

## PRODUCTION WASTE OF THE TEXTILE AND CLOTHING INDUSTRY IN SUSTAINDEVELOPMENT CONTEXT

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**Purpose:** The main aim of the research presented in this article was identification and categorization of the main production waste generated in the textile and clothing industry and their impact on the environment in the context of sustainable development, together with the presentation of several proposals for solutions to the problem of production waste. Nowadays, through the newly emerging EU directives, the increasing population and consumer lifestyle, thus the huge amounts of generated waste, the problem of waste coming from textile and clothing industry will increase and it will be more important to find new solutions to it.

**Design/methodology/approach:** In the research presented in this article, an analysis of the literature on the processes of the textile and clothing industry was used; waste generation from these industries and their impact on the environment along with the concept of sustainable development.

**Findings:** The management of waste from the textile and clothing industry is an important factor influencing the sustainable development of the economy, both in the world and in Poland. Under the newly created EU directives, it will be a very important issue in the future, which will require urgent addressing this topic and finding optimal solutions in the context of sustainable development or the circular economy.

**Research limitations/implications:** In the future, research will be continued in the field of production waste management in the textile and clothing industry, their disposal or recycling.

**Practical implications:** This article provides an overview of quantitative research and diversity of waste from the textile and clothing industry in Poland and in the world. This review shows the importance and scale of the problem and allows for further continuation of research to manage the generated waste. The author has also collected concepts for the further management of post-production waste, which she presented in the article, but they require a broader and more detailed analysis.

**Originality/value:** Based on empirical research, the article shows the scale of the problem that, through the new EU directives on the circular economy and sustainable development, will be a forward-looking and important issue. Additionally, the article presents concepts for waste management from the industrial and consumer perspective.

**Keywords:** textile industry, textile industry waste, sustainable development.

**Category of the paper:** Research paper.

## 1. Introduction

The textile industry is a branch of the light industry that produces semi-finished products and textile products from textile raw materials. This industry includes cast-ironing, spinning, weaving, knitting, as well as non-woven and yarn manufacturing technologies. After the industrial revolution, since the replacement of the hand spindle and loom with spinning machines all over the world, there has been a massive increase in the number of textile factories created, and thus the amount of waste generated. Apart from traditional techniques of fabric production, new ones were introduced (especially in the last quarter of a century): texturing, open-end spinning. New products were also created, such as textured silks, yarns, and laminates, as well as new techniques of finishing fabrics, which gave them special properties, such as non-flammability or moth resistance (PWN, 2022).

Unfortunately, along with the development of the textile industry, the amount of generated waste, which is an indispensable element of this process, has increased. These wastes occur both in liquid form (colored effluents and effluents after finishing and processing fabrics), gaseous (substances emitted into the air) and solid (fibre waste – dust and fluff, yarn and product residues, selvedge, cuttings, defective products, fibres). This waste is often not used, managed, utilized, or recycled in any way, especially liquid and solid waste, which contradicts the idea of sustainable development. Fast fashion, which consists in the constant supply of new, fashionable clothes at low prices, also contributes to the significant development of the industry due to the seasonal demand for new products. People should remember that most of the factories are in developing countries, mainly in Asia, where the water and sewage management together with sewage treatment plants and solid waste disposal methods are not yet developed enough. Therefore, wastewater contaminated with dyes, bleaches or heavy metals most often goes directly to rivers, and solid waste is deposited or incinerated in landfills, which is a heavy burden on the environment.

This procedure is against the idea of sustainable development. Companies producing clothing and footwear should consider the ecological approach (goin' green) to the environment and the life of future generations. The so-called sustainable fashion should refer to processes where new products are designed and manufactured in a rational manner, bearing in mind environmental protection. With this approach, many aspects should be addressed: ecological, social, cultural, and financial in the production of textiles and clothing to minimize their negative impact on the environment (Kramarczyk, 2015; Szewczyk, 2017).

