DOI: 10.55643/fcaptp.4.69.2026.5256

# CHALLENGES OF DIGITAL TRANSFORMATION AND THEIR CONSEQUENCES FOR THE FINANCIAL AND ECONOMIC DEVELOPMENT OF EU COUNTRIES

**Vadym Polishchuk**
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Banking and Insurance, Lutsk National Technical University, Lutsk, Ukraine;
e-mail: vadym.polischuk2@gmail.com
ORCID: 0000-0001-5479-1221
(Corresponding author)

**Lesia Ishchuk**
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Banking and Insurance, Lutsk National Technical University, Lutsk, Ukraine;
ORCID: 0000-0002-1724-0292

**Anzhela Nikolaeva**
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Banking and Insurance, Lutsk National Technical University, Lutsk, Ukraine;
ORCID: 0000-0003-3531-2023

**Nataliia Vakhnovska**
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Banking and Insurance, Lutsk National Technical University, Lutsk, Ukraine;
ORCID: 0000-0002-3057-7834

**Svitlana Pyrih**
Candidate of Economic Sciences, Associate Professor of the Department of Finance, Banking and Insurance, Lutsk National Technical University, Lutsk, Ukraine;
ORCID: 0000-0002-1205-9814

Received: 01/06/2026
Accepted: 05/08/2026
Published: 31/08/2026



## ABSTRACT

Digital transformation shapes the current course of economic development in the European Union. It strengthens the competitiveness of economies and stimulates innovation and labor productivity. However, digitalization also carries the risk of uneven development between countries and sectors. Issues of digital maturity, security, and sustainability are particularly important. The aim of this study is to provide an in-depth analysis of the challenges arising from the digital transformation for the European Union economy. It also assesses the impact of digitalization on financial and economic development. The study covers technological, institutional, social, and financial aspects of digitalization. The methodology is based on statistical, econometric, and scenario analysis. Panel models, the DSGE approach, and system dynamics modeling were used.

The significant positive impact of digitalization on the economic growth of the Member States was revealed. The acceleration of labor productivity due to the introduction of modern digital technologies was analyzed. The emergence of a digital core between the countries of Northern and Western Europe was investigated. The existence of digital asymmetry between different Member States of the European Union was confirmed. The connection between digital transformation, innovation, and sustainable economic development was established. The positive impact of digital maturity on the macroeconomic competitiveness of countries was investigated. The existence of threshold effects of digitalization on economic efficiency was emphasized. Prospective scenarios for the digital development of the European Union until 2030 are proposed.

This study confirmed the systemic nature of the digital transformation of the economy. Digitalization is a significant driver of economic growth and convergence. However, the risk of digital inequality and technological dependence remains. The effectiveness of these transformations depends on the institutional capacity of countries and investments. Developing digital skills among the population and infrastructure remains a priority, although cybersecurity, innovation, and coordinated digital policies are also important.

**Keywords:** innovative technologies, digital maturity, human capital, infrastructure, cybersecurity, DTI index, DSGE model, System Dynamics model, competitiveness, development asymmetry

**JEL Classification:** O33, O52, C33, E37, F42, G28

## INTRODUCTION

The European Union is confronted with the challenges of digital transformation, shaping economic change, as its Member States are required to adopt digital technologies in the management of their production systems and in their financial and social operations. Digitalization is essential for European economies to maintain stability and competitiveness amid increasing international competition, the transformation of global value chains, and the rising importance of innovation. The development of the single European market is seriously hampered by the fact that Member States are at different stages of digital maturity, and firms have differing financial means and scarce human resources.

This investigation calls for a detailed evaluation of the influence of digitalization on the economy, as the effects of novel technologies determine not only the development of business models and innovation opportunities, but also the European Union's response to crises and its efforts to maintain economic growth. Digital transformation promotes market integration but also introduces new security threats and risks to technological independence and fair development.

The relevance of the study is due to the growing role of digitalization in the economic development of countries. Digital transformation ensures the competitiveness of economies in the face of global challenges. It promotes innovation, productivity, and sustainability of economic systems of states. At the same time, there are significant differences in digital maturity between European countries. Such disparities hinder integration and increase the economic asymmetry of states. Digitalization creates new opportunities for the development of business and finance. At the same time, the risks of cybersecurity and technological dependence of EU countries are increasing. Therefore, the study of digital transformations is gaining special scientific and practical significance today.

The digital economy in the EU is at a critical juncture, presenting both promising prospects and dangerous threats that affect economic sustainability and productivity growth. The EU faces difficulties in implementing its strategic goals for the "Digital Decade 2030", as digital transformation creates opportunities for market integration but also raises security risks, challenges technological independence, and poses challenges to inclusive development. The scientific community and public policymakers need to study the challenges of digital transformation that affect EU economic performance, as the digital economy is at a critical juncture between opportunities and threats.

Despite extensive scientific contributions, several important issues remain insufficiently explored. Existing studies rarely integrate digitalization, sustainability, innovation, and resilience simultaneously. Limited attention addresses combined effects of digital maturity and institutions. Insufficient evidence exists regarding threshold effects within European digital convergence. Existing research seldom evaluates long-term interactions between digitalization and sustainability. Scenario modeling of digital transformation consequences remains fragmented across studies. Therefore, this article examines these gaps through integrated analytical approaches.

## LITERATURE REVIEW

The dynamics of digital transformation have become a key determinant shaping the path-dependent financial and economic development patterns of EU countries. Modern digital technologies influence production systems, financial markets, tax administration, labor productivity, energy management, and institutional governance. With the rapid expansion of artificial intelligence, cloud computing, blockchain systems, fintech applications, and digital government, it is clear that digitalization is no longer a technological trend but rather a strategic pillar of economic competitiveness and macro-financial stability.

A considerable number of researchers have analyzed the relationship between digital transformation and economic growth within the European Union. In particular, Andrei J. V., Chivu L., Sima V., Gheorghe I. G., Nancu D., and Duică M. investigated the processes of digital convergence and divergence within the EU economy and demonstrated that significant asymmetries remain between member states despite the gradual strengthening of digital integration processes (Andrei et al., 2023). Their econometric analysis confirmed that less digitally developed countries continue to experience structural barriers in achieving technological convergence.

The relationship between digital transformation and economic growth was also investigated by Olczyk, M., and Kuc-Czarnecka, M., who analyzed the influence of DESI indicators on GDP per capita dynamics in EU countries (Olczyk & Kuc-Czarnecka, 2022). The researchers proved that digital transformation positively affects economic growth, especially in countries with lower initial levels of economic development. In contrast, connectivity and digital public services remain decisive components of digital modernization.

Török L. examined the relationship between digital development and GDP growth using the International Digital Economy and Society Index (I-DESI) (Török, 2024). The researcher concluded that digitally developed countries demonstrate stronger macroeconomic performance and higher competitiveness, while economically weaker member states risk increasing technological backwardness.

Researchers Vărzaru A. A., Bocean C. G., Simion D., Berceanu D., and Mangra M. G. analyzed the interaction between digital transformation, sustainability, and government revenues in the European Union (Vărzaru et al., 2023). Their research confirmed that countries with higher DESI indicators and stronger sustainability performance achieve higher government revenues due to more efficient fiscal systems, digital public administration, and innovation-driven economic structures.


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Another group of researchers investigated the impact of digital transformation during the COVID-19 pandemic. Pisár P., Huňady J., Khawaja S., and Qureshi F. H. investigated the extent of digital readiness in EU states pre- and intra-pandemic (Pisár et al., 2024). Their results revealed that countries with more advanced digital infrastructure and more technologically sophisticated firms adjusted better to crisis environments, while underdeveloped nations still faced significant digital divides.

Hence, the scientific literature, including early drafts devoted to these topics, is influenced by digital intensity, artificial intelligence, and emergent technologies. Mihai F., Aleca O. E., and Gheorghe M. explored the effects of Artificial Intelligence, Cloud Computing, IoT technologies, and Machine Learning solutions on the Digital Intensity Index (DII) of EU companies (Mihai et al., 2023). They demonstrated, through regression analyses, that AI-based technologies have a positive effect on the digitalization of organizations and on the efficiency of their operations.

The role of digital transformation in employment restructuring and technologically advanced sectors was investigated by Sobczak E. (Sobczak, 2025). The researcher demonstrated that digital transformation supports employment growth in knowledge-intensive services and stimulates innovation-oriented economic modernization. At the same time, the study revealed substantial differences among EU countries in employment structures in high-tech and medium-high-tech sectors.

An important direction of scientific discussion concerns financial innovation and digital finance. Naeem M. H., Subhan M., Alam Md. Sh., Al-Faryan M. A. S., and Yameen M. analyzed the role of financial innovation in economic growth across developed and developing economies (Naeem et al., 2023). Their empirical findings confirmed that financial innovation and digital financial instruments positively affect economic growth by improving access to capital, increasing market efficiency, and enhancing financial inclusion.

The transformation of the financial system under digitalization was also investigated by Boros E. and Horváth M., who studied the development of Central Bank Digital Currencies in the context of geopolitical transformation and financial modernization (Boros & Horváth, 2022). Their conclusions indicate that CBDCs may become a key instrument of future financial sovereignty and monetary system transformation.

