

# Analysis of Poland's Innovation Profile Based on the Decomposition of the Summary Innovation Index (SII)

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**Abstract:** Knowledge and new technologies, and thus the innovation created based on them, determine the development opportunities of countries, regions and enterprises. Innovation built on the basis of human resources and their knowledge (and all activities aimed at its development) define the competitive position of the indicated entities and their place on the map of knowledge-based economies. The aim of the article was to analyse Poland's innovative profile against the background of EU countries, based on the latest data. To achieve this goal, first of all, the total Summary Innovation Index (SII) was decomposed and the indicators and data taken into account when determining the level of innovation in individual countries and the entire EU were presented. Then, the considerations focused on the dimensions in which Poland has achieved the most favourable results in recent years, i.e. closest to the EU average, as well as those in which there are the greatest delays. The basis for the research process, during which the method of graphical data presentation and analysis with elements of comparison was used, is the data contained in the European Innovation Scoreboards (EIS) during years 2016-2023. This article is an extension of the study submitted for publication, entitled: "Study of the level of innovation in the European Union - Poland compared to the leading countries". It is an attempt to answer the questions: where is the Polish economy located on the innovation map of the European Union?, what dimensions of innovation have a positive impact on its innovative position, and in which areas do they differ significantly from the EU average? It has cognitive value for the development of knowledge, science, and further improvement of the level of innovation in Poland, thanks to highlighting problem areas and sources of innovative advantage of the innovation leader countries.

**Keywords:** Innovation, Summary Innovation Index, Innovation Dimensions, Knowledge-Based Economy.

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## 1. Introduction

Innovation is becoming more and more important and is a necessary condition for the survival and development of every organization. It also determines the strength of economies and their competitive advantage and is positively related to them (Kim and Koo, 2017; Edghiem and Mouzoughi, 2018; Rajapathirana and Hui, 2018). The key factor in the innovativeness of enterprises and economies is access to knowledge (sharing it) and other intellectual resources. The use of existing knowledge, as well as the creation of new knowledge (in the innovation process), in turn determines the strength and direction of competition (Kokot-Stępień and Krawczyk, 2023; Karaś, 2021; Castandea and Cuellar, 2020).

Innovation, understood as an organization's ability to engage in innovative activities, is key to ensuring organizational survival, improved performance, and growth. The key to innovation, in turn, is knowledge and its management including promoting a culture of innovation and developing innovative teaching programs (Mohamad, Ramayah, and Chiun Lo, 2020; Mondal, Al-Kfairy, and Mellor, 2023; Simeoni, Caballero and Lepez, 2024). The importance of knowledge and intangible resources in modern (knowledge-based) economies is also visible in the way of measuring the innovation of EU countries, including the construction of the basic measure for its assessment, i.e. the Summary Innovation Index (SII). The decomposition of an indicator consisting of sub-indicators allows us to conclude that the knowledge and quality of human resources are incorporated into its construction. Thus, the analysis of its components and the results obtained by Poland should make it possible to answer the questions posed by the authors of the article, i.e. where is the Polish economy located on the innovation map of the European Union?, what dimensions of innovation have a positive impact on its innovative position, and in which they differ significantly from the EU average? An attempt to obtain answers to the indicated questions was the main goal of the undertaken considerations. During the work, an additional question also arose: if the innovative economy is based on knowledge, can it be said that it is/is becoming a knowledge-based economy based on Poland's innovation profile (examined based on the decomposition of the SII index)? In the article, in search of answers to the questions asked, an analysis of Poland's innovative profile against the background of EU countries was carried out. The presentation of the dimensions of innovation in which Poland achieves the most favourable results (based on the European Innovation Scoreboard (EIS) from 2016-2023) was preceded by short theoretical considerations in the field of innovation and knowledge (as the foundation of knowledge-based economies). Methodological aspects of the EU's innovation research were also presented. Due to the limitations of the text's volume, only a brief description of the dimensions of innovation that make

up the Summary Innovation Index is presented. For the same reason, only indicators from those dimensions are presented for which Poland achieved the most favourable results in the last study (EIS 2023). The article uses the method of analysis, synthesis and graphical presentation of data.

