The Impact of Digital Transformation and Innovation on Economic Performance in the European Union

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Abstract

In the current context of the European Union, the global economy is undergoing a profound transformation, marked by rapid advances in technology, digitalization and innovation. In the face of these changes, EU Member States need to adapt to the new economic realities to remain competitive in the global market. The European Union's strategy for digital transformation and innovation aims not only to create a more competitive economy, but also to promote sustainable and equitable development, reduce disparities between Member States and improve the lives of European citizens. This study examines the impact of digital transformation and innovation on economic performance across EU Member States, using an econometric approach to assess the relationships between key variables such as technological innovation, digitization, human capital and digital infrastructure. The results of the study suggest that technological innovation and human capital dedicated to R&D have a significant positive impact on economic performance, while digitization and internet use contribute to GDP growth, but this impact is conditional on equitable access to technology and digital skills training. These results help shape public policy at the European level on the impact of digitalization and innovation on economic performance. Translated with DeepL.com (free version)

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1. Introduction

In the new context in which technology and innovation have become important elements of modern economies, digital transformation is a central element of economic development strategies, with a direct impact on the

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competitiveness and sustainability of countries. The European Union, in the context of globalization and the knowledge-based economy, is confronted with the need to adopt advanced technological solutions and stimulate innovation in order to maintain its position in the global economy. Rapid technological transformations, including digitization and increased investment in research and development (R&D), have the potential to profoundly restructure European economies, generating new sources of economic growth and productivity growth. In this context, studying the impact of digital transformation and innovation on economic performance becomes important for understanding how EU Member States can capitalize on these trends to boost economic prosperity. Patent applications, investment in R&D personnel, the extensive use of the internet and the integration of ICT specialists in the economy play a crucial role in shaping modern economic dynamics. This paper aims to analyze how these factors - innovation and digitalization - influence GDP per capita, a key indicator of economic performance, using econometric data and statistical analysis methods to assess the impact of technological transformations on European economies.

The study answers the following questions:

Q1: How do innovation and the use of digital technologies influence the economic performance of EU Member States?

Q2: What are the effects of the digital transformation on human capital and technological infrastructure?

The answers to these questions are important for the understanding of modern economic dynamics and for the development of effective public policies for economic development based on knowledge and innovation. This research makes a significant and original contribution to the economics literature by comprehensively examining the impact of digital transformation and innovation on economic performance within the European Union, using an econometric model with variables relevant to digitization, innovation and human capital. The main aim is to analyze and assess the impact of digital transformation and innovation on the economic performance of EU Member States, using an econometric approach to identify significant relationships between indicators such as technological innovation, digitization, human capital and digital infrastructure.

The main objectives of the research are:

O1: Literature review on digital transformation and innovation on economic performance;

O2:Assess the effects of digitization and innovation on economic performance using an econometric model

O3: Formulation of public policy recommendations.

The paper continues with the literature review on digital transformation and innovation on economic performance, description of the methodology, presentation of the results and discussions and finally public policies will be formulated.

2. Literature review

Digitization is one of the most transformative factors in modern organizations, fundamentally redefining their structure, processes and the way they

operate. In an ever-changing economic and technological landscape, organizations need to embrace digital technologies to remain competitive and relevant in the marketplace. Rapid advances in technologies such as artificial intelligence, automation, big data and the internet of things (IoT) are not only changing the way day-to-day activities are carried out, but are also influencing the way organizations are structured (Chander et al., 2022; Kliestik et al., 2023). Traditional organizational structures, characterized by strict hierarchies and rigid workflows, are gradually being replaced by more agile, flexible and decentralized models, fostered by increased access to technology and the need to react quickly to market challenges (Pacheco-Cubillos et al., 2024; Rožman et al., 2023). These changes impact not only operational efficiency, but also organizational culture and team dynamics. Organizations are no longer operating in isolation, but are integrating into digital business ecosystems, collaborating in complex networks to innovate and deliver products and services (Aksoy, 2023; Wirtz & Müller, 2023). In this framework, education (Bran et al., 2022), remote working and flexible structures are becoming organizational standards and IT and digital departments play a key role in managing change and optimizing internal processes. The European Union is going through a period of profound economic and technological change, driven in large part by rapid technological advances and the need to remain competitive on the global stage. In recent years, the European Union has recognized the paramount role of digitization in economic growth, innovation and productivity and has integrated these objectives into its economic strategies. Digitization is seen not only as an opportunity for the modernization of Member States' economies, but also as a means of reducing economic and social disparities within the European Union (Burinskienė & Seržantė, 2022; Teixeira & Tavares-Lehmann, 2022; Tiganasu & Lupu, 2023). Digital technologies are transforming traditional economic sectors and creating new economic opportunities. Digital Economy and Society Index (DESI) report (European Commission, 2024b) show progress in the take-up of digital technologies, but differences remain between Western and Eastern European countries. Many studies (Jia et al., 2023; Kılıç & Atilla, 2024; Moschko et al., 2023; Veile et al., 2022) highlights that digitization boosts global competitiveness and facilitates the development of innovative business models, while promoting the flexibility and innovation generated by new digital technologies. The COVID-19 crisis has spurred a significant increase in digitization efforts by EU firms. According to the report Digitalisation in Europe 2022-2023: Evidence from the EIB Investment Survey (European Investment Bank, 2023), More than half (53%) of EU firms took steps in 2022 to improve their digital presence, such as offering online services. The EU has also closed the gap with the United States in adopting advanced digital technologies. By 2022, 69% of EU firms will have deployed advanced digital technologies such as advanced robotics, big data analytics and artificial intelligence, compared to 71% of US firms.

EU digital strategy reflected in the European Digital Agenda (European Union, 2024) and Digital Compass 2030 (European Commission, 2021a), aims to create a digital single market and transform digital infrastructure. Through the Horizon Europe programs (European Commission, 2024a) and Digital Europe

Programme (European Commission, 2021b), EU invests in technological research and development, supporting innovation and digitization of European companies. The literature highlights the competitive advantages for EU economies that invest in technology (Khurshid et al., 2024; Knudsen et al., 2021; Krakowski et al., 2023; Mewes & Broekel, 2022; Tu & Wu, 2021). Digitization brings major benefits to the public sector and the European economy, increasing administrative efficiency and reducing red tape (e-government). Studies by Barbieri et al. (Barbieri et al., 2023), Etemad (Etemad, 2023), Šilenskytė et al. (Šilenskytė et al., 2024) highlights the role of interconnected digital ecosystems in increasing international collaboration. In addition, digitization helps bridge economic and social divides, fostering digital inclusion, especially in rural areas, according to the authors' studies Feurich et al. (Feurich et al., 2024), Lindberg et al. (Lindberg et al., 2024), Gómez-Carmona et al. (Gómez-Carmona et al., 2023). The literature highlights the central role of digitization in boosting economic performance and adapting European companies to a global economy (Brodny & Tutak, 2022; Chenic et al., 2023; Ha et al., 2022; Hung et al., 2023; Skare et al., 2023), countries that invest in digital infrastructure and human capital have better economic performance (Grigorescu et al., 2021; Magoutas et al., 2024; Rehman & Nunziante, 2023), and research by the authors Škare et al. (Škare et al., 2024) și Kádárová et al. (Kádárová et al., 2023) confirms the correlation between digitization and sustainable economic growth.