## 2. Conceptual background

### 2.1. Textile industry

According to the Product Stewardship Institute, the textile and apparel industry is one among the greatest sources of threats to the natural environment, right after the processing of crude oil and gas (Interreg 1, 2020). Moreover, the production processes are mainly based on natural, non-renewable, and ending resources. In 2015, the Ellen MacArthur Foundation released a report which shows that the consumption of non-renewable resources was 98 million tones, considering only the clothing sector. In addition, forecasting by 2050 the consumption of non-renewable resources will triple with the increase in CO<sub>2</sub> emissions to 26% (Ellen MacArthur Foundation, 2015). According to a report by Le K. in Textile Recycling Technologies, Coloring and Finishing Methods, the level of CO<sub>2</sub> emissions increased by about 2.5 billion tons per year (by over 60%). At the same time, there was a 50% increase in the amount of freshwater consumption (Le, 2018). According to Report of the European Parliament in 2015, the clothing and textile industry used 79 billion m<sup>3</sup> of water, this report informs about the scale of the problem – 2700l of water is needed to produce one T-shirt, which is as much as drinking water is consumed by an average person in 2.5 years (European Parliament, 2020). In 2018, the textile and clothing sector generated a turnover of € 178 billion in European Union countries, which allows to state that it is a very important sector for the EU economy. In addition, the EU is the second (after China) largest exporter of clothing and textiles in the world, with the largest producers located in France, Italy, Spain and Germany, who are responsible for the production of approx. 75% of EU production. In 2019, compared to the previous year, clothing exports increased by 13.8% to Switzerland, by 6.8% to the USA and by 2.9% to China. Therefore, the activity of the textile and clothing industry is taken up in many global debates, as 5% of the total amount of waste worldwide comes from this industry (Fisher, Pascucci, 2017).

It must be remembered that in the textile and clothing industry, not only finished products are a waste problem all over the world, but also the so-called production waste. During the production of fabrics, huge amounts of cuttings, pieces of textiles (selvedge), fiber waste (dust and fluff), yarn waste, fibers and defective products are produced, which are rejected at the production stage (Wałętrzak 2016; Szewczyk, 2017).

### 2.2. Outline of technological processes in the production of fabrics

Technological processes in the textile industry include several unit operations, as a result of which utility textiles in the form of woven, knitted fabrics and felt are produced. A yarn is obtained from the fibre, from which a fabric in the form of pig iron is produced on a weaving loom. Then the pig iron is subjected to bleaching, dyeing, and finishing processes to give it special properties, such as resistance to creasing, water, etc. The technological processes of

processing wool, cotton, cellulose, and silk consist of several operations and processes of obtaining, processing, dyeing and processing the raw material (Meinck et al., 1975). Technological processes in textile plants include several intermediate stages listed below (Szosland, 1981; Mihułka, 2003).

**Stage 1** includes knitting, i.e., the application of lubricants (fats, mineral oils) and mechanical processing of the yarn into a textile product.

**Stage 2** is a prewash to remove dirt (animal grease, dirt, dry sheep sweat) and includes:

- washing with water, with the use of detergents and alkaline agents at a temperature of 55-70°C,
- solvent washing - with the use of organic solvents and detergents,
- drying.

**Stage 3** is a chemical treatment that removes natural impurities and previously applied preparations from the fibers and consists in:

- sunbathing – leveling the surface of the fabric over the flame,
- peeling off – removing sizing from the fabric with  $\text{Na}_2\text{CO}_3$  solution,
- mercerization – increasing material strength, giving gloss, improving the sorption properties of the fabric with  $\text{NaOH}$  solution,
- bleaching – removal of the natural color of the fiber (e.g. cotton, linen) with  $\text{H}_2\text{O}_2$ ,  $\text{NaClO}$ ,  $\text{NaClO}_2$ ,  $\text{CH}_3\text{COOOH}$ ,
- thermal stabilization – ensuring the shape stability of fabrics in further stages of processing.

**Stage 4** involves dyeing – giving the fabric colour with the use of reactive, direct, vat and sulphur dyes, whereby dyeing is carried out using various methods:

- bathing methods (periodic, exhaust) – consisting in immersing the fabric in a dyeing bath containing dyes and auxiliary agents for a certain time, which causes the diffusion of dye particles to the surface of the fibres, and then migration of these particles into the interior of the fibre,
- continuous and semi-continuous methods – the fabric is pre-filled with dye by using, for example, sprays or foam, and then using thermal methods (steam, hot air) or chemical methods, the dye is permanently bonded with the fibre,
- fabric washing – removal of unfixed dye particles and residues of chemicals previously added to the dyeing bath.

