Solutions to reduce the environmental pressure exerted by technical textiles: a review

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ABSTRACT – REZUMAT

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This paper highlights the fact that the technical textile industry plays a significant role in the textile and apparel industry and the technical textile subsector is one of the most dynamic, accounting for an increasing share of EU textile output. In recent years, there has been a significant increase in the production of technical textiles in the EU, which in turn leads to an increase in the environmental impact generated by the production and consumption of these products. The entire process of producing technical textile items creates several forms of pollution in the air, water, and soil, as well as noise and visual pollution and contributes significantly to global warming. At the same time, considerable volumes of textile waste are created. The reduction of the environmental impact of technical textiles should be considered throughout their life cycle and after their exit from use. In specialized literature, numerous solutions are presented that as viable for clothing but are only partially transferable to technical textiles. This paper provides a review of these solutions, highlighting the successfully applied ones in the case of technical textiles.

Keywords: *technical textiles, sustainable, environment, waste, recycling*

O analiză a soluțiilor pentru reducerea presiunii exercitate de textilele tehnice asupra mediului

Această lucrare evidențiază rolul semnificativ pe care industria textilelor tehnice îl joacă în industria textilă și de îmbrăcăminte, subsectorul textilelor tehnice fiind unul dintre cele mai dinamice, cu o pondere din ce în ce mai mare în producția de textile din UE. În ultimii ani, s-a înregistrat o creștere semnificativă a producției de textile tehnice în UE, ceea ce duce, la rândul său, la o creștere a impactului asupra mediului, generată de producția și consumul acestor produse. Întregul proces de realizare a textilelor tehnice generează mai multe forme de poluare a aerului, apei și solului, poluare fonică și vizuală și contribuie în mod semnificativ la încălzirea globală. În același timp, se creează volume considerabile de deșeuri textile. Reducerea impactului textilelor tehnice asupra mediului ar trebui luată în considerare pe tot parcursul ciclului lor de viață, cât și după ieșirea lor din uz. În literatura de specialitate sunt prezentate numeroase soluții care sunt viabile pentru îmbrăcăminte, dar care sunt doar parțial transferabile textilelor tehnice. Această lucrare oferă o trecere în revistă a acestor soluții, evidențiindu-le pe cele aplicate cu succes în cazul textilelor tehnice.

Cuvinte-cheie: *textile tehnice, durabil, mediu, deșeuri, reciclare*

INTRODUCTION

The textile and apparel industry is a significant component of the European manufacturing sector and it is vital to the social and economic health of many European areas. The industry has 143,000 enterprises, employs 1.3 million people, and has a turnover of €147 billion, according to data from 2021 [1]. The sector in the EU is based on micro and small businesses. More than 90% of workers are employed by companies with fewer than 50 employees, which also generate over 60% of value-added [2]. Technical textiles play a significant role in this industry. Technical textiles have been trending upwards in the world in recent years due to the improvement in economic conditions. Technical textiles are referred to as "*textiles, fibres, materials and support materials meeting technical rather than aesthetic criteria*" [3]. They provide input for other industries such as automotive, construction, healthcare and agro-food. Advances in technology, increased end-use applications, profitability, sustainability, user-friendliness and eco-friendliness of technical textiles have increased demand in the global marketplace. The technical textile industry has one of the greatest growth rates in the world [4]. Compared to traditional textiles, this sector adds more value and serves a wider range of end markets thanks to its high level of innovation and adaptability [5]. These attributes have caused several countries to convert their textile industry from conventional to technical.

This paper aims to present various solutions for reducing the environmental impact, that can be successfully applied in the case of technical textiles.

Methods of scientific research, that have been used in the paper, are data collection, analysis and interpretation, and summarizing of literature review. In the first part of the paper, are presented the place and role of technical textiles in the EU economy, and the impact of technical textiles on the environment is presented in the second part. In the final part of this paper, are presented various solutions for reducing the environmental impact of technical textiles at different stages of their life cycle.

