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# THE DIVERSITY OF EU MEMBER STATES IN TERMS OF TECHNOLOGICAL COMPETITIVENESS IN 2019 AND 2022

## Abstract

- *Goal* – The aim of the paper is to evaluate the diversity of EU member states in terms of technological competitiveness in 2019 and 2022 and to assess relationships between technological competitiveness and eco-innovativeness. Three research questions were developed: did technological competitiveness deteriorate due to pandemic? Does technological competitiveness influence eco-innovativeness of EU countries? Do external or internal sources of technological competitiveness contribute to the higher level of eco-innovativeness?
- *Research methodology* – Hellwig's method was used to rank EU countries on their technological competitiveness with division to classes of objects with similar features. Relationship between technological competitiveness and eco-innovativeness was researched with the use of Spearman's correlation coefficient and the influence of technological competitiveness' single variables on eco-innovativeness was assessed.
- *Score/results* – The technological competitiveness of EU member states remains below the average level, but it has improved in the analysed period. A strong positive relationship between technological competitiveness and eco-innovations in 2019 has decreased to a moderate level in 2022. A strong correlation was found between patent applications to the EPO and the level of eco-innovativeness of EU countries.
- *Originality/value* – The originality of paper is represented by the chosen research method and the set of diagnostic variables. The value of the research results is associated with identifying features fostering eco-innovativeness which can be strengthened by innovation policy.

**Keywords:** technological competitiveness, eco-innovation, European Union, Hellwig's method.

## 1. Introduction

Technology plays a crucial role in the modern highly globalised and competitive world. Recent decades have brought a rapid growth in technological development influencing the economy, society and environment. Due to this, companies must have adapted their business models to a new environment, where a struggle to achieve a competitive advantage owing to technology becomes fierce. To build and restore such technological advantage firms must adopt and create new technologies in order to outstrip the competition and enlarge market share [Saura, Skare, Riberio-Navarrete, 2022: 172–175].

Pursuit for technological advancement also applies to economies, intense competition among nations for technological supremacy can be observed. Investments in research and development, implementation of new technologies and adaptation to technological changes are essential to ensuring long-term economic growth and improving the quality of life. Technological change is accelerating rapidly and countries which highly support and invest in technology's development achieve higher competitiveness and better positions in the international division of labour [Weresa, 2019: 52].

Nowadays shifting towards a more sustainable socio-economic development has become a key priority for many countries. The sustainable development paradigm changes the competition between economies, because it introduces new criteria and goals that go beyond traditional economic indicators. It is associated with a fundamental change in economic activity and requires a transformation towards the "green economy". Eco-innovation can be regarded as a tool supporting the implementation of sustainable development at the enterprise, society and state levels contributing to the achievement of economic and environmental benefits [Urbaniec, 2015: 179].

The aim of this paper is to assess the technological competitiveness of EU member states in 2019 and 2022, as well as to evaluate the interdependencies between their technological competitiveness and eco-innovativeness. Three research questions were developed: did the technological competitiveness of countries deteriorate due to pandemic? Do countries representing higher technological competitiveness have higher competitive positions in terms of eco-innovativeness? Do external or internal sources of technological competitiveness contribute to the higher level of eco-innovativeness? The research methods included: literature review, Hellwig's method to assess technological competitiveness, Spearman's and Pearson's correlation analysis to study relationships between technological competitiveness and eco-innovativeness.

## 2. Technological competitiveness – review of literature

Technological competitiveness has arisen from the concept of competitiveness, which has undergone a significant transformation – from a narrow focus on costs and productivity to a broad consideration of more complex factors such as innovation, human capital, quality of institutions, as well as social and environmental aspects. Research on competitiveness has started from the concept of price and quality competitiveness representing input approach, and further has evolved to the output approach visible in assessment of outcome competitiveness and achievement of beyond-GDP goals in the context of a more socially inclusive and environmentally sustainable path [Aiginger, Barenthaler-Sieber, Vogel, 2013: 9–14].

