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Circular textile management – environmental causes, current challenges and the social aspect

Gospodarka tekstylna w obiegu zamkniętym – przyczyny środowiskowe, aktualne wyzwania i aspekt społeczny

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Keywords: *circular economy, circular fashion, fast fashion, textile waste, waste recycling*

Abstract
The textile industry's negative impact on the environment, with the simultaneous global increase in textiles consumption, is associated with the need to implement a circular economy that will reduce the consumption of water, energy, and primary raw materials. Currently, the main goal of these activities is to return to good design and production practices, allowing the creation of durable, high-quality textile products. Another challenge is the intensification of textile recycling, allowing waste to be reused as raw materials. The main goal is the implementation of effective textile waste collection systems and the expansion of chemical and mechanical recycling processes application. The basic tool accelerating the above-mentioned changes is the appropriate legislation, which will force producers to apply ecological solutions and extend their responsibility for textile products. The social factor also has a significant impact on closing the loop in the textile industry. Consumer behavior affects both the amount of waste generated and the way it is reused or processed.

Słowa kluczowe: *gospodarka o obiegu zamkniętym, moda cyrkularna, szybka moda, odpady tekstylne, recykling odpadów*

Streszczenie
Negatywny wpływ przemysłu włókienniczego na środowisko, przy jednoczesnym globalnym wzroście zużycia tekstyliów, wiąże się z koniecznością wdrożenia gospodarki o obiegu zamkniętym (GOZ), która zmniejszy zużycie wody, energii i surowców pierwotnych. Obecnie głównym celem tych działań jest powrót do dobrych praktyk projektowych i produkcyjnych, pozwalających na tworzenie trwałych wyrobów tekstylnych o wysokiej jakości. Kolejnym wyzwaniem GOZ jest intensyfikacja recyklingu tekstyliów, pozwalająca na ponowne wykorzystanie odpadów jako surowców. Głównym działaniem w tym zakresie jest wdrożenie efektywnych systemów zbiórki odpadów tekstylnych oraz rozszerzenie stosowania procesów recyklingu chemicznego i mechanicznego. Podstawowym narzędziem przyspieszającym powyższe zmiany jest odpowiednia legislacja, która wymusi na producentach stosowanie rozwiązań ekologicznych i rozszerzy ich odpowiedzialność za wyroby włókiennicze. Istotny wpływ na zamykanie obiegu w branży włókienniczej ma również czynnik społeczny. Zachowania konsumentów wpływają zarówno na ilość wytwarzanych odpadów, jak i sposób ich ponownego wykorzystania lub przetwarzania.

1. Introduction

Textiles have found many applications in the everyday life of society as well as in industries. The basic and most obvious use of textiles is the production of clothing and home textiles, such as bedding, towels, and design elements. The materials used in the textile industry can be divided into natural, artificial, and synthetic [46]. The natural materials are made from fibers of plant and animal origin. Artificial materials are made by chemically treating polymers of natural origin – mainly cellulose, protein, and rubber. The fibers used in the production of synthetic materials are entirely formed by the polymerization of crude oil or coal.

The production and use of textiles have a negative impact on the environment, and the dynamic increase in textiles production and sale in recent decades has intensified this phenomenon. One of the most visible environmental effects of the textile sector development is the increase in textile waste mass. In line with the current economic trends, the textile industry should strive to implement a circular economy. This publication outlines how the textile industry affects the environment, explains why we should strive to implement a closed economic model in this industry, and identifies the main elements of the current system that require the greatest change.

