagenicity of textile dyes (known only by their trade name, used in Pali, identified as one of the most polluted cities in India) and the effluents containing these dyes, and the influence on the health of textile dyeing workers and the environment. The dyes were used in their crude form and no following purification was attempted, because they wanted to test the potential danger that dyes represent in actual use. The results clearly indicated that most of the used dyes are highly mutagenic. Brown et al, published an article in which was showed that it is possible to predict the toxicity of new azo dyes. The systematic backtracking of the flows of wastewater from textile-finishing companies led to the identification of textile dyes as a cause of strongly mutagenic effects. The textile dyes used in the textile-finishing companies in the European Union were examined for mutagenicity and the dyes that proved to be mutagenic have been replaced with less harmful substances. The degradation product of dyes could be carcinogenic. [43]

- Textile dyes can cause allergies such as contact dermatitis and respiratory diseases, allergic reaction in eyes, skin irritation, and irritation to mucous membrane and the upper respiratory tract. Reactive dyes form covalent bonds with cellulose, woollen and PA fibres and it is assumed that in the same way reactive dyes can bond with –NH2 and –SH group of proteins in living organisms. Many investigations of respiratory diseases in workers dealing with reactive dyes have been made. Certain reactive dyes have caused respiratory sensitisation of workers exposed to them. Public perception of water quality is also greatly influenced by the colour. Thus, the removal of colour from wastewater is often more important than the removal of the soluble colourless organic substances. Removal of the dyes from the textile wastewater is often very costly, but a stringent environmental legislation has stimulated the textile sector in developing wastewater treatment plants in order to diminish or suppress the harmful effects. [43]

The potential sources and types of emissions associated with dyeing processes are presented in table 8 [44]:
One of the most important and in-depth works regarding the eco-textile processing belongs to S. Sharma [29, Sharma, S., Processing, Dyeing & Finishing, Eco textile processing & its role in sustainable development, The Indian Textile Journal, http://www.indiantextilejournal.com/articles/FAdetails.asp?id=5518]. The most relevant aspects concerning the sustainable development covered by S. Sharma are presented in the following paragraphs.

Some of the most important aspects regarding the dyes used in the textile industry are [29]:

**Azo-free colorants**

“Azo-free colorants are dyes and pigments that are free of the nitrogen-based compound aromatic amines, also referred to as "Azos". These compounds are toxic and banned in the EU.

<table>
<thead>
<tr>
<th>Operations</th>
<th>Emission sources</th>
<th>Type of emission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Colour kitchen operation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dye preparation</td>
<td>Discontinuous, low-concentration water emission at the end of each batch (cleaning step).</td>
<td></td>
</tr>
<tr>
<td>Auxiliaries preparation</td>
<td>Discontinuous, low-concentration water emission at the end of each batch (cleaning step).</td>
<td></td>
</tr>
<tr>
<td>Dispensing of dyes and auxiliaries (manual)</td>
<td>Indirect pollution from inaccurate dosing and handling of chemicals (spillage, poor shade repeats, etc.).</td>
<td></td>
</tr>
<tr>
<td>Dispensing of dyes and auxiliaries (automatic)</td>
<td>No emission provided that the system is regularly calibrated and verified for accuracy.</td>
<td></td>
</tr>
<tr>
<td><strong>Batch dyeing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dyeing</td>
<td>Discontinuous, low-concentration water emission at the end of each cycle.</td>
<td></td>
</tr>
<tr>
<td>Washing and rinsing operations after dyeing</td>
<td>Discontinuous, low-concentration water emission at the end of each cycle.</td>
<td></td>
</tr>
<tr>
<td>Cleaning of equipment</td>
<td>Discontinuous, low-concentration water emission.</td>
<td></td>
</tr>
<tr>
<td><strong>Semi-continuous and continuous dyeing</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Application of the colorant</td>
<td>No emission from the process unless dye bath is drained.</td>
<td></td>
</tr>
<tr>
<td>Fixation by steam or by dry-heat</td>
<td>Continuous emission to air (generally not significant, except for specific situations such as, for example, the thermosol process, drying of carrier-dyes fabrics, etc.).</td>
<td></td>
</tr>
<tr>
<td>Washing and rinsing operations after dyeing</td>
<td>Continuous low concentration water emission.</td>
<td></td>
</tr>
<tr>
<td>Discharging of leftovers in the chassis and feed storage container</td>
<td>Discontinuous, concentrated water emission at the end of each lot.</td>
<td></td>
</tr>
<tr>
<td>Cleaning of equipment</td>
<td>Discontinuous, low-concentration water emission (it can contain hazardous substances when reductive agents and hypochlorite are applied).</td>
<td></td>
</tr>
</tbody>
</table>
due to their mutagenic, carcinogenic and often allergic properties. These dyes are not biodegradable.” [29]

**Biodegradable dyes**
“Biodegradable refers to dyes that do not require the use of inorganic salts, heavy metals and amines. They are substances that decompose readily and become absorbed by the environment.” [29]

**Chrome-free tanning**
“Chrome-free tanning is the tanning of hides to create leather either through the use of oils or natural tannins instead of chromium salts. This tanning process is more time intensive than chrome tanning, but is better for the environment, as the chromium method uses chrome, a known carcinogen that can be absorbed through the skin and cause contamination of soil and waterways surrounding tanneries.” [29]

**Fibre reactive dyes**
“Fibre reactive dyes are dyes used to colour cellulosic and protein fibres such as cotton, rayon and soy. The dyestuff bonds to the fibres through a chemical reaction and does not require the use of mordants. Therefore, direct dyes require less salts and heavy metals to be used to achieve optimal colouration and fixation than other commodity dyestuffs. When used correctly, this can reduce not only the salt and metal content of the effluent, but also the quantity of water used to remove excess dye and the amount of dye run off.” [29]

**Heavy metal free dyes**
“Heavy metal free refers to dyes that do not require the use of heavy metals to achieve the fixation of colours. Toxic heavy metals, such as chrome, copper and zinc, which are all known carcinogens, are commonly used as fixers in dyes. And, although most heavy metals can be removed from the effluent through waste water treatment, this often does not occur.” [29]

**Low-impact dyes**
“Low-impact refers to synthetic dyes that do not use substantial levels of heavy metals or toxic chemicals as fixers.” [29]

**Natural dyes**
“Natural dyes are dyes that are created from bark, bugs, flowers, minerals, rust and other natural materials. Natural dyes allow small producers to retain their traditional dyeing methods and promote biodiversity. The disadvantage of these dyes is that their mordants are often heavy metals.” [29]

**Non-toxic semi-aniline dyes**
“Non-toxic semi-aniline dyes are non-toxic transparent dyes used to dye leather. These dyes are derived from coal tar and fully penetrate the leather while preserving the appearance of natural grains and markings.” [29]
4.3 Eco finishing aspects

Eco Finishing is a finishing process that is most suitable and within the norms of eco label standards [29]. According to S. Sharma, the most important aspects are presented below.

Certain treatments to achieve a desired colour, effect or performance are used for fabrics or garments. The techniques used vary in the amount of water required and the amount and toxicity of the chemicals used, and the energy required to carry out these techniques. Sustainable dyeing, printing and tanning methods have to focus on reducing the environmental impact.

Finishes used on textiles can be wet or dry. Dry finishes are generally considered environmentally and consumer friendly as they use machinery and heat rather than chemicals. Some wet finishes, which are increasing in selection and availability, such as enzymatic treatments, are eco-friendly. Other wet finishes, such as antimicrobial and stain-resistant, can be beneficial to the sustainability of a garment, as they reduce the need for laundering, conserving water and energy and the amount of chemicals released to the environment. [29]

Sustainable processing also includes bio-processing of textiles. “Bio-processing can simply be defined as the application of living organisms and their components to industrial products and processes, which are mainly based on enzymes. Bio-processing also offers the potential for new industrial processes that require less energy, less water and less effluent problems with effective results. Enzymatic desizing, enzymatic scouring, enzymatic bleaching, bio polishing and enzyme based softeners are few examples of bio-processing of textiles.” [29]

The priorities of textile manufacturers as well as consumer all over the globe are undergoing dramatic changes. Quality and eco-friendliness of process and product plays a key role in the global competition. “Eco-friendly processing is shortly called as Eco Processing.” [29]

Some of the eco-friendly suggestions for textile processing are [29]:

- Reduce water and energy consumption during preparation, colouration and finishing.
- Reduce aqueous waste and off-gases.
- Improve process efficiency.
- Reduce exposure to hazardous chemicals.

Some of the most useful recommendations in finishing processes are [29]:

- Do not use formaldehyde based crease resist/anti-shrinking/wrinkle free finish substances.
- Check the presence of free formaldehyde, if are used any binder type of resins for stiff finish.
- Have the practice of stocking the finish liquor used in stenter padding mangles.
- Go into the details of chemicals in every finishing agent are used, such as anti-pilling agent, antimicrobial agents, etc. The presence of PCP, PCB and TCP should be checked and avoided.
Avoid using Acetic acid in the finishing recipes and better use formic acids wherever possible.

Vapours and fumes of Ammonia, Formaldehyde, Benzaldehyde, etc are injurious to health.

It is also necessary to know the most important environmental negative effects related to textile wet processing and such examples are presented below [29]:

- Chemical intensive wet processing - scouring, bleaching, mercerising, dyeing, printing, etc.
- Heavy metals - iron, copper, lead, etc found in dyestuffs auxiliaries, binders, etc.
- Residual dyestuffs chemicals in water - due to poor fixation of colours.
- PVC and phthalates - used in plastisol printing paste.
- Formaldehyde - found in dispersing agents, printing paste and colorant fixatives.
- Dye effluent - waste water is used.

