Ecodesign in the Textile Sector

Unit 01: Materials: Natural and Man-Made Fibres

Paolo Ghezzo. paolo.ghezzo@centrocot.it

With this unit, students will be able to:

– Know main differences between fibres.
– Have main information concerning environmental aspects of fibres.
– Know main comparative issues on environmental impacts of fibres
– Identify main themes concerning new fibres substitutes.

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1.1. Introduction

The textile industry is one of the longest and most articulated chains manufacturing industry.

The textile production chain, defined as a long chain, is characterized by a large number of production processes that cover the entire production cycle, from the production and processing of raw materials (natural or artificial fibers), to semi-finished ones (yarns, fabrics, knitwear), to finished products (carpets, garments, etc.).

It is a varied and fractionated sector, where companies are diversified by size and generally are focused on a few steps of the entire production chain.

Textile products are classified into three main macro categories of products: clothing, furnishing and industrial use.

This division, in relation to the fragmentation of the textile industry, leads to redefine and subdivide the above macro categories. Therefore, categories of products associated with each production process are highlighted. Below are the most representative sub-sectors:

- production of raw materials, fibres,
- production semi-finished products (yarns, orthogonal fabrics, knitted or non-woven fabrics)
- production finished products (by finishing processes).

The fibres derive both from natural resources (animal or vegetable and mineral origin) and man-made resources. Man-made may take origin from different sources: plants, animals and synthetic polymers derived from oil.

The supply and transformation chain of textile materials requires the use of oil resources and therefore it is essential to consider the environmental impact generated by the entire process (from production / harvest to the final product).

The environmental impact assessment is essential so as to be obliged to analyze, before the verification of the best fiber to be used for a given product, how much the whole production cycle impacts on the environment. The basic elements that determine the environmental impact are mainly five: energy consumption (mainly related with the methods of cultivation/production of raw materials), water consumption and pollution, harmful emissions, waste/scraps treatment and soil consumption).

The environmental aspects to be taken into consideration, both for natural fibers and for Man-Made fibers, are many: impact of the cultivation of the raw material (cotton, wool, other natural fibers), use of non-renewable resources (Petroleum for the production of nylon or polyester), distances between the cultivation and production of semi-finished products, and finally the impacts due to subsequent processing of the products.

It is often thought that the environmental impacts of the production of synthetic fibers are much higher than those generated by the production cycle of natural fibers. Indeed, in different ways, both Man-Made (synthetic) and natural fibers have a great impact on the environment.

For example, the cultivation of 1 kg of cotton may require 3800 liters of water, while for the production of 1 kg of polyester are enough fewer. But the production of the synthetic one requires a double amount of energy from non-renewable resources, compared to the same quantity of cotton.

First it is necessary to consider the choice of the fibres to be used which should be functional to the final product, but should not impact on the ecosystem. Whether with natural or synthetic fibres, the elements to be considered are several: the impact that cultivation may have (such as cotton, wool or other natural fibres), the use of non-renewable resources (such as the use of oil for the production of nylon or polyester), the distance between the places of cultivation and production of the first steps on the sites allocated for the manufacturing of the materials.

The themes related to environmental issues concern also energy consumption, air emissions, waste water (which was poorly controlled in past and which normally keeps track of production processes that have occurred within the various textile plants and that, according to good practice, should be checked) and solid wastes.

Considering the environmental aspects, generated by the production processes and the processing of the fibers, it is imperative to consider four main themes: abundant use of water resources and chemical agents (pesticides used for growing plant fibers), gaseous emissions, high levels of pollutants dissolved in wastewater; wide use of energy and non-renewable sources.

In this context, and a greater awareness of the problems related to the exhaustion of oil reserves and waste disposal difficulties, a niche in the textile sector has moved on the production of biodegradable fibers. This main theme cause an “ethical abandonment” of synthetic fibres derived from oil, non-renewable and non-biodegradable (such as polyester and nylon) production, and an increased interest in natural and cellulosic fibres (such as cotton and lyocell) or biodegradable fibres derived from plants (such as in the case of 'polylactic acid (PLA) also derived from corn starch and soy fibre).

At this point, it is necessary to clarify that the term "environmentally friendly" referred to yarns and fabrics means the use of fibres deriving from biological cultivation, and fair trade chains, treated with natural and biodegradable[1] substances.

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[1] The term "biodegradable substances" refers to a material that undergoes its disintegration through the action of CO2 in organic compounds, such as methane, water, biomass and microorganisms.

In the following pages, we will focus on the nature of the fibers used in the textile industry and on the environmental aspects and impacts related to their production processes, providing a comparative analysis between the main textile fibers on the market for a conscious choice of the raw materials in terms of Eco-Design.

1.2. Natural Fibres

Natural fibers are obtained from naturally occurring materials and used by mechanical processes that do not modify the their structure. They can be of animal origin or of plant origin.

1.2.1 Cotton

Cotton is one of the most important fibres used all over the world.

Over the last 80 years, the total amount of lands dedicated to cotton growing has not changed significantly, but the collection has been increased by three times as much.

Some important factors that contributed to the increase the cotton productivity were: the sophistication and specialization of agricultural techniques and the use of fertilizers and pesticides in crops which led, however, to negative effects on the environment for their strong impact.

The negative effects are: the decreased fertility of cultivated land, the loss of biodiversity, pollution of groundwater and severe health problems related to exposure to acutely toxic pesticides.

Cotton crop is generally intensive in water consumption; the drying up of the Aral Sea in Uzbekistan, after water was diverted from two feeding rivers to irrigate cotton fields, is perhaps the most emblematic example of what changes could derive from the manipulation of water supply network.

