Mapping the Technological Advantages for Circular Economy in the textile and leather sector: Italy vs Rest of the World

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Abstract

This paper aims to analyze the technological and productive specialization of Italian textile and leather industry in the Circular Economy context through the use of patent data. Analyzing USPTO patent data, we try first to identify how the capabilities relavant in these areas are distributed across nations. Then, we try to explore the Italian companies patenting in these technological areas. Our results show that Italy still lags behind other European and non-European countries in terms of technological capabilities for Circular Economy for the areas specific to textile and leather sector. Also, we found that the limited number of patents of Italian companies registered in these fields are located in upstream and raw materials manufacturing industries. The results allow to identify some of the national priorities to foster the competititveness of the pillars of the Made in Italy industries.

Keywords: technological advantages; country competitive advantage; patents; circular economy; textile and leather industry

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1. Introduction: The knowledge-based of traditional industries

Italy maintains a long-term competitive advantage in the textiles and leather manufacturing, as evidenced by the sector's contribution to national exports, which accounts for approximately 10% of the total[1], contributing to the positive trade balance for 23,457 billion € (Italian Trade Agency, 2023). If we look at the technologies associated to those industries, they have a moderate technological and innovation rate compared to other areas, such as "IT methods for management," "digital communication," and "computer technology" (WIPO, 2022). Nevertheless, a country can achieve satisfactory export performance even without significant innovations in cutting-edge technologies (Tylecote, Cho, Zhang, Tylccole, & Zhang, 1998). In the case of Italy, this is partily associated to the strong technological innovation performance in upstream sectors of textiles and leather, particularly in textile machinery (Antonietti, Ferrante, & Leoncini, 2014; Bianchi, Giardino, Labory, Rinaldi, & Solinas, 2021).

However, the stationarity of the sector has been altered by an important fact. In the past years, the textile and leather sector has been pointed as being on of the most polluting one in terms of resource consumption and waste production (Kocabas, Yukseler, Dilek, & Yetis, 2009). To give a few numbers, the clothing and textile industry is responsible for up to 10% of global CO2 emissions (McKinsey, 2020) and approximately 20% of water pollution (European Parliament, 2019). Manufacturing a single cotton t-shirt requires around 2,700 liters of water, sufficient to meet one person's drinking needs for 2.5 years (European Parliament, 2020). Therefore, this unfavourable aspect of the textile and leather industry is facing the current scenario of ecological transition promoted by governments to transform business and society in compliance with environmental sustainability criteria (European Commission, 2019; United Nations, 2015), according to which all industrial sectors are being called upon to adopt more sustainable practices (Ardito & Dangelico, 2018; de Jesus & Mendonça, 2018; Ehrenfeld & Kropfhäußer, 2017). As being one of the most polluting ones, the textile industry urges to become more sustainable (Huq & Stevenson, 2020).

One effective action to transition the textile and leather sector towards a more sustainable production is the adoption of Circular Economy (CE) practices (Colombo et al., 2022; Reike, Hekkert, & Negro, 2023). The CE defines an economy in which waste generated by production and consumption processes becomes input, thereby creating a closed loop that mimics natural systems (Ellen MacArthur Foundation, 2013). The CE is based on three principles (or 3 Rs): 1) eliminating

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[1] According to the ATECO classification which aggregates ATECO 13, ATECO 14 and ATECO 15.

waste and pollution, 2) keeping products and materials in use, and 3) regenerating natural systems (Ghisellini, Cialani, & Ulgiati, 2016). Thus, the CE offers a solution that balances ambitions for economic growth and environmental protection by neutralizing waste in the production and sale of goods (Ghisellini et al., 2016). However, similar to other industries (Bakhtin, Khabirova, Kuzminov, & Thurner, 2020; Zhang, Wang, Song, & Shen, 2023), adopting such models and transforming the typical production processes in the textile and leather manufacturing sectors will require specific technologies for the CE. For example, the recycling of fabrics (mechanical recycling, thermomechanical recycling, thermochemical recycling, chemical recycling, or hydrothermal recycling) necessitates specialized technologies (Ribul et al., 2021), as well as the production of textiles from the bio-mass or food waste (Piribauer & Bartl, 2019).

These aspects have important implications for the textile and leather industry. In fact, the core assets that have for long underpinned Italian companies' competitive advantage in textile and leather manufacturing could become obsolete, while favoring companies that excel in recycling fabrics rather than producing new, high-quality ones—a key strength of the Italian textile industry (Carcano & Lojacono, 2019; Fortis, 2005). In fact, competitive advantages of countries are not eternal (Porter, 1990), and while past performance in textile and leather has been favorable, the ecological transition might pose new challenges.

In this context, it appears crucial to understand which countries hold patents related to these technologies in the textile and leather industries, and consequently assessing Italy's position in this regard. In fact, patents are a primary indicator of a country's technological innovation efforts and performance (Archibugi & Pianta, 1996; Gambardella & Torrisi, 1998). However, the international patent classifications system does not distinguish CE related patents, except that for the CPC classification which includes "climate change mitigation technologies related to wastewater treatment or waste management" (World Intellectual Property Organization) and for the WIPO "IPC Green Inventory" (World Intellectual Property Organization), developed by the IPC Committee of Experts to "facilitates searches for patent information relating to Environmentally Sound Technologies (ESTs), as listed by the United Nations Framework Convention on Climate Change (UNFCCC)". These classifications however, although have been used by previos studies on environmental innovation (Albino, Ardito, Dangelico, & Messeni Petruzzelli, 2014; Hötte & Jee, 2022; Işık, 2024; Radu & Francoeur, 2017; Yamashita & Fujii, 2022), include the patent classes concerning technologies for mitigation or adaptation against climate change in a broad sense, including for instance waste management and energy consumption, missing from considering the specificities of each sector in terms of environmental impact and sustainable practices, as also underscored by previous literature (Portillo-Tarragona, Scarpellini, & Marín-Vinuesa, 2024). An attempt to identify other patent classes concerning the CE has been carried by Portillo-Tarragona et al., (2024), although with limited details about how they achieved the goal and applied to all the manufacturing sectors.