## 2. Innovation in the Times of Knowledge-Based Economies – Chosen Aspects

Organizations are constantly looking for ways to stay ahead of their rivals, and one way to stay competitive is to equip themselves with knowledge, knowledge management, innovation and innovativeness. Innovation is understood as a process in which existing knowledge is acquired, shared and assimilated to create new knowledge that includes products and services, methods and processes, and social and environmental contexts (Castaneda and Cuellar, 2020). The importance of knowledge is obvious because it is an introduction to the company's innovation (Abubakar, et al., 2019; Haberla and Kuźmińska Haberla, 2013). Therefore, knowledge and innovations are the subject of interest for theoreticians and practitioners of socio-economic life, as well as various organizations (including the European Union).

The importance of knowledge and innovation is also visible in one of the interesting phenomena observed in the modern world, i.e. the reorientation of the economy consisting in a gradual transition from an economy consuming materials to an economy based on knowledge and information. Competition between countries and regions based on material resources was replaced by competition based on human resources (knowledge and new technologies). The development opportunities of countries and regions are increasingly influenced by human intellectual potential and knowledge related to the latest achievements of modern science. A knowledge-based economy, in which innovations play a key role, is a fundamental challenge in the 21st century for countries whose goal is to achieve a high level of development and competitiveness (Mosbah, 2020, Dolińska, 2009; Milewska, 2018).

The knowledge-based economy (as well as the knowledge management process) is becoming more and more important for developing countries. This is caused by several factors. First, it enables such countries to participate in the global economy and leverage their strengths in technology, education and innovation. Secondly, the shift towards a knowledge-based economy can help address some key challenges such as poverty, inequality and unemployment. This is possible by creating new opportunities for economic growth, innovation and jobs, especially in the technology and services sectors. Moreover, the knowledge-based economy can also help create a better educated and skilled workforce, which is crucial for sustainable economic growth and competitiveness in the global market (Kulkarni, 2023; Ode and Ayavoo, 2020; Trivedi and Srivastava, 2022). These phenomena are not only the domain of developing countries. The prospects for social, economic and technological development, also in the economically developed countries of the European Union, increasingly depend on the ability to initiate, disseminate and implement innovations in all spheres of life, especially in new sectors oriented on knowledge and high technologies (Melnikas, 2012).

### 1. Dimensions and Sub-Indexes of the SII Index - Methodological Basis

The Summary Innovation Index ranges from 0 to 1. The closer to 1, the higher the level of innovation in a given country. Currently, this index is calculated based on 32 sub-indexes grouped into four categories and twelve dimensions (Crisan and Stanica, 2022; Šofranková, et al., 2022).

The first category included in the SII is "Framework Conditions", which allows you to identify the main factors influencing innovation performance. They consist of the following dimensions (European Commission, 2023):

- Human resources, which measures the availability of a highly skilled and educated workforce,
- Attractive research systems that measure the international competitiveness of the science base,
- Digitalisation - the dimension within which the level of digital technologies is measured.

"Investments" is a category covering investments made in both the public and private sectors, defined by 3 consecutive dimensions (European Commission, 2023):

- Financing and support - includes three indexes, including private financing (venture capital investment), research and development spending in universities and government research organizations, and direct government financing and government tax support for enterprise research and development),
- Corporate investment - includes three indexes on research and development and non-R&D investments, investments that companies undertake to generate innovations, including expenditure on R&D, expenditure on innovation other than R&D and innovation expenditure on employed person,

- Use of information technologies - a dimension that includes two indexes: enterprises actively improving the information and communication skills of their staff and employed ICT specialists.

The next category is: "Innovative activities" analysed in dimensions (European Commission, 2023):

- Innovators, including SMEs introducing innovations,
- Connections – indexes used to measure cooperation between the public and private sectors,
- Intellectual assets illustrating patent activity.

The last category of innovation included in the SII structure is "Impact". This category includes the effects of innovative activities of enterprises in three dimensions (European Commission, 2023):

- Impact on employment - indexes illustrating the level of employment in innovative sectors,
- Impact on sales - sub-indexes relating to the level of sales of innovations on the domestic and foreign markets,
- Environmental impact - indexes of this dimension focused on improvements aimed at reducing the negative impact on the environment.

Table 1 highlights the dimensions for which the EIS 2023 results for Poland are the most favourable, i.e. most similar to those of EU countries.