The quantities of water drawn down in the irrigation of cotton crops vary according to technologies and agricultural practices adopted, and depending on the climate of the area. To produce 1 Kg of collected cotton, the average of employed water is 2,120 liters, with maximum peaks of 3,800 liters. However, it should be noticed that approximately 50%, of cotton cultivated lands are not irrigated but rain fed; in these cases we cannot talk about depletion of resources, since it is the normal and natural water cycle.

It must be highlighted how the dynamics of excessive water consumption are problematic when we refer to inadequate water infrastructure or to contamination with fertilizers and pesticides, which prevent, in fact, the use for other purposes; for example, in Central Asia 60% of the water is lost before reaching the fields due to of poor infrastructure and it generates a huge waste of water resources.

Oil consumption, instead, is mainly determined by the mechanization of the agricultural processes and the fuels used to run the farm machinery whether by road or on air. The oil used for each kg of cotton is variable and ranges between 0.3 and 1 kg.

In order to speed up the process, the cotton is commonly harvested by mechanical means, it is sprayed with defoliant agents, but however it has generally more impurities compared to manual collection, such as seeds, dirt and plant residues than hand-picked cotton.

The affects the following elements in terms of environmental impact:

- the cultivation of cotton requires large amounts of land;
- cotton crops require a very high water demand;
- cotton cultivation involves abundant use of pesticides and fertilizers, and the consequences are pretty serious in terms of environmental impact and health for workers employed in the process;
- the large distances that separate the cotton production processes form the cultivation area determine high emission of CO_2.

Organic cotton and low chemical cotton

There are several fashion brands and textile industries that are engaging organic cotton in order to reassure consumers about the sustainability of their products.

The greatest sustainability challenges for cotton cultivation come all together in one idea based on clear reduction of pesticides, fertilizers and water consumption, linked to disclosure promoting action for farmers so that they can improve conditions.

Cultivating organic cotton means avoiding the use of synthetic pesticides, fertilizers and growth regulators. To the detriment of the needs of production and the obvious lack of elements used in the classic cotton cultivation, it is necessary to use natural methods to control pests, weeds and diseases that can affect plants. Also special attention is paid to the use of local species, the reduction of nutrient losses through wide crop-rotation, and mechanical and manual weed control.

The choice of joining a biological production leads to a drastic reduction in cotton toxicity because the chemicals are attributed marginal roles and used only if necessary.

Engaging the organic production methodology, we can reach a toxicity level of the materials to be zero, while the overall product toxicity is reduced by 93%

It also provide a drastic reduction of the water used for irrigation: for the production of 1 Kg of cotton it decrease from an average of 2.120 liters to 182 liters, with a drop of 91%.

The PED value (Primary Energy Demand), linked to the non-renewable energy sources, passes from 15 MJ per Kg using a traditional system, to 5.8 MJ, a decrease of 62%.

Cultivating and processing cotton according to the organic method means acting in a sustainable manner and in total respect for humans and the environment.

The premise underlying the biological cultivation of cotton is, first of all, the knowledge of the agronomic processes that occur during all phases of the crops, in line with the nature and its timing. For example, an essential element of organic production is the careful selection of varieties suited to local conditions in terms of climate, soil and resistance to pesticides and diseases.

Furthermore special awards were created for farmers who decide to embark on organic production on the remaining land, and that thanks to what they receive are able to compete with traditional large farms.

The standards for the organic cotton also specify rules for the manufacturing of the products: it would not make sense to cultivate organic cotton in accordance with these rules if the benefits are canceled by industrial polluting methods with high environmental impact.

Over two-thirds of organic cotton is produced in India, almost 325,000 hectares are certified for organic cotton cultivation. The cotton produced according to the organic standard has the same quality as that produced in conventional systems. Particular attention must be paid to uniformity, which, on a large scale and high amounts, can become a difficulty when coupled to a limited range of organic fibres for mixing.

Organic farming methods can reduce the use of chemicals in cotton production. They are not based on reducing the use of chemical substances to a level close to zero, but they are based on different methods such as integrated pest management (IPM) and the introduction of genetically modified (GM) varieties. Research conducted in California found that the IPM techniques can get to reduce even more chemicals than the standards for organic cotton production.

The possibility of using genetically modified crops advantages in:

- reduce the use of pesticides harmful to the environment (the harvest turns out to be harmful to the parasites, so it is rarely attacked by limiting the use of specific substances to ward off pests);
- equal efficiency, if not greater;
- the quality of the fibre is not compromised;
- the reduced use of pesticides leads to an increase in income;
- low tillage of the soil, which leads to infer a level of particulate matter in the air and to increased water retention due to the less compacted soil

It is significant to mention the Better Cotton Initiative (BCI), a body composed by representatives of the cotton supply chain (from farmers to retailers), together with the specific task of drawing up an ethical value-chain for cotton production. They consider GM cotton unsuitable for their standards.

An analysis of the first crop of BCI cotton reported a lowering of 50% of pesticides and even water has been shown not used to irrigate. It stands at 30% the reduction of chemical fertilizers used.

1.2.2 Wool

Wool production is, except in rare cases, a secondary product of sheep breeding, since sheep are reared mainly for food.

Sheep are treated with injectable insecticides to control the proliferation of pests and in order to preserve the health of the whole flock.

Commonly sheep are bred for their meat, wool is a secondary product of sheep farming. What ensues is a poor quality fibre, and then with a generally low market value. An exception to this is wool from Merino sheep, the most important is used for clothing. Each Merino sheep can produce around 5 Kg of fine, good-quality wool.

In the production of wool, the main environmental impacts concern the land (direct consequence of the breeding) and the waste generated by the first stages of processing, in particular the wool washing. The wastes from the wool washing operations contain many polluting substances. Secondly, it is necessary to take into consideration the chemical products used in the various phases of wool processing, from washing (detergents, surfactants, softeners, bleaches, etc.) to spinning, from weaving to dyeing and finishing treatments.

