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From Traditional Industry to Smart Regional Specialisation: Textile Industry Transformation in the Łódź Region

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Abstract
The aim of the article is to examine how the textile industry in the Łódź Voivodeship has evolved in the context of building smart regional specialisations. The ideas underlying the concept of smart regional specialisation in order to use this foundation to outline the trends in the development and transformation of the textile industry in Central and Eastern European countries are described. The transformation of the innovative capacity of this industry in the Łódź region is shown. The research used an analysis of existing materials, statistical methods and LQ location indicators.
Specific territorial capital accumulated for over two centuries and encapsulated in tradition, knowledge, skills, and economic relations in the Łódź region has provided a unique economic potential for the development of the textile industry. The period of rapid transformation was followed by stabilisation and the reconstruction of its potential and building smart specialisation, which will become the impetus for regional competitiveness.

Keywords
textile industry, smart regional specialisations, territorial capital, textiles, nonwovens, Łódź region.

1. Introduction

Over the past two decades, the transatlantic productivity, innovation and growth gap has been steadily widening, particularly in the research and development (R&D) as well as high-tech and technology sectors. The widening competitiveness and innovation gap between the European Union (EU) economy and the United States, Japan and China, together with declining economic growth, have given rise to radical decisions aimed at strengthening Europe's position in the global economy. A response to these challenges is the concept of smart regional specialisations. This is a new idea for creating economic specialisations aimed at improving the competitive position of European regions at the international level. It has become the basis for the development of a new regional policy in building the innovative capacity of regions [1].

At the core of the concept of smart regional specialisations is the assumption that regions should selectively choose the domains in which they have the best-developed resources and concentrate their scientific, research and innovation activity within these domains [2]. The originators of this approach point out that the existing policy thinly distributes investment and activity across different fields of scientific and technological research, consequently not making a significant difference in any of these fields. In their view, a more promising strategy seems to be to stimulate activity and develop investment programmes that complement and strengthen the already existing output and innovation capabilities of the region, providing the basis for building a specialisation that would enjoy an international competitive advantage [3].

Consistently, the key challenge to the regional policy is to identify industries having the biggest innovation potential which meet the conditions for the development of smart regional specialisations. The choice of such industries should be a bottom-up and enterprise promoting exercise that engages economic partners. The area of specialisation should be closely linked with market needs while the priority research directions should respond to the needs of the final recipients of the research [4]. The domain of specialisation should be characterised by strong links with the science and R&D sector. The specialisation domain should have well-developed scientific and research facilities with an established market position, economic successes and dense and well-established relations with business [5]. It is also necessary to have a well-developed system of support institutions (the so-called institutional environment), creating links between the R&D and economic sectors [6].

The idea of smart regional specialisations emphasises the importance of endogeneity and specificity (territorial capital), as well as the concentration and complementarity of regional potentials needed for the development of smart specialisation (so-called territorial advantage) [7]. It is highlighted that the regional environment is not neutral in building the innovative capacity of actors, and that technological advantage alone may not be sufficient for the development of a highly competitive specialisation. Embedding the domain of specialisation in the endogenous resources of the region, anchoring it in the socio-economic heritage, creates a specific competitive advantage, resulting from the accumulation of knowledge, experience, traditions and management routines and practices [8,9]. At the same time, the rooting of specialisation in the entrepreneurial environment, through durable and dense network relations and developed cooperation channels, facilitates the flow of information and knowledge and creates a foundation for innovative solutions [10]. On top of that, smart specialisations require complementarity of regional resources, a strong backup for the specialisation from resources supporting its development - e.g. the education system, institutional resources or related industries. In this way, a specialised economic system can be created in the region strongly linked by relations and interdependencies, which can compete internationally [11]. The strength of the accumulated human resources, infrastructure, knowledge, experience, and networks of links within specialisation triggers economies of scale and synergy effects. It leads to the creation of new information, knowledge, innovation resources and their international diffusion [12].

Innovation policy resting on building smart specialisations is recommended, above all, in little developed countries and regions [13]. The need to adopt a new approach to innovation policy and new forms of regional governance are strongly recommended [14,15].

The aim of the paper is to examine textile industry transformation in the Łódzkie Voivodeship. It seeks to answer the question whether in the Łódź region the textile industry is an area of regional smart specialisation and whether changes that have occurred over last decades have enhanced its innovation capacity. Can this industry become the driving force for the growth of the region and a pillar for building a competitive advantage at the international level? The article, in a synthetic way, describes the idea of regional smart specialisations and the transformation of the textile industry in countries of Central and Eastern Europe (CEE) to demonstrate the potential of the growth of the textile industry in the region against this background.

2. Research methodology

2.1. Economic analysis method

A triangulation of research methods was used in the search for answers to the questions posed. The research methods used were as follows: 1) analysis of existing sources, including a critical analysis of the subject-matter literature and strategic documents, reports and expert reports made for the textile industry; 2) statistical methods - indicators of structure and intensity showing the dynamics of transformations taking place in the textile industry; 3) LQ location quotients calculated on the basis of the number of enterprises and employment, enabling identification of the concentration of economic potential in a given industry. The indicators of regional specialisation in the textile industry (simple location quotient - SLQ) were determined on the basis of a comparison of the share of a given branch in the region's economy with a similar share determined at the national level (activities classified according to sections and divisions of the Polish Classification of Activities).

$$SLQ_g^R = \frac{x_g^R / x^R}{x_g^N / x^N}$$

where: x_g^R - people employed in industry g in the Łódź region; x_g^N - people employed in industry g in the national economy; x^R - total working population in the Łódź region; x^N - total working population in the national economy.

If the value of the location quotient for branch g in a region exceeds 1 ($SLQ_g^R > 1$), the concentration of this branch in the region is higher than the average for the country. High spatial concentration is most often understood when the location quotient exceeds a value of 1.25 [16]. By analogy, the LQ index was calculated based on the number of entities.

2.2. Structural analysis of textile

Molecular parameters: molar mass, polydispersity index and molar mass distribution were determined by GPC/SEC (Gel Permeation Chromatography/Size Exclusion Chromatography). The study was performed using the Agilent 1260 gel chromatography system (Agilent Technologies, USA) equipped with an Optilab T-reX refractometer detector (Wyatt Technology, USA). Chloroform HPLC was used as the eluent for analysis. Studies were performed using a PLgel Mixed-C 300mm chromatography column (Agilent Technologies, USA) at a flow rate of 0.7 ml/min. A universal calibration technique was applied using the literature's Mark-Houwink-Sakurada.