**Table 1: Dimensions of innovation for which Poland achieved the most favourable results in EIS 2023**

| SELECTED INDEXES OF INNOVATION IN EU COUNTRIES CALCULATED UNDER SII |   |  |
|---|---|--|
| Dimensions of innovation  | Components of the SII index/ (Year of "availability" of the latest data)                        | Data source  |
| <b>FRAMEWORK CONDITIONS</b>   |   |  |
| <b>Digitalisation</b>   | 1.3.1 Broadband penetration (2022)  | Eurostat   |
|   | 1.3.2 Individuals who have above basic overall digital skills (%share) (2021)                   | Community Survey of ICT Usage and E-commerce in Enterprises<br>EU survey on the ICT usage in households and by individuals |
| <b>INVESTMENTS</b>  |   |  |
| <b>Use of information technologies</b>                              | 2.3.1 Enterprises providing training to develop or upgrade ICT skills of their personnel (2022) | Eurostat, Community Survey of ICT Usage and E-commerce in Enterprises  |
|   | 2.3.2 Employed ICT specialists (2022)   | Enterprises  |
| <b>INNOVATION ACTIVITIES</b>  |   |  |
| <b>Intellectual assets</b>  | 3.3.1 PCT patent applications per billion GDP (in PPS) (2019)                                   | Eurostat   |
|   | 3.3.2 Trademark applications per billion GDP (in PPS) (2022)                                    | Patent data from the OECD  |
|   | 3.3.3 Design applications per billion GDP (in PPS) (2022)                                       | EUIPO  |

Source: own elaboration on European Commission, 2023; European Commission, 2023a.

The SII calculation methodology includes several basic steps, presented in Table 2.

**Table 2: Stages of calculation of the SII index**

| STAGE                              | ACTIONS   |
|------------------------------------|---|
| <b>Setting reference years</b>     | For each indicator, a reference year is identified for all countries based on data availability for all those countries for which data availability is at least 75%. For most indicators, this reference year lags one or two years behind the year in which the EIS is published.  |
| <b>Imputing for missing values</b> | Reference year data are then used for "2023", etc. If data for a year-in-between are not available, missing values are replaced with the value from the previous year. If data are not available at the beginning of the time series, missing values are replaced with the next available year. If data are missing for all years, no data will be imputed (the indicator will not contribute to the Summary Innovation Index). |

| STAGE   | ACTIONS   |
|---|---|
| <b>Identifying and replacing outliers</b>                                       | Positive outliers are identified as those country scores which are higher than the mean across all countries plus twice the standard deviation. Negative outliers are identified as those country scores which are smaller than the mean across all countries minus twice the standard deviation. These outliers are replaced by the respective maximum and minimum values observed over all the years and all countries excluding the identified outliers. With replacing positive (or negative) outliers, more countries can share the highest (lowest) normalised score of 1 (0).  |
| <b>Transforming data that have highly skewed distributions across countries</b> | Most of the indicators are fractional indicators with values between 0% and 100%. Some indicators are unbound indicators, where values are not limited to an upper threshold. These indicators can be highly volatile and can have skewed data distributions (where most countries show low performance levels, and a few countries show exceptionally high levels of performance). For these indicators where the degree of skewness across the full eight-year period is above one, data have been transformed using a square root transformation, i.e. using the square root of the indicator value instead of the original value. |
| <b>Determining Maximum and Minimum scores</b>                                   | The Maximum score is the highest score found for the eight-year period within all countries excluding positive outliers. Similarly, the Minimum score is the lowest score found for the eight-year period within all countries excluding negative outliers.   |
| <b>Calculating re-scaled scores</b>   | Re-scaled scores of the country scores (after correcting for outliers and a possible transformation of the data) for all years are calculated by first subtracting the Minimum score and then dividing by the difference between the Maximum and Minimum score. The maximum re-scaled score is thus equal to 1, and the minimum re-scaled score is equal to 0. For positive and negative outliers, the re-scaled score is equal to 1 or 0, respectively.  |
| <b>Calculating composite innovation indexes</b>                                 | For each year, a composite Summary Innovation Index is calculated as the unweighted average of the re-scaled scores for all indicators where all indicators receive the same weight (1/32 if data are available for all 32 indicators).   |
| <b>Calculating relative-to-EU performance scores</b>                            | Performance scores relative to the EU are calculated as the SII of the respective country divided by the SII of the EU multiplied by 100. Relative performance scores are calculated for the full eight-year period compared to the performance of the EU in 2016 and for the latest year also to that of the EU in 2023. For the definition of the performance groups, only the performance scores relative to the EU in 2023 have been used.  |

Source: own elaboration on European Commission, 2023.

