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Technology Transfer, and Intellectual Property as Key Drivers of Economic Resilience: Comparative Evidence from the European Union and Romania

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Abstract

In recent years, the economies of Romania and other European Union member states have faced significant challenges caused by the COVID-19 pandemic, economic instability, and geopolitical tensions. These crises have highlighted the urgent need for sustainable digital transformation. The purpose of this paper is to analyze the economic impact of sustainable digitalization and to assess the role of technology transfer and intellectual property protection in fostering innovation and long-term growth. The study employs an exploratory research design based on secondary data, focusing on patent dynamics, and digitalization levels across EU economies, with particular emphasis on Romania. The findings reveal a persistent structural gap between Romania and the EU average in terms of R&D intensity, patent activity, and digital performance indicators such as the Digital Economy and Society Index. Despite possessing advanced digital infrastructure, Romania continues to lag behind in innovation capacity and the protection of emerging technology-based inventions. Strengthening technology transfer mechanisms, increasing R&D investment, and modernizing the IP legislative framework are essential for bridging this gap. The paper concludes that sustainable digital transformation, underpinned by effective technology transfer and robust IP protection, should be regarded as an integrated strategy for enhancing competitiveness, stimulating innovation, and ensuring resilient economic development.

Keywords: Economic Resilience, Sustainable Digital Transformation, Technology Transfer, Intellectual Property Rights

Introduction

In recent years, both Romania and other European Union (EU) member states have been strongly affected by global economic, geopolitical and health crises. In response to the emergence of crises, a strong need for sustainable digital transformation across all EU

member states and, implicitly, in Romania has shown off. This transformation entails the adoption of emerging technologies such as artificial intelligence, blockchain (Wang et al., 2019), cloud computing, robotics, and augmented reality across diverse sectors to foster long-term development and to address challenges generated by these crises. The integration of such disruptive technologies has the potential to strengthen economic resilience and enhance long-term competitiveness.

Sustainable digitalization should be regarded as a macroeconomic priority, as it enables the optimization of resources and the improvement of economic processes over time. Furthermore, the use of emerging technologies supports employees' activities, streamlines operational processes, facilitates the resolution of complex problems, and contributes to more efficient time management. The emergence and diffusion of these technologies, both in Romania and across other EU member states, have increased inventors' interest in leveraging them to create new products and solutions that deliver significant improvements across various sectors. However, these advancements have a major requirement that consists of intellectual property (IP) protection (Katleho, 2024).

In addition, with the occurrence of novel digital instruments, challenges in protecting intellectual property rights have emerged (Unnikrishnan, 2024). Whereas in the past IP protection received limited attention with regard to emerging technologies, over time specialists have increasingly focused their research and strategic efforts on this field (Gonzalez and Garcia, 2021). Protecting the rights of creators working with emerging technologies serves not only to foster innovation, but also to strengthen economic competitiveness and reinforce economic security. Achieving these goals requires a well-designed and flexible legislative framework that allows inventors, companies, and government institutions to safeguard their new technology-based ideas. However, recent experience has shown that the widespread use of such technologies has also facilitated intellectual property infringements (Qianlan et al., 2024).

Given these considerations, it can be stated that in an era characterized by the expanding use of emerging technologies regulated by the protection of intellectual property for sustainable digital transformation and in the R&D field became important elements for the strategies of economic resilience. In the case of developing countries in which investments in research remains low and the pace of digital technology adoption is slower, the creation of a robust IP protection system for new technology-based inventions is vital. Such a system contributes to narrowing the innovation gap and strengthening their position within the European single market.

The motivation for conducting this study stems from the increasing importance of sustainable digital transformation as a key factor in strengthening economic resilience both at the level of the European Union and in Romania. Although significant progress has been made in recent years in advancing digitalization, Romania still faces a series of challenges related to research and development activities, digital adoption, and the protection of intellectual property rights. In order to reduce the existing innovation gap and to enhance long-term competitiveness, it is essential to analyze these bottlenecks and address them in a timely and effective manner.

The novelty and contribution of this paper lie in providing an integrated analysis of sustainable digitalization, technology transfer, and intellectual property within the context of the European Union member states. The study combines theoretical perspectives with existing statistical data in order to identify the main strategic actions capable of strengthening innovation and facilitating technology transfer, thereby supporting sustainable economic growth.

Literature Review

Globalization and new technology have led to a shift in emphasis from capital and material assets to information and intangible assets. The focus of TT has recently shifted from capital and tangible assets to assets based on information and people resources due to recognized competitive advantages provided by a global economy. The shift in TT's emphasis to perception, knowledge, and creativity suggests that the process's participants are capable and driven to find opportunities to apply and exchange these goods by advancing them in society. A variety of policy directions, particularly those pertaining to entrepreneurship, as well as intellectual property rights (IPRs), new areas of academic and economic endeavors, cluster policies, and initiatives at the municipal and regional levels are to be considered in order to support and promote the process (Marinko and Domingo, 2021).

