Decoding ICT trends: comparative insights into Romania's economic, employment and innovation dynamics

Business Process Management Journal

Ana Tănăsescu, Mirela Panait, Cristian Bucur and Bogdan George Tudorică
Petroleum-Gas University of Ploiesti, Ploiesti, Romania

Received 15 April 2025
Revised 14 July 2025
8 September 2025
Accepted 11 September 2025

Abstract

Purpose – This study examines the evolution of Romania's Information and Communication Technology (ICT) sector, focusing on economic output, employment and research and development (R&D) investment, while situating the performance of Romania's ICT sector within a broader international context, by comparing it with Bulgaria, Hungary, the United Kingdom and the EU27.

Design/methodology/approach – A multifaceted analytical approach was employed, integrating descriptive statistics, correlation matrices and heatmaps, contour plots, principal component analysis (PCA) and K-means clustering. Time-series data covering the period 1995–2022 were analyzed to capture the temporal dynamics and relationships between variables. Advanced visualization techniques (correlation heatmaps and contour plots) were used to emphasize complex patterns within Romania's ICT sector and the comparison countries.

Findings – The study showed that Romania's ICT sector has experienced steady growth in economic output and employment, while R&D investment remained relatively low. Correlation matrices and heatmaps highlighted significant relationships between these variables over time, and contour plots provided novel insights into the interaction between economic output and employment. PCA and K-means clustering identified distinct development phases, underlining both achievements and structural challenges in the sector.

Originality/value – The novelty of this research lies in the use of advanced statistical methods and visualizations techniques to investigate the ICT sector. Unlike conventional approaches that rely primarily on linear methods and basic visualizations, this study provides a robust framework for policymakers, researchers and industry stakeholders to understand the complex interdependencies within Romania's ICT sector.

Keywords Romania's ICT sector, Correlation heatmaps, Contour plots, Principal component analysis, K-means clustering

Paper type Research article

Introduction

The Information and Communication Technology (ICT) sector is a pivotal component of modern economies, offering a lens through which one can assess a country's economic health, innovation capabilities and labor market dynamics (Heeks, 2017). The term ICT4D has been used since 1996, when the Commission on Science and Technology for Development of the United Nations established a working group with this name (UNCSTD, 1997). The launch of this concept is an important step in the research activity because scholars try to identify the effects of ICT on economic development. Most articles in the academic literature (Hayes and Westrup, 2012; Thapa *et al.*, 2012; Ojo, 2016; Gebre-Mariam and Bygstad, 2019; Bhandari and Burroway, 2023; Lin and Tao, 2024; Parthiban *et al.*, 2024) regarding this concept focus on the ICT field in developing countries. Some researchers (Zheng *et al.*, 2018) consider this approach to be flawed because all countries, regardless of their level of economic development

This research was supported by a grant from the Petroleum-Gas University of Ploiesti, Romania, project number GO-GICS-30707/10.12.2024, within the Internal Grants for Scientific Research.

Business Process Management Journal
Emerald Publishing Limited
e-ISSN: 1758-4116
p-ISSN: 1463-7154
DOI 10.1108/BPMJ-04-2025-0502

or the modern technologies they use, face problems related to inequality and social exclusion, employment, education, public administration, healthcare, etc. At the same time, researchers should show interest in studying this concept for the specific features of this field and not solely for its transformative potential to create a better world (Walsham, 2012). The ICT must be considering a journey with multiple challenges and opportunities, with multifaceted and dynamic social, economic and technological processes rather than a static destination (Zheng *et al.*, 2018). Moreover, the specialists point to the limited potential that ICT has for development despite the massive investments made on a national and international level, the gaps are deepening in some cases, the discrepancies between the poor and the rich are increasing and some complex and wicked social problems persist (Heeks, 2010). The contribution to economic well-being is made by improving work on livelihood conditions, reducing systemic poverty, improving the equality for women and managing the humanitarian crises. In addition, negative externalities generated by the use of ICT, such as Internet crime, identity theft or cyber-attacks, are important, but also ICT can support public authorities in monitoring counter-terrorism risks (Walsham, 2017). Skeptical researchers even consider that ICT did not produce a substantial and lasting impact unless they are embedded in long-term development processes.