THE PLACE AND ROLE OF TECHNICAL TEXTILES IN THE EU ECONOMY

The technical textile industry is generally considered to be a fast-growing value-added industry, where Europe has a strong market position and significant know-how potential. For example: about 60 percent of the value added of the German textile industry relates to technical textiles [6]. However, it is extremely fragmented and has several European SMEs that are experts in a particular product or market niche (such as ballistic protection) or technological niche (e.g., non-crimp fabric manufacturing).

In the EU27, industrial and technical textiles production represents 17% of the total production in the textile and clothing industry and it accounts for a growing share (29%) of total textile production (figure 1). The technical textiles subsector is one of the most dynamic, accounting for an increasing share of EU textile output [1]. Applications across a variety of industries, including healthcare, automotive, construction, agriculture, sportswear, etc., are driving up demand for technical textiles.

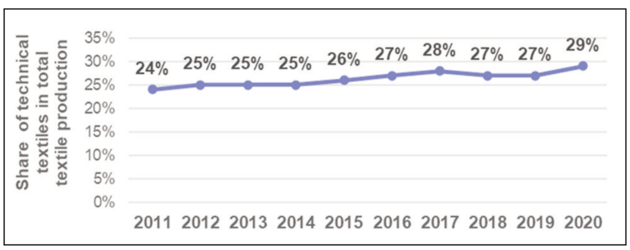

Fig. 1. Share of technical textiles in total textile production, in the EU 27 [1]

The technical textiles industry is still growing in the EU-27, where Germany is the market leader in Europe. In 2018, the largest production volumes of technical textiles were made in Germany (32,000 tons), Italy (18,000 tons) and the UK (15 000 tons). Together they made 47% of the total production of technical textiles from European countries.

The Netherlands, Spain, Belgium, France, Czech Republic, Sweden, Poland, Hungary and Romania are in the following positions, with a total production share of 43% [7].

Production of technical textiles in the European Union has fluctuated by about 140K tons over the last ten years. This sector was also affected by the COVID-19 pandemic, resulting in a significant decline in production in 2020. According to the Eurostat database, this decrease was EUR 977.1 million, in a single year [8] (figure 2).

Technical textiles also play an important role in the EU exports. In 2021, EU exports of technical textiles accounted for 14% of the total EU exports of products in the textiles and clothing industry and ranked third

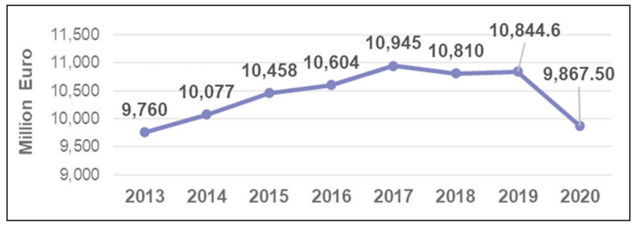

Fig. 2. Evolution of the production value of the technical and industrial textiles, in the EU27 [8]

in the top EU exports of textile and clothing products [1].

It is anticipated that the global market for technical textiles will continue to expand. The development of the technical textiles industry is presented with new prospects by the expansion of the automotive, healthcare, construction, packaging, and other industries. Another rapidly growing segment of the technical textile industry is medical textiles [7].

THE IMPACT OF TECHNICAL TEXTILES ON THE ENVIRONMENT

As it is known, textiles are essential to human existence, both for the production of apparel items and owing to the growth of various fields of use, including the automobile, construction, computer, and agricultural industries [9]. The issues associated with the scarcity of raw materials and environmental harm are exacerbated by the rise in textile demand. The entire process of producing textile items creates several forms of pollution in the air, water, and soil, as well as noise and visual pollution and contributes significantly to global warming [10, 11].