Any type of economic growth that does not negatively impact the environment is by definition considered sustainable. According to Solow (1956), economic growth is directly impacted by the long-term relationship between innovation and growth. This claim has been empirically supported by a variety of research studies.

However, the environment may occasionally suffer as a result of innovation and technology transfer. As a result, the growing use of inventions and technology has raised serious concerns about the cost in terms of environmental harm (i.e., climate change). In international contexts, the word "technology transfer" usually refers to the sale or licensing of intellectual property, but it can also apply to any procedure that allows inhabitants of one nation to access and use technology created in another (Fernandes et al., 2021).

The process of technology transfer between institutions is known as TT. When the receiving organization (the transferee) is able to use and incorporate the transferred technology into its processes and products, the transfer is deemed successful. Additionally, the transfer procedure could involve exchanging technical data, tangible assets, and expertise (Simelytė et al., 2021).The idea of TT has also been presented in relation to people migration or exchange, as well as the transfer of certain technical skills and competencies. Other types of TT include moving technology from developed to developing nations, from lab to industry, or from one field to another. From a narrower standpoint, TT is seen as the practical application of information when technology is considered as information alone (Pandey et al. 2022).

One of the main forces behind innovation is intellectual property, and the more valuable an invention is, the more likely it is to be desired by someone. The approach used to turn intellectual property into an economically viable asset determines its worth. Generally speaking, innovation is a fresh perspective on how businesses should be built and how novel concepts and technologies can be effectively marketed. Whether technology-based businesses commercialize new or upgraded technology, innovation is a key factor in making

them more competitive and can be secured by intellectual property rights (Kokhanovska and Kodynets, 2021).

However, in the new I4.0 era, innovation has also been crucial to technology transfer. Yun et al. (2020) discuss the ways in which closed innovation approaches diverge from the worldwide open innovation movement, which is only growing stronger with I4.0. Conversely, open innovation-enabled patent commercialization raises the likelihood of technology transfer-based commercialization.

The implementation of Industry 4.0 lacks technology transfer. This is particularly the case of developing economies that have a decreased use of digital instruments. Moreover, novel technologies involve an uninterrupted and developing process of technology transfer in order to be adopted.

In the case of developed nations, they are able to generate technology and knowledge via spendings in the R&D sector as well as internal improvements (Hadi, 2024).

One of the most significant technologies introduced by the Fourth Industrial Revolution or 4IR is artificial intelligence (AI), which plays an important role in the optimization of energy, transportation and industries. Safari et al. (2024) states that smart grids utilize this technology in order to control the distribution of energy, to minimize waste, and to encourage the utilization of renewable energy sources. In addition, artificial intelligence is able to monitor the environmental challenges and to aware about climatic hazards, thus building climate resilience (Rolnick et al., 2019). Another role played by AI is represented by smart cities, which are environmental-oriented human settlements (Kwilinski et al., 2024).

This technology shows a great issue in what concerns patent law, whether its applications are able to qualify as patent or not. The debut conference on patenting artificial intelligence was held in 2018, at the European Patent Office (EPO, 2018).In the following year, the report *"Technology Trends 2019 – Artificial Intelligence"* was released by the World Intellectual Property Organization (WIPO)(WIPO, 2019).

With the evolution of artificial intelligence and complementary instruments rise the concerns about the general innovation protection and the applicability of intellectual property rights to the materials, content, and data produced by these technologies. These materials and data may be of an artistic or industrial nature, and they open up a range of commercial opportunities.

In order to achieve its goals of becoming a global leader in AI technologies, safeguarding the EU's industrial and digital sovereignty, ensuring its competitiveness, and promoting and safeguarding innovation, the European Union needs to restructure its industrial policy in a way that respects cultural diversity. Therefore, the European Union has submitted a revised coherent plan for AI as well as a proposal for a legal framework for AI to the European Commission in response to the rapid advancements in technology and the global policy environment in which an increasing number of nations are making significant investments in AI (EU, 2021).

An efficient intellectual property system that is suited for the digital era is necessary for the EU to maintain its position as a global leader in AI and to allow entrepreneurs to launch new goods. To prevent misuses that hurt creative AI inventors, the EU patent system must include robust protections (European Parliament, 2020).The EU creates and executes a number of initiatives to boost the capacity for knowledge generation and innovation development over an extended period of time. The EU has created Digital Innovation Hubs (DIHs) under the Digital Europe Program in this regard. The goal of DIHs is to make sure that all businesses, regardless of size or technology, can take advantage of digital opportunities. When it comes to their business/production operations, goods, or facilities, DIHs are one-stop shops that use digital technology to help businesses become more competitive.

The EU has viewed the idea as a means of addressing important issues with pollution, energy, poverty, and urbanization in addition to generating economic prosperity. Given the heterogeneous nature of the EU environment, the EU's innovation aim is primarily predicated on the notion of creating an eco-system at the European level through knowledge dissemination, experience sharing, and policy borrowing (European Commission, 2025).

