MULTIDIMENSIONAL EVALUATION OF EU AND SLOVAKIA IN THE CONTEXT OF DIGITAL TRANSFORMATION USING DIGITAL ECONOMY AND SOCIETY INDEX

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Abstract

The Covid-19 pandemic highlighted the cardinal intent, in which digital technologies play a key role in building a sustainable future, revealing disparities between digitally equipped companies and those that are still implementing digital solutions. It showed the difference between urban, rural and remote areas with good connections. This paper is divided into two parts. The first aim is to evaluate the performance of the digital economy and society according to its basic dimensions and quantify and compare the position of 28 European Union countries (considering Great Britain as a member) in the international area using DESI –(Digital Economy and Society Index). It will look to evaluate the overall change in the development of the Slovak Republic between individual periods based on the main dimensions of the composite index. The second part aims to find the clusters of the European Union countries by using data on their rankings within the five dimensions of DESI. Correlation analysis is used to meet the first aim, cluster analysis is used to meet the second aim. The data are obtained from the Ministry of Investment, Regional Development and Informatization of the Slovak Republic and the database of the European Centre for Digitization. The results show a statistically significant correlation in the rankings of the EU countries between the analysed years 2016-2020. Moreover, among the European Union countries, there are internally homogeneous and external heterogeneous groups of countries with respect to ranking within DESI dimensions. Cluster analysis has not been used so far in analysing DESI in the existing literature. Therefore, the results of this paper fill such a research gap.

Implications for Central European audience: Quantification and comparison of the position of 28 European Union countries in the international area using DESI can help to identify and improve the digital competitiveness of European Union countries. Knowing five dimensions of DESI, its specific subdimensions, and indicators can help to identify controversial areas to

which the state should pay attention. This paper deals, in more detail, with the position of Slovakia in the digital competitiveness of the EU using DESI.

Keywords: Digital Economy and Society Index; dimensions of DESI; digital economy; digital competitiveness; Industry 4.0
JEL Classification: O57

Introduction

We live in a multidimensional and ambiguous period when the process of social transformation penetrates every area. The changing world of economics, politics, social structures, value orientations, globalisation, automation or digitisation accelerates the development of world science, and contacts, and increases the ability to compete.

Digitisation processes, the shared economy, the shrinking economy and greening are already leading to the transformation of traditional production systems and a change in the understanding of production, services and consumption (see, e.g., Khitskov et al., 2017). Since 2014, the European Commission has been monitoring the progress and level of development of Europe digital competitiveness in each Member State every year through the Digital Economy and Society Index (DESI), which quantifies five basic dimensions. These are the dimension of connectivity, human capital, the use of Internet services, the integration of digital technologies and the level of digital public services (EC, 2021d).

Improving digital skills is the main task of the 2030 Digital Transformation Strategy for Slovakia (MIRDI, 2019) and the related action plan for 2019 - 2022. The European Center for Digital Competitiveness, in the study, takes into account that the world is currently undergoing a digital revolution significantly accelerated by the Covid-19 pandemic. Thanks to it, companies and individual states have focused on the digitisation of work and education. It is assumed that such a global situation can have a positive impact on digital progress and digital transformation (Vinc, 2020).

New issues and challenges are also opening up in the field of development, which reflect restrictions on movement and assembly at the global level. Readiness in the field of digital skills and the ability to use the possibilities of e-learning methods, the implementation of which is associated with a willingness to respond to a dynamically changing situation, is being revised (Blanár, 2020). EU countries' economies will grow with the development of technology, but inequalities between countries need to be balanced, as the structure of the Member States is very differentiated with an emphasis on technological, economic and social development. However, some countries still have a long way to go, and the EU as a whole needs to improve in order to compete on the world stage.

The purpose of the research can be divided into two aims. The first aim of the paper is to evaluate the performance of the digital economy and society according to its basic dimensions, quantify and compare the position of 28 European Union countries in the international area using DESI, also evaluate the overall change in the development of the

Slovak Republic between individual periods based on the main dimensions of the composite index. Considering the first aim of the paper, the following hypothesis was stated:

Hypothesis 1: *We assume a statistically significant correlation in the rankings of countries between the analysed years 2016-2020 in at least one of the DESI indicators (internet connection, human capital, indicators of use of internet services, integration of digital technologies, digital public services).*

The second aim is to find the clusters of the European Union countries by using data on their rankings within the five dimensions of DESI. Considering the second aim of the paper, the following hypothesis was stated:

Hypothesis 2: We assume that among the European Union countries, there are internally homogeneous and externally heterogeneous groups of countries with respect to ranking within DESI dimensions.

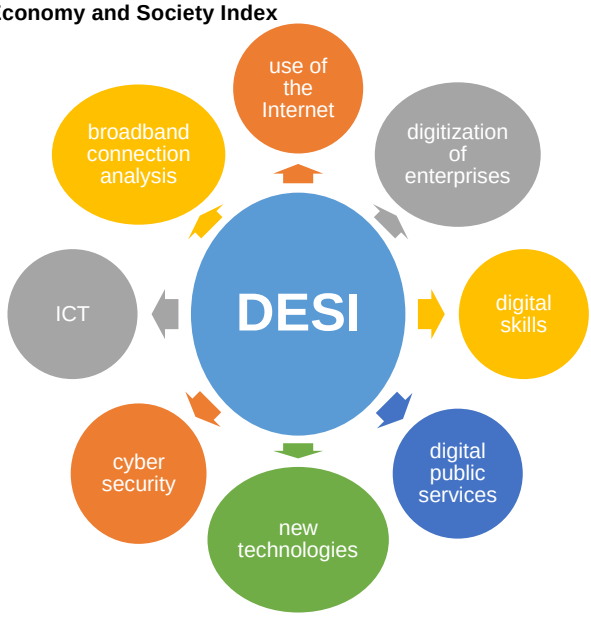
At present, in the field of digital transformation and digital competitiveness, the results of this research can be useful for policymakers, stakeholders and shareholders of companies because, according to Bai et al. (2021), post-COVID-19 digital transformation serves for the sustainable development of companies. In addition, we must emphasise that the digital economy in the conditions of Slovakia was not the subject of research. Slovak scientific research on this issue has been conducted since the beginning of the Covid-19 pandemic.

1 Literature review

The DESI is a composite index developed by the European Commission DG CNECT (Directorate General for Communications Networks, Content and Technology) to assess the development of European Union member states toward the digital economy and society. DESI uses a combination of 44 indicators in five main dimensions of measurement: availability of internet connection (connectivity), human capital, use of internet services, integration of digital technologies and digital public services.

DESI makes it possible to evaluate the overall level of digitisation of society in each EU Member State. Given the division of the five dimensions into specific subdimensions and indicators, it identifies controversial areas to which the state should pay increased attention. The composite DESI index is used to compare the EU Member States. Figure 1 shows all the areas that DESI focuses on.