Most of the processes carried out in textile factories generate air emissions. Air pollution produced during the production processes has significant health concerns that lead to occupational illnesses, such as tuberculosis, byssinosis and asthma [12, 13]. After effluent quality, air emissions have been identified as the textile industry's second-biggest environmental issue. Air emissions include dust, oil mists, formaldehyde, acids, hydrocarbons, softeners and other volatile compounds, odours, boiler exhausts etc [14]. In the case of technical textiles, air pollution occurs both during their production processes during their use, and after their useful life [15].

Water pollution manifests itself in different forms throughout the life cycle of textiles. In various stages of textile production, such as dyeing and printing, the industry employs more than 8000 chemicals [16]. Pesticides removed from cotton, flax and hemp, as well as other compounds (lactic acid, alcohols, peptides and wax) during their processing also contribute to a high level of contamination. For example: the cultivation of cotton uses about 11% of the world's pesticides [17]. Different kinds of acids, alkalis, oils, detergents, dyes, SO_2, H_2O_2, and others, are used in the degreasing, carbonizing, carding, washing, bleaching, and dyeing of wool, all of which have a severe impact on the water quality [18]. The textile industry also employs a wide range of dyes, chemicals, and other materials for various forms of finishes applied to textile products to get various features, and attributes, or to give the fabrics the necessary qualities. The negative effects suffered by water are shown in the pH and colour changes, the presence of dissolved particles or in suspension, pesticides, peptides, lactic acid, phenolites, chlorides, oils and fats, detergents, dyes, etc. [19, 20]. Because of all of this, wastewater is produced. The removal of contaminants from the raw materials themselves and the left-over chemical reagents employed for processing both contribute to the increase in pollution load [21]. The wastewater from wet processing contains toxic substances, such as mutagens, carcinogens, and teratogens, if they are not appropriately treated before discharge, which can seriously harm the environment by contaminating wastewater and exhaust fumes [22]. Loss of lubricants or spinning oil from equipment can result in the unintentional release of hazardous materials. Such contaminants have harmful impacts on aquatic organisms or the development of new species, including algae that reduce water's oxygen content and harm aquatic life. Additionally, aquatic species can occasionally survive after ingesting such dangerous toxins, which they then pass on to humans by way of the food chain [23].

Soil pollution occurs through the use of pesticides, the seeping of polluted water into the soil, and the huge amount of textile waste that reaches landfills. Fibres or chemicals degrade under the influence of air, water, or sunshine, and they can turn in the process into hazardous agents [24, 25]. Several harmful degradation products made from nylon, polyester, or other polymeric materials that have been dumped in water streams and end up in landfills serve as examples of the issue [26].

Twisting, spinning, and weaving operations, for example, can cause noise pollution. Systems of transportation or other equipment used in the textile industry for loading, transporting, or handling may also produce unpleasant, loud noise [27]. Exposure to noise pollution, especially overexposure, is the most significant risk associated with the textile business. Depending on the length of exposure, the intensity and frequency of the noise, as well as individual sensitivity, hearing thresholds can be temporarily or, in the worst circumstances, permanently reduced [28]. Extended exposure to noise pollution has many other negative effects, such as agitation, persistent fatigue, disorientation, migraines, vertigo, hypertension, cardio-arrhythmia, and neurological and psychological diseases [29].

Between 1.22 and 2.93 billion tons of CO_2 are released annually by the textile sector. According to some estimations, the life cycle of textiles (including laundering) is responsible for 6.7% of all global greenhouse gas emissions [30].

At the same time, considerable volumes of textile waste are created [31]. Statistics show that in a single year, in 2020, 1,950,000 tons of textile waste were generated at the EU level [32].

Although manufacturing and using technical textiles have multiple negative effects on the environment, they are often used to reduce the impact on the environment generated by other industries. Technical textiles are widely used to reduce air pollution, being used as filters in various fields. Due to the possibility of creating high-tightness fabrics, these can reduce or even stop the passing through of polluting substances, flue gases, also, dust particles, without preventing the air from passing through [33]. As filters, technical textiles are successfully used to filter used water. They can also be used to separate the oil/water emulsions [34]. Furthermore, they are successfully used to prevent water and soil pollution when they are used as lining materials for landfill sites or when used in agriculture to prevent the dispersion of pesticides or other types of chemical substances used for various crops [5].