The Internet of Things (IoT) is one essential technology of Industry 4.0. It has many uses in sectors as smart cities, healthcare and energy, with the potential of bettering the life quality. This is made possible by offering more real-time automated decision-making and supporting tools for decision optimization. Additionally, IoT can assist the energy industry in moving from a centralized energy system to a distributed, intelligent, and integrated one. Large-scale data gathering and the application of clever algorithms for real-time data analysis can aid in the more effective monitoring of energy consumption trends across various time scales by various users and devices(Schroeder et al. 2020).

Another important technology of Industry 4.0 is Cloud computing. It has become a disruptive force that is changing how companies function, develop, and expand. Cloud computing is the foundation of digital transformation because it enables companies to adjust to shifting market conditions. Additionally, this technology gives businesses the cost-effectiveness, scalability, and flexibility they need to deal with a quickly changing environment. Fundamentally, cloud computing uses the internet to provide on-demand access to computer resources, including servers, storage, and applications. Subscription-based business models have replaced capital-intensive IT investments, democratizing access to cutting-edge technologies and enabling both major corporations and entrepreneurs(Bell, 2024).

Blockchain is another disruptive technology of 4IR, now regarded as a game-changing technology that makes logistics and supply chains more sustainable. Blockchain is a distributed data format in which members share a distributed digital ledger. Blockchain can improve product lifecycle visibility, boost operational efficiency, stimulate sustainability reporting and monitoring, and encourage green consumer behavior since it can guarantee security, traceability, and transparency. Additionally, blockchain technology has been applied in a variety of industries, including healthcare, because of the increased confidentiality and anonymity it offers. One of the most crucial resources in healthcare systems is health records, which must be accurately and efficiently supplied to participants. The healthcare sector could undergo a change thanks to the immutability, decentralization, and security that blockchain technology provides (Qingying et al. 2022).

Methodology

Regarding the research methodology, at the level of this paper, an exploratory analysis has been conducted. The main objective of the study was identifying the evolution of the number of patents related to emerging technologies in recent years, both at the European Union (EU) level and within Romania. In addition, the study examined the annual amounts assigned to research and development (R&D) activities at the national level, as well as the measures adopted by EU member states to stimulate the development of these emerging technologies. Another important aspect of the research focused on assessing the degree of digitalization of Romanian companies and the actions taken to protect the inventions resulting from this process. To achieve these objectives, statistical data available at both national and European levels were analyzed. From a temporal perspective, the study was carried out between July and August 2025 and was based on an analysis of secondary data sourced from reliable and up-to-date official databases.

Results

Table 1 presents the evolution of the number of PCT patents by technological category in Romania and comparable economies in the period 2015–2024. The indicator analyzed within the table was *''5a – PCT publications by technology''*, a subcomponent of the broader *''5.1 – PCT international applications''*, regarding the international patent applications filed under the Patent Cooperation Treaty (PCT). The analyzed data was divided into two categories: the first one comprising patents in the field of ICT (e.g. telecommunications, AI, cloud computing) and the second referring to industrial PCT patents (e.g. domains such as civil engineering, transportation and logistics).

In the case of Romania, the number of PCT patents marked a downturn of around 25% in 2024 compared to 2015, which represent a decrease from 51 patents in 2015 to 38 in 2024. Opposed to, Portugal showed an increase of 46% from 173 patents in 2015 to 253 in 2024. A similar downward trend can be observed in other countries such as Greece, Bulgaria, and Hungary.

Romania's situation highlights the absence of a coherent and sustainable policy framework in the research and development sector, a pattern further reflected in the downward trend of total international patent applications (WIPO, 2025).

Table 1
Evolution of the number of PCT patents by technological category in Romania and comparable economies (2015–2024)

Country	Category	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Portugal	Industry	141	142	188	199	166	214	209	188	210	208
Portugal	Technology	32	29	38	39	33	58	34	43	56	45
Portugal	**Total PCT Patents**	**173**	**171**	**226**	**238**	**199**	**272**	**243**	**231**	**266**	**253**
Czech Republic	Industry	188	214	175	146	174	167	211	234	198	183
Czech Republic	Technology	19	20	22	31	43	20	32	36	27	41

Czech Republic	**Total PCT Patents**	**207**	**234**	**197**	**177**	**217**	**187**	**243**	**270**	**225**	**224**
Hungary	Industry	148	137	157	132	133	136	102	124	111	131
Hungary	Technology	27	26	31	23	31	25	21	16	27	24
Hungary	**Total PCT Patents**	**175**	**163**	**188**	**155**	**164**	**161**	**123**	**140**	**138**	**155**
Greece	Industry	86	89	93	108	101	125	77	97	100	80
Greece	Technology	16	14	5	12	6	11	12	8	26	17
Greece	**Total PCT Patents**	**102**	**103**	**98**	**120**	**107**	**136**	**89**	**105**	**126**	**97**
Bulgaria	Industry	40	49	41	42	50	47	61	26	37	33
Bulgaria	Technology	9	16	12	11	9	8	6	7	6	7
Bulgaria	**Total PCT Patents**	**49**	**65**	**53**	**53**	**59**	**55**	**67**	**33**	**43**	**40**
Romania	Industry	42	28	27	30	26	32	34	37	28	30
Romania	Technology	9	6	7	10	3	4	3	7	10	8
Romania	**Total PCT Patents**	**51**	**34**	**34**	**40**	**29**	**36**	**37**	**44**	**38**	**38**