Therefore, this study has two primary objectives: first, to identify the patent classes related to CE technologies for textiles and leather; second, to explore the innovation capabilities in CE technologies within the Italian textile and leather sector, alongside a comparative analysis with other countries. Our analysis identified 80 patent classes related to CE technologies for the textile and leather industry, categorized into four main technological areas: Additive Manufacturing with leather waste, Chemical Treatment for textile and leather products, Bio-based Textiles, and Artificial Intelligence for Automatic Sorting. While it is well-known that the overall generation of innovations is in Italy lower than its economic partners, what is the innovative activity of the nations in the typical Made in Italy industries? The patent analysis revealed that Italy has a weak position in terms of the technological base for the CE also in the textile and leather industries, while the dominant countries in this field are the USA, Japan, Germany, and South Korea. Moreover, the majority of technological innovations relevant to the CE in the textile and leather sectors originate from Italian companies active in other industries.

We contribute to the competitive advantage literature by providing a case study in which a national industry possesses a relative competitive advantage with respect to its competitors despite not possessing a technological leadership, a conclusion which is in line with Porter's (1985) theoretical framework but that highlight the potential risks for these Italian industries. Failing to embrace this significant transformation could be detrimental to the future competitiveness of Made in Italy industries. Additionally, this study aims to determine whether Italy can preserve and enhance its current position in the textile and leather sectors or if technological advancements will revolutionize the industry, potentially rendering traditional Italian production methods obsolete.

2. Theoretical background

2.1 Countries' competitive advantage

Since the publication of Porter's (1990) seminal work, the determinants of national economic competitiveness within industries have catalysed the emergence of a new domain, gathering the attention of scholars from several different fields such as strategy, innovation studies, and economic geography (Hanafi, Wibisono, Mangkusubroto, Siallagan, & Badriyah, 2017). This strand of literature historically argues that the interactions and interrelationships between local actors at the micro level and the macro-structural conditions that shape the broader economic environment give rise to distinctive and unique national innovation systems (NSI), influencing the strategic choices of firms and industries in general (Lundvall, 2010). Typically, even when internationalized, a firm evolves within its domestic innovation systems, rendering the national economic environment pivotal in defining its identity, the calibre of its leadership, its strategic and organisational methodologies, and in consistently impacting the accessibility and quality of resources available (Grant, 1991). Based on these premises, Porter articulated his ideas within the so-called single-diamond model, which delineates the endogenous and exogenous factors.

In this setting national geography and demography determine the extent of factor endowment, encompassing not merely basic factors such as raw materials and unskilled labour, but crucially, advanced factors like research facilities, specialised skills, and infrastructures (Chang Moon, Rugman, & Verbeke, 1998). In addition, internal demand, particularly if sophisticated and readily accessible, serves as a potent incentive for local firms to enhance product quality and pursue continuous development and innovation (Kharub & Sharma, 2017). The success of a national domestic industry also heavily depends on the scale and competitiveness of related and supporting industries, which provide inputs, complementary competencies, and networks of alliances. Finally, the competitive structure of regional markets and the degree of rivalry among domestic firms significantly influence the extent to which firms are incentivised to innovate and maintain efficiency over time. Nowadays, the most successful industrial regions are the ones in which a large number of firms active in related sectors tend to cluster most (Balland & Rigby, 2017; Kemeny, Storper, Kemeny, & Storper, 2015; Warf & Storper, 1997). Within these territories, ongoing and concentrated interactions among local firms foster economic specialization, enhance learning processes, and facilitate the emergence of new skills that easily spill over (Frenken & Boschma, 2007; Momaya & Lalwani, 2017). Thus, to make NSIs competitive at the global level, it has always been considered crucial to possess highly-specialized clustered regions which works as the core of the national industry (Porter, 1990).

By the way, clusters' competitiveness indeed strongly depends also on regions' ability to attract, source, mix and adapt new, diverse and external knowledge to upgrade specialization profiles, sustain product innovation and help to prevent industrial and technological lock-ins generated by excessive insularity (Bathelt, 2007; Boschma & Iammarino, 2009; Visser, van Eck, & Waltman, 2021). In this context, both trade and FDIs play a major role in promoting connectivity. Exports can constitute not only an outcome of a successful innovative process but also a strong driver of it, providing greater incentives to innovate and adapt products to different needs (Grossman & Helpman, 1990). The integration of multinational enterprises (MNEs) into local economies via inward FDIs is argued to bolster the efficiency of domestic companies by enabling the transfer of new processes, skills and more sophisticated technologies (Iammarino & McCann, 2013). The establishment of overseas subsidiaries via outward FDIs permits parent companies to gain new capabilities, enhance operational efficiency, and create positive externalities in their home markets (Bathelt, Buchholz, & Cantwell, 2023).

2.1 The Italian textile industry

In the academic debate on the Italian traditional sectors, there is a widespread consensus on the idea that the predominance of industrial districts constituted by small and medium-sized enterprises is the key ingredient of success for the industry (Becattini, 1987; Dei Ottati, 2009). Prominent Italian textile centres such as Biella, Prato, Schio, and Valdagno, with their rich history of specialisation dating back to the 17th century, provide an ideal industrial atmosphere for cultivating specialised knowledge and sustaining a skilled labour force (Fontana, Panciera, & Riello, 2010). Leveraging cheap labour costs from the south, decentralization of production to firms within the districts, and favourable exchange rates, the Italian textile industry gained during the 1970s and the 1980s a substantial competitive advantage in exports with respect to all European competitors (Dunford, 2006; Dunford, Dunford, Barbu, & Liu, 2016), and such a growth has been driven particularly by medium-sized firms located in industrial districts (Baffigi & Signorini, 2000).