The impact of ICT on development can be analyzed from the perspective of the production and export of computers, component parts but also of software and offshore computing that generate employment and considerable cash receipts in foreign currency, the contribution to the balance of payments being essential. ICT support the development of specific sectors like healthcare, the financial field and public administration and can contribute to the improvement of living conditions of vulnerable communities or people from rural areas. ICT is an important tool for collecting, organizing, processing and using large amounts of data that can support management decisions. The problem of informational poverty specific to developing countries is solved with ICT, and in this way, the process of implementing development projects, substantiating and implementing decisions is substantially improved. Reducing costs, improving productivity, quality of services and products and increasing national competitiveness are the essential elements that have been identified from the perspective of ICT as a driver of economy (Walsham, 2020).

The conceptualization of the ICT use for development is illustrated in Figure 1.

In the European Union (EU), the development of ICT is considered a vital point in order to increase the competitiveness of the state in the global economy that is in a digital transition process. Ambitious plans and huge investments are projected in order to make

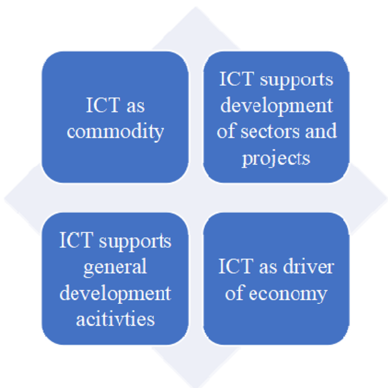

Figure 1. Conceptualization of the ICT use for development. Source: Authors' own work based on Sein and Harindranath (2004)

Europe fit for the digital era (Hysa *et al*., 2024). The European authorities designed specific instruments and financial mechanisms to develop ICT products, services and different applications for e-government, e-learning, e-inclusion, e-culture and e-health. In this way, the EU is a global leader and a model for the digital economy for different countries around the globe.

At the level of the EU, the ICT situation is different considering the endowment with human capital, the presence of foreign investors and access to European funds by companies and public authorities (Akkaya *et al*., 2023). Romania, although a relatively smaller player in the global ICT landscape, presents a compelling case for analysis, given its burgeoning tech industry and strategic location within the EU. This research aims to evaluate Romania's standing in the ICT sector by comparing it against various other economies, namely Bulgaria, Hungary, the European Union (EU27) and the United Kingdom. This study seeks to address this gap by offering a multifaceted analysis of Romania's ICT sector. It focuses on key variables (economic output, employment and R&D investment), while also situating Romania within a broader context by comparing its performance with that of Bulgaria, Hungary, the EU27 and United Kingdom. The objective of this study is to provide actionable insights for policymakers, researchers and industry stakeholders.

Literature review

The relationship between industry structure and firm profitability has been a focal point in ICT sector research. This approach is relevant to this study as it highlights the diverse performance levels within the ICT sector, not just in Romania, but globally (Binsfeld *et al*., 2015). In the article (Kim *et al*., 2023), the researchers assess the value of ICT companies in South Korea, considering profitability efficiency and using data envelopment analysis, as well as Tobit regression for this purpose. The effects of liquidity, company size and leverage on firm value were also analyzed in this study. Hallikas and Lättilä (2012) investigated the firm positioning and performance in seven industries within the ICT sector using a cluster analysis to test the formulated hypotheses.

The industrial organization framework posits that industry structure, including product differentiation and entry barriers, significantly influences firm performance. Murphy (2002) focused his research on the impact of organizational investments on firm performance, which is higher when the methods used in production, management and customer relationships are associated and also when these methods are implemented using ICT technologies. Li *et al*. (2021) assessed how information and communication technology adoption had an impact on organizational performance during the COVID-19 pandemic. Thus, the role of psychometric variables, such as employees' organizational commitment, growth mindset and entrepreneurial orientation, in mediating the relationship between ICT adoption and organizational performance was reviewed.

