Issues in Information Systems
Volume 23, Issue 4, pp. 293-311, 2022

DOI: https://doi.org/10.48009/4_iis_2022_125

Digital transformation of human capital in the EU according to the DESI index

Tünde Zita Kovács, *University of Debrecen, kovacs.tunde.zita@econ.unideb.hu*
Beáta Bittner, *University of Debrecen, bittner.beata@econ.unideb.hu*
Adrián Szilárd Nagy, *University of Debrecen, nagy.adrian@econ.unideb.hu*
András Nábrádi, *University of Debrecen, nabradi.andras@econ.unideb.hu*

Abstract

Since 2014, the Digital Economy and Society Index (DESI) has been one of the key tools for monitoring and measuring the digital development of the European economy and society. In 2021, the DESI index's core indicators were aligned with the objectives of the 2030 Digital Agenda and had four core dimensions: human capital, connectivity, integration of digital technology and digital public services. Continuing our previous research, we tried to determine whether convergence between the Member States could be detected in human capital digital skills and competencies development. The σ-convergence was applied to estimate the reduction over time in the differences between the Member States. The β-convergence was used to calculate the rate of catching up to the initial level of development. The σ- and β-convergence was not confirmed. A cluster analysis was carried out - assuming a non-homogeneous development - which revealed that the differences in the digital development of human capital in the Member States are persistent and that the rate of development is minimal over the period considered. We reviewed DESI's human capital individual indicators to identify critical areas that need to be addressed in the future to ensure that digital development is as broad-based as possible. After a meticulous analysis of the DESI overall index and its core dimensions, we conclude that in areas where convergence is not achieved, the EU's targets will not be met or will be in backlog in 2030. In education, training and retraining, in this case, digital skills development and coherent action are essential.

Keywords: Digitalization, Human Capital, Convergence, DESI, Clusters

Introduction

Starting in 2014, the European Commission will measure and publish its analysis of the Digital Economy and Society Indicators (DESI). The indicators track the evolution and development of the digital competitiveness of EU Member States through the performance of 4 core indicators: digital skills and competencies of human capital; Internet coverage and quality of access; digital technologies in the enterprise; and the penetration of digital public services. In 2021, the DESI index underwent a structural change to better track the initiatives that will impact the digital transformation in the EU in the coming years: the Recovery and Resilience Facility (RRF - from February 2021) and Digital Decade Compass (DDC - from March 2021). According to country-specific needs, the RRF will help the EU Member States in their digital transition through loans and grants, thereby creating jobs and stimulating growth (European Commission, 2021c). To achieve the digital transformation and vision, the DDC will monitor digital progress and address gaps within a robust governance framework, manage multi-country and private sector

investment projects, and support the achievement of targets and projected trajectories (European Commission, 2021d).

Our previous research has already analyzed the DESI overall index and the DESI core indicators, concluding that the digital readiness of human capital is key to the EU's digitalization ambitions (Kovács & Bittner, 2022; Kovacs, Bittner, Huzsvai, & Nabradi, 2022; Kovacs, Bittner, & Nabradi, In Press). In this research, we focus on this main indicator, human capital (desi_1), the first pillar of the DESI index, which comprises two sub-dimensions and seven individual indicators (Table 1), developed based on OECD guidelines and recommendations (European Commission, 2021b). On human resources issues, be it education, training or retraining, the European Union's competence is limited to supporting, coordinating or complementing the actions of the Member States. Therefore, it cannot limit the regulatory discretion of the Member States; it has no right to legislate, and its powers are merely supportive.

Table 1:Components of the Human Capital (desi_1) Indicator

Desi_1 Subdimensions	Individual Indicators
Internet user skills (desi_1a)	At least basic digital skills
	Above basic digital skills
	At least basic software skills
Advanced skills and development (desi_1b)	ICT specialists
	Female ICT specialists
	Enterprises providing ICT training
	ICT graduates

For each country, the desi_1 core indicator is defined as a simple weighted arithmetic average of the subdimensions:

$$desi\_1 = desi\_1a*0.5 + desi\_1b*0.5$$

The number of member states in the European Union has grown steadily over the past decades. Member States that joined in the early 2000s and afterwards aimed to catch up with those that joined earlier, whether in economic, social or, in this case, digital development. Furthermore, approaches in this development must be reflected in convergence. We have examined the evolution and convergence of digital skills of human resources for the EU as a whole (EU-27), for the previously acceded Member States (EU-14) and for the group of countries that joined the EU in 2004 and beyond. Our research aims to use mathematical-statistical methods to look for evidence of the evolution of digital skills of EU Member States' residents over the period 2016-2021, both aggregated and relative to themselves. We formulated our null hypothesis on convergence as follows:

H1: Based on the change of the desi_1 core indicator, we assumed that there is no convergence between the Member States.

The aim of convergence is not to make the Member States of the European Union homogeneous but to enable each country to implement its specific policies and define its specific measures in line with the overall dimension of horizontal measures.

Research has shown that as the digital skills of the human capital increase, labor market indicators improve, which can be a decisive factor in achieving and maintaining a certain competitive position (Baltateanu, 2020; Basol & Yalcin, 2021). A cluster structure analysis was conducted to identify and visualize shifts in

digital skills and competencies of human resources in the context of the digital societal development of EU Member States in the period 2016-2021. Our null hypothesis for cluster structure analysis:

H2: The digital development of human resources in the EU-27 Member States is not homogeneous, and specific clusters of countries can be distinguished, considering the similarities in their performance in this area.

Through our convergence calculations and cluster analyses, we are looking for evidence on whether the concrete actions taken by the Member States in the digital human capital development field align with the EU's overall ambition in this area.

The structure of our study is as follows: in the following section, we review the literature related to human capital and the digital economic and social index. Then, in the methodological section, we present the mathematical-statistical procedures used to analyze the data of the desi_1 core indicator for the period 2016-2021: σ- and β-convergence and Ward's cluster structure analysis. The statistical analyses themselves are presented in the Results section and explained in the Discussion of findings section, followed by the Conclusions and Limitations of our research.

Literature Review

To explore the literature related to human capital or the digitization and digital development of human capital, we used the Web of Science Core Collection - Clarivate Analytics scientific database. In the first round, we searched for ("human capital" or "human resources"). The database returned 54,590 results, which were further narrowed down to ("digitalization" or "digital skills" or "desi" or "digital economy and society"). The search results of the scientific database were reduced to 298 hits. The resulting database was then subjected to a bibliometric analysis using the free software VOSviewer 1.6.17. (Van Eck & Waltman, 2013), to identify the specific keywords of the subject-related articles based on the entire record. The software identified 1,331 keywords in our literature database, among which several similar ones occurred. The similar keywords were merged using a so-called thesaurus file, thus narrowing down the number of keywords to 1327. By setting the minimum rate of occurrence at 8, the software found 29 keywords. The network of relationships between relevant keywords is depicted in (Figure 1) and can be interpreted as follows: the dots' size indicates the frequency of the keywords, and the thickness of the strings indicates how often the keywords occur together. The distance between the dots indicates the strength of the relationships between the keywords. Each color indicates the clusters identified by the bibliometric software.

