Cross-National Comparison of Technology Innovation Capabilities in Automation and Robotics

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Abstract: In today's dynamic and global economic environment, technological innovations are a key determinant of international competitiveness. In the field of automation and robotics, the development of modern technologies is of particular significance, influencing not only industrial progress but also social aspects. Automation and robotics play a crucial role in the concept of modern industry, contributing to the creation of more sustainable, flexible, and human-centric production systems. The article aims to conduct an in-depth analysis of the patent activity in automation and robotics in Europe. Patent documentation serves as a source of knowledge about the directions of research, inventive activities, and consequently, the innovative and competitive potential of the economy. The number of patents over time reflects the dynamics of a country's technological development. The article discusses the use of patent databases to evaluate a country's innovation in automation and robotics. The conducted analysis of data on European countries enabled the identification of trends based on the International Patent Classification and specialisation from a geographical perspective using revealed comparative technological advantage. The European countries were classified using cluster analysis, demonstrating the diversity, and identifying leaders in each group.

Keywords: patents, innovations, future industry, robotisation, automatization, EU

1. Introduction

Measuring innovation is possible and necessary [65], and patents are the most important and frequently used statistical indicators of inventive activity and technological innovation [1-3, 66]. Patents represent intellectual property, which according to dictionary definitions is the idea, invention, or creation that can be protected by law from being copied [67]. World Intellectual Property Organization (WIPO) refers the intellectual property as creations of the mind, e.g. inventions, literary and artistic works, designs, symbols, names and images [68]. The creative works should be presented in a format that allows for dissemination and enables others to replicate, emulate, or produce them [69]. The original reason for patenting was to encourage innovation and promote economic growth by providing incentives for invention and commercialisation [4]. Obtaining intellectual property rights is an important issue for both academic and commercial entities, as well as entire countries as a predictor of economic performance [5, 66]. A region's ability to achieve high economic growth is closely linked to the use of new, innovative technologies [6].

The global patent system allows the submission of a patent to any national patent office to obtain protection in a selected country or the European Patent Office (EPO), which allows protection in European countries. Submitting patents to the World Intellectual Property Organization (WIPO) under the Patent Cooperation Treaty (PCT) is also possible. PCT, established in Washington in 1970, in 2024 provides applicants with the opportunity to secure patent rights in 157 states that are signatories to the Treaty [70]. Determining the patent class is an important element of the application procedure that helps organise and search for patent information. Main patent classification systems are International Patent Classification (IPC) and Cooperative Patent Classification (CPC). IPC and CPC are compatible, with CPC offering greater detail. The layout of complete classification consists of a section (designated by one of the capital letters), class (two-digit number), subclass (a capital letter), and group (either main groups or subgroups, consisting of two numbers separated by a stroke) [71]. The classification of patents in both systems facilitates the search, analysis, and management of patent information, thereby enhancing the ability to conduct comprehensive research.

In recent years, there has been a growing interest in mapping and studying development trends in various technologies utilising patent data, e.g., blockchain [4, 7], nanotechnology [8], pharmaceuticals [9], wind [10] or solar [11, 12] power technologies, hydrogen production [13], artificial intelligence (AI)/machine learning [14], construction robotics [15], electronic design automation [16], Internet of Things [17]. Patent data-

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base searches provide an understanding of the level of development of a wide range of innovative technologies and offer insights into their future direction to make innovation more effective. It is believed that systematic screening of the knowledge contained in patents is a key component of innovation and technology management and it contributes to identifying technical expertise in emerging technologies and allows the seizing of technological opportunities [18, 65]. It is an integral part of technology forecasting, development and adoption [19]. Patent analysis is an important source of anticipatory intelligence in various foresight studies conducted by policymakers and industry actors [20–22]. An example might be the increase in patent activity reflecting technological advances in generative artificial intelligence. The number of patents increased from 733 in 2014 to over 11 600 in 2022, when OpenAI's ChatGPT demonstrated the capabilities of large language models to the public, and reached over 14 000 in 2023 [72].

The article aims to conduct an in-depth analysis of patent activity in automation and robotics. Advances in modern automation and robotics technologies are of great importance, affecting not only industrial progress but also contributing to human welfare [23] by improving the quality of life for individuals and entire nations [24]. Robotisation has the potential to increase regional consumption, investment, income, and public services [25]. Automation and robotics are integral to modern industry. The development of advanced automation and robotics technologies leads to decreased production costs, fewer failures, increased efficiency, and improved product quality to achieve competitive advantage. Accelerating the Industry 4.0 transformation is the most effective way to save resources in the long term and mitigate the linked economic and social risks [26]. Solutions from this family of technologies contribute to greener and human-centric production systems and significantly support compliance with sustainable development goals. In addition to its industrial applications, automation and robotics technologies serve to support people with disabilities, for instance, in physical rehabilitation [27]. At the same time, this area of technological development generates a wide array of societal concerns, uncertainties, and fears. Therefore, understanding the technological trajectories in automation and robotics is key to shaping responsible research and innovation in this field [28–30].

The general definition of automation in the context of engineering and industry is the process of using technology and systems to replace or assist humans in performing specific tasks or operations and can apply to both physical systems and software-based processes. Robotisation involves the use of robots to perform tasks, both physical and virtual. Automation and robotics include machines, devices, programmable controllers, sensors, and information technology systems. A study of the automation and robotics capabilities of different countries can provide valuable insights into the future of industrial production. Patent documentation is a reliable source of information on research directions, inventive activity, and the innovative and competitive potential of the economy. The number of patents granted overtime measures a country's technological development. The key stakeholders in patent analysis are companies and investment funds, as well as universities and research institutes, who can use them to identify research gaps and fields for the commercialisation of research results. Monitoring advanced technology trends is also crucial for policymakers, allowing them to assess the competitive position, predict and actively shape future technological trends, and support appropriate research and development (R&D) decisions to develop sustainable growth strategies [16, 31–33].

The patent analysis methodology is generally consistent with the literature analysis. It involves defining the aims, selecting a patent database, developing a search strategy, conducting the search to collect data, and analysing, visualising, and interpreting the data [73]. The third section of the article presents details of the methodology utilised in this work.

The article addresses the following questions:
1. What trends in automation and robotics can be observed?
2. What is the patent activity in automation and robotics from a geographic perspective?
3. Can regional technological specialisations in automation and robotics be distinguished based on patent databases?

The first part of the article reviews and discusses the recent literature on patent analysis. It consists of (i) a discussion of cross-country comparisons of patent analysis and (ii) patent analysis in automation and robotics. Next, the methodology is described, and an attempt is made to answer the research questions using multidimensional comparative analyses. The core analysis is divided into four main sections: (i) a general discussion on the primary patent determinant, R&D expenditures, (ii) an assessment of patent activity growth, (iii) robotic and automation specialisation, and (iv) regional specialisation in program-controlled manipulators. In conclusion, the article discusses the theses that could be inferred from the patent statistics and identifies future research gaps.

2. Innovation performance and its measures – literature analysis perspectives

2.1. Cross-country comparisons on patent analysis

Innovation assessment and comparative analysis based on patent data are of interest to both researchers and practitioners including policymakers, industry leaders, and investors. By understanding the innovation landscape and benchmarking their performance against global and regional peers, organisations can identify strategic opportunities, take advantage of constraints, allocate resources effectively, and develop policies and strategies that foster innovation and competitiveness. This is reflected in publications including the Global Innovation Index (GII) by WIPO [74], the European Innovation Scoreboard (EIS) by the European Commission [75], World Intellectual Property Indicators 2023 by WIPO [76], OECD Science, Technology and Industry Scoreboard 2017 by OECD [77], as well as in proposals of original innovation indicators based on patent data, e.g. [1]. These works consider the total number of patents granted, by the field of main technologies and other data sources (e.g., R&D investment and grants, GDP, value of scientific literature) to determine the competitive position of countries. The GII 2023 includes 80 indicators categorised into institutions, human capital and research infrastructure, market and business sophistication. EIS 2023 distinguishes framework conditions, investments, innovation activities, and impacts, within them 12 innovation dimensions described by 32 indicators. The interest in comparative analyses is also reflected in the publication based entirely on patents, e.g., Patent Statistics and Country Profiles by WIPO [78] and in tools, e.g. EPO Worldwide Patent Statistical Database (EPO PATSTAT) [79] designed for conducting patent analyses and evaluation, PatentsView [80], which is a patent data analysis and visualisation platform of the U.S. Patent & Trademark Office (USPTO) or PatBase by Minesoft [81] – a searchable patent families database with visualisation and analytical engine.

A patent analysis perspective is used to assess the competence of countries in selected areas, e.g., comparing the differences in nanotechnology between the United States and China from 2001 to 2017 based on data from the USPTO and China National Intellectual Property Administration (CNIPA) [8]. The objects of comparison are not always the countries, but, for example, urban areas based on the inventors' addresses, as in collaboration networks in robotics analyses [34], NUTS 2 regions in a study on R&D indicators impact on innovation performance [35] or on the role of key enabling technologies in regional branching [36]. Bibliometric techniques in patent analysis make it possible to determine the position of a selected country with global trends in robotics patenting, e.g. [37].

In the context of patent-based country comparison, several studies examine barriers and incentives to innovation in patenting or use exogenous variables to adjust output when assessing a country's innovation system. The relationship between GDP per capita, R&D expenditure, and patent applications is often considered since innovation contributes directly and indirectly to economic growth [38]. The estimated correlation between a country's GDP per capita and its patent citations based on patents granted by the USPTO associated with 44 countries in the period 2006–2015 was 0.3 [5]. The positive impact of public R&D support and feed-in tariff schemes on wind power patent activity was revealed via an econometric model based on data from four Western European countries over the period 1977–2009 [10]. Other key drivers of the flow of new technologies are education and human capital, business climate and innovation policy, capital, and technological infrastructure [39]. Striving for long-term environmental sustainability and the need to change the economic model and decouple growth from resource consumption [40] have made environmental issues also a subject of interest in patent analyses. Environmental innovations represented by patents were exploited in the study of the impact of human activity on the environment and econometrically represented in the STIRPAT regression model. Based on data on Nordic economies during the period 2000–2019, it was proven that innovations mitigate the impact of oil and gas on the quality of the environment and reduce carbon dioxide emissions, especially in the long term [41].

R&D activities are undeniably linked to the creation of patents [42, 43] but also considering GDP and population when comparing patent intensity across regions can be a valuable approach to adjusting resident application activity [76].

2.2. Patent analysis in automation and robotics

Focused patent analysis is a common theme in the literature. Awareness of the importance of innovation causes patents and their citations to serve as the primary data source for identifying emerging technologies [18]. Areas of high research activity are reflected in the patent analysis as potential areas for investment and development. The growth in AI-based innovation observed in recent years makes it a topic of interest in multiple publications studying patents (both reports, e.g. [82] and scientific articles, e.g. [44]). A similar trend is visible in relation to graphite and its applications, e.g. [83] or nanotechnology, e.g. [45], blockchain, e.g. [7]. Another exploited area is related to environmental issues [46].