Most recent researchers agree, that competitiveness relates to country's ability to improve economic growth and development, but an increase in the living standards and prosperity can be achieved using different instruments. For Porter, "the only meaningful concept of competitiveness at the national level is productivity. A nation's standard of living depends on the capacity of its companies to achieve high levels of productivity – and to increase productivity over time" [Porter, 2008: 176]. Considered as the state of the art, Porter's concept of competitive advantage of nations and its model extensions had a significant impact on the perception of competitiveness for decades [Zargartalebi, 2021: 73]. Despite the criticism from Krugman [1994], that non-competitive economies with low trade ratios don't collapse, Porter's concept has became a reference point for many contemporary analyses searching to obtain empirical evidence. Moreover, competitiveness is considered as a driver of economic growth rather than a fundamental requirement for its survival, in contrast to companies [Woźnicki, Gawlik, 2024: 1413].

Relating to a neo-Schumpeterian approach appreciating the importance of innovation and technology, Porter has recently stated that country's long-term competitive position depends on creation of new ideas and their commercialisation [Weresa, 2019: 52]. Also Posner has seen in technological potential the source of country's competitiveness. Kolodko has noticed, that knowledge-based economies compete using technology and human capital, which can be regarded as technological competitiveness. Technology has a beneficial impact on efficiency and effectiveness, while knowledge – a scarce factor in developing countries – enables creation and diffusion of new ideas [Woźnicki, Gawlik, 2024: 1414–1415].

Technological competitiveness is a relatively new concept in economic studies and no generally accepted definition has been developed. Fagerberg has defined technological competitiveness as the ability to develop technological efficiency in a world of changing technologies. In foreign literature, Porter and Stern, as well as Porter and Roessner, have conducted studies on technological competitiveness. According to Yglesias the increase in competitiveness stems from a country's capacity to develop, adopt and export technologies. The author proposed a factoral model of technological competitiveness, where input factors comprise socioeconomic infrastructure, national orientation, productive capability and technological infrastructure. In Polish literature, Wysokińska and Zielińska-Głębocka have paid attention to science, technology and innovations as determinants of state's technological competitiveness [Wosiek, 2019: 231–232].

Technological competitiveness for many researchers indicates the general ability of new goods and services to compete effectively in the markets. The concept of technological competitiveness can be defined as a long-term capacity to establish internal economic conditions facilitating the adoption of new knowledge and existing technologies – including their creation and development – to enhance the state's technological potential [Molendowski, Nawracaj-Grygiel, Ulbrych, 2024: 10]. The sources of this technological potential are: technological innovation, knowledge, information and communication technologies and transport infrastructure [Wosiek, 2019: 232].

Howells perceives the country's scientific and technological competitiveness as its ability to create and sustain competitive advantages in the creation, diffusion and implementation of new knowledge, created with the use of its scientific and technological capacity in the context of globalisation. Competitive differences among countries result from differences in technological capabilities – economies differ in terms of their ability to absorb, adapt and use technology to increase efficiency and productivity [Matyushenko et al., 2021; 150]. Technological competitiveness is a less commonly explored topic of research, especially in the context of developing countries. Moreover, developed economies take the lead in creation and usage of the most innovative technologies in industry 4.0 and industry 5.0, while emerging economies have more limited knowledge and technology, which allows differentiation in industry 2.0 and industry 3.0. In developing countries, public policy on science, technology and innovation requires substantial improvement, as it fails to significantly increase their economic development. Furthermore, the lack of financing programs providing the necessary impetus and direction for technological advancement and insufficient cooperation between the government and society, business and the education sector constitute another two major sources of technological gap [Álvarez-Aros, Bernal-Torres, 2021: 1–20].

Technological competitiveness is the ability to innovate, as well as to increase efficiency and reduce costs. It improves the technological advancement of the country's export performance by providing differentiated products of higher quality on international markets [Bierut, Kuziemska-Pawlak, 2016: 5–6]. Technological competitiveness can also be seen through a prism of innovative ability (potential) and adaptive capacity or more broadly as the ability to produce new technical knowledge or develop new economically useful technologies. Most studies on technological competitiveness focus on technological innovation or associate it with productivity [Weresa, 2019: 53–54].

The determinants of technological competitiveness include [Woźnicki, Gawlik, 2024: 1415–1416]:

- productivity, which depends on technological potential and innovation;
- ICT capabilities, but there is not enough empirical evidence found;
- high technological level of exported goods because technologically advanced countries tend to export more technologically advanced goods;
- patent activity and scientific publications.