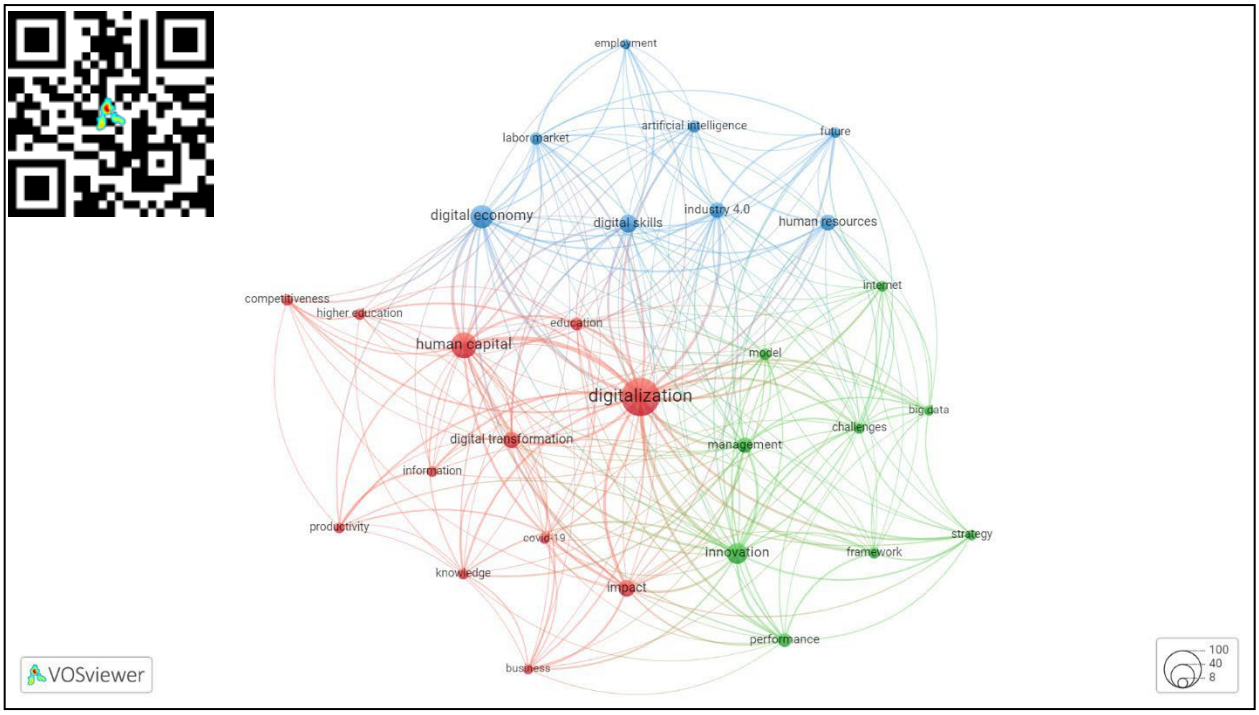

Figure 1: Keywords Visualized

In our database, we identified 3 clusters using a minimum occurrence threshold of 8 times for the keywords and keeping the default resolution of 1.00. The keywords belonging to each cluster are shown in (Table 2), and their grouping by color is illustrated in (Figure 1).

Table 2: Keyword Clusters

Cluster 1 (Red-cluster)	Cluster 2 (Green-cluster)	Cluster 3 (Blue-cluster)
Digitalization	Innovation	Digital economy
Human capital	Management	Digital skills
Impact	Performance	Human resources
Digital transformation	Challenges	Industry 4.0
Education	Model	Labor market
Knowledge	Internet	Artificial intelligence
Productivity	Framework	Future
Business	Big data	Employment
Competitiveness		
Higher education		
Information		
Covid-19		

The main keywords in the central cluster, highlighted in red, are "digitalization" (116 occurrences) and "human capital" (53 mentions), with the most robust relationship in the current database, at 23, indicating the formative power of digitalization in shaping human capital. Human capital has become one of the main drivers for the emergence and development of an innovative, digital-based economy and a knowledge-based economy. The development of digital technologies is leading to the development of digital skills, thus increasing the potential for the digital development of human capital (Chulanova, Satybaldin, &

Koshanov, 2019; Kelchevskaya & Shirinkina, 2020). The development of human capital today means the growing importance of digital competencies and skills, so-called digital literacy, which includes the ability to adapt to rapid change (Merzlyakova, Obukhova, Kazarenkova, Aseev, & Zelenov, 2020; Nadezhina & Avduevskaia, 2021; Rodchenko, Rekun, Fedoryshyna, Roshchin, & Gazarian, 2021; Stryabkova, Lyshchikova, Gerasimova, Kulik, & Weis, 2021). The Covid-19 epidemic has accelerated digitization processes in all areas, including developing human capital's digital skills (Bikse, Lusena-Ezera, Rivza, & Rivza, 2021; Kravchenko, 2021). In the past, the digitization of businesses was aimed at making them easier to access and more competitive by saving resources. The restrictions introduced by Covid-19 have also generated changes in working habits, deepening and advancing the use of digital technology and ICT, both in businesses and educational institutions (Avetisyan & Gevorgyan, 2020; Dvorak, Royny, Grebennikova, & Faminskaya, 2020). In this changing environment, human capital has become a key tool for building competitive advantage (Kichigin, Gonin, & Publishing, 2019). Digitalization and the digital transformation of human capital have also brought with it the possibility of online access to knowledge. Many researchers believe that cultural background, cultural habits and customs play an essential role in the process of digitalization (Jovanović, Dlačić, & Okanović, 2018; Luchko, 2020). Based on Hofstede's (1984) cultural dimensions, states with a high level of individualism and hierarchy, and a higher propensity to take risks and enjoy life, have a higher level of digitization of the economy and society (Vidruska & Univ, 2016).

The next cluster, the green cluster, is organized around innovation and has strong links with, among others, the previous cluster's main keywords, digitalization and human capital. Management, corporate strategy, and performance analysis now require innovative systems that combine cloud computing with big data use, evaluation and analysis (Moldabekova, Philipp, Reimers, & Alikozhayev, 2021; Sahlin & Angelis, 2019). The role of human capital management within an organization is being reassessed as staffing needs to change, requiring personal and professional competencies that enable the design and implementation of a business development strategy (Baranovskiy, Zaychenko, Dubolazov, & Ilin, 2020).

The more prominent keywords of the blue cluster are "digital economy", "digital skills", "Industry 4.0", and "human resources". The articles in this cluster focus on the changes and challenges in the labor market in digitalization and Industry 4.0. The pace of technological change brought about by Industry 4.0, and the resulting Covid-19 has produced a significant gap between the current readiness, skills and competencies of human resources and the expectations - rapid response and adaptability to an online environment (Karas & Brezovska, 2020). The digital skills and competencies of the population are expected to become even more valuable, which the state should support by providing lifelong learning opportunities (Kozlova & Neklyudova, 2019). The digital transition affects not only processes but also jobs. Thus, its influence on the labor market is also significant.

The clustering method applied in the literature analysis was used to group the articles on the relationship between human resources and digitalization. In turn, the clustering of the literature database highlighted the contexts, i.e. the contexts in which the digitization of human resources was examined. The key factors that influence the digital development of human resources were identified, as well as how to increase its effectiveness and what measures would further promote digital development. Three broad themes emerged. The first group analyses the impact of digitalization on human capital and its formative power. The second group contains the work of authors who examine the innovation skills of digitalization. Finally, in the third group, we find papers analyzing the impact of digitalization on the labour market.

Methodology

Convergence calculations are now being carried out in several areas, such as income inequality, social capital development, environmental economics, poverty, etc. Quah (1996, p. 1054) argues that this is evidence that "convergence is simply a basic empirical issue, one that reflects on - among other things -

polarization, income distribution, and inequality. Certainly, understanding economic growth is important. However, growth is only one of many different areas in economics where analyzing convergence sheds useful insight." This paper deals with two types of convergence, σ- and β-convergence.

σ- and β-Convergence

The σ-convergence, or relative standard deviation, is used to show the average relative deviation of the values of the desi_1 core indicator from the mean, expressed as a percentage. If the average relative standard deviation, i.e., the dispersion of development levels, decreases over time, then σ-convergence exists, i.e., the differences between Member States decrease. The σ-convergence is a coefficient of variation that allows comparisons of samples or populations with different characteristics and averages. In the present case, we have a sample of scores measuring the digitalization skills of human resources in the EU-27 Member States for the period 2016-2021. The coefficient of variation is the relative deviation of the metrics from the mean, expressed as a percentage. If the dispersion of the development levels decreases over time, we speak of σ-convergence.