Before being spun, the wool must follow a particular preliminary process (the scouring): it must be is washed, cleaned and to remove grease must be removed. Degreasing involves the use of high temperature and solvents baths. Waste water from scouring is highly polluting.

During this process the loss of material is quite high and stands at around 45% in terms of weight. Through the shaving process it is also recovered wool grease used as raw material for other uses, as lanolin or as addictive for bricks. Unfortunately, the presence of pesticides is also found as a result of the refining process. A good practice is to apply pesticides as far as possible from shearing, in order to preserve the flock and, thanks to natural decadence, have the minimum residue on the fiber

The energy consumption for washing wool is quite high, but if we take into account the whole production process of the wool fiber, it turns out that the energy value used is much lower than the production of other fibers, both natural and Man-Made, that require an amount of energy about 4/5 times higher.

The Mohair or hair of Angora goat, coming from Turkey, has characteristics similar to wool, with long, fine and more tenacity fibers, less extension and less tendency to felting.

Cashemere wool instead is obtained from the homonymous goats widespread in Tibet, China, Mongolia, India, Iran and Afghanistan. It is very precious because it is fine (between 11 and 18 microns) and long (about 90 mm on average) and for its softness and brilliance. On the other hand, it has a lower tenacity than sheep's wool, has a higher rate of hygroscopicity[2] and is more sensitive to chemical agents, in particular alkali[3].

Alalpaca hair, instead, is obtained from the Lama fleece , the fibers have a diameter of 16 - 40 microns, a length of 20-30 mm, and are used to manufacture mixed cotton and wool fabrics especially for outdoor clothing. This fibre, due to its length, is also used for the production of ecological fur, or in blends with wool (usually 80% wool 20% alpaca) for the manufacture of loden type fabrics.

[2] Hygroscopy: ability of a substance or materials to readily absorb water molecules
[3] Compounds which, dissolved in water, have a typical behavior of the bases and therefore cause the water to take a pH> 7 (basic pH).

1.2.3 Silk

Silk is made by silkworm that is particularly sensitive to the environment in which it is bred. Taking care of the worm then is primary importance for silk production.

The breeding of silkworms must be controlled in a detailed manner and the determining element turns out to be the climate: the air must be clean, precise environmental conditions are set by regulating temperatures and humidity. The feeding is composed of mulberry leaves cultivated with few fertilizers and with the use of a few pesticides, because they would be counterproductive, given the extreme sensitivity of the worm.

The chrysalis, once made the cocoon, is killed by the use of steam. The steam is also used to unravel the silk thread that is then washed with warm water and neutral detergents. The wastewater discharged has low pollution impact.

Despite the silk production is a very ancient practice, there are few specific studies related to environmental impact.

In recent years, sensitivity towards animals and environment has brought out a more sustainable type of silk: the"wild silk".

The Wild silk production foresees the breeding of silkworms in open forest and avoid hazardous chemicals. The chrysalis is not killed, but the moth is born, which at that moment breaks the cocoon.

It leads to a drastic decrease in quality because when the moth born breaks the cocoon and damage the single continuous filament into a multi-low cut fibres and it is then degummed as the normal silk by washing with mild detergent. Thus, wild silk is made from short lengths of fibre (or staples) and is spun in a similar way to other staple fibres.

1.2.4 Flax, Hemp and other bast fibres

The Liberian fibers are all those that come from the *phloem* of the plant, i.e. the inner part of the stem. They have important advantages in terms of environmental sustainability.

Generally, chemical agents such as fertilizers and herbicides are normally used for the production of flax, hemp and all Liberian fibers, but in much smaller quantities than in the production of cotton.

This type of culture does not require large attention, but to get fine and high quality fibres, areas with temperate climate and persistent humidity are preferable. So, these crops do not present problems related to high water consumption and to wide environmental impacts.

It must point that bast fibres like flax (and also hemp, jute and kenaf) grow well on unsuitable lands for food production and may help re-cultivate polluted soils with contaminants such as heavy metals.

The selection of optimum-quality flax fibres is carried out manually, which affects the cost, but creates jobs and it reduces the consumption of fuels derived from fossil resources.

The flax process involves the maceration of the stems through immersion in water placed in special tanks, or in running water (rivers). This process is used to separate the fibers from the wood core. However, this decomposition generates a pollution of the waste water.

There are different solutions, compared to the traditional method, to avoid excessive pollution. For example, the natural maceration which is achieved by letting the plants on the ground that will decompose due to humidity and heat of the soil and air. Obviously, the process is longer. An option is a Canadian technology called CRAiLAR that is able to optimize time and reduce impacts on wastewater through treatments with enzymes and steam.

However, with the steam process, in which the bundle of fibers and the wooden heart of the plant are broken and separated with an explosion of steam, the length of the useful fibers is influenced. This method makes the ductile fiber bundle easy to process in subsequent spinning steps, but reduces its toughness due to the shorter lengths.

The process developed by CRAiLAR is, as mentioned, based on enzymes and gives the fibers a softer hand compared to traditional processes. The CRAiLAR manufacturer ensures that 17 liters of water are used to produce 1 kg of sfiber.

The Hemp is considered one of the most important low-impact fibre that can be cultivated. It grows very rapidly, It has natural properties that allow it to protect itself from insects and inhibit weed growth, and also, helps to clear land for other crops, improves the structure of the soil, and its strong roots controlling erosion; it has a high yield and can be grown in cool climates.

Hemp grows between one and four meters tall and yields around six tons per hectare.

The fiber that can be extracted and used for textile production is between 20% and 30% of the plant and its yield is much higher than that of other natural fibers..