The relationships between technological innovation, digitization, human capital and digital infrastructure are key to understanding economic transformation and economic performance in the European Union (EU). These issues are frequently analysed to highlight the role they play in increasing European competitiveness and productivity. Research by Ha et al. (Ha et al., 2022), Brodny & Tutak (Brodny & Tutak, 2022), (Marti & Puertas, 2023), stresses that technological innovation is one of the main drivers of digitalization and economic growth. In a digital economy, emerging technologies such as artificial intelligence, big data and the internet of things are contributing to fundamental changes in all economic sectors. Studies by Javaid et al. (Javaid et al., 2024), Wang et al. (Wang et al., 2023) și Gupta & Jauhar (Gupta & Jauhar, 2023) shows that digital technologies offer companies the ability to automate their processes and become more efficient, allowing them to improve both productivity and innovation (Pricopoaia, O., et al., 2024). This correlation is supported by studies by Hojnik et al. (Hojnik et al., 2023), Kallmuenzer et al. (Kallmuenzer et al., 2024), Suciu et al. (Suciu et al., 2023) which have shown that digitization boosts innovation and competitiveness, enabling companies to adapt quickly to global market demands.

Human capital, in particular the digital and technical skills of the workforce, is a critical factor in supporting innovation and digital transformation. According to current studies (Ben Khalifa, 2023; García-Romanos & Martínez-Ros, 2024; Greenan & Napolitano, 2024), Countries that invest in training employees in digital skills and in research and development (R&D) have a greater capacity to innovate and use new technologies. Studies show that human capital plays a key role in creating an environment conducive to innovation, and EU

Member States that have allocated significant resources to digital education and training have outperformed economically. Authors Molla et al. (Molla et al., 2024), Zervas & Stiakakis (Zervas & Stiakakis, 2024), Venkatachalam & Kannusamy (Venkatachalam & Kannusamy, 2023) also emphasizes the importance of human capital in creating a competitive digital economy, arguing that digitally skilled people are a key factor in the adoption and deployment of new technologies. Digital infrastructure, defined as access to high-speed internet networks and other communication technologies, plays a decisive role in the adoption of digital technologies and in supporting innovation. Studies by Cirillo et al. (Cirillo et al., 2023), Capello & Lenzi (Capello & Lenzi, 2024) shows that European economies that have invested heavily in digital infrastructure have had a higher adoption rate of advanced technologies such as big data and robotics. Research by Priyono & Hidaya (Priyono & Hidayat, 2024), Ochinanwata et al. (Ochinanwata et al., 2024) have highlighted that digital infrastructure is essential for supporting digital business ecosystems and facilitating collaboration between companies, universities and other organizations. Multiple recent studies (Consoli et al., 2023; Ionescu-Feleagă et al., 2023; Li et al., 2023; Ran et al., 2023; Tang & Zhao, 2023) highlighted the interdependence between technological innovation, human capital and digital infrastructure. The authors Liang et al. (Liang et al., 2023), Hetmańczyk (Hetmańczyk, 2024), have shown that the success of digitalization in an economy depends not only on technological innovation and infrastructure, but also on available human capital. Countries with greater access to digital literacy and modern infrastructure were more able to benefit from technological innovations, thereby creating sustainable economic growth. This interdependence is key to reducing disparities between EU Member States, contributing to a more integrated digital single market (Haleem et al., 2022; Javaid et al., 2024; Sanders & Scanlon, 2021). The relationships between technological innovation, digitization, human capital and digital infrastructure are deeply intertwined, so investment in education, research and development, and high quality digital infrastructure are essential for European growth and competitiveness (Petrariu, R. I. et al., 2023). They also underpin the development of a digital ecosystem that facilitates innovation and creates economic opportunities for all EU Member States.

The transition to a digital economy in the European Union is essential for maintaining economic competitiveness and adapting to new global realities. EU policies play a central role in facilitating this transition, and the literature highlights the importance of digitization in stimulating innovation and economic growth. With the implementation of digitization strategies and continued investment in emerging technologies, the EU aims to become a global leader in digital transformation.

3. Methodology

This study aims to investigate the complex relationships between digital transformation, technological innovation and economic performance at the European level, using a quantitative approach based on an econometric multiple linear regression model. The analysis focuses on a series of indicators reflecting

different dimensions of the economy, such as patent applications, research and development (R&D) personnel, research investment, internet usage and information and communication technology (ICT) specialists presented in Table 1. The study is based on data collected from sources such as Eurostat for the period 2010-2022. The dependent variable chosen is Gross Domestic Product (GDP) per capita, an indicator of economic performance at the national level, while the independent variables include factors related to innovation and digitalization.

Overview of indicators

Table 1

Indicator definition	Symbol	Unit of measure	Source
Patent applications to the European Patent Office by applicants' / inventors' country of residence	PAE	Number	Eurostat(Eurostat, 2024g)
R&D personnel	PRD	Percentage	Eurostat (Eurostat, 2024h)
Gross domestic expenditure on R&D	RD	Percentage of GDP	Eurostat (Eurostat, 2024c)
Real GDP per capita	GDP	Euro per capita	Eurostat (Eurostat, 2024i)
Employment rate	EMPL	Percentage	Eurostat (Eurostat, 2024b)
Level of internet access – households	LEVINT	Percentage of households	Eurostat (Eurostat, 2024f)
Internet use by individuals	INTUIN	Percentage of individuals	Eurostat (Eurostat, 2024e)
Employed ICT specialists	SPITC	Total	Eurostat (Eurostat, 2024a)
High-speed internet coverage	HINT	Percentage of households	Eurostat (Eurostat, 2024d)

Source: elaborated by the authors

We used multiple linear regression to estimate the relationships between variables and to assess the impact of each factor on economic performance. This method allows us to identify both the direction and intensity of the relationships between variables in order to obtain robust results. We also applied statistical tests, such as t-test and F-test, to validate the statistical significance of the obtained coefficients and of the whole model. Through this econometric approach, we aim to provide an in-depth understanding of how digitization and innovation contribute to economic growth and provide an empirical basis for the development of economic strategies in the current context of the digital revolution in the European Union.

We formulate the following working hypotheses:

H1: Patent applications have a significant positive effect on economic performance.