The β-convergence is the convergence indicator associated with Barro & Sala-i-Martin, which has its roots in the neoclassical growth theories of Koopmans (1963), Ramsey (1928) and Solow (1956). In our case, β-convergence focuses on finding a possible catching-up process. Based on the hypothesis of absolute β-convergence, the rate of catching-up per member state is explained by the initial level of development alone. The strength of the effect (catching-up) is indicated by the sign and value of the β-coefficient. Univariate linear regression was used to estimate the α and β coefficients. A least-squares procedure based on squared error minimization is used to estimate the α and β coefficients. The β-coefficient was considered significant only if the empirical significance level, denoted by *p*, was less than 5%.

Cluster analysis

The primary aim of cluster analysis is to form homogeneous groups, classifying the EU Member States based on the sub-dimensions that make up the desi_1 index. Our cluster analysis aims to reduce the number of observation units. Our clustering was based on distance measures, considering that our available data can be interpreted on an interval scale; comparisons were made pairwise. Among the clustering procedures used for cluster analysis, we applied the hierarchical clustering method (Malhotra & Dash, 2010), as we had 27 different clusters at the beginning of the analysis process. Within the pooling procedure, we used the variance, also known as Ward's procedure, to calculate the mean of all variables for each cluster and then calculate the squared Euclidean distance for each observation unit. The distances were summed for each observation unit, and at each step, the two clusters with the smallest increase in the within-cluster variance squared were drawn together. Another clustering procedure, the K-means method, has been used to check the reliability, allowing us to fix the number of clusters and the centre of each cluster in advance. Convergence and cluster analysis was carried out using the IBM SPSS Statistics 25 software package, while the figures were prepared using Excel21.

Results

The first core indicator of the Digital Economy and Society Index, called desi_1, provides data on the digital readiness of EU citizens. The European Commission aims to use it to assess the digital skills and capabilities of the population, the progress made in digital development, and whether and to what extent digital convergence is taking place. Our analysis is based on data for the period 2016-2021, available on the European Commission's database (European Commission, 2021a). Figure 2 shows the state of play for the desi_1 core index for 2021. The core index is composed of two sub-dimensions, equally weighted, resulting

in a ranking of Finland as the leader in terms of digital skills of human capital (71.11%), with Sweden in second place, 6.5 percentage points behind. The EU-27 average is 48.47 percentage points, with only ten Member States above the average, and five above the average, while the population's digital skills in the other Member States are below the average.

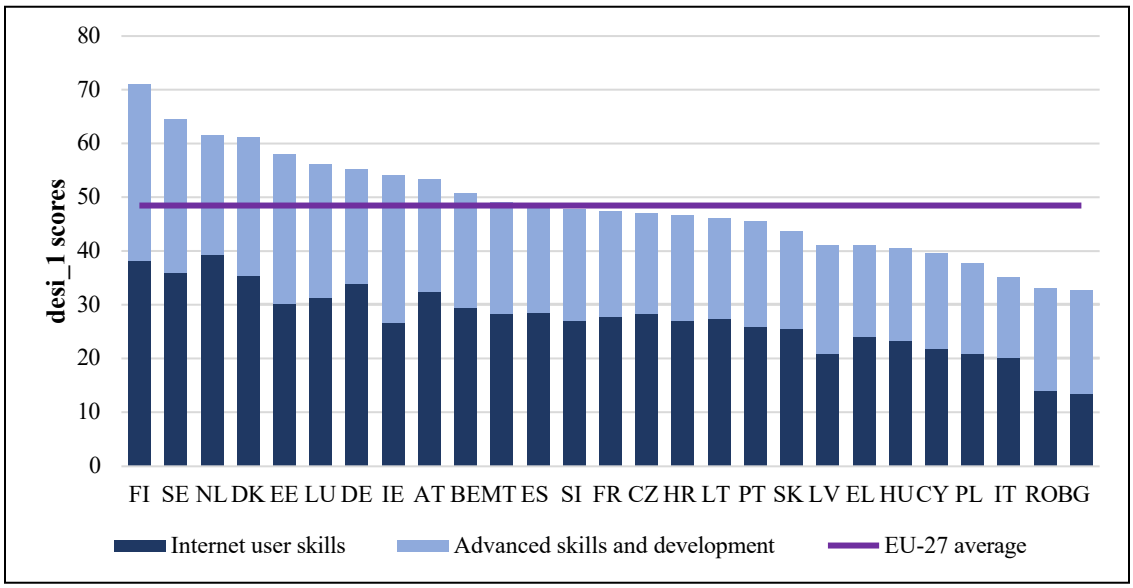

Figure 2: Country Rank Based on Desi_1 Index Subdimensions in 2021

We used σ-convergence to see whether the relative dispersion of the data for this core indicator over the period 2016-2021 could be used to show the cohesion of the EU-27 Member States. The σ-convergence was analyzed for three units: the EU-27, the EU-14 and the group of states that joined the EU in 2004 and after (Figure 3). For the EU, we cannot speak of a reduction in the relative dispersion of digital literacy in human resources. The situation is slightly different when looking separately at the EU-14 Member States and the group of countries that joined in 2004 and onwards. For the EU-14 countries, there is a convergence in the digital skills of the human capital, although even for them, this trend will be reversed by 2020. Most striking, however, is the heterogeneity of the dispersion between the Member States that joined in 2004 and those that joined afterwards, with a clear divergence, i.e., the evolution of human capital digital skills does not show an improving trend between 2016 and 2021, compared to the relative dispersion of the region's development level.

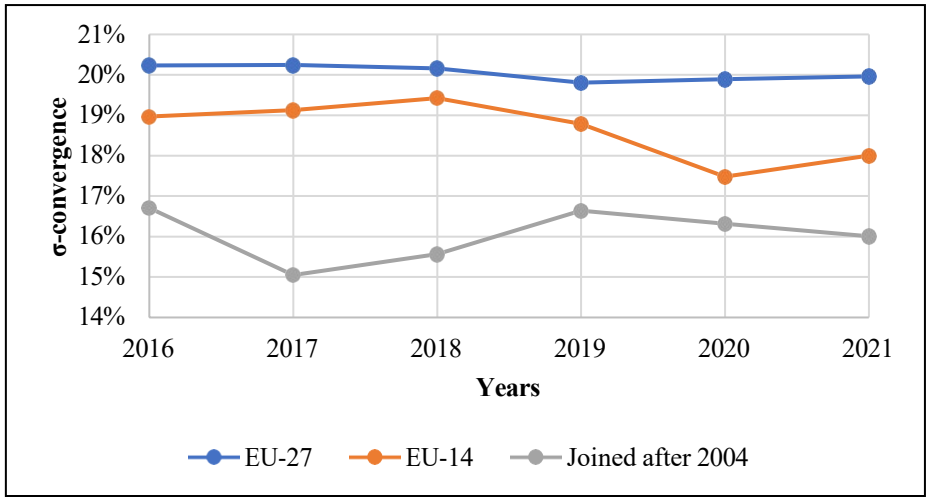

Figure 3: σ-convergence of Desi_1 Core Indicator between 2016-2021

From 2016 - to 2021, no β-convergence is observed for the desi_1 core indicator in the EU Member States. Although we observed a slight negative correlation between initial development levels and the average volume growth rate of the desi_1 core indicator (Table 3), the regression coefficient is not significant ($p>0.05$), so we cannot speak of shrinkage between development gaps.

Table 3: OLS Regression of Desi_1 Index

Observations	R-square	Constant	β	θ	t Stat	P-value
27	0,0034	0,0581	-0,0108	-	-0,9367	0,3578

The core indicator comprises two sub-dimensions: the share of the population with Internet skills and their development (Figure 4) and the share of ICT graduates and ICT sector employees. However, the latter cannot be plotted on a single graph as it uses different benchmarks. In terms of population, the Netherlands, Finland, Sweden, Germany and Denmark have the highest proportions of people with basic digital skills.