Despite the availability of information in patent records, the challenge of isolating the classes and identifying exactly which patent families cover the subject matter remains. In the case of automation and robotics, researchers note the ease of searching for patents only related to robotisation due to the specific and unambiguous nature of the term 'robot' [47]. However, particular inventions may also find applications other than those originally intended.

Among the articles predicting the future direction of robotics technology based on patent databases are those focusing on the development of care robotics in terms of publications, patent activity and networking [48]. The study covering the period until 2009 indicated Japan as the most active in terms of patent applications and publishing. Exploration of the swarm robotics cooperative control strategy based on patent analysis from 2003 to 2021, predicted two technical development directions for this technology: swarm intelligence and self-organising collaborative strategy [49]. A data source of 228 service robotics patents was used to explore the potential of machine learning classification [50]. In terms of patent applications, the following significant players were revealed: China, the United States (US), South Korea, and India. Support vector machines based on patent data showed that China's industrial robot sector had innovation gaps compared to the United States, Germany, South Korea and Japan, especially in terms of university-industry linkages, interdisciplinary competencies, and globalisation intentions [51]. Citation relationships among patents in the field of robotics were analysed to identify globally and locally important patents [52]. Analysis of the structured and unstructured data from the patent database showed the geographical distribution of construction robotics-related patents worldwide. According to the study, China led the ranking in terms of patent publications, followed by the US [15]. A patent study on collaborative robots identified the largest concentration of inventions in China, Japan and Germany [53]. Drawing the information from patents from 2002–2016, the geography of the "hot points" in robotics research, development, structures, and global network cooperation led to the conclusion that urban areas most specialised in robotics R&D are located in Germany, the US, Japan, and Sweden [34]. The analysis including, among others, robotics patent data until 2016 allowed to divide the European robotisation landscape into three groups according to robotics development [54]. The first group has the highest density in both robotics development and implementation (Sweden, Germany, Austria, Denmark and France), the second group is well situated only in some aspects (Spain, Italy, Belgium, the Netherlands and Finland), and the third group includes the lagging countries.

In the field of automation, the research frontier was determined in the electronic design automation technology field based on the IPC/CPC. Patent activity and quality were assessed to describe the competitive position of different countries. The main competitors identified are the United States, China, Japan, the United Kingdom, and Singapore [16]. According to the investigation of the United States Patent and Trademark Office data, the country that emerged as the leader in robotics and AI technologies is the US, followed by the European Union countries together, and Japan. However, Western countries are all losing to Asia. The outstanding performance of South Korea was noticed [47]. A review of the literature also revealed the works that concern selected specialised aspects of automation, e.g., patent analysis of epicyclic gear trains used in automatic transmissions [55], automatic connection devices [56], or integrated circuits [57].

Among recent works, no in-depth, up-to-date analysis comparing countries solely in terms of patents in the broad area of automation and robotics was found, including an assessment of the diversity of European countries.

3. Research methodology

The research process is illustrated in Figure 1. Several databases facilitate access to patent information (Espacenet – provided by the European Patent Office, Google Patents – which allows searching for patents from various jurisdictions, PatentScope – maintained by the World Intellectual Property Organization, USPTO – the United States Patent and Trademark Office contains information on patents granted in the United States). At the initial stage of the analysis, above mentioned the most popular databases were analysed, lately, PatentScope was selected as containing international patent applications filled under the Patent Cooperation Treaty.

In the case of patent analysis, two search approaches can be applied: a term search/bag of words analysis or a traditional

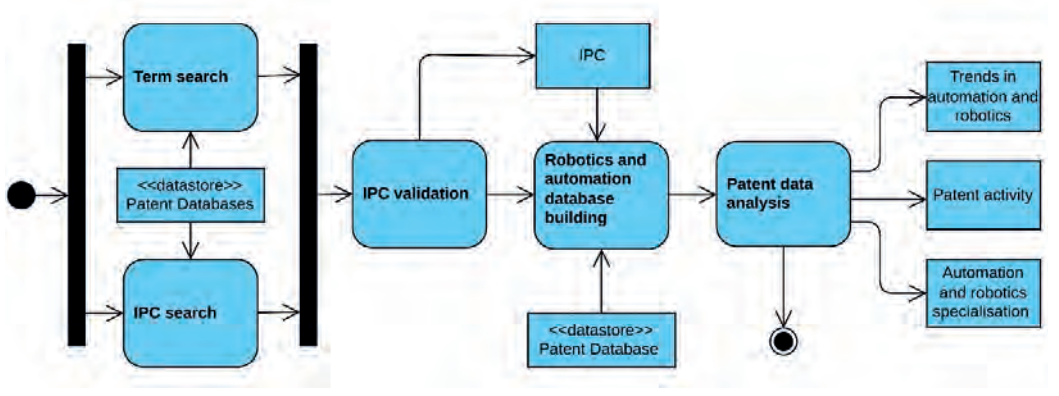

Fig. 1. Research framework
Rys. 1. Proces badawczy

Table 1. The scope of the analyses according to the International Patent Classification/Cooperative Patent Classification
Tabela 1. Zakres analiz według Międzynarodowej Klasyfikacji Patentowej/Wspólnej Klasyfikacji Patentowej

Subclass	Main group	Descriptions
B25J		manipulators; chambers provided with manipulation devices
	B25J 9/00	programme-controlled manipulators
	B25J 13/00	controls for manipulators
B25B		tools or bench devices not otherwise provided for, for fastening, connecting, disengaging or holding
B25C		tools or bench devices not otherwise provided for, for fastening, connecting, disengaging or holding
B60W		conjoint control of vehicle sub-units of different type or different function; control systems specially adapted for hybrid vehicles; road vehicle drive control systems for purposes not related to the control of a particular sub-unit
G05B		control or regulating systems in general; functional elements of such systems; monitoring or testing arrangements for such systems or elements
G05D		systems for controlling or regulating non-electric variables

patent classification. The IPC code search has proven to be stronger and more reliable than a matched keyword in associating a patent with a specific technology field [47]. The use of mixed patent searches is also a valid approach [72].

The approach was narrowed down, excluding patent classes only indirectly related to robotics, despite their utilisation within the field, e.g., G06F, covering electric digital data processing including calculations, computer systems and data processing methods or G06N, computing arrangements based on specific computational models. However, artificial intelligence and decision support systems are used in robots for decision-making, learning, adaptation to the environment and interaction with people. Table 1 includes the scope of the analyses according to the IPC.

Figure 2 visually explores the assigned keywords of the selected patent classification codes with and without distinguishing the country of publication. The keywords indicate areas of intensive exploration and potential patent applications and verify the chosen classification's correctness. The keywords mainly focus on control in the context of devices and systems. Noteworthy is the presence of numerous solutions dedicated to mobile devices, autonomous vehicles, and mobile robots, which indicates great interest in this area.

The period 2014–2023 was selected for analysis. In 2011, at the Hannover Messe (one of the world's largest industrial trade fairs), the term "Industrie 4.0" appeared for the first time and at Hannover Messe 2014, the concept was developed, and progress in implementing the vision was presented. The official framework document for "Industrie 4.0" [84], the Plattform Industrie 4.0, and SmartFactory KL initiatives aimed to promote and coordinate the digital transformation of industry in Germany contributed to the spread of the idea of Industry 4.0 around the world. Many countries have begun to recognise the importance of integrating digital technologies into industry and adapt the concepts into their own industrial development strategies. The term "Industrie 4.0" gave rise to the global concept of "Industry 4.0", as a general term describing the fourth industrial revolution [19]. Industry 4.0, its evolutions such as Industry 5.0, or generally future industry, refers to the intelligent networking of machines and processes for the industry based on cyber-physical systems [59], is a revolution in manufacturing control methodology [58]. Recent years have been a period of rapid digitisation and production automation. Applications of a combination of emerging new technologies are changing production, management, and work organisation methods and generating many new patentable innovations.

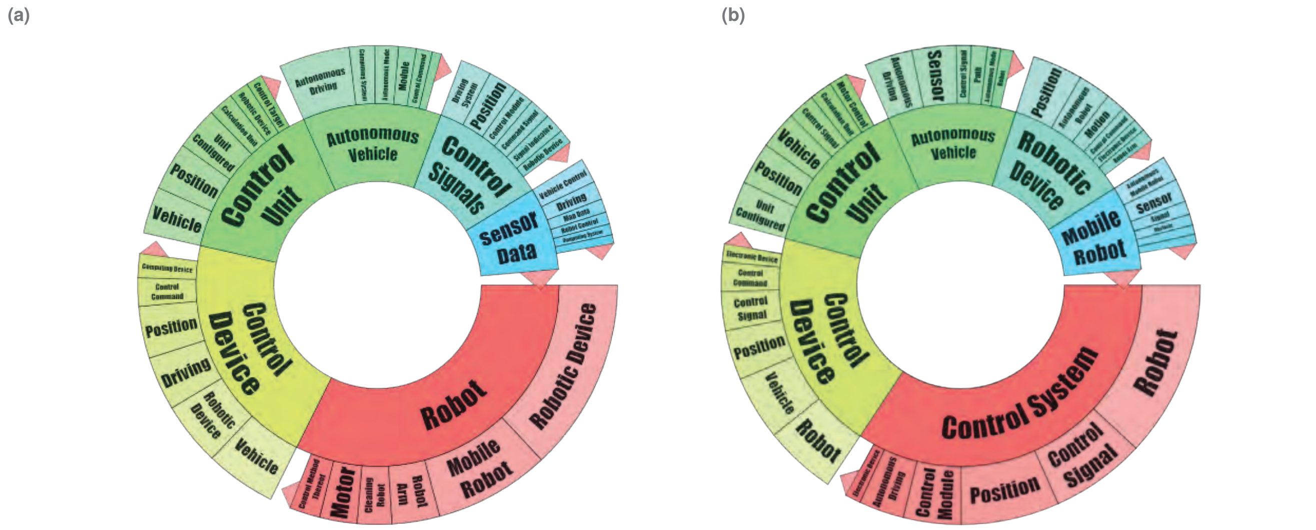

Fig. 2. Keywords analysis of selected subclasses: (a) patents without distinguishing the office of publication [PD=2014:2023 and IC=(B25J OR B25B OR B25C OR B60W OR G05B OR G05D) AND GRANT=(YES) AND ALIVE=(YES)")]; (b) publication office: International Bureau of WIPO [PD=2014:2023 and CC=(WO) and IC=(B25J OR B25B OR B25C OR B60W OR G05B OR G05D) AND GRANT=(YES) AND ALIVE=(YES)]
Rys. 2. Analiza słów kluczowych wybranych podklas: (a) patenty bez rozróżnienia urzędu publikacji; (b) patenty z miejscem publikacji: Światowa Organizacja Własności Intelektualnej

Determining the country of origin of a patent is quite a complex task. The registration of a patent in a specific country does not necessarily indicate the origin of the invention itself. According to PatBase [81], the top 10 jurisdictions are China, the United States, Japan, Germany, the International Bureau of WIPO, EPO, Korea, Canada, Taiwan and India. If one considers only WIPO, the top countries are the US, the International Bureau of WIPO, China, EPO, Germany, Japan, Korea, Canada, Australia, and India. Both the inventors' and the applicant's country may be relevant from different perspectives. Since the country of the applicant might reflect the location of the company's headquarters, as well as state policy and patent procedures, the country of the inventors was considered as a more precise indicator of the origin of the idea and R&D activity that led to the inventions.