The method of calculating the SII index and the thresholds for membership of individual countries in innovation efficiency groups were presented by the authors in the article "Study of the level of innovation in the European Union - Poland compared to the leading countries", which is an introduction to the data presented in this study. On their basis, it can be concluded that Poland is among the countries with the lowest level of innovation.

## 2. Poland's Position in the European Union in Terms of the Use of Information Technologies, Intellectual Assets and Digitalisation Against the Background of the Summary Innovation Index (SII)

While in previous years the EIS data indicated dimensions such as Human Resources, Intellectual Assets and Enterprise Investments as sources of the innovative potential of the Polish economy, in the latest edition of the EIS Poland achieved results most similar to those of EU countries in the following dimensions (European Commission, 2023a; European Commission, 2022; European Commission, 2022a; European Commission, 2018):

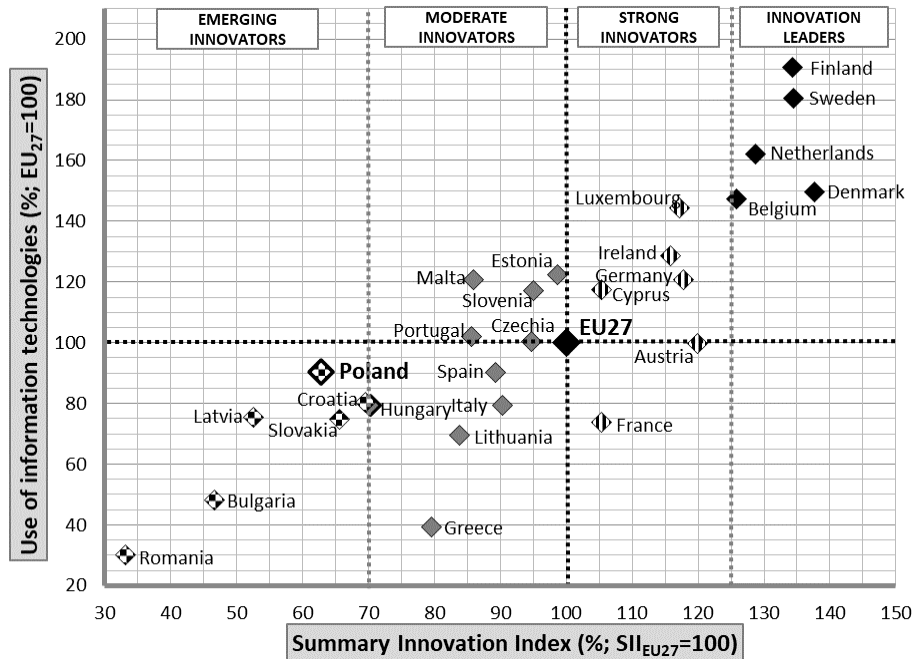
1. Use of information technologies (dispersion of the percentage of the SII sub-index between the EU average and Poland in this category is the smallest:  $SII_{EU27} - SII_{PL} = 9,7pp$ ),
2. Intellectual assets ( $SII_{UE27} - SII_{PL} = 15,8pp$ ),
3. Digitalisation ( $SII_{EU27} - SII_{PL} = 18,9pp$ ).

The Use of information technologies dimension is an element included in the Investments category, covering investments made in both the public and business sectors. It contains two indicators determining the degree of use of information technologies, i.e.:

- 2.3.1 Enterprises providing training to develop or upgrade ICT skills of their personnel,
- 2.3.2 Employed ICT specialists.

Poland's result in the above-mentioned dimension was the best of the 12 dimensions considered. Therefore, first of all, it was analysed and the results on a European scale are graphically presented in Figure 1, assuming the division of countries into groups of innovators in accordance with the classification included in EIS 2023. The EU average was used as the cut-off point, which divided the chart into four parts, at the same time showing the