The resource-based view shifts focus to internal firm characteristics that sustain competitive advantages and drive profitability. This dichotomy in perspectives can provide a rich background for analyzing the Romanian ICT sector. Karim *et al*. (2022) evaluated the impact of ICT on firm performance across different countries with varying levels of ICT development. These researchers used the resource-based view to categorize ICT tools as either general-purpose technology or enabling technology. U.S. Department of Commerce (2024) analyses the effects of ICT on the Romanian economy using a dynamic computable general equilibrium model. The role of ICT in enhancing productivity, competitiveness and welfare was a topical issue for these reports. The authors stated that ICT have improved competitiveness of small and medium-sized enterprises (SMEs) in Romania and investigated the factors that influence the adoption and use of ICT by SMEs, such as human capital, innovation and institutional environment.

Dynamic capabilities and firm performance

One of the research directions in recent decades is represented by the ability of firms to integrate, modify, renew and recreate resources to respond quickly to environmental changes, thereby achieving and maintaining competitive advantages. This concept is known in the literature as dynamic capabilities (Teece *et al.*, 1997; Fainshmidt *et al.*, 2019). This is particularly pertinent in the rapidly evolving ICT sector. Elements like R&D activity, acquisitions and corporate social responsibility have been identified as key dynamic capabilities influencing firm performance in the ICT sector.

Thanh Nhon *et al.* (2020) propose a conceptual model for the relationship between intellectual capital – represented by human, social and organizational capital – and the performance of companies in the ICT sector, analyzing the mediating role of dynamic capabilities on the impact of intellectual capital on the performance of ICT companies. Based on data collected from 350 ICT companies in Vietnam, the authors determined that two of the dynamic capabilities (learning capability and integration capability) play significant mediating roles between the dimensions of intellectual capital and firm performance, with the most substantial effect being attributed to learning capability.

The impact of firms' dynamic capabilities on the IT Governance Framework was analyzed by Khalil and Belitski (2020). Additionally, this article examines the relationship between three components of IT governance and firm performance, based on data collected from 134 European SMEs in Belgium, Bulgaria, Denmark, Spain and the United Kingdom. Erkmen *et al.* (2020) evaluates how sustainable IT capabilities influence company performance. According to the authors, IT capability has three dimensions: managerial IT capability, technical IT capability and human support. The article also highlights that when the organizational climate is innovative, the relationship between IT capabilities and company performance significantly strengthens. The impact of dynamic capabilities and ICT utilization on SMEs' performance is also investigated by Suciningtias *et al.* (2022). Additionally, the researchers analyzed the mediating role played by agile leadership in the relationship between dynamic capabilities and SME performance.

ICT sector's role in economic growth and employment

Another research direction pertains to the impact of the ICT sector evolution on economic growth and employment in Eastern European countries, with a particular focus on Romania. Thus, there are specialized articles highlighting the contribution of this sector to employment, the development of employee skills within companies and economic growth (Mazurencu-Marinescu and TraianPele, 2012; Toader *et al.*, 2018; Bahrini and Qaffas, 2019; Dubyna *et al.*, 2022; Ober, 2022; Akkaya *et al.*, 2023; Gabor *et al.*, 2023; Kupis-Fijałkowska and Misztal, 2023; PARP, 2023; Pawełoszek *et al.*, 2023; Chmielarz, 2024; Salumaa-Lepik and Nisu, 2024; Wiechetek and Gola, 2023).

Dubyna *et al.* (2022) conduct a comparative analysis of the development of the ICT sector in six Eastern European countries (Hungary, Bulgaria, Poland, Romania, Slovakia and the Czech Republic) during the period 2010–2019, exploring the influence of this sector on the economies of these countries. The authors applied the following methods to data retrieved from the Eurostat platform: the index method, correlation analysis and regression analysis. The six analyzed countries have been divided into two groups according to the level of ICT sector development: countries with a dynamic ICT sector development (Hungary, the Czech Republic and Slovakia) and countries with an evolutionary ICT sector development (Bulgaria, Poland and Romania). The authors also classified the six countries into three groups based on the share of the ICT sector in country's GDP. Group I contains countries with the highest ICT sector's share in the country's GDP growth (Hungary and Bulgaria), Group II is represented by countries with a stable ICT sector share in GDP (Czech Republic and Slovakia) and Group III includes countries characterized by an active ICT sector development and gradual GDP growth (Poland and Romania).