According to the European Commission, technological competitiveness is the capacity of a national economy to achieve sustained economic growth, enhance productivity and improve prosperity through technological and innovative development. A high level of education; an innovative infrastructure, including high-quality research institutions; investment in research and development; high levels of competition; extensive cooperation between universities and industry; protection of intellectual property rights and access to venture capital and finance constitute favorable conditions for innovation. Technological competitiveness influences the dynamics of foreign trade and supports industrial modernisation [Matyushenko et al., 2021: 150].

Many studies have been carried out on the subject of technological competitiveness at the micro level, which have shown that innovations driven by internal R&D activities contribute significantly to economic development. Corporations must conduct identification of needed technologies, assessment of available technological options and integration of new technologies into production processes. Moreover, innovations can become an input in other innovation processes leading to the diffusion of innovation in particular sectors. High level of competition on the market may favor the transfer of technology through foreign capital flows, but opportunities arising from external relations can be discounted by companies representing higher absorption capacity, which conducted research and development investments previously [Diaconu, 2011: 132–133].

Also Yoon and Kwon have examined interdependencies between companies' technological competitiveness and their technological and non-technological innovative activities. Their research has shown, that product and process innovations tend to positively impact technological competitiveness, while marketing and organisational activities may complement technological innovation competitiveness supporting adaptation to external environment and securing survival [Yoon, Kwon, 2023: 1–19].

The aforementioned definitions can be synthesised as follows: technological competitiveness relates to economy's capabilities in science, research and development and export of technologically advanced goods [Woźnicki, Gawlik, 2024: 1416]. It can be concluded, that technological competitiveness is an important foundation of economic competitiveness. An increase in the level of technological competitiveness of the state means a simultaneous increase in the level of its international competitiveness, while the reverse relationship does not have to be observed [Wosiek, 2019: 232].

Various indicators are used to measure technological competitiveness, such as the share of high-tech patents in the total number of patents granted, the revealed technological advantage (RTA) index and the world market share of high-tech exports [Weresa, 2019: 57–59].

We can distinguish technological competitive position and technological competitive ability. The results in international trade in technologically advanced goods and services, as well as the results of R&D activities and human capital resources in the form of knowledge are the core of assessment of state's technological competitive position. In turn, technological competitive ability refers to factors affecting technological competitive position [Wosiek, 2019: 232].

## 3. Research methodology

Many authors assess the level of competitiveness using synthetic measures obtained from the partial diagnostic variables [Cheba, Szopik-Depczyńska, 2019: 142]. Synthetic measures enable the analysis of complex phenomena influenced simultaneously by many factors and the comparison of objects described by many measurable variables. To measure the technological competitiveness of EU member states, the author chose to use the Hellwig's method of linear ordering. Introduced in 1968, it belongs to the methods of multidimensional comparative analysis [Bąk, 2016: 24–26]. The classical Hellwig's method and its modifications have been applied in the analysis of: socio-economic development, sustainable development, and quality of human capital in the EU [Roszkowska, Filipowicz-Chomko, Łyczkowska-Hanćkowiak, Majewska, 2024: 2]. It involves the following stages [according to: Skrodzka, 2016: 114–115]:

- Stage 1: Selection of indicators based on substantive and statistical reasons.
- Stage 2: Identification of the type of indicator (stimulant, destimulant, nominant).
- Stage 3: Normalisation of the values of indicators using standardisation.
- Stage 4. Determination of development pattern $z_0$.
- Stage 5. Calculation of the distances ($d_{i0}$) of i-th object from the ideal development pattern using the classical Euclidean distance measure
- Stage 6. Calculating Hellwig's measure $H_i$ for the i-th object
- Stage 7. Linear ordering of objects according to descending values of synthetic measure $H_i$.

$H_i$ is a normalised measure, which ranges typically from zero to one. A greater value of the synthetic measure corresponds to the higher level of a complex phenomenon and a higher ranking position. If $H_i$ takes negative values, it signifies that the analysed object is definitely worse than others.

In this paper, the author assumed that technological competitiveness is the result of the ability of a given country to compete in technology and its competitive position in the international arena. Economies achieving higher technological competitive position will represent higher capacity for competition in technology. Indicators were extracted from the Eurostat, the Conference Board, Elsevier Scopus and the World Bank. Research period covered year 2019 and 2022 due to lack of latest data (in case of 3 variables indicators for 2023 were not available). It enabled the comparison of situation before the pandemic, after several years of prosperity and development, with effects of economic downturn caused by limitation of business activity and reduction of domestic demand due to SARS-CoV-2 disease.