The samples obtained were examined under a scanning electron microscope (SEM) Quanta 200 (W) from FEI (USA). The samples were sputtered with a 20 nm gold layer in a Q 150R S vacuum sputtering machine. The studies were carried out in the HiVac (high vacuum) mode at an electron beam accelerating voltage in the range of 5-20 kV. An ETD detector was used.

3. Transformation of textile industry in countries of Central and Eastern Europe

The textile industry in the European Union is strong as it brings together around 60 000 businesses with over 501 000 employees (Eurostat 2022). It is located mainly in southern and western European countries such as Italy, Germany, France and Spain, which account for around 60% of the value of output sold. Among the countries of Central and Eastern Europe (CEE), Poland remains the leader, ranking 5th in 2020 (in terms of the value of output sold), and has significantly improved its position in recent years (**Fig. 1**) The Czech Republic and Romania are also among the leaders in the CEE bloc, ranking 10th and 11th in the EU, respectively [17].

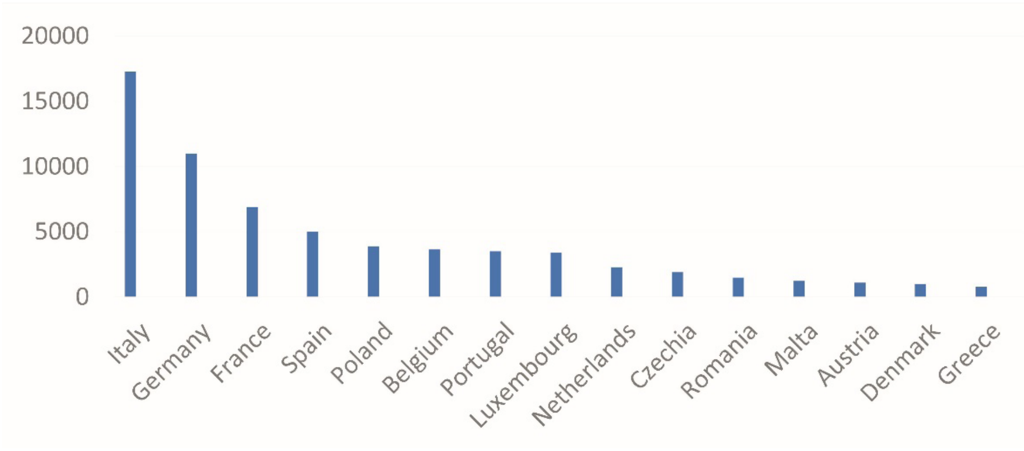


Fig. 1. Value of EU Textile Output in 2020 (million Euro) (Source: EUROSTAT 2022 [17])

The last three decades have been a time of far-reaching transformation of the textile industry in the CEE bloc. It occurred as a consequence of the shift to a market economy in the 1990s leading to the collapse of many state-owned factories, in which the infrastructure and machinery were outdated, labour productivity low, and investment was lacking. An important impulse for the transformation of the textile industry in these countries came from their EU accession in 2004. Access to a larger market, structural funds and opportunities offered by the free movement of goods and services contributed to its advancement. Foreign investment, technological modernisation and an orientation towards quality production have allowed some countries to remain competitive. In Central and Eastern European countries, the competitive advantage is built primarily on lower costs of production than in Western economies and well-educated and skilled human resources. Geographical location in the centre of the continent, which reduces the costs of transport and favours expansion into international markets, is also not without significance.

The restructuring of the textile sector in the CEE countries resulted in the development of new technologies, increased foreign investment, and enhanced exports. New technologies have contributed to increased labour productivity and achieving higher quality of products. In response to the growing environmental concerns of consumers, the output has been reoriented towards the manufacturing of organic and sustainable materials.

The innovativeness of the textile industry in Central and Eastern European countries varies. The leading positions are occupied by Poland and the Czech Republic, which have made significant progress in the development of textile technology and design, introducing modern technologies for the production of textiles and clothing. Integration into global supply chains and cooperation with companies from other countries have paved the way to the transfer of know-how and new solutions. Despite these positive developments, the innovation performance of the textile industry in the countries of the Central and Eastern European bloc is much less impressive. The leaders in the innovative textile industry are Italy, Germany and France. The majority of professionals with advanced materials skills can be found in Belgium, those with advanced manufacturing and robotics skills in Italy, and AI skills in Germany. But also in Poland new, innovative textile technologies are beginning to develop into important sectors.

4. Current trends in the development of the textile sector

The innovative potential of the textile sector is largely due to the fact that products from this industry are used in almost all sectors of the economy. They can be found in medicine, construction, automotive, agriculture, defence, and state security sectors.

The textile industry is extremely flexible and open to novel concepts. Technology boosts its development and promotes the introduction of innovative solutions to respond to the challenges of the modern world. The intense digital transformation observed is being driven by the demand and needs of consumers for personalised products [18;19]. Technological innovations have produced new business models and opportunities for textile companies. The directions of new innovations in textiles are presented in **Figure 2** according to the EU Report 2020“ Advanced Technologies for Industry – Sectoral Watch. Technological trends in the textiles industry [20].

4.1. Medical sector

Advanced materials are in high demand, especially in the medical industry. Surgical implants, extracorporeal devices, tissue engineering, antimicrobial barrier fabrics, cardiovascular devices, and endovascular treatments are important innovations for an aging society. The results indicate that advanced materials is the term most associated with textile sector company websites, followed by nanotechnology and 3D design/printing (**Fig. 3**) [20]. New ideas and technological innovations in textiles are very diverse, examples of which are presented in **Table 1**.