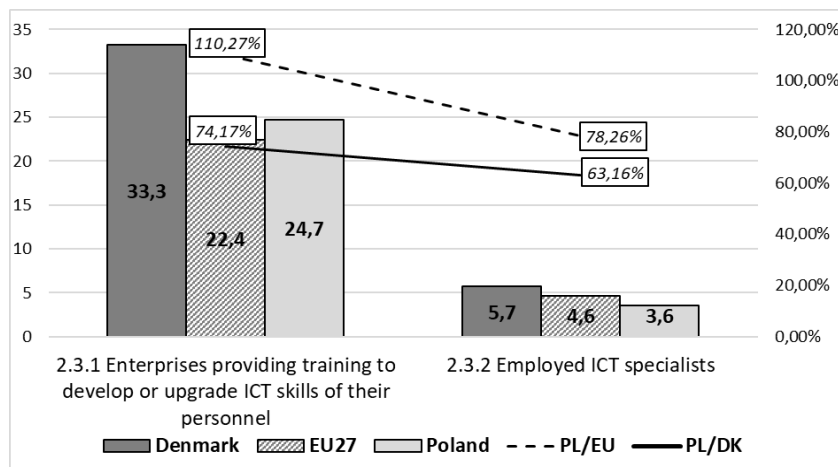
distribution of European countries according to the results achieved under the SII and the Use of information technologies dimension (as a percentage of the EU average). The same way of presenting the results was used in Figures 3 and 5 for the Intellectual assets and Digitalisation dimensions.



**Figure 1: Poland's profile on the Use of information technologies dimension matrix compared to the innovative position of EU member states in 2023 (as a percentage of the EU average)**

Source: own elaboration on Eurostat data.

The undisputed leaders in the Use of information technologies are Finland and Sweden. The analysis of Figure 1 also shows that 9 out of 11 countries whose results differ significantly from the EU average (both on the X and Y axis) come from groups of countries that are strong innovators and innovation leaders. 14 out of 27 European Union member states achieved results in the Use of information technology dimension above the EU average. Poland's position in this dimension has strengthened the most out of all twelve dimensions of innovation calculated under the SII index compared to 2022, which allowed it to rank 16th among European countries (an increase in the index from 71.7% of the EU average in 2022 to 90.3% in 2023). The weakest country in this area was Romania.



**Figure 2: Sub-indexes included in the Use of information technologies dimension for the EU, Denmark and Poland in 2023**

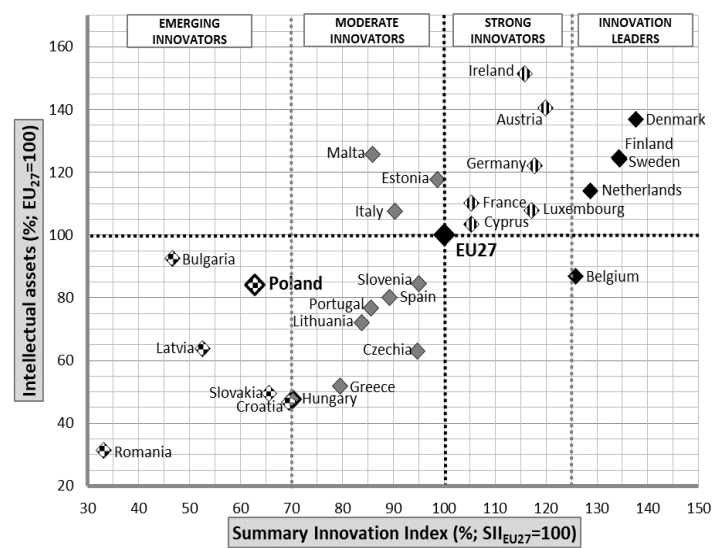
Source: own elaboration on Eurostat data.

ICT skills are particularly important for innovation in today's increasingly digitized economic realities. Eurostat defines ICT professionals as “workers who have the ability to develop, operate and maintain ICT systems and for whom ICT constitutes a core part of their work” (European Commission, 2022). The growing share of enterprises providing training in this area is also an indicator of the overall development of employee skills. The values of both sub-indexes - components of the Use of information technologies dimension - for Poland, the innovation leader - Denmark and the entire European Union in 2023 are presented in Figure 2. Additionally, the values of these indexes achieved by Poland were calculated and shown in relation to the results of Denmark and the EU. According to the analysis of the presented data, in Poland in 2023, for every 100 enterprises, there were nearly 25 entities that undertook to improve the digital competences of their employees. Thus, Poland's result was 74.17% of the result achieved by Denmark (33 enterprises out of 100) and 110.27% of the EU average (22.4 enterprises out of 100) and was the 11th best result in the EU. Unfortunately, this did not translate into the number of ICT specialists employed in companies - in Poland, out of 100 employees, only 3.6 employees had such competences, while in Denmark almost 6, and in the case of the leader - Sweden - 8.6.