Bearing on the literature review, availability of data and comparability purpose, 10 variables were selected and descriptive statistics were calculated. The exclusion of a given feature from the set was possible if the variability level was below 10%. Based on variability levels, there was no need to eliminate any indicator from the set. Then, the correlation indices of variables was calculated – a matrix of Pearson's correlation coefficients was determined. The inverse correlation coefficient matrix method was used [Młodak, 2006]. If the chosen indicators create too much exact interdependencies, its diagonal elements are greater than 10. In the presented study no significant correlation between the features was found [Cheba, Bąk, Szopik-Depczyńska, 2020: 1405–1406]. The set of diagnostic variables used in the research is presented in Table 1.

*Table 1.* Diagnostic variables describing technological competitiveness of EU member states in 2019 and 2022

| Symbol | Variable | Type of variable | Year | Minimum value | Maximum value | Mean | Coefficient of variation (%) |
|---|---|---|---|---|---|---|---|
| X1 | Share of researchers in total employment (%) | stimulant | 2019 | 0.23% Romania | 1.63% Finland | 0.92% | 41.44% |
| | | | 2022 | 0.25% Romania | 2.08% Sweden | 1.04% | 43.70% |
| X2 | Persons with tertiary education and employed in science and technology (%) | stimulant | 2019 | 9.1% Italy | 26.5% Luxembourg | 15.46% | 26.73% |
| | | | 2022 | 9.3% Italy | 29.5% Luxembourg | 17.21% | 27.24% |
| X3 | Government's expenditure on R&D (% of GDP) | stimulant | 2019 | 0.01% Malta | 0.42% Germany | 0.18% | 54.19% |
| | | | 2022 | 0.01% Malta | 0.37% Germany | 0.18% | 54.50% |
| X4 | Business sector's expenditure on R&D (% of GDP) | stimulant | 2019 | 0.17% Latvia | 2.44% Sweden | 1.06% | 64.93% |
| | | | 2022 | 0.29% Romania | 2.56% Sweden | 1.11% | 61.56% |
| X5 | Patent applications to the European Patent Office by applicants' country (per mln inhabitants) | stimulant | 2019 | 2.06 Romania | 669.35 Luxembourg | 142.59 | 124.00% |
| | | | 2022 | 2.42 Romania | 526.72 Luxembourg | 147.34 | 115.06% |
| X6 | Exports of high-tech products (% of total exports) | stimulant | 2019 | 4.6% Cyprus | 38.57% Ireland | 12.21% | 61.58% |
| | | | 2022 | 4.97% Greece | 42.46% Ireland | 12.06% | 70.24% |
| X7 | Imports of high-tech products (% of total imports) | stimulant | 2019 | 6.88% Cyprus | 39.18% Ireland | 13.47% | 47.18% |
| | | | 2022 | 6.98% Cyprus | 26.65% Malta | 12.50% | 40.30% |
| X8 | FDI inflow (% of GDP) | stimulant | 2019 | -13.67% Netherlands | 252.92% Luxembourg | 28.51% | 244.31% |
| | | | 2022 | -360.35% Luxembourg | 126.28% Malta | -5.54% | 1350.04% |
| X9 | Number of scientific publications (per million inhabitants) | stimulant | 2019 | 601 Bulgaria | 4352 Denmark | 2025.5 | 45.92% |
| | | | 2022 | 736 Bulgaria | 5170 Denmark | 2501.7 | 44.22% |
| X10 | Total factor productivity growth (%) | stimulant | 2019 | -4.6% Ireland | 1.9% Latvia | 0.2% | 771.13% |
| | | | 2022 | -5.1% Estonia | 3.5% Portugal | 0.4% | 492.06% |

Source: the author's own elaboration.

Among the included variables there are features describing human capital, as well as research and development activities which constitute the essential elements of country's technological potential. Imports of high-tech products and inflow of foreign direct investments represent external sources of technology transfer. Patent applications, scientific publications and exports of high-tech products reveal how well technological potential transforms into technological advantage. Total factor productivity (TFP) measures growth of productivity attributed to technological progress, which cannot be explained by capital accumulation or increased labor input. Changes of TFP may reflect pure technological change, spill-over effects, enhancements in managerial practices or a shift toward knowledge-intensive production. However, economies of scale, imperfect competition, fluctuations in input prices, brand reputation or measurement errors may also explain growth of TFP [Zielińska, 2018: 357–358].