Hemp, so, can be useful for two different ways: as regards the cultivation, it increases the quality and improve the environmental footprint of the soils and it is useful in a wide range of textile products, i.e. clothing, furniture, technical textiles, although it still has an unexpressed potential for application.

Unfortunately, the psychotropic properties of some varieties of hemp, in particular cannabis sativa, have led to the prohibition of its cultivation in many countries and a deviated image. For this reason it is necessary to specify that varieties with a low content of psychoactive substances are available Tetrahydocannabinol (THC).

Hemp fibre extraction (i.e. by retting) and associated environmental problems are similar to that for flax.

1.2.5 Nettle, Jute and Ramie

Many people consider the nettle as the most sustainable fiber ever, even if the possibility of using it as a sustainable resource is still underestimated.

Nettle is an herb very resistant, spontaneous and it does not require some special attention. Its cultivation does not involve the use of fertilizers or pesticides, and the amount of water is minimal. In some cases irrigation is void because the rains are sufficient for its growth.

All of its parts are used in the production process. The main disadvantage lies in the difficulty of processing the textile production cycle.

The first step of the production process foresees to extract the fibers from the cut plant through enzymatic maceration similar to that of flax and hemp.

The different spinning technologies can lead to different types of yarns, but it should be noted that spinning 100% nettle fibers is particularly difficult, due to the low fiber length. For this reason, during the production process the nettle fibres must be blended with other fibres that provide satisfactory results. This approach allows to develop further research for the use of wild nettle in finished textiles within different sector branches.

The nettle fibre is used in the manufacture of fishing nets as a valid substitute of cotton, and in the paper industry. Regarding the fashion sector has a potential in hid blends due to a different hand-feeling (warm and responsive).

Jute is a soft, shiny vegetable fibre that can be spun into thick and resistant threads. It is one of the cheapest natural fibres, second only to cotton for products volumes and for variety of use. It has been widely used in industrial applications, such as packaging material, and in different sectors such as geotextile applications or carpet production. Developments are also expected in high value-added applications, as a textile base for composite materials and new green technologies.

Jute is 100% recyclable and reusable and its biodegradability has allowed its use in new fields, especially where it would not have been possible to use synthetic materials.

One of the application sectors is strictly connected to the production of geotextiles, large and robust fabrics used to protect the soil from erosion, where the biodegradability characteristic is fundamental.

In order to use it in clothing or furnishings, its fibers must be mixed with other textile fibers, such as nylon, wool, cotton, polypropylene, rayon, which improve its characteristics such as appearance, wearability or versatility.

Ramiè (Boehmeria nivea, also known as "China grass) is a Liberian fibre extracted from the inner bark of the ramiè plant. It is a strong, shiny, soft, and fine fibre. In China it is used in different popular fashion products such as women's dresses, shirts, suits, handcraft products, etc.

The removing process of gum [4], which removes the external waxes, is the most important of preparation phase, about 30% of material is lost. The extracted natural gum can be used as natural resin for other use, for example for the development of jute particle board. The final product will be considered highly ecological because both materials have a natural plant origin.

The most interesting properties of the Ramiè fibre are: the bundle tenacity, breaking elongation, fibre fineness, the color (you can get white fibers or with yellow flames depending on the processes of scouring and bleaching) and a good brightness. For this reason it is often made in blends with cotton fibers, in applications for fashion, clothing and furnishings, to reduce the quantity and lower the price.

[4] Separation process by which natural impurities are removed or acquired during spinning and twisting operations, such as fats, waxes, inorganic salts, etc.

1.2.6 Other natural fibres: Bamboo, banana, coconut, sisal, kapok

The bamboo plant is highly sustainable, because, like nettle, grows naturally without having to use pesticides or fertilizers and is completely biodegradable, so this eliminates the problem of disposal.

The bamboo transformation processes in fabrics can take place mechanically and chemically. The mechanical process is similar to other Liberian fibers: the fibers are extracted by maceration, which can be traditional or through natural enzymes, to break the wooden walls of the plant, after which the extracted fibers are combed and cleaned before being spun.

The main problem regarding bamboo fibers is in the difficulty on manufacturing, which reduces production yields and requires more intensive labor. All this increases production costs, with the risk of positioning the eventual finished product out of the market.

Bamboo can be also used as raw material for viscose, as we explain later.

Banana: The use of fiber derived from banana plants offers the possibility to produce sustainable fabrics strengthen and absorbent.

The fibers extracted from the outer part lead to the production of fabrics similar to cotton, instead, using the most inner part, you will get lighter and thinner products.

After being softened with an emulsion of water and oil for 72 hours, banana leaves are stapled in 20 cm lengths and spun with other materials such as jute, since a spinning at 100% composed of banana fiber shows results rather unsatisfactory due the roughness and the fragility that this yarn brings.

There are several methods to use it, depending on the type of processing used and on the percentage of banana fiber in blends with other materials: it ranges from the production of ropes to the use in ornamental textiles.

In any case, the fact of being able to use this particular fibre lends itself to studies and consequent future developments.

The fibers obtained from the bananas are similar to those of bamboo and ramiè, but finer. Even if they are strong and light, they have a very high moisture absorption capacity and, more importantly, they are biodegradable and eco-compatible, with no toxic effects on the environment and for humans.

Banana fibers can also be used as glass fiber substitutes for some technical applications due to the high cellulose content, which makes them mechanically solid, such as polymeric composite reinforcement components.

Pineapple leaf fibre is extracted from the green pineapple plant leaf, which is normally considered agricultural waste.

It is not possible to spin 100 % pineapple leaf fibre into yarn in cotton-spinning machinery. However, a blend of pineapple and other fibre has been optimized. It allows you to obtain products with their own characteristics, aesthetic and functional. It is common blended with cotton, acrylic fibre for spun yarn. It is sometimes blended with cotton, silk or polyester to create a textile fabric and reducing the use of other more-impact fibres.