Nevertheless, the literature has also stressed the Italian-districts model's weaknesses. Unlike other clusters, such as the technological hub in California or the automotive sector in Germany, the Italian ones cannot rely on sophisticated internal demand sufficient to nourish the industrial production (Brusco, 1982). Consequently, the industry's reliance on exports exposes the Italian production to exogenous shocks which can seriously affect the country's economic performance (He, Chen, & Zhu, 2022). In addition, the small size of firms participating in the districts prevent them from investing in more complex activities such as marketing, financial management and research and development (Brusco, 1992), thus hindering their growth and integration into the global economy (Chiarvesio, Di Maria, & Micelli, 2006; Federico, 2007).

Globalization and the digital revolution, rather than aligning technological capabilities at global level, have intensified competition among NSIs (Archibugi & Michie, 1997), and many advanced economies manufacturing sectors have strongly suffered the import competition with China and other emerging economies (Autor, Dorn, Hanson, Pisano, & Shu, 2020; Autor, Dorn, & Hanson, 2013). More recently, the emergence of significant unexpected upheavals, ranging from the 2008 economic downturn and the worsening of US-China commercial ties to the COVID-19 pandemic and the Russian-Ukraine conflict, has swiftly altered the international geopolitical landscape, pushing towards technological competition and prioritizing technological sovereignty (Edler, Blind, Kroll, & Schubert, 2023; Schmidt, 2023; Wu, 2020).

The Italian textile and leather sectors has not been immune to such issues. Dunford et al., (2016), relying on a dataset on establishments and employment in Italian districts and trade data on the main European economies, showed how the rise of Asian clusters is eroding the Italian and Euro-Mediterranean value-chain leadership since the ‘90s. Emerging market manufacturers, leveraging on labour costs at much lower levels than their advanced economies’ competitors and, particularly after the adoption of the Euro, of a lower exchange rate, are able to perform better, particularly in terms of cost competition.

By combining the theoretical insights derived from the strands of literature discussed above and analyzing the recent empirical findings from studies on Italian districts, we consider the idea that Italy, despite possessing a relative competitive advantage in terms of exports, may not be a leader in the emerging technologies for the green transition. Technological followers, particularly if integrated into a proper web of coalitions for licensing the necessary technologies, still have the potential to obtain and maintain a competitive advantage (Porter, 1985), as long as they do not lose control over those impacting their core activities and market position. Thus, the scope of this study is to assess the Italian textile and leather industries in terms of technological innovation in the domains that are decisive for the green transition, not only to offer renewed evidence on the existence of competitive technological followers but also and furthermost to highlight another potential challenge for the Italian textile and leather industry, which may potentially become an existential threat in the medium-long term.

2.2 Circular Economy for Textile and Leather Industry

The CE is a production approach in which the waste generated by the production processes become the input for new production processes (Ghisellini et al., 2016). The CE was first conceptualized by an Ellen Mac Arthur Foundation report (2013), which defined the CE as “an industrial system that is restorative and regenerative by intention and design” where resources are kept in a loop of production and where the generation of waste is minimized (Centobelli, Cerchione, Chiaroni, Del Vecchio, & Urbinati, 2020), generating a closed loop that mimics the biological living systems. It builds on three pillars, or 3 R’s: “*Reduce”* the resources used in the production and the waste generated, *“Reuse”* the products extending their life cycle and preventing them from becoming waste too soon, and *“Recycle”* the waste and the products at their end of life for new production processes (D’Angelo, Cappa, & Peruffo, 2023; Ghisellini et al., 2016). This strong environmental footprint has made the CE one of the most effective solutions to achieve the environmental and sustainable goals (Murray, Skene, & Haynes, 2015), especially for those sectors which are considered among the most polluting ones, such as the textile and leather industry (Bressanelli, Perona, & Saccani, 2019; Kocabas et al., 2009). In fact, the textile and leather industry is pointed for the intensive use of resources, such as water and energy, and an intensive consumption of chemicals, for instance in dyeing, finishing, and tanning (Kocabas et al., 2009; Verma, Dash, & Bhunia, 2012). This results in environmentally harmful wastewaters that contain surfactants, dyes, pigments, resins, and many other agents heavily loaded with chemical oxygen demand (COD) that can be significantly harmful for the environment especially not adequatel disposed of (Ozturk et al., 2016).

But, in addition to the intensive resource consumption of the textile and leather production processes, this industry is also under the spotlight for the over consumption of the finished products generated amomng the consumers. To get an idea of the magnitude of the phenomenon, the global fiber production has increased from 112 million tons in 2021 to a record of 116 million tons in 2022 according to the Materials Market Report presented by Textile Exchange (2023). And this overproduction, accelerated by the emergence of the fast-fashion brands, results in a further increased textile waste; waste that is unlikely to come from recycled garments and that might face many challenges to be recycled for several reasons. First, the majority of garments such as jeans or jackets are made of several different items, such as buttons, zipper, or strass that can overcomplicate the recycle process (Colucci & Vecchi, 2024). Second, the artificial and synthetic materials are made of different mixed fibres which cannot easily recycled (Franco, 2017). In fact, the mixed fibers require chemical recycling processes, which are more expensive and requires less available and diffused technologies than the mechanical recycling process, be used for single fiber garments such as 100% cotton. Furthermore, it is currently still difficult to separate different fibers since modern technologies cannot precisely identify the material makeup of the many fibers that make up the fabric, and ultimately the majority of waste fabric are converted into things like rags or carpets. Third, recovering abandoned clothing and textiles is frequently more costly than finding alternative alternatives, such discarding them or shipping excess inventory and leftover pieces to underdeveloped nations (Colucci & Vecchi, 2024).