N. A. Kyriazis and L. M. Economou studied the geopolitical risks and the transition to decentralized financial systems (Kyriazis & Economou, 2025). Their results showed that geopolitical uncertainty accelerates the maturation of decentralized finance (DeFi) technologies and other digital financial instruments.

El Khoury R., Nasrallah N., Hussainey, K. and Assaf R. analyze the interaction among fintech markets, ESG frameworks, and the renewable energy industry amid the Russia–Ukraine war (El Khoury et al., 2023). The authors also found high spillovers among digital finance, sustainability measures, and the renewable energy market during a period of geopolitical tension.

The geopolitical aspects of digital finance in European financial governance were studied by Quaglia, L., and Verdun, A. (Quaglia & Verdun, 2023). Their work has illustrated how financial sanctions, digital payment infrastructure, and central banking systems serve as tools for economic security within the EU.

There is also significant scientific research on the connection between digital transformation and sustainability. The article by Karadayi-Usta S. examines whether the European Union's practices for realizing sustainability through digital transformation constitute a cargo cult and finds that digital technologies promote resource efficiency, policies conducive to a green transition, and economic modernization that supports sustainability.

The ESG-firm performance-financial stability nexus was studied by Bruno C. C. and W. J. Henisz, who studied ESG performance and municipal credit risks (Bruno & Henisz, 2024). They concluded that governance mechanisms that favor sustainability enhance financial resilience and reduce the long-run risk of economic activity.

Geopolitical tensions and wars are the subject of investigation in the literature regarding their effects on financial markets. Wang, Zh., Liu, Sh., Wei, Yu., Wang, Sh. investigated the effect of wars on financial assets in the Russia–Ukraine war and showed that geopolitical shocks generate pronounced asymmetries in the financial market (Wang et al., 2023). Pandey D. K. has also examined the evolution of the war-financial market literature and noted a rising scholarly concern with geopolitical risk, policy uncertainty, and their impact on the stock market, banking systems, and investment decisions (Pandey, 2023).

Ukrainian scientists have also made a significant contribution to the study of the digital transformation of financial and economic development. In particular, scientists Shevchenko, I., and Ukhova, N. propose a phased integration model that includes technical stabilization, functional adaptation, and deep integration of Ukraine into the single European digital

space as a factor in modernizing the economy and strengthening economic security (Shevchenko & Ukhova, 2025). Scientists Dluhopolskyi, O., Pakhnenko, O., Lyeonov, S., Semenog, A., Artyukhova, N., Cholewa-Wiktor, M., and Jastrz¸ebski, W. even analyzed the impact of the COVID-19 pandemic on the development of digital financial inclusion in the world by constructing an integral index of digital financial inclusion based on the Global Findex Database data (Dluhopolskyi et al., 2023).

Many authors argue that digital transformation has implications not only for the technology industries but also for the entire institutional structure of the European economy. The literature review suggests that digitalization supports productivity growth, labor market flexibility, reduced transaction costs, and technology-driven development. Simultaneously, experts warn that digital transformation is increasing cybersecurity-related risks, technological dependence, and the risk of economic disintegration among EU member states.

The scientific evidence shows that human capital remains a key determinant of successful digital transformation. The agents of change identified in the research as driving the pace of technological uptake and economic modernization were digital skills, technological literacy, and an education system focused on innovation.

Sovereign technology in the European Union is another significant subject of scientific scrutiny. Researchers highlight that reliance on foreign semiconductors, digital platforms, cloud infrastructure, and external technological systems, for that matter, generates strategic vulnerabilities for the EU economy. As such, the scientific literature increasingly supports the imperative to bolster national innovation ecosystems, cybersecurity systems, and strategic technology industries.

Hence, the literature review indicates that digital transformation has multidimensional effects on economic and financial growth in EU countries. The literature supports the assertion that digitalization creates expanded opportunities for economic growth, innovation, fiscal modernization, financial stability, industrial competitiveness, and sustainable development. Simultaneously, this digital transformation creates serious challenges, including digital divides, geopolitical instability, cybersecurity threats, labor-market restructuring, technological dependency, and regional disparities. The literature suggests that the European Union's future ability to remain competitive and sustain its economy will be largely determined by how effectively the Member States can combine technological upgrading with institutional reforms, investments in human capital, a harmonized EU digital agenda, and a coherent strategy for economic governance.

## AIMS AND OBJECTIVES

The purpose of the study is to conduct a comprehensive analysis of the challenges of digital transformation and to assess their impact on the financial and economic development of the European Union's countries, amid increasing technological competition, geopolitical instability, and differentiated levels of digital maturity among Member States.

In accordance with the stated objective, the following main tasks were identified within the research framework:

1. To study the theoretical and methodological principles of digital transformation in the conditions of modern global challenges of the economy and technology development.
2. To identify the impact of digitalization on the financial and economic growth of the countries of the European Union.To identify the key directions and instruments of digital transformation, including artificial intelligence, cloud technologies, blockchain systems, fintech innovations, and digital public governance.
3. To assess the differentiation of digital maturity among EU Member States and determine its impact on economic competitiveness and macroeconomic dynamics.
4. To evaluate the role of human capital, digital competencies, and innovation ecosystems in accelerating digital transformation processes.
5. To define the main risks and threats to the physical and digital environments, including cybersecurity issues, reliance on technology, infrastructure challenges, and regional digital divides.
6. To assess the effects of geopolitical uncertainties, post-pandemic transformations, and external pressures on digital and financial resilience in the European Union.
7. To substantiate strategic directions for improving EU digital policy aimed at strengthening technological sovereignty, sustainable economic growth, and the integration of Member States into a unified digital economic space.


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## METHODS

An advanced general scientific method was employed, including quantitative, comparative, econometric, and analytical methods to examine the challenges of digital transformation and its impact on the financial and economic development of EU countries. The methodological platform was developed in light of the multifaceted nature of digitalization processes and the need to integrate technological, institutional, financial, macroeconomic, and geopolitical factors into a coherent analytical framework.

The empirical basis of the research includes statistical and analytical data from Eurostat, the European Commission, the DESI Dashboard for the Digital Decade (DESI), IMF databases (IMF Dattamapper), and official reports of EU institutions (Eurostat) covering the period 2010–2025. The study examines indicators characterizing digital maturity, artificial intelligence implementation, enterprise digital intensity, electronic information exchange, cloud technology adoption, innovation activity, labor productivity, cybersecurity preparedness, and macroeconomic competitiveness across EU Member States.

The study employs comparative analysis methods to evaluate asymmetries in digital development among Northern, Western, Central, and Eastern European countries. Statistical grouping and structural analysis were used to classify EU countries by digital readiness, digital infrastructure development, and technological competitiveness. Special attention was paid to the analysis of digital inequality between highly developed and less digitally integrated economies.

Econometric analysis was conducted using panel data models to identify the relationship between digital transformation indicators and macroeconomic variables. Fixed- and random-effects models were applied to assess the influence of digitalization on GDP growth, labor productivity, innovation performance, and financial sustainability. Dynamic relationships between digital investments and economic development were further examined using panel regression and comparative trend analyses.

The research also incorporates elements of DSGE modeling and System Dynamics analysis to evaluate long-term effects of digital transformation on economic systems under conditions of technological and geopolitical uncertainty. The DSGE approach enabled the incorporation of digital capital, technological shocks, and innovation into macroeconomic analysis. At the same time, the System Dynamics method was used to model feedback mechanisms among digital infrastructure, productivity growth, human capital, and economic resilience.

A separate component of the methodology involved graphical and comparative analysis of DESI indicators and enterprise digitalization metrics across EU countries. The study analyzed indicators related to enterprises' use of artificial intelligence, the digital intensity of small and medium-sized businesses, and electronic information exchange systems. These indicators enabled the identification of the degree of enterprises' digital integration into the European digital market and the determination of the structural barriers limiting digital transformation in less developed Member States.

The research additionally applies elements of scenario analysis to assess possible trajectories of digital transformation in the European Union. Alternative development scenarios were considered depending on the pace of AI implementation, investment in digital infrastructure, institutional coordination, cybersecurity capacity, and the effectiveness of EU digital policies. Such an approach enabled the identification of both opportunities and systemic risks associated with accelerated digitalization processes.

The combination of comparative analysis, econometric modeling, statistical assessment, DSGE and System Dynamics approaches, and scenario forecasting enabled the development of a comprehensive analytical framework to evaluate the challenges of digital transformation and their consequences for the financial and economic development of European Union countries.

## RESULTS

The digitalization processes of the EU economy determine both the speed of recovery from the crisis and the direction of future economic development. The emerging digital structure of economic operations uses technological innovations to stimulate economic growth by increasing production flexibility and labor productivity. Deepening the process of digital transformation enables scientific research and investment in modern technological achievements, creating a double advantage: technological superiority and financial stability amid global economic instability.

The rate of digital change necessitates greater investment in science and technology R&D, since this activity lays the technological foundation for future growth. A strong, innovative activity contributes to the renewal of production processes and products, as well as to the improvement of the market position of global firms. Digital transformation thus leads to a

lopsided development pattern across regions and nations: some regions embrace digital trends immediately, while others are held back, exacerbating internal economic disparities.

Digital solutions have protected numerous European businesses from collapse in times of limited mobility and supply chain disruptions. New-generation industrial facilities operate 24/7, using automated systems and remote work. The e-commerce market has experienced rapid growth, demonstrating its ability to adapt quickly to changes in behavior.