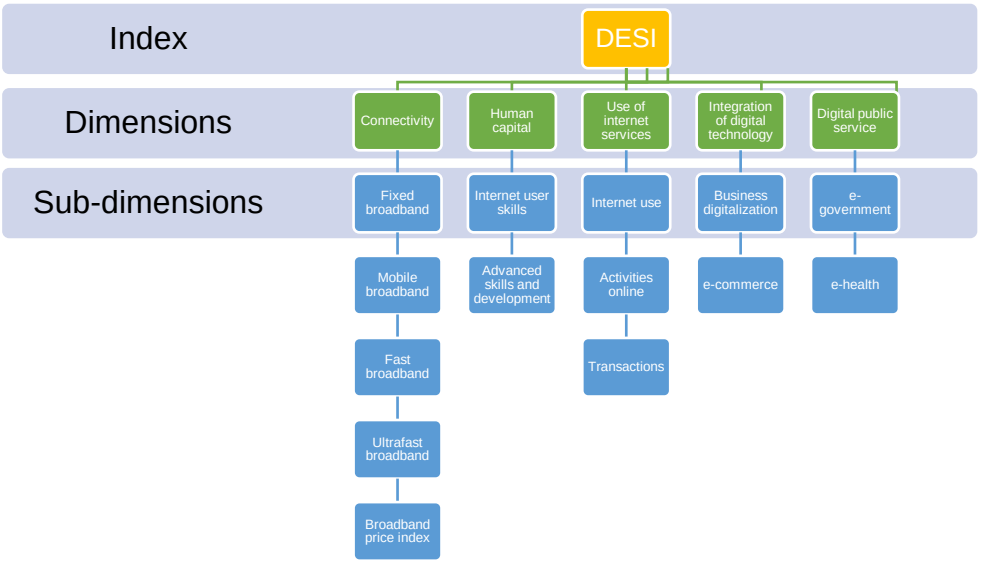
Figure 1 | Digital Economy and Society Index



Source: own processing

The digital economy is defined as the use of information technologies by the public, businesses, and society (Moroz, 2017), while the digital economy is defined as the object of many studies (e.g., Tapscott, 1996; Lane, 1999; Brynjolfsson & Kahin 2000). A digital society is the transformation of a traditional lifestyle into a digital lifestyle (Dufva & Dufva, 2019). Other definitions of the digital society are presented in different studies (e.g., Isin & Ruppert, 2015; Katzenbach & Bächle, 2019). A group of German scientists (Bloching et al., 2015) understands through a digital transformation of the continuous interaction of all business sectors, ensuring the adaptation to the requirements of the digital economy. To answer the question of how much today's societies will accept and keep up with digitalisation, the European Union has established the DESI. The DESI is a composite index that summarises indicators related to the digital performance of European Union member states and monitors the level of digital competitiveness of countries (European Commission, 2019f). It should be noted that in addition to DESI, there is the I-DESI (The International DESI), which differs in several indicators from the European one but allows at least to approximate the level of development of the EU countries with others (DESI, 2018). Chaaben and Mansouri (2017) used the International Digital Economic and Social Index (I-DESI) to compare Tunisia with EU member states, and Yilmaz (2021) used this index to compare Turkey with other countries. There are several other composite indices, for example, the Networked Readiness Index, NRI (World Economic Forum, 2016), ICT Development Index, IDI (Measuring the Information Society Report, 2018), E-Government Development Index, EGDI (UN Department of Economic and Social Affairs: E-Government, 2018). The Moscow School of Management (2018) has developed a methodology for the calculation of the Digital Russia Index for the federal entities of Russia. Figure 2 shows the dimensions and subdimensions of DESI.

Figure 2 | Dimensions of DESI



Source: own processing according to European Commission (2019)

Huawei company explores the trends of the digital economy through its global network interaction index (Global Connectivity Index, or GCI). They note that the growth of the index indicates an increase in the levels of competitiveness, innovation, and productivity in the national economy. The next widely known index is the Digitization Index (DiGiX). It is a composite index that summarises 100 relevant digital performance indicators of a state. The DiGiX is structured around six principal dimensions: infrastructure, households' adoption, enterprises' adoption, costs, regulation, and contents. Each dimension is, in turn, divided into several individual indicators (Camara & Tuesta, 2017).

The DESI has been the subject of several studies. Vidruska (2016) compares the DESI (European Union level) and Network Readiness Index (global level) between Latvia and other EU countries. Želonková (2016) deals with the analysis of the results of surveys on the use of information and communication technologies in households and individuals, which relate to the DESI in the V4 countries. When comparing the results of the surveys for 2015 and 2016 in individual V4 countries, the author examined the development of a significant indicator of the DESI and its Internet use dimension. Esses et al. (2021) examined interconnections between the dimensions of the DESI and the indicators of the Sustainable Development Goal (SDG) targets together in the V4.

Curko et al. (2017) considered DESI from the perspective of smart business and examined the impact of Industry 4.0 on the digital economy. Similarly, Götz (2017) analysed the impact of Industry 4.0 on the economic relations between Germany and Poland, concluding that the digital economy can have a positive effect on the German-Polish relationship. Vrchota et al. (2020), Dzwigol et al. (2020), Backhaus and Nadarajah (2019), Kumar and Kumar (2019), Lenart-Gansiniec (2019), Sanghavi et al. (2019), Vrchota et al. (2019) and Zupan Korže (2019) deal also with the issue of Industry 4.0.

The study by Folea (2017) presents a comparative analysis of the member states from the perspective of their digital performance in 2016. Moroz (2017) evaluated the degree of the development of the digital economy in Poland compared with a number of chosen European countries. Grinberga-Zalite and Hernik (2019) compared Poland with Latvia. Nagy (2019) analysed the significant differences between Ukraine and Hungary in terms of access to the internet and device usage, including smartphones, tablets, and computers. The results showed a certain lag in Ukraine. Ershova et al. (2020) assessed the development of the digital economies of Russia, Ukraine, and developed countries.

Stoica and Bogoslov (2017) compared the five indicators of DESI with the available data for Romania and the EU and analysed them over time. They concluded that Romania had undergone significant development during the period under review (2014–2017). Kontolaimou and Skintzi (2018) published a similar study using data from Greece. Also, Burlacioiu et al. (2018) used the DESI to compare Romania and the other European Union countries. Jurčević et al. (2020) compared the digital development of Croatia with the other EU countries.

Alonso and García (2018) analysed the digital economy in the context of entrepreneurship using DESI. Their research focused on how digitalisation affected the entrepreneurial ecosystem and found that digitalisation changes not only the size of the entrepreneurial market but also its profitability. Jovanović et al. (2018) examined the relationship between digitalisation (DESI) and sustainable development (economic, social, and environmental components). The study explored the correlations of DESI and other composite indices (Global Competitiveness Index, Global Innovation Index, Gross Domestic Products, Global Entrepreneurship Index, The Good Country Index, Sustainable Development Goal Index, Sustainable Society Index) and examined the relationships between Hofstede's cultural dimensions and digital performance.

Nikolov and Krumova (2019) considered the fifth element of DESI, which is e-Government and examined the European Union countries in their model. Urs (2017) also investigated the development of e-Government, focusing on local municipalities in Romania. Scupola (2018) provided an overview of the state of digital transformation in Denmark. The study also reported experiences in e-Government. In addition to mentioned, there are other studies that deal with e-government (e.g., Leogrande et al., 2022b; Yamukova & Milkov, 2021; Dumitrache et al., 2021; Tkáč, 2018; Luhan et al., 2017).

In the study by Mirke et al. (2019), they analysed human capital elements of the Czech Republic and Latvia. Śledziewska and Wloch (2015) analysed the digital competencies of human capital in Poland in comparison to other EU countries. Martin et al. (2013), Katsikas and Gritzalis (2017), Folea (2018) and Huculova and Solcova (2018) underlined the role of human capital as one of the major factors of influence in enterprise digitisation.

Stavytskyy et al. (2019) analyse DESI based on the data of 28 European countries for 2013–2018, using panel regression. They study the influence of the consumption index growth by the purchasing power parity and unemployment among the active population on the structural units of DESI. It is shown that an increase in the consumption index results in a DESI increase, and an increase in unemployment leads to a DESI decline. It is also shown that the

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https://doi.org/10.18267/j.cebr.313

value of DESI is determined by its previous trends, and, therefore, it is impossible to increase this index rapidly.

Gerasenko and Levkovich (2019) built linear and non-linear regression equations to forecast the DESI for Belarus. The study by Česnauské (2019) revealed the digital performance of each Baltic country, comparing them with each other, as well as with other EU countries. As was mentioned, DESI measures the digital competitiveness of EU Member States through defined dimensions and sub-dimensions and ranks the observed countries accordingly. Kutnjak et al. (2020) identify key dimensions and sub-dimension that affect the rank using the decision tree method. The study by Laitsou et al. (2020) used the DESI index to forecast progress in the Greek economic environment. The Gompertz model was used as a methodological tool. Russo (2020), following the European guidelines on the DESI, applied them to the Italian region of Abruzzo to provide a local framework for technological development. The study by Jordanoski and Meyerhoff Nielsen (2021) aimed to assess the readiness of each Western Balkan economy to provide the complete datasets for the DESI indicators. Key findings are that Western Balkan economies are generally ready to provide methodologically aligned data for the DESI indicators. Karnitis et al. (2019) compared the Baltic countries with the EU.

