Rastvortseva and Kameneva
Journal of Economic Structures (2024) 13:11
https://doi.org/10.1186/s40008-024-00334-1

Journal of Economic Structures

RESEARCH Open Access

Development of national specialization in 5G technologies within the European Union

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Abstract

Nowadays the efforts of not only companies, but also governments in different countries are aimed at the development of 5G technologies. On the one hand, the introduction of 5G is an expensive process that requires investments in the development, deployment and maintenance of infrastructure, the involvement of a large number of market participants and service providers, the creation of a stimulating and regulatory legislative framework, the provision of radio frequencies of a more efficient spectrum, the solution of patenting issues. On the other hand, the introduction of 5G technologies will be aimed at developing the economy of many industries, creating social benefits, reducing energy intensity, and will create new opportunities for companies. Currently, the benefits of the digital economy can be most used by the United States, the Republic of Korea and China, which have the highest rates of 5G adoption in the world. The countries of the European Union are also interested in the development of 5G technologies. We analysed key 5G technologies for 74,940 related patents for 23 EU countries for the period 2012–2021. It is shown that the leaders in the number of 5G patents were Sweden, Germany, Finland, France, the Netherlands and Ireland. It is noteworthy that countries can either focus on developing a small number of technologies, or develop a wide range of them. Since 2018, France, Estonia and Germany demonstrate the greatest number of technological specializations primarily creating inventions related to 5G data processing. At the same time, the USA, the Republic of Korea and China still retain their competitive advantages in fields of basic electric elements and electric communication technique for fifth generation networks. To improve positions in the global technology market the EU countries need to specialize in rarer and more complex technologies and develop national policies in this area.

Keywords: 5G technologies, Diversity, Technological profiles, 5G specialization, 5G patents, European Union countries

JEL Classification: O14, L63, L96

1 Introduction

Currently, 5G technologies are strategically important for maintaining the competitiveness of national economies in the global market in the context of a new technological revolution. Developed and developing countries seek to support their dissemination by adopting national programs and roadmaps, allocating funding for individual projects.

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We would like to draw attention to how technologies emerging in some countries are spreading around the world for the benefit of economic development, social relations and the technological revolution as a whole.

The first generation of mobile communications was introduced to Tokyo residents in 1979 (Galazzo 2020), and in 1980 the network was launched at the global level (Goyal and Sahoo 2019). The distribution of the 1G wireless standard throughout Japan was completed in 1984. The main service provider was Nippon Telegraph and Telephone (Wang 2022, p. 218).

The second generation of the Global Mobile Communication System was launched in Finland in 1991 (Galazzo 2020). The new network offered new types of services—SMS, MMS and data transmission (Hutajulu 2020), that is, the transmission of text, graphic and multimedia information became possible, the quality of voice calls was improved (Wang 2022).

The third generation (3G) appeared in 2000–2001 with broadband access technology with speeds up to 2 Mbit/s (Javed and Siddiqui 2017). A revolutionary feature of 3G was the ability to use the Internet, video streaming, video conferencing and video chats appeared (Galazzo 2020). It is noteworthy that 3G technology debuted in Japan, and the implementation of network services was also started by Japanese companies. Realizing the importance of this market, in 2003 the United Kingdom launched its own 3G network service. However, the market was not ready—too few phones capable of supporting 3G pushed back the timing of the introduction of technology (Wang 2022, p. 218).

In Norway, at the end of 2009, the 4th generation Internet was introduced, initially for commercial purposes (Galazzo 2020). According to other sources, the United Kingdom was the first to introduce a 4G network in 2009, and its companies deployed a 4G network in 11 cities of the country (Wang 2022, p. 218). In 2010, 4G was introduced with speeds up to 1 Gbit/s (Gopal and Kuppusamy 2015).

Companies from many countries took part in the development of the 5G network, the preparation for which began back in 2008. The Korean company Samsung announced its development in 2013. Three years later (2016), Google (USA) announced its presence on the market, and British Telecom (United Kingdom) and Huawei (China) signed a partnership agreement to conduct joint research in this area (Wang 2022). In 2017, the official launch of the 5G network was announced by the International Telecommunications Standards Organization and supported by the relevant ministries of a number of countries (Wang 2022).

In 2018, the common 5G network standard was adopted in China, the network was deployed by China Unicom. In 2019, South Korea switched to the commercial use of 5G technologies, stimulating its development in many countries.

The prospects for improving productivity in all sectors of the economy with the use of 5G technologies make them among the national priorities in many countries (Brake 2018). Because the 5G generation is not just about the development of radio and backbone networks, but also a focus on performance and higher bandwidth, the use of cloud technologies and the provision of services (Tranoris et al. 2020), it is assumed that 5G technologies can be implemented in all spheres of the economy, the scale of their impact will be large than in previous generations (Parcu et al. 2022). 5G will not only provide

faster data loading, but also create a more flexible network that can adapt to the needs of different verticals of the economy (Brake 2018).

A distinctive feature of the new generation of networks is the need for more dense placement, therefore, the number of antennas should be greater (Alsharif and Nordin 2017). Three main components are included in communication networks—basic, data transmission and radio access networks (Cheng et al. 2022). From an economic point of view, it is assumed that the high cost of 5G systems takes place due to the need to replace a large number of components with new ones, which is necessary to improve the existing infrastructure. This can include the base station and transit transmissions. Additional costs include equipment shutdown, commissioning, network maintenance, and others (Yan et al. 2017).

5G is designed to implement three broad types of use cases: enhanced mobile broadband, machine-type mass communication or IoT, and ultra-reliable low-latency communication for mission-critical applications (Brake 2018). 5G technologies can be attributed to the number of general-purpose technologies that are the engine of socio-economic development. They become "catalysts of transformative change, predetermine work processes and rewrite the rules of competitive economic advantage" (Campbell et al. 2017).

Thus, telecom operators, due to dynamic and flexible cloud mechanisms, can reduce operating costs, implement and adapt services on a much larger scale. 5G technologies will provide higher productivity of labour and machines in a wide range of industries and will allow implementing new scenarios for consumers (Meneses et al. 2020).

The introduction of 5G technologies provides social benefits that are difficult to monetize and evaluate. This can include reducing environmental pollution, improving the quality of work, improving the processes of product development and marketing.

Hopes are pinned on 5G in the field of ecology. It is assumed that the energy intensity reduction policy will limit the demand for electricity and reduce carbon dioxide emissions. 5G technologies can bring mobile technologies into the exclusive sphere of GPTS.[1]

It is expected that in the coming years, 5G communication will significantly stimulate the development of the Internet of Things market. The new mobile technology allows you to connect machines and devices, providing higher data transfer speeds with low latency and increased availability (Ericsson 2022).