There have been identified five types of filtrations which can be achieved using technical textiles, namely: solid-gas filtration, solid-fluid filtration, solid-solid filtration, fluid-fluid filtration and gas-gas filtration. To achieve all these types of filters, technical textiles must observe certain standards and fulfil several requirements in connection with the fibres they are made of, the type and structure of materials, modality of assembly-all these being essential to the performances of filtering materials [35].

Technical textiles are also used to reduce noise pollution, by applying sound absorbent materials [36].

SOLUTIONS TO REDUCE THE ENVIRONMENTAL PRESSURE EXERTED BY TECHNICAL TEXTILES

The reduction of the environmental impact of technical textiles should be considered throughout their life cycle and after their exit from use. Specialized literature presents several solutions in this regard, solutions that are presented in the following.

Choice of materials

When creating technical textile goods, the first decision to be taken relates to the components of yarns and fabrics. As different fibres are made from various resources, they all have varied effects on the environment and the climate. Significant environmental effects are also caused by the dyeing agents utilized [37–39]. Treatments that are applied to technical fabrics in this situation also show the environmental effect. They entail adding chemicals to a yarn or fabric to give it a range of qualities, such as water-repellentness, flame-retardantness, antistatic or antibacterial properties, and antifungal capabilities.

Different fibre types will require various approaches to advancing circularity and sustainability. The largest strain on the land and water resources is seen while producing natural fibres like cotton, as cotton production makes extensive use of fertilizers and pesticides, runoff might contaminate surface and groundwater [40, 41]. Sustainable cotton production would entail using water and agrochemicals more effectively, switching to less harmful pesticides, and adopting

soil-conserving agricultural practices including composting, crop rotation, and decreased tillage [42]. One of the disadvantages of organic farming is that it can decrease yields, resulting in increased land use [43].
Synthetic fibres, like polyester, have an adverse effect on the environment due to their high energy consumption and reliance on fossil fuels for raw materials. Acrylic and nylon fibres are two other synthetic fibres with significant energy requirements [44].
The utilization of recycled fibres is suggested as a way to minimize energy and resource usage. The drawback of this solution is that the recycling procedures shorten the lifespan of the fibres, reducing the possibility of reuse [45].
Currently, a sizable quantity of yarns is created from a variety of fibres, which makes their recycling challenging. The suggested solution in this situation is to exclusively produce yarns using fibre combinations that can be recycled.
Chemicals used during textile production pose risks to the environment because they frequently leak out during usage and washing [46]. The proposed solutions refer to the reduction of chemicals used in the textile industry and the substitution of dangerous products with less dangerous products for the environment.
There is increasing talk of the use of natural dyes, and the use of pigments, and enzymes to reduce the use of chemicals, water, and energy consumption. To protect freshwater and seawater resources, Greenpeace launched the Detox campaign in 2011, focusing on having more environmentally friendly and toxic-free textiles. The list of substances to be removed increased to approximately 430 compounds [47].
Another solution is to reuse products because reused clothes have been washed many times, and have fewer chemicals in the fabric, which makes their use not only much more environmentally friendly, but also better for the consumer's wallet and their health [48]. Unfortunately, this solution has a very limited area of application in the case of technical textiles.