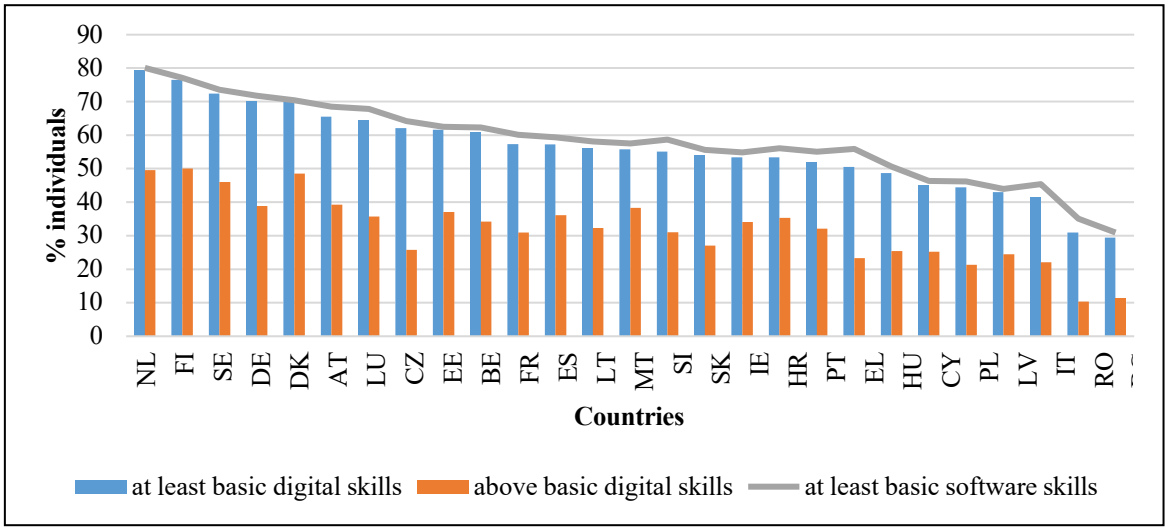

Figure 4: Human Capital with Internet User Skills in EU-27 (2021)

However, it can be seen from (Figure 5) that the proportion of people with basic digital skills and those with at least basic software skills is almost the same, so basic software skills are the same as basic digital skills in this case. One in three people has only basic digital knowledge and skills in Bulgaria and Romania. The situation is only slightly better in Italy, Latvia, Poland and Cyprus, where less than half of the population is at home in the digital world, at least at a basic level. The picture is similar for digital skills above the basic level, with the same countries leading the way and the same top performers.

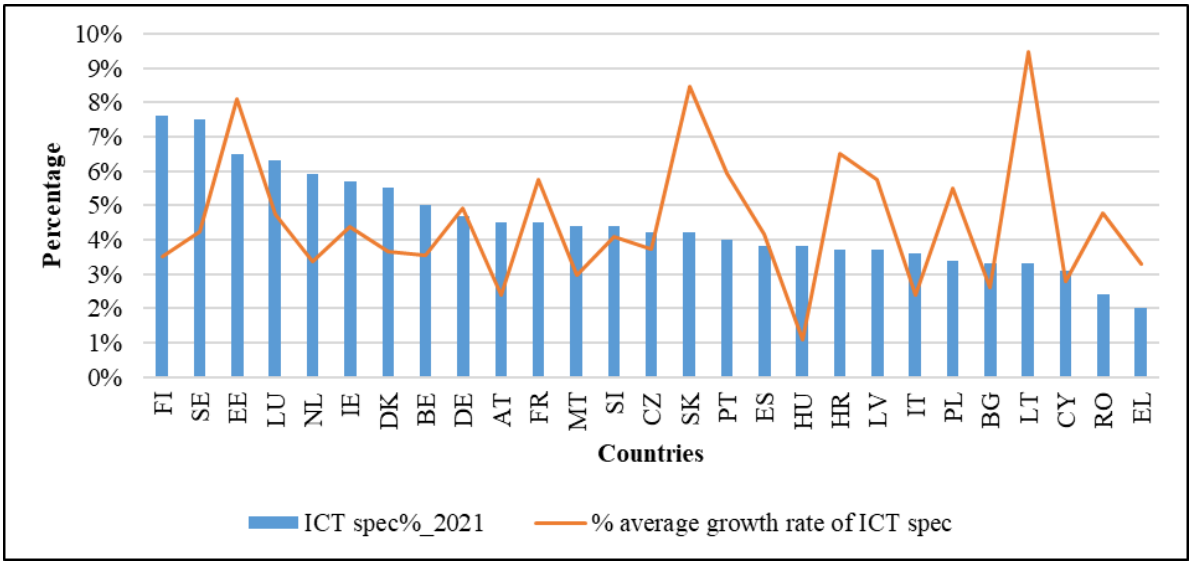

Figure 5: Rate of ICT Specialists in 2021 and Average Growth Rate of ICT Specialists

The EU Member States focus on developing digital skills in school and university education and among the already active (working) population. The highest rates of ICT-related specialists in 2021 are in Finland, Sweden, Luxembourg and Estonia, but we can also see that the percentage of ICT specialists has increased significantly in Lithuania, Slovakia, Estonia, Croatia and Latvia (Figure 6). Estonia has one of the highest proportions of ICT workers and a high proportion of workers with digital competencies, partly due to Estonia's Lifelog Learning strategy (Ministry of Education and Research, 2020).

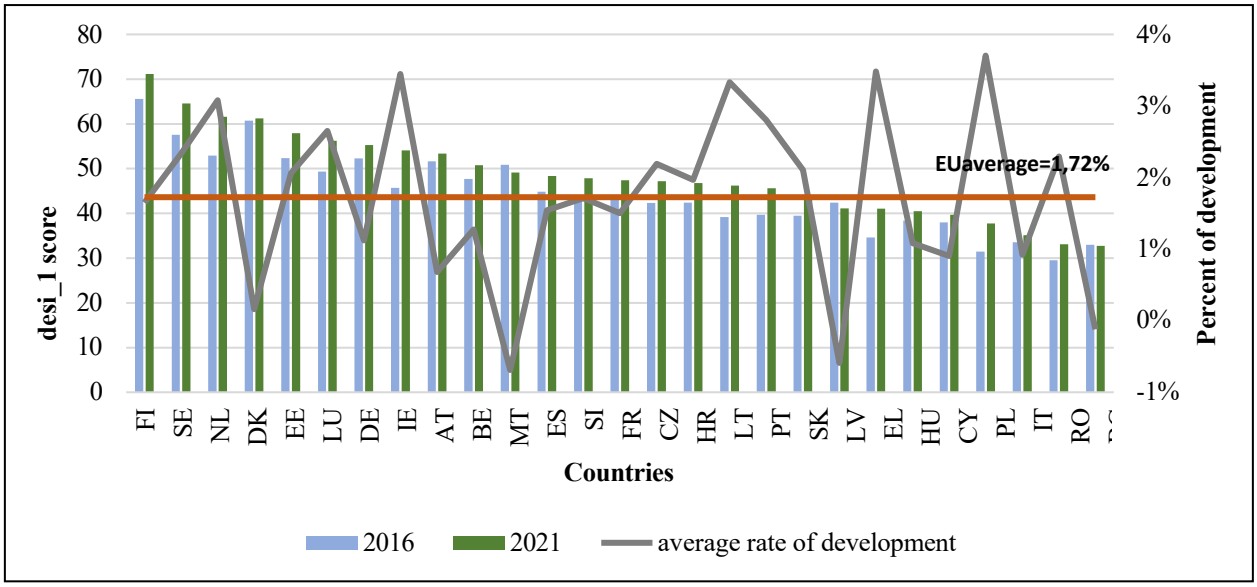

Figure 6: Country Rank by Desi_1 Index in 2021.
Additional Information from 2016 and Average Rate of Development

While the number of people working in the ICT field continues to grow, it is also true that the ICT sector's absorptive capacity is much greater than the current supply. Narrowing this gap can only be achieved through training, retraining and, in particular, over a longer time horizon. Digital skills need to be developed from primary school onwards to become aware users and confidently use this knowledge in their later working life and develop it further.