According to forecasts, 5G technologies will increase the volume of the global economy by $12.3 trillion, generate $3.5 trillion and create 22 million jobs by expanding and complicating the global 5G value chain, invest an average of $200 billion to develop the technological base in business applications and 5G network infrastructure (Campbell et al. 2017).

At the same time, it should be noted that the accelerated development of the digital economy based on data around the world is taking place against the background of the enormous inequality of countries in terms of digital readiness. Thus, 23% of the

[1] GPTS is packet data transfer at higher speeds.

population of the least developed countries of the world do not have access to a mobile broadband network (Digital Economy Report 2021, p. 2).

The main data exchange flows focused on two routes: Europe—North America, China—North America (Digital Economy Report 2021).

It is noted that today the United States and China can use the benefits of the digital economy to the greatest extent. More than half of the major data centres are concentrated in China and the USA. It is in these countries that 5G technologies are being implemented faster. While in most other regions, the issues of the need to prepare infrastructure and legislative framework are being resolved, in the USA and China, about 94% of projects in the field of artificial intelligence have been implemented at a total cost over the past five years. These two countries employ 70% of the world's leading AI researchers, Chinese and American companies and the largest digital platforms account for almost 90% of the market capitalization (Digital Economy Report 2021).

The development of 5G technologies, on the one hand, requires significant financial and technological costs, and, on the other hand, promises great competitive advantages and benefits, issues of technology implementation at the national level should have a scientific economic justification. It is important to understand the existing country specialization and technological profiles in order to conduct an effective policy in the field of 5G technology development.

Most publications on the development of 5G technologies are focused on the field of ICT. There are almost no studies on quantitative empirical analysis in the real sector of the economy, as well as on the assessment of the impact of 5G on everyday life. In this article, we will pay more attention to the prerequisites of technological development, based on information about patents and technologies under development. This will create some picture of the future results of 5G technologies for society.

The aim of the work is to identify the key 5G technologies that exist in the EU countries, as well as to determine how diversified the technological profiles of the countries are.

The work is structured as follows. The first section presents the theoretical foundations of the study and reviews the literature. The following is an assessment of the current trends in the introduction of 5G technologies in the leading countries and regions of the world in this area (Sect. 2) and the countries of the European Union (Sect. 3). The fourth part presents the research methodology and data, the fifth—the results of the study, namely the 5G patent specialization in the countries of the European Union. The sixth section—discussion—is devoted to the definition of difficulties and problems arising during the deployment of 5G technologies. In conclusion, the conclusions are presented.

2 Literature and concept

The existing literature presents several ways to assess the actual and expected impact of 5G technologies on certain aspects of social and economic development of the territory. Let's look at them in more detail.

1. So, in some works, the possibilities of using 5G technologies in various sectors of the economy were considered. Let's look at some of them.

1.1. For example, the introduction of new technologies in railway transport and energy is becoming fundamentally important. In the work by Corujo et al. (2022) on the

example of Portugal, with further scaling for the pan-European case, it is shown that the participants of the project on the implementation of 5G solutions can save significant funds. Pilot projects are being created and implemented within the framework of the H20 5Growth project. The industries "Industry 4.0", transport and energy receive an automated and shared 5G End-to-end solution, which is based on artificial intelligence, allowing to achieve high efficiency indicators (Papagianni et al. 2020). The project participants are industries and companies, telecommunications institutes, laboratories and universities. The economic justification for the introduction of technologies was carried out taking into account savings in investment, operating costs and revenue growth. The savings are significant for all project participants (Corujo et al. 2022).

1.2. Two more major sectors of the economy that need to be studied in connection with the development of 5G technologies are retail and entertainment. In trade, new technologies allow automating and improving processes, primarily processing large amounts of data. These include micro-cloud computing, robotics, the Internet of things, mixed reality, etc. Retailers are actively using new technologies to improve the production, promotion and sale of their products (Sun et al. 2016). In the long term, the use of 5G technologies will allow companies to completely switch to a new business model with active online services in a more advanced logistics system. Studies of the impact of 5G technologies on retail trade are still insufficient (Shankar et al. 2021). Earlier studies focused on assessing the impact of technologies such as ATMs, the Internet, automatic points of sale of goods and others (Varadarajan et al. 2010). The entertainment industry is an expanded and virtual reality, new solutions and new services that meet the growing needs of customers.

1.3. Social spheres, first of all, health care and education. In medicine, 5G technologies make it possible to provide high-speed and reliable communication between doctors and patients, conduct remote consultations, transmit data and carry out diagnostics.

The emergence of 5G technologies creates prerequisites for the emergence of new industries and sets trends in the development of the information revolution (Wang 2022).

2. Earlier we mentioned the emergence of new types of activities in economic and social sectors in general, here we would like to focus on the interests of companies in the development of 5G technologies. It is noted that 5G technologies allow companies to create and master new niches of markets (Nam et al. 2008). Competition plays a huge role in this process. When changing generations of mobile communications, it is necessary to constantly follow the main trends. Market leaders that have significant advantages in their activities and in the use of telecommunications may lag behind younger and more "daring" companies. If a company claims leadership, it must follow innovations, modern trends, environmental changes and actively adapt its market strategies to the new prevailing conditions (Asimakopoulos and Whalley 2017).

3. 5G technologies are important for the development of Smart cities. Many devices, both consumers and service providers, are combined into a single network. A well-developed infrastructure for the use of various sensors is necessary to promote other aspects of the Smart-cities concept (Hall et al. 2000). The goals of technology development in smart cities are to increase the efficiency of all city services, improve mobility, speed of emergency services, waste management, safety and much more.

4. "Green 5G". It is expected that 5G technologies will be more energy efficient than the technologies of previous generations. The benefits of 5G for businesses and the public may lead to more active use of mobile networks, thereby reducing the planned efficiency (Williams and Bergman 2023). Thus, the power consumption of a single 5G base station is about four to four times higher than a similar 4G level. At the same time, we must understand that with a high density, a significant number of installations will be required. The power consumption of new networks can be 12 times more than in previous generations, for example, 4G (Han and Bian 2020). Also, Cheng et al. (2022) showed on the example of the UK that the 5G radio access network will consume an additional more than 2.1% of the total electricity production, which will lead to carbon dioxide emissions in the amount of 990,404 tons in 2023.

Thus, we can assume that in pursuit of the competitive advantage that 5G technologies give, many companies will not pay due attention to reducing environmental damage, and the costs of using new technologies will fall on the shoulders of not only all other market participants, but also the population, and even the population of those countries where 5G technologies not implemented yet.

It is important that the introduction of technologies is accompanied by policies to mitigate the negative effects of climate change (Williams and Bergman, 2023). The introduction of 5G technologies can also lead to more economically efficient processes and stable for the environment. This may be a consequence of "predictive maintenance, on-demand production and the use of intelligent logistics" (Nokia steps…, 2023).