The digital revolution is significantly affecting how states pursue their economic policies. Governments are adopting policies to shape a start-up culture, focusing on building digital infrastructure and driving industrial transformation. A new pattern for the innovation ecosystem is taking shape from this vision through collaboration among the government, business, and the scientific sector. These processes are enhancing technology take-up in regional economies, and thereby expanding pan-European economic potential.

Digital transformation improves global value chain integration, but stronger economic self-protection is required. Investment in research, citizens' digital skills, and innovation-intensive sectors is now among the most significant metrics of the EU's potential future economic success. Digital preparedness has a significant bearing on its ability to withstand external shocks as it transforms its economy to perform in new market conditions. The EU economy reveals stark contrasts in the impact of the digital transformation across its diverse business sectors. Integration of automation technologies with intelligent manufacturing systems enables cost reduction in manufacturing processes in a stable production environment, even during worldwide crises. Using artificial intelligence, robotics, and 3D printing technology enables businesses to better respond to uncertain external conditions while retaining operational flexibility. Innovation in the EU is primarily supported by industry, which applies those solutions to achieve higher modernization rates. Confidence in the enviable stability of the financial sector has been achieved through digitalization, by providing more remote banking services and electronic payment systems at a time when markets are very volatile. The development of fintech solutions has democratized financial services, enabling companies to develop new lending, investment, and insurance models. The financial industry is a shining example of how digital infrastructure can contribute to economic stability, mitigating risk and supporting business continuity.

The energy industry is adopting smart grids and digital transformation to track usage and enhance resource utilization. The EU is very fond of digital solutions to enhance energy efficiency and renewable energy systems. Source: Fossil fuel subsidies in the EU: Could more efficient use of digital tools foster better policy-making? Digital solutions enable improved demand forecasting, which can help prevent energy system instability and enhance overall stability.

Fueled by the expansion of online shopping and the development of remote work tools, the service industry has been digitally transformed. Rapidly adapting to market disruption, such companies' growth in the digital marketplace is. Digitalization has opened new avenues for interacting with customers, leading to the creation of effective earning models that are also useful in global emergencies.

A number of the differences in the pace of recovery from the crisis can be explained by how well each sector was digitally enabled. The industrial and financial sectors demonstrate the most significant progress, but the energy and service sectors face numerous internal barriers due to the need for modernization and infrastructure development. All economic sectors of the EU show a common trend of increasing investment in innovation and technological progress, which in turn stimulates their economic indicators. Digital transformation has become a key driver of the European Union's economic dynamics. The EU countries measure the Digital Economy and Society Index. As is known, a 10% increase in the overall DESI index is associated with a 0.65% increase in GDP per capita, confirming a direct positive relationship between the level of digitalization and macroeconomic indicators. This effect is especially pronounced in countries with lower digital maturity, where the potential return on investment in technology is much higher than in countries that lead in digital technology development.

Digital transformation in EU countries is driven not only by technological innovations but also by large-scale institutional and socio-economic shifts.

The integration of digital solutions into production and financial systems increases productivity, creates new sectors of the economy and transforms business models, while also aggravating cybersecurity problems and regulatory challenges.

The EU Member States must quickly adapt their economies to new digital tools, or their economic performance will suffer. The influence of artificial intelligence, the Internet of Things, blockchain and cloud platforms on the enterprise environment drives innovation, strengthens competition among SMEs and enhances e-commerce. The EU faces the threat of economic exclusion, as rural and poor areas have limited access to digital infrastructure.


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Current economic stability during global crises largely depends on digitalization as a key factor, namely, the creation of digital diversity of the population. The rapid pace of change requires an assessment of the regulatory system, since the current rules do not meet the requirements for fast remote services, leading to reduced costs while accelerating market modernization and expanding service availability in line with technological evolution.

The EU digital economy has significant potential for growth through innovation, but the effectiveness of its implementation depends on combining technological advances with inclusive development and the protection of citizens' socio-economic interests. Harmonization of EU Member States' policies in the field of digital transformation and the strengthening of the common market for digital services are considered key conditions for ensuring sustainable economic dynamics.

The assessment of EU digital transformation reveals a strong relationship between digital infrastructure, the innovation environment, and the competitiveness of Member States' economies. The mass adoption of digital technologies results in the transformation of business models, increased information exchange and reduced transaction costs, which in turn stimulate gains in economic productivity. Three main effects have emerged from the digitalization process, including the expansion of e-commerce, new platform business models, and integration into the international market.

The deepening of digitalization has led to the integration of enterprises into a single digital space within the EU, making it one of the key drivers of growth. The economy now allows traditional sectors to adopt innovative methods that help them enter new, undeveloped markets. The development of high-speed networks and the spread of artificial intelligence tools lay the foundation for the so-called digital dividend, reflected in increased investment, employment, and improved service quality.

The competitive advantages of EU countries depend on the level of readiness for implementing big data processing technologies, cloud solutions, and the Internet of Things. The gradual pace of digital transformation risks leaving individual states behind European development trajectories, leading to unbalanced economic growth. That is why the key task of economic policy is to ensure technological sovereignty, based on its own standards and principles that guarantee the stability of infrastructure and the protection of information resources.

It is also worth noting that the socio-economic impact of the digital transformation in the EU is not confined to the technology sector. They create a new development base that makes competitiveness based on grounding innovation and openness. The evolving digitized market leads to stable, shock-resilient, and internally turbulence-proof economic integration over time.

Let us look at the latest data from EU countries covering the digitalization of business structures. The first such indicator is the use of AI by EU enterprises, which is discussed in Figure 1.

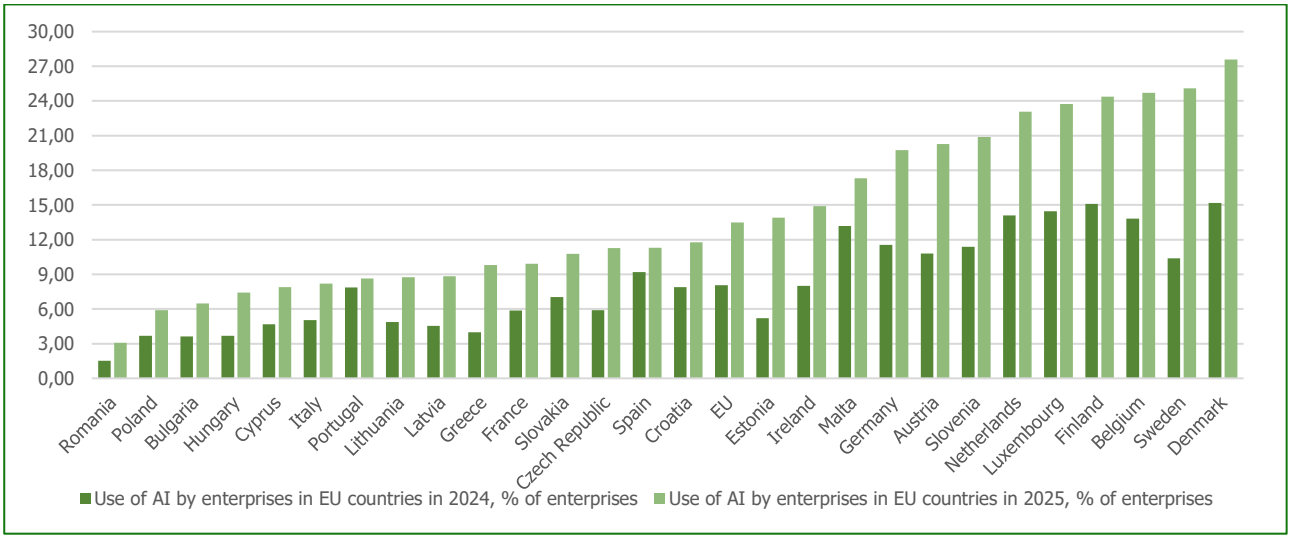


**Figure 1. Use of AI by enterprises in EU countries in 2024-2025, % of enterprises.** *(Source: calculated by the authors based on Eurostat)*

Thus, the graph clearly shows significant differentiation between EU countries. In particular, the level of use of artificial intelligence by enterprises in countries such as Romania, Poland and Bulgaria is 3-5%, and in Denmark, Sweden, Belgium, the Netherlands and Finland it is 20-27%. The average value for the EU ranges from 12% to 14%, reflecting the gradual introduction of AI into business processes. Over the past two years, there have been no significant crises that could negatively affect the EU's economic situation. Nevertheless, the effects of quarantine limitations stemming from the COVID-

19 pandemic are still resonating, and the blatant impact of the full-scale invasion of Ukraine that has already lasted four years is obvious.

So let us highlight the key reasons for the divergence in the adoption of AI in firms' business processes across EU countries. Countries such as Denmark, the Netherlands, and Sweden have developed innovation ecosystems that provide substantial funding for research and development, and support for startups. It should be noted that the level of digital skills in the Scandinavian countries is significantly higher than in Eastern Europe, which affects companies' ability to integrate new technologies into the production process. High investment volumes in the countries of Northern (Denmark, Sweden) and Western Europe (Netherlands, Belgium), which indicate access to project financing, contrast sharply with limited opportunities in less developed economies.