Given these premises, it is of utmost importance to understand what are the technological areas in which the CE can favour the ecological transition of the textile and leather sector. A relevant technological areas which could support the adoption of CE practices in the textile and leather industry concerns the transformation of leather waste in polymers used for the production through Additive Manufacturing (or 3D printing) (Sarkar et al., 2024; Sharma, Sudhakara, Singh, Sanjay, & Siengchin, 2023). The Additive Manufacturing is an Industry 4.0 technology that consists in the creation of a 3D object based on a computer-generated model and made of special polymers, printed in layers to result in a final 3D form (Rüßmann et al., 2015). In these respects, the utilization of leather waste as an input for a new production process perfectly aligns with the principles of the CE. A second technological area which might constitute a fertile ground for the application of CE principles in the textile and leather is related to the technologies for the chemical recycling of fibers, a process employed to recycle mixed fabrics that uses chemical processes to break down textile waste to a molecular level (Ribul et al., 2021). Although being very effective for textile recycle as it produces recycled fibers of the same quality as virgin fibers, it is a developing technology which has only been explored for some fibre types – namely, polyester, cellulose, and polycotton blends. Another relevant area of application is in the field of bio textiles, such as biopolymer like cellulose, starch, pectin, xantam gum, and many others derivatives that are generally derived from agro-waste industries and could be used to replace leather (Ghisellini & Ulgiati, 2020; Provin, Dutra, de Sousa e Silva Gouveia, & Cubas, 2021), and the bacterial cellulose, which is a microbial polysaccharide that thanks to its nano scale fabric structure could be an ecologically-friendly, renewable and organic raw material to be used in the textile industry (Sederavičiūtė, Bekampienė, & Domskienė, 2019). Last, another Industry 4.0 digital technologies has been found to have a significant impact on the diffusion of CE practices in the textile and leather industry, which is the use of Artificial Intelligence to sort waste, a fundamental yet time and labour intensive step of the recycling processes consisting in separating waste into different categories based on their properties (Andeobu, Wibowo, & Grandhi, 2022). In these respects, Artificial Intelligence-powered machines enable to automatize the process of sorting through the use of sensors and computer vision technologies, obtaining different types of waste into different categories in less time and less risk of human error.

The analysis above uncovers the importance of the technology to support the adoption of CE practices in the textile and leather industry. Therefore, it is of utmost importance to understand where are the sources of those technologies located. The remainder of the article is meant to solve the issue.

3. Data and Methods

For the purpose of this analysis, we used patent data to identify the state of the technology regarding CE practices in the textile and leather industry and to determine which countries own such technologies. Indeed, patents are a very powerful source of information on technological innovation production, as they not only provide geographical information about the applicants, inventor, coverage, but they can also be highly disaggregated into groups with additional level of details, thus offering detailed information into both the sector of production and the sector of use of innovations (Archibugi & Pianta, 1996).

To construct our dataset, we based on CE areas of interest in the textile and leather industry by previous literature to select the relevant patent classes for our analysis — those likely to include patents related to CE technologies for textile and leather production. We developed a dictionary for our keyword search from a dual source:

- The European Commission report (Huygens et al., 2023) which has provided us the different recycling technologies for textile and leather waste and the related keywords, and
- A focus group with two industry experts to identify the most relevant technological areas for CE technologies.

After identifying the keywords, we proceeded to query each of them in the EPO Espacenet database to retrieve patents containing the selected keyword/s in the title or abstract.
We then screened the results to determine the patent classes associated with each patent until reaching saturation, meaning when the patent classes became repetitive. In total, we identified 80 sub-classes out of approximately 250,000 sub-classes (the complete list of classes is provided in the Appendix 1). These 80 sub-classes will be defined throughout the remainder of the dissertation as "circular economy for textile and leather classes", and they are divided into four main macro areas:

- Additive Manufacturing with leather waste, which includes the technologies related to the production of leather-based polymers to be used in 3D printing and additive manufacturing processes (21 classes).
- Chemical Treatment for textile and leather products, which includes the technologies for chemical recycling of natural and synthetic fibres (19 classes).
- Bio-based Textile, which includes the technologies to produce manmade fibers, such as nylon and polyester, without fossil fuels (36 classes).
- Artificial Intelligence for Automatic Sorting, which includes the technologies based on Artificial Intelligence to optimize the process of sorting the post-industrial and pre-consumer waste and the post-consumer waste (4 classes).

It is important to point out that the current standard patent classification systems do not provide patent classes for CE specific technologies or for eco innovation. Therefore, the patent classes we selected for the analysis are not limited to CE technologies but might include also patents concerning CE-related technologies, among the others. We downloaded data on patent counts from the ORBIS Intellectual Property database, provided by Moody's analytics company Bureau van

Dijk (https://login.bvdinfo.com/R0/OrbisIntellectualProperty). This source, released in 2022, combines corporate information with global patent data. Allowing for detailed search based on both inventor and applicant nationality, as well as for specific patent classes, this is well-suited for our research. It should be noted that the ORBIS Intellectual Property database does not include patents assigned to private individuals, but only those which have as assignee a corporation. Patents granted to individuals have been steady declining and in the United States now account for less than 10% of the total (National Science Foundatin, 2018).