## 4. Technological competitiveness of EU member states in 2019 and 2022

Table 2 presents the ranking of EU countries in terms of technological competitiveness in 2019 and 2022, measured by the values of the synthetic measure.

Classifications of EU countries in 2019 and 2022 are very similar. Comparing individual results, it turns out that 14 member states have improved their positions in the ranking, 7 member states have dropped in classification, while 6 of them have stable positions.

It can be observed that the values of synthetic measures slightly increased in the analyzed period in case of most objects. Only 2 countries (Luxembourg and Estonia) experienced a decrease of their technological competitiveness measured by the values of synthetic measures. The EU average $H_i$ has increased from 0.210 to 0.260.

In 2019, one member state recorded the value of synthetic measure above 0.4 and 8 member states achieved the score equal or higher than 0.3. In 2022, there were 5 countries with the result of synthetic measure above 0.4, while 11 countries scored above 0.3. Those observations may point to the conclusion, that pandemic did not worsen the technological potential and position of EU member states.

Despite that, the values of synthetic measures are relatively low – far from maximum possible result. It signifies, that member states attained very differentiated results in particular dimensions characterizing their technological competitiveness. It can correspond to the general statement, that the European Union loses in technological competition with other countries like USA, China or Japan.

*Table 2.* Ranking of EU member states by their technological competitiveness in 2019 and 2022

| Rank | Country | Value of synthetic measure of technological competitiveness in 2019 | Rank | Country | Value of synthetic measure of technological competitiveness in 2022 |
|---|---|---|---|---|---|
| 1 | Luxembourg | 0.425 | 1 | Netherlands | 0.484 |
| 2 | Netherlands | 0.382 | 2 | Sweden | 0.472 |
| 3 | Sweden | 0.360 | 3 | Ireland | 0.457 |
| 4 | Germany | 0.325 | 4 | Belgium | 0.436 |
| 5 | Austria | 0.311 | 5 | Denmark | 0.419 |
| 6 | Denmark | 0.309 | 6 | Austria | 0.398 |
| 7 | Finland | 0.301 | 7 | Finland | 0.397 |
| 8 | Belgium | 0.300 | 8 | Germany | 0.382 |
| 9 | France | 0.288 | 9 | France | 0.328 |
| 10 | Czechia | 0.279 | 10 | Czechia | 0.317 |
| 11 | Ireland | 0.263 | 11 | Slovenia | 0.308 |
| 12 | Hungary | 0.226 | 12 | Hungary | 0.266 |
| 13 | Slovenia | 0.213 | 13 | Malta | 0.262 |
| 14 | Estonia | 0.200 | 14 | Spain | 0.220 |
| 15 | Malta | 0.178 | 15 | Portugal | 0.218 |
| 16 | Lithuania | 0.141 | 16 | Greece | 0.193 |
| 17 | Portugal | 0.135 | 17 | Estonia | 0.193 |
| 18 | Spain | 0.133 | 18 | Poland | 0.176 |
| 19 | Cyprus | 0.124 | 19 | Croatia | 0.162 |
| 20 | Italy | 0.116 | 20 | Italy | 0.157 |
| 21 | Greece | 0.113 | 21 | Lithuania | 0.149 |
| 22 | Slovakia | 0.110 | 22 | Cyprus | 0.134 |
| 23 | Poland | 0.109 | 23 | Slovakia | 0.128 |
| 24 | Croatia | 0.106 | 24 | Latvia | 0.108 |
| 25 | Latvia | 0.103 | 25 | Bulgaria | 0.104 |
| 26 | Bulgaria | 0.073 | 26 | Luxembourg | 0.089 |
| 27 | Romania | 0.037 | 27 | Romania | 0.057 |
| | EU average $H_i$ | 0.210 | | EU average $H_i$ | 0.260 |

Source: the author’s own elaboration.

The highest level of technological competitiveness in 2019 was achieved by: Luxembourg, Netherlands, Sweden and Germany. Those states have recorded very high number of patent applications to the EPO per million inhabitants and quite high number of scientific publications per million inhabitants despite the negative rates of TFP growth.