2.Fibers and textiles production and consumption

In 2018, the global production of fibers used in the textile industry amounted to 110 million tonnes. This value was twice as high as 20 years ago, while the population growth in the same period was only 25% [35]. Currently, the annual production of synthetic fibers consumes about 1% of world oil production, i.e. 48 million tons [17]. More than half of all fibers produced in the world are polyester, which is a cheap cotton alternative. Polyamide is also widely used in the production of clothing and home textiles. In 2018, 55 million tons of polyester fibers and 5 million tons of polyamide fibers were produced worldwide. Among natural fibers, cotton has the largest annual production of 25 million tonnes. Cotton cultivation covers about 2.4% of the world's agricultural land [23]. The biggest producers of cotton are China, India, the USA, Pakistan, Brazil, and Uzbekistan [15]. In recent years, artificial fibers (main cellulose) have become more and more popular. The main advantages of those textiles are high hygroscopicity, breathability, delicacy, and hypoallergenicity. Over the years 2001-2014, the global production of cellulose pulp, which is used to produce cellulose fibers and then fabrics, increased from 2.7 to 6.7 million tonnes.

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Textile sales volume has increased significantly over the past decades. Data presented by the Ellen Mac Arthur Foundation [14] show that sales of textiles in the period from 2000 to 2015 have doubled. In China, a similar increase in textile consumption was achieved in less than 10 years (2000-2009) [29]. Currently, the average person owns 60% more clothing than at the beginning of the 21st century [37], and Europeans spend 600 and 150 EUR annually on clothes and footwear [6]. Data from 2017 indicate that a resident of the European Union (EU) purchased about 26 kg of textiles. Only around 30% of the purchased textiles were produced in the EU, the remaining 70% were mainly imported from Asia [16]. In 2020, 8.7 million tonnes of textile products, with a total value of EUR 125 billion, were imported to the EU [6].

Increase in the textiles production and sales, mainly clothing, is driven by the phenomenon of the 'fast fashion' industry. This term refers to the business model based on the maximum reduction of the clothing production time. New collections appear on sale within a dozen or so days from the project creation [31]. The frequent appearance of new products created consumers the need to follow the latest trends, and the attractive price encourages them to buy more often. The largest European clothing brands introduce even more than 20 fashion collections per year. One of the branches of 'fast fashion' is the 'ultra-fast fashion' model, which shortens the period from creating a design to launching products for sale from a dozen to just a few days. One of the popular sales platforms in the first quarter of 2022 launched 314.000 clothes designs. Assuming that, according to the brand's assurances, for each project from 50 to 100 items of clothing are initially made, at least 15.7 million items of clothing were introduced to the market in just 3 months. For comparison, two brands included in the 'fast fashion' sector at the same time introduced 6.800 and 4.400 projects [22].

The phenomenon of 'fast fashion' accelerated the process of textile industry globalization. The need to produce a large amount of cheap clothing initiated the transfer of many stages of its production from Europe to Asian countries [40]. The main goal of these activities is to reduce production costs by using cheap labor. Cutting production costs is very often done at the expense of employees. Working conditions of people employed in the production sector of the fashion industry in many cases do not meet the basic principles of occupational health and safety, working hours are much longer than by European standards and earnings are disproportionately low.

3. The environmental impact of the textile industry

The sourcing of raw materials for the production of textiles, including the cultivation of plants and animal husbandry, as well as each of the stages of fiber production – spinning, weaving, dyeing, finishing and creating finished products, have a negative impact on the environment.

3.1. Manufacture of fibers and textiles

The production of fibers and textiles contributes significantly to greenhouse gas emissions. Most of the energy is used in the production of synthetic and artificial fibers. The highest energy demand, respectively 250 and 175 MJ·kg-1, is required by the production of polyamide and acrylic fibers [1]. The demand for electricity in the production of polyester fiber is 125 MJ·kg-1, which results in CO2 emissions at the level of 27 kg·kg-1 of polyester fabric [32]. In 2015, the textile industry was responsible for the emission of 1.7 billion tons of CO2 [44]. It is estimated that the textile industry is responsible for around 10% of global greenhouse gas emissions [33]. CO2 emissions contribute to climate change, mainly through an increase in global temperature. The aspect of breeding animals that are used to obtain fibers for the production of natural materials is also important. The literature states that the amount of energy needed to produce merino wool fibers is 46 MJ· kg-1, and the dominant energy consumption takes place at the stage of animal breeding [1]. Globalization and the decentralization of the textile industry also contribute to greenhouse gas emissions. Place of obtaining raw materials for fibers production, the production of fibers, yarns, textiles, and then sewing clothes and its distribution, take place in various countries on several continents. The global model of the textile industry causes the necessity of multiple-stage transport of raw materials and products.