H2: R&D personnel have a significant positive effect on economic performance.

H3: Internet use has a significant positive effect on economic performance.

H4: The number of ICT specialists has a significant positive effect on economic performance.

The equation of the multiple linear regression model is presented below:

$$GDP = \beta 0 + \beta 1 \cdot PAT + \beta 2 \cdot PRD + \beta 3 \cdot RD + \beta 4 \cdot EMP + \beta 5 \cdot INTU + \beta 6 \cdot SITC + \beta 7 \cdot HIGIN + \varepsilon$$

Where:

- GDP is gross domestic product per capita (dependent variable).
- PAT stands for patent applications
- R&D personnel represents R&D personnel
- RD is gross expenditure on R&D
- EMP is the employment rate
- INTU is internet usage by individuals
- SITC is the number of information and communication technology specialists
- HIGIN is high speed internet coverage
- β0 is the constant (model intercept).
- β1, β2, β3, β4, β5, β6, β7 are the regression coefficients reflecting the impact of each independent variable on GDP.
- **ε** is the error term that captures variations not explained by the model.

This equation reflects the influence of each variable on GDP per capita, based on the coefficients estimated in the multiple linear regression.

4. Results and discussions

Descriptive statistics show significant differences between European economies in terms of GDP, innovation, R&D investment and level of digitization. The high variability of some of the indicators, such as patent applications, internet usage and high-speed internet coverage, reflects the different challenges and opportunities that European countries face in the process of digitization and innovation.

Descriptive statistics

Table 2

Indicators	count	mean	sd	min	max
GDP	351	25891.46	17002.94	5080	85850
PAT	351	2357.78	5213.98	8	27328
PRD	351	1.19	0.52	0	2.42
RD	351	1.62	0.89	0.38	3.705
EMP	351	70.94	6.55	52.5	82.9
INTU	350	79.93	12.62	35.46	98.93
SITC	351	3.88	1.35	1.1	8.6
HIGIN	351	41.72	28.97	0	100

Source: elaborated by the authors

The statistical analysis presented in Table 2 for the relevant indicators of the European Union countries in the period 2010-2022 reveals a diversified economic landscape, marked by significant discrepancies in the level of economic development, the degree of innovation and the integration of digital technologies. The average GDP per capita stands at €25,891.46, with a high standard deviation of 17,002.94. This highlights considerable economic inequalities between Member States, with values ranging from a low of €5,080 to a high of €85,850. These disparities reflect a significant differentiation in the level of prosperity and economic capacity of EU countries, with highly industrialized economies such as Germany and the Netherlands registering higher values, while Central and Eastern European economies such as Romania or Bulgaria are at the lower end of the spectrum. For patent applications for patents (PAT), the average recorded is 2,357.78, but the extremely high standard deviation of 5,213.98 suggests an uneven distribution of innovative capacity across countries. Countries with an advanced technological infrastructure and a well-developed research ecosystem, such as Germany, France and Sweden, had a significantly higher number of patent applications (maximum 27,328), while other countries, particularly in Eastern Europe, had limited contributions in this area (minimum 8). In terms of personnel involved in research and development (R&D personnel), the European average was 1.19% of the active workforce, with a standard deviation of 0.52. While this reflects the commitment of EU countries to invest in innovation and research, the minimum value of 0% indicates that some economies have failed to allocate significant resources to this area. In contrast, more developed economies with a strong science infrastructure, such as Denmark and Finland, recorded maximum values of 2.42%, demonstrating a strong correlation between investment in human capital and innovation capacity. Similarly, gross expenditure on research and development (R&D), which averaged 1.62% of GDP, with a range between 0.38% and 3.705%, shows a considerable gap between Member States. Countries with advanced economies, such as Sweden and Austria, stand out for their sustained investment in R&D, demonstrating a long-term strategy to boost innovation and economic competitiveness. On the other hand, countries with low R&D investment face difficulties in adapting to the demands of the knowledge economy. The employment rate (EMP) averages 70.94%, with a moderate variation between 52.5% and 82.9%. These data suggest that most Member States have relatively high employment rates, but there are differences between the Nordic countries, which have employment rates around the peak, and the Southern or Eastern countries, where unemployment has remained a persistent problem, especially in the context of the financial and economic crisis of the previous decade. Another significant indicator is internet usage by individuals (INTU), which averages 79.93%, with a range between 35.46% and 98.93%. This indicator reflects the degree of digitization of EU societies and people's access to technology. While Nordic countries, such as Sweden and the Netherlands, have almost universal coverage, other countries, particularly in Eastern and South-Eastern Europe, have

significantly lower percentages, which may be a barrier to economic development and innovation.

In terms of information and communication technology (ICT) specialists, the European average is 3.88% of the total workforce, with a range from 1.1% to 8.6%. This statistic highlights the importance of human capital in technology for the digital advancement of European economies. Countries with a well-trained IT&C workforce, such as Ireland or Estonia, are at the forefront of the digital transformation, while others have had difficulties in attracting and training IT&C specialists. High-speed internet coverage (HIGIN) varies significantly between member countries, with an average of 41.72% and a large standard deviation of 28.97%, showing a significant gap between countries with advanced digital infrastructure and those with limited high-speed internet access. While some countries, such as Luxembourg and the Netherlands, have almost complete coverage (100%), others, particularly in South-Eastern Europe, still have major gaps in the development of digital infrastructure.

Table 3 of paired correlations reveals a number of significant relationships between variables describing innovation, R&D investment, use of digital technologies and economic performance across EU countries.

Pairwise correlations

Table 3

Variables	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
(1) PAT	1.000							
(2) PRD	0.338***	1.000						
(3) RD	0.475***	0.850***	1.000					
(4) GDP	0.238***	0.732***	0.452***	1.000				
(5) EMP	0.254***	0.484***	0.488***	0.334***	1.000			
(6) INTU	0.255***	0.700***	0.577***	0.611***	0.750***	1.000		
(7) SITC	0.135**	0.731***	0.623***	0.651***	0.640***	0.775***	1.000	
(8) HIGIN	-0.131**	0.162***	0.012	0.083	0.426***	0.403***	0.337***	1.000

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: elaborated by the authors

Paired correlation analysis presents a detailed picture of how innovation, R&D investment, internet use and digitization influence economic growth and labor market dynamics in the EU Member States. The positive relationships between research personnel, R&D expenditure and GDP per capita suggest a strong interdependence between innovation and economic prosperity. At the same time, digital transformation, as measured by internet usage and high-speed internet coverage, correlates positively with employment, demonstrating the importance of digitization in boosting the labor market and increasing economic competitiveness.

Table 4 presents the variance inflation factor values.