The average level of technological competitiveness was represented by 20 member states. Nine objects were classified in class II (above EU average $H_i$): Austria, Denmark, Finland, Belgium, France, the Czech Republic, Ireland, Hungary and Slovenia. Only 3 new member states attained higher than average, but medium level of technological competitiveness. The Czech Republic, Hungary and Slovenia recorded positive growth rates of TFP and relatively high share of high-tech products in their imports and exports. Hungary was also quite attractive for the inflow of FDI in 2019.

Class III included eleven objects, the synthetic measures of which were below EU average $H_i$. The group was formed by mostly new member states and southern countries: Estonia, Malta, Lithuania, Portugal, Spain, Cyprus, Italy, Greece, Slovakia, Poland and Croatia. Technological competitiveness of PIGS countries was characterized by their low attractiveness for the inflow of FDI in 2019, and the shares of high-tech imports and exports in total trade were below the EU average, slightly above minimum values.

Latvia, Bulgaria and Romania were classified in class IV. Each country achieved positive growth rate of TFP, but they represented one of the lowest in EU levels of expenditures on research and development activities, both public and private. Moreover, numbers of scientific publications per million inhabitants were very low, inflow of FDI, high-tech imports and exports represent their additional weaknesses in terms of technological competitiveness.

In 2022, the Netherlands, Sweden, Ireland, Belgium, Denmark and Austria attained the highest level of technological competitiveness among EU member states. The leader in classification – the Netherlands – stands out with a high number of patent applications to the EPO per million inhabitants, quite a high number of scientific publications per million inhabitants and a positive TFP growth rate. Sweden, except for high inflow of FDI, has high potential represented by researchers and well educated employees in science and technology, which transforms into a high number of patents and publications. Ireland records high technological advancement of imported and exported goods, as well as a high TFP growth rate.

The average level of technological competitiveness was attained by 17 member states. There are 7 objects in class II: Finland, Germany, France, the Czech

Republic, Slovenia, Hungary and Malta. Technological competitiveness of the Czech Republic, the best new member state, is based on high public expenditure on research and development, as well as high shares of high-tech products in total imports and exports. Measures including private spending on R&D and FDI inflows as a percentage of GDP exceeded the EU average. Malta's upgrade in 2022 can be explained by the transfer of technology through direct and indirect channels (FDI and high-tech imports) and a relatively high share of high-tech products in exports.

The countries classified in class III included: Spain, Portugal, Greece, Estonia, Poland, Croatia, Italy, Lithuania, Cyprus and Slovakia. Poland represents weak potential in terms of human capital in research, science and technology and spending on R&D, but has achieved higher than the average indicators of high-tech imports, FDI inflow and TFP growth rate. Poland is experiencing an ongoing process of technology transfer, but Estonia's better position in the ranking can be attributed to a higher share of employees with tertiary education working in science and technology and higher activity in terms of scientific publications.

In 2022, Latvia, Bulgaria, Luxembourg and Romania were classified in the group of countries with the weakest technological competitiveness in the European Union. The most surprising is the drop of Luxembourg in the ranking, which came as the result of FDI withdrawal, a negative rate of TFP growth and low technological content of international trade.

## 5. The importance of technological competitiveness for eco-innovativeness

Nowadays, eco-innovations are considered essential for achieving sustainable development and strengthening the competitiveness of companies and countries. In response to the changing conditions of economic competition, the EU aims to transition into a modern, competitive and resource-efficient economy through the implementation of the European Green Deal. It involves speeding up innovation, especially in the field of clean technologies crucial for the green transition. Eco-innovation enhances the competitiveness of industries by fostering the development and deployment of new technologies and sustainable practices, which reduce environmental impact and improve resource efficiency [European Commission, 2024: 24]. As a powerful instrument of environment protection with a positive impact on the society and economy, it ensures the EU leadership in creating a resource-efficient society and is implemented at the core of various policies [Hajdukiewicz, Pera, 2023: 148].