In their study, Williams and Bergman (2023) identify two positive sets of expectations regarding the potential of 5G: reducing energy consumption and emissions of mobile networks themselves, and improving the efficiency of processes, reducing resource use and emissions in other areas of social life.

Cheng et al. (2022) conducted a study on the deployment of 5G wireless networks using the example of the UK. From the point of view of ecology, they considered changes in energy consumption and carbon footprint, from the point of view of the company's economy, changes in the structure of operating expenses. From a technical point of view, they showed that 700 MHz and 26 GHz will play an important role in the deployment of 5G. Geopolitical restrictions and embargoes may have a negative impact on the development of 5G technology.

We see that the development of 5G technologies brings common benefits for the economic and social sphere all over the world. At the same time, the rivalry of major powers in trade, growing international competition and emerging issues of intellectual property protection are now moving into the plane of political confrontation on the basis of cybersecurity. Technically, this may be due to the fact that during the development of 2G-4G technologies, network users had to follow the same specifications for the development of equipment and devices or the provision of products and services, the "one-size-fitsal" network (Agarwal and Agarwal 2014). 5G technologies differ in that scenarios for network users are developed or "sliced" for specific segments (Kurtz et al. 2018). Companies that develop, install and maintain equipment can get access to the transmitted information, including technological secrets. This dilemma arose in relation to one of the market leaders—the Chinese company Huawei.

On the one hand, the 5G network technologies offered by Huawei are attractive to many countries that do not have national manufacturers of the corresponding equipment. On the other hand, in the United States, since 2012 (the second term of Barack Obama), an investigation has been conducted into national security issues in connection with Huawei and ZTE. The Investigation recommends paying increased attention to Chinese telecommunications companies, not approving large mergers/acquisitions and not allowing them to access important telecommunications systems.[2] Huawei itself, like the Chinese government, rejects the accusations of the United States and the intelligence services of some other countries that its activities pose unacceptable risks to network security (Krolikowski and Hall 2023).

When making decisions on cooperation with Huawei, the governments of many countries are involved in the confrontation between two major global market players and rely on the opinions of their internal experts, which are also not always unambiguous. It is noteworthy that the countries do not announce the ban publicly, since they all have a large share of mutual trade with China and avoid open confrontation.

In 2018, there was tension between the US and China due to the imposition of tariffs. During the same period, the US Department of Justice prohibits companies from doing business with Huawei and ZTE.[3] Consciously or not, the US is spreading this rhetoric to other countries, limiting their ability to use Huawei and ZTE services, and, therefore, in the development of the 5G technology market as a whole. In the same year, regulations were adopted in Australia restricting the participation of foreign suppliers in the development of 5G networks,[4] a review of the telecommunications supply chain was announced in the United Kingdom with an emphasis on supplier and procurement aspects related to network security,[5] Huawei equipment supplies for local companies were blocked in New Zealand,[6] etc. The European Union has issued a law on cybersecurity of 5G networks, developed a set of risk reduction tools (Lee and Yu 2022, p. 4).

European countries react differently to the need for a balanced development of the 5G sphere and ensuring the reliability and safety of transmitted information. Today, Germany is one of the leaders in the European Union in terms of the development of 5G technologies (Rastvortseva and Bondarenko 2023), while it does not refuse to cooperate with Huawei, despite external pressure (Krolikowski and Hall 2023) and internal negative attitude towards foreign suppliers of equipment for networks (Lenhardt 2022). The Government of the United Kingdom only at the initial stage of the implementation of

[2] Investigative Report on the U.S. National Security Issues Posed by Chinese Telecommunications Companies Huawei and ZTE. A report by Chairman Mike Rogers and Ranking Member C.A. Dutch Ruppersberger of the Permanent Select Committee on Intelligence. U.S. House of Representatives. 112th Congress. October 8, 2012. https://stacks.stanford.edu/file/druid:rm226yb7473/Huawei-ZTE%20Investigative%20Report%20(FINAL).pdf (last visit 11/10/2023).

[3] John S. McCain National Defense Authorization Act for Fiscal Year 2019. Conference Report to Accompany H.R. 5515. July 23, 2018.—Ordered to be printed. https://www.congress.gov/115/crpt/hrpt863/CRPT-115hrpt863.pdf, p. 918.

[4] Joint Release – Treasurer – Government Provides 5G Security Guidance to Australian Carriers. Senator the Hon Mitch Fifield. https://www.mitchfifield.com/2018/08/joint-release-treasurer-government-provides-5g-security-guidance-to-australian-carriers/ (last visit 11/10/2023).

[5] UK Telecoms Supply Chain Review Report. Presented to Parliament by the Secretary of State for Digital, Culture, Media and Sport by Command of Her Majesty. July 2019. https://assets.publishing.service.gov.uk/media/5d358f2ded915d0d101994ff/CCS001_CCS0719559014-001_Telecoms_Security_and_Resilience_Accessible.pdf (last visit 11/10/2023).

[6] New Zealand blocks Huawei imports over 'significant security risk'. Guardian Business. Jasper Jolly. Wed 28 Nov 2018. https://www.theguardian.com/business/2018/nov/28/new-zealand-blocks-huawei-5g-equipment-on-security-concerns (last visit 11/10/2023).

the 5G system cooperated with Huawei, later abandoning the partnership (Krolikowski and Hall 2023). Until 2018, Huawei's investments were encouraged by the French government through receiving tax incentives for research and innovation (Calcara 2023), later cooperation with the company was divided into two directions: creating its own technologies for successful competition in the market and avoiding a "trade war" with Beijing, since up to 30% of the entire European telecommunications sector is made up of Chinese investments (Procaccia 2019). Until 2028, it was decided to gradually withdraw Huawei from the French market.

The refusal of European companies to cooperate with Chinese partners may slow down the development of 5G technologies in countries, bring financial losses and weaken competitive positions not only in this market, but also in some sectors of the economy. We believe that the relationship between cybersecurity and economic development should be balanced.

The competition that is developing today in the field of 5G technologies is not just rivalry in the field of communications, mobile Internet and communications. This is a competition for future development between industries, countries and regions. We can talk about the inclusion of American and Chinese companies in the development of markets in many parts of the world, including in the countries of the European Union.

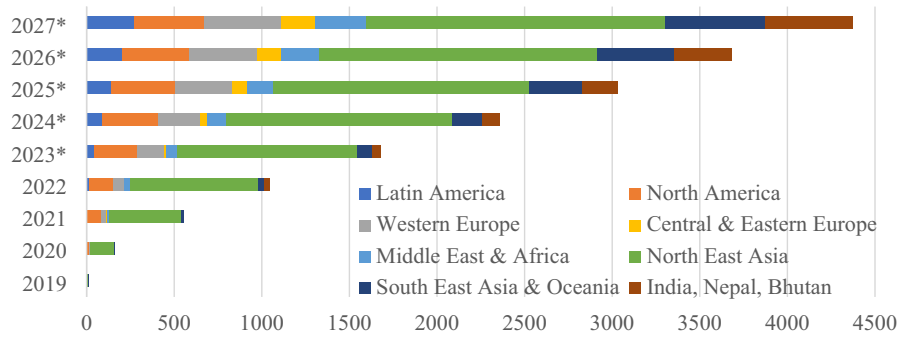
3 The current development of the situation on the implementation of 5G technologies

According to forecasts (Ericsson 2022), the number of 5G subscribers in the world will grow from 12 million in 2019 to 4 billion in 2027. At the same time, a greater number of consumers will be in Northeast Asia, Southeast Asia, India, Nepal and Bhutan (Fig. 1).