Variance inflation factor

Table 4

	VIF	1/VIF
PRD	5.605	0.178
RD	4.775	0.209
INTU	4.178	0.239
SITC	3.41	0.293
EMP	2.776	0.36
HIGIN	1.47	0.68
PAT	1.457	0.686
Mean VIF	3.381	0

Source: elaborated by the authors

Variance Inflation Factor values provide an important measure of the degree of collinearity between the independent variables included in the regression model. Colinearity, or linear correlation between independent variables, can affect the stability and reliability of regression coefficients, and the correct interpretation of VIF values is important to assess its impact on the econometric model. According to the results obtained in Table 4 it is revealed that there is no collinearity of data.

The linear regression results are presented in Table 5.

Linear regression

Table 5

GDP	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
PAT	0.539	0.11	4.90	0	0.323	0.756	***
PRD	33657.836	2131.134	15.79	0	29466.055	37849.616	***
RD	-14862.00	1163.422	-12.77	0	-17150.36	-12573.64	***
EMP	-264.309	120.368	-2.20	0.029	-501.064	-27.554	**
INTU	236.209	76.804	3.08	0.002	85.142	387.277	***
SITC	4371.614	645.578	6.77	0	3101.811	5641.417	***
HIGIN	-116.793	19.827	-5.89	0	-155.792	-77.794	***
Constant	-3542.438	6288.269	-0.56	0.574	-15910.98	8826.114	

Mean dependent var	25877.924	SD dependent var	17025.383
R-squared	0.734	Number of obs	350
F-test	135.082	Prob > F	0.000
Akaike crit. (AIC)	7363.982	Bayesian crit. (BIC)	7394.846

*** *p<.01, ** p<.05, * p<.1*

Source: elaborated by the authors

The results of the econometric model confirm that the included variables significantly explain the variation in GDP per capita across EU Member States. With an R-squared of 0.734, the model provides high explanatory power, and the F-test value and extremely low p-value suggest that the included variables are

relevant to explain economic performance. The AIC and BIC criteria indicate that the model is efficient and well fitted to the data.

The coefficient associated with the PAT variable (patent applications) is 0.539, with a p-value of 0.000, which indicates a very high level of statistical significance ($p < 0.01$). This positive coefficient indicates that an increase in the number of patent applications is associated with a significant increase in GDP per capita, thus proving hypothesis H1. This implies that technological innovations, as measured by the number of patents filed, contribute directly and positively to economic growth. In the context of the European Union, countries with a high number of patent applications tend to enjoy a significant economic competitive advantage. They invest in patentable innovations that not only improve production and industrial efficiency but also stimulate the creation of new technologies and products. The positive effect of patents on GDP underlines the central role of innovation in global competitiveness, demonstrating that European countries with a strong research and development (R&D) infrastructure are able to convert inventions and technological research into tangible economic growth. The coefficient for the PRD indicator (R&D personnel) of 33,657,836 with a p-value of 0.000 indicates that an increase in the proportion of personnel involved in R&D activities has a positive and significant impact on GDP per capita, contributing directly to economic growth, proving hypothesis H2. This result underlines the importance of R&D skilled human capital for the economic performance of European countries. In countries that invest significantly in training and employing R&D personnel, an increase in innovation capacity and an acceleration of economic development are observed. This is explained by the fact that R&D personnel are able to generate new knowledge and technologies which, once deployed, improve the productivity and competitiveness of the national economy. In particular, European countries with a strong tradition in technology education and research funding, such as Germany, Sweden and Finland, are at the forefront of innovation-led economic growth. The INTU indicator (internet use by individuals) has a coefficient of 236.209, with a p-value of 0.002, indicating a significant impact of internet use on GDP per capita ($p < 0.01$). The positive coefficient suggests that an increase in internet usage is associated with a considerable improvement in economic performance, thus proving hypothesis H3. At EU level, Internet access and use are key factors for integrating economies into the digital age and facilitating a knowledge-based economy. Increased internet use boosts operational efficiency, promotes innovation in business models and facilitates access to international markets. Countries with high internet penetration, such as Denmark, the Netherlands and Sweden, have benefited from faster economic growth thanks to widespread digitization, which has enabled companies and individuals to access information quickly, collaborate more efficiently and innovate in real time. The results show a coefficient of 4,371.614 for the SITC variable (ICT specialists), with a p-value of 0.000, indicating a positive and significant impact on GDP per capita ($p < 0.01$). This high coefficient suggests that an increase in the percentage of ICT specialists in the labor force contributes directly to the economic

growth of European countries, demonstrating hypothesis H4. The number of ICT specialists is a key indicator of an economy's ability to integrate digital technologies in its key sectors. Countries that invest in the education and training of ICT specialists benefit from a skilled workforce capable of developing innovative digital solutions, optimizing industrial processes and supporting the transition to a digital economy. In the European Union, countries such as Estonia and Ireland, which have invested heavily in the training of ICT specialists, have succeeded in accelerating the digital transformation and achieving significant economic growth by integrating ICT into various economic sectors. In the European Union, innovation as measured by patent applications, the presence of well-qualified R&D staff, the widespread use of the internet and the number of ICT specialists play a central role in stimulating economic growth. Countries that excel in these areas manage to improve economic competitiveness, generate new development opportunities and boost long-term prosperity. These results underline the importance of public policies that support investment in innovation, technological education and digital infrastructure to ensure sustainable economic growth across the European Union.

Figure 1 is a matrix of scatter plots illustrating the relationships between economic variables and indicators of innovation and digitization at the level of EU Member States.

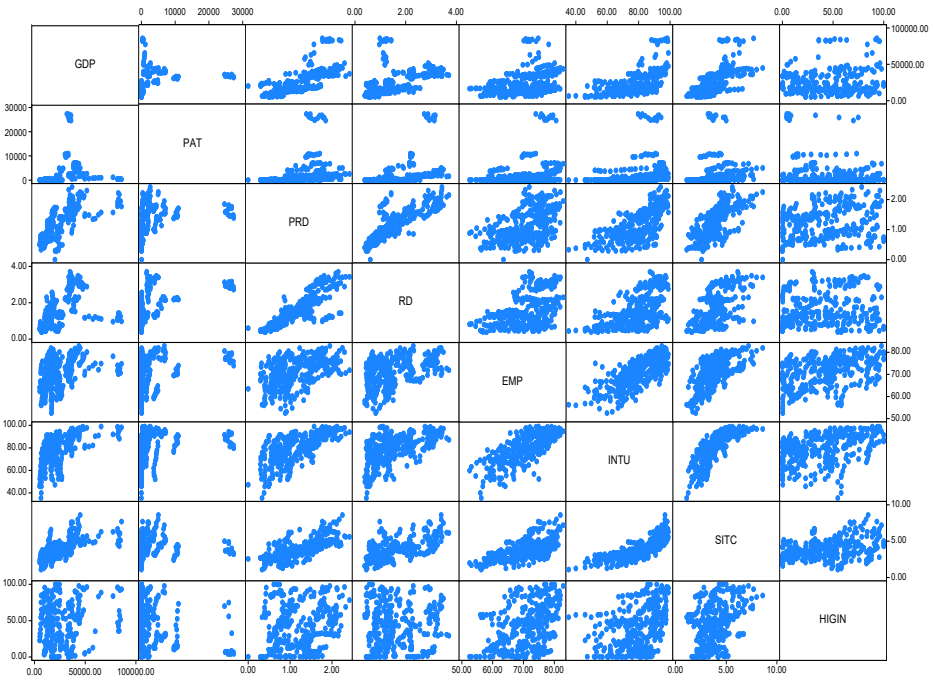

Figure 1. Matrix of scatterplots between economic variables and indicators of innovation and digitization in the European Union