Pineapple fibers, called Piña fiber, come from pineapple waste rich of cellulose and lignin. Recent experiments have produced silk-like textiles when combined with polyester or silk. The fiber is very soft, light, easy to maintain and wash, it combines very well with other fabrics and is elegant, precisely because it is shiny like silk.

Coconut fibre, is extracted from the outer fibrous material of coconut fruit. The most used fibres come from India and Sri Lanka. Two kind of fibres are available: white and brown. White fibres are extracted from the green (tender) coconut, and brown fibres are extracted from matured coconut, which takes 3–6 months of retting in brackish water.

Coconut fibres can be blended with jute as alternative raw material for technical textiles, especially regarding geotextile materials. There are also studies aimed at the softening of the coconut fiber to obtain better flexibility, so as to extend the possible applications. In addition,there have been attempts to develop dyed jute-coconut fibre blended yarn.

The materials obtained from the coconut have been used since ancient times for their resistance and strength to make mats and ropes, and in the naval field for the ability to not rot or degrade in contact with water. Coconut fiber has good thermal insulation properties and excellent sound insulation properties. It is a vapor permeable material, has good resistance to fire, which can be improved with appropriate treatments. It tolerates the humidity and it is resistant to molds, parasites and rodents. It resists well in any condition of use.

Coconut fiber filters are mainly used for the sound insulation of floating floors. They are also used for the thermal-acoustic insulation of walls, ventilated roofs and attics, for the soundproofing of internal partitions.

The coconut fiber is recyclable and reusable in other fields, such as drains for hanging gardens and terraces, or as a reinforcement for steep slopes.

Sisal is a plant fibre (Agave sisalana) normally extracted from the leaf of the dell'Agave Sisalana or sisal. The leaves may exceed 2 meters in length and contain up to 1,200 fine fibrils (some as long as the leaves themselves). The fiber, made by lignin and cellulose, is extracted from mature leaves, broken in lengths between 60 and 120 cm.

It is very tough and robust, due to the presence of a waxy coating on the surface of the fiber, the hand is rough, shiny and resistant to microbial attack despite the high ratio of strength and weight

The main producers are: Brazil, Tanzania, Kenya, Madagascar, China, Mexico, Haiti, Venezuela, Morocco and South Africa.

Sisal fiber is particularly suitable for bio-building, it is 100% organic and vegetable fiber.

Kapok is a natural fiber obtained from the fruits of a very common tree in South America, the Ceiba pentandra, called Ciba, from the Bombacee family. The fruits of this plant, a majestic tree that can reach over 60 m in height, considered in ancient times one of the sacred symbols of the Mayan mythology, contain a dense mass of fiber that, after careful processing, is transformed into a thread that can be used to produce the padding of cushions, mattresses, quilts and fabrics. The most important feature of Kapok, also called "vegetable wool", is its density of 0.35 g / cm^3, which makes it the lightest natural fiber in the world. This is a 2 to 4 cm long hollow fiber, which contains about 80% of air inside. This unique feature has led to the belief that it is impossible to spin the Kapok. Thanks to recent developments in the textile industry and modern methods of spinning, some apparel companies have introduced this new natural fiber, for example in the production of trousers. However the most common use of this material is for the production of cushions. The soft and light fiber of Kapok is able to give a great softness to the fabrics and the padding of cushions and mattresses, makes them resistant to humidity and it is also very organic, eco-friendly and sustainable.

Kapok is a totally biological fiber as it grows spontaneously in nature, it is also extracted by hand from the pods of the plant. Choosing this product helps us to improve the environment: no intensive cultivation is necessary and the fiber is harvested by hand. Thanks to a natural life cycle that respects the environment, its natural / biological origin with its cultivation without the use of fertilizers or pesticides, allows a natural biological disposal.

1.3 Man Made Fibres

Artificial and synthetic fibers are man-made textile fibers. They are made naturally occurring compounds such as cellulose, oil, water, nitrogen and other elements in small quantities. Artificial fibers are obtained from renewable raw materials, such as wood cellulose and cotton linters, and are completely assimilable to natural fibers. Viscose, cupro, acetate, triacetate and lyocell are artificial fibers.

The synthetic fibers derive from different polymers obtained through chemical synthesis and, with their innovative characteristics, represent the “evolution of the species”. The main synthetic fibers: polyester, polyamide (nylon), acrylic, polypropylene, elastane (spandex), modacrylic, aramidic, polyethylene.

1.3.1 Polyester

Polyester is a category of petrochemicals polymers which include the ester functional group in their molecolar chain. Most commonly refers to polyethylene terephthalate (PET). The greatest impact of polyester is the high ecological and social cost of petroleum extraction and its shipment to refineries. For the production of polyester and, in general, of all similar fibers, petroleum is used both as a raw material from which to extract and synthesize the polymer bases, and as fossil fuel for the production of energy necessary for the production process.

In the production of polyester the main chemicals used are terephthalic acid (TA) or dimethyl terephthalate, which are reacted with ethylene glycol. The polyester production process involves a TA purification phase based on bromide-controlled oxidation.

Producing 1 kg of polyester require 109 MJ, the feedstock product weight for 46 MJ in terms of crude oil; the value of energy consumption during the process is 63 MJ.

Water consumption in the production of synthetic fibres is lower than for natural fibres. Polyester manufacturing consumes ‘small amounts’ of water although in same process can require no water.

Polyester manufacturing mills have a controlled compartment that avoids the release of harmful substances in the environment; but, if discharged untreated, emissions to air and water have a medium to high potential of causing environmental damage.