The textile industry uses about 93 billion m3 of water annually, which makes it one of the most water-consuming industries in the world [13]. The main reason for high water use is the wet processing of raw materials and the cultivation of natural fibers. The most water-consuming stages of textile production include fiber production, dyeing, finishing, and yarn preparation. Except for the production phase, the greatest amount of water is used in the cultivation and processing of cotton. It is estimated that from 1 to 6% of global water consumption is used for irrigation of cotton crops, and the production of 1 kg of raw cotton consumes from 10 to 17 m3 of water. The aspect of water consumption in cotton crop cultivation and processing is particularly significant for countries with limited water resources [2]. To protect cotton crops against pests and diseases, pesticides and insecticides in the amount of 10 and 25% of the global consumption of these chemicals are used, respectively. In developing countries, pesticides used in cotton cultivation constitute up to 50% of domestic consumption [15]. Fertilization of cotton crops and protection against pests with simultaneous intensive irrigation contribute to the leaching of various chemicals from the root zone of plants to ground and surface waters, causing their contamination and increased eutrophication [17].

The high water use in the textile industry is associated with the formation of an industrial wastewater stream, contaminated with chemicals used during fiber finishing and dyeing. The literature shows that, depending on the stage of textile processing, from 58 to 81% of the process water is converted into a wastewater stream [36]. The wastewater composition depends on the type of fabric, the stage of its processing, and the chemicals used [3]. For example, wastewater from the dyeing process contains dyes, organic acids, fixatives, antifoams, and oxidizing/reducing substances [43]. Post-process wastewater usually requires multi-stage treatment, involving the use of physical, chemical, and biological processes.

3.2. The use of textiles

After production textiles are transformed e.g. into clothing and products of everyday life and reach consumers. The daily use of textiles, washing, maintenance and subsequent final disposal of textile waste also has a strong impact on the environment.

The most visible negative aspect of strong growth in textile consumption is the amount of generated waste stream. The increase in the mass of fibers produced and textile sales causes an increase in the mass of the generated textile waste. The phenomenon of 'fast fashion' shortens the average time of wearing a garment before throwing it away – this decrease between 2000 and 2015 amounted to 36%. Some clothes are thrown away after being used only several times [31]. Detailed data on the amount of textile waste generated in selected European countries is presented in Table 1.

As shown in table 1. in 2018 in the EU countries over 2 million tons of textile waste were generated. The largest amount of waste stream is generated in Italy. Per capita, the largest amount of textile waste is generated in Belgium (17kg) and Kosovo (16kg). The 2018 report states that approximately 60% of the garments produced are converted into a waste stream within a year of their production [37]. In 2018, one resident of the USA generated over 31 kg of textile waste. Textile waste accounted for 6% of the municipal waste stream [49]. Unfortunately, only a small part of the textile waste was sent for appropriate processing. Over 11 million tons of textile waste (65%) were landfilled. The remaining 35% of textile waste was used for recycling or energy recovery. Estimates indicate that on a global level as much as 73% of textile waste is either thermally processed or landfilled. Only 12% of textile waste is recycled, including chemical recycling of less than 1% of textile waste [14].

Table 1. Generation of textile waste in selected European countries between 2008 and 2018 [18].
Tabela 1. Wytwarzanie odpadów tekstylnych w wybranych krajach Europy w latach 2008-2018 [18].