Of the two main patent evaluation methods (market-based which evaluates patents on commercial market value, patent-based which evaluates patents on their indicators) [57] the patent-based approach was applied.

The following formulas are useful for comparing countries' technological positions and measuring international specialisation based on patents as indicators.

Compound annual growth rate [63]:

$$CAGR = \left(\frac{P_{last}}{P_{first}}\right)^{\frac{1}{y}} - 1, \tag{1}$$

where: P_{first}, P_{last} – the number of patent applications in the first and last year (in the analysis: at the end of 2014 and 2023 respectively), y – the duration of the survey period (in the analysis: 9 years).

The interpretation of $CAGR$ is as follows: $CARG = 0.10$ means that the value increased by an average of 10 % per year, and $CAGR = 0$ means that the value has not changed in the analysed period. $CAGR$ does not reflect the variability of growth in individual years but shows a constant growth rate.

Revealed (comparative) technological advantage (RTA) [5, 34, 46, 59]:

$$RTA_{cit} = \frac{P_{cti} / \sum_i P_{cti}}{\sum_c P_{cti} \sum_c \sum_i P_{cti}}, \tag{2}$$

where: P_{cti} – the number of patents from country c in technology field i in a period t; $\sum_i P_{cti}$ – the number of patents from country c in a period t; $\sum_c P_{cti}$ – the number of patents in technology i worldwide in a period t; $\sum_c \sum_i P_{cti}$ – the number of patents granted worldwide in a period t.

If $RTA > 1$, the country or region has a comparable technological advantage in the field, if $RTA < 1$, on the contrary, the country is less specialised in the field compared to the reference area.

Revealed symmetric technological advantage index ($RSTA$) with a range between -1 and $+1$, addresses the asymmetry in the RTA index making interpretation easier [59]:

$$RSTA_{cit} = \frac{RSTA_{cit} - 1}{RSTA_{cit} + 1}. \tag{3}$$

The closer the value of $RSTA$ to $+1$, the greater the revealed advantage, the closer the $RSTA$ to -1, the lower.

Citations are commonly used measures of the economic and technological value of a patent, and therefore the quality of the region's invention-based [15, 57]. The direct or indirect citation relationship among patents can be used to find the technological clusters and evaluate the importance of patents [52]. Citation databases are provided, among others, by PATSTAT, PatBase, and Google Patents.

Based on citation reports revealed comparative advantage weighted can be estimated ($RTAw$) [5]:

$$RTAw_{cit} = C_{cit} RTA_{cit} \tag{4}$$

where: $C_{cit} = \frac{C_{cti} / \sum_i C_{cti}}{\sum_c C_{cti} \sum_c \sum_i C_{cti}}$ – citation index; C_{cti} – the number of citations of patents from country c in technology field i in a period t.

In the conducted analysis two classes were examined: B25J 9/00 and B25J 13/00.

Around 270 000 under the PCT international applications were published in 2023. The list of the top five origins is consistently occupied by inventors from China, the US, Japan, South Korea, and Germany, accounting for 78 % of applications. China's Huawei Technologies followed by Samsung Electronics from South Korea, Qualcomm from the US, Mitsubishi Electric of Japan, and BOE Technology Group of China remain the top fillers of PCT international applications in 2023 [85, 86]. This study examines the diversity of European countries in automation and robotics in terms of patents. The PCT publication data was selected as a key indicator of patent activity at the international level and a measure of interest in technology or innovation on the global stage (the term search in case of Poland DP:[2014–2023] AND IADC:PL). The analysis encompasses 30 countries: EU member states and additionally EEA countries (Norway, Iceland) and Switzerland.

4. Data analysis

4.1. Patents and R&D expenditures

Innovative outcomes are highly concentrated, and the leading countries in scientific, technological, and innovation capabilities are high-income nations, including the United States, France, Germany, Japan, and South Korea, as well as large economies such as China and India [87]. Although the analysis and modelling of the relationships between factors influencing the number of patents is beyond the scope of this publication, patent quantity examination could not omit the most important determinant, which is R&D expenditure. The analysed European countries are a relatively homogeneous group which are analysed together in many studies as having many common regulations and adopted coherent priorities. However, expressed as a percentage of GDP, R&D spending varies significantly, reaching values in the range between 0.46 % (Romania) and 3.43 % (Belgium), with an average of 1.82 % in 2022 [88]. Being aware that not all R&D investments are dedicated to development expressed directly in patented innovations, and non-patentable technologies contribute to the innovative capabilities, and not depreciating, e.g., basic research, in the case of the countries analysed, there is a very high correlation between R&D expenditure in million Euro and the number of patents. The correlation between lagged cumulative expenses in 2013–2022 and the cumulative number of all patents in 2014–2023 is 0.99, and without outliers such as Germany and France is 0.96 (Fig. 3).

The relationship between the variables allows one to estimate the "cost of patent". Figure 4 shows the million Euro of R&D expenditure per patent.

European leader countries listed in international rankings, e.g., Germany and France, have an under-average cost of obtaining a patent. Greece and Czechia have the highest R&D expenditure per patent. High costs are observed in Portugal, Poland, Iceland, Lithuania, and Croatia.

The patents selected for analysis represent only a fraction of the total number of patents. The percentage of automation and robotics patents in the total number of patents is, respectively, B25J – 0.65 %, B25B – 0.24 %, B25C – 0.03 %, B60W – 0.91 %, G05B – 1.31 %, and G05D – 0.68 %. However, the data presented illustrate the great importance of financial incentives in achieving innovation capability.

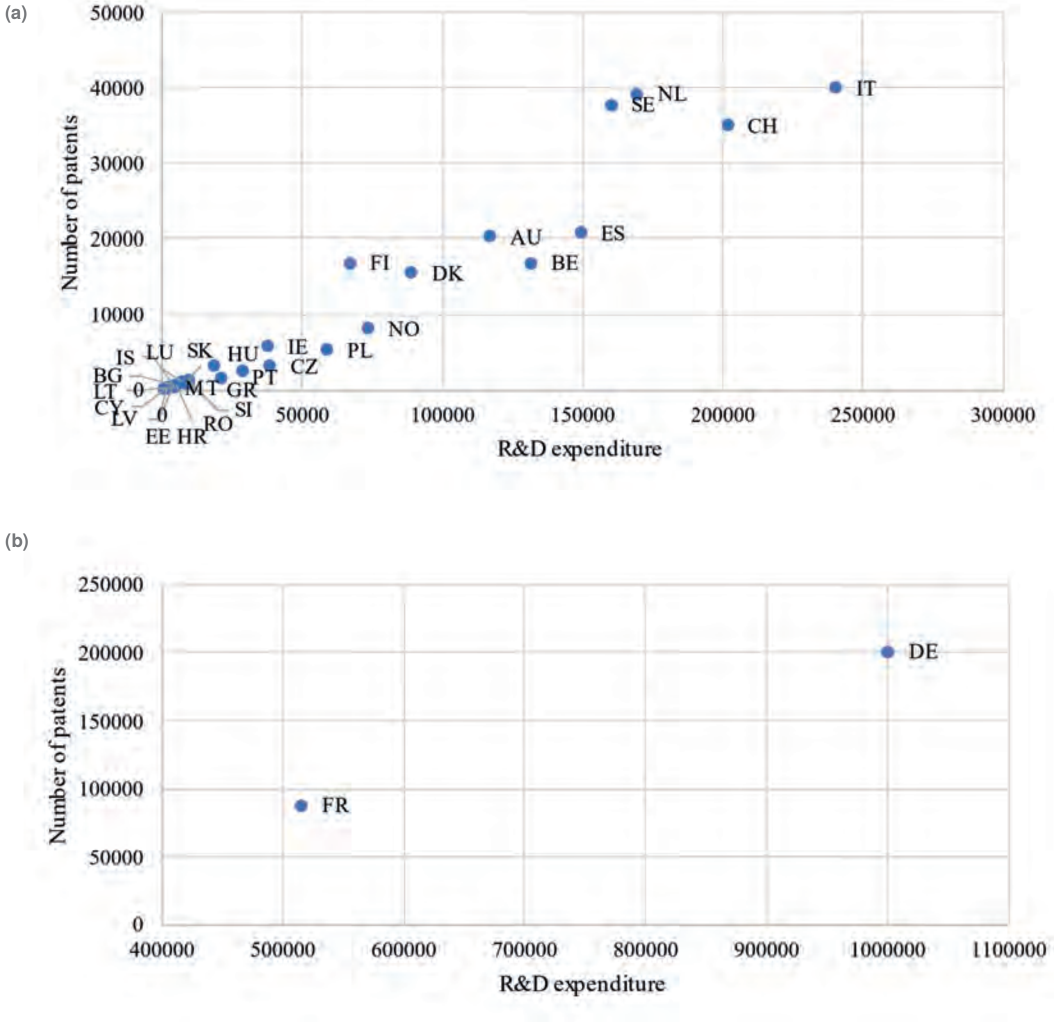

Fig. 3. Correlation between the number of patents and R&D expenditure (aggregated data) [88]
Rys. 3. Zależność liczby patentów i wydatków na badania i rozwój (dane zagregowane) [88]

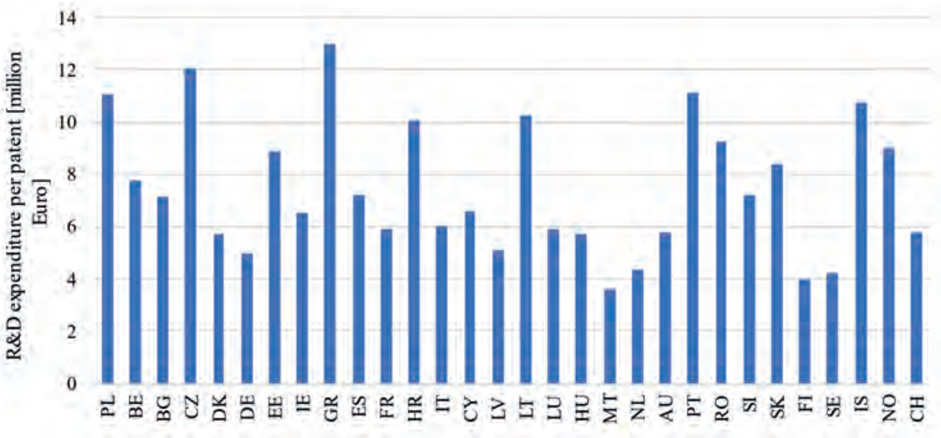

Fig. 4. R&D expenditure per number of patents [88]
Rys. 4. Wydatki na badania i rozwój na liczbę patentów [88]

4.2. Patent activity growth

The number of patents, including those related to robotics, fluctuates with slow growth year by year. Considering the absolute number of patents, European countries may be divided into four groups with regard to their patent activity (Fig. 5a):

- The outstanding – including Germany (DE), which belongs to the top five countries in the world in terms of the number of patents, with circa 20 000 patents in the period 2014–2023, and France (FR, with more than 8 500 patents, which ranks just outside the top ten.
- Top performers – Netherlands (NL), Italy (IT), Sweden (SE), and Switzerland (CH) – with numbers of patents exceeding 3 500.
- Average performers – Spain (ES), Australia (AU), Finland (FI), Denmark (DK), and Belgium (BE) – with more than 1 500 patents.
- Underperformers – Norway (NO), Ireland (IE), Poland (PL), Czechia (CZ), Hungary (HU), Portugal (PT), Greece (GR), Slovenia (SI), Luxembourg (LU), Slovakia (SK), Romania (RO), Bulgaria (BG), Lithuania (LT), Croatia (HR), Latvia (LV), Iceland (IS), Estonia (EE), Malta (MT), Cyprus (CY) – with less than 1 000 patents.