The emissions can include: heavy metal, for example cobalt; manganese salts; sodium bromide; antimony oxide and titanium dioxide.

1.3.2 Polyamide

Also Nylon (or polyamide) fibres are based on a petrochemical feedstock and have the same issues as polyester.

Nylon is a family of molecular, formed by reacting monomers containing amine and carboxylic acid. For example, Nylon 6.6, one of the most commercial type, the feedstock derived from petroleum (hexamethylendiamine and adipic acid) are combined to form a polyamide salt.

The process require high pressure and heat for reacting the moleculars for making the polymer; it is then spun and cooled with water. So the process is energy intensive. 1 Kg of spun yarn require 150 MJ of energy.

With regard to exhaust gases, nylon produces nitrogen oxide emissions, a greenhouse gas.

1.3.3 Acrylic

Acrylic fibres, based on mineral oil or other hydrocarbons, are made by reacting acrylonitrile with various combinations of chemicals process (styrene, vinyl acetate, ammonium persulphate) in aqueous suspension.

It is then solvent spun, washed in hot water to remove residual solvents and salts. The formed fibers then pass into hot water tanks, close to the boiling point (to increase the resistance to the fiber), then the material passes through the immersion in an acid bath for an antistatic treatment, finally the fiber is dried.

Acrylic require about 140 MJ for each Kg of spun yarn, and engage more water than polyester.

1.3.4 Cellulose artificial fibers: Viscose, Rayon, Acetate

Viscose, Rayon, and Acetate are cellulose-derived fibers and not from petroleum sources

They are made by natural polymers that are chemically dissolved in pulp and then extruded as a continuous filament. The sources of cellulose are any natural material containing cellulose: cotton waste from manufacturing process (generally spinning and weaving scraps); fast growing soft woods such as beech; also emerging sources by substituting in conventional process, raw material with more sustainable alternatives, such as bamboo (because it is a rapidly regenerating cultivation) or wastes from food processing of oranges juices.

The raw material for cellulosic fibres can be characterized with a neutral carbon footprint, because the growth phase of the plant absorbs at least the same amount of carbon dioxide from the atmosphere that is the harvested material.

The viscose fibre production process has significant environmental implications: the cellulose is firstly purified and bleached and dissolved in pulp with aqueous sodium hydroxide. It is then treated with carbon disulphide to be spun in a solution of sulphuric acid, sodium sulphate, zinc sulphate and glucose.

Emissions to air of the viscose production include sulphur, nitrous oxides, carbon disulphide and hydrogen sulphide. Emissions to water, if discharged untreated, causes an high environmental impact due their pollution with high levels of bio-chemically degradable substances, organic matter, nitrates, phosphates, iron, zinc, oil and grease. The effluent can be devoid of dissolved oxygen and microorganisms.

1.4 Bio Polimers Fibres

Biopolymers are polymers obtained from renewable natural sources, often biodegradable.

In terms of sustainability, the advantage of biopolymers compared to petrochemical fibers regards several factors: energy savings, lower polluting emissions in air and water and use of renewable resources instead of non-renewable resources.

Despite the advantages listed above, the biopolymers are also linked to negative aspects: firstly, the effects of replacing food production in favor of the production of raw materials must be considered. Secondly, there are negative effects related to intensive agriculture with consequent gaseous emissions of methane, and an increase in the level of eutrophication[5] and ecotoxicity in the atmosphere.

Against this, in the design and material selection phase, a complete assessment of the impact of biopolymers must be provided, including sustainability indicators related to soil consumption, its conservation and nutritional cycles, as well as the most common values, such as the values of greenhouse gas emissions and energy consumption, in order to better understand the potential and manage its use.

[5] Trophic enrichment phenomenon of lakes, ponds and, in general, of water bodies with a weak turnover. It causes the so-called phytoplankton blooms that, by lowering the oxygen rate, make the environment unsuitable for other species (eg, fish).

1.4.1 Polilactic Acid

Polylactic acid (PLA) is a biodegradable and bioactive thermoplastic polyester, defined biopolymer because it derives from annual renewable crops, mainly corn starch, tapioca roots and other similar sources. Its chemical structure makes it biodegradable by specific industrial composting, in order to guarantee the right combination of temperature and humidity to break down the molecules quickly.

The PLA production process begins with the extraction of corn starch, by enzymatic hydrolysis, then the starch is converted into sugar and then fermented to obtain lactic acid. Lactic acid conforms to the traditional spinning processes of synthetic fibers.

Corn is currently the cheapest and most readily available source, however there are alternatives such as waste biomass and marginal crops such as various types of grass, which leads to the presumption that there will be developments in this direction in the future.

PLA fiber has properties similar to polyester, however it has a lower melting point, which may limit its use in some textile processes (such as transfer printing or pleating), or in some finishing and dyeing processes in where the action of the baths at high temperatures can weaken the molecular bonds and consequently reduce the mechanical resistance.

For this reason, PLA requires more dye passages than polyester. The dark nuances are therefore the most difficult to obtain, even if it is expected that these technical difficulties can be resolved in the medium term.

Research indicates that PLA is more sustainable than comparable polymers on the actual market.

The sustainability gain of biopolymers respect petrochemical fibres are: energy savings, fewer emissions and use of renewable resources.

In recent years the fashion industry made progress in terms of its commitment to offering products that respect the environment. The big brands are becoming more aware not only about the environmental impact of the fashion business, but also how it is important to involve and raise awareness of the final consumer in order to be able to create a real sustainable change in this business. With the new lace fabric made with CornLeaf yarns, RadiciGroup, Alcafil Srl (a company active in yarn twisting) and Ritex SpA realize their commitment to sustainable innovation. A novelty that allows these Italian companies to respond to the growing demands on the part of the market, of fabrics with reduced environmental impact, which however maintain high performances.