**Chlorine-free bleaching:**
“Chlorine-free bleaching is the use of hydrogen peroxide to whiten fabrics. Hydrogen peroxide naturally degrades into oxygen and water, leaving no harmful chemical residue on the cloth or in the effluent. It is sometimes referred to as Green Bleach.” [29]

**Cold or low temperature dye processes:**
“Cold or low temperature dye processes save energy by operating at atmospheric temperatures and do not require steaming of the textile to set or fix dyes.” [29]

**Dry-heat fixation:**
“Dry-heat fixation is a method of fixing reactive dyes printed through the ink-jet method. The dyed/printed fabric is passed through hot iron plates in lieu of steam. This method conserves water and energy by using an alternative to steam fixing as well as the ink-jet printing method.” [29]

**Dye bath reuse:**
“Dye bath reuse is the practice of recycling the water used in dye baths for subsequent baths. The water conserved through the bath's reuse is substantial, as anywhere from 10 - 50% of dye from one bath does not fix to the fabric.” [29]

**Eco bleach:**
“Eco bleach is the use of natural phosphates and silicates in cow dung combined with sunlight to achieve whitening of natural fabrics. This is the most eco-friendly form of bleaching.” [29]

**Ink-jet printing:**
“Ink-jet printing is a method of applying pigment and dyes to cloth using an ink-jet printer. It is considered the most eco-friendly and efficient method of printing due to its lower water usage, water wastage and energy consumption compared with other commercial printing methods.” [29]
Vegetable tanning:
“Vegetable tanning refers to the use of natural tannins to create usable leather from hides. Natural tannins are present in bark, wood, leaves and fruits of chestnut, oak and hemlock trees. This process is time intensive, as it can take up to three weeks for the tannins to fully penetrate a hide. From an ecological perspective, vegetable tanning is preferable, however the leather produced is not stable in water as it shrivels and becomes brittle.” [29]

Waste water recycling:
“Waste water recycling is the use of tertiary treated waste water in the dye baths and/or for irrigation purposes. This water is suitable for human contact but is not potable. Its use reduces the strain on potable water supplies particularly in arid climates and is an effective way to re-use this valuable resource.” [29]

5 GREEN CHEMISTRY AND THE TEXTILE INDUSTRY

Sustainability is the capacity to endure. For humans, sustainability is the long-term maintenance of well-being, with its environmental, economic and social dimensions, which include the responsible management of resources. In ecology, sustainability describes how biological systems remain divers and productive over time. By contrast, conventional chemical manufacturing processes based on fossil fuels are unsustainable, because:

- The supply of raw materials is limited;
- The processes generate waste which creates an increased burden on the environment.

Natural biochemical processes involve elements that are both abundant in the biosphere and accessible to the organisms, such as: carbon, hydrogen, oxygen, nitrogen, sulphur, calcium and iron. Industries, by contrast, gather many of their row materials from concentrated deposits and may redistribute them to places where they are unwanted or where they may interfere with natural processes.

Raw materials can be placed in two categories:

- Renewable materials: which grow, are biodegradable and whose seeds enable them to be regrown;
- Non-renewable finite materials: which do not regrow and the supply of which may soon become exhausted if used intensively.

5.1 What is green chemistry

Anastas and Warner defined the term ‘green chemistry’ as the design of chemical products and processes that reduce or eliminate the use or generation of hazardous substances [P. Anastas and J. C. Warner, Green Chemistry: Theory and Practice, Oxford University Press, New York, 1998].
Whereas environmental chemistry studies the effect of environmental pollutants, green chemistry deals with new sciences and technologies concerned with the preventing the formation of any waste, and its principle offer an upstream solution for many of the health, environmental and economic problems spawned by industrial chemicals; it is sometimes also called sustainable chemistry [National Research Council, Sustainability in the Chemical Industry: Grand Challenges and Research Needs – A Workshop Report, National Academies Press, Washington, DC, 2005].

5.2 Principles of green chemistry

Hutchins has recommended the following objectives for green chemistry [G. J. Hutchings, Green Chemistry Has a Gold Future, Europacat 7, Cardiff University, UK, August 2005]:

- **Waste management**: elimination or minimization of waste;
- **Atom economy**: no or lower wastage of atoms;
- **Catalysis**: catalysts are proffered to stoichiometric reagents;
- **Direct reactions**: use of minimum or fewer reaction steps; derivates or intermediate steps use additional reagents and have the potential to generate more waste;
- **Safer reactions**: synthetic methodologies should be designed to use and generate substances that possess little or no toxicity to human health and the environment;
- **Renewable raw materials**: use of renewable and non-depleting feedstocks;
- **Safer production**: preservation of the efficacy of functioning while reducing toxicity;
- **Biodegradability**: use of easily and harmlessly degradable chemicals with no accumulation in the environment;
- **Green auxiliaries**: use of auxiliary substances (e.g. solvents, separation agents) should be avoided wherever possible and where absolutely necessary, should be preferably be innocuous;
- **Energy economy**: saving the energy should be achieved preferably by using reactions that take place under ambient temperature and pressure conditions;
- **Safer by-products**: real-time monitoring and control and reuse of by-products;
- **Hazard control**: avoidance of hazardous chemicals to minimize the chance of explosions, fire and harmful releases.

5.3 Non-eco-friendly substances

The terms ‘environmentally friendly’, ‘eco-friendly’, ‘nature friendly’ and ‘green’ are used to refer to goods and services, laws, guidelines and policies claim to inflict minimal or no harm to the environment [Webster’s New Millennium Dictionary of English, Preview Edition (v0.9.7), Lexico Publishing Group, LLC, USA, 2006].

‘Green’ is a very subjective term that could be interpreted in different ways, but whatever the definition, becoming green is important because it means being committed to protect the people and the planet. Green or eco-friendly goods, services and practices assure the use of environmentally-friendly materials, free from harmful chemicals, compounds or energy waste, which do not deplete the environment during pollution and transportation, whereas
non-eco-friendly substances such as non-biodegradable organic materials, and hazardous substances may do harm to the environment [45].

The main non-eco-friendly substances are [46]:
- **Non-biodegradable organic materials** – substances that are not broken down by microorganisms, have no biochemical oxygen demand (BOD), and have an oxygen demand only if it is a chemical reducing agent;
- **Hazardous chemicals** – those who are a physical hazard or a health hazard;
- **Toxic metals and heavy metals** – Bjerrun defined ‘heavy metals’ those with elemental densities above 7 g/cm³; over the years this definition has been modified by various authors; some health hazards are presented in table 9 [D. A. Phillips, Chemistry and biochemistry of trace metals in biological systems, in Effect of Heavy Metal Pollution on Plants, N.W. Lepp, ed. Applied Science Publisher, Barking, 1981];
- **Toxic volatile organic compounds (VOCs)** – are organic chemicals that have a high vapour pressure under normal atmospheric conditions;
- **Hazardous substances in transit** – due to unprecedented growth of chemical industries in the developing countries, the proportion of the total freight traffic involved in the transport of hazardous chemicals is increasing at a rapid rate. Of the carriers transporting hazardous goods, the majority carry flammable petroleum products including kerosene, petrol, liquefied petroleum gas and naphtha.

### Table 9: Health hazards associated with some heavy metals and metalloids used in the textile industry

<table>
<thead>
<tr>
<th>Metal/metalloid</th>
<th>Associated health hazards</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead (Pb)</td>
<td>Damage to the brain, nervous system and kidneys (causes in mild cases insomnia, restlessness, loss of appetite and gastrointestinal problems).</td>
</tr>
<tr>
<td>Mercury (Hg)</td>
<td>Damage to the brain.</td>
</tr>
<tr>
<td>Cadmium (Cd)</td>
<td>Disorders of the respiratory system, kidneys and lungs.</td>
</tr>
<tr>
<td>Chromium (Cr)</td>
<td>Skin and respiratory disorders, ulceration of skin and cancer of the respiratory tract on inhalation.</td>
</tr>
<tr>
<td>Arsenic (As)</td>
<td>Skin cancer, hyperpigmentation, kurtosis and black foot disease.</td>
</tr>
</tbody>
</table>

The characteristics of green chemicals are as follows [Stanley E. Manahan, Green Chemistry and the Ten Commandments of Sustainability, Chem-Char Research, Inc., Columbia, 2006]:

- prepared from renewable or readily-available resources by environmentally-friendly processes;
- low tendency to undergo sudden, violent, unpredictable reactions such as explosions;
- non-flammable or poorly flammable;
- low toxicity and absence of toxic constituents, particularly heavy metals;
- biodegradable;
- low tendency to undergo bio-accumulation in food chains in the environment.
Harmless chemicals

The attention given to sustainable (green) chemistry can be categorized into the following three focus areas [47, 48]:

- alternative synthesis routes – greener synthetic pathways;
- alternative reaction conditions – the use of greener reaction conditions;
- the design of alternative, safer, less-toxic or less-hazardous chemicals.

Greener energy

One of the best approaches to a greener environment is to save energy by consuming fewer resources. Processes like heating, cooling, stirring, distillation, compression, pumping and separation require electrical energy which is often obtained by burning fossil fuel. This results in the release of carbon dioxide into the atmosphere, thereby contributing to global warming effect.

6 LYFE CYCLE ANALYSIS

6.1 The Supply Chain

Fashion and textiles undergo in production a chain of processes from raw material to finished product, “one of the longest and most complicated industrial chains in manufacturing industry.” The time consuming and resource intensive processes “draw on labour, energy, water and other resources and cumulatively make for a high-impact sector.” (Fletcher, 2008) Traceability is therefore the key to understanding the textile supply chain and reducing environmental impact.