Eco-innovation means "the introduction of any new or significantly improved good or service, process, organisational change or marketing solution that reduces the use of natural resources (materials, energy, water, land) and decreases the release of harmful substances across the life-cycle" [Eco-Innovation Observatory, 2010: 10]. Eco-innovations in a broad sense include all changes in products, processes, marketing methods, social and institutional structures, reducing environmental impacts or contributing to ecological sustainability [Tomala, Urbaniec, 2021: 73]. Eco-innovations comprise not only the latest technological developments, but also all non-technological ideas leading to mitigation or resolution of an environmental problems [Hajdukiewicz, Pera, 2023: 148].

The Eco-Innovation Scoreboard was created in order to measure the EU countries performance in terms of eco-innovations. Eco-Innovation Index (EII) is based on five thematic areas. General dimensions and partial measures included in Eco-Innovation Index 2024 are listed in Table 3.

*Table 3.* Framework of Eco-Innovation Index 2024

| Dimensions of EII | Partial indicators |
|---|---|
| Eco-innovation inputs | • Governments environmental and energy R&D appropriations and outlays<br>• Total R&D personnel and researchers |
| Eco-innovation activities | • Number of ISO 14001 certificates |
| Eco-innovation outputs | • Eco-innovation related patents<br>• Eco-innovation related academic publications |
| Resource efficiency outcomes | • Material productivity<br>• Water productivity (GDP/total fresh water abstraction)<br>• Energy productivity<br>• GHG productivity |
| Socio-economic outcomes | • Exports of environmental goods and service sector<br>• Employment in environmental protection and resource management activities<br>• Value added in environmental protection and resource management activities |

Source: the author's own elaboration based on [European Commission, 2024: 6].

We can observe a significant divergence among the member states in terms of eco-innovation performance. In 2022, the Eco-Innovation leaders were: Finland, Denmark, Austria, Luxembourg, Sweden, Italy, France, Germany and the Netherlands. Leaders represent similar strengths and areas for development, as well as balanced growth across most themes. Spain, the Czech Republic, Slovenia, Ireland, Estonia, Latvia, Lithuania, Portugal and Belgium were classified as the average eco-innovation performers. Resource efficiency strongly contributed to their EII score. Eco-innovation catching-up performers include: Malta, Slovakia, Cyprus, Croatia, Greece, Romania, Poland, Hungary and Bulgaria. Activities and resource efficiency had the greatest influence on their positions, while the inputs theme contributed the least to their EII score [European Commission, 2024: 9–10]. It can be concluded, that eco-innovation development differs due to the level of socio-economic development of countries [Tomala, Urbaniec, 2021: 83].

The existence of a relationship between the rankings of technological competitiveness and eco-innovativeness was examined with the use of the Spearman's correlation coefficient. The result was $r(S)yx = 0.758$ in 2019, which signifies a strong positive relationship between the variables – a higher level of technological competitiveness is accompanied by a higher level of eco-innovativeness. The result $r(S)yx = 0.511$ in 2022 is characteristic for a moderate positive relationship and it indicates a decrease of interdependencies between researched phenomena.

Next, the relationship between technological competitiveness' single diagnostic variables and the level of eco-innovativeness (expressed by the EII) was examined. This allowed to indicate the variables with the greatest impact on eco-innovations among EU countries. Table 4 presents Pearson's linear correlation coefficients.

The values of the Pearson's linear correlation coefficients in 2019 indicate a strong positive linear relationship between the level of eco-innovativeness of EU member states and the share of researchers in total employment, number of scientific publications per million of inhabitants and patent applications to the EPO per million inhabitants. A moderate positive linear relationship was found also between the level of eco-innovativeness and public spending on research and development activities, as well as workers with tertiary education employed in science and technology.

The conclusions for 2022 are quite similar. A strong positive linear relationship was recorded only between patent applications to the EPO per million inhabitants and the level of eco-innovativeness of EU member states. A positive linear relationship between the share of researchers in total employment, number of scientific publications per million of inhabitants and eco-innovativeness has weakened in 2022 (from a strong to moderate level). Positive relationship remained at a moderate level for the eco-innovativeness and public expenditure on R&D and employees with tertiary education working in science and technology.