We then proceeded to download data for each of the four macro areas by including in our searches all patents granted by the United States Patent and Trademark Office (USPTO), from 2000 to 2023 in the Cooperative Patent Classification (CPC) classes identified for each area, therefore obtaining four different sub-datasets. We included only patents whose applicants were primarily located in the most relevant countries: Switzerland (CH), China (CN), Germany (DE), Spain (ES), France (FR), Great Britain (GB), Italy (IT), Japan (JP), Korea (KR), Netherlands (NL), Sweden (SE), Taiwan (TW), USA (US). Those 13 countries account for more than 90% of all patents granted worldwide and include the main economies competing in the textile and leather industry (source: WIPO). For any patent in our dataset, we get the following information:

- the publication number;
- the Cooperative Patent Classification (CPC) code;
- the grant date;
- the country of origin of the applicant.

The patent indicator we use considers patent granted by the United States Patent and Trademark Office (USPTO), the federal agency responsible for granting patents within the USA territory. The reasons for this choice are twofold. First, the USPTO is one of the largest patent offices in the world, processing a significant portion of global patent applications. As a result, it provides a substantial amount of data for analysis, making it a rich source for researchers and analysts. Second, the USPTO has well-established procedures for patent examination, which aim to ensure the quality and validity of granted patents. Despite the various attempts to harmonize intellectual property rights, the costs, time, and procedure to obtain a patent differ significantly in each nation. This implies that compare a patent granted in Germany with one granted in China is somehow improper. On the negative side, by using patent indicators from USPTO, we acknowledge the possibility that our results could be influenced by the “domestic effect” of US patents, meaning that patent data for USA could be inflated. The fact, however, that we have excluded patents granted to individuals, somehow reduce the domestic effect since private individuals are likely to register their innovations only in their country patent office.

4. Results

The analysis has been carried out at different levels. The first is at country level. To what extent the technologies which are crucial for the circular and sustainable Made in Italy are located in Italy or in other nations? What is the share of patents held by Italian companies in these areas? The second is at the company level. Which are the companies that hold these technologies? This will allow to identify the level of integration of these companies with the firms active in the Made in Italy industries.

To gain a better understanding of the growth rate of the patents in the selected classes, we present the distribution of all patents granted by USPTO since 2000 in Figure 1. The total number of patents is increasing, not only in the United States but also in most industrial countries. This is in part associated to an increased investment in R&D and innovation. But the other part is connected to the growing relevance of intellectual property rights (IPRs) in the contemporary economy, which induces companies to implement a wide-ranging IPRs strategies.

We can observe a more significant increase after 2009 followed by a slight decline after 2020, possibly associated to the backlog of applications delayed because of Covid19. For the purpose of the analysis, we distinguish three different periods, 2000-2007, 2008-2015, and 2016-2022. The growth rate of the period 2008-2015 compared to the previous one is equal to 42%, while the growth rate of the period 2016-2022 compared to the previous one is equal to 23%. Those results would constitute the baseline to interpret the results of the analysis for the patent classes selected for our analysis.

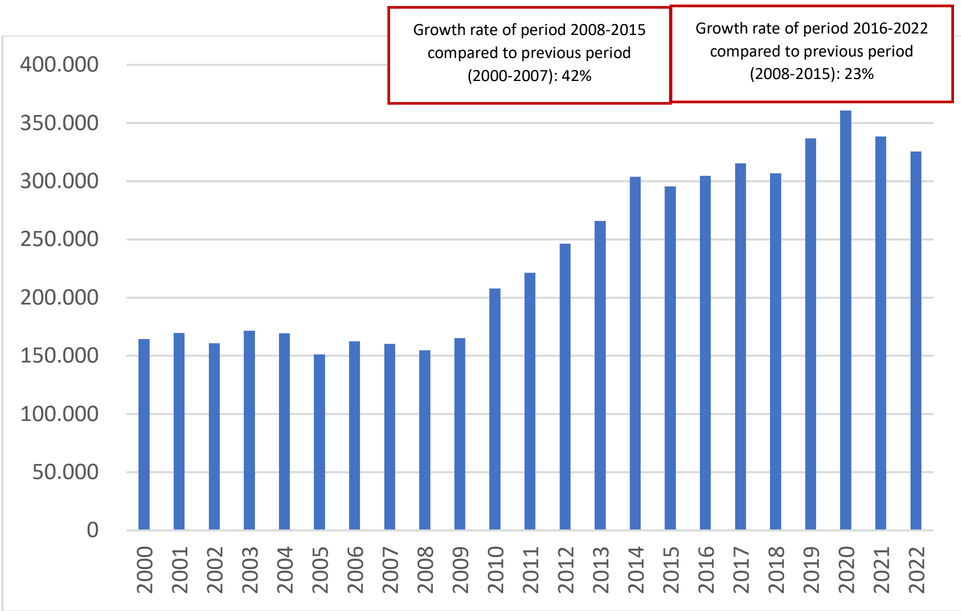

Figure 1: Total patents granted at USPTO (source: USPTO)

4.1 Results across countries in the selected classes

As first step of our analysis, we examined what happens at country level. Table 1 displays patent production in all 80 classes identified for the 13 countries considered across three different periods. We can observe a surge in China, with 4,633 and a growth rate of 262% in the period 2016-1023 compared to the period 2000-2007. Italy has 539 patents in these classes. Compared to other European country such as Germany, with 4,214 patents, France, with 1,024 patents, and Great Britain with 1,037, Italy still lags behind, even in the Made in Italy technological areas. Outside Europe, the USA is leading with 55,437 patents, while Japan and South Korea have 10,662 and 3,443 patents, respectively. In terms of growth rates, China has a spectacular one, followed by Taiwan and Korea, while European countries, with the notable exception of Sweden, have a negative one. Will the countries winning the race in the technologies related to the CE for textile and leather industries also dominate the overall production and trade?