Since the correlation coefficient between population and the number of patents in the analysed period is 0.8, the differences between countries in the number of patents per 1 million people are illustrated (Fig. 5b). In this case, there are no clearly distinguishable groups. The following division can be proposed:

- Top performers – with more than 200 patents per 1 million inhabitants: Switzerland (CH), Sweden (SE), Finland (FI), Denmark (DK), Germany (DE), Netherlands (NL), Austria (AU).
- Average performers – with more than 50 patents per 1 million inhabitants: Luxembourg (LU), Belgium (BE), Norway (NO), Iceland (IS), France (FR), Ireland (IE), Slovenia (SI), Italy (IT), Malta (MT).
- Underperformers – with less than 50 patents per 1 million inhabitants: Spain (ES), Hungary (HU), Czechia (CZ), Portugal (PT), Estonia (EE), Latvia (LV), Cyprus (CY), Lithuania (LT), Slovakia (SK), Greece (GR), Poland (PL), Bulgaria (BG), Croatia (HR), Romania (RO).

The number of patents, including those related to robotics, is fluctuating with slow growth year by year. The *CAGR* for all

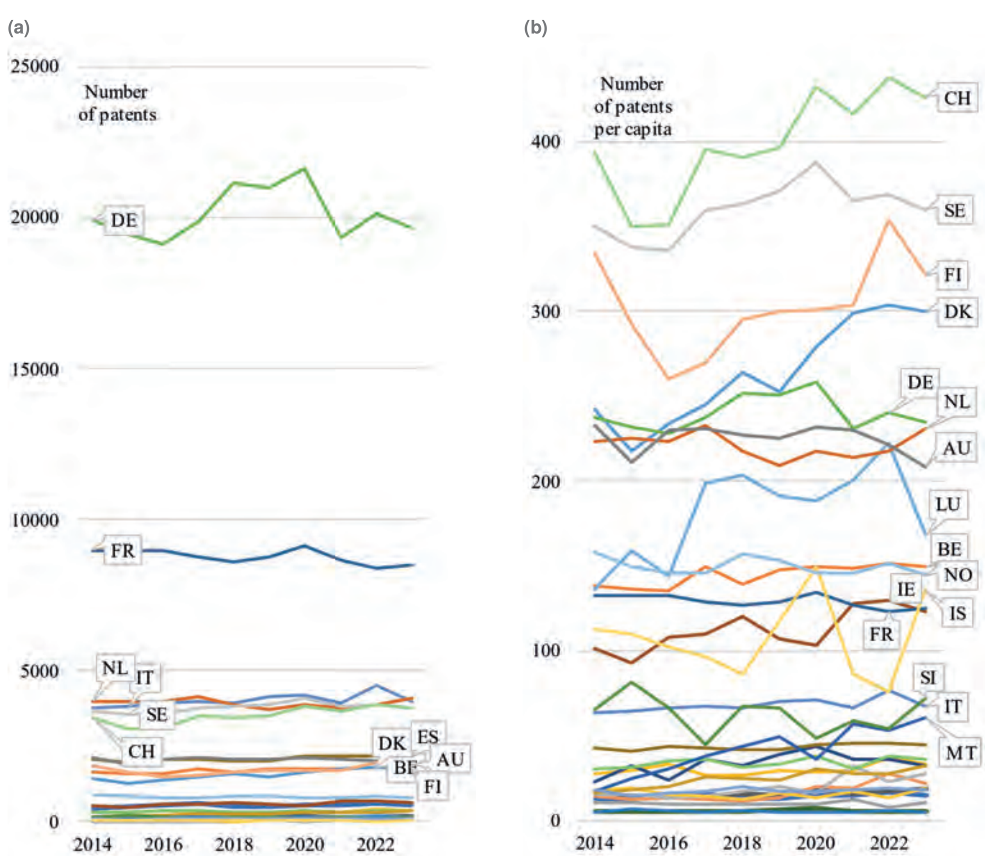

Fig. 5. The number of patents including those related to robotics and automation between 2014 and 2023: (a) absolute value; (b) per 1 million inhabitants
Rys. 5. Liczba patentów, w tym związanych z robotyką i automatyką w latach 2014–2023: (a) wartość bezwzględna; (b) na 1 mln mieszkańców

Table 2. The compound annual growth rate (2014–2023)
Tabela 2. Średnia roczna stopa wzrostu (2014–2023)

		All	B25J	B25B	B25C	B60W	G05B	G05D
WORLD		0.071	0.164	0.065	0.050	0.116	0.115	0.146
Europe		0.053	0.123	0.057	0.049	0.087	0.093	0.098
Poland	**PL**	0.097	0.158	0.182	0.080	0.330	0.169	0.141
Germany	**DE**	0.051	0.134	0.060	0.063	0.081	0.088	0.099
France	**FR**	0.055	0.114	0.041	0.006	0.098	0.092	0.079
Belgium	**BE**	0.055	0.111	0.038	0.000	0.179	0.094	0.090
Bulgaria	**BG**	0.068	0.099	0.000	N/A	0.032	0.088	N/A
Czechia	**CZ**	0.086	0.231	N/A	0.000	0.080	0.127	0.115
Denmark	**DK**	0.052	0.217	0.080	0.080	0.090	0.116	0.070
Estonia	**EE**	0.069	0.292	N/A	N/A	N/A	0.071	N/A
Ireland	**IE**	0.066	0.167	0.025	0.000	0.301	0.125	0.136
Greece	**GR**	0.064	0.080	0.025	N/A	0.064	0.102	0.115
Spain	**ES**	0.067	0.123	0.064	0.032	0.119	0.186	0.123
Croatia	**HR**	0.044	N/A	0.000	N/A	0.032	N/A	0.167
Italy	**IT**	0.061	0.140	0.082	0.000	0.106	0.107	0.108
Cyprus	**CY**	0.079	N/A	N/A	N/A	0.046	N/A	N/A
Latvia	**LV**	0.067	0.167	N/A	N/A	N/A	N/A	0.080
Lithuania	**LT**	0.101	N/A	N/A	N/A	N/A	0.046	0.000
Luxembourg	**LU**	0.072	0.080	0.080	0.000	N/A	0.140	0.092
Hungary	**HU**	0.053	0.225	0.062	N/A	0.220	0.218	0.177
Malta	**MT**	0.148	N/A	N/A	N/A	N/A	N/A	N/A
Netherlands	**NL**	0.050	0.119	0.043	0.080	0.076	0.097	0.066
Austria	**AU**	0.042	0.165	0.045	0.009	0.110	0.100	0.091
Portugal	**PT**	0.101	N/A	0.196	N/A	0.220	0.126	0.125
Romania	**RO**	0.084	N/A	0.000	N/A	0.292	0.318	0.351
Slovenia	**SI**	0.057	0.167	0.038	N/A	0.094	0.167	0.087
Slovakia	**SK**	0.075	0.080	0.000	N/A	0.000	0.260	0.167
Finland	**FI**	0.044	0.110	0.063	0.080	0.100	0.078	0.118
Sweden	**SE**	0.049	0.068	0.054	0.004	0.083	0.084	0.109
Iceland	**IS**	0.047	0.209	0.000	N/A	N/A	0.032	0.130
Norway	**NO**	0.048	0.116	0.086	0.000	0.041	0.080	0.111
Switzerland	**CH**	0.058	0.133	0.059	0.165	0.103	0.095	0.102

N/A — Not Available

PCT patents is 0.071, and for patents originating from Europe, it is 0.053. In the case of robotics and automatisation worldwide, higher average growth is observed in the case of B25J (0.164), G05D (0.146), B60W (0.116), and G05D (0.115). Table 2 displays the *CAGR* for European countries in the analysed patent subclasses from 2014 to 2023. *CAGR* was not calculated for patent subclasses where no patents were filed before 2014.

Regarding CAGR over 0.3, Romania stands out in G05D, G05B, and B60W, while Poland and Ireland in B60W. Estonia has achieved a high result in B25J that is only slightly lower than 0.3. These are the countries that started to be active in the patent subclasses studied during the analysed period. The European countries at the top of the world patent rankings, Germany and France, have not seen a sharp increase in the number of patents. In their case, a stabilisation is observed.

Table 3. Revealed technological advantage
Tabela 3. Ujawniona przewaga technologiczna

		B25J	B25B	B25C	B60W	G05B	G05D
Poland	PL	0.332	0.816	0.782	0.305	0.720	0.432
Germany	DE	1.189	1.867	1.177	2.025	1.627	0.845
France	FR	0.814	0.883	0.332	1.270	0.686	0.661
Belgium	BE	0.444	0.257	0.246	0.520	0.504	0.464
Bulgaria	BG	0.939	0	0	0.215	1.386	0.385
Czechia	CZ	1.009	1.159	0.000	0.421	0.867	0.640
Denmark	DK	1.343	1.155	0.267	0.078	1.118	0.923
Estonia	EE	2.963	1.386	0	0.605	1.361	6.208
Ireland	IE	0.435	0.647	0	0.682	0.893	0.672
Greece	GR	0.360	0.758	0	0.248	0.426	0.369
Spain	ES	0.858	1.254	0	0.189	1.072	0.628
Croatia	HR	1.113	0	0	0.255	0.164	0.684
Italy	IT	1.012	1.766	0	0.551	0.802	0.841
Cyprus	CY	0	0	0	0.653	0.420	0
Latvia	LV	1.213	0	0	0.371	0.239	0.331
Lithuania	LT	0.655	0	0	0.000	0.387	0.269
Luxembourg	LU	0.373	0.523	0	0.456	0.734	1.427
Hungary	HU	1.168	1.135	0	1.898	1.168	1.105
Malta	MT	1.362	0	0	0.626	0.805	2.793
Netherlands	NL	0.523	0.190	0.212	0.173	0.675	0.308
Austria	AU	0.818	2.713	0.817	0.439	1.009	1.181
Portugal	PT	0.404	0.972	1.629	0.265	0.648	0.946
Romania	RO	0.882	0.619	0	2.430	0.955	1.687
Slovenia	SI	0.334	0.938	0	0.614	0.395	1.005
Slovakia	SK	0.618	0	0	0	1.278	0.380
Finland	FI	0.551	0.736	0.247	0.313	0.867	1.075
Sweden	SE	1.217	2.577	0.550	2.596	1.292	1.557
Iceland	IS	3.230	0	0	0	0.636	0.589
Norway	NO	1.513	1.744	0	0.182	1.202	1.698
Switzerland	CH	0.735	1.469	10.438	0.224	1.072	0.538

4.3. Robotic and automation specialisation

The RTA was used to divide European countries into several groups considering the six patent subclasses (Table 3). Many countries do not have any patents in B25C, which is also true, but to a lesser extent, for B25B.