*Table 4.* Pearson's linear correlation coefficients for variables of technological competitiveness and the synthetic measure of eco-innovativeness of EU countries in 2019 and 2022

| Symbol | Variable | Value of Pearson's linear correlation coefficients in 2019 | Value of Pearson's linear correlation coefficients in 2022 |
|---|---|---|---|
| X1 | Share of researchers in total employment | 0.765 | 0.640 |
| X2 | Persons with tertiary education and employed in science and technology | 0.593 | 0.518 |
| X3 | Expenditure on R&D of government | 0.673 | 0.571 |
| X4 | Expenditure on R&D of business sector | 0.311 | 0.238 |
| X5 | Patent applications to the European Patent Office by applicants' country | 0.751 | 0.785 |
| X6 | Exports of high-tech products | 0.086 | 0.036 |
| X7 | Imports of high-tech products | 0.075 | -0.038 |
| X8 | FDI inflow | -0.036 | -0.325 |
| X9 | Number of scientific publications | 0.758 | 0.689 |
| X10 | Total factor productivity growth | -0.427 | -0.255 |

Source: the author's own elaboration.

The results may signify that mostly internal determinants of technological competitiveness influenced the eco-innovativeness of member states in 2019 and 2022. The correlation analysis tracked no significant impact of external direct and indirect channels of technology transfer. Those findings come in accordance with the research of the European Commission. The Pearson correlation coefficient between the Summary Innovation Index (SII) and the Eco-Innovation Index (EII) between 2017 and 2023 ranged between 0.79 and 0.84, indicating a strong correlation. This means that countries performing well in innovation are very likely to perform well in environmental sustainability measured by EII [European Commission, 2024: 22–23].

## 6. Conclusions

The research results point to the general conclusion that the technological competitiveness of EU member states remained below the average level, but improved in the analysed period. The EU average $H_i$ increased from 0,210 in 2019 to 0,260 in 2022. 14 countries improved their positions in the classification, while 7 countries worsened their ranks. The values of synthetic measures mostly increased, only Luxembourg and Estonia experienced a decrease of their technological competitiveness measured by the values of $H_i$.

The highest level of technological competitiveness in 2019 was represented by: Luxembourg, the Netherlands, Sweden and Germany. In 2022, the Netherlands, Sweden, Ireland, Belgium, Denmark and Austria were classified as the technological leaders. Such results can be treated as a confirmation of the validity of the implemented technological development strategies, aiming to strengthen their competitive capabilities and technological competitive positions.

Latvia, Bulgaria and Romania were classified in the group of states with the weakest technological competitiveness. In 2022, these countries had the lowest levels of private expenditures on R&D, shares of researchers in total employment, numbers of patents and scientific publications per million inhabitants, but technological levels of imported and exported goods were also relatively low.

Poland's result below the EU average $H_i$ should be perceived as unsatisfactory, but its performance in eco-innovativeness is even worse. Poland is experiencing the process of technology transfer, evidenced by higher than the EU average high-tech imports, FDI inflow and TFP growth, which contributed to improvement of its technological position from 23th in 2019 to 18th in 2022. To increase Poland's weak competitiveness, the state's policy should be aimed at strengthening competitive potential in terms of human capital and spending on R&D. 25th position in terms of eco-innovativeness can be attributed to lack of systemic support for this area and the attitude of Polish entrepreneurs toward adopting innovative, ecological solutions [Ostraszewska, Tylec, 2019: 212].

In 2019, a strong positive relationship between technological competitiveness and eco-innovations was tracked, but it decreased to a moderate level in 2022.

It was caused mostly by external sources of technology transfer – the author's calculations indicate that Spearman's correlation coefficient would have been higher without including in calculations the high-tech imports and FDI inflow. It means that internal determinants of countries' innovativeness have a more stable impact on creation, adoption and development of eco-innovations.

Nevertheless, external technology transfer proved to have an important influence on technological competitiveness of economies. Any deterioration in inflow of technology to EU member states due to economic turmoil may worsen the influence of technological competitiveness on the level of their eco-innovativeness. The transfer of technology, in combination with other features representing internal technological potential, influences the competitiveness of economies and their eco-innovation performance.

Moreover, in 2019 and 2022 a strong positive linear correlation was found especially between patent applications to the EPO per million inhabitants and the level of eco-innovativeness of EU states. Patent applications constitute a measure how well county's technological potential transforms into technological competitive position. Technological competitive abilities evidenced by patenting activity seem to have been influenced also by external sources of technology transfer.

A general conclusion can be drawn from the aforementioned research results: countries should strive for FDI inflow and imports of high-tech product, because it increases their technological competitiveness during times of economic prosperity and supports the creation and development of eco-innovations.

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