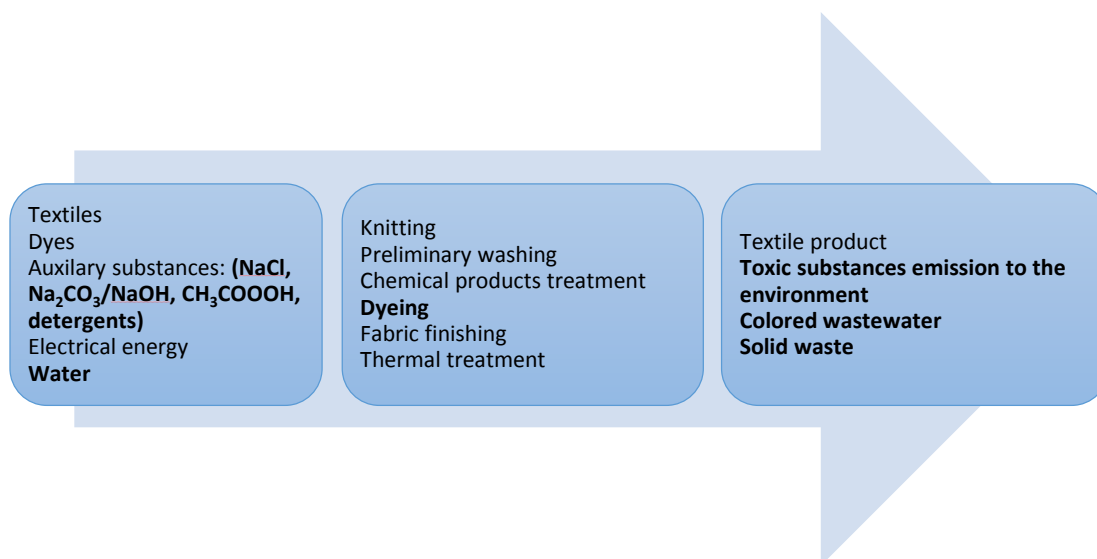
After the dyeing process is completed, the used dye bath with the remaining dye and auxiliary agents is discharged into the sewage. Likewise, during washing, dye wastewater is also produced and discharged into the sewage system. An important and basic technical and technological parameter of dyeing apparatuses is the concept of the bath multiplication factor ( $k$ ,  $\text{dm}^3/\text{kg}$ ), i.e., the appropriate ratio of the mass of the dyed product to the minimum mass of the bath, to obtain the proper dyeing effects. This parameter also influences the amount and

physicochemical properties of the generated wastewater – the greater the bath ratio, the more dye is used, which at the same time causes more dye to be transferred to the wastewater. In addition, for higher values of the multiplication factor of the bath, the specific consumption of water and heat energy is higher.

**Stage 5** includes finishing the products by giving them the desired properties utilities and consists of the following unit operations:

- anti-wrinkling finishing – cross-linking agents, catalysts, additives (softening, hydrophilizing agents, etc.),
- waterproof finishing,
- softening finishing,
- anti-inflammatory finishing,
- molar resistant finishing.

**Stage 6:** thermal treatment, as the final stage of production, consists in fixing the previously applied chemicals by high temperature (150-190°C). A general outline of the technological processes of fabric processing, considering the places of dye application and the formation of colored wastewater, solid waste and the emission of toxic substances into the air is presented in Figure 1.



**Figure 1.** Selected raw materials, technological processes and products created in textile processes, considering the places where dyes are used and the formation of colored wastewater.

Source: own elaboration.

### 2.3. The environmental impact of production waste

Currently, the textile industry is considered the most water-intensive and energy-intensive. The volume of wastewater generated in factories dealing with the processing and finishing of fabrics (including dyeing and modification to give specific properties) may reach values from 100 dm<sup>3</sup>/kg of raw material for artificial fibers, up to over 300 dm<sup>3</sup>/kg for woolen products. In addition, 90% of the amount of water used produces sewage, and the remaining 10% is

evaporated or disposed of with fiber (Anielak, 2002). World production of textile products reaches 40 million Mg/year, which results in the generation of 4-8 million m<sup>3</sup> of sewage containing dyes (Wang et al., 2004). The European Parliament estimates that the textile industry is responsible for around 20% of global clean water pollution due to dyeing and finishing processes.