Banhidi et al. (2020) investigate the five principal dimensions of DESI using a series of multivariate statistics. First, they analyse the linear relationships between dimensions by correlation analysis, partial correlation analysis, and principal component analysis. In the partial correlation analysis, causal relationships between the dimensions show high correlations. Second, they assign countries into groups with cluster analysis and multi-dimensional scaling. Finally, they rank the European Union (EU) countries using statistical methods and compare them with the results obtained with the overall DESI. The correlation between the two rankings shows a strong linear relationship. Liu (2022) used the DESI indicators to determine the digital policy performance of various European countries in 2017. To visualise and classify countries based on their correlations with similar variables, he used the co-plot method. The top-performing European Union countries had strong correlations with at least one of these indicators.

The aim of the work by Parra et al. (2021) is to find a link between variables of DESI technology indicator and the gross domestic product per capita during the period 2015-2018. Other authors (e.g., Arnold et al., 2016; Gortazar, 2018) also deal with the issue of links between DESI and GDP per capita. In the study by Turuk (2021), the panel method on data from 2015 to 2019 was used to show the influence of the different DESI components on the Central and Eastern European countries' GDP per capita. In the analysis by Borowiecki et al. (2021) used time series and cluster analysis on the data of EU-28 countries on the DESI from 2015 and 2020.

The study of Basol and Yalcin (2021) determines the effects of the DESI (connectivity, human capital, use of internet service, integration of digital technology and digital public services) on labour market indicators (labour market insecurity, long-term unemployment rate, employment rate, and personal earnings) for 23 EU countries in 2018. Results of this study show that an increase in the DESI has increased the employment rate and personal earnings and has decreased the long-term unemployment rate and labour market insecurity.

In the paper by Gurau (2021), there are presented a comparative analysis between the DESI at the level of developed and least developed countries, a composite index that summarises relevant indicators of Europe's digital performance and tracks the evolution of EU Member States in terms of digital competitiveness. The study by Marino and Pariso (2021) measured the potential existence of a correlation between DESI and its dimensions and four socioeconomic indexes (Social Progress Index, Corruption Perception Index, Global Innovation Index, Doing business). The study by Marcysiak and Pleskacz (2021) analysed the degree of digitisation (DESI) in the Polish economy in comparison with the EU average, with particular emphasis on SMEs.

Kovács et al. (2022) used correlation analysis and principal component analysis to analyse the digital economy and society index. Leogrande et al. (2022a) analysed the determinants of the "Broadband Price Index" in 28 European countries between 2014 and 2021 and used data of DESI. The data were analysed using the panel data with random effects, panel data with fixed effects, pooled ordinary least squares, weighted least squares and dynamic panel.

Moreover, many studies focused on measuring and quantifying the digital divide (e.g., Vicente & Lopez, 2006, 2011; Billon et al., 2010; Stanimir, 2015; Unguru, 2017; Chetty et al., 2018; Dumitrescu, 2019; Goliński, 2019; Ivanova, 2019; Barna & Epure, 2020; Kwilinski et al., 2020; Benecchi et al., 2021; Guseynov, 2021; Milan, 2021).

According to the theoretical background of existing studies dealing with DESI, we are not aware of some examining the digital transformation of Slovakia. This study, therefore, fills this research gap.

2 Methodology

The first aim of the paper is to evaluate the performance of the digital economy and society according to its basic dimensions, quantify and compare the position of 28 European Union countries in the international area using DESI, also evaluate the overall change in the development of the Slovak Republic between individual periods based on the main dimensions of the composite index. The second aim is to find the clusters of the European Union countries by using data of their rankings within five dimensions of DESI. (Note: We are also considering Great Britain, although it is no longer a member of the EU).

The data are obtained from the Ministry of Investment, Regional Development and Informatization of the Slovak Republic and the database of the European Centre for Digitization (i.e., EC, 2019a, 2019b, 2019c, 2019d, 2019e, 2021a, 2021b, 2021c, 2021d). The data are analysed for the period from 2016 to 2020. The programs Statistica and Stata are used for the statistical solution. Considering the aims of the paper, the following hypotheses were stated:

Hypothesis 1: We assume a statistically significant correlation in the rankings of countries between the analysed years 2016-2020 in at least one of the DESI indicators (internet connection, human capital, indicators of use of internet services, integration of digital technologies, digital public services).

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https://doi.org/10.18267/j.cebr.313

Hypothesis 2: We assume that among the European Union countries, there are internally homogeneous and externally heterogeneous groups of countries with respect to ranking within DESI dimensions.

In verifying formulated hypothesis 1, we want to find out whether the position of countries within the DESI dimensions changed during the period under review or not. We want to see whether we can say that countries that are at the forefront in one year are still there in the following years or not; on the contrary, whether the countries with the lowest digital competitiveness have changed their position over time. Correlation analysis is used to quantify and compare the position of the 28 European Union countries in the international area using DESI. Specifically, we use Kendall's coefficient of concordance r_k to verify the established research hypothesis 1. We display visual changes over time on boxplots.

To verify hypothesis 2, we use cluster analysis. Cluster analysis is a group of procedures designed to decompose a set of objects into several relatively homogeneous subsets (clusters) so that objects belonging to the same cluster are as similar as possible, while objects originating from different clusters should be as different as possible. All clustering procedures are based on some measure of distance or similarity between units (Trebuňa & Béreš, 2010). Hierarchical methods are based on sequentially joining of clusters, their number decreases continuously until finally, all clusters are combined into one. The result is graphically displayed as a tree diagram (cluster dendrogram). Within the cluster analysis hierarchical procedure, we use Ward's method, which involves an agglomerative clustering algorithm. It looks for groups of leaves that it forms into branches, the branches into limbs and eventually into the trunk. Ward's method starts out with n clusters of size 1 and continues until all the observations are included in one cluster. Ward's method uses the Euclidean distance defined by the formula:

$$d_{ij} = \sqrt{\sum_{k=1}^{n} \left(x_{ik} - x_{jk}\right)^2}, \tag{1}$$

where x_{ik} is the value of "*k*" variable for *i*-th object and x_{jk} is the value of „*k*" variable for *j*-th object. For calculated distance is than determined the rule of linking statistical units into clusters. To determine the number of clusters, we use cluster-analysis Duda-Hart *Je*(2)/*Je*(1) stopping-rule index that is associated with pseudo T^2 value (Stata, 2021). To provide cluster analysis, we use the program Stata.

The index method is used to evaluate the overall change in the development of the Slovak Republic between individual periods based on the main dimensions of the composite index. The development is assessed in absolute and relative terms using a chain index, a base index, a growth rate, and a geometric mean.

3 Results and Discussion

3.1 Correlation Analysis

As we mentioned, we use Kendall's coefficient of concordance to verify the established research hypothesis 1. The values of the given coefficient range from 0 to 1. We can say that values close to zero would represent a discrepancy in the rankings of countries between the

analysed years; on the other hand, values close to 1 represent a high correlation in the rankings. The results of the testing are in Table 1.