The leaders in each group analysed are as follows:

- B25J – Iceland (IS) and Estonia (EE) (with a relatively small number of patents in total);
- B25B – Austria (AU) and Sweden (SE);
- B25C – Switzerland (CH);
- B60W – Romania (RO) and Sweden (SE);
- G05B – Germany (DE);
- G05D – Estonia (EE).

The two countries that stand out the most are Switzerland and Estonia in terms of the *RTA* in classes B25C and G05D, respectively. Additionally, Iceland is the leader in B25J with zero patents in other classes. No country has a zero number in G05B. Analysing all subclasses together, Switzerland and Estonia emerge as strong players among European countries, although Sweden and Germany also perform well. This is confirmed by *RSTA* presented in summary in Figure 6. When

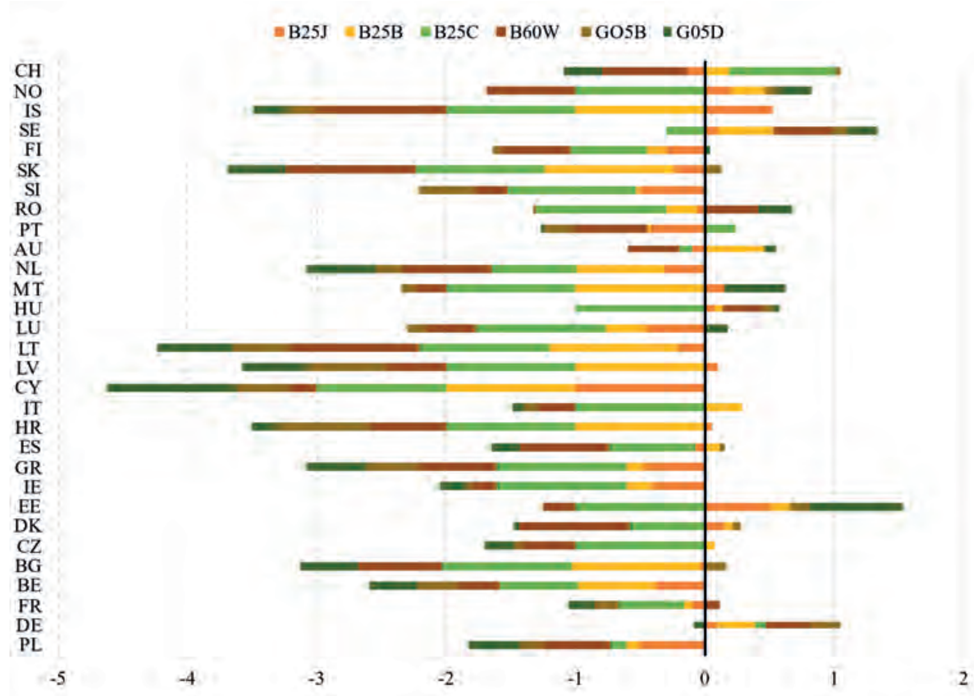

Fig. 6. Revealed symmetric technological advantage index (RSTA)
Rys. 6. Ujawniony symetryczny wskaźnik przewagi technologicznej (RSTA)

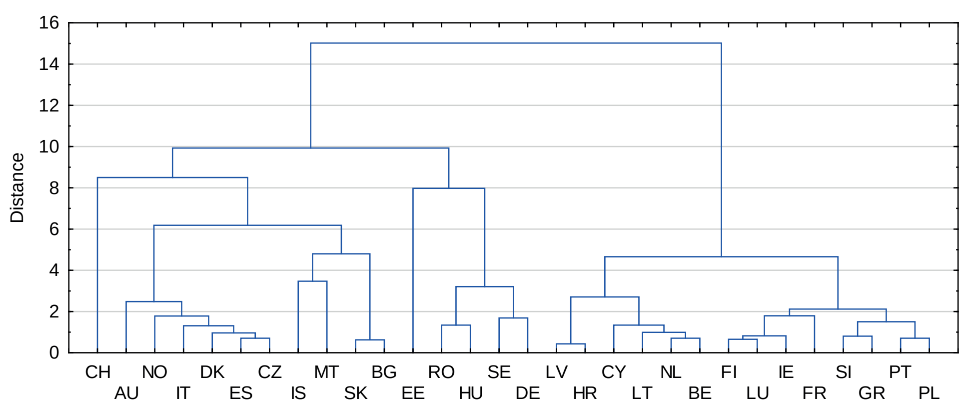

Fig. 7. The results of agglomerative cluster analysis
Rys. 7. Wyniki aglomeracyjnej analizy skupień

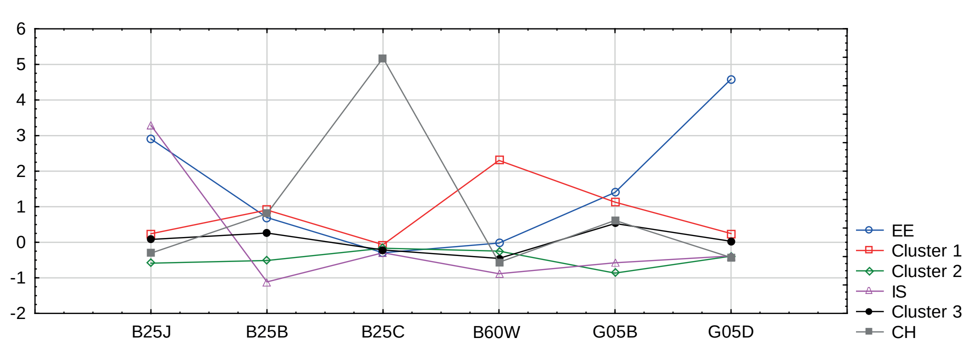

Fig. 8. Cluster Mean Plot
Rys. 8. Wykres średnich w klastrach

comparing European countries, Sweden and Germany stand out as having the greatest advantage in most of the patent classes. Estonia, Switzerland, and Austria show a balance in their achievements. Hungary, Romania, and Norway also stand out positively in the overall analysis.

Additionally, a cluster analysis was performed to determine whether it is possible to separate groups. Figure 7 presents the results of exploration clustering using the agglomeration method for standardised data.

European countries can be divided into six groups based on Ward methods to give the smallest within-group variance and Euclidean distance. A connecting distance greater than six was assumed:

- two clusters with individual entities: Switzerland (CH), and Estonia (EE)
- Latvia (LV), Croatia (HR), Cyprus (CY), Lithuania (LT), Netherlands (NL), Belgium (BE), Finland (FI), Luxembourg (LU), Ireland (IE), France (FR), Slovenia (SI), Greece (GR), Portugal (PT), Poland (PL);
- Austria (AU), Norway (NO), Italy (IT), Denmark (DK), Spain (ES), Czechia (CZ);
- Iceland (IS), Malta (MT), Slovakia (SK), Bulgaria (BG);
- Romania (RO), Hungary (HU), Sweden (SE), Germany (DE).

K-means clustering into six groups designated in the hierarchical approach (assuming preliminary cluster centres to maximise distances) distinguishes, in addition to clusters with only Switzerland (CH), and Estonia (EE), a separate group for Iceland (IS), and the remaining groups are:

- Germany (DE), Hungary (HU), Romania (RO), Sweden (SE) – countries with averages exceeding the mean values;
- Bulgaria (BG), Czechia (CZ), Denmark (DK), Spain (ES), Italy (IT), Malta (MT), Austria (AU), Slovakia (SK), Finland (FI), Norway (NO) countries with average mean values;
- Poland (PL), France (FR), Belgium (BE), Ireland (IE), Greece (GR), Croatia (HR), Cyprus (CY), Latvia (LV), Lithuania (LT), Luxembourg (LU), Netherlands (NL), Portugal (PT), Slovenia (SI) – countries with lower mean values of the analysed variables.

Plots of cluster average values are shown in Figure 8.

As demonstrated above, EU countries cannot be considered homogeneous in terms of patents in analysed subclasses. According to *RTA*, it cannot be concluded that the clusters coincide with the traditional division into Eastern and Western Europe, Scandinavian, and Southern countries.

4.4. Regional specialisation in programme-controlled manipulators

Forward citation can be interpreted as an indicator of the impact or importance of a given patent in the context of further technological development. Table 4 includes the total number of granted patents published in 2014–2023 registered in WIPO indexed in PatBase. On average, patents receive 12 citations but subclasses G05B, G05D, and main group B25J 13/00 positively stand out with an average citation count of about 15.

B25J 9, in the context of modern industry, relates to the latest trends and innovations in the field of program-con-

Table 4. The number of patents and their forward citations
Tabela 4. Liczba patentów i ich cytowań po publikacji

Subclass	Number of patents	Number of citations
B25J	14 958	148 276
B25J 9	9 288	104 902
B25J 13	4 001	60 688
B25B	5 071	50 931
B25C	746	6 988
B60W	19 471	180 199
G05B	28 147	435 548
G05D	23 309	347 613
B25J OR B25B OR B25C OR B60W OR G05B OR G05D	80 459	851 349

Source: PatBase [PD=2014:2023 and CC=(WO) and IC=(B25J13) AND GRANT=(YES)]