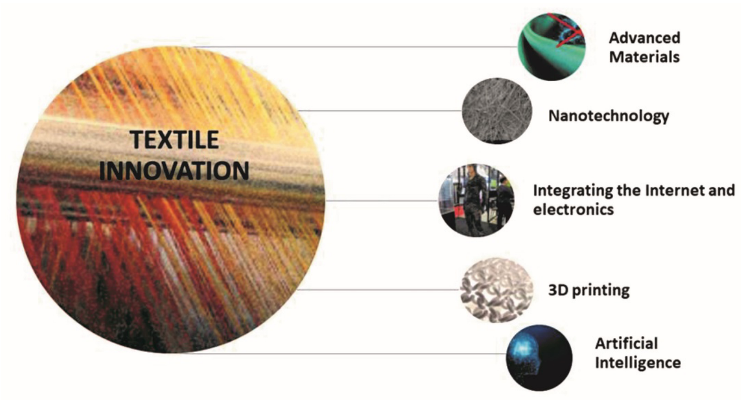


Fig. 2. Technological trends in the textile industry

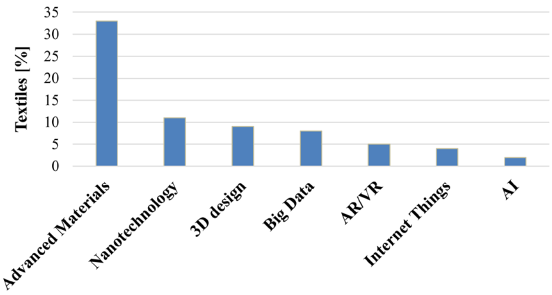


Fig. 3. Share of textile company websites in relation to advanced technologies [20]

Technological trends	Innovation
Advanced Materials	• antibacterial, antiviral function • materials from biobased source polymer • biodegradation/composting • surface modification • composite materials • recycling • drug delivery • new structure
Nano-technology	• antimicrobial • UV-blocking • antistatic • flame retardant • water and oil repellent, wrinkle-resistant • self-cleaning properties • photonic technologies • optical fibres and LEDs
Integrating the Internet and electronics	• electro-textiles for sensing/monitoring body functions • delivering communication facilities • data transfer • individual environment control
3D printing	• innovative structure • composite materials
Artificial Intelligence	• detect visual defects • measure wrinkles in fabric machine learning to identify previously hidden patterns from raw data to help businesses improve efficiency and maintenance • machine learning to optimise inventory and supply chain management • AI-based yarn fibres for new design prototypes and materials • AI algorithms to track consumer behaviour

Table 1. Innovation ideas and technologies according to trends identified in the EU Report 2020, Source: Technopolis Group based on text-mining company websites [20]

During the COVID-19 pandemic, one of the important innovations in advanced materials was a modification intended to generate antipathogenic activity through textiles. The aim was to reduce the transmission of infections and protect people (**Fig. 4).** Various elements and compounds, such as silver, zinc oxide, copper or natural polysaccharide compounds, such as chitosan, were used for modification (**Fig. 5**) [21-24]. Other solutions involved the development of filtering materials that can act as barriers to pollutants, bacteria or viruses. Manufactured using, e.g., melt-blown nonwovens with an elementary fibre diameter of approximately 3um, allowed the development of medical devices, such as medical masks or FFP filters (**Fig. 6**).

4.2. Biodegradation of nonwovens

In recent years, the textile industry has undergone a profound transformation in response to growing environmental concerns and sustainability imperatives. The quest for eco-friendly solutions has become central to the industry's ethos, prompting manufacturers, researchers, and consumers alike to seek innovative and sustainable alternatives to traditional textile products. This transformation has led to a surge in the exploration of biodegradable materials and processes as a key component of sustainable textile practices.

The impetus for this shift towards eco-friendly solutions is multifaceted. Environmental consciousness has reached new heights, driven by increasing awareness of the detrimental impact of conventional textile production and waste. The textile industry, known for its resource-intensive processes and substantial contributions to pollution, has come under scrutiny [25,26]. Consequently, stakeholders are actively seeking ways to mitigate the industry's environmental footprint and reduce its contribution to landfills and pollution.

One prominent avenue of exploration is the integration of biodegradability into textile materials and products.

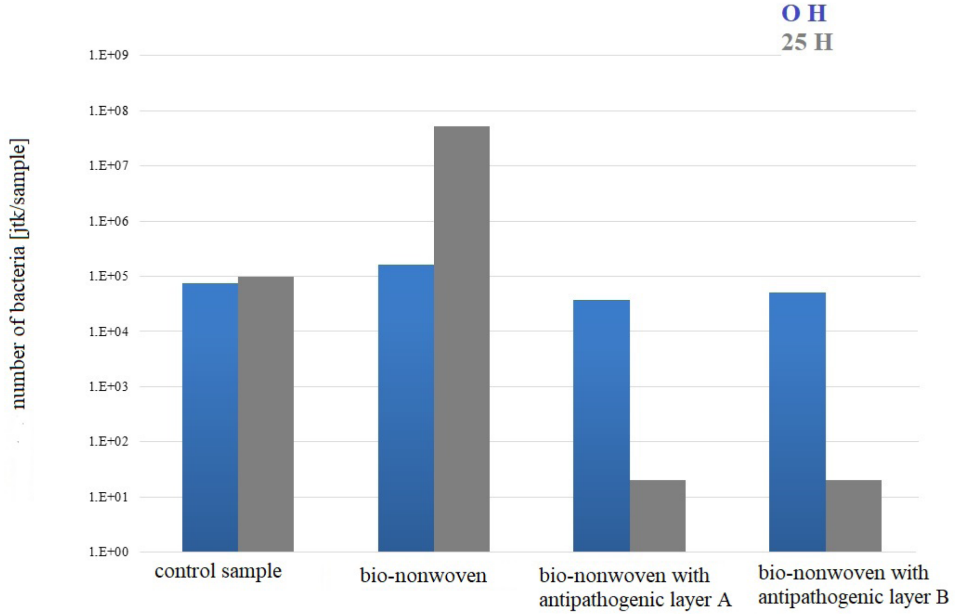


Fig. 4. Growth of E.coli bacteria after modification of bio-nonwoven (own elaboration)

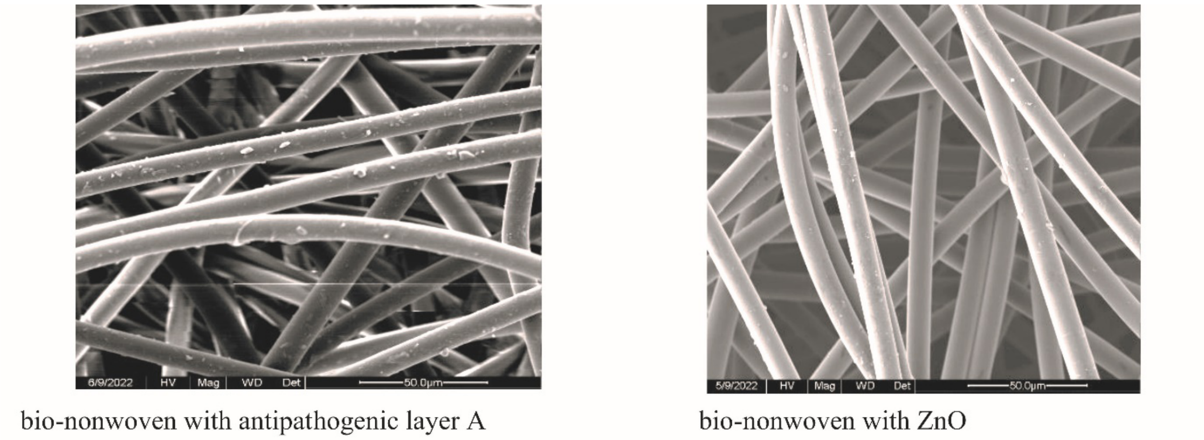


Fig. 5. SEM images of the modified nonwoven. (own elaboration mag. 1500x)