It is also worth mentioning that public policies and strategies in national digital economy development programs, e.g., Finland and the Netherlands, promote the dissemination of AI technology. Thus, we note that in the leading countries in terms of the level of implementation of AI, enterprises are already creating additional productivity, reducing production costs, and new business models are emerging. On the other hand, in countries outside the AI industry, the low level of AI implementation may become a factor in economic backwardness, as the productivity gap between enterprises across countries will only grow in the near future. It should be noted that the dynamics of the AI implementation rate by enterprises of EU countries illustrate one of the global challenges of digital transformation, which is the uneven adaptation of innovations between countries.

Another important indicator of the Digital Economy and Society Index is the presence of small and medium-sized businesses with at least a basic level of digital intensity in EU countries, as shown in Figure 2.

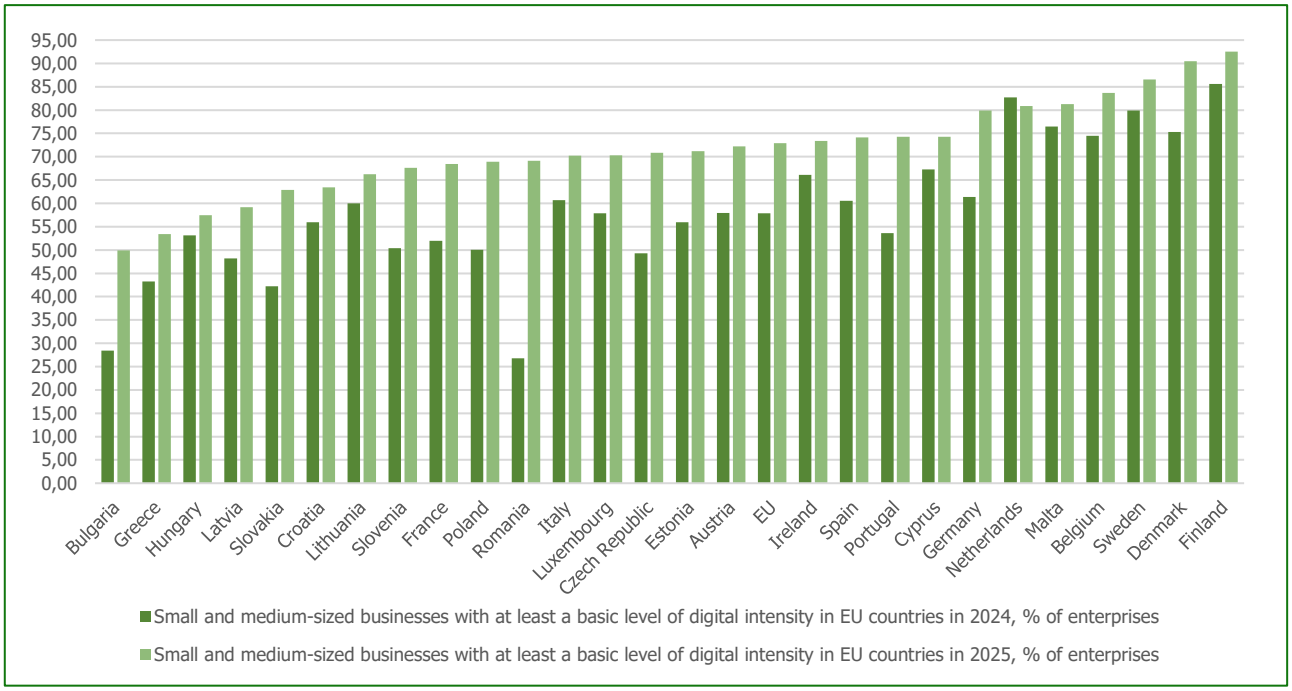


**Figure 2. Small and medium-sized businesses with at least a basic level of digital intensity in EU countries in 2024-2025, % of enterprises.** *(Source: calculated by the authors based on Eurostat)*

Let us note the existing gap between EU countries in terms of the presence of small and medium-sized businesses with at least a basic level of digital intensity. Namely, for countries such as Bulgaria, Romania, and Hungary, this indicator fluctuates within 50%. In contrast, in Finland, Denmark, Sweden, and Belgium, we note the indicator at the level of 85-90%. The average indicator for the EU exceeds 70%, indicating that most small and medium-sized enterprises integrate digital tools into their operations. From this, the effectiveness of the EU policy on the digitalization of the economy (DigitalEurope NextGenerationEU initiatives) is evident, and the EU is providing financial and technical support to small and medium-sized businesses.

Let us pay attention to differences among EU countries in the context of this indicator's analysis. In particular, the leaders include Finland, Denmark, Sweden, Belgium, and the Netherlands, where the share of small and medium-sized enterprises with basic digital intensity exceeds 85%. These countries maintain their leading positions thanks to a combination of


DOI: 10.55643/fcaptp.4.69.2026.5256

progress in digital education and significant infrastructure investments. If the level of basic digital intensity fluctuates between 65% and 75%, we can say that such countries belong to the middle group. This group includes Italy, Germany, France, and Spain, where digital technologies are clearly implemented. The countries that are unconditional outsiders in this indicator are Bulgaria, Romania, Hungary, and Slovakia, where only 45-55% of small and medium-sized enterprises have achieved digital intensity. Let us note the main factors influencing the basic digital intensity indicator for small and medium-sized enterprises in EU countries. First of all, we note the developed digital infrastructure (broadband Internet, cloud solutions, e-commerce platforms). EU funding for small and medium-sized enterprises yields better development outcomes for countries that use these resources effectively. The level of digital competences of the workforce directly affects the ability of economic entities to integrate digital technologies; i.e., the potential of human resources is a significant factor in the development of enterprises' digital intensity. It should also be noted that national digital transformation platforms in Western European countries are much more effective than in Central and Eastern European countries.

Based on a study of the dynamics of the indicator describing the basic level of digital intensity of small and medium-sized businesses in EU countries, we determined that the global challenge of digital inequality threatens to increase the asymmetry in the pace of economic development. The EU should increase funding for digital infrastructure to help small and medium-sized enterprises access modern technological systems across all Member States with lower performance indicators.

In addition, an important indicator of the Digital Economy and Society Index is the electronic exchange of information by enterprises in EU countries, as shown in Figure 3.

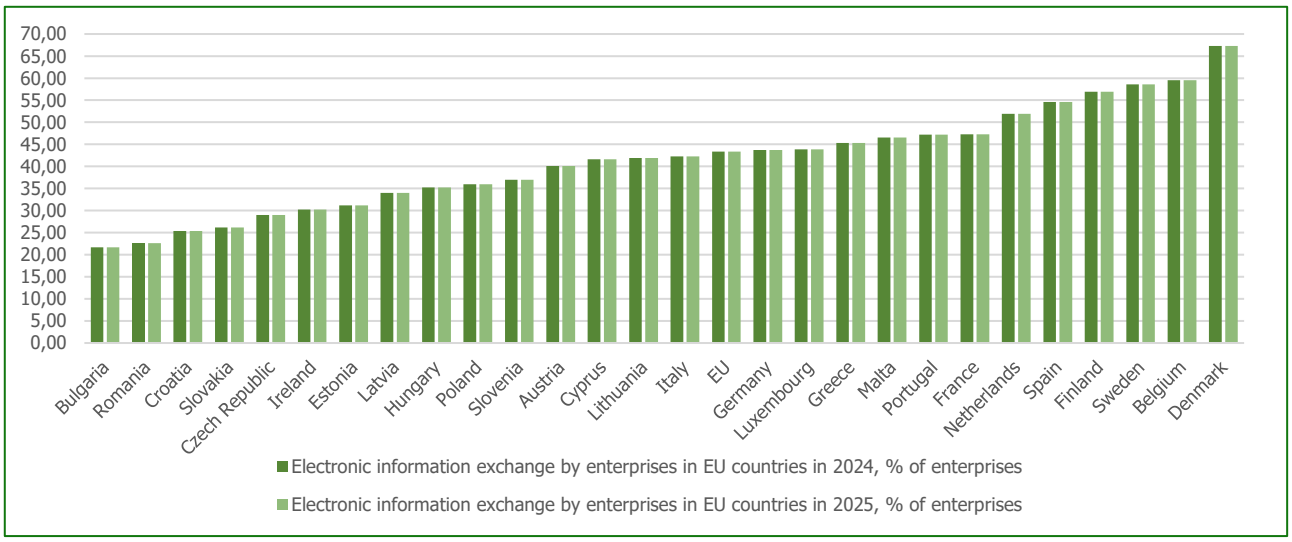


**Figure 3. Electronic information exchange by enterprises in EU countries in 2024-2025, % of enterprises.** *(Source: calculated by the authors based on Eurostat)*

Therefore, this indicator is a key indicator of a business's digital maturity and its integration into the internal digital market. It determines how ready enterprises are to work in the format of the "digital data economy." Organizations can increase operational efficiency by using electronic document management systems, thereby reducing transaction costs. That is, this directly affects the development of transparency and enhances enterprises' competitiveness.

On average, the share of enterprises that exchange information electronically exceeds 40-45% across the EU, although there is noticeable variation between countries. In general, there is a positive trend in business digitalization, though the asymmetry is somewhat pronounced. Positive changes are inherent in state programs for digital transformation, the "Digital Single Market" policy, and the development of e-government infrastructure.