The desi_1 index, which measures the digital readiness of a country's human capital, is one of the most important indicators of the EU's digitalization ambitions. The competitiveness of national economies and companies depends on their ability to make digitalization work for them (Rezer, 2019). The bottleneck in achieving these ambitions is human resources and the digital literacy of workers (Ivanenko, Timoshchuk, & Zotova, 2020; Pouliakas, 2018). In our literature review, we found that other papers and studies have used a clustering procedure to classify the EU Member States, but all of them have used the performance of the DESI overall index, mainly in order to compare it with the results of another classification system, looking for similarities (Bánhidi, Dobos, & Nemeslaki, 2020; Borowiecki et al., 2021; Sevgi, 2021). We grouped the EU Member States by 2016 and 2021 human capital indices using Ward's clustering analysis, and the validity was tested using K-means cluster analysis. For both years under study, four clusters are distinguished. The classification of the countries in clusters was based on the values of the desi_1 core indicator and its sub-dimensions. Cluster 1 includes the Member States with the lowest desi_1 values, and Cluster 4 includes the Member States with the highest values for both the core indicator and the sub-dimensions in the years under review. The structure clusters and information about average values and the shifts during the reviewed period are shown in (Figure *7*).

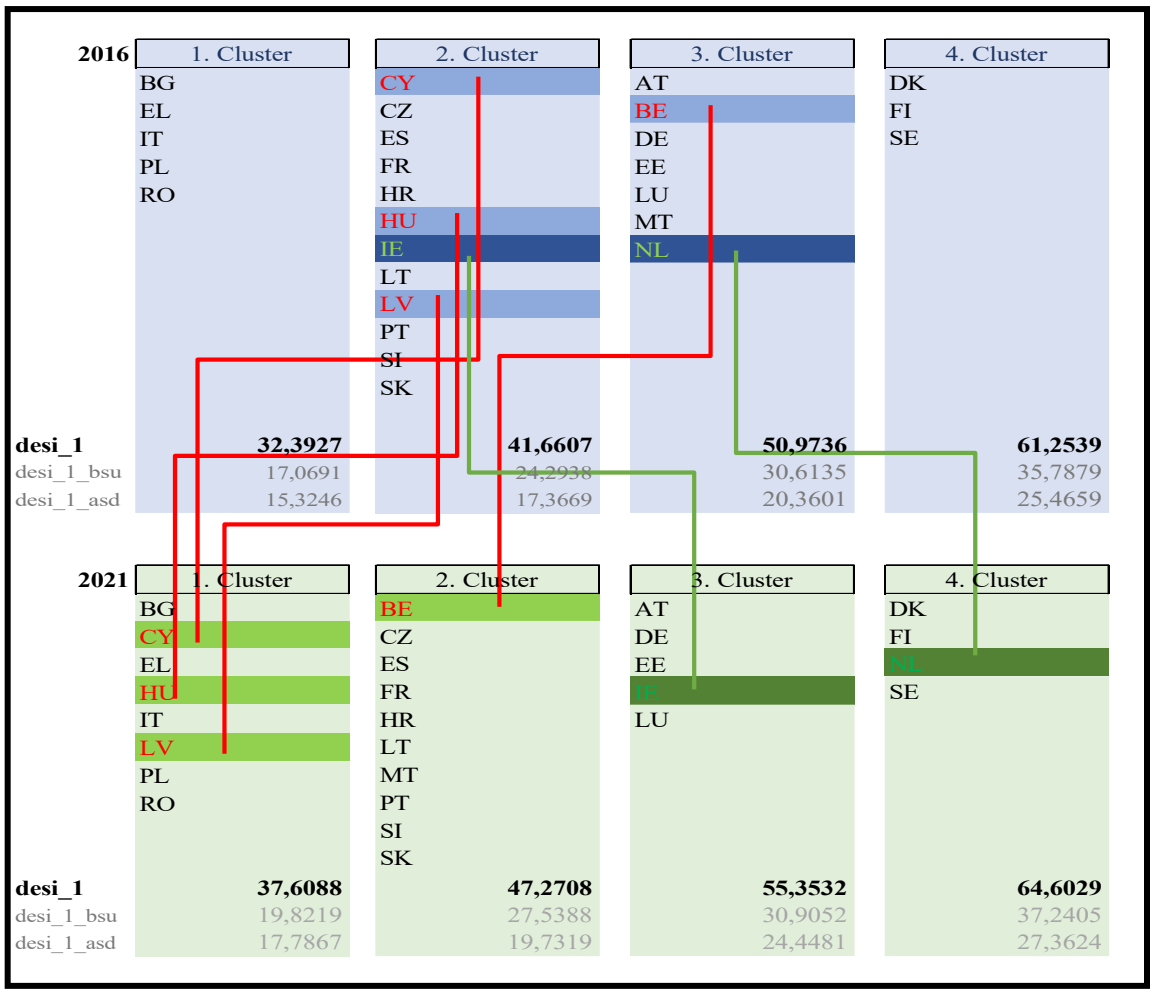

Figure 7: Desi_1 Values in a Cross-section of Isolated Clusters

- In 2016, 5 Member States were in Cluster 1: Bulgaria, Greece, Italy, Poland and Romania, with an average cluster value of 32.29%. By 2021, the number of members of this cluster had increased, with Cyprus, Hungary and Latvia joining, and there was a shift of 5% in the average value.
- The number of Cluster 2 members in 2016 was 12: Cyprus, the Czech Republic, Spain, France, Croatia, Hungary, Ireland, Latvia, Lithuania, Portugal, Slovenia, Slovakia and Slovakia, making it the most populous. By 2021, the cluster had undergone a significant reorganization, with the number of members falling to 10 and an improvement of almost 6% in the average value. Ireland moved up one cluster, Cyprus, Hungary and Latvia moved down one cluster. The cluster classification of the other countries remained unchanged.
- In 2016, 7 Member States were placed in Cluster 3: Austria, Belgium, Germany, Estonia, Luxembourg, Malta and the Netherlands. The average value of the cluster is 50.97%. By 2021, the average value of Cluster 3 will also rise by almost 5%. Regarding group composition, Belgium has moved down one cluster, while the Netherlands has moved up one cluster. In 2021, Cluster 3 will include 5 Member States in total.
- In 2016, Cluster 4 included 3 Member States, Denmark, Finland and Sweden, with an average cluster size of 61.25%. Five years later, the Netherlands joined the best-performing cluster, bringing the total number of clusters to four, and the cluster's average increased by almost 3.5%.

The ranking of countries has not changed significantly, at the top or the bottom of the list, according to the desi_1 core indicator (Figure 6). Finland has maintained its top position, although its rate of progress (1.65%) is slightly below the EU-27 average (1.72%). Denmark has slipped back a little, given that the desi_1 indicator is barely improving (0.16%), but it is still in the lead. However, the case of Latvia and Malta is interesting, where there is no progress in the digital competencies of human capital, with a decrease of more than 0.5% in the value of the indicator in 2021 compared to t_0. Similarly, in the case of Bulgaria, the digital skills of human capital are also on the decline (-0.12%). A series of deteriorations in the values of the individual indicators that make up the desi_1 indicator can be observed for these countries, such as the proportion of the population with basic digital skills, the proportion with digital skills above basic and the proportion of ICT professionals. The slight increase in ICT graduates cannot compensate for the decrease in the other individual indicators.