We see that in 2019, 5G mobile communication technologies were present mainly in Northeast Asia. The share of this region will remain the highest in 2027—39.01%, but not only because of the high population—today a fifth of the world's inhabitants live in this region (UN 2023), but also due to the high rates of economic and technological development. It is noteworthy that the second share in the number of subscribers will be taken by Southeast Asia and Oceania (according to the forecast, 13.07% in 2017), followed by India, Nepal and Bhutan (11.39%) and only then Western Europe (10.02%) and North America (9.15%). 5G network coverage is an important characteristic of the development of the national economy. In countries with high 5G coverage, companies will be more willing to take advantage of new technologies. The leaders in terms of coverage are the USA and some Asian countries. At the same time, in the countries of the European Union, a number of countries also have a high level of the indicator.

If we talk about patents for 5G technologies, a large share belongs to Chinese copyright holders (41% as of September 2021) and South Korean companies (almost 20%, IPlytics GmbH 2021). Let's take a closer look at 5G technology patents by country and by copyright holders (Fig. 2).

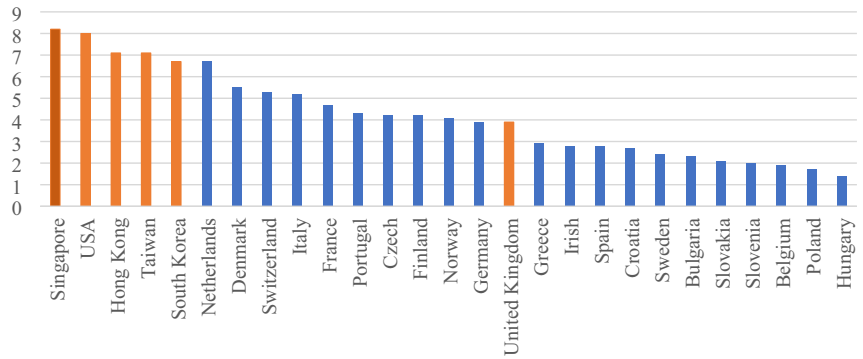
As noted earlier, in general, China and South Korea are leading in the number of patents for 5G technologies. This is followed by the USA with a share of 15.34%, Japan (8.86%), Finland (8.34%), Sweden (4.69%) and Taiwan (1.45%). In the "5G granted and



Based on: Forecast number of mobile 5G subscriptions worldwide by region from 2019 to 2027. Statistic as Excel data file. November 2022. https://www.statista.com/statistics/521598/5g-mobile-subscriptions-worldwide/

* - forecast

a) the number of 5G mobile subscribers



Based on: Opensignal Ltd 2023. https://www.opensignal.com/2023/05/17/understanding-5g-and-overall-coverage-worldwide

b) the level of 5G coverage experience (0-10 score), 2023

Fig. 1 Dynamics of the number of 5G mobile subscribers (**a**) and the level of 5G coverage experience in 2023 (**b**) in the world by region from 2019 to 2027 (in millions), from 2023 – forecast

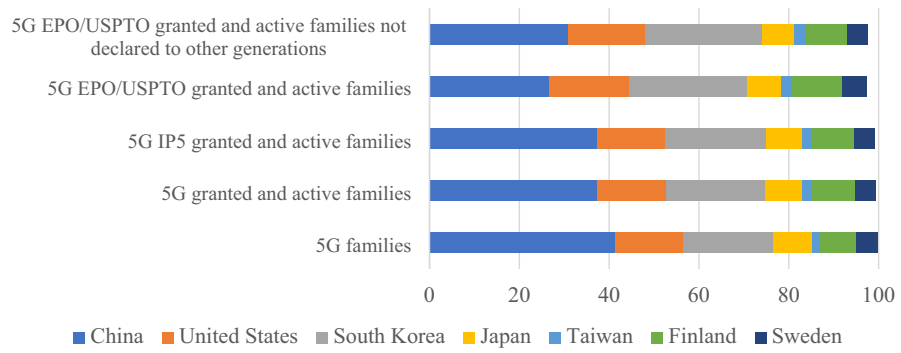


Fig. 2 The structure of the aggregate of patents by country and by copyright holders in the world in 2021, %. Based on: Ownership distribution of 5G patents worldwide as of September 2021, by country. Statistic as Excel data file. IPlytics GmbH. 30 Sept 2021. http://www.statista.com/statistics/1276691/leading-owners-of-5g-patents-worldwide-by-country/

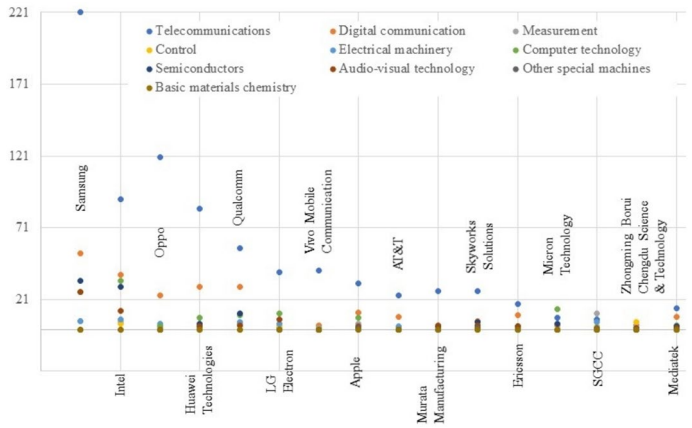


Fig. 3 Global 5G chipset patents 2020, by company & technology. Based on: Number of 5G chipset patents worldwide as of 2020, by company and technology. Statistic as Excel data file. Sagacious IP. 2020. http://www.statista.com/statistics/1249340/5g-chipset-patents-worldwide-by-company-technology/

active families" group, Finland is slightly ahead of Japan in terms of the share of patents, the position of other countries practically does not change. A similar situation occurs in the group "5G IP5 granted and active families".

In the "5G EPO/USPTO granted and active families" group, the shares of China and South Korea are almost equal—about 26%. The shares of the USA, Sweden and Taiwan are slightly higher than in other groups. The situation is similar for the group "5G EPO/USPTO granted and active families not declared to other generations".