The highest values of the indicator describing the electronic exchange of information among enterprises in EU countries are observed in Denmark, Belgium, Sweden, Finland, and the Netherlands (about 60-70% of all enterprises). The obvious reasons for the high results are the systematic development of electronic platforms and cloud services, strategic investments in digital infrastructure and cybersecurity, active use of e-governance, and high digital literacy of enterprise personnel.

Several EU countries can be classified as middle according to the indicator of electronic exchange of information between enterprises. We are primarily talking about Germany, France, Italy, Spain, Portugal, Austria, and Greece. These countries

demonstrate the indicator at 40-50%. Let us note the characteristics of the middle group of countries: large companies focused on international trade, greater use of electronic information exchange by large businesses, and access to state subsidies for the implementation of digital services.

The outsider countries, according to the indicator of electronic exchange of information between enterprises, are Bulgaria, Romania, Croatia, Slovakia, and Hungary (less than 30-35%). The above-mentioned countries demonstrate a lower development in the implementation of broadband Internet. In addition, during the monitoring, we observed limited investment in implementing digital tools among small and medium-sized businesses. The growth of cyber threats has increased distrust in electronic services in such countries.

The following are the factors that have the most impact on the overall situation of EU countries in the electronic information exchange among enterprises. The EU policy (The Digital Europe program, The Digital Decade 2030) promotes a digital technology development policy, though its effectiveness seems to vary from one country to another. The pandemic has prompted the introduction of electronic document transfer in these digitally advanced countries. EU funding enables businesses across sectors to accelerate their digital transformation across multiple countries. Trust in digital technology and the role of the state in guaranteeing digital security in EU countries may suggest that cultural and institutional sources of influence are transforming.

Thus, electronic exchange of information between enterprises in the EU countries has already become the standard for developed economies, although it is not without problems in Central and Eastern Europe. The process of digital transformation enables leading countries to enhance their competitiveness in development, while peripheral countries risk being left behind the digital core. Therefore, the global challenge of digital transformation for the EU is not only the implementation of electronic tools but also overcoming the digital development asymmetry across countries, which will be crucial for the EU's future economic dynamics.

The last five years of digital transformation in European Union countries have shown how different models of economic growth have emerged. There is a close connection between the growth of states' digital maturity and their ability to achieve higher GDP growth rates. The increasing penetration of digital technologies into business processes has been a major driver of productivity growth, but has also highlighted gaps in the development of digital infrastructure across countries. Those countries that have so far invested in digital skills and technology development, such as artificial intelligence, now enjoy massive competitive advantages. Countries with weak policy coordination and limited financial resources have suffered from shrinking economies.

Although the digital maturity of EU businesses is steadily increasing, their progress towards the Digital Decade 2030 targets is still lagging. Different organizations report different cloud services adoption rates – 45.2% in 2023, and big data analytics – 29.2% in 2023. Large companies show systematic adoption, while small and medium-sized enterprises tend to have only point solutions, such as sales or communication solutions; overall, transformation efficiency decreases. However, even with the stimulus of the COVID-19 pandemic, which pushed more people to shop online and work remotely, the consistent upward trend in digital business activity – measured by how many people were conducting business and for how much money – still hasn't leveled off.

Technological progress has far-reaching consequences for the labor market. However, on the other hand, digitalization creates new job opportunities and makes work accessible to unskilled people. In 2024, only 55.6% of the EU population aged 16-74 had at least basic digital skills, far from the 2030 target of 80%.

Both the business sector and public authorities have to contend with genuine barriers to innovation, particularly due to a lack of skilled personnel, which, in turn, creates imbalances in the labor market that hinder economic development. However, now generative AI models are beginning to eliminate the need for many of those traditional "entry-level" roles for fledgling specialists - and that means fewer practical experience opportunities for new grads, and the risk that it will get even harder for them to find a job. The lack of digital skills and IT professionals is the key barrier to innovation reaching its full potential. Most firms cite a shortage of labor as the biggest barrier to investing in digital technologies.

The infrastructure base also remains a weak link. Despite the expansion of household access to the Internet (in 2024, 94% of households had access), the implementation of 5G and fiber-optic networks lags behind the set targets. The EU's dependence on imports of key technologies is critical (over 80% of Europe's digital infrastructure relies on imported technologies), particularly semiconductors and cloud services, creating risks to technological sovereignty and economic sustainability. An additional constraint is the high level of energy-saving achieved by new technologies, which strengthens the interconnection between digital and green transformations. The growing frequency of cyberattacks on critical infrastructure systems poses a significant security threat to the global community. Although certain strategies were adopted and European security institutions established, the response was hampered by poor coordination between member states and by


DOI: 10.55643/fcaptp.4.69.2026.5256

the non-inclusion of civil and military aspects. Digitalization is conducive to economic development but also poses a series of systemic security risks that can only be addressed by a joint-defense strategy.

The economic dynamics of EU countries in the context of digital transformation are determined not only by the availability of technologies or the volume of investments, but also by the ability to form a comprehensive policy aimed at developing digital competencies, removing infrastructure barriers, as well as strengthening cyber defense and supporting small and medium-sized businesses. The EU needs to accelerate its efforts to turn digital innovation into a sustainable driver of economic growth, as this will determine the success of its transformation.

EU countries are undergoing profound structural changes across the economy, the social sphere, and political institutions. The development of modern production and management systems requires deep digital integration, which in turn creates competitive economic systems. Research shows that the intensity of digital transformation stimulates productivity growth, market expansion, and business model innovation.

The European Union is demonstrating varying levels of success in its digital transformation programs. Northern and Western European countries have achieved the highest performance in the digital economy, reflected in the large-scale implementation of artificial intelligence, cloud solutions, automated production systems, and the latest communication technologies. The countries of Southern and Eastern Europe are characterized by an asymmetry in digital transformations, manifested in lower levels of innovation penetration and limited adaptation capabilities among small and medium-sized businesses.

The study shows that the key drivers of the digital economy are the development of human capital, high-quality communication infrastructure, the intensity of digital technology integration into business models, and the efficiency of e-government services. The economy expands faster thanks to digitally literate people with quick access to the network. On the other hand, low digital literacy in some EU countries slows down transformation processes and increases the risks of socio-economic imbalances.

Through digital transformation, enterprises become stronger in their markets, either through increased competitiveness or by providing radical solutions to global problems. Digital technology has furthermore enabled enterprises to persist in times of crisis, not just during pandemics but also during geopolitical crises. At the same time, the accelerating pace of digitalization brought challenges such as the digital divide, cybersecurity threats, and the need for harmonization on various information standards.

Digital transformation creates a new economic system for the EU thanks to technological progress, which is associated with social cohesion, and the digital skills of the population stimulate economic growth.

So, we are presented with a system of formalized dependencies that logically follow from our research: the dependence of GDP per capita on the level of digitalization; the dependence of labor productivity on digital maturity; the model of digital competitiveness; the dependence of economic sustainability on digital maturity; the dependence of the digital intensity of SMEs on human capital; the model of asymmetry of digital development; the dependence of AI implementation on the innovation ecosystem; the dependence of transaction costs on digitalization; the model of the digital dividend; the dependence of cybersecurity risks on digital intensity.

Based on the entire logic of the research, a complex function can be constructed:

$$ED = f(DM, HC, INF, AI, R\&D, CS, GOV), \quad (1)$$

*where:* $ED$ *– economic development;* $DM$ *– digital maturity;* $HC$ *– human capital;* $INF$ *– infrastructure;* $AI$ *– artificial intelligence adoption;* $R\&D$ *– research and development;* $CS$ *– cybersecurity;* $GOV$ *– quality of digital governance.*

In expanded econometric form, the study looks like this:

$$GDPGrowth = \alpha + \beta_1 * DM + \beta_2 * HC + \beta_3 * INF + \beta_4 * AI + \beta_5 * R\&D + \beta_6 * CS + \beta_7 * GOV + \varepsilon. \quad (2)$$

From a scientific point of view, the derived dependencies can be further evaluated and tested on EU panel data. In addition, it is worth using the dependencies to build a DSGE or System Dynamics model. It is likely that the dependencies will be integrated into the EU sustainable development and digital convergence model.

At the same time, we determine key variables (DESI index, GDP per capita, R&D spending, human capital, digital infrastructure indicators, etc.) from official sources (Eurostat) and form a balanced model for 2010-2023. For panel analysis, we use fixed (FE) and random effects (RE) models, dynamic panels (Arellano-Bond), instrumental variables (IV/GMM), and

check the results for stability and causality (tests for autocorrelation, heteroscedasticity, stationarity, cross-sectional dependence, and Grenier causality). To assess "digital shocks", we develop a DSGE model with aggregated agents (households, firms, government), where digital technology is included in the production function or is formed through R&D investments. We calibrate the model on EU data (in particular, on the shares of capital, labor, and human capital in GDP), and conduct a Bayesian assessment of shocks. In addition, we formulate a System Dynamics model with the main components: infrastructure capital, human skills, technology, and digital capital, feedback loops ("digital capital – productivity – growth – investments in digital technologies"), and scenarios (investments in digital education/infrastructure). The results will allow us to integrate digital effects into sustainable development models (using "digital growth" indices and convergence/convergence indicators). The results will also allow for the development of practical recommendations for policymakers: in particular, priorities for investing in digital innovation to stimulate GDP and reduce digital divides. The study has limitations, including the potential endogeneity of variables (e.g., a bidirectional relationship between wealth and digitalization). There is also the risk of bias due to unrecorded shocks and the need to test alternative specifications.