Source: Adapted from WIPO, 2025

Based on the statistical data presented earlier, which illustrate the situation of PCT patent applications in Romania and in countries with comparable economies, *Table 2* below was developed to depict the evolution of the share of technology-related patents within the total number of PCT applications. The proportion of patents originating from the technology sector has shown a relatively stable evolution during the period 2015–2024, fluctuating between 13% and 18%. Between 2015 and 2020, this proportion remained steady, ranging from 14% to 16%, which reflects a modest yet consistent contribution of the technological sector to the overall volume of international patent applications.

Starting in 2021, a gradual upward trend can be observed, reaching 18% in the years 2023–2024. This progression indicates a strengthening of technological innovation activities in recent years. After a period of relative stagnation, the share of technology-related patents within total PCT filings has increased, suggesting a growing orientation toward digitalization, information technologies, and technological innovation across the economy (WIPO, 2025).

Table 2
Share of technology patents in total international PCT applications, 2015–2024

Category	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024
Industry	85%	86%	86%	84%	84%	85%	87%	86%	82%	82%
Technology	15%	14%	14%	16%	16%	15%	13%	14%	18%	18%
Total PCT Patents	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Source: Adapted from WIPO, 2025

Table 3 presents the dynamics of R&D spending as a share of GDP at the level of the European Union. The data presented in the table indicates that Romania is situated on the last position within the EU member states in terms of the share of R&D spending in GDP. Romania's ten-year average is 0.48%, while the five-year average is 0.47%, significantly below the European Union average of 2.16%. Romania's growth rate shows a slight negative trend

(-0.01%), suggesting a stagnation in R&D investment. This situation stands in sharp contrast to the performance of countries such as Finland and Malta, which, despite starting from different levels, have managed to record steady increases in research and innovation investment.

The analysis of the deviation from the mean, estimated at 3.7%, indicates a low annual variability of R&D expenditures, but in a negative direction, as the five-year average is lower than that of the previous period. The coefficient of variation, calculated as the ratio between the deviation from the mean and the ten-year average, stands at 8%, confirming a relative stability of the indicator, yet at a very low level.

Romania's slow pace of growth and the low level of investment reveal an economy that fails to fully capitalize on the potential of innovation and technological progress, thereby limiting its long-term competitiveness. In this context, the adoption of coherent public policies, the strengthening of both public and private investments, as well as the implementation of an integrated strategy to support the R&D ecosystem play an essential role in reducing the structural gap between Romania and the other EU member states (Eurostat (a), 2025).

Table 3
Dynamics of R&D spending as a share of GDP in the European Union

Country	Ten-Year Average	Five-Year Average	Growth Rate	Values for 2023	Deviation from the Mean	Coefficient of Variation
Sweden	3.39%	3.37%	-0.02%	3.64%	14.4%	4%
Austria	3.15%	3.12%	-0.03%	3.26%	6.7%	2%
Finland	2.92%	2.99%	0.07%	3.09%	13.7%	5%
Germany	3.01%	2.97%	-0.03%	3.13%	10.3%	3%
Denmark	2.96%	2.96%	0.00%	3.07%	9.5%	3%
EU Average	2.18%	2.16%	-0.02%	2.26%	6.7%	3%
Slovakia	0.91%	0.90%	-0.02%	1.03%	10.4%	11%
Bulgaria	0.80%	0.77%	-0.03%	0.79%	6.0%	8%
Latvia	0.68%	0.68%	0.00%	0.82%	11.4%	17%
Malta	0.60%	0.62%	0.03%	0.64%	5.6%	9%
Cyprus	0.64%	0.61%	-0.03%	0.68%	11.5%	18%
Romania	0.48%	0.47%	-0.01%	0.52%	3.7%	8%

Source: Adapted from Eurostat (a), 2025

Figure 1 illustrates the dynamics of research and development (R&D) spending as a share of GDP during the period 2012–2023. Within thee figure, the top three EU member states with the highest level of R&D spending, along the last three states were analyzed, as well as Romania and the EU average.

As it can be observed, Romania consistently ranked in the lower segment of the European classification, being most of the time on the last position. Its five-year average stands at 0.47%, being substantially below the EU average that is 2.16%, as well as below the levels recorded by Cyprus and Malta, both registering an average share of 0.62%.

The evolution of this indicator in Romania reveals a structural stagnation, with a value of 0.46% in 2012 and only 0.52% in 2023, while the EU average increased over the same period to 2.26%. The considerable gap between Romania and the European average underscores the persistent disparity in research and innovation investments.