Design stage

The design stage is very important in the development of a circular value chain for technical textiles.
The decisions taken at this stage will have a considerable impact on the environmental and climatic effects of textile goods, as well as on their potential for circularity in later stages of the product's lifecycle. This stage is known by a variety of names in literature, including eco-design, design for the environment/design for sustainability, and sustainable product design.
Ecodesign is a design approach that takes into account a product's environmental impact from raw materials through manufacture and use to the end of its useful life. Ecodesign tries to enhance the product's visual appeal and functionality while simultaneously reducing the product's negative environmental impact [49].
Design for the environment or design for sustainability describes a change in product design, where the environmental impact (rather than only the economic impact) directs the direction of design decisions. Design for sustainability expands on ecodesign's work by taking economic and social problems into account, and its methodology incorporates both incremental and radical innovation [50, 51].
Sustainable product development and design look to minimise adverse sustainability impacts and maximise sustainable value throughout the life-cycle of the product [52]. Sustainable product design is a design theory and approach that emphasizes creating goods that contribute to social and economic well-being, have minimal negative effects on the environment, and can be made from renewable resources over the long term [53].
Design decisions have an impact on the different stages of the material and product life cycle. Because they make it easier to provide novel business models, allow reusing and recycling, and give chances to incorporate recycled materials or repurposed parts into new products, they are important key drivers in the development of more circular goods [54].
The lifetime, durability, and reparability of textiles are improved by the careful selection of materials at the design stage. The product's capacity to last longer and its ease of repair are both influenced by the materials utilized. Several fundamental design concepts, such as technical specifications for colourfastness and fabric resilience, as well as practical requirements for textiles to be suitable for their intended use, and readily available repair kits and/or replacement components, boost the longevity and quality of textile goods [55].
A large variety of eco-design tools are available. This allows designers to integrate environmental considerations into product development processes. They provide information on potential environmental issues and help to choose between various aspects [56].
The most usable tools with quantitative measures are life cycle assessment (LCA), streamlined LCA, matrices, ecolabels, and footprints. There are other types of tools for improving the environment, such as qualitative guidelines and manuals. They can be more straightforward to use early in the process of developing a product [57]. Also, introducing sustainable and environmentally friendly materials is very important to change the behaviour of consumers. Interdisciplinarity (between designers, chemists, material designers, etc.) is necessary for eco-design in both vocational training and programs for industry professionals who are involved in lifelong learning [58].

Sustainable production

One of the important pathways is optimized resource use to lower pressures. Companies in the textile industry are concentrating on lowering and optimizing water and energy usage, air emissions, and water

pollution, by employing secure chemicals and a variety of biodegradable materials [55].
Industry modernization and automation are required to provide cleaner manufacturing processes, which need less labour and resources. Resource-efficient production is a key element in a sustainable textile system. Moving towards healthy and renewable materials and energy would reduce the environmental impact of the textile industry. Moreover, to address the negative social impacts of the textile industry, it is necessary to improve workers' wages and working conditions [58].
Eco-design guidelines have been established to maximize resource utilization throughout production. Reduced emissions, waste, and inputs like water, chemicals, and energy are a few of them. Another one is the production of fibres from renewable sources or recycled content. Design requirements that certify a minimum content of recycled materials could optimize the use of resources. The collection of materials for recycling and reuse may also be indirectly increased by design requirements [59].

Sustainable textiles consumption

Reducing the amount of textiles purchased is one option which is open to all customers. As a result, the textile system's effects on the environment and the climate may be reduced. If fewer things are purchased, production and distribution will also decline, mitigating the negative effects on the environment, the climate, and the generation of waste. This may be accomplished through shared use, longer use, and reuse of textiles [60, 61]. In the case of technical textiles, the first 2 solutions can be applied.
Reusing them is not feasible for several reasons [62]:
- Technical textiles typically enter their end-of-life position because they were damaged rather than because they are old-fashioned.
- Protective garments (such as uniforms) must be destroyed since they serve as identifying characteristics (such as in the military) and are inadequate for reuse.
- Technological textiles and nonwovens are often used in complex items like vehicles. For economic considerations, it is not justifiable to disassemble end-of-life items. Vehicles are frequently shredded, after which is impossible to recycle the fibre parts.
- Medicinal fabrics, which are frequently polluted, must be burned.
- In the case of technical textiles used in composite materials, due to the strong adhesion between the fibre and matrix, separation is challenging and not economically feasible. Only for expensive fibres, like carbon fibres, the separation would be economically feasible.