No.	Country	2008	2010	2012	2014	2016	2018
		thousands of tons					
1.	European Union (EU-28)	2 420	2 150	1 860	2 220	2 190	2 370
2.	Italy	541	434	395	440	466	519
3.	Germany	213	238	310	344	392	338
4.	United Kingdom	275	190	231	212	210	199
5.	Belgium	166	257	175	206	170	199
6.	Turkey	389	85	161	214	206	232
7.	France	391	380	149	175	210	239
8.	Netherlands	129	107	114	95	102	126
9.	Poland	84	83	94	261	104	132
10.	Spain	138	100	77	110	99	94

Incorrect management of the textile waste stream poses a threat to many components of the natural environment. According to data presented by UCL Institute for Sustainable Resources [49], each year about 60.000 tons of textile waste are shipped to Chile and at least 39.000 tons are dumped in the Atacama desert. Textiles also end up in illegal landfills in Africa (e.g. in Ghana). This waste represents excess production of clothing and/or waste with too low market value for sale in the secondary circulation, transported from Europe, Asia, and the USA. Landfill of waste in an unsuitable place causes the penetration of chemicals used in the production of textiles and microfibers into environmental components [4]. In the textile industry, over 18.000 types of chemicals and dyes are used [7]. The Swedish Chemicals Agency's research covering 2.400 chemicals used in the textiles production confirmed that 30% of them showed toxic properties [20].

Chemicals and microfibers can also be released from textiles during washing and daily maintenance. A surface water study in China showed that the amount of microplastic fibers derived from synthetic textiles ranged from 2 to 71 particles per dm3 [10]. The microfibers get into the soil through the agricultural use of sludge from municipal wastewater treatment [53]. Up to 90% of microfibers flowing in with the wastewater stream are present in the sludge, and their concentration may range from 1.500 to 56.400 molecules per kg. The ocean's microplastic pollution derived from textiles is also worrying. Synthetic fibers are present in water, they accumulate in bottom sediments, rocks, and a coral reef [10]. For example, the content of microplastics in the Northeast Pacific seawater was up to 9.200 particles per m3, and 75% of them were origin from textiles [11]. Literature reports also confirm the presence of textile fibers in the indoor air [52].

4.Change in the current model of the textile industry

Increasing knowledge of human living and economic activities' impact on climate change has resulted in different perceptions of the linear model of the global economy. In this model, for production primary raw materials were used. To ensure the continuity of new product sales, the assumption was to create products with "planned durability". In the textile industry, planning and designing the aging of products is achieved by creating non-functional clothing that is easily damaged and/or quickly becomes unfashionable [30]. Such activities create the demand for new products, driving sales and development of companies.

The opposite of the linear economic model is the circular economy model. The beginnings of the circular economy idea date back to the 1960s, but its implementation has become a reality only for several years [26]. This process is driven by legislative activities. The assumptions of a circular economy include production with the minimum use of primary raw materials and energy, which does not inhibit economic and social growth while minimizing the negative impact on the environment. In a closed loop, the value of products, materials, and resources is kept for as long as possible [8].

The negative impact of fibers and textiles production and use on the environment initiated considerations about closing the cycle of raw materials and energy use in the textile industry. For circular fashion, 16 general principles and practices of good conduct have been defined. They concern the stages of design, material selection, use, and the final life stage of textile products [13]. The transition to a circular economy model in the textile industry should primarily focus on moving away from the creation of short-lasting products and supporting the reuse of products and/or acquired raw materials. Durable and high-quality textiles do not lose their properties even after long use and can also go into the second circulation [39]. The implementation of the circular economic model is to be supported by an extended producer responsibility (EPR) policy. According to the OECD definition [34], EPR is understood as an "environmental policy approach in which a producer's responsibility for a product is extended to the post-consumer stage of a product's life cycle". These activities allow for more effective collection and processing of waste and have already been implemented, for example, for electrical and electronic equipment waste and packaging waste [19].

