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# REFRESHING THE DESIGN OF A REGIONAL ECONOMIC GROWTH MODEL IN THE CONTEXT OF THE NEW DIGITAL DECADE

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**Abstract.** The digital economy is a significant objective of future development of the European space and is included alongside other strategic objectives in the 2030 and 2050 Agenda of the European Union. According to the European Union's Digital Economy and Society Index (DESI), the Nordic countries (Finland, Denmark, the Netherlands, and Sweden) are the top performers of the European Union. In the same time, Romania ranks last in the 2022 ranking. Current research analyses the four areas of the digital economy (human capital, digital technology integration, connectivity, and digital public services) in a mix that is correlated with regional indicators of sustainable development to design a regional model of digital economy growth. The methods of study include restructuring the DESI rankings and regional reclassification based on the criteria of correlative ranking of digital economy indicators in correlation with sustainable development indicators and the design of structural equations. The study results will form the basis of a public policy proposal to accelerate digital development for disadvantaged European regions.

**Keywords:** digital economy, regional development, sustainable economic growth, structural equations.

**JEL Classification:** O3, R58, Q01.

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## 1. Introduction

In the current social and political context, digitization has the potential to drive global economic growth, its evolution being fostered by the COVID-19 pandemic-related constraints and the need to progress sustainably. In the pandemic and post-pandemic periods, telework has developed at an accelerated pace, increasing its share from 32% at the end of 2019 to 55% in July 2020 at the European Union (EU) level (McKinsey & Company, 2020). In this context, the European labour market registered a record level of one million specialists entering the information technology sector (Eurostat, n.d.-c). A significant contribution was made by the development and use of artificial intelligence in business. In contrast, using big data has been difficult due to the lack of digital skills (McKinsey & Company, 2020). In the same context, different developments occurred at the regional level between large firms and SMEs, as almost ¾ of large firms turned to cloud services, compared to less than 50% of SMEs (Eurostat, n.d.-a). The European Commission is concerned with developing sustainable solutions that enable the digital transformation of the European Union, and correspondingly, it has set three major objectives for the period 2020–2025: technologies that support the needs of citizens; developing a fair and competitive economy; achieving an open, democratic and sustainable society.

The European concept of digitalisation is based on the values of a democratic society fostering the well-being of European citizens. In the context of using the digital solutions, economic excellence will be promoted and supported by specific implementation measures. The current and future digitisation goals must increase public confidence in achieving a developed European economy and its best international position. Both goals will increase global equity and ensure a better understanding of the digital economy.

The digital economy is an alternative to the classical economy, supported by investment and research-development-innovation efforts from the European fora and the Member States, which understand the importance of the field in the context of the pandemic and geopolitical crises.

At the EU level, there are steps to improve digitalisation of the less developed member states, with Italy, Poland and Greece making significant progress in this area over the last five years through their efforts and European funding. Overall, member states have an EU allocation of 127 billion Euros to reform and develop digitisation at national and regional levels in line with social cohesion policy and the digital decade (The European Parliament & The Council of the European Union, 2021). As a requirement for financing national recovery and resilience plans, the European Commission has set a threshold of at least 20% for digital transformation. In countries such as Austria and Germany, the level of funding for digitisation targets exceeds 50%, while in Ireland, Lithuania and Luxembourg, the percentage of allocations exceeds 30%. The lowest allocations for digitalization are found in countries such as Romania and Croatia. Most states (17 out of 25) have foreseen allocations between 21 and 27% for the digital targets. Most digital projects developed through the national recovery and resilience plans target objectives such as developing microelectronics, developing European digital innovation hubs, and cloud technologies. Another significant chapter in these plans is the development of 5G corridors. At the opposite pole, no projects have been submitted for digital vocational education.

In the context of the military conflict in Ukraine, the importance of developing digital solutions, technologies, and related infrastructure is growing, and so is the need to strengthen cyber security. As a result, the European Code of Practice on Misinformation and the Document on Digital Services has been revised at the European level to enhance security measures in the use of online platforms (The Council of the European Union, 2014). The European Commission recognizes that EU Member States will have different contributions in implementing the Digital Decade, yet European principles and values in this area will be continuously upheld at a national level. The main objectives of the Digital Decade are to increase the digital capacity of professionals, ensure a secure and sustainable digital infrastructure, transform businesses, and digitize public services.

Despite these efforts, there are still significant research gaps in the field of digital economy and regional development. Previous studies have largely focused on specific aspects of the digital economy (Li et al., 2025; Liang & Li, 2023; Skare et al., 2023; Zhao & Weng, 2024), such as human capital development (Boon et al., 2024; Jiang et al., 2024; Lu et al., 2023), integration of digital technologies (Holzmann & Gregori, 2023; Kwilinski, 2024; Wei et al., 2025), or connectivity (Bănică et al., 2024; Garashchuk et al., 2025; Reveiu et al., 2023), but few have addressed these dimensions comprehensively within a unified framework (Liu et al., 2024; Plekhanov et al., 2023). The lack of an integrative approach combining all four core components of the digital economy (human capital, digital technology integration, connectivity, and digital public services) in the context of regional development represents a gap in the current body of knowledge. This fragmented perspective limits our understanding of how these factors interact and contribute to sustainable economic growth at the regional level.

The present study seeks to fill this gap by proposing a novel model that interlinks these dimensions in a structured manner. By correlating the Digital Economy and Society Index (DESI) indicators with regional sustainable development indicators, this research provides a comprehensive framework to identify and address disparities in digital economic development across European regions. This approach not only highlights the multifaceted nature of the digital economy but also offers actionable insights for policymakers aiming to foster balanced and inclusive growth.

The paper aims to analyse the four areas of the digital economy in a mix correlated with regional indicators of regional development to identify regional disparities in the digital economy's growth and formulate appropriate public policies to accelerate sustainable digital development.

The objectives of the study are to analyse the literature on the results of the development of the digital economy in the framework of the strategic goals of alignment with sustainable development (O1), to consolidate a database on sustainable regional development to identify the key variables for model design (O2); to design the new regional model of economic growth in the context of the new digital decade (O3) and to formulate public policy proposals to accelerate the digital transformation in disadvantaged European regions (O4).

## 2. Literature review

In the current context within the European Union, the accelerated dynamics of digital technological progress has emerged as a key determinant of regional economic growth. An in-depth review of the literature on disparities in regional development is thus necessary, focusing on various indicators of the digital economy, such as human capital, digital technology integration, connectivity and socio-economic development. Such analysis is vital to unravel the complexity of the interactions between digitization processes and sustainable growth at the regional level, thus providing a solid basis for formulating effective policies to support this transition.

## 2.1. Analysis of regional disparities in human capital

Previous studies have emphasized both the essential role of human capital in fostering the development of the digital economy, in particular in the context of the European Union's strategic objectives for sustainable development, and the positive correlation between technological innovation, economic resilience and human capital, highlighting the essential role of digital technologies and human capital in mitigating the impact of adverse economic shocks.

The correlation between human capital – and sustainable regional development is analysed by Çakar et al. (2021) based on a survey covering 21 EU Member States from 1994–2018. Statistical data are modelled using a panel smooth transition regression model. With accelerated regional economic growth, the authors find the impact of human capital in terms of increased carbon dioxide emissions. A similar effect is found for regions with scarce financial resources. However, the authors support investment in human capital because they believe it stimulates innovation and improves regional environmental protection. An additional stimulus for human capital development is digitalization. Using regression analysis, several authors (Grigorescu et al., 2021; Tiganasu & Lupu, 2023; Hernández de Rojas et al., 2024; Cave, 2023, among others) addressed the connection between digitisation, human capital and well-being across EU Member States. The analyses show a direct positive connection between the digitization of the economy, human capital development and the increase in the population's well-being.

The question of digitization' impact in terms of factors such as talent, tolerance, technology, and the imprint it has on regional economic management is discussed by Belitski et al. (2023). The analysis covers the 2008–2015 period and 112 regions in 21 European countries. This analysis focuses on the role of digital technologies in the emergence of new firms and employment based on the premise that there is a complementarity between digital technologies, culture and human capital development at a regional level.

An interesting regional analysis by Cappelli et al. (2021) quantifies the impact of economic crises on the link between economic and technological resilience. The authors define a technological resilience variable for each region based on the region's 'historical' ability to maintain its level of knowledge in face of adverse shocks. The analysis concludes that the level of regional economic development determines an interaction between technological resilience and human capital. In addition, technological resilience and human capital are weakly effective in protecting women and older workers during economic downturns. Disparities in these correlations are extremely high at the regional level across the EU.

According to Égert et al. (2020), financing higher public spending on education has positive effects on human capital and per capita income. The authors also consider educational management measures aimed at prioritizing preschool education, increasing the autonomy of educational institutions at all levels, lowering pupil/teacher ratios, etc. Attention is drawn to these measures, especially for European countries facing ageing populations and significant fiscal constraints. The financing of investment in human capital through the EU's European cohesion policy at NUTS IV and V level is studied by Biedka et al. (2022) in the case of Poland. The authors emphasize the direct correlation between investment in human capital and income levels at the municipal level. Also, interventions on net migration and the effectiveness of cohesion policy assistance positively affect regional development.

Using a modified Nelson-Phelps model, authors such as Akhvlediani and Cieślik (2020) quantify human capital's impact on regional total productivity growth. The analysis covers EU Member States over the 1950–2014 period. The first conclusion of this research is that there is a clear correlation between human capital, technological progress and the diffusion of its effects. On the other hand, this process is very different across Member States, so it cannot support European convergence. Countries on the periphery of the EU and non-EU countries are even worse off in this respect.

An interesting correlation between human capital, education, health and regional economic development was addressed by Demirgüç-Kunt and Torre (2022) based on the definition of an indicator capable of quantifying the level of human capital development. The analysis covers the more developed countries in Europe and Central Asia, and the newly defined index exceeds the World Bank's Human Capital Index. The analysis results are atypical, to say the least, with the authors stating that in countries with an average level of development, newborn children will have a productivity 50% lower than those in developed countries due to the health and education conditions they will benefit from throughout their lives. On the other hand, potentially good human capital development outcomes in economically developed countries and regions may be offset by the high prevalence of adult health risk factors (smoking, obesity, incidence of certain cancers, etc.).

Some authors, such as Jagódka and Snarska (2023), consider that the unequal distribution of human capital and innovation drives regional disparities in economic development. The authors aim to quantify the speed at which economically underdeveloped regions can catch up with developed regions by promoting human capital.

### 2.2. Analysis of regional disparities related to the integration of digital technologies

Teruel et al. (2022), among others, have studied new digital technologies and their impact on the internationalization of fast-growing European firms. The analysis covers the EU27 and the United Kingdom and highlights a positive relationship of dependence between internationalised firms and those that adopt new digital technologies. Foreign direct investment plays a significant role in this process. Connectivity supported by digitization can lead, according to Głowacka et al. (2021), when human rights issues arise. The authors believe that EU legislation on the development of new digital technologies must be harmonized with combating "digital authoritarianism" so these technologies do not serve the interests of authoritarian regimes.

Shaping the security policies of technology companies is a challenge for European regional development in the context of connectivity development. Mügge (2023) believes that security policies must be extended to areas dominated by commercial motives. Due to the new challenges we face in this area, the EU is implementing a regulation on the use and effects of artificial intelligence. The issue of implementing this directive becomes even more critical in the context of the complex possible uses of artificial intelligence for military purposes.