Source: elaborated by the authors

Figure 1 highlights the importance of innovation and digitization factors for the economic performance of European Union Member States. Investments in research and development, the formation of skilled human capital and the expansion of internet access are essential to stimulate economic growth in a globalized and digitized economy. However, variations in the impact of these factors reflect the fact that the effects of these investments are conditioned by a number of other contextual factors, including existing infrastructure, the skills of the population and the ability to turn innovations into tangible economic results. In order to maximize the benefits of innovation and digitization, EU Member States need to implement coherent policies that support not only investment in research and technology, but also human capital development and the integration of digital technologies across all sectors of the economy. Also essential is a holistic approach that recognizes that technological infrastructure, without a framework conducive to innovation and its effective use, will not be sufficient to stimulate long-term economic growth. In order to maximize the impact of innovation, digitization and human capital development on economic growth, EU Member States need to implement a set of coherent, interconnected and long-term oriented public policies that support both the technological infrastructure and the skills training needed to harness their potential.

1. Policies to support R&D and strengthen the innovation ecosystem. Member States should increase the level of public and private investment in R&D by creating a favorable tax environment for R&D performing companies and academic institutions. Fiscal incentive policies, such as tax deductions for R&D expenses or direct grants for research projects, can encourage increased investment in R&D. To mitigate the short-term negative effects of R&D spending on GDP, governments need to implement strategies to assess the impact of innovations and create programs that facilitate access to finance for innovative start-ups, thus helping the transition from innovation to practical application and growth.

2. Policies for human capital development and technological skills training. In the context of globalization and digitization, Member States need to implement education and training policies adapted to labour market requirements, with a focus on digital and technological skills. Lifelong learning and retraining programs must be prioritized to ensure that the workforce is prepared to seize the opportunities offered by new technologies and the digital transition. These programs should be financially supported by both governments and companies through upskilling and reskilling initiatives to enable employees to adapt to new economic realities. It is also crucial to create STEM (science, technology, engineering and mathematics) education programs starting at school level in order to train generations of specialists who are able to actively contribute to innovation and technological development processes. In addition, integrating entrepreneurship and innovation courses in universities and technical colleges can foster a culture of innovation and prepare young people to become leaders in the technology sector.

3. Policies to develop digital infrastructure and promote equitable access to technology. To reap the full benefits of digitization, Member States must

continue to invest in expanding digital infrastructure, including by ensuring widespread and equitable high-speed internet coverage in all regions, including in rural and remote areas. To this end, policies to bridge the digital divide need to be implemented to ensure that all citizens have equal access to digital resources, regardless of geographical region or socio-economic status. Governments should also promote public-private initiatives for the development of 5G networks to support the development of the digital economy by accelerating connectivity and improving access to technology. In addition, digital support programs for SMEs should be expanded so that small and medium-sized companies can rapidly adopt digital technologies that enable them to compete effectively in the global marketplace. Special focus should be given to digitizing administrative and government processes by adopting e-government solutions to streamline interactions between citizens and authorities and reduce red tape.

4. Policies to support innovation sustainability and the green transition. In the context of the European Green Pact and the decarbonization agenda, it is essential to implement public policies that support sustainability-oriented innovations. Governments should stimulate the development of green technologies by subsidizing research projects in areas such as renewable energy, energy efficiency and the circular economy. These policies can include tax incentives for companies that invest in sustainable technology solutions, as well as support for start-ups developing innovative climate technologies. In addition, there is a need to promote sustainable public procurement policies whereby governments prioritize innovative and environmentally friendly products and services in public procurement processes. This would help to stimulate demand for green technology solutions and create an ecosystem conducive to the transition to a low-carbon economy.

The implementation of these public policies provides EU Member States with a strategic framework to support innovation, digitalization and sustainable economic development.

5. Conclusions

This study has highlighted the link between digital transformation, innovation and the economic performance of European Union Member States. Using an econometric model, we have demonstrated that factors related to digitization, innovation and human capital have a significant impact on GDP per capita, thus contributing to competitiveness and sustainable economic growth. Widespread use of the internet and the integration of digital technologies have a significant positive impact on GDP per capita. Countries with a well-developed digital infrastructure and high internet penetration experience faster economic growth due to increased access to resources, operational efficiency and the development of new business models. This result underlines the importance of continuing to invest in digital infrastructure and expanding access to high-speed internet in order to fully exploit the potential of digitization. Patent applications, as

a measure of innovation capacity, have a significant positive impact on economic performance. Countries that invest in research and technological development and support the protection of intellectual property enjoy a substantial competitive advantage. Innovation is a key driver of economic growth, offering new solutions to increase productivity, create new industries and increase efficiency in traditional economic sectors. Research and development (R&D) personnel have a very strong impact on GDP per capita, underlining that investing in training and attracting skilled human resources in innovation is important for long-term economic performance. Countries that devote significant resources to the training and development of specialized research personnel tend to have more dynamic and innovative economies. This research confirms that digital transformation and innovation are key determinants of the economic performance of EU countries. States that invest significantly in digital infrastructure, human capital formation and innovation are better positioned to benefit from sustainable economic growth and global competitiveness. As European economies continue the transition towards a knowledge-based and digitized economy, it is essential that public policies support these efforts through coherent investment, technological education and innovation. In this way, the European Union can ensure sustainable economic growth and respond effectively to the challenges of the global economy.