5G technology patents are distributed among leading companies as follows: Huawei (China)—3147 patents, Samsung (South Korea)—2795, ZTE (China)—2561, LG (South Korea)—2300, Nokia (Finland)—2149, Ericsson (Sweden)—1494, Qualcomm (USA)—1293, Intel (USA)—870 (according to Global number…, 2020).

According to the main companies and 5G technologies, the distribution of patents is shown in Fig. 3.

In the presented sample of patents, we can note the clear leadership of Samsung—372 patents or 26.1% of the analysed population, Intel—222 or 15.6%, Oppo—152 or 10.7%, Huawei Technologies—134 or 9.4% and Qualcomm—123 or 8.6%. More than half of all patents (57.19%) are in the field of Telecommunications. Other major areas are Digital communication (16.28%), Computer technology (8.42%) and Semiconductors (6.67%).

4 Introduction of 5G technologies in the countries of the European Union

The countries of the European Union (EU) are of particular interest in the development of 5G technologies, since for them, along with national support measures, there is a unified innovation policy that takes into account regional peculiarities, for example, the Horizon 2020 program. Despite the fact that a large number of scientific papers pay attention to the development of innovations and technologies in the EU countries, there is a shortage of comparative studies devoted to their technological specialization in the field of 5G.

The development of 5G policy in the EU began in 2013 after the signing of an agreement between the European Commission and the 5G Infrastructure Association (5G-IA), which

provided support for projects of major industry players in the form of public–private partnerships. So, by 2018, investments in 5G distribution projects through the Horizon 2020 program amounted to 700 million euros, and the total amount of state funding was 4 billion euros. In addition, during the same period, the European Commission developed a strategic plan "5G for Europe: An Action Plan" until 2025, which envisaged the creation of national roadmaps for the transition to 5G communications, standardization of technologies and attraction of additional funds to support the industry. Nevertheless, according to the researchers, despite the fact that a common framework of measures to support the development of 5G was created in the EU, significant differences in this area were observed at the level of individual countries due to the lack of uniform standards, requirements and corresponding business models (Sgora 2018).

The problems of the development of 5G technologies in the EU are also considered in the scientific literature from the point of view of maintaining the competitiveness of countries in the global market and reducing dependence on imported solutions. Thus, the analysis of the 5G Technology Sovereignty Index (TSI) for the EU showed that European countries have a weak degree of technological sovereignty compared to China and the United States due to the lack of specialized human capital and the trend of outsourcing in the relevant technology segments (da Ponte et al. 2023). Studying the cases of key players in the 5G market in the EU allowed researchers to come to the conclusion that until 2018, the technological leader in the European market was the Chinese company Huawei, which, after the introduction of restrictions on activities, lost its positions to the Finnish company Nokia and the Swedish company Ericsson. This allowed the EU to develop technological advantages in certain areas (Ghiretti 2021).

Speaking about technological diversification in the EU, it is worth noting that the countries have a policy of "smart specialization", which is designed to stimulate the development of more complex technologies in the EU regions. This is beneficial for countries in terms of long-term economic growth, but the implementation of the policy is difficult, since less economically developed regions of the EU prefer to specialize in less knowledge-intensive technologies (Balland et al. 2018).

Thus, based on existing studies, it can be concluded that in order to assess the prospects for the development of 5G in the EU, an analysis of the diversity and ubiquity of technologies associated with this generation of mobile communications is necessary.

5 Research methodology and data

The database of the European Patent Office (EPO) was used to identify key 5G technologies in the EU countries. For the period 2012–2021, at the request of "5G OR Fifth generation", 753,062 patents were unloaded for 23 countries, from which 74,940 patents were then selected for three key groups of 5G technologies mentioned in the scientific literature and identified on the basis of the Cooperative Patent Classification (CPC): H01 (Basic electric elements), H04 (Electric communication technique), G06 (Computing; calculating; counting). The most common subgroups were identified for each technology group (Table 1).

The next stage of the analysis was the calculation of the coefficient of relative comparative advantage (*RCA*) for 23 EU countries and the key developers of 5G such as China, the

Table 1 Classification of key 5G technologies

Group	Subgroup	Technology
H01. Basic electric elements	H01L	Semiconductor devices; electric solid-state devices
	H01M	Processes or means, e.g. batteries, for the direct conversion of chemical energy into electrical energy
	H01Q	Antennas, i.e. radio aerials
H04. Electric communication technique	H04B	Transmission
	H04J	Multiplex communication
	H04L	Transmission of digital information, e.g. telegraphic communication
	H04M	Telephonic communication
	H04N	Pictorial communication, e.g. television
	H04W	Wireless communication networks
G06. Computing; calculating; counting	G06F	Electric digital data processing
	G06K	Graphical data reading; presentation of data; record carriers; handling record carriers
	G06N	Computing arrangements based on specific computational models
	G06Q	Information and communication technology [ICT] specially adapted for administrative, commercial, financial, managerial or supervisory purposes; systems or methods specially adapted for administrative, commercial, financial, managerial or supervisory purposes
	G06T	Image data processing or generation
	G06V	Image or video recognition or understanding

USA and the Republic of Korea. This indicator allows to assess whether a country can be an exporter of a certain technology, and is calculated using the formula:

$$RCA_{ct} = \left(\frac{P_{ct}/P_c}{P_t/P} \right),$$

where *Pct* is the number of patents of country *c* in the technology *t*, *Pc* is a total number of patents in all technologies for country *c*, *Pt* is the total number of patents of all countries in the technology *t* and *P* is the total number of patents. A country which showed a value higher than or equal to 1 has a comparative advantage in the technology *t* in relation to other countries.

The RCA helps to estimate *diversity* of 5G technologies for each considered country, which indicates how many specializations emerge in this area. In addition, the RCA can also be used to demonstrate *ubiquity* of individual specializations, which defines how rare they are in the analysed sample of countries.

6 Research results: specialization of 5G technologies in the countries of the European Union

During the period from 2012 to 2021 the number of patent applications for 5G technologies registered annually in European countries gradually increased by an average of 11%, as can be seen from Fig. 4. The peak of patent activity occurred in 2021, when 126,563 patents were registered.