According to research by Usai et al. (2021), the development of digital technologies and connectivity is improving, among others, the innovative capacity of companies at the regional level. Practical examples of the use of current digital technologies, however, lead in most cases to the conclusion that they have a very low impact on firms' innovation performance. The statistical information is analysed using the main components and multivariate variance methods, and EU27 is covered. The main result of the research is that research and development spending is the most reliable predictor of innovation.

The correlations between financial resources, turnover, sustainability and digital technologies SMEs use in the pandemic crisis are analysed by authors such as Del Baldo et al. (2022) using a multi-criteria model. The authors analyse SME statistics in the context of EU regions using multiple linear regression, clustering techniques and correlation analysis. An exciting study by Elia and others (Elia et al., 2021) focuses on digital export drivers for 102 firms in different regions of Italy. These firms operate in design, furniture, fashion, food, and beverages, pursuing internationalization through digital technologies. The analysis reveals that irrespective of their size, firms that leverage digital technologies increase their digital exports faster.

Research also links human capital with the digital transformation of EU regions. A team of specialists (Švarc et al., 2021) build on an extensive meta-analysis in the field and defined a conceptual model of human capital preparedness for digital connectivity. Significant disparities in human capital preparedness for digitalization and connectivity across EU regions were highlighted. According to Rusch et al. (2023), digital technologies and connectivity support sustainable economic development of EU regions. The meta-analysis conducted in this respect concludes that circular economic development can creatively support increased connectivity at the regional level through digital technologies. The problem of the connection between digital technologies, connectivity and the circular economy was resumed by Schöggl et al. (2023), which, based on a questionnaire applied to managers of 132 companies from different regions of Austria, believes that Internet of Things (IoT) technology is the most widely implemented, followed by extensive data analysis, artificial intelligence and blockchain technology. The information collected highlighted the significant regional disparities related to the deployment of digital technologies and digital connectivity.

## 2.3. Analysis of regional disparities related to connectivity

The European Commission supports cooperation under the European Digital Connectivity Agenda 2030. According to a study by Okano-Heijmans and Vosse (2021), this agenda must be coupled with digital cooperation with third areas, such as the Indo-Pacific region. According to the authors, the EU's focus on increasing digital connectivity with the Indo-Pacific is underpinned by the sustained economic development, the impact of China's Digital Silk Road and the consequences of the US-China technology conflict. Widmann (2021) took up the issue of Europe-Asia digital connectivity. The author emphasizes that the EU wants to expand digital connectivity with Africa and Latin America. Concrete policy recommendations are identified in this context on financing, sustainable deployment of digital connectivity as well as possible cooperation with the US and China. In this context, the EU aims to become a promoter of global digital connectivity.

Comprehensive research by Ha et al. (2022) considers indicators such as digital connectivity, digitally skilled human capital, internet use, integration of digital technology in business and digital public services to determine the environmental impact of digitization. The analysis covers 25 European countries over the 2015–2020 period. The study's results argue that digital connectivity improves environmental performance, even if digitization has adverse short-term effects. Digitization in terms of digital connectivity, internet uses, e-business, e-commerce and e-government is studied by Ha (2022) regarding the impact on European regional financial markets and institutions. The authors find that digital connectivity boosts access to financial markets. E-commerce and e-government will positively impact regional financial markets in the long term.

Some researchers, such as Karjalainen (2023), underline the financial limits faced by the EU in realizing the Single Market for connectivity compared to the amounts allocated by China for the Belt and Road Initiative. The solution found by the EU in this geopolitical competition is to compensate the lower investment with quality connectivity capable of providing more secure and cheaper services to beneficiaries. A study of the official documents in this area shows that this new EU27 regional connectivity strategy supports regionalism, prescribes connectivity standards and defines values to be applied in connectivity projects.

Public digital connectivity, public governance and digital transformation at the EU27 level are studied by Crăciun et al. (2023) using longitudinal data modelling over the 2010–2021 period. Multiple statistical and econometric approaches are used to process regional statistical data (structural equations, Gaussian and Mixed-Markov modelling, Gauss-Makovian graphical models). The authors find that there is an actual demand for digital services to be connected, predominantly fixed and mobile broadband.

The digital convergence of European regional-specific markets through connectivity was analysed by Borowiecki et al. (2021); the Digital Economy and Society Index (DESI) for the 2015–2020 period shows an inevitable convergence between the digital economy's development and society through connectivity, human capital, use of internet services and digital public services. The DESI index is also used by some specialists, such as Ghazy et al. (2022), and the analysis results show a strong correlation between digital connectivity and entrepreneurship. The DESI index with five components (including digital public services) is used by authors such as Laitsou et al. (2020) to quantify the competitive advantage of Greek firms and regional economies. The authors define and test a new model on the digital competitiveness of Greek regions. The model implementation results highlight that Greece exhibits a low level of digital connectivity and faces institutional and governmental constraints in this area. Convergence of digitization in the European Union in terms of DESI over the 2015–2020 period is presented by Andrei et al. (2023). The process of digital convergence at regional level is also tracked through the gross value added and education index indicators. It can be observed that the digitalization gap between EU countries tends to narrow, which may also have positive effects on regional economic development. Europe's digital sovereignty over digital platforms and cyberspace is a challenge addressed by Renda (2020). The author makes a critical analysis of European Commission documents on digital data, the Internet Access Regulation, the Digital Services Act or the European Cloud Federation and find that all these regulations are insufficient to support the EU as a world leader in the sustainable use of digital technology and connectivity.

### 2.4. Analysis of regional disparities in socio-economic development

The production of essential goods and services is critical for Hansen's conception (Hansen, 2022) of regional economic development policies. In studying this issue, the author identifies three significant challenges related to social polarization, interregional inequality and environmental sustainability. Using a sample of 229 European regions, Barbero and Rodríguez-Crespo (2022) analyse the impact of information and communication technologies on economic development and reducing the risk of exclusion. The analysis covers the 2007–2018 period and concludes that institutional and geographical factors can also contribute to the definition and implementation of viable regional economic development policies.

Other authors, such as Hervas-Oliver et al. (2020), argue that digitization supported by digital innovation hubs supports regional economic development. The authors analyse ten digital hubs in Spanish regions in the context of promoting multi-actor collaboration platforms. Such platforms incentivise public-private partnerships to support initiatives to digitize regional economic activity. The high spillover effects of the digital economy on regional development were studied by Pircoiog et al. (2023) through indicators related to job creation, economic resilience and sustainability. The analysis covers the 2008–2018 period and focuses on NUTS2 regions in the EU27, the United Kingdom and Norway. Combining econometric techniques with geographic localization allows quantifying the regional potential for digital innovation with specific economic effects. Several authors, such as Jenčová et al. (2023), Bruno et al. (2023), Teixeira and Tavares-Lehmann, (2022), Senna et al. (2023) study post-pandemic digital economic development disparities using DESI. The analysis shows that there are internally homogeneous and externally heterogeneous groups of countries within the EU countries regarding DESI rankings.

A taxonomy of the leading European approaches to rural digitization and highlighting of good practices in the field is provided by Feurich et al. (2023), starting from the idea that EU Member States apply fragmented and different digitization to their regions. The authors follow a cluster approach and group Member States according to how much they use digital technologies.

## 3. Methodology

This study employs Structural Equation Modeling (SEM) to analyze and validate the relationships between key dimensions of the digital economy (human capital, digital technology integration, connectivity, and regional development) and sustainable regional growth indicators. SEM is particularly suited to this research because it allows for the simultaneous examination of multiple dependent and independent variables, accounts for measurement error, and integrates latent variables derived from observed data. The used indicators are:

- Human Capital (CU): PO – employed population (Eurostat, n.d.-d);
- SOM – unemployed stock (Eurostat, n.d.-c);
- Connectivity (CN): IA – Internet access for households; IIA – Internet access for individuals; Eurostat ICT Usage in Households and by Individuals (Eurostat, n.d.-f);
- Integration of digital technologies (TD): LAC – lack of access to computers; ED – use of digital economy; Eurostat The Digital Economy and Society Index (European Commission, n.d.-d);

- Regional development (DR): PIBR – Regional GDP/inhabitant at purchasing power parity in 2010; VABR – gross value added at regional level. Eurostat Gross Domestic Product (GDP) and Gross Value Added (GVA) in Volume by NUTS 2 Regions (Eurostat, n.d.-e).

The indicators were collected from the Eurostat database (n.d.-b) and cover the period of 2011–2022. The selection criteria for data included relevance to the four dimensions of the digital economy (human capital, digital technology integration, connectivity, and digital public services), alignment with sustainable development indicators, and availability across all EU regions. Specific indicators, such as employed population, household internet access, regional GDP per capita, and the use of digital public services, were selected based on their representativeness. Data inclusion required completeness for the analyzed period, and datasets with significant missing values were excluded to maintain the integrity of the analysis. Outliers were identified using interquartile range (IQR) analysis. The interquartile range (IQR) method was applied to identify and manage outliers across the dataset. For each key indicator (e.g., digital connectivity, regional GDP), Q1, Q3, and the IQR were calculated. Data points falling outside the lower and upper bounds ($Q1-1.5\times IQR$ and $Q3+1.5\times IQR$, respectively) were flagged as outliers. Identified outliers (519 of 23233 obseservation) were addressed through winsorization to mitigate their influence while preserving the dataset's integrity. This approach ensured that the analysis remained robust and unbiased by extreme data points. Statistical methods based on structured equation modelling were applied, assigning correlation values of the indicators with the four analysed parameters (human capital, digital technology integration, connectivity and regional economic development) and calculating the correlation differences using the dedicated AMOS software.

The analysis was performed for the following defined working Hypotheses:

**H1:** *Under conditions of significant regional disparity, the value of unitary digital economic development tends to dissipate, requiring public policy intervention to accelerate reforms in less developed regions.*

**H2:** *The trend of digital regional development shows inertia concerning the multi-annual strategic objectives and is sensitive to general drivers (pandemics) for the digital economy.*

**H3:** *The development of digital technologies to accelerate the transfer to the European digital economy is possible under normal economic conditions, with changing priorities as an unfavourable factor in the context of the dependence of sector's development on a significant need for funding.*

**H4:** *Access to digital technologies is directly influenced by the need to use digital technologies, especially in times of crisis (pandemic, geopolitical, etc.).*

**H5:** *Periods of economic stability and prosperity significantly influence the digital capacity and skills of citizens, ensuring that the transition to a sustainable digital regional economy accelerates.*

**H6:** *Increasing the digital capacity of human resources is directly dependent on the existence of a stable and sustainable macroeconomic climate and the promotion of effective policies to develop the digital capabilities of human capital.*

**H7:** *A strong and sustainable economic infrastructure is a prerequisite for accelerating the digital economy.*

After defining the correlations, the residual variables were assigned to each parameter, and the regression standardisation level was tested annually by means of factor coefficients and by determining the squares of multiple correlations. The estimation of correlations was tested for each of two output variables of the four tested, obtaining the table of variables, the summary of parameters, and the results of the estimators as regression coefficients, standardized covariance coefficients and squared multiple correlations. Model results were validated by baseline comparisons of the Bentler-Bonett normalized fit index (NFI) which compares the fit of the proposed model to a null or baseline model, where no relationships exist between variables, Tucker-Lewis Index (TLI) which adjusts for model complexity, penalizing overfitting, the Bollen incremental fit index (IFI), which measures how well the proposed model fits the data compared to a baseline model, the comparative fit index (CFI) which compares the fit of the proposed model to an independent baseline model and Root Mean Square Error of Approximation (RMSEA) which assesses how well the model approximates the data per degree of freedom. Annual validation was conducted by recalibrating the model with updated datasets, ensuring robustness across temporal and regional contexts. Bayesian inference was also applied to optimize parameter estimates and enhance model stability.