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References

1. Aksoy, C. (2023). Digital Business Ecosystems: An Environment of Collaboration, Innovation, And Value Creation in The Digital Age. *Journal of Business and Trade*, *4*(2), 156-180. https://doi.org/10.58767/joinbat.1358560
2. Barbieri, N., Consoli, D., Napolitano, L., Perruchas, F., Pugliese, E., & Sbardella, A. (2023). Regional technological capabilities and green opportunities in Europe. *The Journal of Technology Transfer*, *48*(2), 749-778. https://doi.org/10.1007/s10961-022-09952-y
3. Bran, F., Angheluţă, P. S., Pargaru, O. C. I., Popescu, M. L., & Coroban, L. (2022). Aspects regarding the Level of Education in the Context of Sustainable Development. *Revista de Management Comparat Internationa*l, 23(5), 604-611.
4. Ben Khalifa, A. (2023). Impact of research and development (R&D) and information, and communication technology (ICT) on innovation and productivity evidence from Tunisian manufacturing firms. *Economics of Transition and Institutional Change*, *31*(2), 341-361. https://doi.org/https://doi.org/10.1111/ecot.12340
5. Brodny, J., Tutak, M. (2022). Analyzing the Level of Digitalization among the Enterprises of the European Union Member States and Their Impact on Economic Growth. *Journal of Open Innovation: Technology, Market, and Complexity*, *8*(2), 70. https://doi.org/https://doi.org/10.3390/joitmc8020070

6. Burinskienė, A., Seržantė, M. (2022). Digitalisation as the Indicator of the Evidence of Sustainability in the European Union. In *Sustainability* (Vol. 14, Issue 14). https://doi.org/10.3390/su14148371
7. Capello, R., Lenzi, C. (2024). 4.0 Technological transformations: heterogeneous effects on regional growth. *Economics of Innovation and New Technology*, *33*(5), 627-646. https://doi.org/10.1080/10438599.2023.2204523
8. Chander, B., Pal, S., De, D., & Buyya, R. (2022). *Artificial Intelligence-based Internet of Things for Industry 5.0 BT - Artificial Intelligence-based Internet of Things Systems* (S. Pal, D. De, & R. Buyya (eds.); pp. 3-45). Springer International Publishing. https://doi.org/10.1007/978-3-030-87059-1_1
9. Chenic, A. Ș, Burlacu, A., Dobrea, R. C., Tescan, L., Creţu, A. I., Stanef-Puica, M. R., Godeanu, T. N., Manole, A. M., Virjan, D., & Moroianu, N. (2023). The Impact of Digitalization on Macroeconomic Indicators in the New Industrial Age. In *Electronics* (Vol. 12, Issue 7). https://doi.org/10.3390/electronics12071612
10. Cirillo, V., Fanti, L., Mina, A., & Ricci, A. (2023). The adoption of digital technologies: Investment, skills, work organisation. *Structural Change and Economic Dynamics*, *66*, 89-105. https://doi.org/https://doi.org/10.1016/j.strueco.2023.04.011
11. Consoli, D., Castellacci, F., & Santoalha, A. (2023). E-skills and income inequality within European regions. *Industry and Innovation*, *30*(7), 919-946. https://doi.org/10.1080/13662716.2023.2230222
12. Etemad, H. (2023). The increasing prevalence of multi-sided online platforms and their influence on international entrepreneurship: The rapid transformation of entrepreneurial digital ecosystems. *Journal of International Entrepreneurship*, *21*(1), 1-30. https://doi.org/10.1007/s10843-023-00331-8
13. European Commission. (2021a). *2030 Digital Compass: the European way for the Digital Decade*. https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021DC0118
14. European Commission. (2021b). *Digital Europe Programme*. https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/digital-europe-programme_en
15. European Commission. (2024a). *Horizon Europe*. https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en
16. European Commission. (2024b). *Shaping Europe's digital future*. https://digital-strategy.ec.europa.eu/en
17. European Investment Bank. (2023). *Digitalisation in Europe 2022-2023: Evidence from the EIB Investment Survey*. https://doi.org/10.2867/745542
18. European Union. (2024). *Digital agenda for Europe*. https://www.europarl.europa.eu/factsheets/en/sheet/64/digital-agenda-for-europe
19. Eurostat. (2024a). *Employed ICT specialists - total*. https://ec.europa.eu/eurostat/databrowser/view/isoc_sks_itspt/default/table?lang=en
20. Eurostat. (2024b). *Employment rates by sex, age and citizenship (%)*. https://ec.europa.eu/eurostat/databrowser/view/lfsq_ergan/default/table?lang=en
21. Eurostat. (2024c). *Gross domestic expenditure on R&D by sector*. https://ec.europa.eu/eurostat/databrowser/view/sdg_09_10/default/table?lang=en&category=sdg.sdg_09
22. Eurostat. (2024d). *High-speed internet coverage, by type of area*. https://ec.europa.eu/eurostat/databrowser/view/sdg_17_60/default/table?lang=en

23. Eurostat. (2024e). *Internet use by individuals*. https://ec.europa.eu/eurostat/databrowser/view/tin00028/default/table?lang=en&category=t_isoc.t_isoc_i.t_isoc_iiu
24. Eurostat. (2024f). *Level of internet access - households*. https://ec.europa.eu/eurostat/databrowser/view/tin00134/default/table?lang=en&category=t_isoc.t_isoc_i.t_isoc_ici
25. Eurostat. (2024g). *Patent applications to the European Patent Office by applicants' / inventors' country of residence*. https://ec.europa.eu/eurostat/databrowser/view/sdg_09_40/default/table?lang=en
26. Eurostat. (2024h). *R&D personnel by sector*. https://ec.europa.eu/eurostat/databrowser/view/sdg_09_30/default/table?lang=en&category=sdg.sdg_09
27. Eurostat. (2024i). *Real GDP per capita*. https://ec.europa.eu/eurostat/databrowser/view/tipsna40/default/table?lang=en
28. Feurich, M., Kourilova, J., Pelucha, M., & Kasabov, E. (2024). Bridging the urban-rural digital divide: taxonomy of the best practice and critical reflection of the EU countries' approach. *European Planning Studies*, *32*(3), 483-505. https://doi.org/10.1080/09654313.2023.2186167
29. García-Romanos, J., Martínez-Ros, E. (2024). Digitalization and employment in Europe: the role of firm's size and the complementarity of R&D. *R&D Management*, *54*(4), 695-712. https://doi.org/https://doi.org/10.1111/radm.12656
30. Gómez-Carmona, O., Buján-Carballal, D., Casado-Mansilla, D., López-de-Ipiña, D., Cano-Benito, J., Cimmino, A., Poveda-Villalón, M., García-Castro, R., Almela-Miralles, J., Apostolidis, D., Drosou, A., Tzovaras, D., Wagner, M., Guadalupe-Rodriguez, M., Salinas, D., Esteller, D., Riera-Rovira, M., González, A., Clavijo-Ágreda, J., … Bujalkova, N. (2023). Mind the gap: The AURORAL ecosystem for the digital transformation of smart communities and rural areas. *Technology in Society*, *74*, 102304. https://doi.org/https://doi.org/10.1016/j.techsoc.2023.102304
31. Greenan, N., Napolitano, S. (2024). Digital technologies, learning capacity of the organization and innovation: EU-wide empirical evidence from a combined dataset. *Industrial and Corporate Change*, *33*(3), 634–669. https://doi.org/10.1093/icc/dtad064
32. Grigorescu, A., Pelinescu, E., Ion, A. E., & Dutcas, M. F. (2021). Human Capital in Digital Economy: An Empirical Analysis of Central and Eastern European Countries from the European Union. In *Sustainability* (Vol. 13, Issue 4). https://doi.org/10.3390/su13042020
33. Gupta, M., Jauhar, S. K. (2023). Digital innovation: An essence for Industry 4.0. *Thunderbird International Business Review*, *65*(3), 279-292. https://doi.org/https://doi.org/10.1002/tie.22337
34. Ha, L. T., Huong, T. T. L., & Thanh, T. T. (2022). Is digitalization a driver to enhance environmental performance? An empirical investigation of European countries. *Sustainable Production and Consumption*, *32*, 230-247. https://doi.org/https://doi.org/10.1016/j.spc.2022.04.002
35. Haleem, A., Javaid, M., Qadri, M. A., & Suman, R. (2022). Understanding the role of digital technologies in education: A review. *Sustainable Operations and Computers*, *3*, 275-285. https://doi.org/https://doi.org/10.1016/j.susoc.2022.05.004
36. Hetmańczyk, P. (2024). Digitalization and its impact on labour market and education. Selected aspects. *Education and Information Technologies*, *29*(9), 11119-11134. https://doi.org/10.1007/s10639-023-12203-8