A supply chain is a network of suppliers, factories, warehouses, distribution centers and retailers, through which raw materials are acquired, transformed, produced and delivered to the customer (figure 10). The supply chain consists in all the activities associated with the flow and transformation of goods, beginning with the raw material stage all the way to the end user, and the associated information flows. [64]

To get the best (and most accurate) understanding of the supply chain, continuous and transparent communication with suppliers is imperative, asking questions such as [65]:

- What traceable and verifiable information can be obtained from the suppliers regarding environmental impacts as well as animal husbandry?
- Are used mechanical or chemical methods to process the fibres/fabrics?
- If are used chemical methods for fibre processing, what measures are undertaking to minimize pollution to air and water?
- How can be reduced the impact of wet processing and finishing?

![Supply Chain Diagram](image)

**Figure 10:** Example of the supply chain management (adapted after Parray S.H and Kadri S.M, 2007)

*The main textile supply chain 10 steps to go green* are as following [66]:

- Farming - Ginning - Spinning - Knitting - Dyeing - Finishing - Cutting - Sewing - Packaging - Shipping

1. **Go Organic**
2. **Reduce Cotton Waste:** only 20% of the original cotton mass is used in the final product; therefore it is very important to find uses for what is considered waste.
3. **Switch to Green Energy**
4. **Ethical Trade practices**
5. **Reduce, Re-use, Recycle:** minimise packaging; use post-consumer recycled materials; use recyclable material.
6. **Transportation**
7. **Look after water**
8. **Lower the water footprint**
9. **Lower the Carbon Footprint**
10. **Inform customers.**

*Traditional versus green supply chain*

In a traditional supply chain, the flow of materials and information is linear and from one end to the other. There is a limited collaboration and visibility. Each supply chain partner has limited information regarding, for example, the carbon footprint and greenhouse gas emission of the other partners. Hence, each player may be concerned about his own footprint and may try to reduce this, irrespective of the impact on upstream and
downstream supply chain. There may be some focus on end-to-end supply chain costs but due to limitations of information sharing, the costs are far from optimized in most cases. An example is presented in figure 11.

Figure 11: Traditional Supply Chain Management (source [67])

In contrast, Green Supply Chains consider the environmental effects of all the processes of the supply chain, from the extraction of raw materials to the final disposal of goods (figure 12) [67].

Figure 12: Green Supply Chain Management (source [67])
Within the Green Supply Chain each player motivates other players to go Green and provides the necessary information, support, and guidance. Environment objectives and performance measurement have to be integrated with financial and operational objectives. With this integration, the Green Supply Chains could: minimize waste and environmental impact while assuring maximized consumer satisfaction and healthy profits. [67]

The green supply chain management is a type of modern management which could comprehensively consider the environmental influence and efficient resource utilization in the whole supply chain. GSCM finds its definition in the supply chain management. In order to add the green component to the supply chain management, one needs to assess the impact the supply chain management on the natural environment [67]. In a nutshell:

GSCM = Green purchasing + Green manufacturing /materials management + Green Distribution / marketing + Reverse logistics.

6.2 General aspects of Life Cycle assessment

Quantifying the overall impact of a product on the environment demands an account of all the inputs and outputs throughout the life cycle of that product from its birth, including design, raw material extraction, material production, part production and assembly, through its use and final disposal.

In the case of a textile in a global market, much of the variability will be in the production of the fibre, which is illustrated in table 10:

<table>
<thead>
<tr>
<th>Fibre</th>
<th>Energy use in MJ per KG of fiber</th>
</tr>
</thead>
<tbody>
<tr>
<td>flax fibre (MAT)</td>
<td>10</td>
</tr>
<tr>
<td>cotton</td>
<td>55</td>
</tr>
<tr>
<td>wool</td>
<td>63</td>
</tr>
<tr>
<td>Viscose</td>
<td>100</td>
</tr>
<tr>
<td>Polylpropylene</td>
<td>115</td>
</tr>
<tr>
<td>Polyester</td>
<td>125</td>
</tr>
<tr>
<td>acrylic</td>
<td>175</td>
</tr>
<tr>
<td>Nylon</td>
<td>250</td>
</tr>
</tbody>
</table>

[Source: “LCA: New Zealand Merino Wool Total Energy Use”, Barber and Pellow]

Life cycle assessment determines the environmental impacts of products, processes or services, through production, usage and disposal.

- **Life Cycle Assessment is:**
A systematic set of procedures for compiling and examining the inputs and outputs of materials and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle.

- **Life Cycle is:**
  The consecutive and interlinked stages of a product or service system, from the extraction of natural resources to the final disposal.

[ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines]

The study which measures these elements is called a *Life Cycle Assessment (LCA)*, figure 13 [10]. Such a study might also include further industrial operations down the pipeline and consumer operations, until final disposal or recycling. Man-made fibers are very diverse in their properties and performance, going through a wide range of processes, before being used in an enormous range of technical and textile applications. This makes it very difficult to track the complete LCA, which is called cradle-to-cradle. This is the reason why many product LCA’s go from cradle to factory gate only. [10]

![Figure 13: Example of LCA (adapted after Man-Made Fibres and Sustainability, source [10])](image)

Typical process steps or life cycle stages are: *Raw materials, Fibre production, Fabric Production, Dyeing, Printing and Finishing, Conversion to the End Product, Transportation, Product Use and Maintenance, Recycling, Incineration or Disposal.*

The process of measuring the sustainability performance can be carried out at production or plant level. The result of this evaluation indicates the potential for the product and process improvement, with the ability to focus the efforts on the lifecycle that is most likely to
produce the greatest result. Consequently, man-made fibre producers are focused on all the aspects of improving the LCA and sustainability of their product.

Thus, LCA, also known as life cycle analysis, ecobalance or cradle-to-grave analysis, involves a systematic scientific approach to examine the environmental impacts of the entire life cycle of a product or service. It is not simply the quality of the product or the amount of waste that ends up in a landfill or an incinerator, but the whole life cycle of the product that determines its environmental impact. LCA is the technique associated with all the stages in the life cycle of a product, from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. LCA is also a way of collecting metrics about whether green improvements have been made or not. LCA is used for much more than just waste minimization; it is also used for estimating CO₂ and GHG emissions and is probably the most common way to investigate the flow of energy and water in any type of process.

The Environmental Management and Audit Scheme (EMAS) is currently used as guidelines and standards for environmental strategies for LCA. The main environmental strategies are (source: Biodegradable and Sustainable Fibers):

1. "Strategy based on environmental requirements and laws, where the company's strategy is based on observance of environmental laws and other requirements."

2. "Strategy based on preventive actions, when the company is concentrating on the prevention of environmental hazards and risks."

3. "Strategy based on ecological competitiveness by an effective use of resources and by making use of the eco-marketing possibilities."

4. "Strategy based on the principles of a sustainable development. The company's environmental strategy pays attention to the social justice and to the rights of the future generation in addition to an effective ecological policy."

The strategies listed cover all the important economic, social and environmental aspects of a designer's strategy to develop sustainably. Strategy 1 and 4 fall under the social aspect, strategy 2 falls under the environmental aspect, and strategy 3 falls under the economic aspect.

A more complex diagram describing the LCA process is presented in figure 14 (source: Biodegradable and Sustainable Fibers, [38]).
6.3 Techniques used in LCA

Life Cycle Assessment (LCA) – (figure 15) [101] is a technique for assessing the potential environmental aspects and potential aspects associated with a product (or service), by:

- compiling an inventory of relevant inputs and outputs,
- evaluating the potential environmental impacts associated with those inputs and outputs,
- interpreting the results of the inventory and impact phases in relation to the objectives of the study.

- ISO 14040.2 Draft: Life Cycle Assessment - Principles and Guidelines
Life-cycle assessments (LCAs) involve cradle-to-grave analyses of production systems and provide comprehensive evaluations of all upstream and downstream energy inputs and multimedia environmental emissions. LCAs can be costly and time-consuming, thus limiting their use as analysis techniques in both the public and private sectors. Streamlined techniques for conducting LCAs are needed to lower the cost and time involved with LCA and to encourage a broader audience to begin using LCA.

- Research Triangle Institute (RTI)

Life-cycle assessment has emerged as a valuable decision-support tool for both policy makers and industry in assessing the cradle-to-grave impacts of a product or process. Three forces are driving this evolution:

- First, government regulations are moving in the direction of "life-cycle accountability;" the notion that a manufacturer is responsible not only for direct production impacts, but also for impacts associated with product inputs, use, transport and disposal.
Second, business is participating in voluntary initiatives which contain LCA and product stewardship components. These include, for example, ISO 14000 and the Chemical Manufacturer Association's Responsible Care Program which seek to foster continuous improvement through better environmental management systems.

Third, environmental "preferability" has emerged as a criterion in both consumer markets and government procurement guidelines. These developments have placed LCA in a central role as a tool for identifying cradle-to-grave impacts, both of products and the materials from which they are made.

An example of LCA for compostable, biodegradable fibers is presented in figure 16 [38, 100].

The "life-cycle" or "cradle-to-grave" impacts include:
- the extraction of raw materials;

![Image of Idealised life cycle for a green, compostable biodegradable fibre](source: Biodegradable and Sustainable Fibers [38] and Keneth Buddha Jeans [100])

**Figure 16:** Example of LCA for compostable, biodegradable fibers (source: Biodegradable and Sustainable Fibers [38] and Keneth Buddha Jeans [100])
- the processing, manufacturing, and fabrication of the product;
- the transportation or distribution of the product to the consumer;
- the use of the product by the consumer;
- the disposal or recovery of the product after its useful life.