To reduce this gap, Romania must intensify its efforts to finance research and development activities, aiming for a gradual alignment with the levels recorded by countries with comparable GDP sizes, such as the Czech Republic (five-year average of 1.85% of GDP), Portugal (1.44%), and Hungary (1.40%). In this regard, it is essential to design and implement a national strategic plan aimed at progressively increasing the share of R&D spending in GDP, with the purpose of reducing the competitiveness gap and strengthen Romania's innovation capacity (Eurostat (b), 2025).

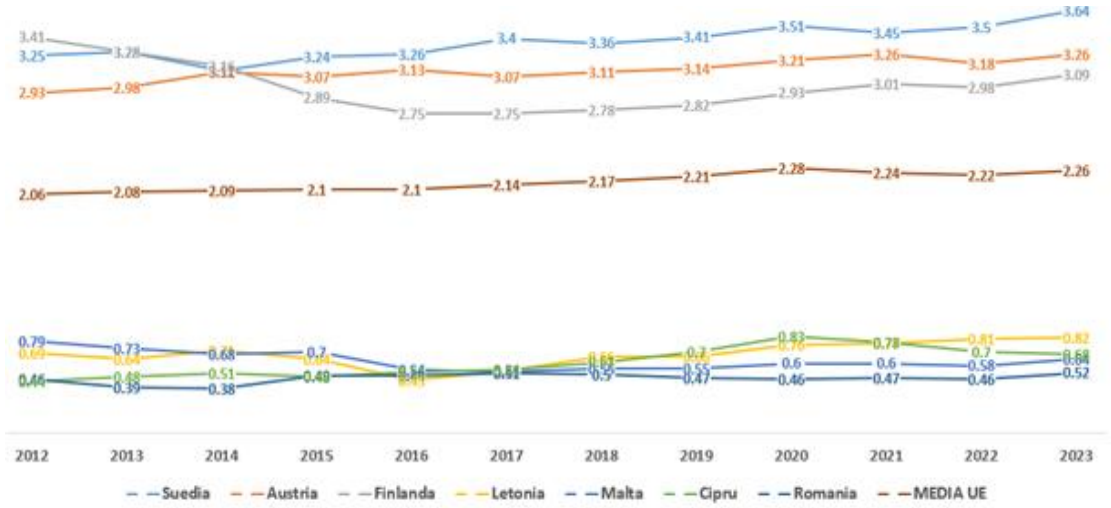

Figure 1. Dynamics of research and development (R&D) spending as a share of GDP during the period 2012–2023
Source: Eurostat (b), 2025

To assess the level of digitalization of European economies and societies, data provided by the European Commission regarding the Digital Economy and Society Index (DESI) and its components were analyzed. The DESI index is calculated annually for each European Union member state and is structured around four main dimensions:

- Human capital
- Digital infrastructure
- Integration of digital technologies into the economy (e-commerce)
- Digitalization of public administration (e-Government)

The first dimension, referring to human capital, evaluates the population's competencies in using the internet, as well as the development of advanced digital skills. The second component reflects the level of adoption of fixed and mobile broadband connections, network coverage, and the competitiveness of service pricing. The third dimension, integration of digital technologies, captures the degree of digitalization within the business environment and the extent of e-commerce adoption. The final component, digitalization of public services (e-Government), assesses the degree of digital transformation in public administration and the availability of electronic services provided to citizens.

Figure 2 presents the use of Electronic Government (e-Government) Services for Online Interaction with Public Authorities in the Last 12 Months (% of Internet Users) in the year 2021.

At the European Union level, the average utilization of electronic services for interacting with public administration is approximately 60%. The highest values are recorded in Sweden, Denmark, and Finland, where over 90% of citizens use e-government services. In contrast, Romania ranks last among EU member states, with a usage rate below 20%, significantly lower than Bulgaria (approximately 35%), and well below the EU average.

The results obtained by Romania indicate a low level of digitalization within public administration and a limited adoption of e-government services. The main contributing factors include low public trust in governmental digital platforms, the limited availability or suboptimal functionality of online public services, insufficient digital skills among the population, as well as the persistence of bureaucracy and traditional, predominantly offline administrative processes (Eurostat, 2022).