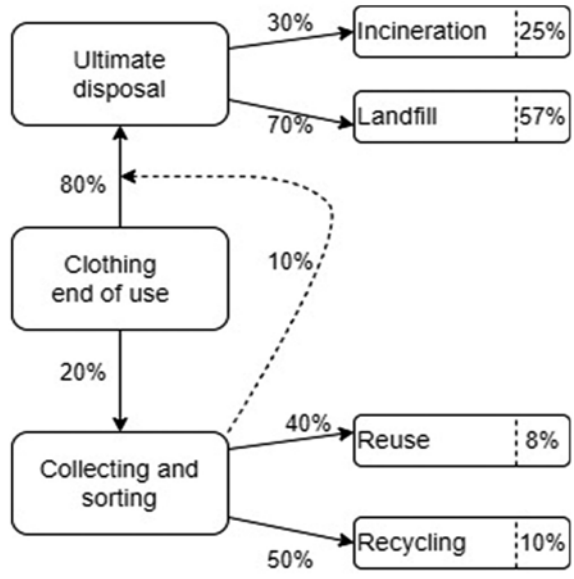

Fig. 1 Garment waste stream processing (based on [44])
Rys.1. Przetwarzanie strumienia odpadów odzieżowych (na podstawie [44])

A 2017 report shows that less than 20% of waste garments are now properly collected and either recirculated or recycled [44]. Details are shown in Figure 1. As mentioned in chapter 3.2. globally more than 70% of textile waste is either thermally disposed of or landfilled [31]. Therefore, the key challenge in implementing a circular economy in the textile industry seems to be the correct collection and processing of textile waste, enabling the circulation of products and the reuse of raw materials.

5.Collection and management of textile waste

The main challenge in the context of proper textile waste management is its suitable collection [13]. The selective collection creates the optimal conditions for textile reuse and recycling. Currently, only a few countries have regulations regarding the separate collection of textile waste. In the EU, the pioneers of legislative action are France and Estonia, which have already implemented legal requirements regarding the principles of separate collection of this waste [25]. Moreover, since 2007, France has been implementing an EPR policy for end-of-life clothing, underwear, and footwear. From 2020, EPR has also been extended to home textiles. These activities resulted in a three-fold increase in post-consumer textiles collection and recycling, which account for 50% [5],[19]. According to the Waste Framework Directive of 2018, a separate collection of textile waste in all EU Member States should be introduced by January 1, 2025, at the latest [12]. At the moment, a significant stream of textile waste goes to mixed municipal waste, where due to heavy contamination it loses its market value. In Poland, the provisions of the Act on maintaining cleanliness and order in municipalities indicate, that textiles should be collected by selective municipal waste collection points. Such activities are carried out for example in Łódź [24] an Wrocław city [50].

Despite the lack of legal regulations and systemic solutions for proper textile waste collection, a significant stream of this waste goes to the correct processing through commercial, charity, pro-ecological, and social initiatives. Textiles are collected mainly in special containers located in easily accessible places [28]. A popular solution implemented in recent years by fashion brands is also collecting textiles in their stores. Very often, donating unnecessary textiles is rewarded with shopping discounts or other benefits. For example, the H&M brand in 2016 collected over 16.000 tons of clothing [44]. The above actions are dictated mainly by economic reasons. After sorting the good-quality textiles are circulated in second-hand stores. The biggest disadvantage of the commercial textile waste collection system is the low transparency of enterprises. Very often, containers for the textiles collection are placed illegally, by non-existent companies or companies that do not document how they deal with textiles (figure 2). The greatest doubts are raised by the processing of textile waste that is not suitable for circulation. The cooperation between charities patronizing textile waste collection and companies leading recycling of clothes is also not based on clearly defined rules about the donated clothes value.