Table 1 | Kendall's coefficient of concordance for hypothesis 1 for each DESI dimension

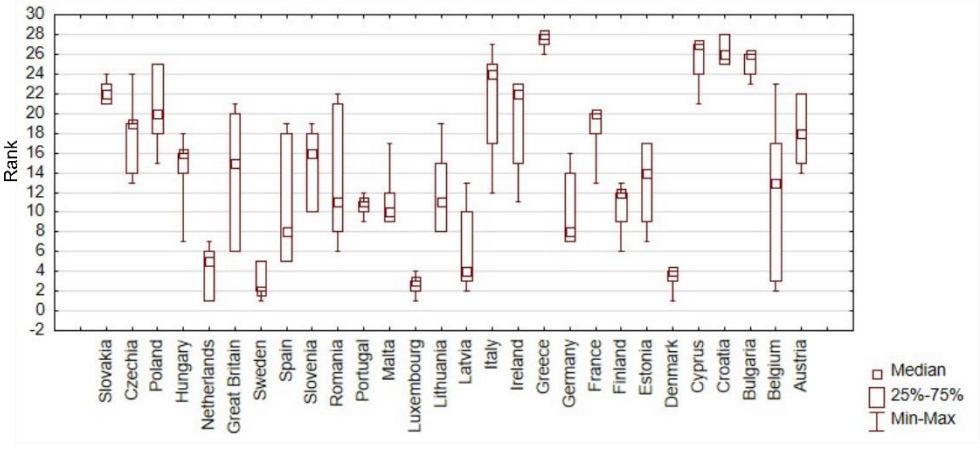
Dimension	Kendall's coefficient of concordance r_k
Connectivity	0.76423
Human capital	0.95431
Use of internet services	0.93290
Integration of digital technology	0.93991
Digital public service	0.94872

Source: own processing in program Statistica

All calculated coefficients are statistically significant at the significance level of $\alpha = 0.05$. We can confirm established research hypothesis 1. According to the size of Kendall's coefficient of concordance, we can say that the order of countries has changed the least in time within the indicator of human capital, where the correlation is the highest ($r_k = 0.95431$). On the contrary, the lowest, although still statistically significant, correlation is within the indicator of internet connection ($r_k = 0.76423$). The results can be visually confirmed based on boxplots in Figures 3 - 7, where we see the changes in the order of the analysed 28 European Union countries.

We see that in the indicator of internet connection (Figure 3), the location of Greece (26th, 27th, 28th place), Denmark (1st, 3rd and 4th place), Croatia (25th, 26th and 28th place), or Bulgaria (23rd, 24th and 26th place) changed the least, but also in Slovakia, Portugal, and Luxembourg. On the contrary, we see the biggest change in Belgium, which ranked 2nd in 2016 but was only 23rd in 2019. In 2020, it was in 13th place.

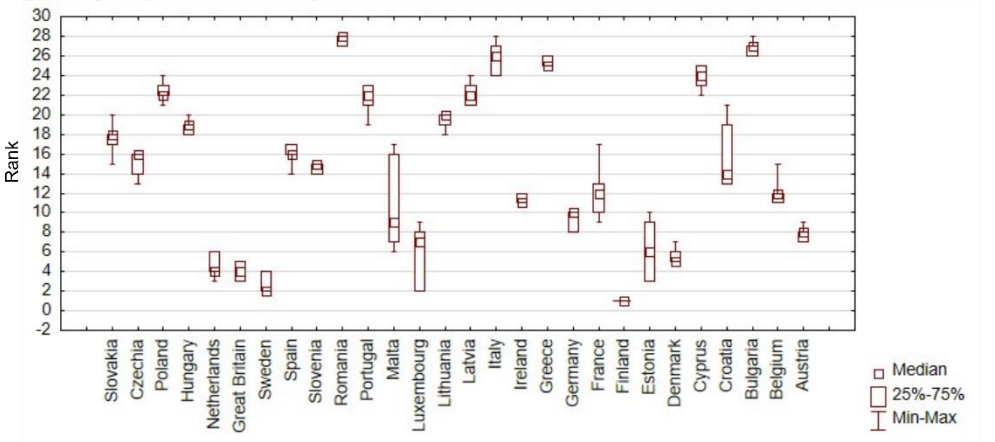
Figure 3 | Boxplot – Connectivity



Source: own processing in program Statistica

The ranking of countries in the human capital indicator (Figure 4) was the most stable, as evidenced not only by the highest value of the European Union but also by the boxplot in Figure 4. Throughout the period under review, only Finland ranked the same. The biggest changes occurred in the ranking of Malta, which moved from 17th place in 2017 to 6th place in 2020; Luxembourg, which fell from second place to 9th place; France, which also took a deterioration from 9th place to 17th place, and Croatia, which in turn advanced from 21st place in 2016 to 13th place in 2018 and 2020.

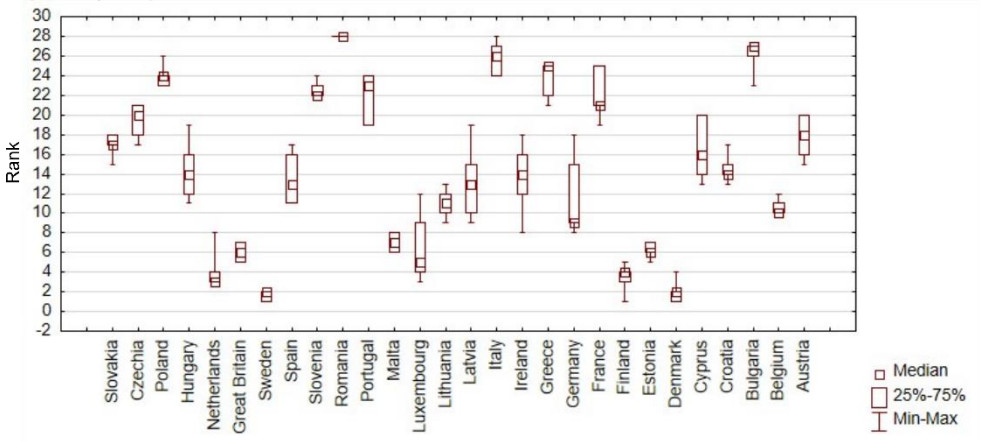
Figure 4 | Boxplot – Human capital



Source: own processing in program Statistica

Considering the indicator of the use of Internet services in Figure 5, the most stable position was held by Romania, which ranked last in the 28th place in each monitored year. Sweden also ranks among the countries with a stable position within the given indicator, as it has always held first or second place. Among the countries that balanced on almost the same places are the United Kingdom (5th, 6th, 7th place), Slovenia (22nd, 23rd, 24th place), Malta (6th, 7th, 8th place), Estonia (5th, 6th, 7th place) and Belgium (10th, 11th and 12th place). On the other hand, the biggest changes occurred in Latvia, which fell from 9th place in 2016 to 19th place in 2020; Ireland, which moved from 18th place in 2016 to 8th place in 2020; Germany, Hungary, and Luxembourg.

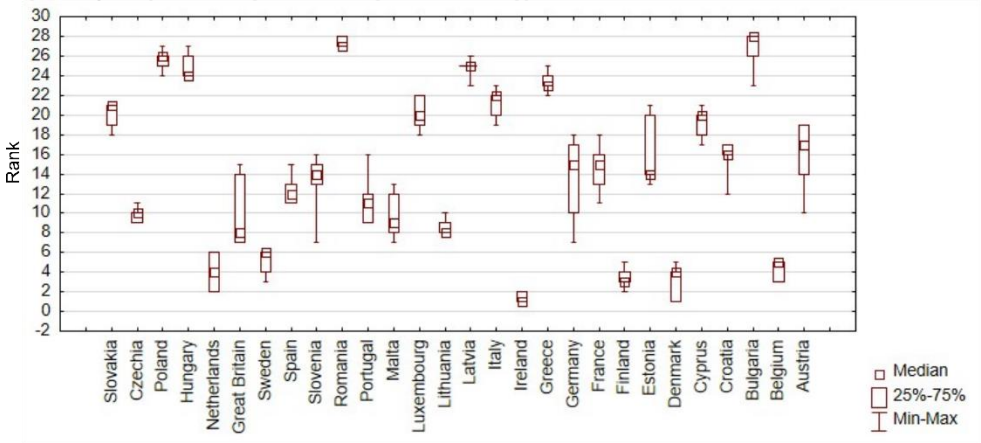
Figure 5 | Boxplot – Use of internet services



Source: own processing in program Statistica

Even with the indicator of the integration of digital technologies (Figure 6), we see a high correlation in the rankings between the individual years. These are mainly countries, Ireland (1st or 2nd), Romania (27th or 28th), Belgium (3rd or 5th), Czech Republic (9th, 10th, or 11th), Lithuania (8th, 9th or 10.), but also Poland, Greece, or Finland. We see great variability, especially in the United Kingdom, which moved from 15th place in 2017 to 7th place in 2018 and 2019; Slovenia, which fell from 7th place in 2017 to 16th place in 2019; Germany, which fell from 7th place in 2016 to 18th place in 2020, Estonia and Austria.