The conceptual model used for annual multiple correlation testing is shown in Figure 1.

Testing the model over the years led to the following regional annual growth patterns of the digital economy:

The projected annual models (Figure 2) revealed a significant regional gap in terms of the development and acceleration of digitization, especially on the branch of correlations between regional development outputs in line with the exploitation of digital technologies, but also on the branch of connectivity exploitation in line with the level of European regional development. Stable results were obtained for the link between human capital and connectivity until the pandemic when the indicators showed significant regional asymmetries.

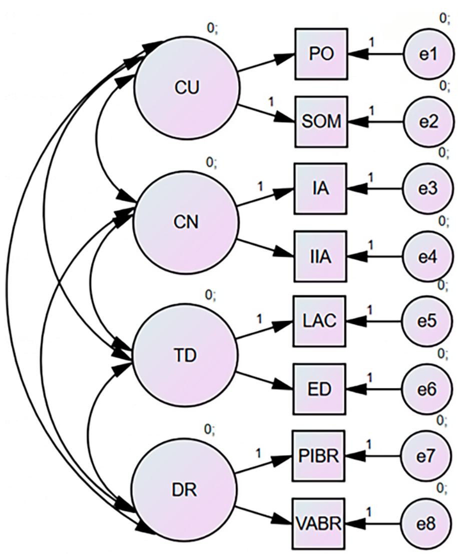



**Figure 1.** Conceptual model
(source: developed by the authors using AMOS Graphics software version 21)

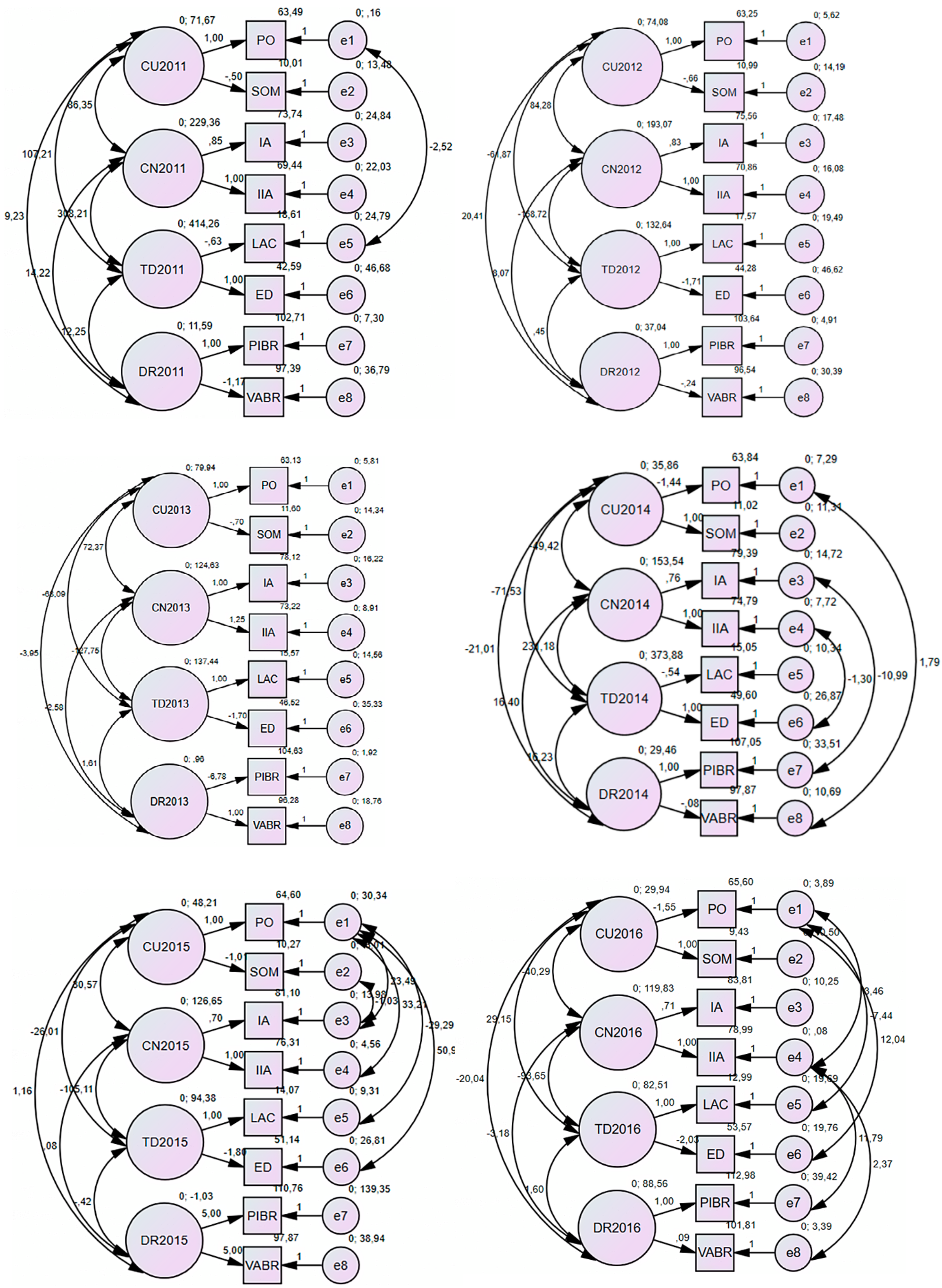



**Figure 2.** *Continued on next page*

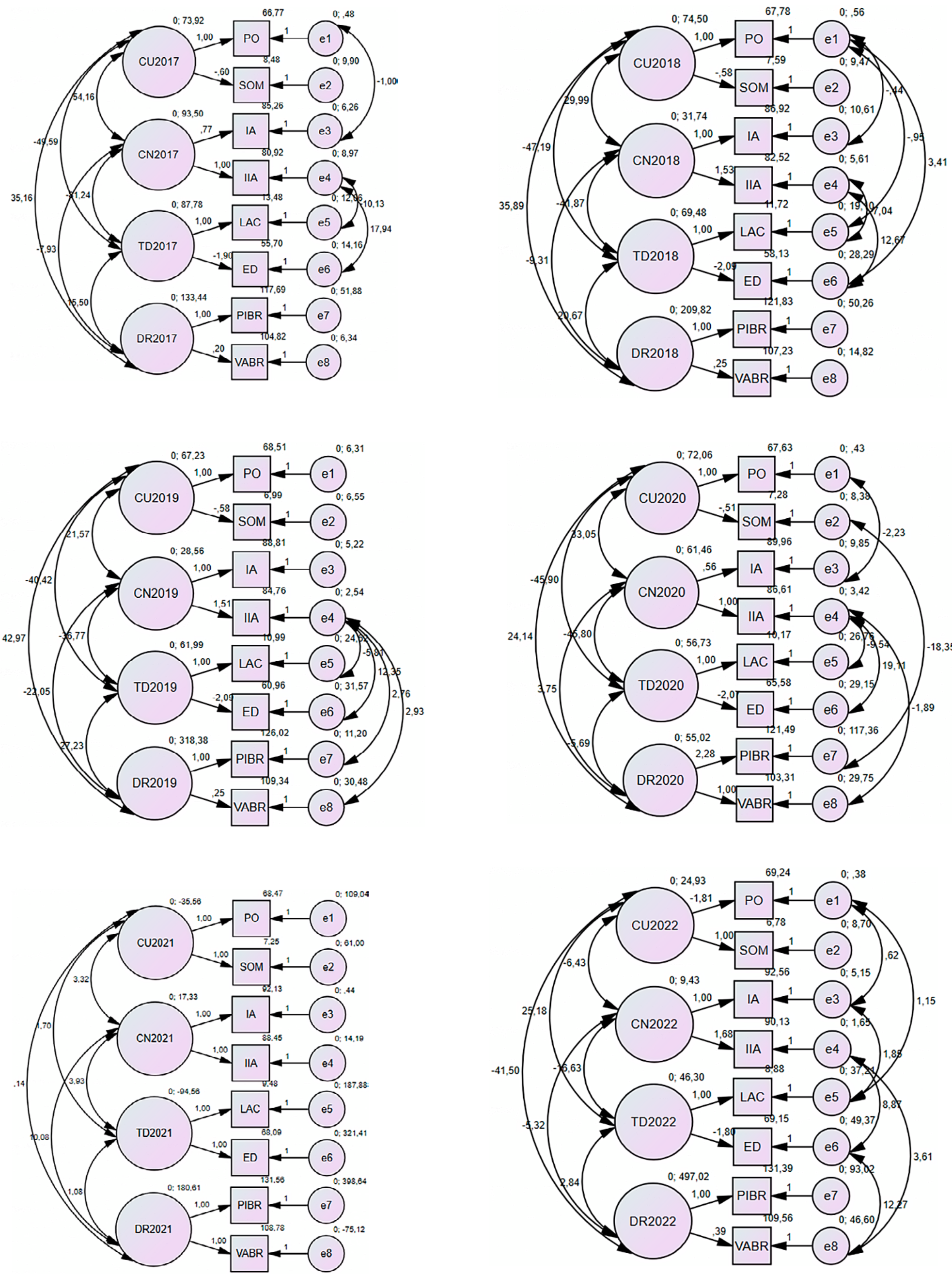


**Figure 2.** Annual patterns of digital regional development
(source: developed by the authors using AMOS Graphics software version 21)

## 4. Results and discussions

Regarding the connection between human capital (analysed through digital technologies) and regional development, the correlation levels were significant, except for 2013 year, which registered disturbances in the correlation index, leading to a decrease of model's significance on this branch. Outstanding results were obtained for the correlation between connectivity and the development of digital technologies and between the growth of digital capabilities of human capital and the development of digital technologies. All these align with the results from the annual covariance table in Table 1.

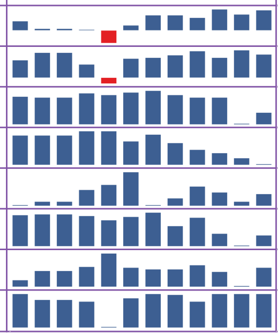
The results of the models tested by the multiple quadratic correlations generated mostly valid values as shown in Table 2.