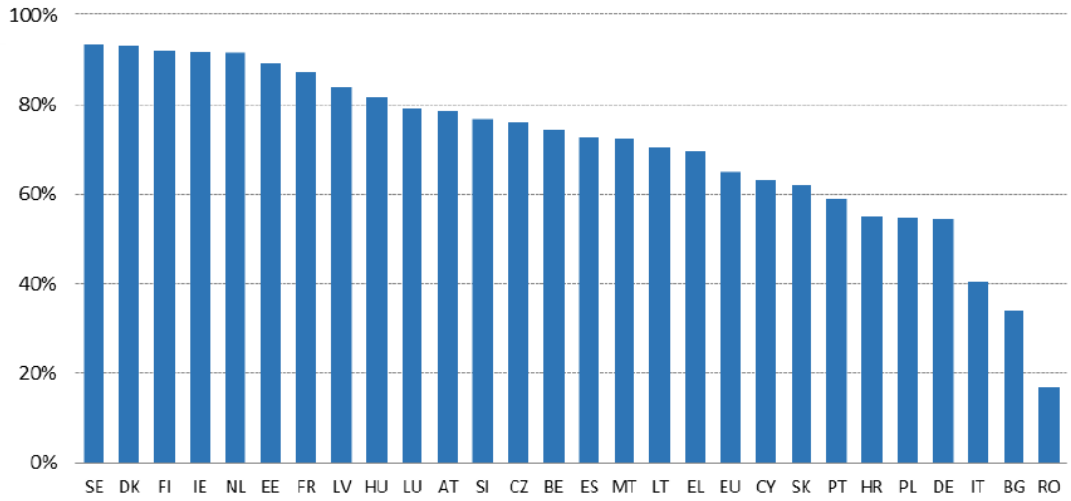

Figure 2. Use of Electronic Government (e-Government) Services for Online Interaction with Public Authorities in the Last 12 Months (% of Internet Users) in 2021
Source: Eurostat, 2022

Figure 3 shows an analysis of the DESI report from 2022. It can be observed that Romania is situated on the last position with a score of 30 points, compared to the EU that recorded 56 points.

The lowest score recorded by Romania was in the area of public service digitalization (e-government). In contrast, the connectivity component (IT infrastructure) contributes positively to Romania's overall DESI score. From the perspective of digital infrastructure, Romania benefits from a high-performance fiber-optic and broadband network, comparable even to that of more developed countries such as Germany or France.

However, this structural advantage remains insufficiently leveraged through the digitalization of public institutions and the development of citizens' digital skills, resulting in an overall low level of DESI performance. Considering these findings, it should be noted that Romania

possesses the necessary infrastructure to accelerate digital transformation, yet the lack of effective implementation of e-government policies and digital training programs continues to limit its convergence capacity with other EU member states (Eurostat, 2022).

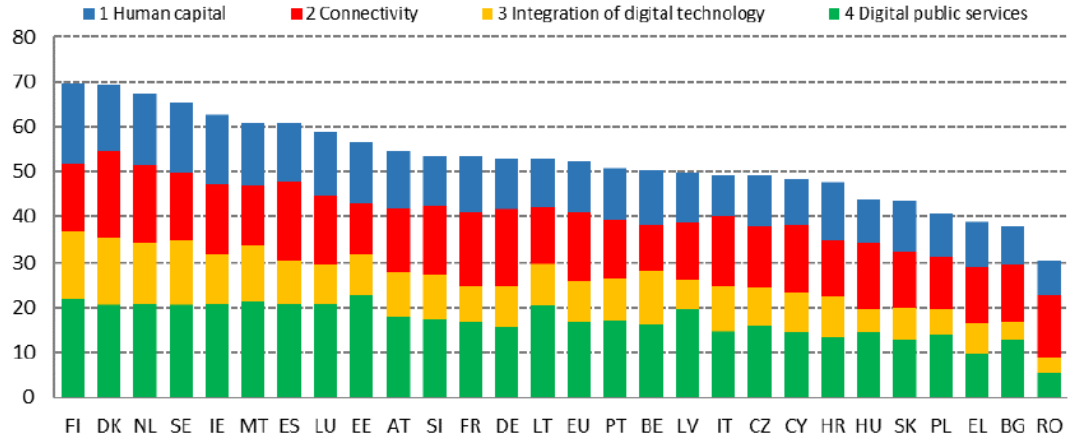

Figure 3. Digitalization level of the economy and society within the European Union according to the DESI Index, 2022
Source: Eurostat, 2022

Another important aspect addressed in this study concerns the analysis of patent applications in the field of digital communication that can be seen in *Figure 4*. This analytical approach serves as a fundamental instrument for understanding the global dynamics of technological innovation and for identifying emerging centers of excellence within this strategic domain. Digital communication represents the foundational infrastructure of contemporary economic transformation, exerting a direct influence on critical areas such as artificial intelligence, the Internet of Things, telecommunications networks, and cyber security.

Examining the geographical distribution of patent applications enables the assessment of each economy's capacity for research, development, and technological transfer, while also offering insights into the global balance of technological competition. In this regard, comparative analysis between countries highlights the degree of national engagement in shaping and consolidating the future global digital ecosystem, indicating the priority directions of investment and innovation strategies.

The field of digital communication encompasses a wide range of fundamental technologies, from basic electronic circuits to complex electronic communication systems. Among these are components such as amplifiers, decoders, and telegraphic communication systems, which form essential elements of modern information infrastructure. Consequently, the analysis of patents in this sector not only reflects the pace of technological progress but also contributes to understanding the interdependencies between innovation, economic competitiveness, and technological security on a global scale.

The results for the year 2024 illustrate the distribution of patent applications in digital communication by country of origin, providing a clear picture of the geographical concentration of innovative activity. The data reveal a predominance of applications

originating from the United States (29%) and China (27%), with these two economies together accounting for more than half of the global total. This dominance reflects the consolidated position of the two major technological innovation hubs, where robust digital ecosystems, advanced research infrastructures, and supportive innovation policies foster continuous development of emerging technologies.