Figure 6 | Boxplot – Integration of digital technology



Source: own processing in program Statistica

As in the indicator of the use of Internet services, in the indicator of the digital public service (Figure 7), Romania was a country that steadily ranked 28th in the whole monitored period. The order of Estonia (1st or 2nd), Denmark (2nd, 3rd, or 4th), Croatia (24th, 25th or 26th) and

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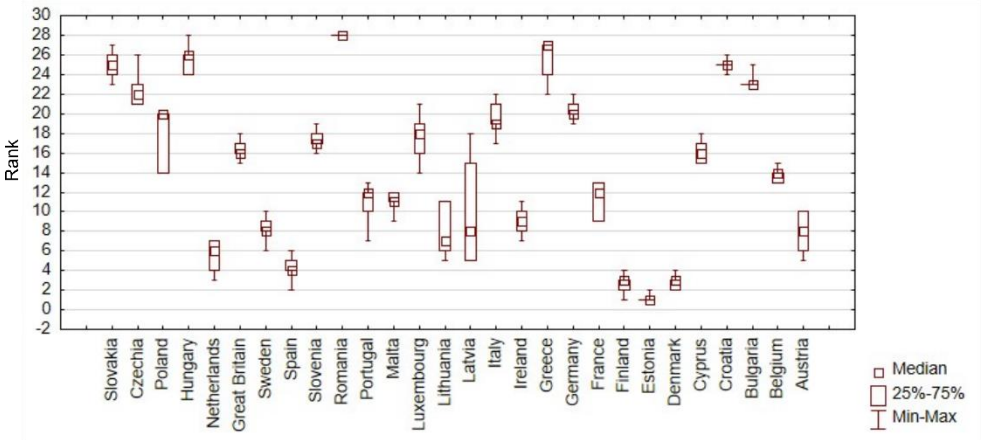
https://doi.org/10.18267/j.cebr.313

Belgium (13th, 14th, or 15th) changed only slightly. We see the biggest change in Latvia, which was ranked 5th in 2019 and 2020, but only 18th in 2016.

Figure 7 | Boxplot – Digital public service



Source: own processing in program Statistica

3.2 Cluster Analysis

Our second aim is to find the clusters of the European Union countries by using data of their rankings within five dimensions of DESI, specifically, connectivity, human capital, use of internet services, integration of digital technology and digital public services. The result is graphically displayed as a tree diagram known as a cluster dendrogram. We model individual dendrograms for each analysed period from 2016 to 2020. We used Duda-Hart *Je*(2)/*Je*(1) stopping-rule index to decide on how many groups of countries should be split. The Duda-Hart index has an associated pseudo T^2 value, while a large index value and a small pseudo T^2 value indicate distinct clustering. In Table 2, we present only the optimal results of the Duda-Hart stopping-rule index.

Table 2 | Duda-Hart stopping-rule index

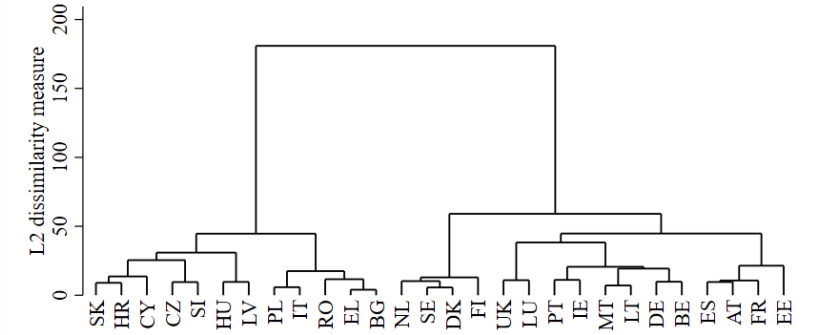
Year	Number of clusters	Duda-Hart *Je*(2)/*Je*(1)	Pseudo T^2
2016	3	0.6867	4.56
2017	5	0.6906	4.48
2018	3	0.7091	5.74
2019	5	0.6943	3.08
2020	3	0.7357	5.39

Source: own processing in program Stata

Following Figures 8-12 represent dendrograms showing the distribution of the 28 European Union countries into the resulting number of clusters (see Table 2) for the individually analysed year.

For 2016 (see Figure 8), the first cluster consists of countries ranked in the worst places: Slovakia, Czech Republic, Poland, Hungary, Slovenia, Romania, Latvia, Italy, Greece, Cyprus, Croatia, and Bulgaria. The second cluster consists of the best-placed countries: Denmark, Finland, Sweden, and the Netherlands. The third cluster is made up of the United Kingdom, Estonia, Portugal, Malta, Luxembourg, Lithuania, Ireland, Germany, France, Belgium, Spain, and Austria. This cluster consists of states that are placed in the middle of the ranking.

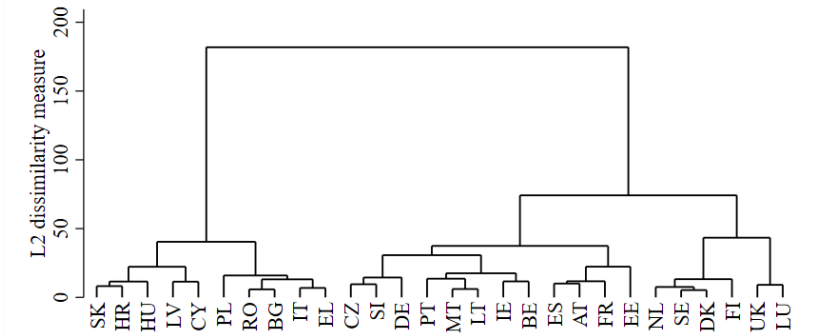
Figure 8 | Dendrogram 2016



Source: own processing in program Stata

For 2017 (see Figure 9), the first cluster consists of Slovakia, Hungary, Latvia, Cyprus, and Croatia. These countries were grouped mainly based on placement in the human capital dimension. The second cluster consists of Bulgaria, Greece, Italy, Romania, and Poland. For these countries, the main factor of similarity is placement in the connectivity dimension. The third cluster is made up of the Czech Republic, Spain, Slovenia, Portugal, Malta, Lithuania, Ireland, Germany, France, Belgium, Austria, and Estonia. The fourth cluster consists of Denmark, Sweden, Finland, and the Netherlands. This cluster is made up of the best-placed states in 2017. The fifth cluster is made up of the United Kingdom and Luxembourg. These countries were grouped mainly based on placement in the digital public services dimension and placement in the human capital dimension.

Figure 9 | Dendrogram 2017



Source: own processing in program Stata

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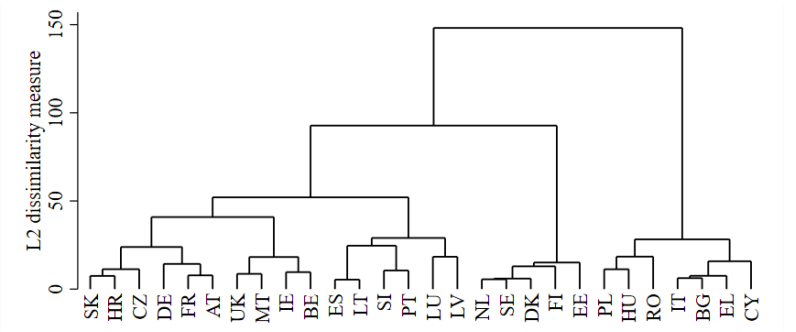
For 2018 (see Figure 10), the first cluster consists of Slovakia, Czech Republic, United Kingdom, Spain, Slovenia, Portugal, Malta, Luxembourg, Lithuania, Latvia, Ireland, Germany, France, Croatia, Belgium, and Austria. This cluster consists of states that are placed in the middle of the ranking. The second cluster consists of the Netherlands, Sweden, Finland, Estonia, and Denmark. This cluster is made up of the best-placed states in 2018. The third cluster is made up of Poland, Hungary, Romania, Italy, Cyprus, Bulgaria, and Greece. This cluster consists of the states of the European Union, which in 2018 ranked in the worst places.