As a result of the study, it was found that the integrated index DTI (Digital Transformation Index) indicates that the digital transformation of EU economies is not linear but systemic and multiplicative. Its construction allowed for aggregating several key dimensions, namely: digital infrastructure, the level of digital skills of the population, business digitalization, e-government, innovative activity, and financial and technological adaptability.

The main results of the DTI are as follows. First, the countries of Northern and Western Europe (Finland, Denmark, the Netherlands, Sweden) have formed a stable "core of digital convergence" with high index values. Second, the countries of Central and Eastern Europe have demonstrated the effects of catching up in digitalization, but with a high asymmetry between technological infrastructure, institutional quality, and digital competencies.

A strong positive relationship was found between digitalization and labor productivity, as well as between digitalization and green transformation, and between digitalization and economic resilience to crises.

The threshold effects presented in Table 1 indicate that after reaching a certain level of digital maturity, economic efficiency gains accelerate. The index showed that digital transformation is a factor in the EU's structural convergence, but at the same time can widen the digital divide between countries with insufficient institutional coordination.

**Table 1. Fixed Effects (FE) and Random Effects (RE) Estimation Results for EU Countries (2010–2023).** Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

| Variables | FE Model (GDP per capita) | RE Model (GDP per capita) |
|---|---|---|
| DTI Index | 0.412*** (0.071) | 0.398*** (0.068) |
| Human Capital | 0.285*** (0.054) | 0.271*** (0.051) |
| R&D Expenditures | 0.193** (0.082) | 0.205** (0.079) |
| AI Adoption | 0.164** (0.067) | 0.152** (0.064) |
| Digital Infrastructure | 0.376*** (0.063) | 0.359*** (0.061) |
| Cybersecurity Preparedness | 0.118* (0.059) | 0.111* (0.057) |
| Institutional Quality | 0.247*** (0.058) | 0.231*** (0.055) |
| Constant | 3.184*** | 3.096*** |
| $R^2$ | 0.71 | 0.69 |
| F-statistic / Wald $\chi^2$ | 42.7*** | 167.4*** |
| Hausman Test | $\chi^2 = 18.63$*** | - |

Econometric testing on panel data of EU countries showed statistically significant relationships between digitalization, innovation, sustainability and economic growth. DTI has a statistically significant positive impact on GDP per capita, productivity, innovation activity, and ESG-efficiency. The study confirmed the long-term cointegration between digitalization, green transition and innovative economy. The dynamic GMM presented in Table 2 shows the presence of lag effects and that digital investments affect the economy with a time lag of 2-4 years.


DOI: 10.55643/fcaptp.4.69.2026.5256

**Table 2. Dynamic Panel GMM Estimation Results.** Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

| Variables | Difference GMM |
|---|---|
| Lagged GDP per capita | 0.624*** (0.073) |
| DTI Index | 0.287*** (0.064) |
| Human Capital | 0.176** (0.071) |
| R&D Expenditures | 0.144** (0.067) |
| AI Adoption | 0.129** (0.058) |
| Digital Infrastructure | 0.221*** (0.063) |
| ESG Factor | 0.117* (0.061) |
| Constant | 2.487*** |
| Arellano-Bond AR(1) | -2.91*** |
| Arellano-Bond AR(2) | -0.84 |
| Hansen Test (p-value) | 0.274 |
| Number of Instruments | 29 |
| Observations | 378 |

The panel VAR presented in Table 3 revealed a two-way relationship in the following context: digitalization stimulates economic growth, and economic growth increases opportunities for digital investment. Heterogeneity of effects was also revealed: in countries with high institutional quality, digitalization has a much larger multiplier effect; in countries with weak institutions, part of digital investments is not transformed into productivity. The conducted model stability tests confirmed the absence of critical multicollinearity, the statistical reliability of the parameters, and the stability of the results when changing the specifications.

The FE and RE estimations demonstrate that digital maturity, digital infrastructure, human capital, and institutional quality significantly influence GDP per capita growth in EU countries. The Hausman test supports the fixed effects model, indicating the presence of country-specific heterogeneity within the European Union.

**Table 3. Panel VAR Estimation Results.** Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

| Dependent Variable | Shock Variable | Short-Term Effect | Long-Term Effect |
|---|---|---|---|
| GDP per capita | DTI Index | 0.214*** | 0.387*** |
| Labor Productivity | AI Adoption | 0.176** | 0.312*** |
| Innovation Activity | R&D Expenditures | 0.231*** | 0.401*** |
| ESG Efficiency | Digital Infrastructure | 0.154** | 0.288** |
| Financial Stability | Cybersecurity Preparedness | 0.137* | 0.249** |
| DTI Index | GDP per capita | 0.192*** | 0.341*** |

The dynamic GMM model confirms the existence of lag effects in digital transformation processes. Investments in digital infrastructure, artificial intelligence, and innovation technologies influence economic growth with a time lag. The model's statistical reliability is confirmed by the Hansen test and by the absence of second-order autocorrelation according to the Arellano-Bond test.

Analysis of the impulse responses verifies the two-way dynamics between digitalization and economic growth. Positive digital shocks have a positive impact on labor productivity, innovative activity, ESG-oriented efficiency, and financial stability, as well as on macroeconomic outcomes.

The DSGE model is built as a system of micro-founded equations for households, firms, the state, the digital sector, and the "green" sector. The key feature of the model is that digital capital is introduced as a separate factor of production. The DSGE model includes various shocks, including technological, digital, institutional, and climate shocks.

System Dynamics is based on both flows and stocks, and on feedback loops. The main blocks of the model are digital infrastructure, human capital, innovation, productivity, CO2 emissions, and institutional efficiency. The loop in the positive

cycle looks like this: digitalization - innovation - productivity - income - new digital investments. The following loop characterizes the negative cycle: digital divide - inequality - weak adaptation - reduced policy effectiveness. The loop in the green cycle is as follows: digital technologies - energy efficiency - emission reduction - increased sustainability.

The obtained research results are integrated into the EU sustainable development model through several levels. The first level is integration into the SDGs model. In particular, DTI is used as an explanatory variable for: SDG 8 (economic growth), SDG 9 (innovation and infrastructure), SDG 11 (sustainable cities). It is worth noting that at this level, digitalization is associated with increased resource efficiency, accelerated green transformation, and reduced transaction costs.

The second level is integration into the digital convergence model. In this case, DTI is used as an indicator showing the speed of digital convergence, structural asymmetry, and digital readiness of countries. The research results showed partial convergence of the EU and the formation of a "digital core" and a "digital periphery."

The third level is integration into EU policy scenarios. The models allow evaluation of programs such as the Digital Europe Program, the Green Deal, Smart Specialization, the AI Act, and NextGenerationEU. Using DSGE/System Dynamics, the effects of subsidies, the impact of digital infrastructure, labor market transformation, and decarbonization are analyzed. The fourth level is integration into forecast models. It should be noted that the obtained dependencies are used for scenarios until 2030-2050. Moreover, both accelerated digitalization and fragmentation scenarios, as well as green-digital synergy and technological polarization scenarios, are modeled.

Let us analyze an example of scenario modeling of the EU development until 2030 within the framework of an integrated model of digital transformation, sustainable development, and economic convergence. The logic of the scenarios is based on a combination of: the integral DTI index, DSGE/System Dynamics approach, panel assessments of EU countries, and SDGs-oriented forecasting. For modeling, we adopt the base horizon of 2025-2030.

The key variables of the model are:

$DTI_t$ - digital maturity;

$GDP_t$ - GDP;

$GTF_t$ - green transition factor;

$HC_t$ - human capital;

$INEQ_t$ - digital inequality;

$CO2_t$ - emissions;

$PROD_t$ - productivity.

Basic structural dependence:

$$GDP_t = f(DTI_t, HC_t, GTF_t, INST_t, INNOV_t) \quad (3)$$

*where:* $INST_t$ *- institutional quality;* $INNOV_t$ *- innovative activity.*

*Scenario 1. Accelerated Digital-Green Convergence (optimistic).*

The assumptions for this scenario are: Digital Europe is fully operational, massive investment in AI, the Green Deal is aligned, fast rollout of 5G/6G, high-paced digital education, and strong use of GovTech and FinTech. The dynamics, according to this scenario, are as follows:

$$DTI_{2030} = DTI_{2025} * (1 + 0.08)^5 \quad (4)$$

It follows that the average DTI growth will be 7-8% per year. Moreover, by 2030, EU GDP growth will be at the level of +16-22%, labor productivity +18-25%, CO2 reduction -28-35%, and the share of AI in the economy will be 18-22% of GDP. In addition, the level of digital convergence is expected to be high by 2030, and innovation activity will accelerate sharply. In this scenario, the systemic effects include the formation of a single, highly integrated digital market, reduced transactional fragmentation, increased resilience to crises, and the "green digital multiplier" effect. Digital capital in the DSGE model becomes the dominant driver of TFP. At the same time, structural unemployment is reduced, and inflationary shocks are stabilized due to automation.