The validation of the structural equations by the multiple correlation test for the gross value-added indicator in the regional development direction of the 242 regions studied showed a sizeable regional disparity over the period analysed, with the regression coefficient being the least significant of the 8 indicators modelled. The value of the correlation coefficient ranges

**Table 1.** Covariance table of the annual regional development models (source: elaborated by the authors)

| | | | | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimators | DR | <--> | TD | 12.3 | 0.5 | 1.6 | 16.2 | –0.4 | 1.6 | 15.5 | 20.7 | 27.2 | –5.7 | 7.4 | 2.8 |
| | CN | <--> | TD | 308.2 | –158.7 | –127.7 | 231.2 | –105.1 | –93.7 | –81.2 | –41.9 | –36.8 | –45.8 | –33.8 | –16.6 |
| | CU | <--> | CN | 86.4 | 84.3 | 72.4 | –49.4 | 30.6 | –40.3 | 54.2 | 30.0 | 21.6 | 33.0 | 4.8 | –6.4 |
| | CU | <--> | TD | 107.2 | –61.9 | –68.1 | –71.5 | –26.0 | 29.1 | –49.6 | –47.2 | –40.4 | –45.9 | –50.8 | 25.2 |
| | DR | <--> | CN | 14.2 | 8.1 | –2.6 | 16.4 | 0.1 | –3.2 | –7.9 | –9.3 | –22.1 | 3.8 | –40.6 | –5.3 |
| | DR | <--> | CU | 9.2 | 20.4 | –4.0 | –21.0 | 1.2 | –20.0 | 35.2 | 35.9 | 43.0 | 24.1 | 129.8 | –41.5 |
| Standard error | DR | <--> | TD | 5.7 | 5.0 | 1.2 | 10.1 | 0.3 | 6.6 | 7.9 | 8.9 | 9.8 | 4.1 | 12.7 | 11.5 |
| | CN | <--> | TD | 29.6 | 15.4 | 12.5 | 22.2 | 10.1 | 9.3 | 9.3 | 4.7 | 4.2 | 7.1 | 4.0 | 2.5 |
| | CU | <--> | CN | 10.2 | 9.9 | 8.4 | 6.3 | 7.0 | 5.1 | 6.6 | 4.2 | 3.5 | 4.9 | 7.9 | 1.3 |
| | CU | <--> | TD | 13.5 | 8.0 | 8.5 | 9.7 | 6.0 | 4.3 | 6.3 | 6.1 | 5.5 | 5.7 | 6.5 | 3.5 |
| | DR | <--> | CN | 4.4 | 6.0 | 1.7 | 6.5 | 0.3 | 8.4 | 8.4 | 6.0 | 6.9 | 4.2 | 13.2 | 4.9 |
| | DR | <--> | CU | 2.4 | 3.9 | 2.4 | 3.5 | 0.3 | 4.3 | 7.7 | 9.2 | 10.3 | 5.1 | 25.5 | 8.5 |
| Correlation coefficients | DR | <--> | TD | 2.1 | 0.1 | 1.3 | 1.6 | –1.5 | 0.2 | 2.0 | 2.3 | 2.8 | –1.4 | 0.6 | 0.2 |
| | CN | <--> | TD | 10.4 | –10.3 | –10.2 | 10.4 | –10.4 | –10.1 | –8.7 | –8.8 | –8.8 | –6.5 | –8.4 | –6.7 |
| | CU | <--> | CN | 8.4 | 8.5 | 8.7 | –7.8 | 4.4 | –7.9 | 8.2 | 7.1 | 6.2 | 6.7 | 0.6 | –5.1 |
| | CU | <--> | TD | 7.9 | –7.7 | –8.1 | –7.4 | –4.3 | 6.8 | –7.9 | –7.7 | –7.4 | –8.1 | –7.8 | 7.2 |
| | DR | <--> | CN | 3.3 | 1.4 | –1.5 | 2.5 | 0.2 | –0.4 | –0.9 | –1.6 | –3.2 | 0.9 | –3.1 | –1.1 |
| | DR | <--> | CU | 3.8 | 5.2 | –1.6 | –6.0 | 4.5 | –4.6 | 4.6 | 3.9 | 4.2 | 4.7 | 5.1 | –4.9 |
| P- value | DR | <--> | TD | 0.0 | 0.0 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.2 | 0.2 | 0.1 |
| | CN | <--> | TD | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| | CU | <--> | CN | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | 0.1 | *** |
| | CU | <--> | TD | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** | *** |
| | DR | <--> | CN | 0.0 | 0.2 | 0.1 | 0.0 | 0.3 | 0.2 | 0.1 | 0.1 | 0.0 | 0.4 | 0.0 | 0.3 |
| | DR | <--> | CU | *** | *** | 0.1 | *** | *** | *** | *** | *** | *** | *** | *** | *** |

**Table 2.** Table of multiple quadratic correlations of the annual regional development models (source: elaborated by the authors)

| VAR | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | Histogram |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DRVAB | 0.300 | 0.067 | 0.067 | 0.019 | –0.371 | 0.161 | 0.468 | 0.473 | 0.390 | 0.649 | 0.490 | 0.613 |  |
| DRPIB | 0.614 | 0.883 | 0.883 | 0.468 | –0.228 | 0.692 | 0.720 | 0.807 | 0.966 | 0.708 | 0.989 | 0.842 | |
| TDED | 0.899 | 0.892 | 0.892 | 0.933 | 0.919 | 0.945 | 0.957 | 0.915 | 0.895 | 0.893 | 0.645 | 0.753 | |
| TDLAC | 0.870 | 0.872 | 0.872 | 0.913 | 0.910 | 0.807 | 0.879 | 0.784 | 0.716 | 0.679 | 0.624 | 0.554 | |
| CNIIA | 0.912 | 0.923 | 0.923 | 0.952 | 0.965 | 0.999 | 0.912 | 0.930 | 0.962 | 0.947 | 0.922 | 0.942 | |
| CNIA | 0.869 | 0.884 | 0.884 | 0.859 | 0.814 | 0.853 | 0.899 | 0.750 | 0.845 | 0.662 | 0.528 | 0.647 | |
| CUSOM | 0.568 | 0.696 | 0.696 | 0.760 | 0.939 | 0.740 | 0.727 | 0.723 | 0.775 | 0.688 | 0.486 | 0.741 | |
| CUPO | 0.998 | 0.929 | 0.929 | 0.910 | 0.614 | 0.949 | 0.994 | 0.993 | 0.914 | 0.994 | 0.994 | 0.995 | |

between –0.371 points in 2015 and 0.649 points in 2020, revealing a low statistical significance and thus confirming working Hypothesis H1: *Under conditions of significant regional disparity, the value of unitary digital economic development tends to dissipate, requiring public policy intervention to accelerate reforms in less developed regions*.

The validation of the structural equations by the multiple correlation test for regional GDP expressed in terms of purchasing power in the regional development directorate of the 242 regions studied showed a sizeable regional disparity in the period analysed, with the regression coefficient being significant in 8 out of 12 periods analysed.

The value of the correlation coefficient ranges from –0.228 in 2016 to 0.989 in 2021. Regression analysis of the multiple quadratic squared correlations showed that stabilization of digital regional development required public policy financing until 2016 from European funding programs. Subsequently the digital regional economy uniformization's trend nearly normalizes in relation to the other econometrically correlated indicators, with a beneficial impact of the pandemic, as it corroborated the change in the mentality of using digital technologies in the labour market and public services. This result validates working hypothesis H2: *the trend of digital regional development shows inertia concerning multiannual strategic objectives and is sensitive to general drivers (pandemics) for the digital economy*.

The validation of the structural equations by the multiple correlation test for the indicator development of the regional digital economy of the 242 studied regions of the Directorate for the Development of Digital Technologies showed an average regional disparity in the analysed period, with the regression coefficient being significant in 11 out of 12 analysed periods. The value of the correlation coefficient ranges from 0.645 points in 2021 to 0.957 points in 2017. In general, the digital economy has evolved in line with the development of digital technologies, with the pandemic being a factor favouring the deceleration of technologies amid the change in priorities for action required by the social and health protection measures specific to this phenomenon. This evidence validates working hypothesis H3: *The development of digital technologies conducive to accelerating the transfer to the European digital economy is possible under conditions of economic normality, with changing priorities constituting unfavourable factors in the context of the dependence of the development of the branch on a significant need for funding*.

Validation of the structural equations by multiple correlation test for the indicator number of computers used in regional households in the Directorate for the Development of Digital Technologies showed an average regional disparity in the analysed period, with the regression coefficient being significant in 9 out of 12 analysed periods. The value of the correlation coefficient ranged from 0.554 points in 2022 to 0.913 points in 2014. Lack of access to computers is the hallmark of regional underdevelopment in digital technologies, with this indicator showing significant sensitivity to the influence of the pandemic crisis in terms of extensive computer use, which highlighted the undercapacity of this indicator to the increased need for use. This supports Hypothesis H4: *Access to digital technologies is directly influenced by the need to use digital technologies*, *especially in times of crisis* (*pandemic*, *geopolitical*, *etc*.).

The validation of the structural equations using the multiple correlation test for the number of people with internet access in the region in the digital connectivity directorate showed very little regional disparity in the analysed period, with the regression coefficient significant in all analysed periods. The value of the correlation coefficient ranges from 0.912 points in 2012 to 0.999 points in 2016. Except for disparities related to gender, age, sex, profession and education, it seems the level of disparity is sensitive to the influence of crises, with the lowest values of correlation coefficients for this indicator being specific to periods of the economic crisis (2011–2013) and of the multiple crises (2020–2022). The analysis shows that periods of economic stability and prosperity significantly influence the growth of citizens' digital capacity and skills, ensuring the acceleration of the transition to a sustainable digital regional economy (working Hypothesis H5).

Validation of the structural equations by multiple correlation test for the number of households with internet access in the region within the Digital Communications Development Directorate showed an average regional disparity in the analysed period, with the regression coefficient being significant in 9 out of 12 analysed periods. The value of the correlation coefficient ranges from 0.899 points in 2017 to 0.528 points in 2021. In case of households, the pandemic crisis influenced the increase of regional disparity on this research axis. In the same time, the period of economic stability favoured the acceleration of connectivity. Crises have a disruptive effect on connectivity, which demonstrates working Hypothesis H5.

Validation of the structural equations by multiple correlation tests for the regional unemployment rate indicator of human capital digital capabilities development directorate showed a high regional disparity in the analysed period, with the regression coefficient being significant in 7 out of 12 analysed periods. The value of the correlation coefficient ranges from 0.939 points in 2015 to 0.486 points in 2021. The indicator is sensitive to disruptions induced by economic crises such as the 2008–2012 pandemic crisis, which mainly affected human resources through the indirect impact of the halt in economic activity as a measure to limit the spread of the disease. This fluctuating evolution with maximum regional homogeneity during periods of economic stability shows that human resources require not only policies to promote the growth of digital capabilities but also a stable economic environment (job security), which is what working hypothesis H6 proposes: *Increasing the digital capability of human resource is directly dependent on the existence of a stable and sustainable macroeconomic climate and the promotion of effective policies on the development of digital capabilities of human capital*.

Validation of the structural equations by multiple correlation test for employed population at the regional level within the direction of developing digital capabilities of human capital showed a low regional disparity in the analysed period, with the regression coefficient being significant in 11 out of 12 analysed periods. The value of the correlation coefficient ranges from 0.614 points in 2015 to 0.998 points in 2011. The analysis has shown that real opportunities for integration into the labour force do not constitute an impediment to the development of the European digital regional economy. It follows that in the case of the EU, the level of economic development allows a functional infrastructure for employment as a result of sustainable development supported by the Union's governing bodies. These aspects demonstrate working hypothesis H7: *The acceleration of the digital economy is possible with a strong and sustainable economic infrastructure*.

To validate the model, goodness-of-fit tests were applied, and benchmark comparisons were interpreted in the multi-year model results. The results confirmed the validation of the statistical model as follows:

Using the Normalized Fit Index (NFI), the difference between the fitted model, the independence model (poor fit) and the saturated model (perfect fit) was analysed. A value of 1 indicates a perfect fit, while models evaluated <0.9 can usually be substantially improved. In the model, the NFI index was estimated for the whole analysed period and showed a value that allows the validation of the model (see Figure 3).

The trajectory of the Tucker-Lewis Index (TLI) reveals a pattern that consistently demonstrates good stability over the 2011 to 2021 period with a depreciation stability in 2022. Starting 2011, with a value of 0.803, the index shows a gradual and sustained improvement, peaking at 0.912 in 2015. This upward trend indicates a pattern that increasingly aligns with observed data, while maintaining good resilience to over-adjustment. The drop in 2022 to 0.628, while notable, most likely reflects potential external challenges caused by multiple economic crises and the uncertain geopolitical context in 2022 (see Figure 4).