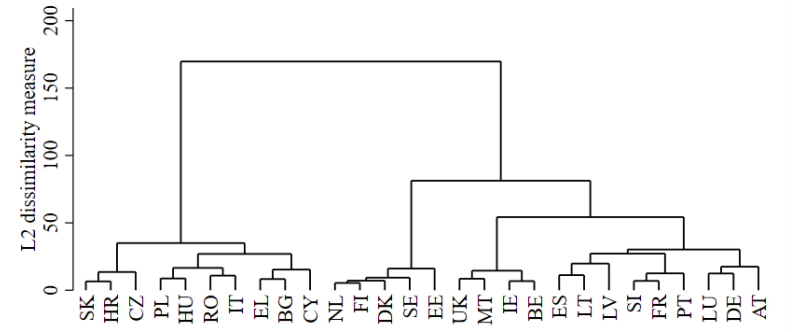
Figure 10 | Dendrogram 2018



Source: own processing in program Stata

For 2019 (see Figure 11), the first cluster consists of Slovakia, the Czech Republic, and Croatia. The second cluster consists of Poland, Hungary, Romania, Italy, Greece, Cyprus, and Bulgaria. For these countries, the main factor of similarity is placement in the integration of the digital technology dimension. The third cluster is made up of the Netherlands, Sweden, Finland, Estonia, and Denmark. This cluster is made up of the best-placed states in 2019. The fourth cluster consists of the United Kingdom, Malta, Ireland, and Belgium. The fifth cluster is made up of Spain, Portugal, Slovenia, Luxembourg, Latvia, Lithuania, Germany, France, and Austria.

Figure 11 | Dendrogram 2019

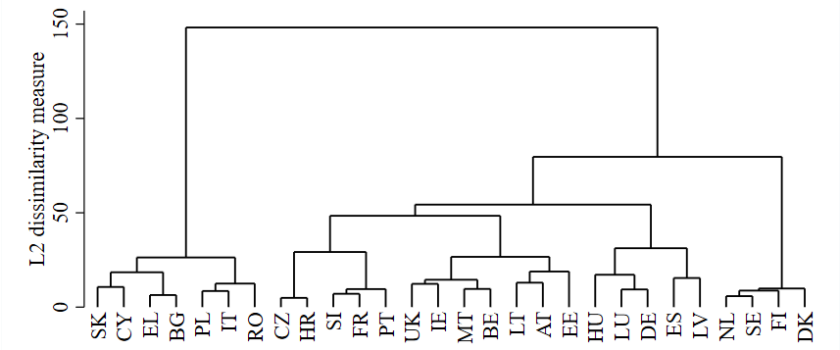


Source: own processing in program Stata

Finally, for 2020 (see Figure 12), the first cluster consists of Slovakia, Poland, Romania, Italy, Greece, Cyprus, and Bulgaria. This cluster consists of the states of the European Union,

which in 2020 ranked in the worst places. The second cluster consists of the Czech Republic, Hungary, United Kingdom, Spain, Slovenia, Portugal, Malta, Luxembourg, Latvia, Lithuania, Ireland, Germany, France, Estonia, Croatia, Belgium, and Austria. This cluster consists of states that are placed in the middle of the ranking. The third cluster is made up of Netherlands, Sweden, Finland, and Denmark. This cluster is made up of the best-placed states in 2020.

Figure 12 | Dendrogram 2020



Source: own processing in program Stata

We can confirm hypothesis 2 that among the European Union countries, there are internally homogeneous and externally heterogeneous groups of countries with respect to ranking within DESI dimensions.

In each dendrogram (see Figure 8-12), the clusters, made up of Denmark, Finland, Sweden, and the Netherlands, have proven that these countries are indeed leaders in digitalisation (see EC, 2019f). According to the EC (2019f), the United Kingdom, Luxembourg, Ireland, Estonia and Belgium should belong to one cluster because these countries follow global leaders. This is what our results showed in 2016, in 2020, and in 2018 (except for Estonia, which belonged to the leaders). Lithuania, Latvia and Ireland should also belong to one cluster, which was confirmed in 2018 and 2020.

Our results cannot be compared with existing research because, as stated in Literature Review (see Section 1), we are not aware that there exists research that has focused on cluster analysis. The research focuses mainly on comparing only a few countries (e.g., Moroz, 2017; Stoica & Bogoslov, 2017; Burlacioiu et al., 2018; Kontolaimou & Skintzi, 2018; Grinberga-Zalite & Hernik, 2019; Karnitis et al., 2019; Nagy, 2019), or other methods were used (e.g., Gerasenko & Levkovich, 2019; Kovács et al., 2022; Kutnjak et al., 2020; Leogrande et al., 2022a). Therefore, this paper filled research.

3.3 The position of Slovakia in the digital competitiveness of the EU

The Covid-19 pandemic confirmed that companies that digitised their production processes were better able to cope with the problems. The pandemic is better managed by those companies that have already managed to implement automated technologies and digitise production (see, e.g., Sneader & Sternfels, 2020; Siderska, 2021). Tworek (2021) analysed

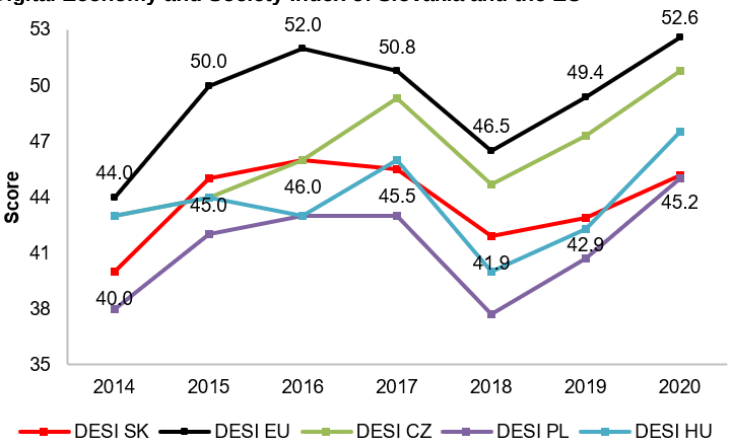
the elements of IT reliability and their influence on IT performance in conditions of the Covid-19 epidemic crisis.

Companies that relied more on Industry 4.0 processes confirmed better results and preparedness for sudden outages caused by a pandemic. The importance of innovation in the industry will significantly strengthen the next period. The digital transformation of companies is one of the EU's top priorities. The importance of good digital infrastructure in businesses has been highlighted by Štefko et al. (2021). Slovak companies are largely lagging in digital transformation. Even though Slovakia is falling in the global and European competitiveness rankings, it supports its companies less than other countries.

According to experts, the development of digitisation alone can bring Slovakia 21.7 billion EUR by 2025 in additional GDP (Novak et al., 2018). This would increase the country's global competitiveness and enable it to join Europe's most digitally developed economies. According to reports from the European Center for Digital Competitiveness, in recent years, the Slovak Republic has made minimal progress in increasing digital competitiveness. In the category of digital skills, Slovakia ranked 20th among EU countries. Among the V4 countries, apart from the Czech Republic, Slovakia lags behind Hungary. In the ranking for 2016, Slovakia ranks 21st out of 28 countries, while the loss to other member states is deepening and, in some indicators, Slovakia even has a declining trend.

Figure 13 presents the development of DESI of Slovakia, Czech Republic, Poland, Hungary, and the European Union for the period 2014-2020. Slovakia does not reach the EU average for the monitored period.