37. Hojnik, J., Ruzzier, M., Konečnik Ruzzier, M., Sučić, B., & Soltwisch, B. (2023). Challenges of demographic changes and digitalization on eco-innovation and the circular economy: Qualitative insights from companies. *Journal of Cleaner Production*, *396*, 136439. https://doi.org/https://doi.org/10.1016/j.jclepro.2023.136439
38. Hung, B. Q., Nham, N. T. H., & Ha, L. T. (2023). The importance of digitalization in powering environmental innovation performance of European countries. *Journal of Innovation & Knowledge*, *8*(1), 100284. https://doi.org/https://doi.org/10.1016/j.jik.2022.100284
39. Ionescu-Feleagă, L., Ionescu, B.-Ștefan, & Stoica, O. C. (2023). The Link between Digitization and the Sustainable Development in European Union Countries. In *Electronics* (Vol. 12, Issue 4). https://doi.org/10.3390/electronics12040961
40. Javaid, M., Haleem, A., Singh, R. P., & Sinha, A. K. (2024). Digital economy to improve the culture of industry 4.0: A study on features, implementation and challenges. *Green Technologies and Sustainability*, *2*(2), 100083. https://doi.org/https://doi.org/10.1016/j.grets.2024.100083
41. Jia, Y., Su, J., Cui, L., Wu, L., & Hua Tan, K. (2023). Platform business model innovation in the digitalization era: A "driver-process-result" perspective. *Journal of Business Research*, *160*, 113818. https://doi.org/https://doi.org/10.1016/j.jbusres.2023.113818
42. Kádárová, J., Lachvajderová, L., & Sukopová, D. (2023). Impact of Digitalization on SME Performance of the EU27: Panel Data Analysis. In *Sustainability* (Vol. 15, Issue 13). https://doi.org/10.3390/su15139973
43. Kallmuenzer, A., Mikhaylov, A., Chelaru, M., & Czakon, W. (2024). Adoption and performance outcome of digitalization in small and medium-sized enterprises. *Review of Managerial Science*. https://doi.org/10.1007/s11846-024-00744-2
44. Khurshid, A., Huang, Y., Cifuentes-Faura, J., & Khan, K. (2024). Beyond borders: Assessing the transboundary effects of environmental regulation on technological development in Europe. *Technological Forecasting and Social Change*, *200*, 123212. https://doi.org/https://doi.org/10.1016/j.techfore.2024.123212
45. Kılıç, C., Atilla, G. (2024). Industry 4.0 and sustainable business models: An intercontinental sample. *Business Strategy and the Environment*, *33*(4), 3142–3166. https://doi.org/https://doi.org/10.1002/bse.3634
46. Kliestik, T., Nagy, M., & Valaskova, K. (2023). Global Value Chains and Industry 4.0 in the Context of Lean Workplaces for Enhancing Company Performance and Its Comprehension via the Digital Readiness and Expertise of Workforce in the V4 Nations. In *Mathematics* (Vol. 11, Issue 3). https://doi.org/10.3390/math11030601
47. Knudsen, E. S., Lien, L. B., Timmermans, B., Belik, I., & Pandey, S. (2021). Stability in turbulent times? The effect of digitalization on the sustainability of competitive advantage. *Journal of Business Research*, *128*, 360-369. https://doi.org/https://doi.org/10.1016/j.jbusres.2021.02.008
48. Krakowski, S., Luger, J., & Raisch, S. (2023). Artificial intelligence and the changing sources of competitive advantage. *Strategic Management Journal*, *44*(6), 1425-1452. https://doi.org/https://doi.org/10.1002/smj.3387
49. Li, C., Razzaq, A., Ozturk, I., & Sharif, A. (2023). Natural resources, financial technologies, and digitalization: The role of institutional quality and human capital in selected OECD economies. *Resources Policy*, *81*, 103362. https://doi.org/https://doi.org/10.1016/j.resourpol.2023.103362