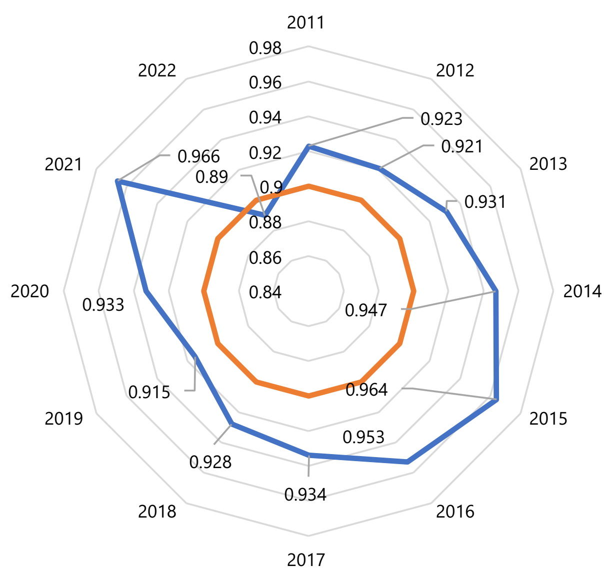



**Figure 3.** Model validation using the NFI index

Using the Incremental Fit Index (IFI), the model's closeness to the optimal values was tested by applying the 10% significance threshold for error representation. A significant fit of the model outputs over the selected representation interval was observed for the whole period (see Figure 5).

The Comparative Fit Index (CFI) value typically varies in the closed range of 0–1, where 1 indicates the maximum model fit (perfect fit). The validation limit for the 10% error representation threshold is 0.9, and we observe that the proposed model fulfils the validation requirements by applying the Comparative Fit Index criteria, as shown in Figure 6.

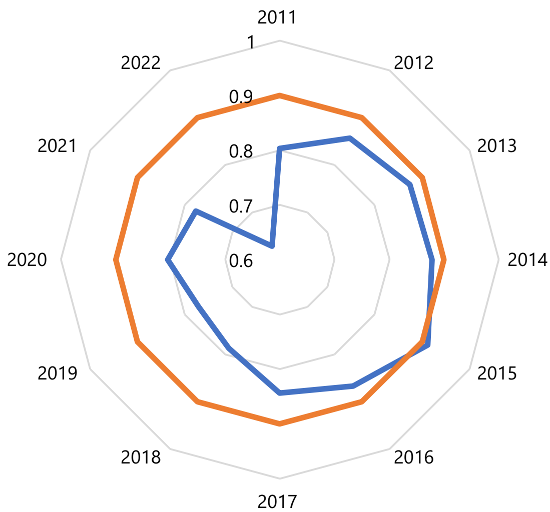



**Figure 4.** Model validation using the TLI index

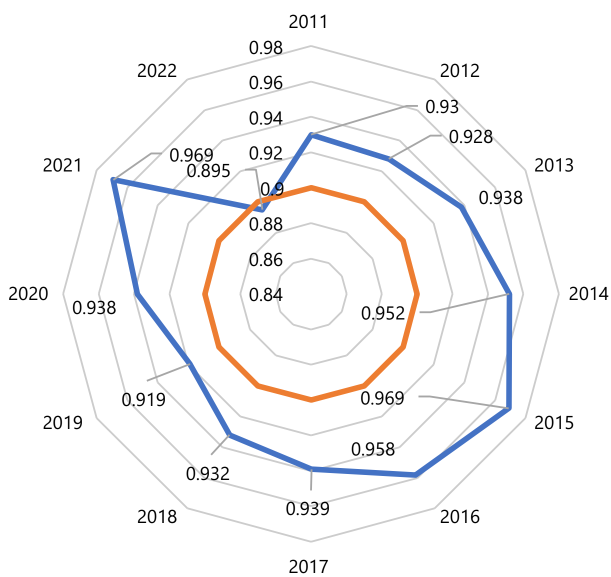



**Figure 5.** Model validation using the IFI index

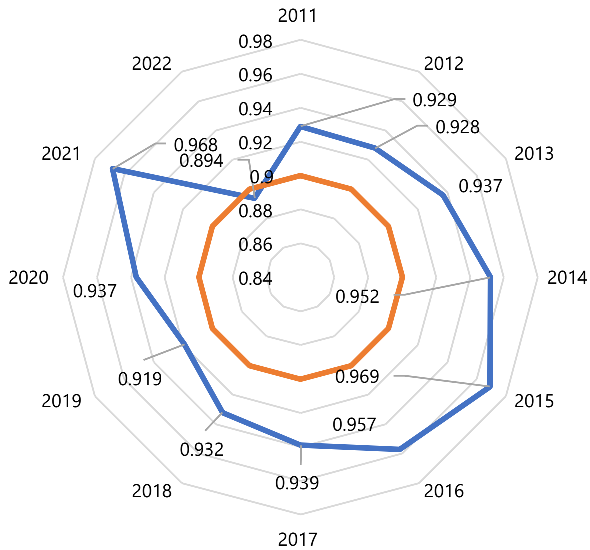



**Figure 6.** Model validation using the CFI index

The RMSEA (Root Mean Square Error of Approximation) values provided for the years 2011–2022 reflect a nuanced evolution in the quality of model fit over time. The values fall within the generally accepted threshold for a reasonable model fit (RMSEA ≤ 0.08), and in 2015 they approach the range of a close fit (RMSEA ≤ 0.05). The year 2022 marks a notable departure, with RMSEA increasing to 0.093. The corresponding confidence intervals, reflected by the LO 90 and HI 90 values, support this observation by encompassing ranges increasingly diverging from the ideal thresholds (Table 3).

**Table 3.** RMSEA model fit values over the period 2011–2022 (source: elaborated by the authors)

| Year | RMSEA | LO 90 | HI 90 | PCLOSE | Significance |
|---|---|---|---|---|---|
| 2011 | 0.065 | 0.055 | 0.075 | 0.000 | ** |
| 2012 | 0.064 | 0.055 | 0.075 | 0.000 | ** |
| 2013 | 0.062 | 0.052 | 0.073 | 0.000 | ** |
| 2014 | 0.060 | 0.048 | 0.074 | 0.000 | ** |
| 2015 | 0.051 | 0.036 | 0.067 | 0.000 | ** |
| 2016 | 0.063 | 0.049 | 0.078 | 0.000 | ** |
| 2017 | 0.071 | 0.060 | 0.082 | 0.000 | ** |
| 2018 | 0.076 | 0.063 | 0.089 | 0.000 | ** |
| 2019 | 0.080 | 0.069 | 0.091 | 0.000 | ** |
| 2020 | 0.069 | 0.056 | 0.083 | 0.000 | ** |
| 2021 | 0.070 | 0.048 | 0.097 | 0.000 | ** |
| 2022 | 0.093 | 0.081 | 0.105 | 0.000 | * |

*Notes:* *** RMSEA ≤ 0.05; ** RMSEA ≤ 0.08: * RMSEA≤ 0.10.

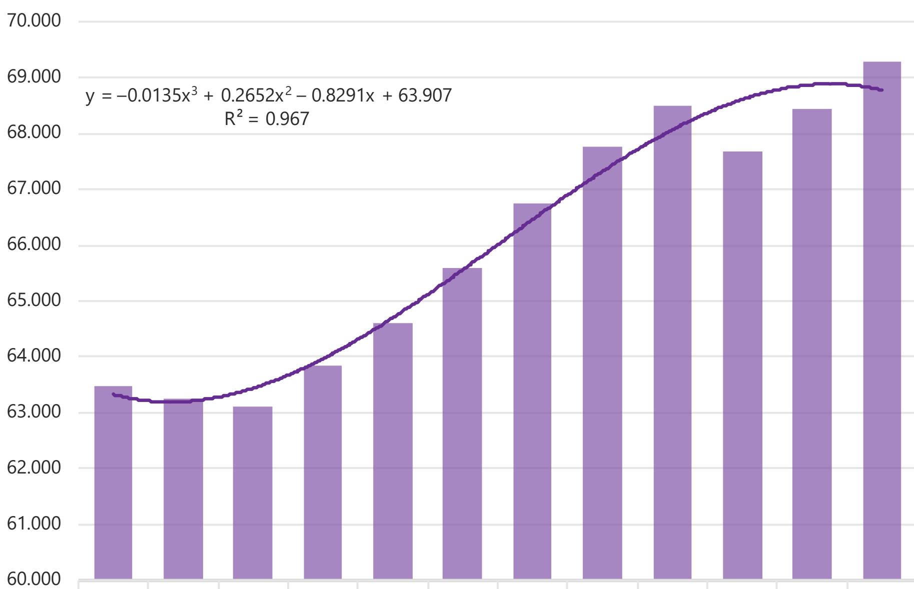
The proposed model provides an adjusted representation of the regional digital economy's acceleration based on applying the structural equation optimization procedure to the conceptual model, using a number of 242 records for each observed regression item and a 12-years analysis period.

After checking the structural equations for model improvement adjustments, a Bayesian test was performed, which generated a fit to the optimal model of the possible variations of the annual models, generating the following optimal configuration in terms of the acceleration of the digital economy (the predicted results of the annual models).

The employed population dynamics variable was estimated by the Bayesian intercept test as an increasing trend over the analysed period 2011–2022 from an employment rate for the digital economy of 63.119 percentage points in 2013 to an employment rate of 69.286 percentage points in 2022 (see Figure 7).

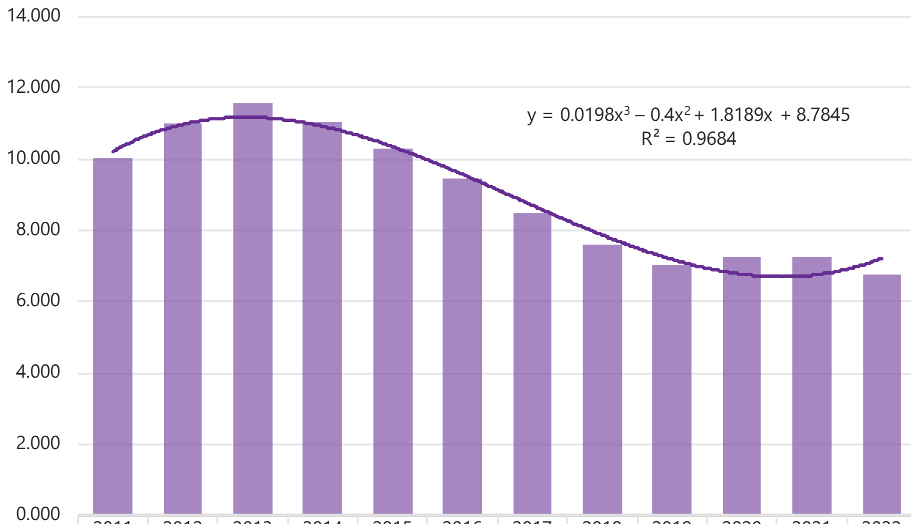
The covariance of the indicator on the human capital-connectivity branch was best in 2022 (3.156 percentage points). At the opposite pole, the covariance also indicates a high level of regional disparity, which reached its lowest value in 2012 (13.670 percentage points).