There are four linked components of LCA:

- **Goal definition and scoping**: identifying the LCA’s purpose and the expected products of the study, and determining the boundaries (what is and is not included in the study) and assumptions based upon the goal definition;

- **Life-cycle inventory**: quantifying the energy and raw material inputs and environmental releases associated with each stage of production;

- **Impact analysis**: assessing the impacts on human health and the environment associated with energy and raw material inputs and environmental releases quantified by the inventory;

- **Improvement analysis**: evaluating opportunities to reduce energy, material inputs, or environmental impacts at each stage of the product life-cycle.

*Tellus Institute*

Life Cycle Assessment is a process to:

- evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment;
- assess the impact of those energy and materials used and releases to the environment;
- identify and evaluate opportunities to affect environmental improvements; the assessment includes the entire life cycle of the product, process or activity: encompassing, extracting and processing raw materials; manufacturing, transportation and distribution; use, re-use, maintenance; recycling, and final disposal.

*Guidelines for Life-Cycle Assessment: A ‘Code of Practice’, SETAC, Brussels*

Life Cycle Assessment (LCA) is used as a tool to assess the environmental impacts of a product, process or activity throughout its life cycle, from the extraction of raw materials through to processing, transport, use and disposal. In its early days it was primarily used for product comparisons, for example to compare the environmental impacts of disposable and reusable products. Today its applications include government policy, strategic planning, marketing, consumer education, process improvement and product design. It is also used as the basis of eco-labelling and consumer education programs throughout the world.

*Life Cycle Assessment: How Relevant is it to Australia? M. Demmers and H. Lewis*
Life Cycle Assessment or LCA can be defined as a systematic inventory and analysis of the environmental effect that is caused by a product or process starting from the extraction of raw materials, production, use, etc., up to the waste treatment. For each of these steps, an inventory concerning the use of material and energy and the emissions affecting the environment will be drawn up. With this inventory an environmental profile will be set up, which makes it possible to identify the weak points in the lifecycle of the system studied. These weak points are the focal points for improving the system from the environmental point of view.

- VITO (Flemish Institute for Technological Research)

A schematic representation of the LCA, according to Matsushita Graphic Communications Systems Inc., is presented in figure 17 [68].

![Diagram of LCA](image_url)

**Figure 17:** A model of LCA, according to Matsushita Graphic Communications Systems Inc. [68]

- Matsushita Graphic Communications Systems Inc.
Combining Economic Input-Output Models and Life Cycle Assessment

Manufacturing a product can be very complex. Raw materials come from many different sources, and processing each one of these materials involves different series of inputs, outputs and processes, with different impacts on the environment. To identify the total environmental impact of a product it is necessary to do a life cycle analysis.

The main stages in LCA which includes green design are as following (figure 18) [69, 99]:

*Figure 18: Life cycle analysis*

The first stage of a life cycle analysis is called the "inventory analysis." The goal of this analysis is to examine all the inputs and outputs in a product's life cycle, beginning with what the product is composed of, where the materials came from, where they go, and the inputs and outputs related to those component materials during their lifetime. It is also necessary to include all the inputs and outputs during the product's use. The purpose of the inventory analysis is to quantify what comes in and what goes out, including the energy and material associated with materials extraction, product manufacture and assembly, distribution, use and disposal and the environmental emissions that result. [69]

The next stage of a life cycle analysis is the impact analysis in which the environmental impacts identified in the previous stage are enumerated, such as those generating energy for the processes and the hazardous wastes emitted during the manufacturing phases. Once the environmental impacts of all the inputs and outputs of a product's lifecycle are analyzed, it is generated a number that represents how much the environment is affected. The major purpose of the analysis is to evaluate how the product affects the environment throughout its lifecycle, based on the inputs and outputs that are quantified. Once its general environmental impact is calculated, the next step is to conduct an improvement analysis. The necessary change is operated within the inventory analysis by recalculating its total environmental impact [69].

A new possible life cycle approach is suggested in figure 19.
In order for Lifecycle evaluation to lead to the development of sustainable waste management and recycling policy, it is necessary to be able to evaluate the external costs of these schemes in comparison with the alternative methods of waste disposal.

7 TOOLS IN ASSESSING THE SUSTAINABILITY

The complex evaluation of sustainability involves different measurements and tools; some of them are presented below.

The measurement of the entire impact of chemical usage involves:
- Air, water and soil;
- \( \text{CO}_2 \) emission;
- Waste;
- Health.

Measuring sustainability in textile manufacturing implies:
- Life cycle assessment of textiles;
- Carbon footprint;
- Water footprint;
- Resources utilization: water, energy, chemicals;
- Assessment of social responsibility.

So, the main parameters involved in the sustainability measurement in wet processing are as following (figure 20):
Figure 20: Sustainability measurement in wet processing (adapted after: “Sustainable Textiles?” presented by Dr. S. Pervez Abbas, October 2012)

The life cycle assessment (LCA), as it was presented before, enables:

- Estimation of cumulative environmental impacts results from all stages of the product life cycle;
- A “cradle-to-grave” approach “for assessing the environmental aspects and potential impacts associated with a product by:
  - compiling an inventory of relevant inputs and outputs of a system;
  - evaluating the potential environmental impacts associated with these inputs and outputs;
  - interpreting the results of the inventory and impact phases in relation to the objectives of the study.” (ISO 14040)

The carbon footprint (CS): also named Carbon profile, is the overall amount of carbon dioxide (CO₂) and other greenhouse gas (GHG) emissions (e.g. methane) associated with a product, along its supply-chain and sometimes including the use and the end-of-life recovery and disposal. A low–carbon sustainable world requires business leadership and innovation to address the problems of the surrounding climate change.

The calculation of a company’s or of a product’s carbon footprint is a way to measure the impact of that company or product on global warming. This footprint is the consequence of using fossil fuels for energy or as raw material (e.g. synthetic fibres). The reduction of the energy or renewable energy sources (wind, water, sun) used will lower the carbon footprint.

The water footprint (WFP): of a product is an empirical indicator of how much water is consumed, when and where, measured over the whole supply chain. The water footprint of an individual, community or business, is defined as the total volume of fresh water that is used to
produce the goods and services consumed by the individual or community or produced by the business. [27, 49]

**Social Responsibility**: Without people, we could not develop, produce, or sell any products. Social factors are increasingly included in the sustainability assessments. The argument for inclusion is that the necessary workforces cannot be sustained over time without basic rights and fair treatment. The problem from an assessment standpoint is not that social factors are unimportant, but that they are often difficult to measure and quantify. The main factors that are often included in these assessments are: workers and community health and safety regulations, working conditions, worker rights and “Living Wage”, forced labour, child labour and guarantees of non-discrimination, training opportunities, employee input and freedom to innovate [20].

The main new tools, standards and test methods for assessing the textiles and apparel sustainability are presented below.

### 7.1 Sustainable Textile Production (STeP)

A new tool to help fashion brands and retailers to evaluate and choose the sustainability of their suppliers is the Sustainable Textile Production (STeP), figure 21 [104].

![Figure 21: Sustainable Textile Production (STeP) certification system (source [104])]()

STeP is the new OEKO-TEX® certification system for brands, retail companies and manufacturers from the textile chain who want to communicate their achievements regarding sustainable production to the public in a transparent, credible and clear manner. Certification is possible for production facilities of all processing stages from fibre production, spinning mills, weaving mills, knitting mills, to finishing facilities and manufacturers of ready-made textile items. STeP replaces the previous OEKO-TEX® Standard 1000. [51, 104]
The aim of STeP certification is to provide fashion brands, retailers and manufacturers with the needed documentation of sustainable production across the international textile supply chain. This will allow an objective assessment of the sustainability of textile factories. This certification could be used to provide consumers with understandable and traceable documentation of a retailer's commitment to sustainability when sourcing its products.

The new system is intended to offer a single solution to the wide range of independent certification systems that cover different conditions in textile plants, including the internal working ones; it also addresses the plant's impact on the environment. It is a 'modular analysis' that scores facilities on issues such as quality management, use of chemicals, environmental protection, environmental management, social responsibility, health and safety. This model means that STeP-certified companies can compare themselves with other firms in the sector, align themselves with examples of best practice, and work on continuous improvement. It also offers advantages for fashion brands and retailers in the global sourcing process, enabling them to choose the suppliers based on their sustainability performance in a specific area. Production facilities can be audited by one of the Oeko-Tex institutes, including unannounced visits, and can be integrated with existing company certificates, such as ISO 9000, ISO 14001, SA 8000 and OHSAS 18001. The new STeP certification also supports other existing sustainability initiatives such as the Higg Index from the Sustainable Apparel Coalition and the Zero Discharge of Hazardous Chemicals (ZDHC) campaign [50].

**Concept**

The objective of STeP certification is the permanent implementation of environmentally friendly production processes, optimum health and safety and socially acceptable working conditions. The dynamic further development of the STeP standard and the benchmarks allows certified companies to continuously improve their environmental protection achievements and their social responsibility as well as their efficiency. This in turn enables them to achieve the best possible competitive position on the market.

**Advantages for brands and retailers**

STeP allows globally operating brands and retail companies to search for suitable suppliers worldwide who meet their demands regarding environmental protection and social responsibility. This enables them to clearly and completely document their joint sustainable commitment to end consumers together with the supply chain.