The characteristics of the yarn: A mass dyed thread with a bacteriostatic effect, made of Ingeo ™ polylactic acid (PLA) based biopolymer, a material of 100% natural origin derived from renewable vegetable resources. Thanks to its properties and the production process that characterizes it, CornLeaf fully meets the requirements of eco-sustainability such as the reduction of CO2 emissions and the consumption of water and energy. Mass dyeing technology during the spinning process means that the production of CornLeaf requires less water and energy consumption than traditional dyeing and finishing processes. This product is available in a wide range of colors with high resistance to light and washing treatments. The effectiveness of the bacteriostatic activity is obtained by inserting a special micro-compound containing silver inside the fiber and is certified according to ISO 20743: 2007. The compound is designed not to interfere with compostability. CornLeaf is functionalized with HEIQ Materials. CornLeaf also combines the advantages of natural fibers with those of synthetic fibers: lightness, toughness, comfort, UV resistance, safety.

The characteristics of the fabric: Thanks to the use of CornLeaf, the fabric proposed by Ritex SpA guarantees maximum sustainability and, at the same time, excellent performance: lightness, softness, durability, excellent color resistance and bacteriostatic effect. The natural origin of the yarn allows to have in contact with the skin a safe and hypoallergenic fabric.

1.4.2 Lyocell

Lyocell is a cellulosic fiber developed in the '80s, is based on the use of a wood pulp from eucalyptus processing waste that is dissolved in solution (amine oxide) and then spun just like the cellulosic artificial fibers.

The process includes the washing step to extract the solvent from the extruded yarn which is then recovered, purified and then re-introduced into the main process in a closed cycle to preserve the environment. In this way the solvent itself will not be neither toxic nor corrosive, in addition working in a closed cycle does not have effluents that impact the environment.

For this, the Lyocell is claimed ‘an environmentally responsible fibre utilizing renewable resources as its raw materials’.

Other environmental benefits are:

- full biodegradability because it takes only six weeks to be completely degraded;
- it is a renewable raw material because eucalyptus reaches maturity in seven years;
- careful to sourcing wood pulp from sustainably managed forests;

- fibre is clean and it do not need bleaching process;
- low use of chemical, water and low energy consumption in dyeing;
- it can be laundered in low-temperature treatment.

1.4.3 Soybean fibre

In this case it is a class of artificial fibers derived from regenerated proteins.

The two main sources are animals, such as from milk (casein) and vegetables, the most important is soy seed.

Born before World War II and increased their use during the 1950s due to the general shortage of raw materials, were been substituted whit petrolchemical fibres. Recently, due the environmental issue, those fibres are going to have a renaissance thanks to their low environmental impact and biodegradable characteristic.

In the current processes, some of the problems that presented the processes of the '50s, such as strength and wearability, have been improved, using bioengineering techniques to modify proteins thanks to enzymes and polyvinyl alcohol (PVA).

Soybean protein is a globular protein, and is spun by wet-spinning process, using non-toxic agents. Once the protein has been extracted waste can be used as animal feed. Main phases of this process are: the extraction of oil from the seeds, extraction of proteins, denaturation and degradation of the proteins, dissolution with PVA, spinning the pulp into an acid bath through a spinneret; and finally washing and drying the fibres.

The main impact of Soyobean production regards as in above-mentioned examples Lyocell and PLA.

1.5 Recycled fibre

Recycled fibres are an alternative to traditional resources.

In the design phase, then in the selection phase of the raw material, a good knowledge of the characteristics of the recycled fibers is required. This knowledge makes it possible to take them into consideration, maximizing the potential for sustainability and at the same time reducing the critical points they present in the manufacturing process.

The most significant advantages are a low impact, low consumption of energy and low usage of chemical material, reduce the consumption of virgin material and decrease waste in landfill.

The traditional recycling process, commonly used for natural fibers, can involve both industrial waste (waste from the production process) and textile at the end of its life.

Specifically, by means of the appropriate cards, the disused products are "broken" up to the separation of the individual fibers, so that they can be reintroduced into the traditional textile cycle. With the usual recycling process it is therefore possible to produce both new yarns, to be used in weaving and knitting processes, as well as non-woven fabrics.

This process, however, reduces the quality and lenghts of the fibres due mechanical stress; furthermore it cannot guarantee the uniformity of color and material because the various scraps are mixed indiscriminately. Therefore, yarns and textiles are low quality characterized.

Another mechanical process, but exclusively for synthetic materials, obtains fibres from post-consumer plastic, for example, using used PET bottles, these are ground and melted, then the fiber is extruded, so that it can be used in the traditional weaving process.

Some synthetic fibres, mainly polyester and nylon, can be recycled by chemical approaches, by polymer dissolution and then repolymerizing it.

This process leads to better quality than the mechanical method, even if it requires a higher consumption of energy. Compared to the production of virgin raw materials, this process saves about 80% of the energy.

It should be noted that several studies are underway that seek to develop recycling processes in order to improve the quality and performance of recycled textile products.

The theme of fiber recycling is presented and analyzed in Unit 08 of this course.

1.6 Fibre comparisons and assessments

As seen so far, producing textile fibers means evaluating all aspects related to environmental sustainability. The most important issues that emerge for the production of natural fibers are related to the aspects coming from cultivation, while as regards on the synthetic fibers, there are problems related to the supply from oil sources, to the consumption of energy (during the spinning processes) and to the emissions of pollutants both in air and in water.

On unit 06 we will focus on Life Cycle Assessment of textiles: the remarks made in this unit constitute the first step of a life cycle assessment which, in some cases, have a significant impact.

Focusing on the raw material, we can mention a report for the UK Department of Environment, that compare the energy consumption and water use for the production of 1 Kg of several fibres (Figure 1.1).