As for the covariance of the relationship between human capital and digital technologies, a favourable value was recorded in 2022 (1.927 percentage points). At the opposite pole, the covariance also indicates a high level of regional disparity, which reached its weakest value in 2012 (–2.381 percentage points). The variable on the dynamics of the regional unemployment rate in the digital economy was estimated by the Bayesian intercept test as a decreasing trend over the analysed period 2011–2022 from a rate of 11.596% in 2013 to a rate of 6.757% in 2022 (see Figure 8).




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CUPO | 63.486 | 63.256 | 63.119 | 63.832 | 64.599 | 65.604 | 66.742 | 67.767 | 68.487 | 67.678 | 68.450 | 69.286 |

**Figure 7.** Optimized variation of regionally employed population in the digital economy




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CUSOM | 10.016 | 10.994 | 11.596 | 11.029 | 10.282 | 9.440 | 8.504 | 7.604 | 7.006 | 7.254 | 7.250 | 6.757 |

**Figure 8.** Optimized regional variation of unemployment in the digital economy

The covariance of the indicator on the human capital-connectivity branch was best in 2022 (3.156 percentage points). At the opposite pole, the covariance also indicates a high level of regional disparity, which reached its lowest value in 2012 (13.670 percentage points).

As for the covariance of the relationship between human capital and digital technologies, a favourable value was recorded in 2022 (1.927 percentage points). At the opposite pole, the covariance also indicates a high level of regional disparity, which reached its weakest value in 2012 (–2.381 percentage points).

The variable on the dynamics of household internet access at the regional level in the digital economy was estimated by the Bayesian intercept test to be on an upward trend over the analysed period 2011–2022, from an access rate of 73.757% in 2011 to an access rate of 92.581% in 2022 (see Figure 9).

The covariance of the indicator on the connectivity-digital technology branch was best in 2022 (5.982 percentage points). At the opposite pole, the covariance indicating a high level of regional disparity reached its worst value in 2012 (–18.070 percentage points). The covariance of the relationship between connectivity and regional development, recorded a favourable value in 2020 (14.370 percentage points). At the opposite pole, the covariance also indicates a high level of regional disparity, which reached its weakest value in 2012 (–5.380 percentage points). The variable on the dynamics of individuals' access to the Internet at the regional level in the digital economy was estimated by the Bayesian intercept test as an upward trend over the analysed period 2011–2022 from an access rate of 69.512% in 2011 to an access rate of 90.166% in 2022 (see Figure 10).

The covariance of the connectivity-digital technology branch registered its best level in 2002 (5.982 percentage points). At the opposite pole, the covariance indicating a high level of regional disparity reached its lowest value in 2012 (–18.070 percentage points).

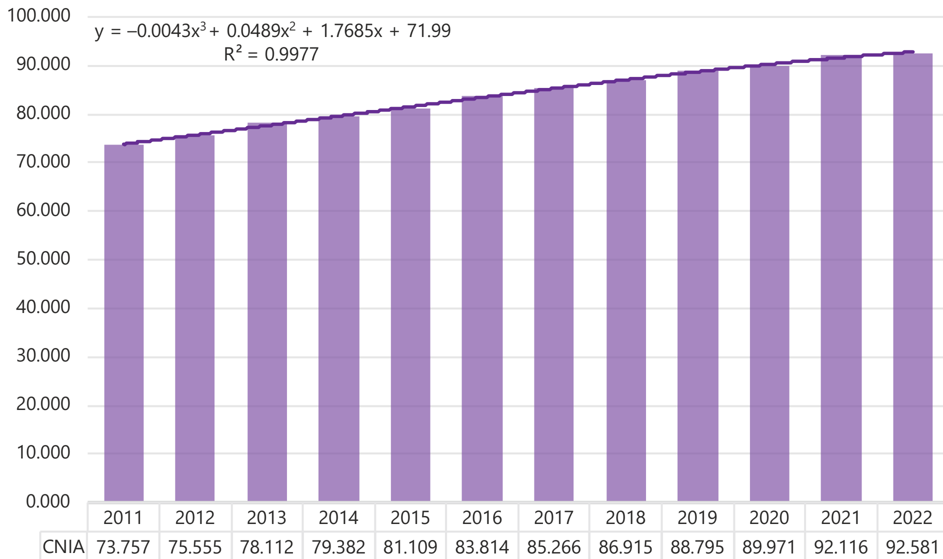



**Figure 9.** Optimized variation of household internet access at the regional level in the digital economy

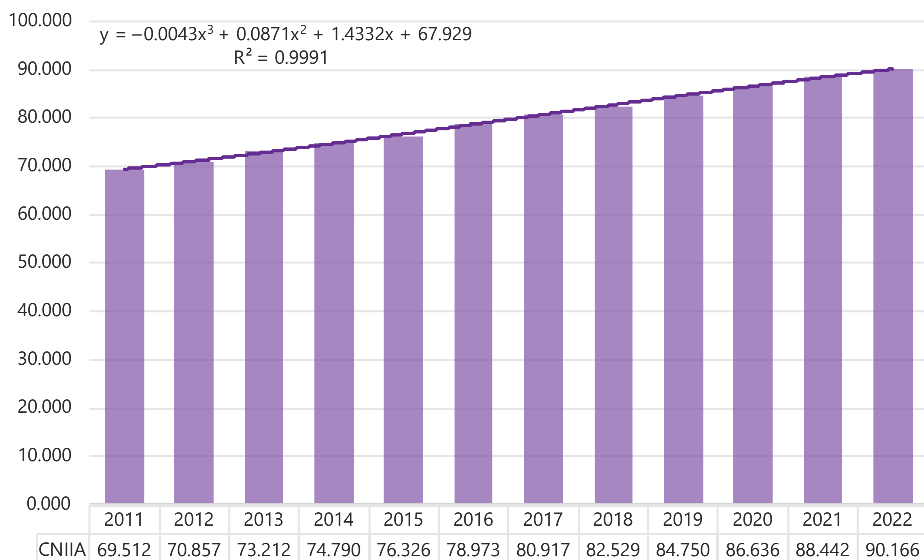



**Figure 10.** Optimized variation of individuals' access to the Internet at the regional level in the digital economy

The covariance of the relationship between connectivity and regional development, recorded a favourable value in 2020 (14.370 percentage points). At the opposite pole, the covariance indicating a high level of regional disparity reached its lowest value in 2012 (–5.380 percentage points).

The variable on the dynamics of households' access to computers at the regional level in the digital economy was estimated by the Bayesian intercept test as favourably downward trending over the analysed period 2011–2022, from 18.621% in 2011 to 8.865% in 2022 in terms of lack of access rates (see Figure 11).

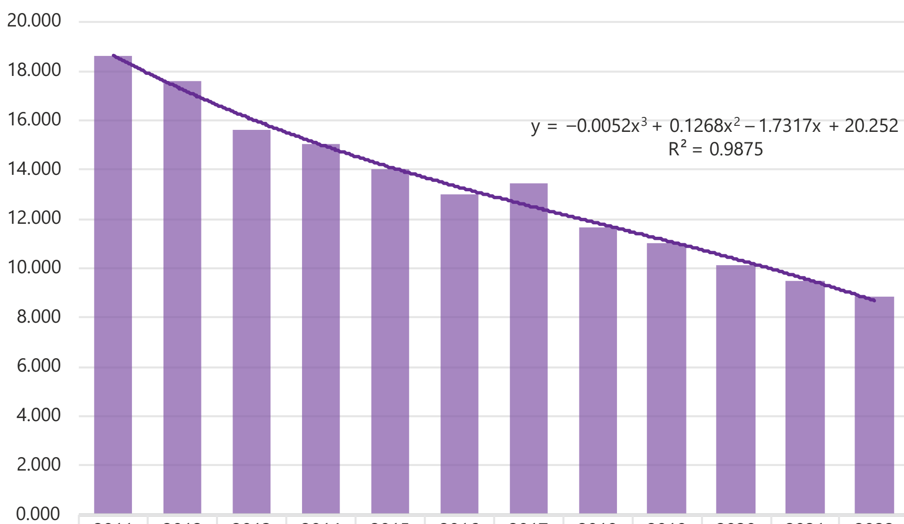
The covariance of the indicator on the human capital-digital technology branch registered its best value in 2002 (1.927 percentage points). At the opposite pole, the covariance also indicates a high level of regional disparity, which reached its worst value in 2012 (–2.381 percentage points).

The covariance of the relationship between digital technologies and regional development, recorded a favourable value in 2022 (4.816 percentage points). At the opposite pole, the covariance indicates a high level of regional disparity, reaching its weakest value in 2020 (–7.999 percentage points).

The variable on the acceleration of the digital economy at the regional level was estimated by the Bayesian intercept test as having a favourable upward trend, from a growth rate of 42.540% in 2011 to a growth rate of 69.149% in 2022 (see Figure 12).

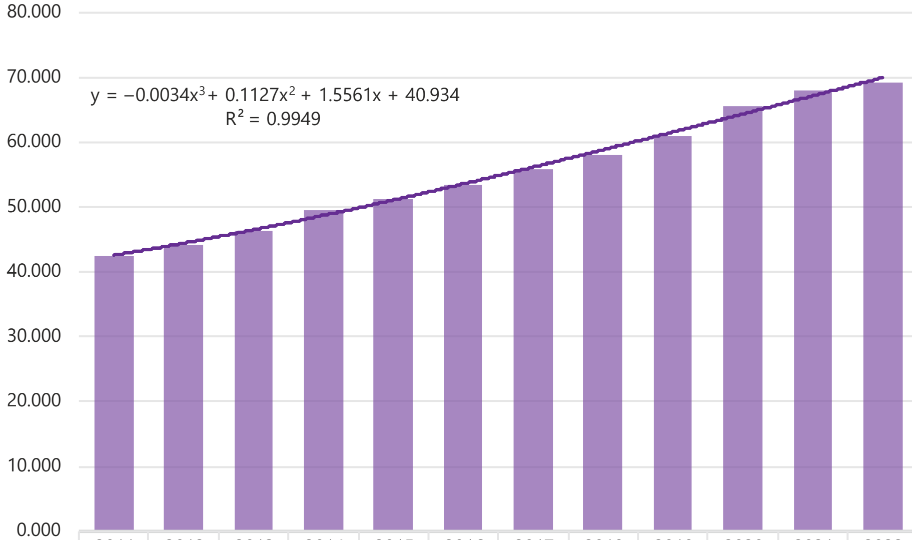
The covariance of human capital-digital technology branch was best in 2002 (1.927 percentage points). At the opposite pole, the covariance indicates a high level of regional disparity, which reached its worst value in 2012 (–2.381 percentage points). Also, the covariance of the relationship between digital technologies and regional development, registered a favourable value in 2022 (4.816 percentage points). At the opposite pole, the covariance indicating a high level of regional disparity reached its weakest value in 2020 (–7.999 percentage points).

The variable on regional development in the digital context was estimated by the Bayesian intercept test with a favourable upward trend over the analysed period, from a growth rate of 102.712% in 2011 to a growth rate of 131.415% in 2021 (see Figure 13).