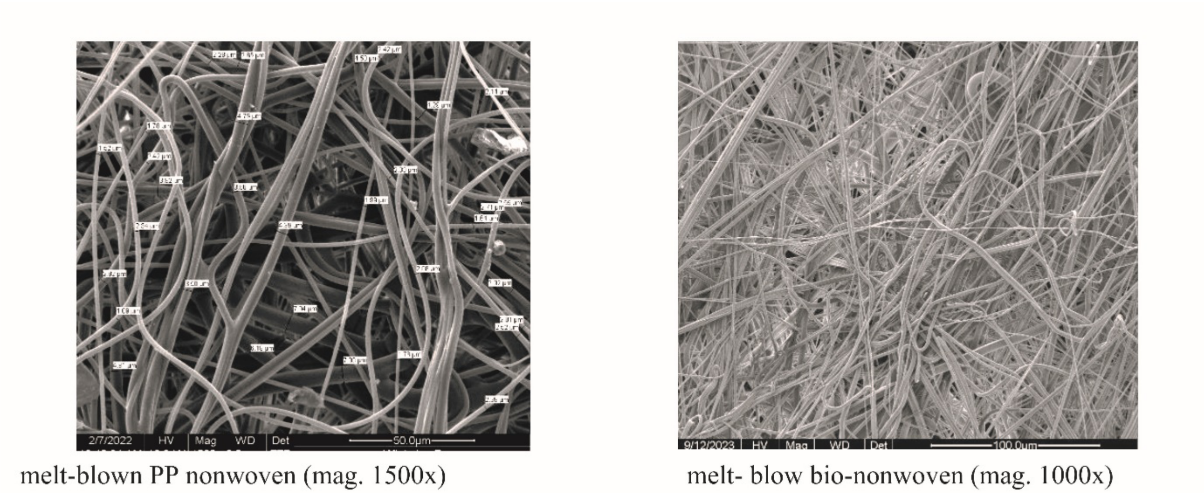


Fig. 6. SEM images of the melt blown nonwoven (own elaboration)

Biodegradation offers the potential to address multiple sustainability challenges simultaneously. It allows textile products to naturally break down at the end of their life cycle, reducing the burden on landfills and minimizing the persistence of non-degradable textile waste in the environment. Additionally, the incorporation of biodegradable materials aligns with the broader goal of conserving natural resources and reducing the reliance on petrochemical-derived raw materials [27-29].

The Organisation for Economic Cooperation and Development (OECD) defines biodegradability as a process of decomposition of organic substances by microorganisms into simpler substances such as carbon dioxide, water and ammonia [30,31]. Energy and oxygen, carbon, phosphorous, sulphur, nitrogen, calcium, magnesium, and other elements are required for microorganisms to grow and reproduce. This process leads to the complete mineralization of organic substances into carbon dioxide (CO_2), water (H_2O), and biomass, leaving no harmful residues or persistent waste. The energy obtained can be used by the microorganisms or lost as heat. Biodegradation can be conducted under both aerobic and anaerobic conditions [32].

Biodegradability of textile materials is important for several key reasons, such as [33-35]:

- environmental pollution reduction: traditional textile materials, such as polyester and nylon, are composed of synthetic polymers that are highly durable and resistant to natural degradation. When these materials end up in landfills or are littered in the environment, they can persist for decades or even centuries, contributing to environmental pollution;
- resource conservation: the production of traditional textiles from petrochemical-derived raw materials consumes significant energy and natural resources. In contrast, biodegradable materials like organic cotton or polylactic acid-based (PLA-based) nonwovens help reduce the demand for fossil fuels and mitigate the environmental impact associated with resource extraction;
- protection of aquatic ecosystems: inadequately disposed textile waste can find its way into rivers and oceans, posing threats to aquatic ecosystems and marine organisms. Biodegradable materials have the advantage of breaking down more rapidly in aquatic environments, reducing the risk of waterborne pollution;
- support for sustainable agriculture: biodegradable textile materials find application in agriculture, aiding in soil erosion control, enhancing water retention, and reducing the need for chemical pesticides. They align with sustainable farming practices and contribute to soil health;
- microplastic mitigation: synthetic textile fibres, particularly those used in clothing, can shed microplastics during washing and wear. These microplastics can enter water bodies and the food chain. Biodegradable materials offer a solution by avoiding the generation of persistent microplastic pollution;
- promotion of environmental awareness: the adoption of biodegradable textile materials helps promote environmental consciousness among consumers and manufacturers alike. It empowers individuals to make informed choices and encourages companies to prioritize sustainable production practices;
- advancing sustainable industry: the textile and packaging industries can transition towards more sustainable practices by utilizing biodegradable materials that naturally degrade over time. This supports the long-term sustainable development of economies.

The latest scientific articles underscore the urgency of addressing textile waste and pollution through the adoption of biodegradable materials. Researchers have made significant strides in developing innovative biodegradable textiles and exploring their potential applications across various sectors. These advancements align with global efforts to reduce the environmental footprint of textile production and consumption [36].

Biodegradability depends on the structure and composition of the material. The relationship between the chemical composition and biodegradability is difficult to predict. Nevertheless, some general relations were described, like the influence of the physical state and surface conditions, which have an effect on the accessibility of extracellular enzymes. The process can be effected by the glass transition temperature, melting temperature, modulus of elasticity and crystallinity. The higher the melting temperature, the lower the rate of biodegradation. Enzymes degrade first the amorphous areas of the material. Thus, the higher the crystallinity, the lower the biodegradation rate. Other important factors that may affect biodegradation are environmental conditions, such as water and oxygen availability, temperature and microbial activity. The process can be carried out in sewage, soil, compost and marine environments. The choice of test conditions should result from the way of utilization [37]. An example of the biodegradation process of bio-textiles is shown in **Table 2**. SEM images and results from the analysis of sample weight loss during the process are presented, as well as the weight-average molar mass values of the biopolymers. In the SEM images, damage to the structure was already observed after 1 week, and after 16 weeks there is no fibrous structure. The weight-average molar mass (M_w) value after the 4th week of biodegradation was only 4,800g/mol. Relative to the M_w value of the starting sample, the change was 92%.