**Advantages for production facilities**

Textile and clothing manufacturers can make their production processes much more efficient on the basis of a STeP certification. The system helps them to determine the company's positioning with regard to sustainability and shows areas for improvement. The independent proof of sustainable production conditions also provides an image boost allowing the companies to open up new markets and supplier relations.
Comprehensive approach and textile-specific criteria

In contrast to other certification systems, which take into account only certain individual aspects of sustainability, STeP allows comprehensive analysis and evaluation with regard to sustainable production conditions. In addition to this, the requirements and criteria of the STeP certification are specifically adapted to the situation in the textile and clothing industry. The STeP criteria are standardised around the world to ensure global comparability. These are continuously analysed, evaluated and updated, if required.

Modular structure

Through modular analysis of all relevant company areas such as management of chemicals, environmental protection, environmental management, health and safety, social responsibility and quality management, the STeP certification allows a comprehensive and reliable analysis of the extent of sustainable management provided by a production facility.

Requirements

The prerequisite for STeP certification is the compliance with certain minimum requirements in the individual company areas. Based on this, the following issues are relevant:

√ Management of chemicals:
  - Compliance with the guidelines of a restricted substances list (RSL);
  - Introduction of a suitable harmful substances management;
  - Compliance with the principles of ‘green chemicals’;
  - Periodical training and further education regarding the handling of the chemicals used;
  - Obligation for appropriate communication regarding the chemicals used and their risks;
  - Monitoring the use of chemicals.

√ Environmental protection:
  - Compliance with the stipulated limit values;
  - Use of best available production technologies;
  - Optimisation of production processes;
  - Efficient use of resources;
  - Responsible handling of waste, waste water, emissions etc.;
  - Reduction of the CO₂ footprint.

√ Environmental management:
  - Proof of a suitable environmental management system for targeted coordination and systematic implementation of all environmental protection measures;
  - Commitment to environmental targets;
  - Periodic creation of environmental reports;
  - Appointment of an environmental representative;
  - Periodic training regarding the implementation of environmental targets and measures;
  - Implementation of existing environmental protection systems (e.g. ISO 14001).
√ **Social Responsibility:**
- Ensuring socially acceptable working conditions in the sense of the UN and ILO conventions;
- Execution of performance appraisals for employees;
- Implementation of existing social standards (e.g. SA 8000);
- Guaranteed training for employees regarding the social issues of an operation.

√ **Quality management:**
- Implementation of a suitable QM system, e.g. in line with ISO 9001 or operational approaches;
- Guaranteed traceability, responsibility and appropriate documentation regarding the flow of goods and manufactured products;
- Advanced management aspects such as risk management or corporate governance.

√ **Health and safety:**
- Proof of suitable measures to ensure the required health and safety in the workplace (e.g. filter systems, ear protection etc.);
- Guaranteed safety of buildings and production plants (e.g. through constructive measures, escape plans, separation of production areas etc.);
- Risk prevention;
- Implementation of existing safety standards (e.g. OHSAS 18001).

**Scoring**

STeP certification encompasses three different levels describing the extent to which the company has achieved sustainable production and working conditions:

- Level 1 = entry level;
- Level 2 = good implementation with further optimisation potential;
- Level 3 = exemplary implementation in the sense of a best practice example.

The STeP certificate shows the following scoring results:
- the sustainability level achieved;
- an overall evaluation in per cent;
- an individual evaluation of the analysed company areas in per cent.

The STeP scoring creates more transparency because it allows the sustainability of production facilities along the textile value chain to be compared on all relevant company levels across country borders and beyond legislative regulations. The detailed representation of the assessment results allows a sound definition of the company's positioning with regard to sustainability and illustrates in particular which company areas have further potential for optimisation. [51]
7.2 The Higg Index

The Higg Index is a sustainability tool designed to assess the environmental and social impact. The current version of the Higg Index focuses on measuring water use and quality, energy and greenhouse gas, waste, chemicals and toxicity. The Higg Index aims to dramatically reduce sustainability measurement redundancy and create a common means to benchmark performance in the industry [52]. The Higg Index 1.0 was released on June 26, 2012, and has been used by hundreds of organizations, both SAC (Sustainable Apparel Coalition) Members and others. The Higg Index 2.0 was released on 11 December 2013 and represents a significant step forward. The Higg Index 2.0 is a suite of sustainability assessment tools. These assessments, called modules, evaluate impacts through three different lenses: Facility, Brand and Product (figure 22). The Higg Index 2.0 is primarily an indicator based assessment tool for apparel and footwear products. The Index asks practice-based, qualitative questions to gauge environmental sustainability performance and drive behavior for improvement. It is based largely on the Eco Index, Nike’s Apparel Environmental Design Tool, Global Social Compliance Program (GSCP) reference tools, and Social/Labor Best Practice Tools (e.g., SAI Social Fingerprint, FLA Sustainable Compliance Initiative, etc.) [sources 52 and 54].

![Figure 22: Individual tools in the Higg Index 2.0. (sources [52, 54])](image)

The Higg Index 2.0 is:

- a self-assessment tool that enables rapid learning through identification of environmental sustainability hot spots and improvement opportunities;
- a starting point of engagement, education and collaboration among stakeholders in advance of more rigorous assessment efforts.
The Higg Index 2.0 is a learning tool for both small and large companies to identify challenges and capture on-going improvement. It targets a spectrum of performance that allows beginners and leaders in environmental sustainability, regardless of company size, to identify opportunities. It was developed for both environmental and social/labor performance. The Higg Index 2.0 is based on life-cycle thinking and spans the apparel life cycle (materials, manufacturing, packaging, transportation, use and end-of-life). Retail activities are not included in The Higg Index 2.0 and will be considered for future releases.

The three main tools of the Higg Index 2.0 are briefly presented below:

**Facility Tools**

There are two tools that are ready to be used by facilities, vendors or manufacturers to assess specific facility sites:

- *Facility Module – Social/Labor: Apparel/Footwear - Beta*: used to assess the social and labor performance of material, packaging and manufacturing facilities.

The Facility Module was based on the criteria of the Global Social Compliance Program (GSCP), a program previously developed by leading retailers to improve environmental and social responsibility within their shared global supply chains. It was designed to assess and drive improvement in suppliers to many different industries, and the scope of the program covered eleven different environmental areas of focus.

The Facility Module tailored the questions and criteria of the GSCP to be more specific to the apparel industry, and it focuses on seven environmental areas, which are a subset of the eleven included in GSCP. The Facility Module environmental areas address: environmental management systems, energy use and greenhouse gas emissions, water use, and waste water, emissions to air, waste management, and pollution prevention /hazardous substances. [53]

**Brand Tools**

There are three tools that are useful to Brands:

- *Brand Module – Social/Labor: Apparel/Footwear - Beta*: assesses social and labor apparel and footwear product-specific social and labor practices at the Brand level.

**Product Tools**

There are two tools that can help to understand the impacts of the products:
- **Rapid Design Module (RDM) – Beta**: is a prototype to test how designers can be guided on sustainable product design with directionally correct information and streamline decision support framework.

- **Materials Sustainability Index (MSI) Data Explorer**: is an online platform that allows the users to understand the data and the methodology behind MSI Base Material Scores, which can be seen in the RDM - Beta. It also serves as a data submission platform to improve the quality of material scores or to add new materials. [54]

### 7.3 The sustainable apparel index

The sustainable apparel index evaluates the impacts of the entire life cycle of apparel products: materials, manufacturing, packaging, transportation, use and end-of-life. The main areas of consideration are [16]:

- Water use and quality;
- Energy use and greenhouse gases;
- Waste, chemicals and toxicity;
- Social and labor.

### 7.4 Standards and test methods for textiles sustainability

The demand for eco-friendly materials and textiles has increased significantly among consumers and there is also noticed a strong emphasis on sustainability from various pressure groups. This determined a significantly increased pressure on brands and retailers to meet various eco standards. Thus, retailers and brands are nowadays responding to sustainable demands in a more proactive manner. Due to the stricter environmental legislations, retailers and brands are more aware of the restricted chemicals and substances which need to be avoided in the end product. As a result, textile and clothing manufacturers are determined to meet the requirements of eco parameters set by brands in order to be environmentally compliant both during the manufacturing and the consumption of the product. This situation determine an increased demand for ecological testing against the eco parameters set by various legislative and certification bodies and global brands, at every stage of manufacturing. There is a continuously demand for testing facilities that can provide fast and reliable eco testings for the supply chain partners in the textile industry. [57]

**DyStar** has always taken the environmental impacts of its products very seriously and understands the requirements of testing the restricted substances in its raw materials and manufactured products. With the acquisition of Texanlab in India, DyStar has gone further in showing its commitment towards environmental compliance through testing for eco parameters in textiles.

**Texanlab** has built an immense expertise in the areas of routine and eco testing for textiles over the past few years. They have the necessary expertise and processes to identify the ecology issues, test the parameters and give expert advice in solving the problem. According to Texanlab, many substances are restricted for use in industry and consumer products,
including textiles and garments. Their use is limited for different reasons, including consumer and worker safety and environmental issues.

Certain chemicals are now restricted by legislation and must not be present in the final textile products. Others are restricted by brands and eco labels. Conformance to these and other emerging standards concerning consumer safety is imperative for the major suppliers of textiles and clothing to Europe and USA. In countries with economies in transition the industry has been more reactive rather than proactive and their specifications for textile products often do not contain such norms. This situation has to change very quickly over the next few years.

An awareness of restricted substances is critical for all the parties involved in the textile supply chain. The testing for restricted substances in textiles is a highly specialized area; a specific procedure must be developed or employed for each specific problem of testing brought to the analytical laboratory. [57]

Some of the most important testing procedures, regulations, certifications and standards are presented below.

7.4.1. RSL (Restricted Substance List) testing

RSL testing is probably one of the most complex fields of analytical chemistry because of the need for isolation and determination of substances at the milligram, microgram and sometimes pictogram levels.