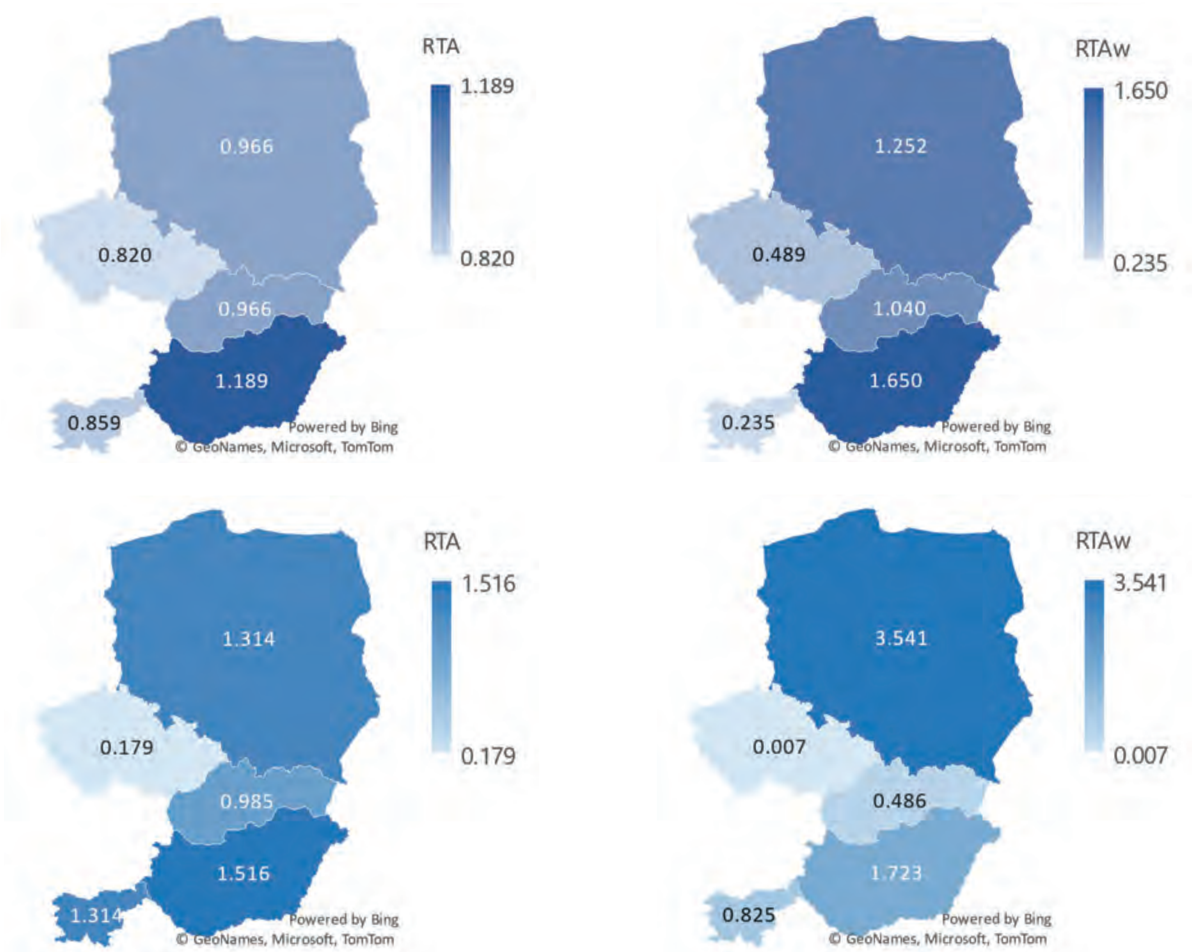

Fig. 9. Achievements of Central European countries: (a) B25J 9 Revealed technological advantage – RTA; (b) B25J 9 Revealed comparative advantage weighted – RTAw; (c) B25J 13 Revealed technological advantage – RTA; (d) B25J 13 Revealed comparative advantage weighted – RTAw
Rys. 9. Osiągnięcia krajów Europy Środkowej: (a) B25J 9 Ujawniona przewaga technologiczna – RTA; (b) B25J 9 Ujawniona przewaga komparatywna ważona – RTAw; (c) B25J 13 Ujawniona przewaga technologiczna – RTA; (d) B25J 13 Ujawniona przewaga komparatywna ważona – RTAw

Table 5. Country ranking based on RTA and RTAw
Tabela 5. Ranking krajów na podstawie RTA i RTAw

<table>
<tr><th>Ranking</th><th colspan="2">B25J 9</th><th colspan="2">B25J 13</th></tr>
<tr><td></td><td>RTA</td><td>RTAw</td><td>RTA</td><td>RTAw</td></tr>
<tr><td>1</td><td>Hungary</td><td>Hungary</td><td>Hungary</td><td>Poland</td></tr>
<tr><td>2</td><td rowspan="2">Poland
Slovakia</td><td>Poland</td><td rowspan="2">Poland
Slovenia</td><td>Hungary</td></tr>
<tr><td>3</td><td>Slovakia</td><td>Slovenia</td></tr>
<tr><td>4</td><td>Slovenia</td><td>Czechia</td><td>Slovakia</td><td>Slovakia</td></tr>
<tr><td>5</td><td>Czechia</td><td>Slovenia</td><td>Czechia</td><td>Czechia</td></tr>
</table>

*Green fill indicates the achievement of comparative advantage (RTA > 1 or RTAw > 1)

trolled manipulators, which is of key importance for the competitiveness and development of various economic sectors. The general class B25J pertains to manipulators in general. It may include manually operated, mechanically controlled manipulators, as well as those operated through various control systems, including programmatically controlled systems. The patents in subclass B25J 9 focus on software-controlled manipulators, which is a key area of innovation in robotics. Studying these patents can help to monitor the latest developments in robot control and industrial process automation.

To examine the disparities in patent activity, the Central European states (as defined by the OECD) based on the main group B25J 9/00 (programme-controlled manipulators) within the subclass BJ25 (manipulators; chambers provided with manipulation devices) were compared. The WIPO database [85] and citations disclosed in Google Patents [89] were utilised. Revealed technological advantage ($RTA > 1$) indicated only Hungary ($RTA = 1.189$) as competitive. The weighted RTA, considering the number of patents and the number of citations apart from Hungary (1.650), also distinguishes Poland (1.252) and Slovakia (1.040) and lowers the position of Czechia and Slovenia (Figure 9a and Figure 9b).

Similarly, the main group B25J 13 was analysed, which allowed Hungary, Slovenia, and Poland to be distinguished in the context of $RTAw$. Poland leads with a score of 3.542 in $RTAw$, followed by Hungary with a score of 1.723 (Figure 9c and Figure 9d). In the case of Poland, the number of citations radically changed the results.

To illustrate the influence of incorporating citations on the ranking of the five analysed countries, Table 5 displays the positions and identifies the countries that have gained a comparative advantage.

The change in ranking positions is not radical; this is a shift up/down by one position, but the country's classification as having a cooperative advantage has changed. Therefore, citations may influence the perception of inventions' technological and economic value.

5. Discussion

Patent statistics are an important source of information about the current level of economic development. However, a one--dimensional analysis of patents is not justified. Qualifying patents for a selected thematic area is a big challenge because, in many cases, the limits of their future application cannot be predicted with certainty. The work analysed patents in the following subclasses B25J (B25J 9, B25J 13), B25B, B25C, B60W, G05B, G05D.

Despite the significant progress observed in the industry and the gradual implementation of the Industry 4.0 concept, no significant increase in the number of patented inventions in automation and robotics has been observed. The interpolation of this result is consistent with the forecasts formulated in the report Top 100 Global Innovators 2024 [90]. It is predicted to increase and improve in government and academic research, software, media, fintech, mining and metals, telecommunications and stabilisation in semiconductors, electronics and computing equipment, industrial systems, energy and electrical segments. $CAGR$ is over 0.3 only in the case of Poland and Ireland in B60W, Romania in G05B and G05D. These are the countries that are new players in the innovation market with a small absolute number of patents. The inability to calculate $CARG$ for many countries could be seen as positive, since the first patents just appeared in the analysed period, proving the sector's development.

European countries are diverse in terms of patent activity and specialisation. When analysed together, they perform best in the G05D subclass with an average RTA above 1.02, but also in the B25J subclass with a result of 0.95. The smallest variation is in G05B. Individually, Switzerland should be singled out in subclass B25C, Estonia and Iceland in B25J, Austria and Sweden in B25B, Romania and Sweden in B60W, Germany in G05B, and Iceland in G05D. Based on the clustering method, three groups of countries can be identified after excluding outliers with excellent RTA results in single subclasses (Switzerland – B25C, Estonia – G05D and B25J, and Iceland B25J). Germany, Hungary, Romania, and Sweden perform best, achieving above-average results from the perspective of a selected set of subclasses.

The revealed comparative advantage weighted proved that considering not only the number of published patents but also citations may change a country's position. Poland ranks 27th in terms of the number of total patents per million inhabitants among the 30 European countries (it occupied last place among Central European countries) and does not stand out among European countries in terms of RTA in subclasses. However, in the case of selected main groups and when considering the number of citations, it has a distinctive $RTAw$ score of B25J 13 and a significant B25J 9 among Central European countries.

6. Conclusion

The relationship between research and development achievements, production technology and competitiveness has been a subject of scientific interest for years. It is widely acknowledged that a means to facilitate economic development involves leveraging and adapting existing innovation capabilities [86]. Patents do not reflect all of the research and innovative efforts behind an invention [66]. Some technological development activities do not result in patentable inventions, and not all inventors apply for patent protection [65]. However, patents as codified knowledge, are an essential component of the innovation process, linked to the invention, and measure the direct output and productivity of the scientific system. Patent analysis allows the extrapolation of upcoming trends. Along with the review of scientific publications, Delphi analysis, scenario analysis, or agent-based simulation, it is successfully used in technology foresight and forecasting.

The industry has benefited greatly from automation and robotics. The differences observed in this comparative study suggest that there is potential to stimulate research activity and innovation in many countries and to build human capital capable of creative problem-solving to support organisations introducing innovations. There is room for improvement of the practices and procedures, including those at universities, to increase the awareness of the academic and managerial staff.

Another problem is the insufficient commercialisation [87]. R&D efforts that lead to innovations that translate into patents must prove successful in markets [42] and many patents are never implemented. This leads to attempts to estimate the likelihood of commercialisation [60]. Incentives and disincentives for patent commercialisation remain an interesting research topic.

Future research directions might include the following:

1. It is worth assessing the coherence of technological research development in the field of automation and robotics with the level of maturity of the implementation of the Industry 4.0 concept. Future studies might investigate the diffusion of invented robotics technologies and their dissemination and adaptation in the form of solutions or applications. They could also assess the maturity of the innovation system by examining the scope of cross-sectoral cooperation in the field of robotics.
2. Published results prove that AI techniques can be utilised effectively and efficiently in applications covering digital indicators [61]. Although attempts to use text mining tools have already been made in various patent analyses [57, 62–64]. Further research should explore more in-depth the extent to which patent documents can serve as a data source for machine learning applications in automation and robotics, including advanced natural language processing systems.
3. The study of factors influencing the number of granted patents focused on automation and robotics, their citation frequency and commercialisation remains a rich and unexploited field with significant research and analytical potential.
4. Future research based on patent analysis could aim to offer a comprehensive analysis of individual automation and robotics technologies and their relevance and significance to different industrial sectors.

The robotics and automation market has grown significantly in recent years and is expected to continue to grow in the future. In addition, the share of technology-oriented research is increasing. The global landscape is therefore expected to change dynamically, both in terms of geographical distribution and thematic focus. The emergence of new technologies could have a significant impact on various industries, and the analysis could proactively anticipate and address any potential implications. This requires ongoing monitoring of the geographical dynamics of innovation capabilities in automation and robotics.