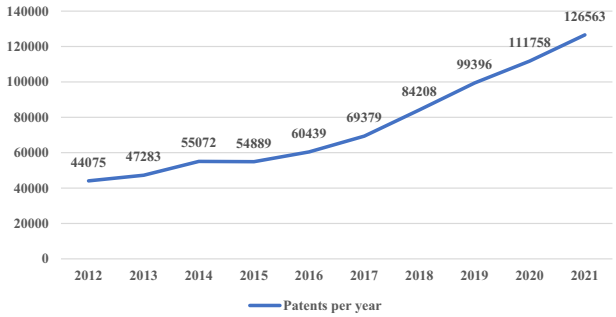


Fig. 4 Dynamics of patents in the field of 5G registered in the EU countries in 2012–2021. Based on the data of the European Patent Office

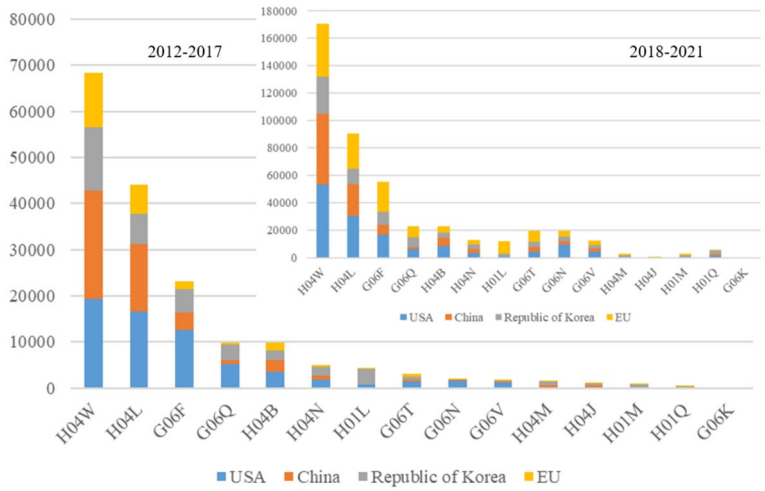


Fig. 5 The number of patents for the main groups of 5G technologies in the European Union countries, USA, China and the Republic of Korea in 2012–2017 and in 2018–2021. Based on the data of the European Patent Office

The distribution of the number of patents for specific technologies among the EU countries in the comparison with leaders in 5G field (the USA, China and the Republic of Korea) is shown in the Fig. 5. It should be noted that the largest number of patents is observed in the sector of Wireless communication networks (38.96%), Transmission of digital information, e.g. telegraphic communication (25.19%) и Electric digital data processing (13.26%). In 2012–2017 the USA, China and the Republic of Korea patents accounted for more than 80% of all inventions related to these technologies, while the EU countries did not have equally significant results and did not exceed an average of 13.20%.

However, since 2018, when Huawei's activities in the European market were limited, there has been a noticeable structural change in the distribution of the key groups of 5G technologies. First of all, the share of European patents increased in all technological areas, amounting to an average of 32.70%, and reached the highest value in Semiconductor devices; electric solid-state devices (78.62%). Secondly, during this period there was a growth in the number of applications for patents in fields of Image data processing or generation (1.74% of total in 2012–2017 vs. 4.36% of total

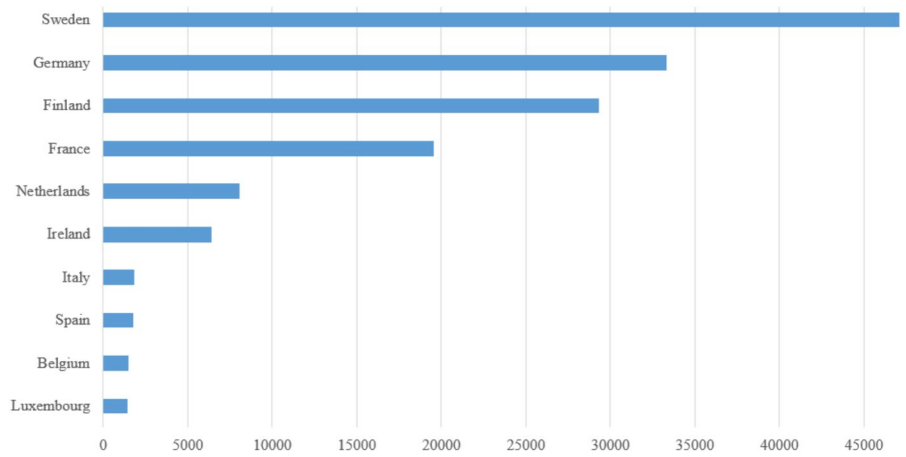


Fig. 6 The leading countries of the European Union in the number of patents in the field of 5G technologies, 2012–2021. Based on the data of the European Patent Office

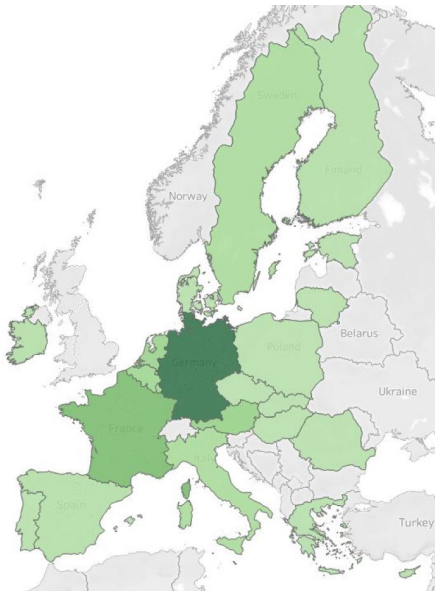
in 2018–2021), Computing arrangements based on specific computational models (1.10% vs. 4.28%) and Image or video recognition or understanding (0.98% vs. 2.74%).

Figure 6 below demonstrates the key leaders in the number of patent applications registered for 5G technologies among the countries of the European Union. For the analysed decade, the greatest activity in developing innovations is observed in Sweden (30.34% of total European patents), Germany (21.46%), Finland (18.88%), France (12.60%), Netherlands (5.20%) and Ireland (4.12%).

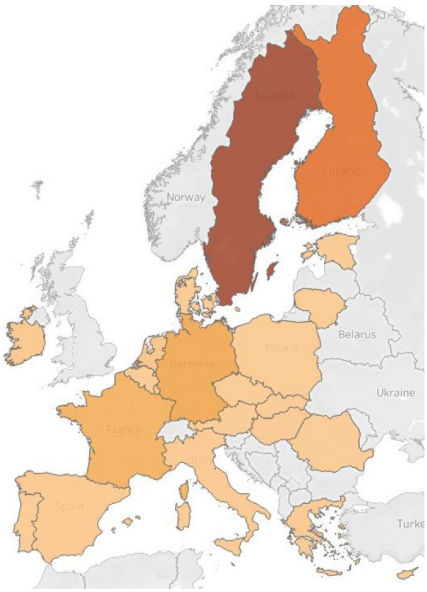
However, it is interesting to note that the distribution of patents, connected with three key 5G technology sectors, differed significantly across the European Union in 2012–2021 (Fig. 7).

We see that Germany (49.37% of the total number of patents), France (17.17%), Austria (7.71%), the Netherlands (6.45%), Belgium (5.51%) and Luxembourg (5.37%) are leading in the Basic electric elements (H01) sector for the analysed period. Sweden (46.37%), Finland (26.31%), Germany (11.3%), France (8.61%) and the Netherlands (2.16%) stand out in the Electric communication technique (H04) sector. In such a sector of 5G technology development as Computing; calculating; counting (G06) the largest shares among patents are Germany (34.15%), France (19.15%), the Netherlands (10.75%), Ireland (9.94%), Finland (8.98%) and Sweden (6.29%).