Colored wastewater that enters the aquatic ecosystems causes the color of the water, which reduces the photosynthesis process, and as a result, oxygen deficit conditions may arise in the ecosystem. They also have a direct or indirect negative effect on all levels of the ecosystem's trophic chains. The breakdown of azo dyes by aquatic microorganisms can generate DNA adducts, which changes their genetic code (Bell et al., 2010). Synthetic dyes that get into the environment in the form of industrial wastewater pose a serious threat not only to organisms found in aquatic ecosystems but are also not indifferent to higher organisms such as mammals, including human health. They can also be carcinogenic and mutagenic (Attia et al., 2006; Aravindhana et al., 2007). As shown in the literature (Amin et al., 2010), rats administered orally with aqueous solutions of the two azo dyes Tartrazine (dose 15 or 500 mg/kg body weight) and Kamizine (dose 8 or 100 mg/kg body weight) showed insufficiency multi-organ system – especially the liver and kidneys. The research showed that both pigments change the biochemical markers of the liver and kidneys and induce oxidative stress through the formation of free radicals. Moreover, Sudan 1 azo dye is considered carcinogenic to the liver and bladder of mammals, including humans, and Sudan 2 dye is considered genotoxic to rat liver cells (Xu et al., 2010). Therefore, tests for determining toxicity play a very important role in environmental protection.

Due to the ionic nature of the pigments, the adsorption process takes place in soils, and in aqueous solutions the process of complete or partial dissociation takes place. The solubility of non-ionic azo dyes is lower than that of ionic dyes, which is related to their low mobility in soil and sediments, so that dyes will accumulate in the surface layers of the soil (Baughman et al., 1991; Tabaraki et al., 2007).

Another group of waste is solid waste in the form of cuttings, shavings, fibers or defective products, e.g. in 2018 according to Oakdene Hollins Report, the total amount of production waste generated in the EU countries was 9.35 million tonnes (Oakdene, 2014). During the production of textile products, large amounts of process waste are generated, which are sometimes purchased and sold to other companies or transformed into other products, e.g., Resyntex or Sinoma, but it is still done on a small scale. Moreover, often raw textiles purchased by intermediaries are not provided with reliable information from suppliers about the quantity, type and quality of agents applied to the fibers of the material (preparations, pesticides, knitting oils). Knowledge of such residual compounds on fabrics is very important as further environmental impacts can be controlled as it is known that these fabrics will be further processed. In the entire clothing industry in the EU, only 13% of the material used for production is recycled. In contrast, less than 1% of the material used in the production of