RSL testing essentially consists of the following steps:
   a) Sampling – how a representative sample is obtained from the test specimen.
   b) Extraction of digestion, Concentration, Cleanup, Derivatization if required.
   c) Determination by Chromatography (for organic) or Atomic absorption or emission (for metals) or Spectrophotometry (both for metals and certain organic substances) methods.
   d) Evaluation of obtained data.

All of the above steps need to be in line with standard processes and reliable so as to ensure the final report accuracy and repeatability.

*Instruments used in testing*

A range of analytical techniques are used in the RSL testing for textiles including:
- Gas Chromatography with Mass Spectrophotometer (GC/MS).
- Gas Chromatography with Electron Capture Detector for chlorinated compounds (GC/ECD).
- High Performance Liquid Chromatography with Diode Array Detector (HPLC/DAD).
- High Performance Liquid Chromatography with Mass Spectral Detector (LC/MSD) for non-volatile compounds.
- Atomic Absorption Spectrophotometer with Graphite tube Atomization (AAS/graphite) for metals.
- Inductively Coupled Plasma with Mass Spectrometer (ICP/MS) for metals.
- UV-Visible Spectrophotometer for metals and certain organics.
- Absorbable Organic Halogen (AOX) Analyzer for organochlorines.

**Restricted substances**

The number of substances that can be restricted is vast and not all of the compounds listed are appropriate for textile products. The most common substances that may be considered when carrying out restricted substance testing are [56, 57]:

- Formaldehyde.
- Chlorinated phenols (PCP, TeCP) and Orthophenylphenol (OPP).
- Banned Amines from Azo dyes.
- Allergenic Disperse Dyes.
- Carcinogenic Dyes.
- Heavy Metals.
- Organotin compounds.
- Alkylphenol Ethoxylates (APEOs).
- Chlorinated Organic carriers.
- Phthalates.
- Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS).
- Pesticide residue.
- Flame retardants.
- Short chain chlorinated paraffins (SCCP).
- Polychlorinated biphenyl (PCBs).
- Polyaromatic hydrocarbons.
- pH of the aqueous extract.
- REACH / SVHC.

Texanlab has a complete set up and the necessary expertise to carry out the complete testing methods for the restricted substances list imposed by various retailers and brands, and to recommend the limit values for restricted substances.

**7.4.2. REACH**

REACH is a European Community Regulation on chemicals and their safe use (EC 1907/2006). It deals with the Registration Evaluation, Authorization and Restriction of Chemical substances. The Regulation applies not only to chemicals but also to mixtures (preparations) and to other substances that can be found in final products such as clothing. It contains:

- Restrictions on the manufacture, placing on the market and use of dangerous substances, preparations and articles (Annex, XVII).
- Articles and packaging materials containing over 0.1% (by weight) SVHC substances (Substances of Very High Concern).
- Articles (products) containing substances which are intentionally released during their normal life-time use, e.g. perfumery finishes on textiles.
REACH provisions are also applicable to consumer articles. So far, the ECHA has released a list of 15 chemicals classified as SVHCs or substances of very high concern, which triggers obligations for manufacturers and retailers under REACH. As a global manufacturer and supplier of dyestuffs and auxiliaries, DyStar has completed the pre-registration under the REACH legislation of all the chemicals which are used for the manufacturing of its products globally. The fully equipped Texanlab testing laboratory understands the testing requirements arising from the manufacturers and exporters to fulfill the REACH requirements as per EU legislations and offers testing facilities for most of the SVHC’s considered banned as per REACH legislations. Texanlab is continuously working on increasing their capability and facility to test most of SVHC’S mentioned in REACH.

7.4.3. CPSIA (Consumer Product Safety Improvement Act)

According to CPSIA (Consumer Product Safety Improvement Act), all components of garments/made-ups meant for Children (kids below 12 years of age) will be required to independently adhere to the norm. CPSIA requirements for Lead, flammability and phthalates have been notified. The requirements or limit values will undergo changes; for example, the reduction in limits on Lead has already been notified. With such stringent testing procedures, many laboratories have equipped and applied for the accreditation for the CPSIA testing as per their norms on textiles. Texanlab is now one of the few approved and accredited laboratories by CPSIA for lead testing. [56]

7.4.4. GOTS

GOTS is an Organic textile standard set by four groups promoting the interests of the organic textile industry: OTA (Organic Trade Association) in the USA, SA (Soil Association) in the UK, JOCA (Japanese Organic Cotton Association) in Japan, IVN (Internationaler Verband der Naturtextilwirtschaft e.V. – International Association Natural Textile Industry) in Germany. GOTS sets specific requirements for the complete production cycle of organic textiles, including the cultivation of cotton. This standard sets clear requirements and, where necessary, limits for:

- Organic fiber production.
- Product labeling.
- Textile auxiliaries, dyes and pigments.
- Stages in the production process, e.g. spinning, weaving, knitting, pre-treatment, dyeing, printing, finishing, etc.
- Accessories.
- Environmental management.
- Storage, packaging and transport.
- Quality assurance systems.
- End products.
- Residues in accessories.
- Social compliance.
Texanlab is one of few institutes in Asia that has the expertise to perform analysis in compliance with GOTS. Testing for GOTS conformance includes AOX, Formaldehyde, Chlorinated Phenols, Biodegradability, Toxicity tests, APEOs, heavy metal content and banned amines. [56]

7.4.5. Other tests, regulations and certification

In the EU there are a lot of initiatives and sustainability labels to guarantee good labour conditions and the reduction of environmental impacts associated to the textile sector. This ranges from consumer labels and B2B certificates to worldwide multi-stakeholder initiatives. Certification or participation in such an initiative may be a good way to improve the environmental performance and communicate about this to the buyers. The CBI published several documents on this matter:

- Sustainability labels and other initiatives in the textile sector.
- Sustainable cotton labels and initiatives.
- Retailers’ sustainability initiatives for non-food products.

The textiles industry is responding to legislation such as the EU Landfill Directive (1999) by developing new fibres that can be properly regulated and certificated.

Other important tests and certificates are presented below.

Chemical tests for heavy metals and ecological toxicity: Textile testing helps to protect the interest of both manufacturers and consumers. The growing list of controlled chemicals includes: Formaldehyde; Chlorinated phenols (PCP, TeCP) and Orthophenylphenol (OPP); Banned Amines from Azo dyes; Allergenic Disperse Dyes; Carcinogenic Dyes; Heavy Metals; Organotin compounds; Alkylphenol Ethoxylates (APEOs); Chlorinated Organic carriers; Phthalates; Perfluorooctanoic Acid (PFOA) and Perfluorooctane Sulfonate (PFOS); Pesticide residue; Flame retardants; Short chain chlorinated paraffins (SCCP); Polychlorinated biphenyl (PCBs); Polyaromatic hydrocarbons. ([www.eco-label.com](http://www.eco-label.com)).

Eco-Textile Testing: A European and U.S. ecological requirement is that textiles are free from heavy metals. Heavy metals are constituents of some dyes and pigments, and may also be found in natural fibres due to absorption by plants through soil. Metals may also be introduced into textiles through finishing processes. The main Eco-Textile Testing used is presented in table 11 [57].

Table 11: Eco-Textile Tests [57]

<table>
<thead>
<tr>
<th>Test</th>
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<tbody>
<tr>
<td>Acute toxicity to fish OECD 203</td>
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<tr>
<td>Acute toxicity to Daphnia 84/449/EWG C.2</td>
<td></td>
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<tr>
<td>Acute toxicity to algae OECD 201</td>
<td></td>
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<tr>
<td>Earthworm toxicity EC50 OECD 207</td>
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<tr>
<td>Terrestrial plant toxicity OECD 208</td>
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<tr>
<td>Mutagenicity test 9Ames test) OECD 471</td>
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<tr>
<td>Acute oral toxicity to rats LD50 OECD 423</td>
<td></td>
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<tr>
<td>Primary skin irritation - rabbit OECD 404</td>
<td></td>
</tr>
<tr>
<td>Primary skin irritation of the mucus membrane - rabbit OECD 405</td>
<td></td>
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<tr>
<td>Guinea pig OECD 406 (modified Buehler test)</td>
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</tbody>
</table>

Currently, DIN V 54900, EN 13432 and ASTM D 6400 are the relevant standards for the determination of compostability in Europe. Each of these standards is being applied by a number of certification organisations in the testing and assessment of compostable products and materials. The standards are very similar in their general construction, the applicable tests and the necessary pass levels. As a rule, the assessment of compostable materials and products comprises five different parts:

- characterisation/chemical testing (including for heavy metals);
- determination of ultimate biodegradability;
- determination of compostability (disintegration);
- analysis of the quality of the compost;
- determination of ultimate anaerobic biodegradability (voluntary).

EN 13432 is currently the most relevant standard because it is a harmonised, mandated European standard, which gives it a special legal relevance.

**Certifications:**

Regulatory guidelines and standards for composting revolve around four basic criteria: Material Characteristics, Biodegradation, Disintegration, and Ecotoxicity (Compost Quality). Description of the requirements of these testing can be found in the appropriate geographical area: DIN V 54900-1 (Germany), EN-13432 (EU), ASTM 6400-04 (USA), GreenPla (Japan).

DIN CERTCO is responsible in Germany for testing, certification and awarding of the compostability mark [58].
In order to reduce the volume and impact of landfill waste, a new generation of biodegradable products is required. However, this new generation of biodegradable products must also be sustainable and preferably renewable, in order to minimise the consumption of fossil fuels, water and energy.