Several international organizations and standardisation bodies have produced guidelines and criteria for evaluating and quantifying biodegradability. These standards help ensure consistency and accuracy in assessing the environmental impact of products and materials. Due to the fact that nonwovens and textiles are used in many industries (fashion, agriculture, packaging, etc.), many standards can be used to assess their degradation. **Table 3** shows selected

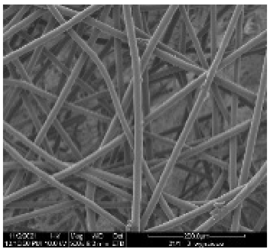
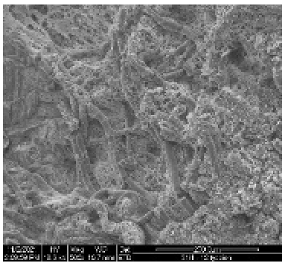
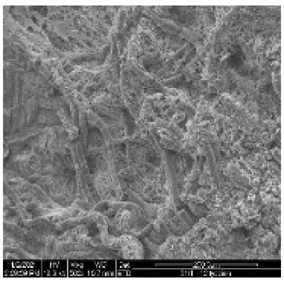
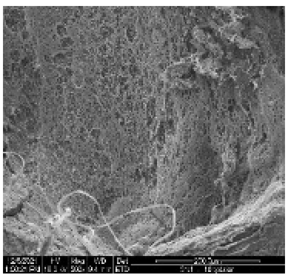
Time of biodegradation [weeks]	melt-blown bio-nonwoven		
	mag. 500×	mass reduction [%]	M_w [g/mol]
0		-	63 600
1		1.0	46 300
4		14.5	4 800
8		24.0	1 900
12		41.0	1 700
16		70.7	1 200

Table 2. Biodegradation of melt blown melt-blown bio-nonwovens

Standard	Title	Environment	Ref.
OECD 301 B	CO2 Evolution (Modified Sturm Test)	aqueous medium	38
ISO 9439	Water quality — Evaluation of ultimate aerobic biodegradability of organic compounds in aqueous medium — Carbon dioxide evolution test	aqueous medium	39
ISO 14852	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium — Method by analysis of evolved carbon dioxide	Activated sludge	40
ISO 14851	Determination of the ultimate aerobic biodegradability of plastic materials in an aqueous medium — Method by measuring the oxygen demand in a closed respirometer	aqueous medium	41
ADTM D5338	Standard test method for determining aerobic biodegradation of plastic materials under controlled composting conditions, incorporating thermophilic temperatures	compost	42
ISO 14855	Determination of the ultimate aerobic biodegradability of plastic materials under controlled composting conditions — Method by analysis of evolved carbon dioxide — Part 2: Gravimetric measurement of carbon dioxide evolved in a laboratory-scale test	compost	43
EN 14046	Evaluation of the ultimate aerobic biodegradability and disintegration of packaging materials under controlled composting conditions - Method by analysis of released carbon dioxide	compost	44
EN 13432	Packaging. Requirements for packaging recoverable through composting and biodegradation. Test scheme and evaluation criteria for the final acceptance of packaging	compost	45
ASTM D6400	Standard specification for labelling of plastics designed to be aerobically composted in municipal or industrial facilities	compost	46
ISO 17556	Plastics — Determination of the ultimate aerobic biodegradability of plastic materials in soil by measuring the oxygen demand in a respirometer or the amount of carbon dioxide evolved	soil	47
DIN EN ISO 11721-1	Textiles — Determination of resistance of cellulose-containing textiles to micro-organisms — Soil burial test — Part 1: Assessment of rot-retardant finishing	Soil	48
DIN EN ISO 846	Plastics — Evaluation of the action of microorganisms	fungi and bacteria and soil microorganisms	49
ISO 21701	Textiles —Test method for accelerated hydrolysis of textile materials and biodegradation under controlled composting conditions of the resulting hydrolysate	compost	50
ISO 17088	Specifications for compostable plastics	compost	51

Table 3. International standards and guidelines for testing biodegradability

methods which are the most commonly used in these tests.

4.3. Recycling of nonwovens

The current state of textile recycling worldwide is marked by both progress and challenges. Textile recycling has gained increased attention in recent years due to growing environmental concerns and sustainability efforts. Globally, approximately 75% of textile waste is disposed of in landfills, 25% is reused or recycled, and less than 1% of all textiles is recycled back into clothing [52].

Increased interest in textile recycling comes from a growing awareness of the environmental impact of the fashion industry and the need for sustainable practices. Simultaneously, the global trend for fast fashion can be observed and contributes to the problem by producing low-quality, disposable clothing, which creates a substantial waste stream. Addressing this issue is a major challenge. Additionally, the global nature of the textile industry complicates recycling efforts due to supply chain complexities and logistics challenges. Nowadays, a shift towards a circular economy model, where textiles are reused, remanufactured, or recycled, is gaining momentum. This promotes sustainability and reduces the reliance on virgin materials. Innovations in textile recycling technologies, such as chemical recycling and mechanical recycling, are on the rise, making it easier to reprocess textiles into new products. Encouraging consumers to buy sustainable, long-lasting clothing and to recycle their old garments remains a significant challenge [53,54].

Textile recycling is typically classified as mechanical or chemical recycling. The first one leads to the transformation of waste into products that can be used as decorations or materials to be used in construction, agriculture, and gardening. Chemical recycling is a process in which polymers are depolymerized or dissolved. In the process fibres of equal quality compared to virgin materials can be obtained [55].