After collection, according to the assumptions of circular economy, textile waste should first be directed to the sorting process to put into the second circulation. Sorting can take the form of manual or mechanical sorting. For good-quality textiles, the best is manual sorting which allows for a better estimation of the market value. It is estimated that the capacity of manual sorting is from 100 to 150 kg·h-1 per person whereas, for mechanical sorting, the capacity may be over 1000 kg·h-1 [25]. Waste sent for recycling can be sorted mechanically, which consists in separating textiles in terms of their composition and color. Sorting can also be realized with combined technologies.

Recycling of textile waste includes mechanical and chemical recycling. Currently, on a larger scale only mechanical processes for materials, fibers, or fabrics recovery are used. Textiles processed in this way are directed to the production of cleaning cloths, they constitute upholstery filling or acoustic damping [25]. Chemical recycling involves 'fiber-to-fiber' processing. The depolymerization of individual fabrics to monomers and the following repolymerization process allows the production of new fibers and materials. The dissolution route may be also used in chemical recycling for cotton-polyester blends [9]. Those forms of textile recycling are the most desirable, but due to high costs and numerous process difficulties, they are not currently widely used. Currently, only 0.06% of textile waste is chemically recycled and reused in production [17]. The main technological limitations of implementing chemical recycling of textiles include shortening the length of the fibers, the inability to separate the fibers in mixed materials, the presence of persistent chemical impurities, and the lack of a constant supply of raw materials [23], [41], [51]. Economic aspects are also important – a less ecological, but cheaper solution is still the use of primary raw materials. Some fashion brands, wishing to present themselves as pro-ecological, introduce clothing collections partly made of polyester from recycled PET (rPET) bottles. Contrary to appearances, such solutions are not beneficial in the circular economy. Under normal conditions, rPET can be recycled many times, while in the textile industry it is only recycled once [45]. A solution for the above-mentioned problems can only be achieved by implementing directives that mandate the use of recycled textile fibers.

Fig.2 Textile collection containers in Wrocław, Poland.

Rys.2. Pojemniki do zbiórki tekstyliów we Wrocławiu.

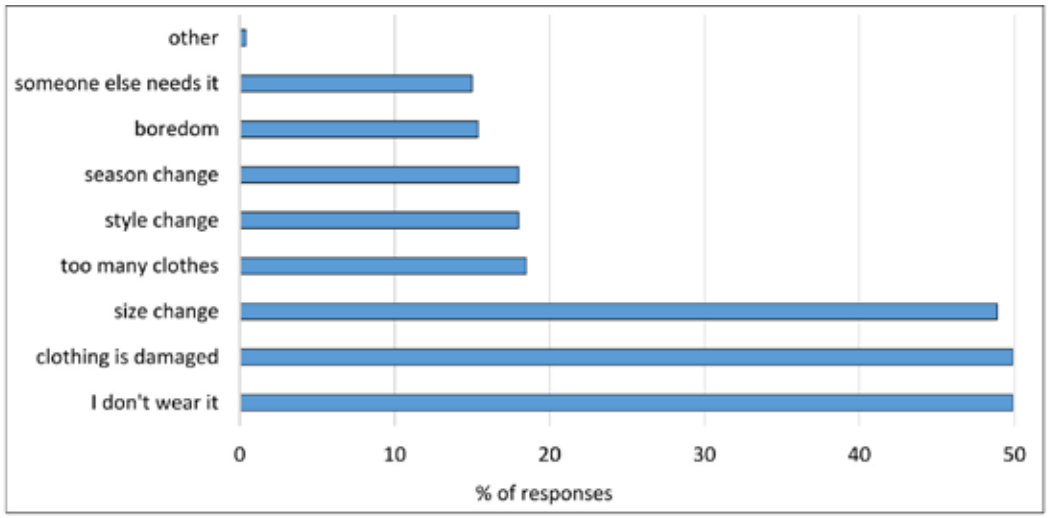

Fig. 3 Reasons for garment disposing (three answers possible), (based on [38]).

Rys.3. Powody pozbywania się odzieży (możliwe trzy odpowiedzi), (na podstawie [38]).