Table 1: All the Circular Economy for Textile and Leather Patents

	Number of patents				**Growth rate (%) compared to previous period**	
Country	**2000-2007**	**2008-2015**	**2016-2023**	**Total**	**2008-2015**	**2016-2023**
Switzerland	502	1126	840	2468	124,3	-25,4
China	105	1280	4633	6018	1119,0	262,0
Germany	3,488	4,915	4,214	12,617	40,9	-14,3
Spain	42	175	99	316	316,7	-43,4
France	674	1,455	1,024	3,153	115,9	-29,6
Great Britain	484	1,067	1037	2,588	120,5	-2,8
Italy	385	687	539	1611	78,4	-21,5
Japan	6,559	9,151	10,662	26,372	39,5	16,5
Korea	636	2,256	3,443	6,335	254,7	52,6
Netherlands	538	1,152	967	2,657	114,1	-16,1
Sweden	142	270	324	736	90,1	20,0
Taiwan	339	1,153	1,649	3,141	240,1	43,0
United States	30,507	46,535	55,437	132,479	52,5	19,1
TOTAL 13 countries	**44,401**	**71,222**	**84,868**	**200,491**	**60,4**	**19,2**

Source: Orbis IP on the ground of USPTO

Country data were examined also for each of the four macro areas identified. Table 2 provides data on the patents related to the technologies for “Additive manufacturing with leather waste” for each of the 13 countries considered. We can observe that in the period 2016-2023, USA, Japan and Korea hold the top three positions for what concerns the patent production, with 3,151, 860, and 339 patents, respectively. For what concerns Italy, the patent production in the specific area of additive manufacturing with leather waste is similar to the results with the total CE for textile and leather classes, with a total of 44 patents, lagging behind other European countries such as France, Germany, Switzerland and Netherlands. For what concerns the growth rate, we can observe an overall negative trend for the period 2016-2023 compared to the period 2008-2015 except that for China, with a growth rate of 7,1 %, Korea, with a growth rate of 22,4%, and Taiwan, with a growth rate of 52,0%. China is assuming a central position for the control of the knowledge and technologies related to additive manufacturing with textile waste, although we are aware that the quantity of granted patents does not necessarily correlates with their value. It is also worth noting that European countries exhibit overall uniformity in terms of patenting activities in additive manufacturing with leather waste, with double-digit patent production for Italy, France, Great Britain, and the Netherlands. Germany obtained239 patents, being the third nation after the USA and Japan.

Table 2: Patents in Additive Manufacturing with Leather Waste

	Number of patents			**Growth rate (%) compared to previous period**	
Country	**2000-2007**	**2008-2015**	**2016-2023**	**2008-2015**	**2016-2023**
Switzerland	19	114	70	500,0	-38,6
China	5	99	106	1880,0	7,1
Germany	180	280	239	55,6	-14,6
Spain	2	2	0	0,0	-100,0
France	60	137	96	128,3	-29,9
Great Britain	13	37	33	184,6	-10,8
Italy	46	49	44	6,5	-10,2
Japan	495	872	860	76,2	-1,4
Korea	38	277	339	628,9	22,4
Netherlands	33	126	90	281,8	-28,6
Sweden	3	16	4	433,3	-75,0
Taiwan	18	50	76	177,8	52,0
United States	1,596	3,203	3,151	100,7	-1,6

TOTAL 13 countries	**2,508**	**5,262**	**5,108**	**109,8**	**-2,9**

Source: As for Table 1

Table 3 reports the results of the 13 countries patent production in the field of the CE related to "Chemical treatments for textile and leather products". The most active countries in those technologies are the US with 5,071 patents, followed by Japan with 581 patents, and Germany with 552 patents. The strong performance of Germany in this technological area reflects its the long-term expertise in chemical industry, as it is also the largest chemical producer in Europe (Statista, 2021). Italy, with 24 patents, falls behind Great Britain with 60 patents and Taiwan with 69 patents. In terms of growth rate, the overall negative trend (except for China) might result from the decreasing interest in investing in this medium-to-high technology sector.

Table 3: Patents in Technologies for Chemical Treatment for Textile and Leather

	Number of patents			**Growth rate (%) compared to previous period**	
Country	**2000-2007**	**2008-2015**	**2016-2023**	**2008-2015**	**2016-2023**
Switzerland	139	240	115	72,7	-52,1
China	31	177	358	471,0	102,3
Germany	1,142	1,157	552	1,3	-52,3
Spain	14	32	7	128,6	-78,1
France	170	254	110	49,4	-56,7
Great Britain	151	220	60	45,7	-72,7
Italy	38	70	24	84,2	-65,7
Japan	1,301	1,186	581	-8,8	-51,0
Korea	169	299	249	76,9	-16,7
Netherlands	27	108	13	300,0	-88,0
Sweden	32	46	21	43,8	-54,3
Taiwan	38	87	69	128,9	-20,7
United States	7,837	7,949	5,071	1,4	-36,2
TOTAL 13 countries	**11,089**	**11,825**	**7,230**	**6,6**	**-38,9**

Source: As for Table 1

Table 4 presents the results of patent production for 13 countries in the area of "Technologies for bio-based textile", which encompasses 36 classes, making it the broadest technological area among the four considered. Nevertheless, USA, Japan and Germany occupy the top three positions with 19,813 patents, 3,658 patents, and 2,149 patents, respectively. Italy still lags behind, with 360 patents and a performance worse than in the previous period, although it shows a better performance than Great Britain, which accounts for 325 patents. The negative growth rate observed in most of the countries considered might suggest that bio-based textile will not be a significant technological area in the near future, and that these countries are directing their technological innovation efforts and investments towards more promising areas.