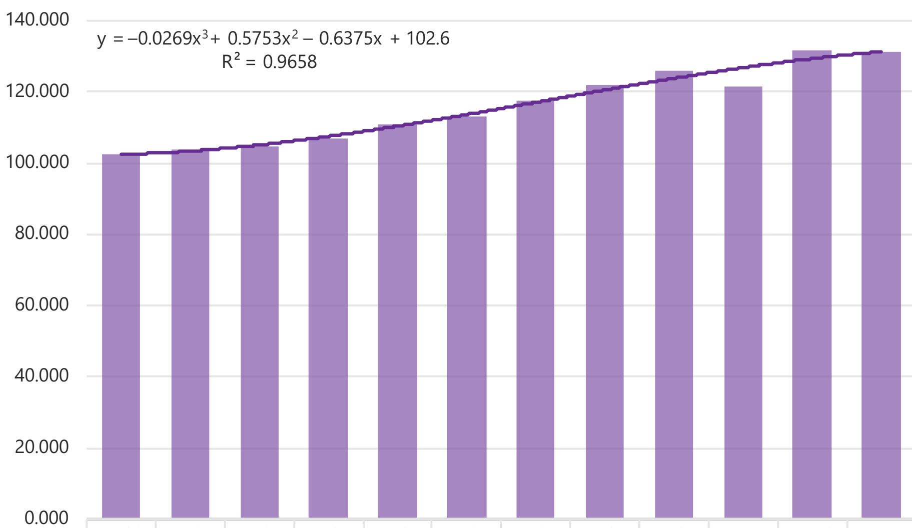

| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDLAC | 18.621 | 17.587 | 15.593 | 15.063 | 14.047 | 12.996 | 13.441 | 11.697 | 10.997 | 10.164 | 9.475 | 8.865 |

**Figure 11.** The optimized variation of household access to computers at the regional level in the digital economy




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TDED | 42.540 | 44.242 | 46.482 | 49.574 | 51.199 | 53.546 | 55.758 | 58.164 | 60.964 | 65.536 | 68.090 | 69.149 |

**Figure 12.** Optimized variation of digital economy's acceleration at regional level




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DRPIB | 102.712 | 103.641 | 104.628 | 107.043 | 110.754 | 112.978 | 117.677 | 121.849 | 126.018 | 121.447 | 131.548 | 131.415 |

**Figure 13.** The optimized variation of regional development in the digital context

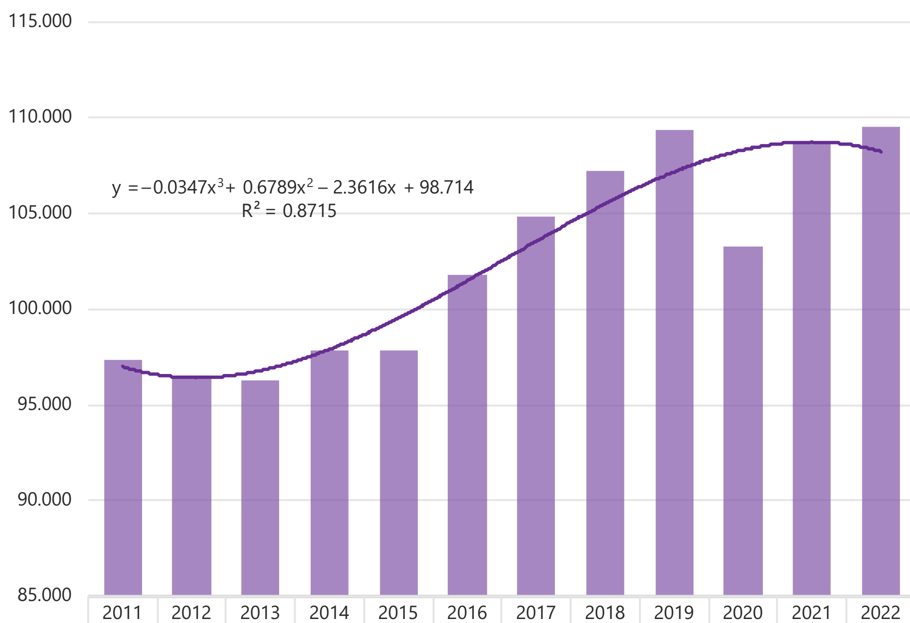
The covariance of the indicator on the regional development-human capital branch was the best in 2020 (0.588 percentage points). At the opposite pole, the covariance indicates a high level of regional disparity, which reached its worst value in 2019 (–2.516 percentage points). The covariance of the relationship between connectivity and regional development, recorded a favourable value in 2020 (14.370 percentage points). At the opposite pole, the covariance indicated a high regional disparity level, reaching its weakest value in 2011 (–5.380 percentage points).

The Bayesian intercept test estimated the variable on regional gross value added in the digital context to have a favourable upward trend over the period 2011–2022, from a growth rate of 96.289% in 2013 to a growth rate of 109.570% in 2022 (see Figure 14).

The covariance of the indicator on the regional development – human capital branch recorded its best value in 2020 (0.588 percentage points). On the other hand, the covariance indicating a high level of regional disparity reached its lowest value in 2019 (–2.516 percentage points). The covariance of the relationship between connectivity and regional development, registered a favourable value in 2020 (14.370 percentage points). At the opposite pole, the covariance indicated a high regional disparity level, reaching its worst value in 2011 (–5.380 percentage points).

The observed trends in the growth of the digital economy, human capital, and regional development are profoundly significant, revealing both the transformative potential of digitalization and the challenges that currently impede its equitable progression. These trends underscore the interplay between technological advancement, skill development, and the equitable distribution of resources and opportunities across regions.

To illustrate the model's applicability and enhance its practical relevance, selected regional case studies provide insights into effective digital transitions. For instance, Estonia has become a benchmark in digital governance by implementing a comprehensive e-Residency program and fully digitizing public services, which significantly improved administrative efficiency and citizen engagement (Espinosa & Pino, 2024). Similarly, the Basque Country in Spain has




| | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DRVAB | 97.386 | 96.532 | 96.289 | 97.868 | 97.874 | 101.808 | 104.811 | 107.224 | 109.358 | 103.293 | 108.763 | 109.570 |

**Figure 14.** Optimized variation of regional gross value added in the digital context

successfully integrated smart manufacturing technologies through its Industry 4.0 initiative, supported by regional innovation hubs and tailored vocational training programs (Müller et al., 2024; Sandulli et al., 2021). These examples underscore the importance of coordinated public-private efforts, targeted education policies, and strong digital infrastructure in facilitating successful regional digital transformations.

The expansion of the digital economy marks a paradigm shift in how goods and services are produced, distributed, and consumed (Belezas & Daniel, 2023; Javaid et al., 2024; Xiao & Abula, 2024). At its core, the digital economy enhances productivity through automation, data analytics, and the integration of advanced technologies such as artificial intelligence and blockchain. The increased adoption of digital platforms and services facilitates global market access, allowing small and medium enterprises (SMEs) to transcend traditional geographic barriers and compete internationally. For example, regions that have embraced digital innovation have seen significant growth in sectors such as e-commerce, financial technology, and digital marketing (Ballerini et al., 2023; Jula et al., 2024; Macca et al., 2024; Modgil et al., 2022; Tajudeen et al., 2025; Yang et al., 2023). Moreover, the digital economy accelerates the pace of innovation (Capello et al., 2023; Kastelli et al., 2024; Luo et al., 2023; Pan et al., 2022; Savchenko et al., 2024). By fostering cooperation and creating ecosystems of interconnected technologies and industries, it enables the rapid development of new products and services. This, in turn, stimulates economic diversification and resilience. During the COVID-19 pandemic, the digital economy mitigated the economic fallout by supporting remote work, telemedicine, and online education, showcasing its critical role in maintaining socio-economic stability during crises (Battisti et al., 2022; Leporatti & Montefiori, 2024; Jaumotte et al., 2023). The benefits of the digital economy are not uniformly distributed. Disparities in digital infrastructure, access to technology, and levels of digital literacy across regions create significant inequalities (Baffour Gyau et al., 2025; Consoli et al., 2023; Feurich et al., 2024; Raihan et al., 2024). These gaps emphasize the importance of targeted investments in infrastructure and digital capacity-building programs to ensure that the digital economy serves as an inclusive driver of growth.

Human capital is the cornerstone of the digital economy (Marchesani et al., 2025; Murillo-Ramos et al., 2023; Ran et al., 2023; Török, 2024; Yi et al., 2024). The development of digital skills and competencies among the workforce is pivotal for harnessing the full potential of digital technologies. Regions with a strong foundation in education and vocational training in information and communication technology (ICT) fields tend to exhibit higher levels of innovation and economic resilience. The entry of over one million ICT specialists into the European labor market highlights the critical role of human capital in driving the digital transition (Dimian et al., 2023; Laitsou et al., 2025; Santos et al., 2023; Satı, 2024). Beyond technical skills, the digital economy requires adaptive and creative problem-solving abilities, emphasizing the need for comprehensive education and lifelong learning systems. The positive correlation between human capital and economic performance demonstrates that investments in education and workforce development yield significant returns in terms of productivity, innovation, and quality of life. The unequal distribution of digital skills exacerbates regional disparities. In less developed regions, the lack of access to quality education and training limits the workforce's ability to engage with the digital economy, perpetuating cycles of underdevelopment. Addressing these disparities requires not only investments in education but also policies that promote digital inclusion, such as subsidized training programs and the integration of digital literacy into school curricula.

The growth of the digital economy and human capital development is inextricably linked to regional development. Digital technologies have the potential to bridge regional disparities by enabling access to markets, resources, and services that were previously inaccessible to remote or disadvantaged areas. Advancements in connectivity, such as the rollout of 5G networks, have the potential to revitalize rural economies by supporting smart agriculture, remote work opportunities, and e-health services (Beltozar-Clemente et al., 2023; Kaur et al., 2022; Kumar et al., 2022; Ma, 2023; Stefanelli, 2023). The data analysis also reveal persistent regional inequalities in the adoption of digital technologies and their integration into economic activities. Highly developed regions tend to attract more investment and talent, creating a virtuous cycle of growth, while less developed regions struggle to keep pace (Bai & Zheng, 2024; Jansen et al., 2023; Jooss et al., 2024; Petrucci et al., 2025). This digital divide underscores the need for tailored regional policies that address specific barriers to digital adoption, such as inadequate infrastructure, limited access to funding, or socio-cultural resistance to change. At a broader level, regional development driven by the digital economy can foster social cohesion and resilience. By enabling more equitable access to education, healthcare, and economic opportunities, digital technologies can reduce socio-economic disparities and enhance the overall quality of life. For instance, digitized public services improve governance efficiency and transparency, fostering trust in institutions and empowering citizens.

The development of the digital economy across regions necessitates the adoption of targeted policy interventions that address both immediate challenges and long-term objectives. Drawing on successful examples from various regions and countries can provide valuable lessons for policymakers in the European Union, offering adaptable strategies to foster inclusive and sustainable digital growth. A notable case is the Nordic countries, which consistently rank high in the European Union's Digital Economy and Society Index (DESI) (European Commission, n.d.-d). Finland, Denmark, and Sweden have implemented comprehensive digital strategies that combine substantial investments in digital infrastructure with robust educational initiatives (Bambi & Pea-Assounga, 2024; Kwilinski et al., 2023; Saunavaara et al., 2022; Senna et al., 2023; Teixeira & Tavares-Lehmann, 2022). Finland's national digital skills program emphasizes lifelong learning and the integration of digital literacy in school curricula, contributing to a digitally competent workforce. Similarly, Denmark's focus on public-private partnerships has facilitated the deployment of 5G networks and smart city projects, significantly enhancing connectivity and regional competitiveness. Another example is Singapore's "Smart Nation" initiative (Foong et al., 2024; Smart Nation, 2025; Woods et al., 2024), which integrates advanced technologies such as IoT, AI, and blockchain into public services, healthcare, and transportation systems. This approach highlights the potential of holistic, technology-driven policies to improve quality of life and drive economic growth. Policymakers in the EU could adapt similar frameworks, especially in regions lagging behind in digital infrastructure and public service digitization.