DOI: 10.55643/fcaptp.4.69.2026.5256

*Scenario 2. Fragmented Digital Europe (pessimistic).*

This time, the preconditions are: asymmetric development of EU states; regulatory fragmentation; underinvestment; digital divide; geopolitical disruptions; energy volatility. The dynamics, according to this scenario, are as follows:

$$DTI_{2030} = DTI_{2025} * (1 + 0.025)^5 \quad (5)$$

This implies that the average DTI growth will be 2-3% per year. Labor productivity is expected to be +4-7% by 2030, EU GDP growth +5-8%, and CO2 reduction -10-14%. In addition, the digital divide will increase significantly in 2030, innovations will be concentrated in the "core", and social inequality will increase. In this scenario, a digital core and a digital periphery will be formed, and the technological dependence of individual countries will also increase. At the same time, the System Dynamics model will show an increase in negative feedback loops and the accumulation of structural asymmetry.

*Scenario 3. AI-Driven Hypertransformation (technological breakthrough).*

The scenario hinges on: generative AI becoming mass-adopted; digital systems becoming autonomous; governance being AI-driven; robotics; quantum computing; and tokenization of finance. The key productivity function according to this scenario is as follows:

$$PROD_t = \alpha * DTI_t + \beta * AI_t + \gamma * HC_t \quad (6)$$

Labor productivity, according to this scenario, is expected to be +30-40% by 2030, the share of automated processes is 45-60%, AI contribution to GDP is 25-30%, and the reduction in transaction costs is planned at -35-50%.

At the same time, it is worth noting the risks. In particular, it is worth noting technological unemployment and the growth of cyber risks. In addition, the concentration of digital power is possible. At the same time, we note that this model shows a sharp acceleration in economic dynamics and also indicates a simultaneous increase in the system's instability.

*Scenario 4. Sustainable Resilient Europe (balanced).*

Let us immediately note that this scenario is the most realistic. The conditions in this case are: moderate digitalization, strong regulatory coordination, ESG-oriented policies, fostering digital skills, and assistance to regional convergence. The sustainability model, according to this scenario, will look like this:

$$SD_t = \lambda_1 * DTI_t + \lambda_2 * GTF_t + \lambda_3 * HC_t - \lambda_4 * INEQ_t \quad (7)$$

According to calculations, by 2030 the EU GDP growth will be at the level of +12-15%, labor productivity +14-18%, CO2 reduction -22-27%. We also project a moderate reduction in digital inequality by 2030, along with stable convergence.

The main effect, according to this model, is that digitalization becomes a tool not only for economic growth but also for enhancing the EU's systemic stability.

The comparative scenario analysis is summarized in Table 4.

**Table 4. Comparative Matrix of Scenarios up to 2030.**

| Parameter | Accelerated Digital-Green Convergence | Fragmented Digital Europe | AI-Driven Hypertransformation | Sustainable Resilient Europe |
|---|---|---|---|---|
| GDP Growth | High | Low | Very high | Medium-high |
| Digital Convergence | High | Low | Asymmetric | Stable |
| ESG Effect | Strong | Weak | Uncertain | Maximum |
| Social Stability | High | Low | Medium | High |
| AI Intensity | High | Moderate | Extreme | Controlled |
| Inequality Risk | Moderate | High | Very high | Low |

Therefore, the models show that by 2030, the main factor for the EU's success will not be simply the level of digitalization, but the quality of institutions and the speed of adaptation of human capital. In addition, the integration of digital and green policies, as well as the ability to reduce digital inequality, will be important.

## DISCUSSION

We agree with the opinion of scientists Nimani A., Spahija D., that "since 2020, the global economic system has been seriously affected by the epidemiological crisis caused by the coronavirus infection; the pandemic has had a negative impact on the development of many sectors of the economy, including the financial, transport, social, medical, educational, manufacturing, and logistics sectors" (Nimani & Spahija, 2023).

The analysis confirms that digital transformation has become one of the most influential determinants of financial and economic development in the European Union. The results obtained generally align with the conclusions of Andrei J., Chivu L., Sima V., Gheorghe I. G., Nancu D., and Duică M., who demonstrated that the EU continues to experience significant asymmetry in digital convergence processes (Andrei et al., 2023). The present study additionally confirms that digital divergence directly affects macroeconomic stability, competitiveness, and investment attractiveness among EU member states.

The findings also support the conclusions of Olczyk, M., and Kuc-Czarnecka, M. regarding the positive relationship between DESI indicators and economic growth (Olczyk & Kuc-Czarnecka, 2022). Similar to their results, the conducted analysis demonstrates that digital transformation contributes to GDP growth, especially in economies with lower levels of digital maturity. At the same time, the findings indicate that the effects of digitalization are highly uneven across the European Union, creating risks of long-term technological stratification.

The paper corroborates Török L.'s findings, which state that digitally developed countries are more economically successful and more competitive (Török, 2024). The analysis bears out that nations with a more robust digital infrastructure, human capital, and digital public services are more resilient to financial and geostrategic shocks.

It also corroborates the results of Vărzaru A. A., Bocean C. G., Simion D., Berceanu D., & Mangra M. G., which allow for a positive correlation between digital transformation, sustainability, and government revenue (Vărzaru et al., 2023). Digitalization plays a pivotal role in achieving better public financial management, effective tax administration, and fiscal sustainability, as evidenced by the present findings. At the same time, the findings reveal that the efficiency of digital public finance is contingent on the institutional quality and technology level of national economies.

This study supports the statements of Mihai F., Aleca O. E., and Gheorghe M. regarding the increased contribution of AI, cloud technologies, and IoT systems in enhancing the digital intensity of organizations (Mihai et al., 2023). The study confirms the growing role of AI, cloud technologies, and IoT systems in enhancing organizational digital intensity. The results show that AI-based approaches have a positive impact on operational efficiency, financial flexibility, and innovation capacity. However, the results also suggest that the "digital divide" may widen if some countries are denied access to certain advanced technologies.

The conclusions of this research are consistent with those of Sobczak E., who demonstrated that digital transformation stimulates the development of knowledge-intensive sectors and influences employment structures (Sobczak, 2025). The conducted analysis confirms that digitalization increases demand for highly qualified labor while simultaneously intensifying labor-market polarization and structural transformation.

The study also supports the findings of Naeem M. H., Subhan M., and Alam Md. Sh., Al-Faryan M. A. S., and Yameen M. regarding the positive influence of financial innovation on economic growth (Naeem et al., 2023). The present analysis confirms that fintech development, digital banking systems, and electronic financial services improve capital accessibility and strengthen financial market efficiency. At the same time, rapid financial digitalization increases systemic cybersecurity risks and technological dependence.

The current research corresponds with the conclusions of Boros E. and Horváth M. concerning the growing significance of Central Bank Digital Currencies in the transformation of modern monetary systems (Boros & Horváth, 2022). The findings indicate that CBDCs may become an important instrument for strengthening financial sovereignty and increasing the operational flexibility of central banking systems within the European Union.

This analysis also confirms the findings of Kyriazis N. A. and Economou E. M. regarding the influence of geopolitical turmoil on decentralised financial markets (Kyriazis & Economou, 2025). The Russia–Ukraine conflict and escalating geopolitical tensions fuelled demand for decentralized financial products and other digital-based alternative financial structures. The research shows that geopolitical uncertainty hastens the development of financial infrastructure, and where technological sovereignty becomes more strategically significant.

The results also corroborate the findings of El Khoury, R., Nasrallah, N., Hussainey, K., and Assaf, R., which showed that geopolitics fostered more meaningful interactions among the fintech markets, the ESG systems, and the renewable energy


DOI: 10.55643/fcaptp.4.69.2026.5256

sector (El Khoury et al., 2023). This study reveals that the digital transformation is increasingly linked to sustainability strategies and green finance instruments, especially under the European Green Deal.

The findings of this paper also affirm the arguments of Quaglia, L., and Verdun, A., on the ever-increasing geopolitical importance of digital financial infrastructure and financial sanctions (Quaglia & Verdun, 2023). The analysis also confirms that digital finance has become a key pillar of economic security, and that technological mastery of financial systems is increasingly a determinant of geopolitical power.

The study also supports the conclusions of Karadayi-Usta S. concerning sustainability-oriented digital transformation in the European Union (Karadayi-Usta, 2024). The findings demonstrate that digital technologies contribute to resource efficiency, environmental sustainability, and smart energy management systems. Nevertheless, the results additionally indicate that the green transition and digital transformation require substantial investment resources and coordinated institutional policies.

The impact of sustainability on financial resilience, as discussed by Bruno C.C. and Henisz W.J., is also evident from the current study (Bruno & Henisz, 2024). Mechanisms of governance based on ESG enhance the financial soundness and resilience of economic systems during times of crisis and uncertainty.

The results of the investigation reveal that digital banking enhances both operational flexibility and access to financial services, but it also creates new cyber and technological threats to the European financial industry.

The impact of the digital economy on financial efficiency and public finance reform was also found in our study. The results show that digitalization enhances revenue potential, increases administrative transparency, and improves efficiency in digital public governance.

The conducted analysis additionally demonstrates that innovation-oriented digital ecosystems strengthen regional competitiveness and facilitate technological modernization across EU countries.

The current research confirms that digital transformation creates positive long-term effects for productivity growth, innovation activity, financial development, and international competitiveness within the European Union.