Table 4: Patents in Technologies for Bio-based Textile

	Number of patents			**Growth rate (%) compared to previous period**	
Country	**2000-2007**	**2008-2015**	**2016-2023**	**2008-2015**	**2016-2023**
Switzerland	310	637	461	105,5	-27,6
China	44	572	709	1200,0	24,0
Germany	1,964	2,871	2,149	46,2	-25,1
Spain	21	106	62	404,8	-41,5
France	367	710	437	93,5	-38,5
Great Britain	218	554	325	154,1	-41,3
Italy	248	459	360	85,1	-21,6
Japan	3,408	4,470	3,658	31,2	-18,2
Korea	282	1,134	1,143	302,1	0,8
Netherlands	307	607	486	97,7	-19,9
Sweden	79	142	94	79,7	-33,8
Taiwan	186	558	581	200,0	4,1
United States	16,200	24,118	19,813	48,9	-17,8
TOTAL 13 countries	**23,634**	**36,938**	**30,278**	**56,3**	**-18,0**

Source: As for Table 1

Table 5 presents the results of patent production for the selected countries in the field of the "Technologies for Artificial Intelligence applications for automated sorting". Being one of the most cutting-edge technologies of our age with a broad variety of applications, it is one of the most dynamic and fast-growing areas in terms of patent production. This is evidenced by the overall significant growth rate of the countries analyzed, with most of them surpassing the three-digit percentage. In line with the previous areas, USA heads the list with a total of 27,402 patents granted in the period 2016-2023, followed by Japan with 5,563 patents, and China with 3,460 patents. Italy, with 111 patents, reports weak performance, lagging behind all the countries considered except Spain, which accounts for 30 patents. Even considering the growth rate, Italy does not perform as well as the other countries considered, with a growth rate of 1,8% in the period 2016-2023 compared to the previous one. On the other hands, the significant growth rate of China (700,9%), Korea (213,6%), USA (145,7%), and Great Britain (141,8%) hint the possibility of these nations acquiring a dominant role in controlling the technologies for artificial intelligence for the CE applications, which is also one of the most promising and dynamic area for future technological activities (Truant, Giordino, Borlatto, & Bhatia, 2024).

Table 5: Patents in Technologies for Artificial Intelligence for Automated Sorting

	Number of patents			**Growth Rate (%) compared to previous period**	
Country	**2000-2007**	**2008-2015**	**2016-2023**	**2008-2015**	**2016-2023**
Switzerland	34	135	194	297,1	43,7
China	25	432	3,460	1,628,0	700,9
Germany	202	607	1274	200,5	109,9
Spain	5	35	30	600,0	-14,3
France	77	354	381	359,7	7,6
Great Britain	102	256	619	151,0	141,8
Italy	53	109	111	105,7	1,8
Japan	1,355	2,623	5,563	93,6	112,1
Korea	147	546	1712	271,4	213,6
Netherlands	171	311	378	81,9	21,5
Sweden	28	66	205	135,7	210,6

Taiwan	97	458	923	372,2	101,5
United States	4,874	11,265	27,402	131,1	143,2
TOTAL 13 countries	**7,170**	**17,197**	**42,252**	**139,8**	**145,7**

Source: As for Table 1

Hence, we can summarize the aforementioned results as follows:

- The most relevant positions in terms of technological innovation for the CE in the textile and leather industry are held by USA, Japan, Korea, and Germany.
- China is very active in the areas concerning cutting-edge technologies such as Artificial Intelligence, while it is less active in areas with stronger and established competitors, such as the chemical sector.
- Italy lags far behind the most important countries. The growth rate in patents related to the CE in the textile and leather industry does not indicate any significant shift. It does not emerge that the Italian expertise in the leather and textile industries is really marching in the direction of a major transformation towards sustainability.

4.2 The performance of Italian companies in the selected classes

Are textile and leather companies active in the technologies related to the CE? As second step of the analysis, in order to gain a more detailed overview of the technological competences of the Italian companies, we investigated their patenting activity. Table 6 presents the patents granted to the top 20 Italian textile and leather companies (measured according to the number of employees), extracted from the AIDA Bureau van Dijk (https://aida.bvdinfo.com/). Two thirds of these companies do not have any patents granted between 2000 and 2023 in all the four areas considered. The total number of patents obtained by the top 20 companies in these industries is 110 only. Since the total patents granted by Italian companies in these areas are 1,611 (as reported in Table 1), the companies in the industries account for less than 7%. The innovative potential is obviously pursued by these Italian companies through external rather than internal sources. These external sources include the acquisition of machinery, equipment, technical assistance and others.

Table 6: Patents granted by the Italian textile and leather companies between 2000 and 2023

Company	Patents
SUEDWOLLE GROUP ITALIA SPA	0
ALCANTARA S.P.A.	74
ZEGNA BARUFFA LANE BORGOSESIA S.P.A.	0
LIMONTA S.P.A.	0
CANDIANI S.P.A.	3
COTONIFICIO ALBINI S.P.A.	0
OLIMPIAS GROUP S.R.L.	0
RATTI S.P.A. SOCIETA' BENEFIT O IN FORMA ABBREVIATA RATTI S.P.A. SB	0
SAATI S.P.A.	29
LANIFICIO ERMENEGILDO ZEGNA E FIGLI S.P.A.	0
VITALE BARBERIS CANONICO - S.P.A.	0
VULCAFLEX SPA	0
FULGAR S.P.A.	0
SUCCESSORI REDA - S.P.A. SOCIETA' BENEFIT	0
MANTERO SETA-S.P.A	0
LANIFICIO LUIGI COLOMBO - S.P.A.	0
PARA SPA	4
AVERY DENNISON RIS ITALIA S.R.L.	0
MARZOTTO WOOL MANUFACTURING S.R.L.	0
KLOPMAN INTERNATIONAL S.R.L.	0
TOT TOP 20 ITALIAN TEXTILE AND LEATHER COMPANIES	**110**
TOTAL ITALIAN PATENTS IN CE TECHNOLOGIES CLASSES	**1,611**

Source: Aida and Orbis IP.