Bibliography

1. Ponta L., Puliga G., Manzini R., *A measure of innovation performance: the Innovation Patent Index*, “Management Decision”, Vol. 59, No. 13, 2021, 73–98, DOI: 10.1108/MD-05-2020-0545.
2. Gazni A., *The growing number of patent citations to scientific Papers: Changes in the world, nations, and fields*, “Technology in Society”, Vol. 62, 2020, DOI: 10.1016/j.techsoc.2020.101276.
3. Nazarko J. (red.), *Podlaska strategia rozwoju nanotechnologii do 2020 roku. Przełomowa wizja regionu*, Oficyna Wydawnicza Politechniki Białostockiej, Białystok 2013, [https://pbc.biaman.pl/dlibra/publication/31469/edition/30265/content].
4. Dehghani M., Mashatan A., Kennedy R.W., *Innovation within networks – patent strategies for blockchain technology*, “Journal of Business & Industrial Marketing”, Vol. 36, No. 12, 2021, 2113–2125, DOI: 10.1108/JBIM-05-2019-0236.
5. Mora-Apablaza L., Navarrete C., *Patents as indicators of the technological position of countries on a global level?*, “Scientometrics”, Vol. 127, No. 3, 2022, 1233–1246, DOI: 10.1007/s11192-022-04268-y.
6. Nazarko J., *Kształtowanie polityki proinnowacyjnej regionu np. foresightu technologicznego <<NT FOR Podlaskie 2020>>*, „Optimum. Studia Ekonomiczne”, Vol. 2, No. 50, 2011, 241–251.
7. Clarke N.S., Jürgens B., Herrero-Solana V., *Blockchain patent landscaping: An expert based methodology and search query*, “World Patent Information”, Vol. 61, 2020, DOI: 10.1016/j.wpi.2020.101964.
8. Wu L., Zhu H., Chen H., Roco M.C., *Comparing nanotechnology landscapes in the US and China: a patent analysis perspective*, “Journal of Nanoparticle Research”, Vol. 21, No. 8, 2019, DOI: 10.1007/s11051-019-4608-0.
9. Gadiya Y., Gribbon P., Hofmann-Apitius M., Zaliani A., *Pharmaceutical patent landscaping: A novel approach to understand patents from the drug discovery perspective*, “Artificial Intelligence in the Life Sciences”, Vol. 3, 2023, DOI: 10.1016/j.ailsci.2023.100069.
10. Lindman Å, Söderholm P., *Wind energy and green economy in Europe: Measuring policy-induced innovation using patent data*, “Applied Energy”, Vol. 179, 2016, 1351–1359, DOI: 10.1016/j.apenergy.2015.10.128.
11. De Paulo A.F., Graeff C.F.D.O., Porto G.S., *Uncovering emerging photovoltaic technologies based on patent analysis*, “World Patent Information”, Vol. 73, 2023, DOI: 10.1016/j.wpi.2023.102181.
12. Hu F., Mou S., Wei S., Qiu L., Hu H., Zhou H., *Research on the evolution of China’s photovoltaic technology innovation network from the perspective of patents*, “Energy Strategy Reviews”, Vol. 51, 2024, DOI: 10.1016/j.esr.2024.101309.
13. Arsad S.R., Ker P.J., Hannan M.A., Tang S.G.H., et al., *Patent landscape review of hydrogen production methods: Assessing technological updates and innovations*, “International Journal of Hydrogen Energy”, Vol. 50, 2024, 447–472, DOI: 10.1016/j.ijhydene.2023.09.085.
14. Iqbal Z., Sadaf S., *Artificial Intelligence/Machine Learning-based Innovations – A Review of Patent Eligibility Standards, Policies, Open Issues and Guiding Framework*, “Expert Systems with Applications”, Vol. 239, 2024, DOI: 10.1016/j.eswa.2023.121819.
15. Liu Y., Alias A.H.B., Haron N.A., Bakar N.A., Wang H., *Technology status tracing and trends in construction robotics: A patent analysis*, “World Patent Information”, Vol. 76, 2024, DOI: 10.1016/j.wpi.2023.102259.

16. Wang X., Daim T., Huang L., Li R., Shaikh R., Kassi D.F., *Monitoring the development trend and competition status of high technologies using patent analysis and bibliographic coupling: The case of electronic design automation technology*, "Technology in Society", Vol. 71, 2022, DOI: 10.1016/j.techsoc.2022.102076.
17. Ardito L., D'Adda D., Petruzzelli A.M., *Mapping innovation dynamics in the Internet of Things domain: Evidence from patent analysis*, "Technological Forecasting and Social Change", Vol. 136, 2018, 317–330, DOI: 10.1016/j.techfore.2017.04.022.
18. Jiang M., Yang S., Gao Q., *Multidimensional indicators to identify emerging technologies: Perspective of technological knowledge flow*, "Journal of Informetrics", Vol. 18, No. 1, 2024, DOI: 10.1016/j.joi.2023.101483.
19. Gładysz B., Corti D., Montini E., *Forecasting the Development of RFID Technology*, "Management and Production Engineering Review", 2021, 38–47, DOI: 10.24425/MPER.2021.136870.
20. Nazarko Ł., *Istota foresightu i jego percepcja w Polsce*, „Optimum. Studia Ekonomiczne", No. 4, 2011, 224–233.
21. Ejdys J., Nazarko Ł., *Foresight gospodarczy – instrumentem orientacji na przyszłość*, „Prace Naukowe Uniwersytetu Ekonomicznego we Wrocławiu", No. 340, 2014, 651–664, 10.15611/pn.2014.340.58.
22. Glińska U., Kononiuk A., Nazarko Ł., *Przegląd projektów foresightu branżowego w Polsce*, „Nauka i Szkolnictwo Wyższe", Vol. 2, 2008, 60–73.
23. Zieliński C., *Robotyka: techniki, funkcje, rola społeczna. Cz. 3. Roboty a problemy społeczne*, „Pomiary Automatyka Robotyka", Vol. 27, No. 2, 2023, 5–20, DOI: 10.14313/PAR_248/5.
24. Mytareva L.A., Gorshkova N.V., Shkarupa E.A., Yalmaev R.A., *The Cyber Economy and Digitization: Impacts on the Quality of Life*. [In:] Filippov V.M., Chursin A.A., Ragulina J.V., Popkova E.G. (eds), *The Cyber Economy. Contributions to Economics*. 2019, Springer, Cham. DOI: 10.1007/978-3-030-31566-5_3.
25. Gao Z., *Shadow of Technology: Robotics Development and Regional Economic Inequality*, "Journal of Knowledge Economy", 2024, DOI: 10.1007/s13132-024-01856-6.
26. Pollak A., Hilarowicz A., Walczak M., Gąsiorek D., *A Framework of Action for Implementation of Industry 4.0. an Empirically Based Research*, "Sustainability", Vol. 12, No. 14, 2020, DOI: 10.3390/su12145789.
27. Klimasara W., Pilat Z., *Urządzenie do wspomagania rehabilitacji ruchowej*, Patent 212834.
28. Nazarko Ł., *Responsible Research and Innovation in Enterprises: Benefits, Barriers and the Problem of Assessment*, "Journal of Open Innovation: Technology, Market, and Complexity", Vol. 6, No. 1, 2020, DOI: 10.3390/joitmc6010012.
29. Nazarko Ł., Melnikas B., *Operationalising Responsible Research and Innovation – tools for enterprises*, "Engineering Management in Production and Services", Vol. 11, No. 3, 2019, 21–28, DOI: 10.2478/emj-2019-0017.
30. Nazarko Ł., *Responsible Research and Innovation in Industry: From Ethical Acceptability to Social Desirability*, [In:] "Corporate Social Responsibility in the Manufacturing and Services Sectors", Golińska-Dawson P., Spychała M. (eds.), 2019, 127-138, DOI: 10.1007/978-3-642-33851-9_7.
31. Marino A., Pariso P., *Comparing European countries' performances in the transition towards the Circular Economy*, "Science of The Total Environment", Vol. 729, 2020, DOI: 10.1016/j.scitotenv.2020.138142.
32. Nazarko J., Glińska E., Glińska U., Ejdys J., *Kierunki rozwoju nanotechnologii w województwie podlaskim. Mapy. Marszruty. Trendy*, Oficyna Wydawnicza Politechniki Białostockiej, Białystok 2013, [https://pbc.biaman.pl/dlibra/publication/27112/edition/25904/content].
33. Chodakowska E., Nazarko J., *Hybrid Rough Set and Data Envelopment Analysis Approach to Technology Prioritisation*, "Technological and Economic Development of Economy", Vol. 26, Np. 4, 2020, 885–908, DOI: 10.3846/tede.2020.12538.
34. Scherngell T., Schwegmann K., Zahradnik G., *The geographical dynamics of global R&D collaboration networks in robotics: Evidence from co-patenting activities across urban areas worldwide*, "PLoS ONE", Vol. 18, No. 4, 2023, DOI: 10.1371/journal.pone.0281353.
35. Halásková M., Bednář P., *Effect of public and private sector R&D indicators on innovation performance and competitiveness: Case of the western European NUTS 2 regions*, "Journal of Competitiveness", Vol. 15, No. 3, 2023, 104–121, DOI: 10.7441/joc.2023.03.06.
36. Montresor S., Quatraro F., *Regional Branching and Key Enabling Technologies: Evidence from European Patent Data*, "Economic Geography", Vol. 93, No. 4, 2017, 367–396, DOI: 10.1080/00130095.2017.1326810.
37. Klincewicz K., *Robotics in the Context of Industry 4.0: Patenting Activities in Poland and Their Comparison with Global Developments*, "Problemy Zarządzania", Vol. 17, No. 2, 2019, 53–95, DOI: 10.7172/1644-9584.82.3.
38. Dritsaki M., Dritsaki C., Tsianaka E., *The effect of macroeconomic and environmental factors on innovation in EU member countries*, "Journal of Infrastructure, Policy and Development", Vol. 7, No. 3, 2023, DOI: 10.24294/jipd.v7i3.2560.
39. Furman J.L., Porter M.E., Stern S., *The determinants of national innovative capacity*, "Research Policy", Vol. 31, No. 6, 2002, 899–933, DOI: 10.1016/S0048-7333(01)00152-4.
40. Nazarko J., Chodakowska E., Nazarko Ł., *Evaluating the Transition of the European Union Member States towards a Circular Economy*, "Energies", Vol. 15, No. 11, 2022, DOI: 10.3390/en15113924.
41. Alola A.A., Bekun F.V., Obekra H.O., Adebayo T.S., *Explaining the environmental efficiency capability of energy mix innovation among the Nordic countries*, "Energy Reports", Vol. 11, 2024, 233–239, DOI: 10.1016/j.egyr.2023.11.051.
42. Baumann M., Domnik T., Haase M., Wulf C., Emmerich P., Rösh C., Zapp. P., Naegler T., Weil M., *Comparative patent analysis for the identification of global research trends for the case of battery storage, hydrogen and bioenergy*, "Technological Forecasting and Social Change", Vol. 165, 2021, DOI: 10.1016/j.techfore.2020.120505.
43. Grosse Ruse-Khan H., Metzger A. (eds.), *Intellectual Property Ordering Beyond Borders*, Cambridge University Press, 2022, DOI: 10.1017/9781009071338.
44. Rusek K., Kleszcz A., Cabellos-Aparicio A., *Bayesian inference of spatial and temporal relations in AI patents for EU countries*, "Scientometrics", Vol. 128, No. 6, 2023, 3313–3335, DOI: 10.1007/s11192-023-04699-1.
45. Porter A.L., Markley M., Snead R., Newman N.C. *Twenty years of US nanopatenting: Maintenance renewal scoring as an indicator of patent value*, "World Patent Information", Vol. 73, 2023, DOI: 10.1016/j.wpi.2023.102178.
46. Amoroso S., Aristodemou L., Criscuolo C., Dechezleprete A., Dernis H., Grassano N., Moussiegt L., Napolitano L., Nawa D., Squicciarini, M. and Tuebke, A., *World Corporate Top R&D investors: Paving the way for climate neutrality*, Publications Office of the European Union, Luxembourg, 2021, DOI: 10.2760/49552.