Figure 13 | Digital Economy and Society Index of Slovakia and the EU



Source: own processing

In the ranking of DESI for 2020, Slovakia ranked 22nd among 28 EU countries. Its score reached 45.2 percentage points. Based on data before the pandemic (42.9), Slovakia's score increased slightly due to improvements in the areas of connectivity, Internet use and digital public services. Most indicators have not improved enough to catch up with the EU average of 52.6 percentage points in 2020. The largest decline in Slovakia and EU countries was recorded in 2018.

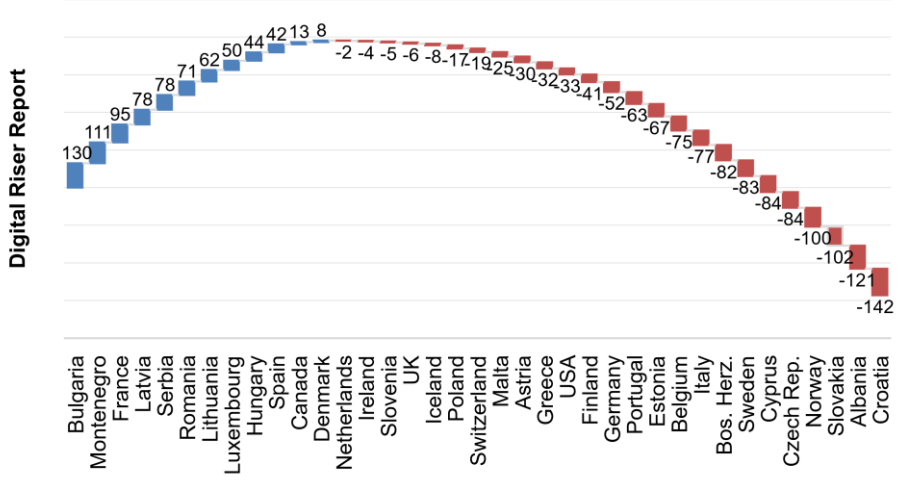
The results of DESI 2019 show that most EU Member States have improved their digital performance. Finland, Sweden, the Netherlands, and Denmark have the highest ratings and are among the global leaders in digitisation. These countries are followed by the United Kingdom, Luxembourg, Ireland, Estonia, and Belgium. If we follow the ranking of the V4 countries ahead of Slovakia (22nd in the ranking in 2020), the Czech Republic is in the whole period, which in 2020 occupied 17th place.

The Digital Riser 2020 ranking reveals how individual economies have advanced in digital-driven transformation over the past three years. Based on available data according to the European Center for Digital Competitiveness (ECDC, 2021), the ranking of 37 countries is compiled, which is shown in Figure 14. We can see that only Albania and Croatia are behind Slovakia, Norway, the Czech Republic, and Cyprus are just ahead of Slovakia. According to the study, the greatest progress in digitisation during this period has taken place in Bulgaria, Montenegro, and France. Perceived as a leader in the digital industry, the United States ranked 23rd in the ranking.

The authors Meissner et al. (2020) analyse the DESI ranking of all countries in the world, emphasising the G7 and G20 countries. Within the G7, France, Japan and Canada are leaders, followed by the United Kingdom, the USA, Germany, and Italy. Within the G20, the leaders are Saudi Arabia, France, Indonesia, and China, followed by Argentina, Japan, Canada, and Korea. The EU is at the bottom of the ranking.

According to MIRDI (2021) reports, the ranking of countries in the Digital Riser 2020 does not correspond to their overall level of digitisation but reflects the progress and set of policies to support digitisation in these countries over the last three years. Several factors were considered in the country assessment, including the deployment of digital technologies, the availability of labour and the quality of education and the business environment.

Figure 14 | Digital competitiveness of 37 countries according to Digital Riser Report 2020



Source: own processing according to ECDC (2021)

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According to Miškerík (2021), Slovakia must use 9 billion EUR by the end of the programmed period in 2023, and there is no operational program or department that could cope with the additional allocation in such a volume. Because Slovakia is unable to exhaust the funds and is forfeited, a large number of funds intended for better and more efficient digitisation of the country is lost. Slovakia will continue to lag other European countries, which will be evident in the annual evaluation of DESI. The model for a positive trend toward increasing the digital competitiveness of Slovakia is the cooperation of universities and companies.

According to MIRII data, an estimated 500 million EUR is spent on information technologies in Slovakia per year, which, in total, since 2007, represents almost 5 billion EUR. Slovak companies are not immune to these pressures, but their behaviour does not indicate that they are fully aware of the extent of the forthcoming changes and the need to modernise or fundamentally overhaul their business models (Lelovský, 2016).

According to a survey by PwC and the monthly Forbes, Slovak company directors attach only about half the importance to digital technologies as foreign business leaders. In the digital economy to which the world is heading, companies have the chance to make full use of the possibilities and potential of digital technologies, whether to improve efficiency and productivity or to sell products or services to consumers. "Without further digitisation and the resulting improvement in efficiency and productivity, Slovak companies will have problems succeeding in the global digital economy" (Lelovský, 2016).

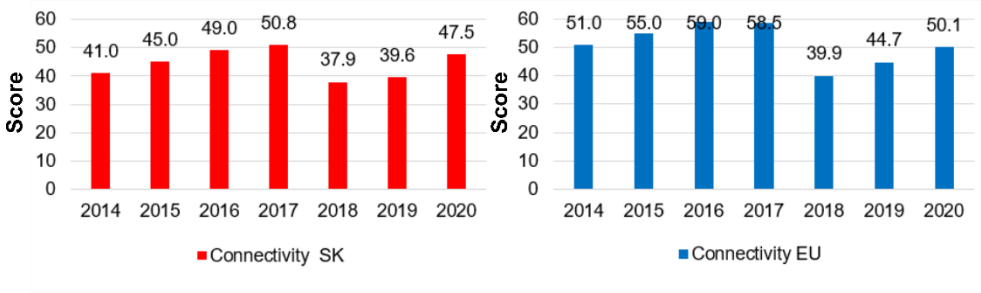
Digitisation gives us space for several new opportunities in the European market, where, in 2020, more than 500,000 vacancies for data experts and cyber security experts remained vacant. The Digital Decade Roadmap aims to translate the EU's digital ambitions by 2030 into concrete action. It will serve as a governance framework for meeting the objectives of the Digital Decade at the Union level in the areas of digital skills and infrastructure, digitisation of business models and public services, and will be based on an annual cooperation mechanism with the Member States. Its aim is to identify and implement large-scale digital projects involving the EC and EU Member States (TASR, 2021). In line with European values, the digital decade should strengthen the European Union's important position in the digital field and promote a sustainable digital policy that empowers businesses.

3.4 Connectivity and Human Capital Dimensions of DESI in Slovakia and the EU

The following analysis is focused on the connectivity and human capital dimensions of DESI, considering the development of Slovakia and the EU average.

Figure 15 shows connectivity dimension scores as a subdimension of the development of DESI for Slovakia and the EU average over the period 2014-2020.

Figure 15 | Connectivity dimension of Slovakia and the EU



Source: own processing

The score of Slovakia in 2020 was ranked 21st out of 28 EU countries, while it was at level 94% of the EU average score. Table 3 shows the percentages of the individual Internet connectivity items. The rate of mobile broadband usage (95 subscribers per 100 people) has made some progress and is close to the EU average (100). The number of households with 4G network coverage is 89%, which is below the EU average of 96%.