East Asia continues to play a significant role in advancing global digital communication, through the consistent contributions of South Korea (9.9%) and Japan (7.5%), confirming its status as a region with advanced technological capacity and a well-established tradition in electronics and telecommunications. In contrast, Europe exhibits a more fragmented structure, with notable shares in countries such as Sweden (6.4%), Finland (5.1%), and Germany (3.9%), followed by France and the Netherlands. Although these contributions are regionally relevant, they do not establish a dominant position in the global landscape of digital innovation.

Overall, the analysis indicates that innovation in digital communication is heavily concentrated around two major centers, the United States and East Asia (particularly China, South Korea, and Japan), while Europe maintains a consistent yet dispersed presence, characterized by localized technological specializations and increased transnational collaboration (European Patent Office (a), 2025).

of origin

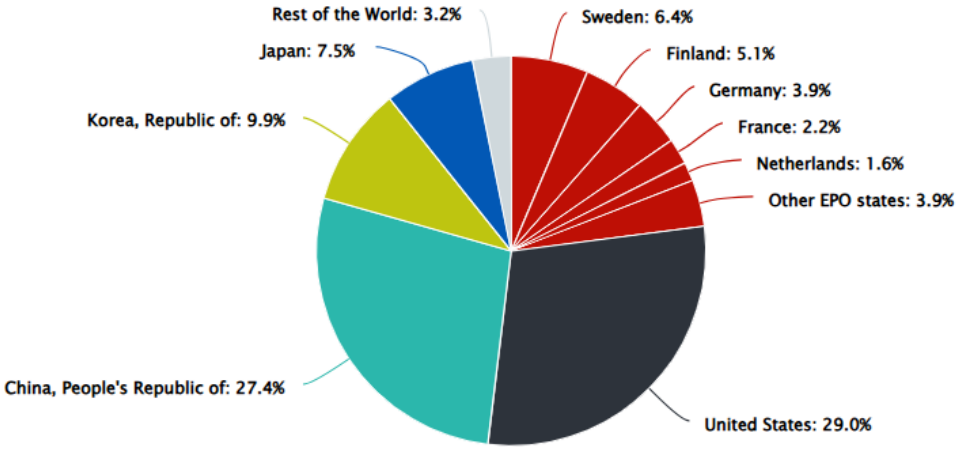

Figure 4. Distribution of patent applications in the field of digital communications by country
Source: European Patent Office (a), 2025

Building upon the distribution of patent applications, which confirms the concentration of innovation around major technological powers, it was deemed necessary to extend the analysis to encompass the entire spectrum of advanced technologies. The investigation in *Figure 5*was based on patent applications submitted in 2024 within the technological sector as a whole.

This broader perspective provides an integrated view of how the world's economies contribute to global scientific and technological progress. It also enables the identification of dominant innovation trends and the assessment of competitive dynamics among leading

economic regions, reflecting the ways in which national research and development strategies shape the global technological landscape.

The United States holds the largest share of patent applications, accounting for approximately 24% of the global total, nearly one quarter of worldwide innovation activity. This position underscores the central role of the U.S. as a primary driver of technological advancement and knowledge transfer at the international level. Europe, considered as a collective entity, contributes significantly but exhibits a structurally fragmented pattern across multiple member and associated states.

A more detailed breakdown reveals that Germany contributes 12.6%, followed by France (5.5%), Switzerland (5.0%), the Netherlands (3.5%), the United Kingdom (3.1%), Sweden (2.5%), and Italy (2.4%), with additional European Patent Office (EPO) member states accounting for 8.7%. Taken together, these figures yield a total European share of approximately 43.3% of global patent applications (European Patent Office (b), 2025).

This distribution highlights Europe's continuing role as a major hub of innovative and economic activity on the global stage. However, its performance is characterized by a pronounced geographical dispersion, lacking a single dominant center of innovation. In contrast, the United States demonstrates a more unified and consolidated model of technological development, while Europe's strength lies in its collective capacity, built upon diversity and transnational collaboration.

Meanwhile, Asia, particularly the economies of East Asia, is experiencing a phase of rapid expansion, increasingly approaching the level of technological performance seen in the United States. This evolution outlines a new global architecture of innovation, structured around a triad of major centers, the United States, Europe, and East Asia, regions that collectively define the strategic directions of technological progress worldwide.