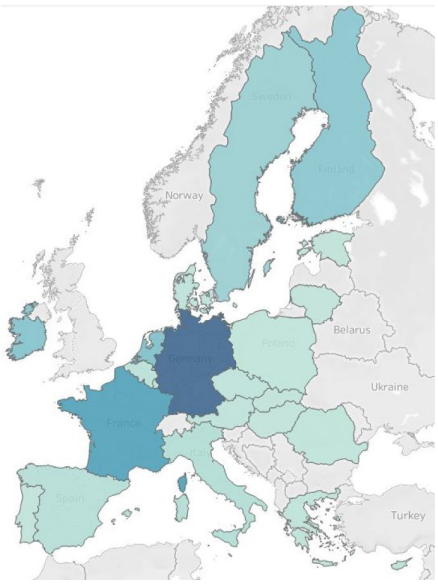
The calculation of the RCA before and after 2018 allowed to identify technologies in which EU countries have the greatest potential and compare them with countries that are leaders in the field of 5G (Fig. 8). In particular, in 2012–2017 the largest number of specializations was observed in countries such as the Republic of Korea (7 specializations), Finland (7 specializations), Ireland (7 specializations), Netherlands (6 specializations) and the United States (6 specializations). At the same time, other European countries had less diverse technological profiles—minimum values of the indicator were in the Czech Republic (1 specialization), Malta (1 specialization), Austria (2 specializations), and Denmark (2 specializations). However, since 2018 technological specialization of most countries has become more explicit. For instance, the largest increase in the



a) H01. Basic electric elements



b) H04. Electric communication technique



Based on the data of the European Patent Office

c) G06. Computing; calculating; counting

Fig. 7 Distribution of the number of patents in the three 5G technology sectors by European Union countries, 2012–2021, units

RCA coefficient compared to the previous period was observed for Lithuania (from 0 to 6 specializations), Portugal (from 2 to 7 specializations), Germany (from 4 to 8 specializations) and Estonia (from 4 to 8 specializations). On the contrary, China and the USA demonstrated less diverse technological profiles.

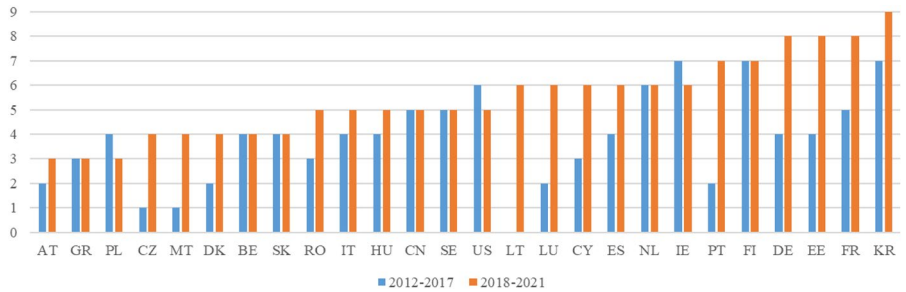


Fig. 8 Indicator of the diversity of technological specializations in the EU countries, USA, China and the Republic of Korea, 2012–2017 and 2018–2021. Based on the data of the European Patent Office

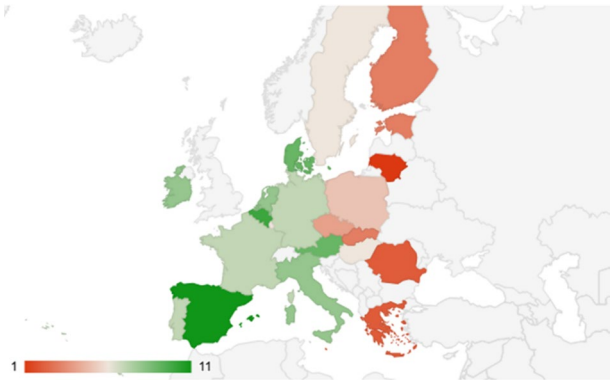


Fig. 9 Diversity of technological specializations in the EU countries, 2021. Based on the data of the European Patent Office

Nevertheless, in recent years, due to the increased interest of governments in supporting the development of 5G networks and an increase in the number of patent applications, new leaders in this technological field may emerge in the European Union. For instance, in 2021 the most diversified technological profile was in Spain (11 specializations), where the Ministry of Economic Affairs and Digital Transformation implemented the UNICO I+D program to reinforce research, development and innovation actions of national companies and allocated 15 million euro to 5G networks creation[7] (OECD, 2023). High diversity index values in 2021 are also observed in Belgium (10 specializations), Austria (9 specializations) and Denmark (9 specializations) (Fig. 9).

Thus, recently, the EU countries have been specializing mainly in technologies related to analysis and use of various types of data obtained from 5G networks: Information and communication technology [ICT] specially adapted for administrative, commercial, financial, managerial or supervisory purposes; Electric digital data processing and Image data processing or generation. At the same time, technologies necessary for the operation of the 5G equipment (Multiplex communication, Batteries for the direct conversion of chemical energy into electrical energy and Transmission) are rare in EU countries. The ubiquity of technology specializations among EU countries in 2021 is shown in Fig. 10.

[7] OECD STIP Compass, 2023. UNICO R&D programme—digital connectivity https://stip.oecd.org/stip/interactive-dashboards/policy-initiatives/2023%2Fdata%2FpolicyInitiatives%2F99997187 (22.09.2023).

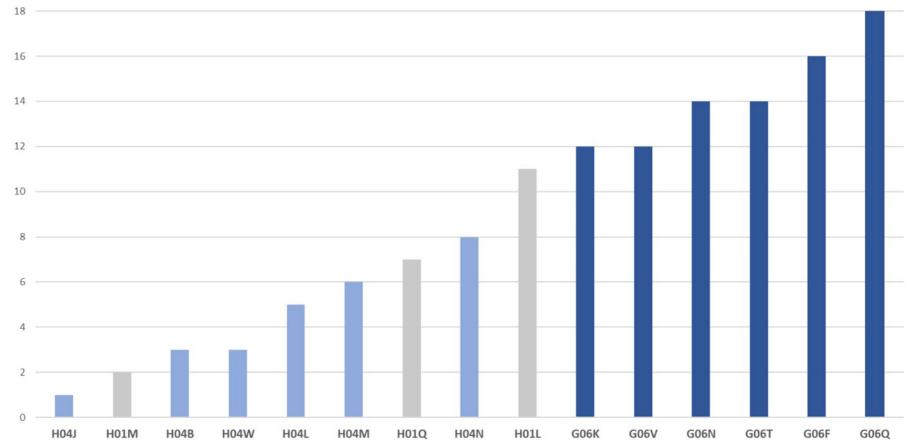


Fig. 10 Ubiquity of technological specializations among EU countries in 2021. Based on the data of the European Patent Office