47. Santarelli E., Staccioli J., Vivarelli M., *Automation and related technologies: a mapping of the new knowledge base*, “Journal of Technology Transfer”, Vol. 48, 2013, 779–813, DOI: 10.1007/s10961-021-09914-w.
48. Goeldner M., Herstatt C., Tietze F., *The emergence of care robotics – A patent and publication analysis*, “Technological Forecasting and Social Change”, Vol. 92, 2015, 115–131, DOI: 10.1016/j.techfore.2014.09.005.
49. Fang X., Xu H., Chen B., Fang K., Li G., Mao Z., Zheng L., Jiang J., *Analysis of Swarm Robotics Cooperative Control Strategy from the Patent Perspective*, [In:] 2022 International Symposium on Intelligent Robotics and Systems (ISoIRS), 2022, 159–164, DOI: 10.1109/ISoIRS57349.2022.00039.
50. Kreuchauff F., Korzinov V., *A patent search strategy based on machine learning for the emerging field of service robotics*, “Scientometrics”, Vol. 111, 2017, 743–772, DOI: 10.1007/s11192-017-2268-3.
51. Kong D., Zhou Y., Liu Y., Xue L., *Using the data mining method to assess the innovation gap: A case of industrial robotics in a catching-up country*, “Technological Forecasting and Social Change”, Vol. 119, 2017, 80–97, DOI: 10.1016/j.techfore.2017.02.035.
52. Qiu Z., Wang Z., *Technology Forecasting Based on Semantic and Citation Analysis of Patents: A Case of Robotics Domain*, “IEEE Transactions on Engineering Management”, Vol. 69, No. 4, 2022, 1216–1236, DOI: 10.1109/TEM.2020.2978849.
53. Borregan-Alvarado J., Alvarez-Meaza I., Cilleruelo-Carrasco E., Garechana-Anacabe G., *Mapping Technological Profile of Collaborative Robots by Patent Analysis*, “International Journal of Human-Computer Interaction”, Vol. 39, No. 20, 2023, 3920–3935, DOI: 10.1080/10447318.2022.2108640.
54. Cséfalvay Z., Gkotsis P., *Robotisation race in Europe: the robotisation chain approach*, “Economics of Innovation and New Technology”, Vol. 31, No. 8, 2022, 693–710, DOI: 10.1080/10438599.2020.1849968.
55. Ding H., Cai C., *Patent Analysis and Structural Synthesis of Epicyclic Gear Trains Used I Automatic Transmissions*, “Applied Sciences”, Vol. 10, No. 1, 2019, DOI: 10.3390/app10010082.
56. Zhen-guo L., Gong-chang R., Yue-xin Y., Le W., *Application and research of patent evasion design in automatic connection device*, “Journal of Physics: Conference Series”, Vol. 1948, 2021, DOI: 10.1088/1742-6596/1948/1/012094.
57. Hu Z., Zhou X., Lin A., *Evaluation and identification of potential high-value patents in the field of integrated circuits using a multidimensional patent indicators pre-screening strategy and machine learning approaches*, “Journal of Informetrics”, Vol. 17, No. 2, 2023, DOI: 10.1016/j.joi.2023.101406.
58. Saniuk S., Grabowska S., Straka M., *Identification of Social and Economic Expectations: Contextual Reasons for the Transformation Process of Industry 4.0 into the Industry 5.0 Concept*, “Sustainability”, Vol. 14, No. 3, 2022, DOI: 10.3390/su14031391.
59. Lai M.-L., *Using Patent Data to Evaluate the Knowledge Dissemination of the Offshore Wind Power Industry*, “IEEE Transactions on Engineering Management”, Vol. 71, 2023, 7128–7133, DOI: 10.1109/TEM.2023.3277481.
60. Svensson R., *Patent value indicators and technological innovation*, “Empirical Economics”, Vol. 62, No. 4, 2022, 1715–1742, DOI: 10.1007/s00181-021-02082-8.
61. Tümer A.E., Kabaklarlı E., *Forecasting Gross Domestic Product (GDP) of OECD Countries Based on Digital Transformation Indicators: ANN Approach*, “EDPACS”, Vol. 69, No. 1, 2024, 88–102, DOI: 10.1080/07366981.2024.2312015.
62. Hamzah A.S.S.S.A., Saipan@Saipol H.F., Nordin S.Z., Shaffiei Z.A., Ohshima N., *Adopting Text Mining for Patent Analysis to Determine the Attribute and Segment in Automotive Industries*, “Journal of Advanced Research in Applied Sciences and Engineering Technology”, Vol. 37, No. 2, 2024, 94–103, DOI: 10.37934/araset.37.2.94103.
63. Mann K., Puttmann L., *Benign Effects of Automation: New Evidence from Patent Texts*, “The Review of Economics and Statistics”, Vol. 105, No. 3, 2023, 562–579, DOI: 10.1162/rest_a_01083.
64. Chen P.P.J., Trappey A.I.C., Lin B.H.L., Trappey C.V., *Patent Analytics of Robotics Technology for Intelligent Manufacturing in the Semiconductor Industry*, [In:] 2018 IEEE 22nd International Conference on Computer Supported Cooperative Work in Design (CSCWD), 2018, 213–217, DOI: 10.1109/CSCWD.2018.8465276.

Other sources

65. OECD, Eurostat, *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation*, 4th Edition, [In:] The Measurement of Scientific, Technological and Innovation Activities, OECD, 2018, DOI: 10.1787/9789264304604-en.
66. OECD, *OECD Patent Statistics Manual*, OECD, 2009, DOI: 10.1787/9789264056442-en.
67. Cambridge University Press, *Intellectual Property*, [In:] Cambridge Dictionary, [https://dictionary.cambridge.org/dictionary/english/intellectual-property].
68. World Intellectual Property Organization, *What is Intellectual Property*?, [www.wipo.int/about-ip/en].
69. The United States Patent and Trademark Office, *Patent essentials*, [www.uspto.gov/patents/basics/essentials].
70. World Intellectual Property Organization, *The PCT now has 157 Contracting States*, [www.wipo.int/pct/en/pct_contracting_states.html].
71. World Intellectual Property Organization, *Guide to the International Patent Classification*, 2024.
72. World Intellectual Property Organization, *Patent Landscape Report: Generative Artificial Intelligence,* 2024, DOI: 10.34667/tind.49740.
73. World Intellectual Property Organization, *The WIPO Manual on Open Source Analytics*, 2nd edition, 2022, [https://wipo-analytics.github.io/manual/index.html].
74. World Intellectual Property Organization, *Global Innovation Index 2023. Innovation in the face of uncertainty*, 16th edition, 2023, DOI: 10.34667/tind.48228.
75. Es-Sadki N., Hollanders H., *European Innovation Scoreboard 2023*, Report, Publications Office of the European Union.
76. World Intellectual Property Organization, *World Intellectual Property Indicators 2023,* DOI: 10.34667/tind.48541.
77. OECD, *OECD Science, Technology and Industry Scoreboard 2017*, OECD, 2017, DOI: 10.1787/9789264268821-en.
78. World Intellectual Property Organization, *WIPO Statistical Country Profiles*, 2022, [https://wipo.int/ipstats/en/statistics/country_profile].
79. Worldwide Patent Statistical Database, *EPO PATSTAT*, [www.epo.org/en/searching-for-patents/business/patstat].
80. U.S. Patent & Trademark Office, *PatentsView*, [https://patentsview.org].
81. Minesoft, *PatBase*, [www.patbase.com].
82. World Intellectual Property Organization, *WIPO Technology Trends 2019 – Artificial Intelligence,* 2019, DOI: 10.34667/tind.29084.
83. World Intellectual Property Organization, *Graphite and its applications,* 2023, DOI: 10.34667/tind.47589.

84. Industrie 4.0 Working Group, *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0*, 2013, [https://en.acatech.de/wp-content/uploads/sites/6/2018/03/Final_report___Industrie_4.0_accessible.pdf].
85. World Intellectual Property Organization, *WIPO IP Statistics Data Center*, 2023, [https://www3.wipo.int/ipstats/key-search/indicator].
86. World Intellectual Property Organization, *PCT NEWSLETTER*, 2024, No. 03/2024, [www.wipo.int/pct/en/newslett].
87. World Intellectual Property Organization, *World Intellectual Property Report 2024: Making Innovation Work for Development,* 2024, DOI: 10.34667/tind.49284.
88. European Commission, *Eurostat*, [https://ec.europa.eu/eurostat/web/science-technology--innovation/database].
89. Google, *Google Patents*, [https://patents.google.com].
90. Clarivate, *Top 100 Global Innovators 2024*, [clarivate.com/top-100-innovators].

Porównanie krajów pod względem zdolności innowacyjnych w obszarze automatyki i robotyki

Streszczenie: W dzisiejszym dynamicznym i globalnym środowisku gospodarczym innowacje technologiczne są kluczowym wyznacznikiem międzynarodowej konkurencyjności. W dziedzinie automatyki i robotyki szczególne znaczenie ma rozwój nowoczesnych technologii, które wpływają nie tylko na postęp przemysłowy, ale także na aspekty społeczne. Automatyka i robotyka odgrywają kluczową rolę w koncepcji nowoczesnego przemysłu, przyczyniając się do tworzenia bardziej zrównoważonych, elastycznych i skoncentrowanych na człowieku systemów produkcyjnych. Artykuł ma na celu pogłębioną analizę aktywności patentowej w dziedzinie automatyki i robotyki w Europie. Dokumentacja patentowa jest źródłem wiedzy o kierunkach badań, działalności wynalazczej, a co za tym idzie, potencjale innowacyjnym i konkurencyjnym gospodarki. Liczba patentów w czasie odzwierciedla dynamikę rozwoju technologicznego kraju. W artykule przedstawiono dotychczasowe wykorzystanie baz patentowych do oceny innowacyjności krajów, w tym w automatyce i robotyce. Przeprowadzona analiza danych dotyczących krajów europejskich pozwoliła na identyfikację trendów w oparciu o Międzynarodową Klasyfikację Patentową, a także specjalizacji z perspektywy geograficznej za pomocą wskaźników ujawnionej komparatywnej przewagi technologicznej. Kraje europejskie sklasyfikowano za pomocą analizy skupień, wykazując różnorodność i identyfikując liderów w każdej grupie.

Słowa kluczowe: patenty, innowacje, przemysł przyszłości, robotyzacja, automatyzacja, UE

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