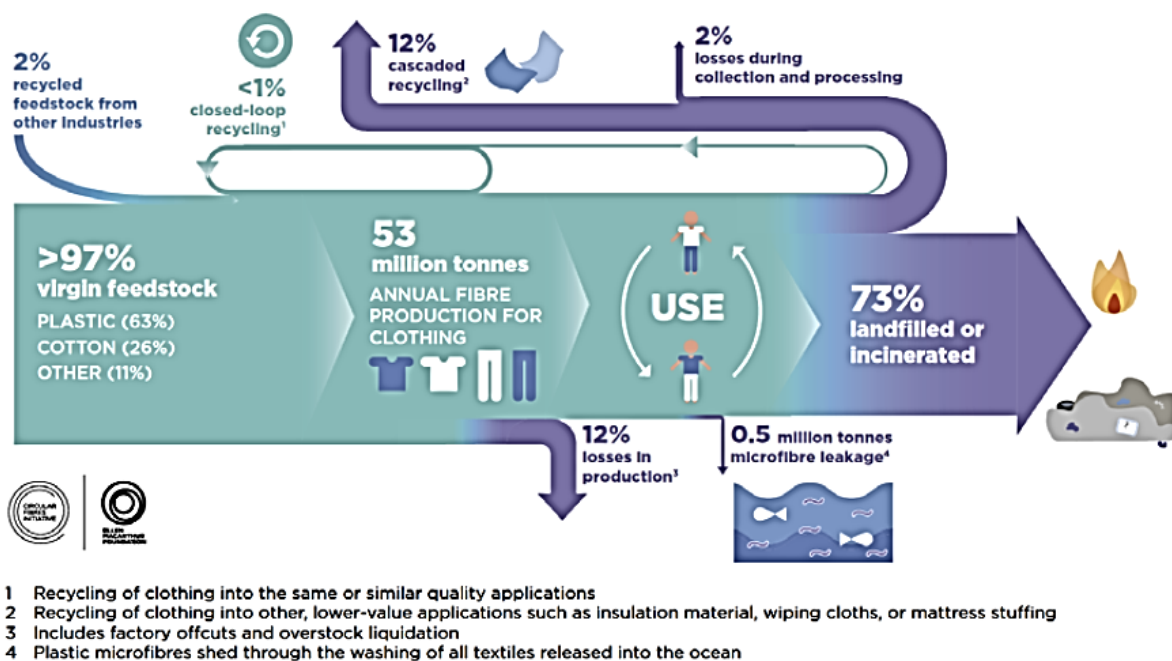


clothing is recycled into new clothing. Most of the recycling of materials consists in using them in other industries, e.g., insulation materials or fabrics for wiping or mattress fillings, but in this form, they are difficult to recover and therefore most likely it will be their last use (Interreg 2, 2018). In less developed industrially and economically, e.g., China or India, which are the main importers of clothing and textiles, such treatments are not practiced and, unfortunately, most of the textile waste ends up in landfills (Szewczyk, 2017). An example of this is the Atacama Desert in Chile, where 60 000 tons of old clothes are deposited there every year, the decomposition time of which can be up to 200 years (Bankier.pl, 2021).

What's more, during pre-washing of the finished product and when washing synthetic clothes, every year as much as half a million microfibers end up in the seas and oceans. Washing of synthetics accounts for 35% of the primary microplastics released into the environment, e.g., when washing polyester, 700 000 microfibers may be released and can get into the food chain and accumulate in the trophic chain, even in man as the final consumer (Boucher, 2017; European Parliament, 2020).

The last type of waste is gaseous waste - mainly carbon dioxide. According to the European Parliament's data, the clothing industry is responsible for 10% of global CO<sub>2</sub> emissions - much more than emissions from international flights and shipping, inclusive. According to the World Environment Agency's in 2017 purchases of textiles in the EU resulted in the emission of 654 kg CO<sub>2</sub> per person (European Parliament, 2020).

A summary of the places where production waste is generated along with the percentage of its management is shown in Figure 2.



**Figure 2.** Global material flows for clothing in 2015.

Source: Wicker, 2016.

### 3. The concept of sustainable development

“Sustainable development is one in which the needs of the present generation can be met without compromising the chances of future generations to meet them” (World Commission Report, 1987). One of the main challenges facing the textile and clothing industry is more efficient management of natural resources (non-renewable) and increasing the innovation of waste recycling. The changes cover 3 spheres of life:

- economic (prosperity) – reducing the costs of raw materials and energy consumption and waste disposal, creating new business networks, which gives new market opportunities,
- environmental (planet) – optimization of the consumption of natural resources, reduction of environmental impact and reduction of gas emissions, avoiding landfilling, recovering energy from waste,
- social (people) – raising the standard of living, more green jobs (increase in employment).

To strive for a more sustainable development, the activities of the textile and clothing industry should focus on (Oakdane 2014, Zitting, 2017, Safer, 2018):

- a. changing the logistics of collection and transport of materials for recycling – new business models, new waste collection schemes,
- b. acquiring new stakeholders – creating new companies that will deal with the processing of e.g., synthetic fibers into natural ones,
- c. exchange of information on the development of recycling technologies – perhaps replacing mechanical treatment with chemical treatment will allow to obtain more valuable materials and use them later,
- d. automating the sorting and identification of fibers – exact knowledge and the identification of the chemical and structural composition of the textile waste stream is necessary for the efficient processing of the fibers and maintaining them in a better quality,
- e. systematization of information on waste and traceability – knowledge of the materials and chemicals used in textiles and clothing during production would allow for safer subsequent management of the given fiber,
- f. financing – costs are a significant barrier for various companies to expand their research and update recycling technologies. Therefore, mutual assistance and cooperation of government, companies and universities can help in the development of technology,
- g. measuring and distributing chemicals – accurate measuring and dosing of chemicals and dyes will allow for the optimal use of these compounds without using them in excess,



- h. selection and use of chemicals and dyes – considering the need to use a given auxiliary agent or dye, replacing chemicals with products with higher biodegradability, lower toxicity, lower emissions to air and a milder odor,
- i. using appropriate equipment – in the case of surfactants or anti-foaming agents, the use of devices with lower air entrainment will reduce the foaming of the agents.