The desi_1 core indicator, measured in 2020, shows a slight increase in absolute terms between 0.13% and 2.6% compared to 2019. There was no increase in the desi_1 core indicator for Bulgaria, Germany, Cyprus, Italy, France, Belgium and Malta. For these countries, the value of the desi_1 indicator decreased slightly compared to the previous year, 2019, by between 0.02% and 0.8%.

Discussion of Findings

In September 2021, the European Parliament and the Council adopted the proposal for a policy programme, "Path to the Digital Decade 2030" (European Commission, 2021d), which set out specific digital goals, including the digitization of human capital. This policy will see the EU institutions and Member States working together to achieve EU-level targets for a digitally literate population and highly skilled digital professionals by 2030:

- at least 80% of 16 - 74-year-olds have at least basic digital skills;
- at least 20 million ICT professionals are working in the EU, with a gender balance of at least women and men.

As we have stressed above, the European Union's competence in human resources matters is limited to supporting action by the Member States, and it has no power to legislate. Nor is the 2030 policy agenda binding on the Member States.

According to the first hypothesis (H1), we hypothesized that, based on the values of the desi_1 core indicator, no convergence between the EU Member States, both aggregated and relative to themselves, could be observed in the period 2016-2021. Using σ-convergence, we sought to find out whether the relative dispersion of the data of this core indicator could be used to show the convergence of the EU-27 Member States. The σ-convergence was analyzed for three units: EU-27, EU-14 and the group of countries that joined in 2004 and after (Figure 3), and we cannot speak of a reduction in the relative dispersion of digital literacy in any of the units of analysis. Similarly, there is no evidence of β-convergence. However, we find a slight negative correlation between initial levels of development and the average volume growth rate of the desi_1 core indicator (Table 3). The regression coefficient is not significant ($p>0.05$), so we cannot speak of shrinkage between development gaps. Based on our tests for σ- and β-convergence, we accept the null hypothesis H1.

In our second hypothesis (H2), we assumed that the digital development of human capital is not homogeneous, with specific clusters of countries distinguished by their performance in this area. From the cluster analysis, it is clear that there are persistent differences in human capital development across the Member States, and the pace of progress is not very encouraging. There are only minimal shifts when comparing the clusters from 2016 and 2021 and their averages (Figure 7). There was a positive shift for

countries where the average rate of progress exceeded 3% (Ireland and the Netherlands) and a negativeshift with Cyprus, Hungary, Latvia and Belgium, where the desi_1 indicator has barely increased or, in the case of Latvia, has even decreased, falling one cluster (Figure 6). Thus, the null hypothesis of our H2 hypothesis is accepted. According to Folea (2018), Fleaca (2017), and Condruz-Bacescu (2019), the EU's Digital Agenda places a high priority on measures to support digital skills education, thus supporting and promoting the development of digital skills in the population. Member States should commit to increasing the number of people with digital skills at primary and tertiary levels (Jaculjakova & Stofkova, 2020; Rodrigues, Cerdeira, Machado-Taylor, & Alves, 2021; Tumbas, Sakai, Pavlicevic, & Rakovic, 2019). However, education alone is not enough to achieve the European Union's digital ambitions; the availability of technology is equally important to ensure that the knowledge acquired can be applied and developed (Matkovic, Maric, Rakovic, & Sakal, 2019; Štofková, Soltes, & Stofkova, 2019). López Peláez, Erro- Garcés, and Gómez-Ciriano (2020) contrasted the digital skills of British youth with the expectations of the labour market and argued that the digital divide between the two could only be bridged through education and digital skills development. Kwilinski, Vyshnevskyi, and Dzwigol (2020) found in their research that the higher the level of digitalization in a society, the lower the risk of poverty and social exclusion. Our research shows that the Member States with the highest real GDP per capita score highly in terms of human capital, digital readiness and use of internet services. The DESI index also implies increased employment and personal incomes, reducing long-term unemployment and labour market insecurity (Basol & Yalcin, 2021; Stavytskyy, Kharlamova, & Stoica, 2019). Neamtu, Hapenciuc, and Bejinaru (2019) and Bejinaru (2017) argue that Industry 4.0, together with ICT, has completely rewritten the global economic system, and further transformations are expected. Regarding digital readiness, the Nordic countries of Europe are performing better, while Eastern Europe is lagging (Stankovic, Marjanovic, Drezgic, & Popovic, 2021). Romania also lags behind the European average in several aspects of digitalization, such as the adoption of e-government measures (Murariu & Bedrule-Grigoruta, 2020; Todorut & Tselentis, 2018), the digital skills of the population (Gaftea, 2016), and the use of digital technology at the enterprise level (Baltateanu, 2020; Iliescu, 2020). Esses, Csete, and Németh (2021) and Kuncová and Doucek (2018) assess the performance and progress of the Visegrad countries, while Herman (2020) stresses that the share of ICT employment and its contribution to GDP in the V4 countries and Romania is below the EU average.

In order to achieve the EU's digitization objectives, a comprehensive and coherent approach to the issue would be needed to eliminate extreme differences. In our previous research (Kovacs et al., 2022), an analysis of the DESI overall index found that human capital, the first core indicator of the DESI Index, is a key element for realizing digitalization ambitions (Kholod et al., 2021). Instead of the European Commission's weighting of 25%, we consider a weighting of 30%, as proven by mathematical-statistical methods, to be more appropriate. By examining the variation of the DESI overall index, where the combined impact of the four core indicators: 1) Digital skills and competencies of human capital (desi_1); 2) Connectivity (desi_2); 3) Integration of digital technology (desi_3) and 4) Digital public services (desi_4) was analyzed, we find that both convergences (σ- and β) are statistically verifiable. However, it was already indicated that examining the core indicators one by one is justified, as convergence may not always be the case. Our hypothesis confirms that convergence does not hold for the core indicators desi_1 and desi_3 (Kovács & Bittner, 2022). Both indicators are inextricably linked to human capital since while the desi_1 core indicator measures human capital's digital skills and competencies, the desi_3 core indicator with the use of digital technology in the company is closely correlated with human capital. After a meticulous analysis of the DESI overall index and its core constituent indicators, we conclude that in areas where convergence is not achieved, the EU's targets will not be met or will be significantly behind in 2030. In education, training and retraining, in this case, digital skills development and coherent action are essential. Digital literacy is now as critical as learning to read and write.

Conclusions

In the present study, we sought evidence of the digital development of the EU's human capital based on the values of the desi_1 core indicator. The present study is the fourth stage of an ongoing research project on the evolution of the DESI overall index and its main constituent indicators. To our knowledge, we are the first to apply σ- and β-convergence methods to study the DESI index and its constituent core indicators. We have not only examined the evolution of the states separately but also used σ- and β-convergence and clustering. We found that, over the period under study, the average growth rate of the digital development of the EU's human capital ranged from -0.69% to 3.7%. Statistical calculations have shown no decrease in the differences (relative standard deviation) between the indicators measuring the digital readiness of the EU human capital, i.e. no σ-convergence. The negative correlation between initial levels of development and the average volume growth rate is not significant, i.e. no β-convergence. We then clustered the Member States into homogeneous groups to see which Member States were similar regarding digital readiness of human resources.

Convergence does not aim to make the Member States homogeneous; as we can see, this is not the case regarding the digital readiness of human capital. However, clustering, i.e. grouping Member States based on similarities, can help EU policymakers to provide guidance and support to the Member States as needed. In our view, measures, proposals, and support options along the lines of each cluster are more likely to be effective, including in the area of human resources, be it education, training or retraining. Convergence should be pursued for each of the four core indicators that constitute the DESI overall index, which is not yet the case for the main indicators desi_1 and desi_3.