The second dimension of innovation, in which Poland achieved the best results, includes Intellectual assets. This dimension is one of three areas of innovative activities, including: Innovators (two indexes, including SMEs introducing innovations), Connections (three indexes illustrating cooperation between the public and private sectors) and Intellectual assets (three indexes illustrating patent activity). The indexes that make up the Intellectual assets group include:

- 3.3.1 PCT patent applications per billion GDP (in PPS),
- 3.3.2 Trademark Applications per billion GDP (in PPS),
- 3.3.3 The number of industrial designs submitted per billion GDP (in PPS),

The results of the European Union member states for the Intellectual Assets dimension are presented in Figure 3, assuming the same assumptions as for Figure 1. According to its analysis, the countries that lead in the Intellectual assets dimension are Ireland and Austria, respectively (1st and 2nd place in the hierarchy). It is noteworthy that very good results in this dimension are achieved not by innovation leaders (Denmark, Finland, Sweden), but by countries classified as strong innovators (the above-mentioned Ireland and Austria, Germany) and moderate innovators (Malta, Estonia). Poland, with the results of indexes within this dimension presented in Figure 4, qualified in 18th place, taking into account the EU average (14th place). This result was most significantly influenced by the value of index 3.3.3, regarding the number of reported industrial designs per billion of GDP. Achieving over 150% of the EU average for registered industrial designs allowed Poland to rank fourth among the 27 EU member states. In turn, the European leader in innovation - Denmark - achieved much better results in the case of registered trademarks (per billion GDP). On average, in the European Union, there are 3.28 registered patent applications per billion GDP, over 7 registered trademarks and approximately 4 registered industrial designs.



**Figure 3: Poland's profile on the Intellectual assets dimension matrix compared to the innovation position of EU member states in 2023 (as a percentage of the EU average)**

Source: own elaboration on Eurostat data.

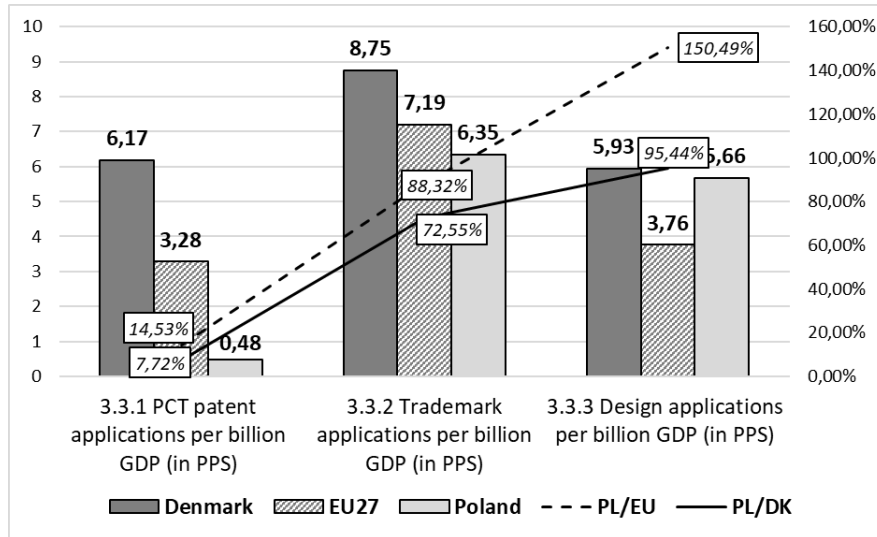


Figure 4: Sub-indexes included in the Intellectual assets dimension for the EU, Denmark and Poland in 2023

Source: own elaboration on Eurostat data.

The last dimension in which Poland achieved the best results as a percentage of the EU average was the Digitalisation dimension. This dimension falls within the SII category called “Framework conditions” and includes two indexes:

- 1.3.1 Popularization of broadband connections among enterprises (% share),
- 1.3.2 People with post-basic general digital skills (% share).

Framework conditions capture the main factors influencing the innovation performance of countries' economies. They consist of the following dimensions: Human resources, Attractive research systems and the above-mentioned Digitalisation. Digitalisation measures the level of digital technology through the spread of broadband connections among businesses and the supply of people with post-basic general IT skills.