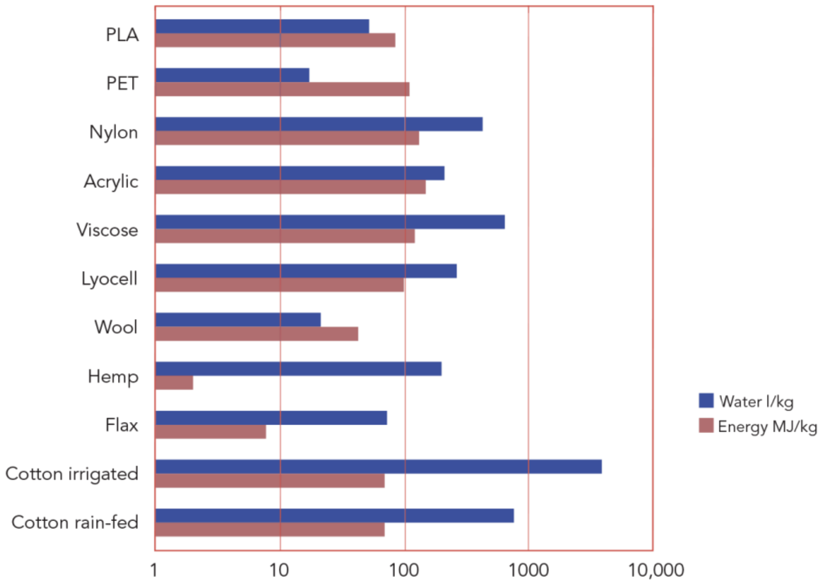

table 1.1 Water and energy consumption [1]

Following, an analysis of the most used fibers with respect to the use of energy, the use of water, for greenhouse gas emissions, of land use.

Literature studies[6] show which of the fibers present on the market have greater environmental impact on the various indicators considered.

Cotton is the second fiber consumed in the world after polyester and accounts for 31% of global raw materials (data: Assofibre Cirf s, 2010). Literature studies[7] show which of the fibers on the market have the most environmental impact on the various indicators considered.

[6] European Commission's Joint Research Centre - Environmental Improvement Potential of Textiles.
[7] Monitoring of the environmental impacts of textile companies

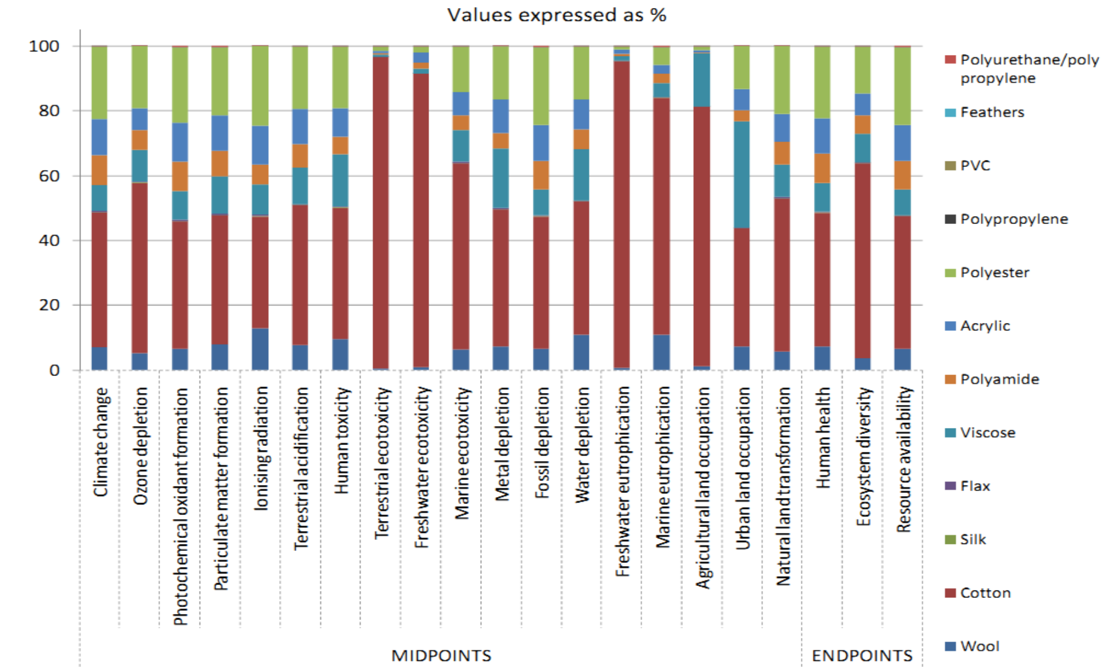

TABLE 1.2 - EVALUATION OF ENVIRONMENTAL IMPACTS: COMPARISON BETWEEN FIBERS

Cotton is definitely the fiber that contributes most to the environment, for all indicators; in particular for Eutrophication and Ecotoxicity, it has an impact of around 60-80% of the total and this is due to the very high consumption of water linked to the cultivation phase (Water depletion). The second fiber to be taken into consideration is Polyester, with impacts around 20% of the total, followed by viscose and acrylic fiber. Among the last places in the ranking, and therefore rewarding from the environmental point of view, the polyamide with impacts also almost nil for indicators such as Ecotoxicity.

Natural Fibers	Man-Made Fibers
High water consumption	Low water consumption
High use of chemicals with consequent environmental pollution	Petroleum origin, low degree of emissions
Variable energy consumption	High energy consumption
High fuel consumption for transport from fields to manufacturing companies	The production of fiber and yarn coincide
High biodegradability	Low biodegradability

Processi migliorativi	
Organic/Bio fibers	Recycling productions
Research /fibre biotech- OGM	
New cellulosic fibers	

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