Complementing the descriptive statistics currently used in analyzing the desi_1 core indicator with the methods presented in this study could help connect macroeconomics to solutions. The evolution of the DESI index and its main constituent indicators, and their monitoring, will provide evidence of whether the Member States currently lagging in the digitalization process are catching up and the effectiveness of the improvements.

Limitations

To perform the σ- and β convergence calculations, we used the values of the DESI overall index, which are presented as a transformed percentage. This database was used as the basis for our analysis and was not compared with other databases monitoring the digital development of human capital.

The study examines the digital development of human resources based on the DESI index, which is limited to the Member States of the European Union. Extending our research geographically beyond the EU borders would require a survey and database based on a similar methodology, which is unavailable to our knowledge.

References

Avetisyan, P. S., & Gevorgyan, N. M. (2020). Free Educational Environment as the Basis of Human Capital and Relationships between Social Sectors. *Ekonomika Regiona-Economy of Region, 16*(2), 494-506. doi:10.17059/2020-2-12

Baltateanu, A. M. (2020, 15-16 Oct 2020). *Digitalization. Global Challenges and Economic Prosperity Example: Romania.* Paper presented at the 8th International Academic Conference on Strategica - Preparing for Tomorrow, Today, Bucharest, Romania.

Bánhidi, Z., Dobos, I., & Nemeslaki, A. (2020). What the overall Digital Economy and Society Index reveals: A statistical analysis of the DESI EU28 dimensions. *Regional Statistics, 10*(2), 42-62. doi:10.15196/RS100209

Baranovskiy, V. Y., Zaychenko, I. M., Dubolazov, V. A., & Ilin, I. V. (2020, Apr 01-02). *"Personal" Business Model of Human Resource Management in The Formation of An Enterprise Development Strategy in The Context of Digital Business Transformation.* Paper presented at the 35th International-Business-Information-Management-Association Conference (IBIMA), Seville, Spain.

Basol, O., & Yalcin, E. C. (2021). How does the digital economy and society index (DESI) affect labor market indicators in EU countries? *Human Systems Management, 40*(4), 503-512. doi:10.3233/hsm-200904

Bejinaru, R. (2017). Knowledge strategies aiming to improve the intellectual capital of universities. *Management & Marketing-Challenges for the Knowledge Society, 12*(3), 500-523. doi:10.1515/mmcks-2017-0030

Bikse, V., Lusena-Ezera, I., Rivza, P., & Rivza, B. (2021). The Development of Digital Transformation and Relevant Competencies for Employees in the Context of the Impact of the COVID-19 Pandemic in Latvia. *13*(16), 9233.

Borowiecki, R., Siuta-Tokarska, B., Maron, J., Suder, M., Thier, A., & Zmija, K. (2021). Developing Digital Economy and Society in the Light of the Issue of Digital Convergence of the Markets in the European Union Countries. *Energies, 14*(9). doi:10.3390/en14092717

Chulanova, Z. K., Satybaldin, A. A., & Koshanov, A. K. (2019). Methodology for Assessing the State of Human Capital in the Context of Innovative Development of the Economy: A Three-Level Approach. *Journal of Asian Finance Economics and Business, 6*(1), 321-328. doi:10.13106/jafeb.2019.vol6.no1.321

Condruz-Bacescu, M. (2019, 2019 April 11-12). *E-learning Market in Romania.* Paper presented at the 15th International Scientific Conference on eLearning and Software for Education (eLSE) - New Technologies and Redesigning Learning Spaces, Bucharest, Romania.

Dvorak, M., Royny, P., Grebennikova, V., & Faminskaya, M. (2020). Economic impacts of Covid-19 on the labor market and human capital. *Terra Economicus, 18*(4), 78-96. doi:10.18522/2073-6606-2020-18-4-78-96

Esses, D., Csete, M. S., & Németh, B. (2021). Sustainability and Digital Transformation in the Visegrad Group of Central European Countries. *Sustainability, 13*(11), 5833.

European Commission. (2021a). *Digital Economy and Society Index*. Retrieved from: http://semantic.digital-agenda-data.eu/dataset/DESI

European Commission. (2021b). Digital Economy and Society Index 2021 Methodological Note. Retrieved from https://digital-agenda-data.eu/datasets/desi/indicators website: https://www.juntadeandalucia.es/institutodeestadisticaycartografia/digitalizacion-sociedad-digital/metodologia/Notas-Metodologicas-DESI.pdf

European Commission. (2021c). *Recovery and Resilience Facility*. Bruxelles: European Parliament and of the Council Retrieved from https://eur-lex.europa.eu/eli/reg/2021/241/oj

European Commission. (2021d). State of the Union: Commission proposes a Path to the Digital Decade to deliver the EU's digital transformation by 2030 [Press release]. Retrieved from https://ec.europa.eu/commission/presscorner/detail/en/ip_21_4630

Fleaca, E. (2017). Entrepreneurial Curriculum through Digital-Age Learning in Higher Education - A Process-based Model. *Tem Journal-Technology Education Management Informatics, 6*(3), 591-598. doi:10.18421/tem63-22

Folea, V. (2018, 2018). *European public policies in the area of the digital economy and society: country performance analysis.* Paper presented at the CBU International Conference Proceedings.

Gaftea, V. (2016, 21-22 Apr 2016). *Awarness in eEducation Given by Strategies and Indicators.* Paper presented at the 12th International Scientific Conference on eLearning and Software for Education (eLSE), Bucharest, Romania.

Herman, E. (2020, 03-04 October 2019). *The Influence of ICT Sector on the Romanian Labour Market in the European Context.* Paper presented at the 13TH International Conference Interdisciplinarity in Engineering (INTER-ENG 2019), Targu Mures, Romania.

Hofstede, G. (1984). Cultural dimensions in management and planning *Asia Pacific Journal of Management, 1*(2), 81-99. doi:10.1007/bf01733682

Iliescu, M. E. (2020, 15-16 Oct 2020). *Barriers to Digital Trannsformation in SMES: A Qualitative Exploration of Factors Affecing ERP Adoption in Romania.* Paper presented at the 8th International Academic Conference on Strategica - Preparing for Tomorrow, Today, Bucharest, Romania.

Ivanenko, L., Timoshchuk, N., & Zotova, A. (2020, Sep 09-10). *Innovation and education cluster in the region: staff potential development.* Paper presented at the 13th Annual Conference of the EuroMed-Academy-of-Business (EuroMed) - Business Theory and Practice Across Industries and Markets, Electr Network.

Jaculjakova, S., & Stofkova, K. R. (2020, 2020 March 02-04). *Analysis of Basic Digital Skills of Citizens in Selected Region.* Paper presented at the 14th International Technology, Education and Development Conference (INTED), Valencia, Spain.

Jovanović, M., Dlačić, J., & Okanović, M. (2018). Digitalization and society's sustainable development–Measures and implications. *Zbornik radova Ekonomskog fakulteta u Rijeci: časopis za ekonomsku teoriju i praksu, 36*(2), 905-928.

Kelchevskaya, N. R., & Shirinkina, E. V. (2020, Apr 16-17). *Institutional Model of Drivers of Digital Development of Human Capital in the Strategic Perspective.* Paper presented at the 2nd International Scientific and Practical Conference on Modern Management Trends and the Digital Economy - from Regional Development to Global Economic Growth (MTDE), Yekaterinburg, Indonesia.

Kholod, S., Pavlova, V., Spitsyna, A., Maistrenko, Y., Anufrieva, O., & Lukianykhin, V. (2021). Transformation of the Personnel Management System in the Conditions of Digitalization of HR Processes. *Estudios De Economia Aplicada, 39*(6). doi:10.25115/eea.v39i6.5015

Kichigin, O., Gonin, D., & Publishing, I. O. P. (2019, Nov 21-22). *Human capital as a catalyst for digitalization of regional economy.* Paper presented at the International Scientific Conference on Digital Transformation on Manufacturing, Infrastructure and Service (DTMIS), St. Petersburg, Russia.