The analysis demonstrates that sustainability-oriented digitalization strengthens resilience against economic and geopolitical instability and supports the implementation of long-term green transition strategies within the European Union.

Findings on geopolitical risk and financial instability are also in line with those of Wang Zh., Liu Sh., Wei Yu., & Wang Sh. (Wang et al., 2023). The achieved results show that war and geopolitics have a major impact on the stability of the financial market and the investment system, which in turn affects macroeconomic stability. Similar trends were observed by Pandey D. K., who highlighted the growing importance of geopolitical uncertainty in determining the behaviour of modern financial markets.

In summary, the discourse that has been compiled has allowed us to see that digital transformation has both positive and destabilizing effects on the development of finance and the economy in European Union countries. On the plus side, digitalization is positively related to productivity growth, financial innovation, fiscal modernization, sustainability, and macroeconomic resilience. Meanwhile, the exponential growth of digital technologies is also exacerbating risks related to cybersecurity, technological dependence, labor market polarization, and the digital divide within and across EU member states.

Thus, the findings of this research suggest that digital transformation success in the European Union is not merely contingent upon technological modernization but rather on the degree to which governments can enable institutional adaptability, strategic digital governance, cybersecurity resilience, investment in human capital, and equitable regional digital development. In this regard, a concerted European digital policy is the essential presumption for safeguarding long-run economic competitiveness and financial stability in an era of increasing global uncertainty.

One of the limitations of the study is the possible influence of unaccounted external factors. The results may be affected by geopolitical events and economic crises. Certain limitations are related to the availability of statistical data from EU countries. The digitalization indicators used do not cover all technological aspects of transformation. There may be endogeneity between digitalization and economic growth. Some effects of digital investment appear only after a certain time. The results obtained depend on the selected model assumptions of the study. Differences in national institutions may change the strength of the identified relationships. Some digital processes are characterized by a high rate of modern changes. Therefore, the results require periodic updating and additional verification.

## CONCLUSIONS

Based on the evidence analysis, the digital transformation process is nowadays one of the key determinants of the financial and economic growth of the EU-27 states, in the context of increased competition in technology, the unpredictability of geopolitics, and the restructuring of the world economy. The results of the study indicate that digitalization plays an important role in ensuring macroeconomic stability, productivity growth, competitiveness, innovation, financial soundness, and in enhancing the resistance of economic systems to external shocks. At the same time, the analysis results show that the impact of digitalization within the EU is still uneven due to large disparities in the level of digital maturity, technological readiness, infrastructure, and quality of human capital across the Member States.

The analysis demonstrated how digital technologies – including artificial intelligence, cloud computing, blockchain platforms, fintech solutions, and digital government – are becoming political-economic tools for modernization. Their application in industry, finance, energy, and services allows for cutting transaction costs, increasing operational flexibility, spurring innovation, and enhancing labor efficiency. On the other hand, the findings also confirmed that more digitally ready countries are more resilient to crisis phenomena, such as the ripples of the COVID-19 pandemic, contemporary geopolitical instability, and the disruption of global value chains.

The study additionally demonstrated that digital transformation intensifies structural differentiation between EU countries. Northern and Western European states maintain leading positions due to developed innovation ecosystems, high levels of digital literacy, substantial investment in research and development, and advanced digital infrastructure. In contrast, several Central and Eastern European countries continue to face limitations due to insufficient digital infrastructure, limited investment capacity, weaker institutional support, and shortages of qualified human capital. Such asymmetry creates risks of long-term digital fragmentation within the European Union and threatens the balanced development of the single European market.

The study verified that human capital and digital skills continue to play key roles in the determinants of a successful digital transformation. The digital competence level directly influences the speed of innovation diffusion, the degree of enterprise digitization, and the labor market's reaction intensity to technological changes. Meanwhile, the rapid growth of automation and artificial intelligence technology exacerbates the risk of labor market polarization and structural employment transformation, which demand the renewal of educational systems and lifelong learning mechanisms.

Special attention was given to the nexus between digitalization and the financial system. The results suggest that the development of fintech, digital financial services such as internet banking and mobile money, electronic payment mechanisms, and DFIs contributes to increasing financial inclusion and enhancing financial stability. Yet, with increased reliance on digital infrastructure, there is also a rising threat to cybersecurity, technological and systemic risks, and financial system risks. The analysis carried out reveals that cybersecurity and technological sovereignty are increasingly important elements in the EU's long-term economic security.

The studies also confirmed an increasing convergence between digitalization and sustainability in the modernization of the economy. Digitalization enables energy efficiency, intelligent resource management, renewable energy integration, and ESG-focused governance models. In this perspective, digitalization and the Green Deal are shaping up more and more as a pair of interrelated, strategic directions of EU development policy. At the same time, the execution of digital and green transformation is an expensive process, requiring institutional coordination and congruent regulatory regimes.

The results showed that the success of EU digital policy depends not only on the technological modernization process itself but also on the extent to which governments can foster institutional adaptability, invest in innovation systems, protect cybersecurity, promote balanced regional development, and pursue coordinated economic governance. The execution of the "Digital Decade 2030" strategy needs to narrow the digital divide among Member States, increase digital infrastructure, enhance technological sovereignty, and promote innovation-intensive industries.

Therefore, the impact of digital transformation on the financial and economic development of the EU states is double-sided: both a significant opportunity and a systemic risk. Digitalization promotes growth in productivity, innovation, financial development, and macroeconomic stability on the one hand. It also increases processes of cybersecurity, technological dependence, digital fragmentation, and socio-economic asymmetries. As a result, the future competitiveness and sustainability of the Union will hinge on whether Member States can marry technological advancement with inclusive growth, institutional reform, strategic digital governance and coordinated European economic policy in an environment of escalating global uncertainty.

Prospects for further research are related to the assessment of the long-term consequences of digitalization. Particular attention should be paid to digital investments and institutions. It is advisable to use modern panel econometric models


DOI: 10.55643/fcaptp.4.69.2026.5256

of analysis. An important direction remains the study of lagged digital effects. The impacts of artificial intelligence on the economy require further study. It is necessary to investigate the relationship between digitalization and cybersecurity of states. It is promising to improve integral indices of digital maturity. It is important to combine them with indicators of sustainable development. Of particular interest is the assessment of digital and green transformation. It is advisable to model scenarios of digital convergence of the countries of the European Union. An important task remains the reduction of interstate digital disparities.

## ADDITIONAL INFORMATION

### AUTHOR CONTRIBUTIONS

*All authors have contributed equally.*

### FUNDING

*The Authors received no funding for this research.*

### CONFLICT OF INTEREST

*The Authors declare that there is no conflict of interest.*

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*Поліщук В., Іщук Л., Ніколаєва А., Вахновська Н., Пиріг С.*

## ВИКЛИКИ ЦИФРОВОЇ ТРАНСФОРМАЦІЇ ТА ЇХ НАСЛІДКИ ДЛЯ ФІНАНСОВО-ЕКОНОМІЧНОГО РОЗВИТКУ ДЕРЖАВ ЄС

Цифрова трансформація формує сучасний курс економічного розвитку країн Європейського Союзу. Вона зміцнює конкурентоспроможність економік і стимулює інновації та продуктивність праці. Однак цифровізація також несе ризик нерівномірного розвитку між країнами та секторами. Особливо важливими є питання цифрової зрілості, безпеки та сталості. Метою цього дослідження є поглиблений аналіз викликів, що виникають унаслідок цифрової трансформації для економіки Європейського Союзу. Також оцінено вплив цифровізації на фінансовий та економічний розвиток. Дослідження охоплює технологічні, інституційні, соціальні та фінансові аспекти цифровізації. Методологія базується на статистичному, економетричному та сценарному аналізі. Використані панельні моделі, підхід DSGE та моделювання системної динаміки.

Виявлено значний позитивний вплив цифровізації на економічне зростання держав-членів. Було проаналізовано прискорення продуктивності праці завдяки впровадженню сучасних цифрових технологій. Було досліджено виникнення цифрового ядра між країнами Північної та Західної Європи. Підтверджено існування цифрової асиметрії між різними державами-членами Європейського Союзу. Встановлено зв'язок між цифровою трансформацією, інноваціями та сталим розвитком економіки. Досліджено позитивний вплив цифрової зрілості на макроекономічну конкурентоспроможність країн. Підкреслено існування порогових ефектів цифровізації на економічну ефективність. Запропоновано перспективні сценарії цифрового розвитку Європейського Союзу до 2030 року.

Це дослідження підтвердило системний характер цифрової трансформації економіки. Цифровізація є значним рушієм економічного зростання та конвергенції. Однак ризик цифрової нерівності й технологічної залежності залишається. Ефективність цих трансформацій залежить від інституційного потенціалу країн та інвестицій. Розвиток цифрових навичок серед населення та інфраструктури залишається пріоритетом, хоча кібербезпека, інновації та скоординована цифрова політика також є важливими.

**Ключові слова:** інноваційні технології, цифрова зрілість, людський капітал, інфраструктура, кібербезпека, DTI index, DSGE-модель, System Dynamics модель, конкурентоспроможність, асиметрія розвитку

**JEL Класифікація:** O33, O52, C33, E37, F42, G28


DOI: 10.55643/fcaptp.4.69.2026.5256