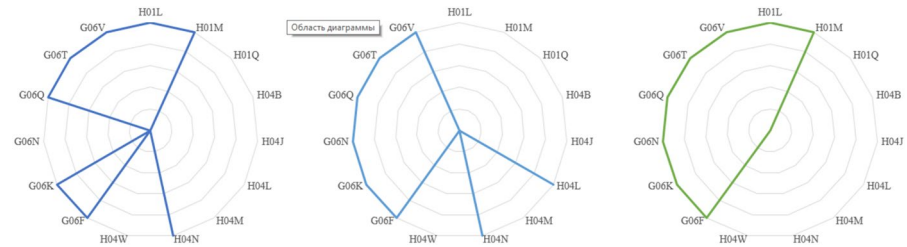


Fig. 11 Technology profiles of the leading countries in terms of the diversity of 5G specializations. Based on the data of the European Patent Office

Fig. 12 Technology profiles of the leading countries by number of 5G patents. Based on the data of the European Patent Office

More specifically, differences between technological profiles of individual EU countries and the leaders in 5G field are presented in Figs. 11 and 12. For example, France, Estonia and Germany have competitive advantages mostly in technologies related to data processing. Basic electric elements and Electric communication technique inventions are almost not represented in the countries under consideration, with the exception of Batteries for the direct conversion of chemical energy into electrical energy, Pictorial communication, e.g. television and Transmission of digital information.

The opposite is true for the USA, China and the Republic of Korea whose technological profiles are less diverse, but include inventions that are rarer for European countries—Telephonic communication, Multiplex communication, Antennas, etc. This fact

indicates that despite the growing number of specializations in EU countries, they still potentially cannot establish 5G technologies apart from the existing patents of the global leaders because they lack their own inventions necessary to create a 5G infrastructure.

7 Discussion: problems to be solved

Let's identify the main difficulties and challenges that arise in the deployment of 5G technology.

1. Many countries today are in need of investments to restore the economy and social sphere after the pandemic, to switch to renewable energy sources, to develop education and professional training. The development of 5G technologies can be an expensive process. This is especially true of geographically vast countries. Full coverage requires the installation of a large number of stations and antennas. Without solving the problems accumulated earlier, the population of these countries will not be able to benefit from the digital revolution (World Economic… 2023). In advance, less developed countries of the world may become laggards in this area.
2. Modern economy, flexible and complex production chains require the rapid transfer of large amounts of data. In such conditions, the formation of an infrastructure that meets high requirements becomes not only an engineering task, but also an important economic task (Zander 2017). Today, companies have a growing need for new innovative business models that could provide technically scalable solutions to increase the capacity of a wide area, while not going beyond certain restrictions on energy consumption and cost (Oughton et al. 2018).
3. The architectural shift requires a much larger number of sites (Brake 2018). This means that accelerated infrastructure development may require state support in the form of loans, subsidies,[8] participation in the form of public–private partnerships and the acquisition of infrastructure facilities by government organizations of different levels—from local to national. For example, Brake (2018) recommends that, when implementing appropriate policy in the United States, not consider the possibility of creating a public network, but rather focus more on providing favourable conditions for the private sector in the deployment of networks. We can also assume that market participants—service providers—can become not only large providers, as it was in previous generations, but also small firms and, conversely, large companies to meet their needs in 5G technology. Thus, the set of technology suppliers will become more diverse, which in the future may have a positive impact on the formation of prices for consumers. Such a different approach to offering services or accounting entails the following complexity.
4. The need to regulate the legislative framework may also be relevant due to the provision of dedicated frequencies for 5G mobile networks, which can be reserved for the needs of various departments. Access to various spectral resources, including millimetre wave (mmWave) between 24 and 86 GHz, determines how much 5G technologies will be able to meet the demand for mobile data transmission services, as

[8] The development of technologies again, formally, can also be attributed to an innovative type of activity, which falls under the policy of innovation support.

well as the services of new wireless broadband applications. in turn, they will develop industrial automation, virtual and augmented reality (Study on… 2018).

5. Patenting. Currently, active work is underway on research, development and, as a result, patenting. Intellectual property rights protection (Brake 2018) is becoming an important task of deploying 5G technologies. The dynamic nature will contribute to an increase in the number of patents in this area, which will increase competition and widen the existing gap between the leading countries and outsiders.

8 Conclusion

The paper represents an attempt to identify the key 5G technologies in the EU countries and to determine in what extent technological profiles of the countries are diversified compared to key leaders in the field—the USA, China and the Republic of Korea. Thus, the analysis showed that most EU countries specialize in technologies related to the processing of data obtained from 5G networks, while the technologies needed to create and improve the operation of towers (elements of electrical networks and electrical communication equipment) are less common. This feature can potentially be the reason for the preservation of the technological dependence of the EU countries on imported solutions.

In addition, it was revealed that despite the fact that the largest number of patents in the field of 5G is observed in Sweden, Germany, Finland, and France, new leaders in the number of specializations are emerging among the EU countries—Spain, Belgium, Austria and Denmark. That is why, future analysis of 5G development in the EU needs to take into account not only the scale of inventions, but also the nature of countries' specializations. It can also be assumed that the EU's position in the global 5G market could improve if countries specialized in rarer and more complex technologies and improved coordination of national policies in this area.

The results of this study will be of interest to representatives of business and governmental people and could make an important contribution to the development of national policies and business strategies in the field of 5G. Moreover, this study provides directions for subsequent analysis of the EU countries technological specializations. As the next stage of the study, it is necessary to assess the relationship between diversity and ubiquity indicators, as well as to identify related technologies whose development in the future could potentially accelerate the spread of 5G in the EU.

Acknowledgements
We would like to thank the two anonymous referees for their useful comments and suggestions. Their meticulous feedback has been instrumental in refining our research. The Article Processing Charge was covered by the funds of PAPAIOS and JSPS (KAKENHI Grant No. JP21HP2002).

Author contributions
EK analysed and interpreted the variety of technological specializations and technology profiles in the EU countries. SR made substantial contributions to the conception of the work, analysed the current development of the situation on the implementation of 5G technologies and wrote the article. All of the manuscript's conclusions and verifications were made concurrently.

Funding
Support from the Research Program of the Faculty of World Economy and International Affairs at HSE University is gratefully acknowledged.

Availability of data and materials
The datasets for the present study are available publicly: European Patent Office (https://www.epo.org/searching-for-patents/data.html).

Declarations

Competing interests
The authors declare that they have no competing interests.

Received: 24 July 2023 Revised: 13 October 2023 Accepted: 10 August 2024
Published online: 27 August 2024

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