Textile waste management

The term "waste prevention" refers to actions conducted before a (textile) product becomes garbage [63]. There must be a differentiation between quantitative and qualitative prevention. The extension of textile items' useful lives is a component of quantitative prevention. Once these wastes are produced, they must be collected. Greater reuse and recycling of textile waste, as well as avoiding its incineration or landfilling, depend on better textile waste collection, sorting, and management [64].
Recycling is any method of recovering waste materials and using them to create new products, materials, or substances that can be used for the original or different purposes. Energy recovery and backfilling activities are not included. Many studies show that recycling has greater benefits for the environment than landfills and incineration [65, 66]. For instance, Dutch aWEARness calculated that recycled textiles can save 64%, 95%, and 73% more energy, water, and carbon dioxide than conventional, non-recycled textiles. Another study shows that recycling textiles has a far better potential for reducing GHG emissions and energy savings than incineration [67].
The literature in the field presents a multitude of fields and modalities to recycle textile waste. One of them is the construction field, where textile waste can be used for the thermal and soundproofing of buildings [68] or they can be integrated into brick manufacturing [69]. Cotton waste has proved to be a very good catalyst in treating wastewater and removing Bisfenol from the water [70]. Textile waste can be successfully used in the automobile industry for manufacturing the materials used for lining seats, roofs or carpets as well as in the furniture industry, manufacturing mattress covers, upholstery and also as stuffing material for various furniture items. In agriculture, textile waste can be used as a ground covering layer to prevent it from drying, increasing thus the crop output [71]. Textile waste can also be used in manufacturing paper or various types of toys [70].
The variety of conventional textile and technical textile types makes it very difficult to collect them separately. Statistics and data on the quantities of technical textiles that are collected separately are rarely available. This is compounded by the multitude of fields in which technical textiles are used, which require various collection systems and, subsequently, distinct recycling programs. Contrary to apparel, technical textiles are in use for a considerable amount of time and are not immediately recyclable [72].
Recycling technical textiles is more complicated, but not impossible, as shown by research in recent years.
The potential of recycling flame-resistant protective clothing is described in the European patent EP3260595. Enzymatic hydrolysis is used to break down technical textiles, and the residual fibres (typically, aromatic polyamides go through a fibre-tearing process to obtain individual fibres suitable for subsequent yarn creation) [73].
In the TEX2MAT project, a novel method was established that incorporates the enzymatic hydrolysis of cellulose, where cotton can be converted into glucose and polyester remains as the only polymer and is, therefore, accessible to a relatively easy recycling process [74].

The Dutch carpet manufacturer Desso was one of the first companies to re-use closed-loop products in the carpet industry. Non-harmful raw materials are re-used to produce carpet tiles. The modular carpet tiles permit smart maintenance since it is possible to change only the tiles which are visibly worn or torn. In this way, Desso prolongs the life span of tiles placed in “low-traffic” areas, before ultimately taking them in for remanufacturing [75].

CONCLUSIONS

In the textile industry, technical textiles are a growingly significant market category. Because the production volume of technical textiles has seen an upward trend at the EU level in recent years, special attention must be paid to aspects related to their impact on the environment. In this sense, solutions must be implemented regarding the circular economy, preventing and reducing waste, but also finding viable ways to recycle it. The reduction of the environmental impact of technical textiles should be considered throughout their life cycle and after their exit from use. Viable solutions for clothing are only partially transferable to technical textiles. Specialized literature presents several solutions in this regard, starting with the choice of materials and finishing with waste management. Among these, the most effective are those related to the exclusive production of yarns using combinations of fibres that can be recycled and the reduction of chemicals used in the textile industry or the replacement of hazardous products with less hazardous products for the environment. Developing a circular value chain for technical textiles from the design phase, maximizing the use of resources during production, and reducing emissions, waste and water, chemical and energy consumption are other solutions whose effectiveness has already been proven. Recently, new solutions, such as the use of highly specific enzymes for the decomposition of polymers and fibre-mixed materials, are currently being tested for possible industrial application on a large scale.

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