Textile products are produced, distributed, sold and used worldwide. A quantitative assessment of sustainability in the textile manufacturing chain is therefore extremely important. It involves technical, economical, and environmental data from the various processes in the chain, and investigates the impact of textiles throughout the entire supply chain, starting with the raw fibre and continuing with fabric production, consumption and disposal. The textile process technologies and methods, for specified quality and functions, have also to be examined in order to reduce textile waste and improve sustainability.

### 7.5 Eco labels

#### The EU Ecolabel

The EU Ecolabel helps to identify products and services that have a reduced environmental impact throughout their life cycle, from the extraction of raw material through to production, use and disposal. Recognised throughout Europe, EU Ecolabel is a voluntary label promoting environmental excellence which can be trusted ([http://ec.europa.eu/environment/ecolabel/](http://ec.europa.eu/environment/ecolabel/)) [60].

It is a scheme designed to encourage businesses to market products and services that are kinder to the environment and for European consumers - including public and private purchasers - to easily identify them. The EU Ecolabel for Textiles promotes the production and consumption of products with a reduced environmental impact along the life cycle and is awarded only to the best (environmental) performing products in the market. Similarly, the Green Public Procurement (GPP) addresses public authorities seeking to procure environmentally friendly goods and services. The EU Ecolabel and GPP criteria are based on the requirements addressed in the EU Ecolabel Regulation 66/2010 and Communication COM(2008) 400 "Public Procurement for a better Environment". The criteria will be defined on the basis of the environmental information derived from Life Cycle Assessment and product oriented environmental performance assessment studies. Several environmental, safety, technical and functional aspects will be considered. Moreover, during the EU Ecolabel and GPP criteria development, continuous wide consultation is foreseen with experts and stakeholders of manufacturers, supply chain industry, consumer organizations and NGOs.

#### The EU Flower

This European Eco-label encourages businesses to market products and services that are kinder to the environment. The European Eco-label is symbolized by the Flower. The European eco-label, which is the only sign of environmental quality
both certified by an independent organization and valid throughout Europe, presents a unique opportunity to satisfy the customer’s expectation. EU flower is applicable to all textile products including textile clothing and accessories, fibers, yarns, fabrics and interior textiles, except wall and floor coverings. EU Flower has detailed criteria for all the products to be tested at various stages of the textile manufacturing. Texanlab is one of those few laboratories which have been accredited to conduct the testing of textile and related materials as per EU flower requirements. More information on EU flower can be obtained from http://europa.eu.int/ecolabel, www.eco-label.com.

Other eco-labels are:

**Blue Angel**

The Blue Angel was initiated by the German government and awarded by an independent Jury to products that are environmentally friendlier than others serving the same use. Each label specifies that the product or service focuses on one of four different protection goals: health, climate, water and resources.

**Compostability Mark of European Bioplastics**

Enables compostable products to be identified by a unique mark and channeled for recovery of their constituent materials in specially developed processes. The Compostability Mark thus conveys product information to waste-disposal plant operators and product image to consumers.

**Coop Naturaline: Switzerland**

It is dedicated to textiles and natural cosmetics made from cotton by controlled biological cultivation according to the guidelines of BIO Suisse or the European Union. It covers the entire textile chain and undertakes additional pollution testing by external labs and Coop quality safety.

**Global Organic Textile Standard**

The Global Organic Textile Standard (GOTS) was developed with the aim to unify the various existing standards and draft standards in the field of eco textile processing and to define world-wide recognised requirements that ensure organic status of textiles, from harvesting of the raw materials, through environmentally and socially responsible manufacturing up to labelling, in order to provide a credible assurance to the end consumer. Processors and manufacturers shall be enabled to supply their organic fabrics and garments with one certification accepted in all mayor selling markets. The Basic Features are:

- GOTS requires the use of **certified organic fibres**.
- GOTS provides both demanding environmental and social criteria
- GOTS criteria are applicable to all *processing stages*
- GOTS certification must base on *independent on-site inspections*

[http://www.global-standard.org]

**Green Mark**
Grenn Mark is used to promote the concept of recycling, pollution reduction and resource conservation.

**GUT**
GUT enhances environmental friendliness through the entire life-cycle of carpet from production to installation and from usage to recycling.

**Made in Green**
AITEX has created a green seal for overall quality. Made in Green is a symbol for all those who provide or who are seeking textile products manufactured with the guarantee that they are free from substances harmful to the environment and health.

**Nordic Ecolabel or "Swan"**
Swan demonstrates that a product is a good environmental choice. The "Swan" symbol, as it is known in Nordic countries, is available for 65 product groups. The Swan checks that products fulfill certain criteria using methods such as samples from independent laboratories, certificates and control visits.

**NSF/ANSI 140 Sustainability Assessment for Carpet**
This standard for carpet includes a rating system with established performance requirements and quantifiable metrics throughout the supply chain for: public health and environment; energy and energy efficiency; bio-based, recycled content materials; environmentally preferable materials; manufacturing; and reclamation and end-of-life management.
**NSF Sustainability Certified Product**

The NSF Sustainability Certified mark is available to products that meet conformity assessment to a NSF/ANSI or other national or international sustainable product standards.

Use of the NSF Sustainability Certified Mark is granted once certification has been completed through product evaluation, conformity assessment against standards and protocols, and production systems review.

**Oeko-Tex Standard 100**

The Oeko-Tex Standard 100 is a globally uniform testing and certification system for textile raw materials, intermediate and end products at all stages of production.

**Oeko-Tex Standard 1000**

To complement the product-related Oeko-Tex Standard 100, the Oeko-Tex Standard 1000 is a testing, auditing and certification system for environmentally-friendly production sites throughout the textile processing chain.

**Oeko-Tex Standard 100plus**

Oeko-Tex Standard 100plus is a product label providing textile and clothing manufacturers with the opportunity to highlight the human-ecological optimisation of their products as well as their efforts in producing ecology to consumers.

**Soil Association Organic Standard**

It is an organic certification for farmers, growers, food processors and packers, retailers, caterers, textile producers, health and beauty manufacturers and importers, in the UK and internationally. [61]

More information on the European standards in Ecodesign and Energy Labelling are presented in table 12 [63].

<table>
<thead>
<tr>
<th>Short name:</th>
<th>Ecodesign and Energy Labeling – Framework Directives</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modification:</td>
<td>[-]</td>
</tr>
<tr>
<td>Guide for application:</td>
<td>Guidance on CE marking for professionals</td>
</tr>
</tbody>
</table>
DG Enterprise and Industry, Sustainable Industrial Policy and Construction Unit, Website: Sustainable and responsible business - Ecodesign. |

For information about the content and availability of European standards, contact the European Standardisation Organisations.

8 THE CONSUMER AND FUTURE CHALLENGES

8.1 The better consumer in Europe

Impacts generated by consumers deserve a special mention. D. Early in the work ‘What is Sustainable Design’ from 1993, defined sustainability as the integration of natural systems to human behaviour patterns. Ehrenfeld (1999 and 2002) and Suzuki and Dressel (2002) placed sustainability at the individual level. Teresa Presas, in her work ‘Interdependence and Partnership: Building Blocks to Sustainable Development’ (2001), claims that a real transition towards sustainable development requires a new way of thinking. It requires the use of a collective learning mechanism for all types of environments and stakeholders and the creation of the necessary space for a dialogue on what our vision of sustainable society is. But
a sustainable society is not possible without sustainable individuals (Cavagnaro and Curiel 2012). Individual capacities seem to be at the heart of the issue, and these definitions should lead to a more responsible attitude from the consumer.

Annie Sherburne, designer from Kingston University, UK, in her work entitled ‘Achieving Sustainable Textiles: A Designer’s Perspective’ (2009), pointed out: “The biggest impacts of textiles and garments occur when they are being used by the consumer (estimated at 75–95% of the total environmental impact) and is mainly explained by the use of electricity, hot water and washing and drying processes. This contributes to the generation of greenhouse gases and global warming.” It is also very important to consider the large amount of waste caused through consumption [24].

Consumers have never historically trusted businesses much; around 75% of consumers are suspicious of corporate sustainability pledges and do not trust businesses fully. An equal percentage has the opinion that large companies do not care about the environment. Additionally, 82% of all consumers have noticed a form of “environmental friendly” claim from companies. However, among these, 54% state that they do not trust any ‘eco’, ‘green’ or ‘sustainability’ claims. [70]

Consumers are heavily influenced by certifications when making purchases. Approximately 80% of consumers state that labelling helps them to make better choices when shopping. This data is consistent across all major European markets. The level of knowledge about a specific label and certification correlates with the level of trust that consumers have in a specific label. In other words, those that know a specific label well, tend to trust it more than those whose knowledge about it is limited. People are willing to pay extra, up to 20%, for better products, but this is only the case when such products perform at least on the same level as their conventional equivalents. [70]

Global brands should also be aware that terminology varies from country to country. This situation affects consumer-based communications; for example, if in the UK the concept of sustainability is very broad and encompasses environmental and social concepts, in Germany it is strongly associated only with environmental issues. This is a real challenge for global brands that aim to sell and communicate coherently in different markets. In Europe it was found that the further north and west a market is, the more aware and demanding consumers are about resource optimisation and better sustainable and quality production. Therefore, the consumers located in northern and western European countries are more aware of the importance of sustainability aspects, which leads to a high demand for quality products. This is not the case for the markets located in Southern and Eastern Europe. [70].

8.2 Future challenges

The EU Commission (DG Agriculture) has prepared a comprehensive review of the EU organic regulation, looking at four key issues:

- Simplifying the legal framework, whilst ensuring standards are not watered down;
Co-existence of GM crops with organic farming;
Better control systems and trade arrangements for organic products;
Impact of labelling rules.