The state of textile recycling is globally evolving with growing awareness and technological advancements. While

	2005	2010	2015	2020	2021
Sold production of the textile industry (in millions of PLN)	7680	8161	12440	16188	18564
Financial result of industrial enterprises by ownership (in millions of PLN)	147.7	348.6	597.8	835.5	927.2
Employed persons (in thousands)	-	53.2	53.8	54.9	56.0
Average paid employment indices in the industry (previous year = 100)	-	-	105.2	95.3	102.7
Labour productivity in the industry, measured by the gross value added per paid employee (in thousands)	-	-	86.9	106.7	115.9
Average monthly gross wages and salaries in the industry by ownership (in PLN)	1585	2180	2709	3875	4276
Average monthly gross wages and salaries indices in the industry (previous year = 100)	-	-	104.6	107.0	110.4
Investment outlay indices in the industry	-	-	106.8	70.2	103.4
Industry exports (in millions of PLN)	-	6115.3	9456.2	14027.1	16358.1

Table 4. Dynamics of changes in the textile industry in Poland – basic data
Sources: author's own compilation based on data of Statistics Poland

challenges persist, there is a concerted effort to make the fashion industry more sustainable. Poland, like other European countries, is working on improving its textile recycling infrastructure, but progress is influenced by factors such as consumer behaviour, infrastructure, and technology adoption.

5. Innovative capacity of the textile industry in the Łódź region to build smart specialisation

5.1. Textile industry transformation in the Łódź region

Poland is one of the leaders in textile production in the countries of Central and Eastern Europe. Following a period of deep transformation, the last decade has witnessed economic stabilisation and technological progress in the industry. Automation, computerisation and modern production technologies have significantly contributed to the development of the industry in Poland. According to Statistics Poland, enterprises that introduced product innovations or innovative business processes in the textile industry between 2019 and 2021 accounted for 19.7%. The positive transformations taking place in this industry are also confirmed by the growing number of people employed in R&D-related jobs, from 171 in 2020 to 226 in 2021. Also, the increase in exports of the textile industry and labour productivity in the industry, measured by the gross value added, indicate an improvement in the economic standing and competitive position (Table 4).

Located in the centre of Poland, the Łódź region, whose economy was dominated by textiles for almost two centuries, is the leader in textile manufacturing in Poland. The region's capital, Łódź, is seen as Poland's most representative industrial city from the 19th century. The long-lasting economic monoculture in the city collapsed with the launch of the systemic transformation and the shift to a free market economy in the early 1990s [56]. There was a spontaneous and deep decline of the textile industry, which led to the degradation of the entire city and region and the impoverishment of its residents. Large state-owned industrial plants failed to successfully face the conditions of the market economy and cope with the strong competition of, on the one hand, high-quality products coming from Western European countries, and, on the other hand, low-quality products originating from Asia [57]. For example, in the early 1990s, the unemployment rate in Łódź exceeded 25% and the volume of textile production in the Łódź region fell by as much as 40% in only three years (between 1988 and 1991 [58].

Despite the decline and deep economic transformation of Łódź and the region, the textile heritage is still visible in the economy of the city and the region. However, its structure and character have changed. Large economic entities - really colossal, employing several thousand people at the peak of their development - were transformed into small and medium-sized (often family-owned) companies utilising the potential of knowledge, experience and skills accumulated in previous decades. Employees of state-owned factories started a bottom-up and spontaneous process of creating their own micro-enterprises, thus making use of available and qualified human resources, as well as production machinery and equipment sold off from bankrupt industrial plants [59]. The 1990s saw an explosion of entrepreneurship and an emergence of small and medium-sized enterprises in the textile industry [60].

The structure of the textile sector in Łódź and the region is still strongly dominated by micro enterprises, subject to strong fluctuation and market correction. After two decades of shrinkage in the number of entities and employment, the last decade has seen a consolidation of the economic structure (**Fig.7**). Since 2010, the industry structure has remained relatively stable, indicating the end of a deep transformation process and the entry into the phase of stabilisation. In 2022, there were more than 1,700 enterprises

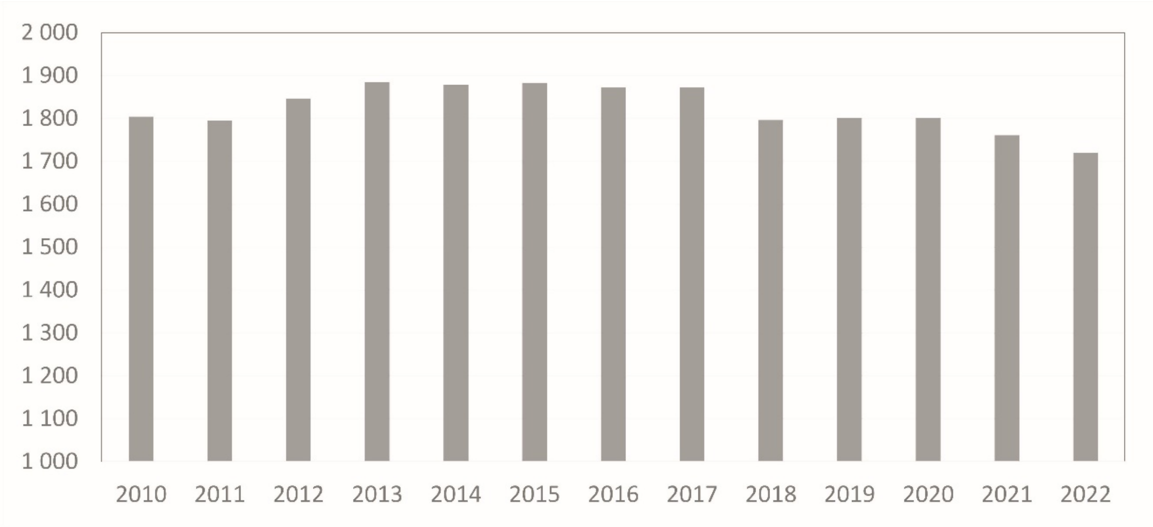


Fig. 7. Businesses in the textile industry in the Łódź voivodeship [61]