Koopmans, T. C. (1963). *On the concept of optimal economic growth*. Retrieved from New Heaven, Connecticut:

Kovács, T. Z., & Bittner, B. (2022). Examination of the category of digitalization of public services in the Digital Economy and Society Index among the Eastern Enlargement of EU. *Industry 4.0, 7*(1).

Kovacs, T. Z., Bittner, B., Huzsvai, L., & Nabradi, A. (2022). Convergence and the Matthew Effect in the European Union Based on the DESI Index. *Mathematics, 10*(4), 23. doi:10.3390/math10040613

Kovacs, T. Z., Bittner, B., & Nabradi, A. (In Press). *The Integration of Digital Technologies in the European Union based on the DESI Index* Paper presented at the ENTRENOVA - ENTerprise REsearch InNOVAtion, Opatija. https://hrcak.srce.hr/ojs/index.php/entrenova

Kravchenko, S. A. (2021). New transmission mechanism for the sustainable and humanistic development of human capital: Demand for the 'rigidity turn'. *Rudn Journal of Sociology-Vestnik Rossiiskogo Universiteta Druzhby Narodov Seriya Sotsiologiya, 21*(3), 433-443. doi:10.22363/2313-2272-2021-21-3-433-443

Kuncová, M., & Doucek, P. (2018). *Comparison of ICT Development in V4 Countries*. Paper presented at the 16th International Scientific Conference on Hradec Economic Days, Hradec Kralove, Czech Republic.

Kwilinski, A., Vyshnevskyi, O., & Dzwigol, H. (2020). Digitalization of the EU Economies and People at Risk of Poverty or Social Exclusion. *Journal of Risk and Financial Management, 13*(7), 14. doi:10.3390/jrfm13070142

López Peláez, A., Erro-Garcés, A., & Gómez-Ciriano, E. J. (2020). Young people, social workers and social work education: the role of digital skills. *Social Work Education, 39*(6), 825-842. doi:10.1080/02615479.2020.1795110

Luchko, M. (2020). Positions of Nordic Countries through the Prism of International Ratings. *Contemporary Europe-Sovremennaya Evropa*(3), 83-95.

Malhotra, N. K., & Dash, S. J. M. R. (2010). An applied orientation. *2*.

Matkovic, P., Maric, M., Rakovic, L., & Sakal, M. (2019, 11-13 November 2019). *Enhancing Digital Competences in Higher Education.* Paper presented at the 12th Annual International Conference of Education, Research and Innovation (ICERI), Seville, Spain.

Merzlyakova, E., Obukhova, A., Kazarenkova, N., Aseev, O., & Zelenov, A. (2020, Apr 01-02). *Transformation of Human Capital in The Digital Economy.* Paper presented at the 35th International-Business-Information-Management-Association Conference (IBIMA), Seville, Spain.

Ministry of Education and Research. (2020). *Estonian Lifelong Strategy*. Republic of Estonia, Retrieved from https://www.hm.ee/et/elukestva-oppe-strateegia-2020

Moldabekova, A., Philipp, R., Reimers, H. E., & Alikozhayev, B. (2021). Digital technologies for improving logistics performance of countries. *Transport and Telecommunication Journal, 22*(2), 207-216. doi:10.2478/ttj-2021-0016

Murariu, M., & Bedrule-Grigoruta, M. V. (2020, 2020 May 15). *Digitalization- A Sine-qua-non Condition for the Romanian Public Managament.* Paper presented at the European Finance, Business and Regulation International Conference (EUFIRE), Alexandru Ioan Cuza Univ Iasi, Fac Econ & Business Adm, Iasi, Romania.

Nadezhina, O., & Avduevskaia, E. (2021, Sep 02-03). *Genesis of Human Capital Theory in the Context of Digitalization.* Paper presented at the 22nd European Conference on Knowledge Management (ECKM), Coventry Univ, ELECTR NETWORK.

Neamtu, D. M., Hapenciuc, C. V., & Bejinaru, R. (2019, 2019 Mar 21-22). *The Impact of Digitalization on Business Sector Development in the Knowledge Economy.* Paper presented at the 13th International Conference on Business Excellence (ICBE) - Sustainable Business Models and Innovation in the Knowledge Economy, Bucharest, Romania.

Pouliakas, K. J. A. a. S. (2018). Determinants of automation risk in the EU labour market: A skills-needs approach.

Quah, D. T. (1996). Empirics for economic growth and convergence. *European Economic Review, 40*(6), 1353-1375. doi:10.1016/0014-2921(95)00051-8

Ramsey, F. P. (1928). A mathematical theory of saving. *The economic journal, 38*(152), 543-559.

Rezer, T. (2019, Nov 11-13). *State control of the education digitalization in russia and abroad.* Paper presented at the 12th Annual International Conference of Education, Research and Innovation (ICERI), Seville, Spain.

Rodchenko, V., Rekun, G., Fedoryshyna, L., Roshchin, I., & Gazarian, S. (2021). The effectiveness of human capital in the context of the digital transformation of the economy: The case of Ukraine. *Journal of Eastern European and Central Asian Research, 8*(2), 202-213. doi:10.15549/jeecar.v8i2.686

Rodrigues, A. L., Cerdeira, L., Machado-Taylor, M. D., & Alves, H. (2021). Technological Skills in Higher Education-Different Needs and Different Uses. *Education Sciences, 11*(7). doi:10.3390/educsci11070326

Sahlin, J., & Angelis, J. (2019). Performance management systems: reviewing the rise of dynamics and digitalization. *Cogent Business & Management, 6*(1), 21. doi:10.1080/23311975.2019.1642293

Sevgi, H. (2021). Analysis of the digital economy and society index (DESI) through a cluster analysis. *Trakya Üniversitesi Sosyal Bilimler Dergisi, 23*, 37-51.

Solow, R. M. (1956). A contribution to the theory of economic growth. *The quarterly journal of economics, 70*(1), 65-94.

Stankovic, J. J., Marjanovic, I., Drezgic, S., & Popovic, Z. (2021). The Digital Competitiveness of European Countries: A Multiple-Criteria Approach. *Journal of Competitiveness, 13*(2), 117-134. doi:10.7441/joc.2021.02.07

Stavytskyy, A., Kharlamova, G., & Stoica, E. A. (2019). The Analysis of the Digital Economy and Society Index in the EU. *Baltic Journal of European Studies, 9*(3), 245-261. doi:10.1515/bjes-2019-0032

Štofková, Z., Soltes, V., & Stofkova, J. (2019, 11-13 Nov 2019). *Survey of the Citizens Digital Skills in the Region.* Paper presented at the 12th annual International Conference of Education, Research and Innovation, Seville, Spain.

Stryabkova, E. A., Lyshchikova, J. V., Gerasimova, N. A., Kulik, A. M., & Weis, E. V. (2021). Transformation of the reproduction of human capital in the context of the digital economy. *Nexo Revista Cientifica, 34*(1), 477-488. doi:10.5377/nexo.v34i01.11325

Todorut, A. V., & Tselentis, V. (2018). Digital Technologies and the Modernization of Public Administration. *Quality-Access to Success, 19*(165), 73-78.

Tumbas, P., Sakai, M., Pavlicevic, V., & Rakovic, L. (2019, 11-13 Mar 2019). *Digital Competencies in Business Informatics Curriculum Innovation.* Paper presented at the 13th International Technology, Education and Development Conference (INTED), Valencia, Spain.

Van Eck, N. J., & Waltman, L. (2013). VOSviewer manual. *1*(1), 1-53.

Vidruska, R., & Univ, L. (2016, 12-14 May 2016). *The Digital Economy & Society Index and Network Readiness Index: Performance of Latvia on European Union Arena.* Paper presented at the International Conference on New Challenges of Economic and Business Development - Society, Innovations and Collaborative Economy, Univ Latvia, Riga, Latvia.