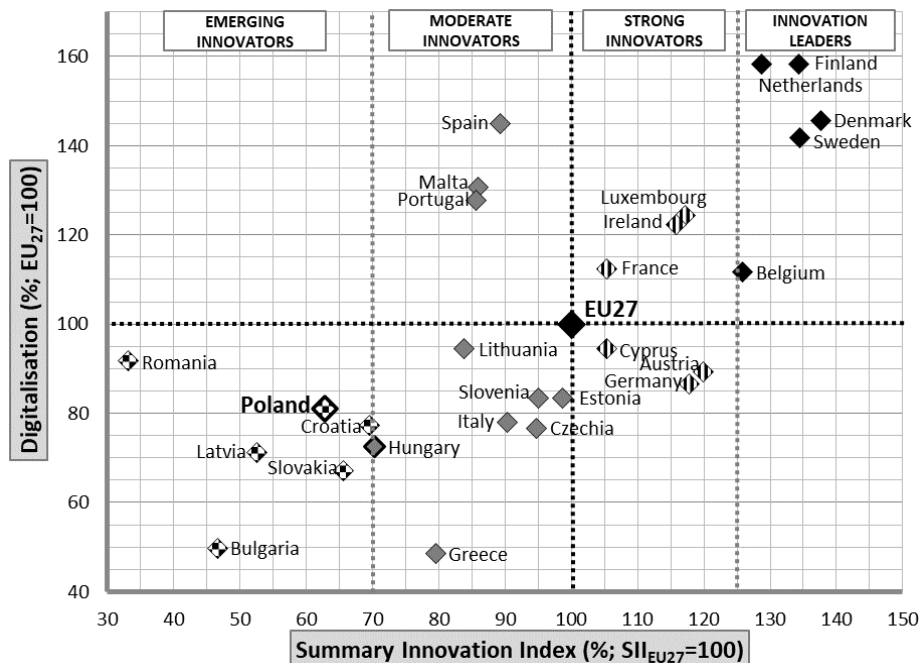
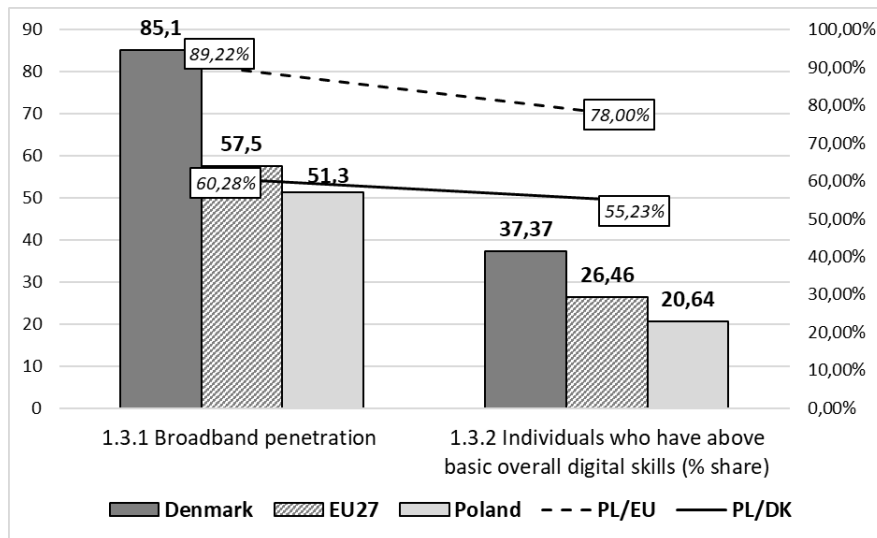


Figure 5: Poland's profile on the Digitalisation dimension matrix compared to the innovation position of EU member states in 2023 (as a percentage of the EU average)

Source: own elaboration on Eurostat data.



**Figure 6: Sub-indexes included in the Digitalisation dimension for the EU, Denmark and Poland in 2023**

Source: own elaboration on Eurostat data.

In Figure 5, Digitalisation (as a percentage of the EU average, which was assumed to be 100%) is compared on the X-axis with the percentage of the SII indicator (assuming that  $SII_{UE27}=100\%$ ). The results obtained indicate that the leaders in the European Union in the area of digitalisation are two countries - the Netherlands and Finland, with results of 158.3% and 158.2% of the EU average, respectively. Denmark - as a leader in innovation on a European scale - was in third place. The level of digitalisation of 81.1% of the EU average allowed Poland to rank 19th out of 27 member states. The EU average was 12th in the ranking of EU member states.