6.Social aspects

Society may influence closing the loop in the textile industry on many levels. The basics of consumers activity should include making responsible and thoughtful purchases. Buying unnecessary and non-functional textiles contributes to artificially boosting production and increasing the waste stream. Similarly, environmental aspects are influenced by purchasing perishable, poor-quality textile products, which very quickly turn into a waste stream that is unsuitable for recycling. Another social aspect of circular fashion is the proper handling of unnecessary textiles and waste. People can try to direct their products to secondary circulation, e.g. through exchange with other people or resale. If consumers decide to throw away textiles, first of all, this waste should be properly deposited. Only selective collection of textiles enables their efficient processing. The literature indicates that the main factors affecting the method of depositing textile waste are individual factors (lifestyle, beliefs, psychological factors), situational factors (economic conditions, house situation) and waste properties (value of products) [21]. Laitala and Klepp [27] indicate that the manner of dealing with textile waste is also influenced by age and gender.

The Polish textile recycling company 'Wtórpol' surveyed the knowledge of Poles about clothing recycling [38]. 78% of respondents believe that clothing recycling helps protect the environment, and clothing production has been identified as one of the leading sources of environmental pollution. However, the awareness of the negative textile industry impact on the environment does not translate into more conscious decisions about buying and disposal of clothing. Almost 50% of respondents discard their clothes because they are not wearing them. As many as 18.5% of respondents admitted that the main reason for getting rid of clothes is having too much of them, and 15.4% of people throw away their clothes because they are bored with them. A survey conducted in the UK showed that 35% of respondents throw away clothes because they do not like them or do not need them [39]. Detailed data about the reasons for the garment disposal are presented in Figure 3.

Getting rid of good-quality clothes allows to sell them in secondary circulation. The second cycle of textiles is the basic assumption of the circular fashion model. As many as 70.9% of the respondents declared that they buy second-hand clothes. The main reasons for buying second-hand clothing include economic aspects (the ability to purchase good-quality and branded clothes at affordable prices), the ability to get original and unique clothes and care for the natural environment. 43.3% of respondents who do not buy second-hand clothes say that the main reason is the will to have new things. Almost 37% of these people say that no factor could change their minds. Research presented in other publication shows that one of the main factors contributing to a negative attitude towards second-hand clothing is hygiene aspects [42]. Research conducted in China indicates, that buying second-hand garments is also associated with financial and status inferiority and/or emotional discomfort [29].

Own observations indicate that many people do not buy used clothes because of the second-hand stores' appearance. They are usually unattractive in terms of design, presentation of clothing and specific smell. In this regard, a lot has changed in Poland in recent years as well. A good example is the "clothes to donate" organization that creates circular boutiques located in large shopping galleries. The stores have designer décor and the clothing sold, sourced from consumers and sorted, is in very good condition and is properly organized. Currently, there are 14 such stores in 7 cities in Poland (including Warsaw, Wrocław, Kraków and Poznań). The organization pursues sustainable development and circular economy goals while being transparent – each kg of donated clothing is turned into 1 PLN donation to charitable foundations [47].

7.Summary

The production and use of textiles undoubtedly have a negative impact on the pollution of almost all components of the natural environment. For this reason, the transformation of the textile industry from a linear to a circular model is needed. The implementation of the circular economy in the textile industry is driven mainly by the creation of appropriate legal regulations at the level of producers and consumers. A circular economy in the textile industry should be based on minimizing the resulting waste stream. This can be achieved through the creation of sustainable products and the use of waste as raw material through recycling. The foundation of the circular economy for textiles is their reuse in the second circulation. The social factor is not without significance in this matter. It is the consumers' responsibility to properly deposit their waste. It is also important to make proper purchasing decisions taking into account the product's quality and durability. Therefore, it is necessary to constantly raise public awareness of the textile industry's impact on the natural environment and to encourage responsible and thoughtful consumer purchases.

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