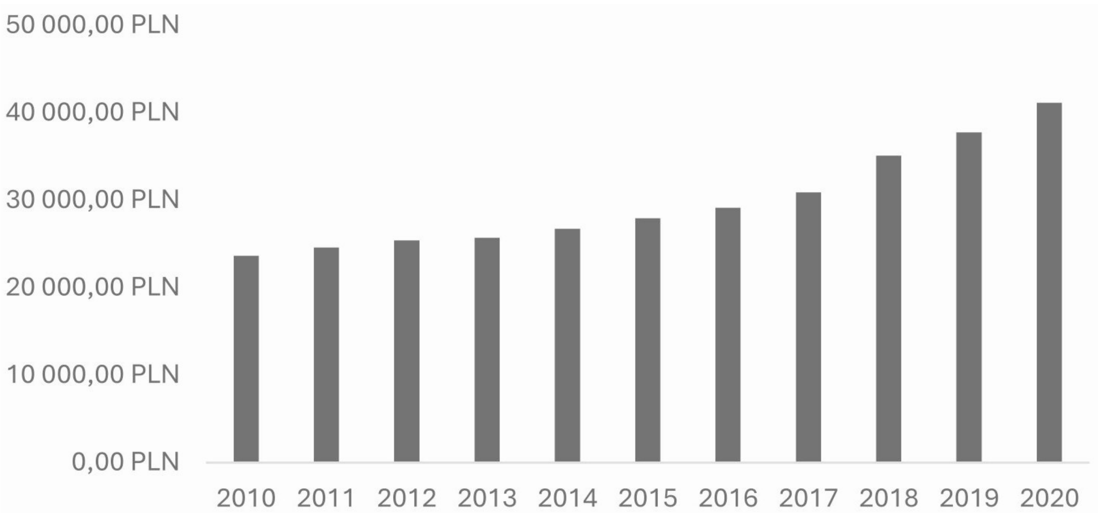


Fig. 8. Average annual salaries (in PLN) in the textile industry (Source: own compilation based on BDL data)

in the Łódź region, 91% of which were micro and small enterprises [61]. At that time, the textile industry in the Łódź region was characterised by the highest sales growth among other industries (compared to 2021) [62].

The textile sector accounts for about ¼ of all jobs in manufacturing in Łódź alone and about 16% of jobs in the Łódź region [63]. At present, in the textile industry the demand for labour exceeds supply, which is why salaries are growing (**Fig. 8**), suggesting a boom in this sector. Developments in the labour market result from two phenomena: firstly, the economic recovery in the textile industry, and secondly the loss of old staff and the lack of generational replacement. The unfavourable image of the textile industry in Łódź, associated with an outdated and decapitalised economic sector, results in a decline in interest among young people in getting vocational, technical secondary, and higher education that would cater for the needs of this industry. This is one of the key barriers to the development of the sector in the region.

The economy of Łódź and the Łódź region continues to be marked by a strong concentration of textile industry. This is confirmed by the LQ specialisation indices for the Łódź region (**Fig. 9**). The index, calculated on the basis of employment in recent years, oscillates around 3.6, while that calculated on the basis of the number of businesses is 3.2. Assuming that a value higher than 1.5 suggests a high concentration of economic entities and strong specialisation, in the Łódź region we are still presented with an exceptionally strong and rare concentration of this industry in the region's economy. Despite the fact that in Poland LQ indices are slightly increasing, while in the Łódzkie Voivodship they are slightly decreasing [63], Łódź and the Łódź region undoubtedly still have a textile image. What is more, the employment rate at a stable level, with a decreasing concentration of economic entities, testifies to the development of enterprises in this sector.

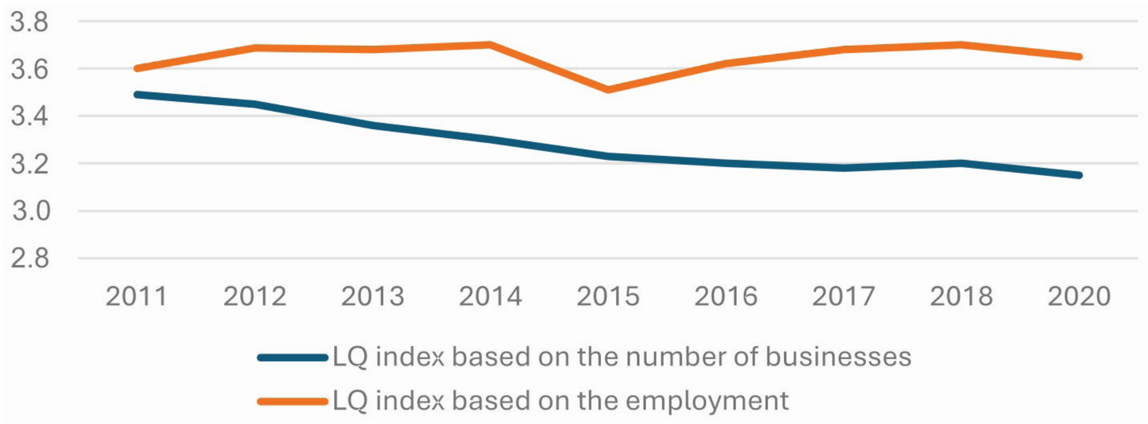


Fig. 9. Textile industry concentration in the Łódź region between 2011 and 2020 (Source: own compilation based on data from Statistics Poland)

The textile industry in the region is based on direct contacts and spatial proximity, creating dense and sustainable cooperation networks. This results in the emergence of numerous formal and informal clusters and other forms of coopetition in Łódź that foster the creation of improved and new products. Among others, the Textile Innovation Cluster and the Cluster of Advanced Technologies for the Textile and Clothing Industry operate here.

The textile industry is a component of territorial capital firmly rooted in the Łódź region. Its transformation was based on endogenous mechanisms, mobilisation and entrepreneurship of the local community. The industry did not receive any external support and its transformation demonstrates the strength of the local, textile economy. The region's industrial heritage and traditions still create favourable conditions for the development of this economic activity. The economic environment is also conducive to this - concentration of research and development activity, academic facilities and the development of related industries (e.g., the clothing industry, fashion industry, medical industry).

5.2. Innovation in the textile industry in the Łódź region

The fundamental importance of the textile industry for the development of the Łódź region is demonstrated by the voivodeship's development plans - Strategy for the Development of the Łódź Voivodeship, Development Strategy for the Łódź Metropolitan Area 2020+ and Regional Innovation Strategy for the Łódź Voivodeship. The textile industry, which is linked to the clothing and fashion industry, is seen these as one of the strategic industries with a high innovative potential.