When decomposing the Digitalisation dimension into the above-mentioned two sub-indexes (Figure 6), it should be noted that Poland's results do not differ significantly from the EU average in this respect, constituting 89.22% and 78% of the EU average, respectively. This means that over 51% of enterprises in Poland have access to broadband Internet, and every fifth Pole has above-average IT skills (every fourth EU citizen). In the case of Denmark, these shares are correspondingly higher - 85% of enterprises use broadband connections, and 37% of the population has above-average IT skills. However, the decomposition of this dimension into component indexes leaves no doubt that despite Poland's good result against the background of 12 dimensions of innovation, this area is not the country's strongest point. The use of Poland's full e-potential depends on creating conditions for the development of e-commerce and the Internet, as well as on constantly improving the basic general digital skills of citizens aged 16-74 on the Internet, covering the areas of information, communication, problem solving and content creation. Considering that - according to the EIS 2023 report - within these two sub-indexes of the Digitalisation dimension, Poland is in 17th and 23rd position in the EU, respectively, it can be confidently stated that the country's innovative position is weak and requires intensification of financial outlays from the government.

### 3. Conclusions

Knowledge and innovation are the pillars of the knowledge-based economy. Without knowledge there is no innovation, information society and knowledge-based economy. The emergence of innovations, economic development, progress in scientific and technical knowledge, and the creation of an information society are considered important social problems, both in individual countries and in the entire European Union. Therefore, special attention should be paid to creating innovation, including through the development of knowledge - the potential to create a knowledge-based economy. The development prospects of the European Union and its role in the global system depend on the use of innovation potential, including the dissemination of humanitarian and democratic values, in order to create a new society which, among other things, through innovation in the field of technology, will create a knowledge-based economy. It should also be emphasized that human and intellectual resources provide enormous opportunities for activating innovation in the European Union. Their diversity, highly developed infrastructure for activating and developing education, science, experience in creating and developing high technologies and maintaining international connections are sources of innovative potential and gaining a competitive advantage (Melnikas, 2012; Rynio, 2010; Kucznik, 2019).

The European Union is an organization of culturally, socially and economically diverse countries. Even a cursory analysis of the level of innovation and the innovation potential of individual countries allows us to observe many differences and disproportions. However, the analysis of EU innovation research results indicates innovation leaders who have been setting the direction for innovation for several years, constantly increasing expenditure on research and development and promoting the development of the economy whose basic pillar is knowledge. The dominant role of the Scandinavian countries can be seen here, and with the change in the methodology of monitoring innovation, the position of countries such as Luxembourg and Germany has decreased. Poland belongs to the group of countries with a level of innovation that differs unfavourably from the average calculated for the 27 European Union countries - indexes in all dimensions of innovation for Poland were below the EU average, and Poland itself was in 24th position on the EU innovation map, measured by the value of the SII index.

In response to the research questions posed in the introduction of the article, it should be noted that when analysing Poland's position, based on the dimensions included in the SII index, it was found that the Polish economy achieves the best results for three dimensions: Use of information technologies, Intellectual assets, Digitalization. Unfortunately, the term "best results" does not mean that these are the results that justify calling Poland an innovative or knowledge-based economy. Poland's innovativeness in these three best areas gives it only 16th, 17th and 19th place in the ranking of 27 European countries and is always lower than the EU average. The Polish economy performs worst in the area of attractive research systems, as an innovator - with a low percentage of SMEs introducing innovations in products and business processes, as well as in the field of environmental sustainability. Of course, the dimensions include indexes whose results clearly indicate a good or very good position of Poland in the examined area (for example, Poland's high, 4th position is given only by one measure included in the Intellectual assets dimension, i.e. the number of registered industrial designs per billion GDP, and the 11th place is due to the high percentage of enterprises that have undertaken to improve the digital competences of their employees, included in the dimension of the Use of information assets). This gives rise to the claim that the Polish economy is moving towards a knowledge-based economy, but time, effort and many resources are still needed to reduce development backwardness and minimize arrears based on access to funds co-financing various types of development projects, including innovative ones. Changes are also needed in the country's innovation policy, focusing on increasing expenditure on research and development.

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