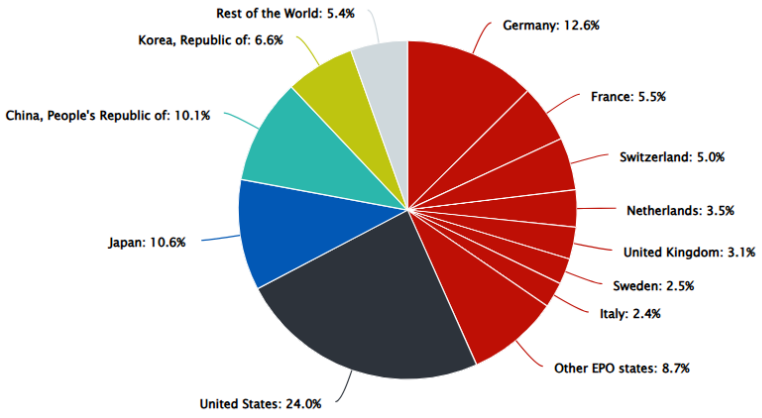

Figure 5. Distribution of patent applications in the technological field by country of origin, 2024
Source:European Patent Office (b), 2025

Figure 6 analyzes the Proportion of information and communication technology (ICT) specialists in total employment. In 2024 Sweden situated on the first place within the

European Union when it comes to ICT professionals proportion. Other countries that registered high ICT employment proportions were the Netherlands, Denmark, Belgium, Austria, Germany and Croatia. At the opposite end, Greece and Romania reported the lowest share of ICT specialists in total employment, with 2.5% and 2.8%, respectively. Among the candidate countries of the European Free Trade Association (EFTA) that provided data for 2024, Serbia recorded the highest proportion of ICT specialists, 4.3% of total employment. Although below the EU average, this figure reflects a positive trajectory toward alignment with the European digital transformation trend (Eurostat (c), 2025).

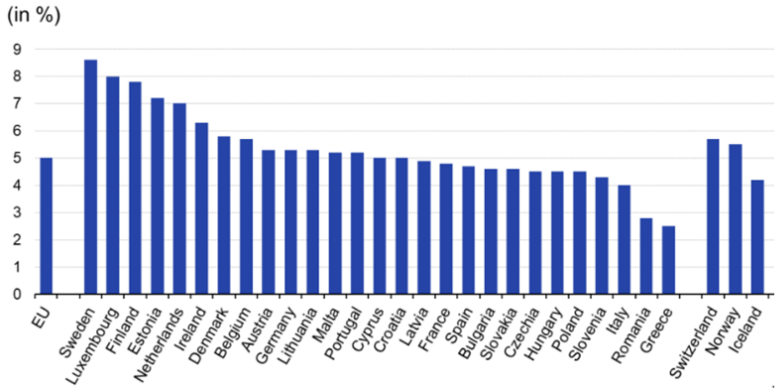

Figure 6. Proportion of information and communication technology (ICT) specialists in total employment
Sursa: Eurostat (c), 2025

Based on the analyzed statistical data, it can be stated that Romania is currently facing a significant structural gap compared to the EU average when it comes to investments in R&D and innovation, and also in the digital transformation process. The downturn that took place in the number of international patents filed under the Patent Cooperation Treaty (PCT), the low level of research and development (R&D) expenditures as a share of GDP, and the country's persistent position at the lower end of the DESI ranking all reflect a limited capacity to harness its scientific and technological potential. These findings highlight the need to reconfigure national strategies in the fields of innovation and digitalization, through more effective integration of academic research with the economic environment and by stimulating both public and private investments in R&D.

In the medium and long term, Romania should adopt an integrated strategic approach focused on enhancing economic competitiveness through innovation, strengthening human capital endowed with advanced digital skills, and developing a sustainable national innovation ecosystem connected to European research and technology transfer networks. Furthermore, increasing R&D funding, modernizing institutional infrastructure, and advancing the digitalization of public administration should be regarded as essential priorities for achieving convergence with advanced European economies. In this context, Romania has the potential to transform its existing advantages, such as a performant digital infrastructure and a young, dynamic labor force, into a catalyst for economic development driven by knowledge, innovation, and sustainability.

Conclusions

The turbulence of recent years, both in Romania and across the European Union (EU), has demonstrated that sustainable digital transformation must be regarded by all states as a fundamental pillar of economic resilience. The adoption of emerging technologies, including artificial intelligence, cloud computing, blockchain, and virtual and augmented reality, can no longer be viewed merely as a means of improving activities in individual sectors, but rather as a macroeconomic necessity for optimizing resources and enhancing long-term productivity.

At present, Romania faces notable disparities compared to the European average when it comes to the number of patents registered for novel technologies, the share of investments assigned to R&D and the level of digitalization within companies. These gaps highlight the need for more flexible public policies, tailored to the requirements of inventors and the business environment. A legislative framework oriented toward stimulating innovation could simultaneously reduce macroeconomic vulnerabilities and accelerate the process of digital transformation.

Within this context, the protection of intellectual property (IP) rights and the transfer of technology emerge as critical strategic factors. To ensure resilient economic growth, these two components must be recognized as indispensable drivers capable of strengthening national economies and supporting the broader economic development of the EU. In Romania, intellectual property protection for emerging technologies and technology transfer should be treated as strategic priorities, requiring the strengthening of the legislative framework, the promotion of R&D investment, and the expansion of partnerships between the public sector, private enterprises, and universities.

In conclusion, sustainable digitalization, founded on emerging technologies and supported by a precise and adjustable legislative framework for intellectual property protection and also through active technology transfer, must be regarded as an integrated strategy for economic development. Supporting these three fundamental pillars can help limit economic risks, stimulate long-term competitiveness, and ensure durable and resilient economic growth.

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