Over the last decade, the textile industry has been the area of growing technological and innovation potential in the economic structure of the region. This is well illustrated by the dynamics of innovation outlays reported by enterprises from the Łódź Voivodeship. Between 2009 and 2015 only these outlays increased by a factor of six. One in four businesses in the textile industry declares that they are undertaking innovative activities [63]. Textile exports are also recovering, which confirms the growing competitiveness of Łódź textile products [64]. The internationalisation of Łódź enterprises in the field of production (outsourcing, sales or purchase of modern machinery and equipment) is progressing successively. It is increasingly ceasing to be simple cost competition based on low wages, and is becoming competition based on high quality production resulting from the use of modern technologies. This production is strengthened by the favourable location of the region and the many years of experience of Łódź entrepreneurs and employees in the industry. This is confirmed by the receipt of a number of certificates and recognition in the textile community. One example is the international OEKO-TEX® certificate. This is the world's leading safety mark for textile products. Products awarded with this mark are free of harmful substances in concentrations that affect human health.

Current trends in the development of the textile sector in the Łódź region are the result of growing economic links with high-tech players. Particularly high potential exists in the areas of: biotechnology, nanotechnology, functional materials, communication and information technologies and mechatronics. The transformation of the textile industry primarily involves innovative solutions in:

1. Providing natural and synthetic materials for the textile industry through:
   - ✓ the production of biodegradable environmentally-friendly fibres/textiles [21],
   - ✓ the production of textiles for special applications [65],
   - ✓ the production of environmentally friendly textiles for agriculture[66];
   - ✓ the modification and functionalisation of textile products using biotechnological methods [22; 67].
   - ✓ the modification of the surface layer of textiles towards giving it sensory properties (smart textiles) [68],
   - ✓ methods for producing smart textiles [69],
   - ✓ the production of textile materials intended for elements of special clothing protecting against physical

factors, such as electromagnetic fields, electrostatic fields, high and low temperatures, flame, etc., [70].

2. Products and technologies in the area of technical textile products, i.e.:
- ✓ materials for medicine (hygiene and dressing materials) [65; 71],
- ✓ implant materials used in biomedical area [21; 65],
- ✓ functional textile materials used in animal husbandry and plant breeding [66]
- ✓ products for air purification and filtration [72,73],
- ✓ insulation materials for the construction industry and structural composites,
- ✓ textile products with conductor properties [74],
- ✓ multifunctional textile products for the automotive industry and transport applications [75].

3. Textronic technologies and materials:
- ✓ applicable to wireless data transmission [76],
- ✓ methods of manufacturing optoelectronic and photonic materials, e.g., for monitoring vital functions [77],

4. Personalisation of textile products, i.e.:
- ✓ manufacturing 3D textiles with therapeutic properties applicable to medical products [65],
- ✓ manufacturing methods for smart clothing [78].

The power of the Łódź textile industry lies not only in the tradition and its being deeply rooted in the region but also in the economic potential surrounding this sector, which helps in building innovation capacity. In Łódź there are many R&D centres carrying out intensive innovation activities at the border of the textile industry and other sectors and technologies. These are:
- Łukasiewicz Research Network-Lodz Institute of Technology,
- Faculty of Material Technologies and Textile Design of the Lodz University of Technology,
- Centre of Molecular and Macromolecular Studies of the Polish Academy of Sciences,
- Institute of Organic Chemistry of the Lodz University of Technology,
- Institute of Polymer and Dye Technology of the Lodz University of Technology,
- Department of Molecular Physics, Faculty of Chemistry of the Lodz University of Technology,
- Institute of Applied Radiation Chemistry of the Lodz University of Technology,
- Faculty of Civil Engineering, Architecture and Environmental Engineering of the Lodz University of Technology,
- Faculty of Physics and Applied Informatics of the University of Lodz,
- Institute of Medical Biology of the Polish Academy of Sciences in Łódź,
- Faculty of Mechanical Engineering of the Lodz University of Technology,
- Nofer Institute of Occupational Medicine in Łódź,
- Faculty of Textile Art And Fashion Design of the Strzemiński Academy of Fine Arts,
- Institute of Security Technologies Moratex.

The growing development potential of the textile sector in the Łódzkie Voivodeship is also the effect of cooperation capabilities present within the industry and the business and science cooperation at the local level (64). The existing cooperation networks focus their attention on developing technologically advanced products. The leading role is played by medium-sized enterprises, such as Ariadna S.A., Fabryka Nici BORUTA SOFT Sp. z o.o., Tricomed S.A., Szarpol, PTAK S.A., Yaro Tex Optex S.A., Telimena Sp. z o.o., Syntex Sp. z o.o, Textil, Fibeco Sp. Z o.o., Szarpol Production and Trade Centre, YAVO Sp. z o.o., FERAX GROUP: Gatta, Zenit, Wola, CORIN, ZWOLTEX SPÓŁKA Z O.O., WELTOM, or Arlen Group), which offer high quality textile products and are internationally renowned.

An important backup for the development of the textile industry in Łódź comes from higher education. The strong concentration of qualified personnel, unique technical knowledge and skills, and specialised competences passed on inter-generationally is reinforced by the extensive educational expertise at the tertiary level. There are a number of higher education faculties oriented towards the demands of the textile industry, including industrial design, design, materials engineering, and textile science.

In popular opinion, the textile industry is perceived in the Łódź region as a traditional industry and an unwanted economic legacy, with little chance of development in the era of a global and highly competitive economy. Meanwhile, the transformations taking place in the last decade show that the region's territorial and technological advantages are triggering mechanisms for creating an innovative economy. A prerequisite for the development of this industry is a well-programmed, place-based regional policy that takes into account the specificity of Łódź resources and development mechanisms.

6. Conclusion

After 1990, the textile industry in Łódź experienced significant changes and challenges. The country's accession to the European Union in 2004 opened up new opportunities for Łódź textile manufacturers to access larger markets and benefit from EU subsidies. Many companies invested in new technologies to improve productivity and product quality. Some have also changed their business strategies to focus on higher-value products, such as technical textiles or clothing made from sustainable materials. One noticeable trend in the Łódź textile industry is the development of small and medium-sized enterprises that compete effectively by specialising in niche markets and offering customised products and services.

The textile industry continues to be an important part of the region's economy, providing jobs and generating income. This territorial capital accumulated over centuries (e.g. traditions, knowledge, experience, higher education, research and development units, network relations, related industries) is gradually transforming the traditional textile industry into a modern, high-tech-based economic sector. This is creating a specialised economic system in the region, strongly linked by relationships and interdependencies, capable of competing internationally. The strength and complementarity of the pooled resources trigger economies of scale and synergy mechanisms. In the Łódź region, the textile industry forms an area of smart regional specialisation, and the changes that have taken place in recent decades are leading to the strengthening of innovation capacity. The sector is becoming a locomotive for growth in the region and a pillar for building a competitive edge internationally.

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