Organic textiles are not currently included in the EU organic regulation, which cover organic food and farming in Europe. This means that the use of the term ‘organic’ is not controlled in the European market, so there are inappropriate and inaccurate claims made, resulting in consumer confusion.

DG Agri has concluded that the legal basis of the organic regulation should not be extended to cover products such as textiles and cosmetics, stating that “organic farming should remain focused on agriculture since it is a crucial instrument to deliver environmental services and boost development, innovation and employment in rural areas.” This leaves a significant gap in the organic legal framework. [71]

Organic textiles are an important part of the overall organic market. They provide an opportunity to improve sustainability with a global reach. The organic label, based on robust standards and verification, will help in providing confidence to consumers and building the organic textiles market. The EU Commission’s DG Enterprise and Industry are responsible for textile labelling, and a recent report on the need and options to harmonize labelling has looked at the scope for recognizing GOTS as a basis for regulating organic textile labelling (as is the case in the USA). This is the reason why GOTS has been invited to participate in the EU Expert Group on Textile Names and Labelling. [Source: Global Organic Textile Standard (GOTS), 71]

According to the report ‘Sustainable Textiles for Apparel: Fact, Fiction and Future Prospects’ [72], a doubling in the number of consumers and an 84% hike in demand for textile fibres over the next 20 years will stretch resources to breaking point.

The discharge of hazardous chemicals used in textile manufacturing has already impacted 70% of the rivers, lakes, and reservoirs in China, with similar results in other manufacturing economies. In addition, the use of hazardous chemicals in apparel manufacturing is responsible for 17-20% of the world's industrial water pollution.

The outsourcing of fabric and apparel manufacturing to Asia and Africa has also multiplied the environmental burden of apparel worn in the West.

**Options and innovation**

When it comes to options, natural fibres are generally perceived as being more environmentally-friendly. However, the traditional cotton farming relies on large quantities of water, fertilizers, and pesticides; the mulesing of sheep is considered unethical and non-sustainable; harvesting silk requires dropping the cocoons into boiling water, killing the pupae inside; just to mention some examples. (According to the Report: Sustainable Textiles for Apparel: Fact, Fiction and Future Prospects, January 2014, Publisher: just-style.com, [73])
Cellulosics such as rayon and lyocell are increasingly being substituted for cotton, but the viscose rayon production process can also damage the environment. Likewise synthetic fibres, including polyester, polyamide and elastane, also have an impact on the environment in terms of resource depletion, energy consumption and emissions.

The use of hazardous chemicals in the processing of fabrics for apparel is responsible for 17 to 20% of the world's industrial water pollution, putting the industry under pressure from a number of environmental groups, including Greenpeace. This has prompted many apparel brands to try to eliminate toxic chemicals from their supply chains, and chemical companies to introduce greener alternatives.

Other technologies such as waterless dyeing, fibre modification, solution or "dope" dyeing, as well as digital printing are helping to reduce the environmental impact of textile dyeing and printing.

Although indigo-dyed denim accounts for high levels of global wastewater pollution, eco-friendly dyestuffs can help to eliminate many of the harmful chemicals, and reduce water and energy usage. Denim finishing techniques such as bleaching and sandblasting are now being replaced by lasering and ozone processes.

**Transparency**

Although apparel brands and retailers have made progress in using environmentally preferred fibres and textiles, the proliferation of metrics can make the concept of sustainability confusing to consumers.

Besides Sustainable Apparel Coalition's Higg Index, there are also third party certification systems and more than 24 eco-labels.

A collaborative supply chain is perhaps the most critical component of a sustainable business plan. With many brands sourcing from the same suppliers, collaboration encourages the development of industry-wide standards, and the adherence to those standards by the suppliers.

Companies can also improve their environmental footprint by rethinking their methods of transportation, as well as by setting up localised or regional supply chains. [72, 73]

Bio-based innovation - using renewables to create new sustainable fibres - including genetically modified spider silk and polymers based on milk proteins, could transform the world of textile materials in the future.

Some future challenges seem to be [73]:

- improving cotton’s sustainability;
- the cotton alternative;
- a new world of fibre innovation;
- ecological chemicals, dyes, finishing, printing;
- re-thinking recycling;
- sustainability metrics, transparency, and the collaborative supply chain.

The future of fabrics: healthy and sustainable

The fabric industries in the United States and Europe face new challenges; they must operate under more stringent and expensive environmental regulations, for emissions to air, noise, and water pollution, than in other parts of the world. In order to move to more sustainable choices, manufacturers and consumers must address the health and environmental issues in each of the major aspects of production: fibers; finishes or treatments; coloring and/or dyes. For each of these aspects, innovative companies could develop creative alternatives that are able to reshape the market. Fiber manufacturers are responding to these challenges and concern by developing and bringing to market fabrics that use greener chemistry including [74]:

- plastics, such as polyethylene or thermoplastic polyolefins, with less toxic problems in their life cycle;
- products made from post-consumer recycled content; and
- bio-based products.

The future clearly lies in technologies that close the material loop either through recycling petroleum plastics or by growing bioplastics (plastics made from plant materials instead of from fossil fuels) and composting or recycling at the end of life. [74]

Treatment and finishing manufacturers are finding that the chemicals they have relied upon are now identified as being toxic. In this context, some of the most significant actions undertaken by the more innovative finishing manufacturers to avoid key chemical groups of concern are [74]:

- replacing perfluorochemicals (PFCs) used for stain resistance with non-halogenated compounds;
- replacing halogenated flame retardants (HFRs) such as PBDEs (polybrominated diphenyl ethers) with non-halogenated retardants, redesigning the fiber for inherent flame resistance, or redesigning the products so they do not need a flame-resistant fabric;
- reducing or eliminating volatile organic compounds (VOCs);
- reformulating dyes to avoid heavy metals;
- questioning the use of nanotechnology until there is sufficient regulation and publicly available safety testing; and
- eliminating antimicrobials.

Several efforts are also to help healthcare specifiers, purchasers and the fabric industry to work together in developing healthier and more sustainable fabrics [74]:

- Increasingly rigorous standards for limiting VOC emissions.
- Green design assessments that reward use of healthier fabrics.
Product assessment frameworks and standards that help define green fabrics across a range of attributes.

The key to market transformation to healthier products that are better for the planet and people lies in the concerted actions of the purchasers. Several major players have shown responsibility and commitment through their actions to research the issues, and engage with manufacturers to guide them to better product designs. In some cases, research and development funds will have to be devoted to examining the safety and performance characteristics of the new technologies and textile products. Fabric manufacturers can reduce or remove certain chemicals quickly, without compromising the performance and aesthetics of the material. Innovative efforts can also bring more sustainable products with even greater performance and aesthetic characteristics. With greater awareness of the health issues in relation to fabric, end-users and designers can make more informed decisions and reshape the market by their specifications and purchasing power. Fabrics have the potential to be much more than mere design elements. [74]

**Future challenges?**

The textile and fashion industry does not respond entirely to the threats presented by the world’s uncertain future, including climate change, resource scarcity, vulnerable economic conditions, changing consumer behaviour and so on. So, the future challenge is to understand these threats and take appropriate action to safeguard its future, protect the environment and improve the lives of its customers, workers and suppliers around the world. [105, 109]

The perspectives for the next 25 years could rely on a foreseen scenario that starts with a shift in today behaviour. This behaviour develops really slowly and has a large duration and rage of diffusion from innovators to late adopters; this is called a trend. Many analysts, such as Lidewij Edelkoort, have been studying both the future of Fashion and the Sustainability trend and their inevitable correlation with the Environment Zeitgeist topic that influences our behaviour. It is crucial to identify and understand possible external drivers that can change trends throughout the next years and generations. Political, social and cultural factors can influence style and affect changes made to the law and the introduction of new environmental policies. Thus, sudden and profound shifts in the environment and/or scientific discoveries could impact the future of the textile and fashion industry forever, where we all, as professors, specialists and researchers, must bring an important contribution. [106, 109]

One of the fashion’s new trends for the 21st century is the Eco Couture, where fashion should be as good for population as well as for the planet. Eco-friendly brands as well as sustainable industries already exist, but still people don’t pay much attention, as they should, to this issue that will become very important if we want to save our planet from the predicted ecological disasters. More and more brands and industries related to the textile and fashion market are engaging to this trend by becoming eco-conscious. Moreover, they are developing different methods for the usage of environmentally friendly materials and socially responsible procedures in the production of new textiles and garments, transforming the “Eco-Friendly Fashion” in a must have for the future. In the near future, it is estimated that the Eco Couture
will play a key role within the Fashion Industry; therefore, becoming Green could be the hottest trend in the world, as technology is constantly evolving and, as a consequence, people, designers and companies become more eco-conscious. [107, 109]

But are there scenarios that we have to worry about?

Skinsucka (figure 5), for instance, is a design provocation which explores and questions our attitudes to consumerism, robotics and biotechnology in a timeframe of 10 to 20 years from now. SkinSucka was a collaboration between Clive van Heerden, Jack Mama together with Bart Hess, Nancy Tilbury, Peter Gal and Harm Rensink. The SkinSucka draws attention to the hyper-consumerism that blinds us to the exploitative forces that make it possible to produce a garment in Asia and ship it half way around the world to a high street in Europe, for less than the cost of junk food. Skinsucka reveals a scenario where microbial powered autonomous micro-devices share our living spaces and eat household dirt. It challenges us to consider the ethical issues of where we source the products we consume, the processes that have been employed to produce them and the social and environmental impact of our consumption. [108, 109]

Figure 5: Images from the SkinSucka project (source 108)

References