Comparing the effectiveness of education-focused policies with infrastructure investments reveals distinct benefits. Investments in education, particularly in digital skills development, have a multiplier effect, enabling individuals to participate in the digital economy and fostering innovation. Germany's digital education initiatives, supported by federal and regional governments, have improved digital literacy and reduced unemployment rates in technology sectors (Engel et al., 2023; Digital Skills & Jobs Platform, n.d.; Taimur & Onuki, 2022; Weßner et al., 2024). Infrastructure investments, such as those in Ireland and Lithuania, have prioritized expanding broadband access and 5G coverage (European Commission, n.d-a, n.d.-b, n.d.-c; Garashchuk et al., 2025; Lnenicka et al., 2024; Parcu et al., 2023). These initiatives have catalyzed business growth, particularly for SMEs, and enhanced access to global markets. The interplay between these approaches suggests that a balanced strategy – one that combines foundational investments in digital infrastructure with comprehensive human capital development – yields the most significant and sustainable outcomes.

For the EU, adopting a hybrid approach that draws from these successful examples could accelerate digital transformation across regions (Appio et al., 2024; Bansal et al., 2023; Plekhanov et al., 2023; Riso et al., 2024; Saihi et al., 2023). By focusing on both immediate infrastructure improvements and long-term educational reforms, policymakers can bridge existing digital divides and ensure that all regions are positioned to leverage digital technologies for sustainable growth. Tailored interventions, such as targeted funding for underserved regions or incentives for digital skills training, can further enhance the impact of these policies.

In the study context, the observed trends highlight several practical implications. Policymakers must prioritize investments in digital infrastructure, particularly in underserved regions, to ensure that all areas can benefit from the opportunities offered by the digital economy. Efforts to develop human capital should focus on both technical and soft skills, with particular attention to marginalized groups to promote inclusivity. Regional development strategies should integrate digital transformation as a core component, emphasizing the creation of digital innovation hubs, support for SMEs, and incentives for private sector investment in technology. The trends in the growth of the digital economy, human capital, and regional development reflect the transformative potential of digitalization while highlighting critical challenges that require concerted action. By addressing disparities and promoting inclusive growth, these trends can pave the way for a more equitable and prosperous future, where technology serves as a catalyst for sustainable development across all regions.

## 5. Conclusions

This research promoted the design of a new regional index of socio-economic disparity in the context of the digital economy, based on the established research objectives, namely, analysing the potential of the digital economy through the prism of monitoring indexes implemented in the European practice, studying the bibliographic resources from the international literature to identify the main directions of development of the digital economy in the regional context and under the threat of uncertainty factors; analysing the regional digital economy domains (human capital, digital technology integration, connectivity and regional development) in a mix correlated with the regional indicators of sustainable development; defining, testing and validating a new model and index of regional socio-economic disparity at EU27 level.

The design of the regional growth model of the digital economy was achieved employing structural equations with IBM-SPSS and AMOS statistical software. The results were optimized using the Bayesian method, obtaining valid models for accelerating the development of the digital economy in the regional context. The four sectors analysed were found to be sensitive both to EU27-funded stimulus policies and to uncertainties induced by multiple economic crises. Economic stabilization and job security have been found to be factors that accelerate the shift to the digital economy.

The study highlights the persistent challenges in regional digital development, particularly the uneven distribution of digital infrastructure, disparities in human capital, and the limited integration of advanced technologies in less developed regions. These issues hinder the equitable participation of all regions in the digital economy, perpetuating socio-economic imbalances and limiting the potential for inclusive growth. Addressing these current gaps requires immediate policy interventions focused on improving connectivity, expanding access to education and training, and fostering regional collaborations to bridge the digital divide. Looking forward, the future of regional digital development hinges on achieving comprehensive and sustainable transformation through targeted investments in digital infrastructure, the development of digitally skilled workforces, and the integration of smart technologies across all regions. By emphasizing inclusivity, fostering innovation, and leveraging public-private partnerships, policymakers can create a resilient digital ecosystem that promotes equitable growth. The trajectory toward these goals underscores the importance of aligning current policy efforts with long-term strategic objectives, ensuring that digitalization becomes a catalyst for sustainable regional development and cohesion across the European Union.

In the current context characterized by multiple economic crises and geopolitical uncertainties, the development of the digital economy has become a strategic priority for the European Union, reflecting not only the need to modernize economic structures, but also the imperative to ensure regional cohesion and resilience. Recent public policies have emphasized the importance of stimulating the digital economy as a key driver of sustainable economic growth, particularly as economic stability and job security have been identified as catalysts for this transition. However, the digitization process has not proceeded uniformly at regional level and economic disparities between developed and less developed regions in the European Union remain a significant challenge. In this respect, public policies need to address the identified vulnerabilities in the acceleration of the digital economy, either as measures to support economic cohesion or initiatives to stimulate the uptake of digital technologies at regional level. In addition to the recent economic and pandemic crises, Europe's digital sector has faced challenges related to the semiconductor crisis and the high costs of deploying new technologies, which have been discussed in various public policy proposals. During the implementation of the model, the working hypotheses were validated, which allowed the identification of vulnerabilities in the acceleration of the digital economy to be addressed through public policy proposals (see Table 4).

The research has shown that the digital economy has become an undeniable reality of the contemporary world and a means of promoting socio-economic progress, including at the regional level.

The limitations of the study, while not undermining its validity, highlight areas where further research and methodological refinement could enhance the robustness and applicability of the findings. The study relies on data sourced primarily from the Eurostat database. Certain regions may lack consistent data coverage for all the indicators analyzed. This constraint may

**Table 4.** Public policy proposals to mitigate the deceleration effects of the digital regional economy in Europe

| Hypothesis | Impact | Policy proposals |
|---|---|---|
| H1: Under conditions of significant regional disparity, the value of unitary digital economic development tends to dissipate, requiring public policy intervention to accelerate reforms in less developed regions. | ▪ Increased economic cohesion gaps in the EU27;<br>▪ Creation or expanding of disadvantaged areas;<br>▪ Favouring labour migration. | ▪ Identify stable regional development models and finance them;<br>▪ Accelerating trans-national cooperation as a factor of welfare and transfer;<br>▪ Creating a stable economic climate through sustainable policies. |
| H2: The trend of digital regional development shows inertia concerning the multi-annual strategic objectives and is sensitive to general drivers (pandemics) for the digital economy. | ▪ Increased socio-economic disparities in the post-pandemic period;<br>▪ Ineffective implementation of measures to accelerate the digital switchover;<br>▪ Reduced willingness of the population to join the digital economy. | ▪ Implementation of economic recovery measures, including recovery and resilience plans;<br>▪ Stimulating the widespread introduction of digitalisation of public services;<br>▪ Stimulating people's digital skills through training programs. |
| H3: The development of digital technologies to accelerate the transfer to the European digital economy is possible under normal economic conditions, with changing priorities being unfavourable factors in the context of the dependence of the sector's development on a significant need for funding. | ▪ Restoring budgetary priorities in the context of economic and geopolitical crises at the expense of regional digital economy development;<br>▪ The high cost of implementing new digital technologies;<br>▪ The impact of the energy and food crisis on digitalization allocations at the regional level. | ▪ Support digitization funding at an optimal level;<br>▪ Fostering technology transfer between regions;<br>▪ Promoting good practices in the digital development of regions. |
| H4: Access to digital technologies is directly influenced by the need to use digital technologies, especially in times of crisis (pandemic, geopolitical). | ▪ Increasing demand for digital services and technologies in times of crisis;<br>▪ Lack of key components in the development of digital technologies (semiconductor crisis);<br>▪ Unable to adapt supply to demand. | ▪ Support the launch of new digital applications to improve the quality of public services;<br>▪ Reorientation towards new sources of materials and semi-finished products in the field;<br>▪ Launch EU-wide initiatives to tackle the semiconductor crisis. |
| H5: Periods of economic stability and prosperity significantly influence the digital capacity and skills of citizens, ensuring that the transition to a sustainable digital regional economy accelerates. | ▪ Accepting digitization as a viable solution for both the population and public institutions in pre- and post-pandemic contexts;<br>▪ Emphasizing sustainable socio-economic development, in which digitalization plays a key role. | ▪ Promote policies to stimulate learning and create the necessary skills to support digitization in society;<br>▪ The widespread introduction of digitization of public services;<br>▪ Implementation and promotion of one-stop-shop. |
| H6: Increasing the digital capacity of human resources is directly dependent on the existence of a stable and sustainable macroeconomic climate and the promotion of effective policies to develop the digital capabilities of human capital. | ▪ Modification of the university curriculum in the sense of introducing subjects that can form the basic package in the implementation of digitization;<br>▪ Increasing access to regional digital technologies for individuals and households;<br>▪ Creating digital exchange programs. | ▪ Promoting the concept of digital economic regions;<br>▪ Increasing the share of digital jobs in public administration;<br>▪ Promote aggressive marketing in the field of digitization implementation at the regional level;<br>▪ Create reliable funding programs for digital human capital capacity building. |
| H7: A strong and sustainable economic infrastructure is a prerequisite for accelerating the digital economy. | ▪ Sustainable economic growth supports the promotion of digitization in socio-economic life;<br>▪ Economic restructuring is taking place in the context of new European strategies in which digitization plays an important role. | ▪ Regional economic restructuring policies for digitalization;<br>▪ Creating new jobs and new digitalization-related activities and services at the regional level. |

introduce biases or limit the generalizability of the findings for under-represented regions. Significant disparities in regional development, infrastructure, and socio-economic conditions across the European Union pose challenges to creating a universally applicable model. While the model accounts for correlations between human capital, digital technology integration, connectivity, and regional development, it may not fully capture localized factors, such as cultural differences, governance efficiency, or region-specific economic shocks. These unaccounted variables could lead to overgeneralizations when applying the model to diverse regional contexts. The structural equation modeling (SEM) approach employed in this study, while powerful for analyzing complex relationships, is inherently limited by its reliance on pre-specified assumptions. The model's reliance on covariance structures may mask potential causal relationships or feedback loops that could provide deeper insights. Additionally, although the inclusion of a broader range of indicators could potentially enhance the generalizability of the model.The choice of indicators, while guided by relevance to the four dimensions of the digital economy (human capital, digital technology integration, connectivity, and regional development), may not capture the full spectrum of factors influencing digital transformation. Emerging technologies such as artificial intelligence and blockchain, as well as intangible aspects like digital culture and trust, are not explicitly modeled, which could limit the study's ability to address the most current challenges and opportunities. By acknowledging these limitations, the study provides a foundation for future research to address these gaps. Building on the current findings, future research could pursue several complementary directions to deepen the understanding of digital economy dynamics in the context of regional development. The integration of additional indicators – such as digital entrepreneurship, AI adoption, cybersecurity capacity, and regional digital literacy – would provide a more nuanced perspective on the multi-dimensional nature of digital transformation. Also, longitudinal comparative studies between EU and non-EU countries could offer insights into the effectiveness of European digital policy frameworks in a broader international context. Future studies could benefit from incorporating qualitative data through case studies, expert interviews, or stakeholder surveys, thus enriching the quantitative analysis with contextual understanding. Additionally, spatial econometric models or agent-based simulations may reveal complex interdependencies and feedback loops between digital infrastructure, human capital, and innovation capacity across regions.

## Disclosure statement

The authors declare no competing interests.

## Authors contribution

All authors contributed to the study's conception and design.

## Data availability statement

All data generated or analysed during this study are included in the published article.

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