Table 3 | Connectivity dimension of Slovakia and EU average in 2020

Code	Connectivity	2016	2017	2018	2019	2020	EU 2020
1a1.	Overall fixed broadband take-up (% households)	72	72	70	70	72	78
1a2.	At least 100 Mbps fixed broadband take-up (% households)	-	8.3	10	13	15	26
1b1.	Fast broadband (NGA) coverage (% households)	67	75	70	73	76	86
1b2.	Fixed Very High Capacity Network (VHCN) coverage (% households)	-	-	41	43	47	44
1c1.	4G coverage (% households – an average of operators)	-	80	82	87	89	96
1c2.	Mobile broadband take-up (subscriptions per 100 people)	63	73	84	88	95	100
1c3.	5G readiness (assigned spectrum as a % of total harmonised 5G spectrum)	-	-	-	0	33	21
1d1.	Broadband price index (score 0 to 100)	-	88	-	-	60	64

Source: own processing

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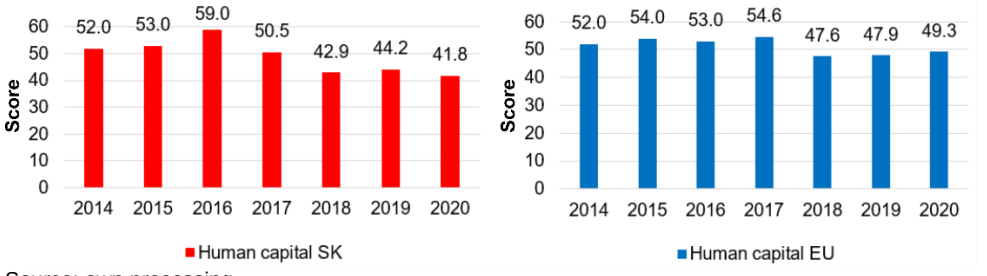
In the area of human capital, the results are determined by DESI, which measures digital and software skills. In the area of human capital, where Slovakia fell by three places year-on-year, and in the dimension of the integration of digital technologies by companies, where Slovakia fell from 17th to 20th place. The decrease by one place, even though Slovakia achieved a slightly higher score than last year, sends a clear signal that companies in other countries are advancing faster than Slovak, so that Slovak companies lag in areas such as online trading, social media or electronic the exchange of information is deepening. The dimension of human capital within DESI has changed between its items. In the period 2016-2017, ICT specialists were determined based on the percentage of the population. Figure 16 shows the human capital dimension scores of Slovakia and the EU average over the period 2014-2020.

Figure 17 | Human capital dimension of Slovakia and the EU



Source: own processing

Within the DESI 2020 evaluation (see Table 4), 27% of the population of Slovakia has above basic digital skills, which expresses a negative development in relation to the EU average, which is 33%. At least 54% of the population have at least basic digital skills, while the EU average is 58%. 56% of the population has at least basic software skills, which is a negative decrease compared to previous years, by almost 7%. Slovakia lags behind the EU average in basic software knowledge by 5%. ICT specialists represent 3.2% of the total employment. This is a positive increase of 0.4% compared to the previous period. Slovakia lags the EU average by 0.7%.

Table 4 | Human capital dimension of Slovakia and EU average in 2020

Code	Human capital	2016	2017	2018	2019	2020	EU 2020
2a1.	At least basic digital skills (% individuals)	53	55	59	59	54	58
2a2.	Above basic digital skills (% individuals)	-	-	33	33	27	33
2a3.	At least basic software skills (% individuals)	-	-	63	63	56	61
2b1.	ICT specialists (% total employment)	-	-	2.9	2.8	3.2	3.9
2b2.	Female ICT specialists (% female employment)	-	-	0.6	0.8	0.9	1.4
2b3.	ICT graduates (% graduates)	-	-	2.9	3.2	3.3	3.6

Source: own processing

According to the report (DESI, 2021), the intention is to adapt the education system and focus on the skills required in employment. The strategy identifies the need to develop soft skills and competencies to engage in the functioning of the digital society (digital citizenship). At the same time, businesses are increasingly calling for a reform of the education system to reduce the mismatch between the skills that graduates acquire at school and the skills that employers require.

The dimension of the use of Internet services is assessed by 11 subdimensions. According to DESI 2020, which evaluated the year 2019, in Slovakia, 12% of the population never used the internet, in 2018, it was 14%. For comparison, in 2019, 9% of the population in the EU did not use the internet. The number of internet users has increased from 79% to 82%, which is 3% less than in the EU. In Slovakia, 66% of Internet users use it for music, games, and videos, which is 15% less than the EU average. On the other hand, Slovakia, with its share of 66%, exceeds the EU average by 6% in the use of video calls and by 7% in the use of social networks. It lags by 100% in participation in online courses, whereas the EU is 11%. In the field of electronic banking, Slovakia is at the level of the EU average (66%), also in online shopping, where the EU average is 71%.

In the category of integration of digital technology, Slovakia ranked 21st overall, with 31% of companies sharing electronic information and lagging the EU by 3%. 3% of businesses use big data, less than the 12% EU average. Small and medium enterprises use 11% of Internet sales, which is up to 7% less than the EU average. E-commerce turnover represents the level of EU turnover, which is 11%. Businesses in Slovakia suffer from an insufficient level of digitisation on the part of public institutions.

In the field of digital public services, Slovakia ranked 26th. Only 52% of Slovak Internet users who need to send forms to public institutions do so online. In the previous year, this share was 54%. The EU average reached 67%.

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Conclusion

Since 2014, the European Commission has been monitoring the progress and level of development of Europe's digital competitiveness in each Member State every year through the DESI, which quantifies five basic dimensions. These are the dimension of connectivity, human capital, the use of Internet services, the integration of digital technologies and the level of digital public services.

In the ranking of DESI for 2020, Slovakia ranked 22nd among 28 EU countries. Its score reached 45.2 percentage points. Based on data before the pandemic (42.9), Slovakia's score increased slightly due to improvements in the areas of connectivity, Internet use and digital public services. Most indicators have not improved enough to catch up with the EU average of 52.6 percentage points in 2020.

The digital transformation of companies is one of the EU's top priorities. Slovak companies are largely lagging in digital transformation. The Slovak Republic did not reach the EU average for the monitored period (2016-2020). Improving digital skills is the main task of the Digital Transformation Strategy of Slovakia 2030 and the related action plan for 2019 - 2022. In terms of basic digital skills, Slovakia lags behind the average of EU member states by 5%. Slovakia has the biggest shortcomings in the field of digitisation of public services.

In established hypothesis 1**,** we assumed a statistically significant correlation in the rankings of countries between the analysed years 2016-2020 in at least one of the DESI indicators (internet connection, human capital, indicators of use of internet services, integration of digital technologies, and digital public services). We confirmed it for all 5 dimensions. According to the size of Kendall's coefficient of concordance, we can say that the order of countries has changed the least in time within the indicator of human capital, where the correlation is the highest. On the contrary, the lowest, although still statistically significant, correlation is within the indicator of Internet connection. Moreover, we also confirmed hypothesis 2 that among the European Union countries, there are internally homogeneous and externally heterogeneous groups of countries with respect to ranking within DESI dimensions.

The realised study fills the research gap in examining the digital transformation of Slovakia using DESI and in using cluster analysis for examining DESI. According to the individual dimensions of the DESI, this paper provides a holistic view of the level of digitisation of society among European Union Countries, especially Slovakia. Policymakers in this area thus know which countries have a similar level of DESI and, on the other hand, which countries are the most different in this way. We see implications for science in this regard. Increasing the level of digitalisation is problematic in all countries in terms of funding. Considering the contributions for practice, we think that the best way to get closer to the best EU countries in terms of digitalisation is to increase the funding to develop the digital economy. This should be a priority for all governments.

The Digital Decade Roadmap aims to transform the EU's digital ambitions by 2030 into concrete action. It will serve as a governance framework for meeting the objectives of the Digital Decade at the Union level in the areas of digital skills and infrastructure, digitisation of business models and public services, and will be based on an annual cooperation mechanism with the Member States. Its aim is to identify and implement large-scale digital projects

involving the EC and EU Member States (TASR, 2021). In line with European values, the digital decade should strengthen the European Union's important position in the digital field and promote a sustainable digital policy that empowers businesses. EU countries' economies will grow with technological development, but inequalities between countries need to be balanced, as the structure of the Member States is very differentiated with an emphasis on technological, economic and social development.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under contract no. APVV-20-0338. This paper was supported by the research grant KEGA no. 001PU-4/2022 “Application of Modern Trends in Quantitative Methods in the Teaching of Financial and Managerial Subjects”.

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The research article passed the review process. | Received: December 14, 2021**; Revised:** May 18, 2022**; Accepted:** May 20, 2022**; Published online:** July 29, 2022**; Published in the regular issue:** March 20, 2023.