50. Liang, H., Shi, C., Abid, N., & Yu, Y. (2023). Are digitalization and human development discarding the resource curse in emerging economies? *Resources Policy*, *85*, 103844. https://doi.org/https://doi.org/10.1016/j.resourpol.2023.103844
51. Lindberg, J., Runardotter, M., & Ståhlbröst, A. (2024). Bridging the Gap. Policies to Accelerate Social Change for an Inclusive Rural Digital Transformation in Sweden. *European Countryside*, *16*(1), 26-42. https://doi.org/doi:10.2478/euco-2024-0003
52. Magoutas, A. I., Chaideftou, M., Skandali, D., & Chountalas, P. T. (2024). Digital Progression and Economic Growth: Analyzing the Impact of ICT Advancements on the GDP of European Union Countries. In *Economies* (Vol. 12, Issue 3). https://doi.org/10.3390/economies12030063
53. Marti, L., Puertas, R. (2023). Analysis of European competitiveness based on its innovative capacity and digitalization level. *Technology in Society*, *72*, 102206. https://doi.org/https://doi.org/10.1016/j.techsoc.2023.102206
54. Mewes, L., Broekel, T. (2022). Technological complexity and economic growth of regions. *Research Policy*, *51*(8), 104156. https://doi.org/https://doi.org/10.1016/j.respol.2020.104156
55. Molla, A., Gekara, V., Karanasios, S., & Snell, D. (2024). Modeling digital skills beyond the IT workforce: construct definition, measurement and impact on digitalization value. *Information Technology & People*, *ahead-of-print*(ahead-of-print). https://doi.org/10.1108/ITP-04-2023-0385
56. Moschko, L., Blazevic, V., & Piller, F. T. (2023). Paradoxes of implementing digital manufacturing systems: A longitudinal study of digital innovation projects for disruptive change. *Journal of Product Innovation Management*, *40*(4), 506-529. https://doi.org/https://doi.org/10.1111/jpim.12667
57. Ochinanwata, C., Igwe, P. A., & Radicic, D. (2024). The institutional impact on the digital platform ecosystem and innovation. *International Journal of Entrepreneurial Behavior & Research*, *30*(2/3), 687–708. https://doi.org/10.1108/IJEBR-01-2023-0015
58. Pacheco-Cubillos, D. B., Boria-Reverter, J., & Gil-Lafuente, J. (2024). Transitioning to Agile Organizational Structures: A Contingency Theory Approach in the Financial Sector. In *Systems* (Vol. 12, Issue 4). https://doi.org/10.3390/systems12040142
59. Petrariu, R. I., Năstase, M., Croitoru, G., Florea, N. V., Cristache, N., & Ibinceanu, M. C. O. (2023). Analysis of Responsible Energy Consumer's Behaviour in the Context of REPowerEU Plan. Amfiteatru Economic, 25(64), 743-759.
60. Pricopoaia, O., Busila, A. V., Cristache, N., Susanu, I., & Matis, C. (2024). Challenges for entrepreneurial innovation: Startups as tools for a better knowledge-based economy. *International Entrepreneurship and Management Journal*, *20*(2), 969-1010.
61. Priyono, A., Hidayat, A. (2024). Fostering innovation through learning from digital business ecosystem: A dynamic capability perspective. *Journal of Open Innovation: Technology, Market, and Complexity*, *10*(1), 100196. https://doi.org/https://doi.org/10.1016/j.joitmc.2023.100196
62. Ran, R., Wang, X., Wang, T., & Hua, L. (2023). The impact of the digital economy on the servitization of industrial structures: the moderating effect of human capital. *Data Science and Management*, *6*(3), 174-182. https://doi.org/https://doi.org/10.1016/j.dsm.2023.06.003
63. Rehman, N. U., Nunziante, G. (2023). The effect of the digital economy on total factor productivity in European regions. *Telecommunications Policy*, *47*(10), 102650. https://doi.org/https://doi.org/10.1016/j.telpol.2023.102650
64. Rožman, M., Tominc, P., & Štrukelj, T. (2023). Competitiveness Through Development of Strategic Talent Management and Agile Management Ecosystems.

Global Journal of Flexible Systems Management, *24*(3), 373-393. https://doi.org/10.1007/s40171-023-00344-1

65. Sanders, C. K., Scanlon, E. (2021). The Digital Divide Is a Human Rights Issue: Advancing Social Inclusion Through Social Work Advocacy. *Journal of Human Rights and Social Work*, *6*(2), 130–143. https://doi.org/10.1007/s41134-020-00147-9
66. Šilenskytė, A., Butkevičienė, J., & Bartminas, A. (2024). Blockchain-based connectivity within digital platforms and ecosystems in international business. *Journal of International Management*, *30*(3), 101109. https://doi.org/https://doi.org/10.1016/j.intman.2023.101109
67. Skare, M., de las Mercedes de Obesso, M., & Ribeiro-Navarrete, S. (2023). Digital transformation and European small and medium enterprises (SMEs): A comparative study using digital economy and society index data. *International Journal of Information Management*, *68*, 102594. https://doi.org/https://doi.org/10.1016/j.ijinfomgt.2022.102594
68. Škare, M., Gavurova, B., & Porada-Rochon, M. (2024). Digitalization and carbon footprint: Building a path to a sustainable economic growth. *Technological Forecasting and Social Change*, *199*, 123045. https://doi.org/https://doi.org/10.1016/j.techfore.2023.123045
69. Suciu, M. C., Plesea, D. A., Petre, A., Simion, A., Mituca, M. O., Dumitrescu, D., Bocaneala, A. M., Moroianu, R. M., & Nasulea, D. F. (2023). Core Competence—As a Key Factor for a Sustainable, Innovative and Resilient Development Model Based on Industry 5.0. In *Sustainability* (Vol. 15, Issue 9). https://doi.org/10.3390/su15097472
70. Tang, J., Zhao, X. (2023). Does the new digital infrastructure improve total factor productivity? *Bulletin of Economic Research*, *75*(4), 895-916. https://doi.org/https://doi.org/10.1111/boer.12388
71. Teixeira, J. E., Tavares-Lehmann, A. T. C. P. (2022). Industry 4.0 in the European union: Policies and national strategies. *Technological Forecasting and Social Change*, *180*, 121664. https://doi.org/https://doi.org/10.1016/j.techfore.2022.121664
72. Tiganasu, R., Lupu, D. (2023). Institutional quality and digitalization: Drivers in accessing European funds at regional level? *Socio-Economic Planning Sciences*, *90*, 101738. https://doi.org/https://doi.org/10.1016/j.seps.2023.101738
73. Tu, Y., Wu, W. (2021). How does green innovation improve enterprises' competitive advantage? The role of organizational learning. *Sustainable Production and Consumption*, *26*, 504-516. https://doi.org/https://doi.org/10.1016/j.spc.2020.12.031
74. Veile, J. W., Schmidt, M.-C., & Voigt, K.-I. (2022). Toward a new era of cooperation: How industrial digital platforms transform business models in Industry 4.0. *Journal of Business Research*, *143*, 387-405. https://doi.org/https://doi.org/10.1016/j.jbusres.2021.11.062
75. Venkatachalam, N., Kannusamy, R. (2023). Digital skills recruitment challenges in small enterprises: the role of blockchain. *Small Enterprise Research*, *30*(3), 301-317. https://doi.org/10.1080/13215906.2023.2279043
76. Wang, Z., Lin, S., Chen, Y., Lyulyov, O., & Pimonenko, T. (2023). Digitalization Effect on Business Performance: Role of Business Model Innovation. In *Sustainability* (Vol. 15, Issue 11). https://doi.org/10.3390/su15119020
77. W., Müller, W. M. (2023). An Integrative Collaborative Ecosystem for Smart Cities — A Framework for Organizational Governance. *International Journal of Public Administration*, *46*(7), 499-518. https://doi.org/10.1080/01900692.2021.2001014
78. Zervas, I., Stiakakis, E. (2024). Economic Sustainable Development through Digital Skills Acquisition: The Role of Human Resource Leadership. In *Sustainability* (Vol. 16, Issue 17). https://doi.org/10.3390/su16177664