Consumers can also themselves influence the quantity and quality of clothes and textile products produced by:

- a. education and promotion of a minimalist approach of consumers to the clothes they buy - consumers will buy less clothes, their purchases will be more thoughtful, and the clothes they choose will be more universal and functional. This is the so-called slow fashion. All these treatments should reduce the amount of clothes produced, and thus the amount of waste generated,
- b. re-use of worn-out clothes – this is extending the life of a given product by repairing, mending, sewing, or modifying it (shortening, narrowing). There are also companies offering the possibility of selling and buying their belongings (e.g., Vinted) and secondhand shops. You can also give used clothes to the poor (Wtórpol containers, PCK).
- c. recycling – processing of used clothes, scraps of materials, cuttings, and other waste into new fibers of comparable value.

The eco-design trend is part of the concept of sustainable development. It is an approach to design that considers its environmental impact throughout the entire life cycle of a product. It concerns design that minimizes the harmful effects of the production and use of products on the environment. The concept of eco-fashion is directly related to the concept of eco-design. Eco-fashion products are characterized by (Muthu, Gardetti 2016; Gwilt, Rissanem, 2011):

- the use of organic raw materials grown without pesticides,
- the use of textiles without the use of chemicals and bleaches,
- reusing recycled materials or fibers,
- durability and quality so that consumers can keep them for longer,
- considering the principles of fair trade.

#### **4. Summary and conclusion**

At every stage of production, dyeing and repeated use of colored products, contaminants are created that get into sewage, surface waters and soil. The tanning, food, paper, and cosmetics industries are responsible for generating large amounts of colored pollutants, but the largest amounts of colored wastewater are produced by the textile industry (4-8 million m<sup>3</sup>/year). Coloring substances belong to the compounds that are difficult to biodegrade and are not

susceptible to light and temperature and other chemicals. It has been shown that even partial biodegradation of dyes can result in the formation of many harmful and toxic products. Problems during dyeing such as excess dyes used, their residues in dyeing baths, or the loss of dyes in the subsequent stages of fabric processing, affect the release of dyes to the wastewater, and in combination with the insufficient effectiveness of conventional treatment methods, may cause the degradation of the aquatic environment.

In addition to dyes, waste from the textile and clothing industry is a big problem, i.e., scraps, selvedge, fibers, fluff, and dust. In less developed countries, they are not properly managed, but deposited in landfills, which poses a threat to environmental protection. What's more, in contact with water (e.g., washing of synthetic materials), they release huge amounts of microfibers that get into the seas and oceans, causing accumulation in living organisms, not only in marine but also in humans.

The high carbon dioxide emissions are also a big problem with a huge carbon footprint, even greater than the CO<sub>2</sub> emissions of the aviation and maritime industries.

The textile and clothing industry is the second most water-absorbing and energy-intensive from all industries, besides the oil processing industry. It also produces a very large amount of production waste as well as colored wastewater along with chemicals from the fabric finishing processes, which are very difficult to clean and use later. Therefore, the textile and clothing industry should be more consistent with the concepts of sustainable development. Textile wastewater treatment processes as well as methods of collecting and recycling production waste in developed countries are at the crawling stage, while in less developed countries they are usually absent, and colored wastewater and wastes are deposited directly in the environment (discharge into rivers or landfills). Therefore, further directions of the textile and clothing industry should be related to the concept of sustainable development. Financial and administrative relief from the state would encourage industry to develop technical developments in the treatment of production and textile waste, as well as waste management and recycling. The next step could be the creation of well-functioning production waste collection systems and cooperation with other collection companies. Additionally, international expert networks and platforms can be developed that will enable the matching of textile waste. The next step may be to move towards a circular economy and eco design. All these activities would be aimed at slowing down the growth rate of the consumption of natural resources and the consumption of secondary raw materials.

This article presents some of the many solutions for the management of production waste, which can be the basis for introducing changes aimed at including the textile and clothing industry in the concept of sustainable development. The presented solutions apply not only to the industry itself, but also to consumers, which proves that every person in their home, with a few small choices, can affect the environment. Recycling of production waste is strongly related to innovation and the development of enterprises, so by following the path of sustainable development, you can contribute to the development of new technologies and have a positive impact on the economy and the surrounding natural environment.

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