To investigate who controls the larger portion of Italian patents in the CE related classes, it is worth analyzing the most prolific Italian companies in terms of patenting activity, and Table 7 reports the Top 20 companies sorted out by patents granted in the selected classes. The first four companies belong to upstream manufacturing sectors, such as plastic raw materials (BASELL POLIOLEFINE ITALIA S.R.L.), and basic chemicals (NOVAMONT S.P.A.). In addition, also manufacturers of equipment might hold relevant patent for the CE (STMICROELECTRONICS S.R.L.). Interestingly, this rank include also companies somehow related to the textile and leather industry, such as SANTONI S.P.A. and LONATI S.P.A., both in the manufacturing of machineries for textile and leather production, ALCANTARA S.P.A. which manufactures the unique alcantara material, and GOLDEN LADY COMPANY SPA, which manufactures yarns and hosiery. This result evidences that there are some companies from the textile industry or from related sectors which might own technologies related to the CE for textile and leather, but that they are not comprised among the major companies in the textile and leather sector as they do not compare in the list provided in Table 6, except that for Alcantara S.p.A, whose activity defined by the NACE sector is “manufacture in other textile” (source: AIDA). However, as previously mentioned, since the patent classes considered for this analysis do not include only the CE and eco innovation related patents, but they might contain also patents related to the CE for textile and leather application, we cannot infer that this company is actively involved in innovating in technologies for the CE for textile and leather.

Table 7: Top 20 Italian companies for patents granted between 2000 and 2023
in circular economy related technologies

Company	**Patents**	**NACE Sector**
BASELL POLIOLEFINE ITALIA S.R.L.	247	Manufacture of plastic raw material
NOVAMONT S.P.A.	86	Manufacture of basic chemicals
STMICROELECTRONICS S.R.L.	41	Manufacture of electronic components
SOLVAY SPECIALTY POLYMERS ITALY S.P.A.	37	Manufacture of paints
POLITECNICO DI MILANO	20	Scientific research
DATALOGIC IP TECH S.R.L.	14	R&D electronics
TELECOM ITALIA S.P.A.	13	Telecommunication
SANTONI S.P.A.	12	Manufacture of machinery for textile, apparel and leather production
VERSALIS S.P.A.	12	Manufacture of basic chemicals
MONDO SPA	12	Manufacture of other rubber products
ALCANTARA S.P.A.	11	Manufacture of non-wovens
MONTEFIBRE MAE TECHNOLOGIES S.R.L.	10	Other professional, scientific and technical activities
CONSIGLIO NAZIONALE DELLE RICERCHE	10	Scientific research
GOLDEN LADY COMPANY SPA	9	Manufacture of knitted and crocheted hosiery
ENI SPA	9	Extraction of crude petroleum

LONATI S.P.A.	9	Manufacture of machinery for textile, apparel and leather production
LAMBERTI S.P.A.	9	Manufacture of other chemical products
PRYSMIAN S.P.A.	9	Manufacture of telecommunication equipments
AGC BIOLOGICS SPA	9	Research and experimental development on natural sciences and engineering
ALMA MATER STUDIORUM - UNIVERSITA' DI BOLOGNA	9	Scientific research
TOTAL TOP 20 COMPANIES WITH PATENTS IN CIR.ECO.CLASSES	**588**	

Source: Aida and Orbis IP.

5. Discussion and Conclusions

In this study, we identify the technological areas for CE in textile and leather industrial activities and the related patent classes according to the CPC classification. Then, we map and analyze the countries' technological advancements in those areas by analyzing patent data. Our results carry out several contributions for research, managers and policy makers. First, our results provide scholars with a selection of the patent classes for CE technologies in the textile and leather industry, overcoming an important obstacle in the analysis of "green" technological and innovation activity in specific sector (Albino et al., 2014; Hötte & Jee, 2022; Işık, 2024; Radu & Francoeur, 2017; Yamashita & Fujii, 2022). Second, our country comparison shows the different nature of countries' technological activities, in line with the findings of extant literature (Pavitt & Patel, 1990; Vertova, 1998). Third, the analysis carried out in the present study indicates that, concerning technological competences, the desired transformation of the Italian economy towards the CE of the textile and leather industries has major weaknesses. We give for granted that these industries are at the core of the Made in Italy model, a model which in terms of competitiveness has been rather successful for several decades. But no nation can give for granted that it will preserve its competitiveness. If there is a reasonable expectation that textiles and leather production will move towards being more sustainable, it is reasonable to explore what is the technological potential behind their success and if the companies in the textile and leather sectors are well equipped to innovate successfully into the new circular and green paradigm.

- The top Italian companies in these industries have a low internal innovative potential, as measured by patents and look like to be supplier-dominated. As long as there is a strong interaction, almost symbiosis, between downstream users and upstream suppliers (or according to the Pavitt taxonomy (1984), between supplier dominated and specialized suppliers firms), this weakness could be bypassed. But if the linkages between these firms would become weaker, for example because some of the specialized suppliers would be acquired by foreign corporations, Italian companies in the textile and leather industries will be in serious difficulties to move towards circular and sustainable production.

- To strengthen their competitive position, Italian companies in these industries should therefore develop strong connections with upstream suppliers. The results of this study show that the technological areas with the most significant growth rate are robotics, health, and mobility technologies for a more sustainable socio-economic future. The traditional Made in Italy productions, including textile and leather, are not among them. This reinforces the notion that, to be competitive in a dynamic world, a much larger effort is needed to preserve Italian production and trade in these industries.

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Appendix 1: Full list of patent classes identified for the analysis