A detailed overview of the current state of the ICT sector in Poland and its future trends is provided in the study of Wiechetek and Gola (2023). Poland has a young and rapidly expanding ICT sector, characterized by a robust foundation supported by a favorable geographical location, a skilled workforce and advanced infrastructure. However, Poland ranks below the EU average in terms of e-administration and e-commerce usage. Furthermore, investments in R&D and innovation are also suboptimal. Although Poland is a regional ICT leader, with the highest number of IT specialists in Central and Eastern Europe, it still has untapped potential in the digitalization of public administration and in consumer-oriented innovation. The future trends of this sector will be closely linked to AI, big data, cloud computing and Industry 4.0.

Pawełoszek *et al*. (2023) investigate the manner in which micro-enterprises in Poland perceived and adopted digital transformations during the COVID-19 pandemic. The study was performed in the first four months of 2022 on a sample of 400 companies, of which 168 were micro-enterprises. The research methodology employed in this study was the Computer-Assisted Web Interviewing technique. A substantial proportion of the surveyed enterprises regard the digital transformation as an important component of their business strategy during the pandemic. The most preferred IT solutions were remote communication tools, which enabled services such as online consultations, order processing and the launch of online sales.

Estonia, another Eastern European country, is a successful example in terms of e-governance services (ETAG, 2023). By building a secure and flexible digital ecosystem, the country has achieved an extremely high level of transparency in governance by implementing e-voting, an electronic identification system and the X-Road platform. It is estimated that Estonia saves over 1,400 years of working time annually through digitalization (Salumaa-Lepik and Nisu, 2024).

Mazurencu-Marinescu and Traian Pele (2012) conducted a study with the objective of identifying the factors that have contributed to the success of ICT companies in Romania. A total of 6,071 companies were analyzed, covering the period from 2002 to 2008. The authors employed techniques such as principal component analysis (PCA), binary logistic regression and multinomial logistic regression. The study posits that net working capital, turnover, total equity, total assets and financial results were the pivotal factors contributing to the success of ICT companies. Conversely, the number of employees and long-term debt were found to exert no statistically significant influence on the performance of these companies.

Vargas *et al*. (2022) evaluated the relationship between ICT development and GDP in Romania using the Augmented Dickey Fuller test and the Granger causality test. U.S. Department of Commerce (2024) provided an overview of the ICT sector in Romania, including its market size, growth potential, opportunities and challenges. Additionally, the key trends and developments in the sector, such as digital transformation, e-government, cybersecurity and e-commerce were highlighted in this report. Bakari (2022) examined the impact of digitalization and patents on economic growth in Romania using an autoregressive distributed lag model.

Challenges and opportunities in the Romanian ICT sector

Addressing the challenges and opportunities specific to Romania's ICT sector is vital. The sector faces issues like growing labor costs, lack of market information and the need for effective marketing strategies. Danileţ (2022) analyzes the impact of digitalization on the Romanian economy and society, focusing on the ICT sector. The main drivers and barriers of digitalization, such as competences of persons employed by companies, infrastructure of companies, revenues and investments were discussed. Radovici (2023) examined the paradox of the Romanian ICT systems, which are characterized by high performance and low adoption and explored the factors that influence the digitalization of the Romanian economy and society, such as education, culture and governance. The paradox of Romania's ICT sector is also highlighted by the article (Bălăcescu *et al*., 2023) that analyzes the online purchases made by individuals, considering six social and technological factors associated with both demand and supply. According to this study, Romania remained in cluster C, the low-performance cluster, throughout the analyzed period (2012–2021). The country recorded high values for variables related to households with Internet access and individuals who used the internet in the last 12 months but showed low values for people with tertiary education and companies using e-commerce and secured transactions.

Filip *et al*. (2022) evaluated the potential of the digital economy for Romania and other Central and Eastern European countries and identified the key challenges and opportunities for digitalization, such as skills, infrastructure, innovation and regulation. However, there are also significant opportunities, such as the increasing demand for IT services and software products in Western Europe, the growth of IT clusters in cities like Bucharest, Timisoara and Cluj-Napoca and the potential for e-commerce market expansion.

The specialized literature presents a study that analyzes the development of Cluj-Napoca as an innovative city-region in a country with a transitional economy (Fan *et al*., 2019). The authors conducted a multi-level analysis of six companies (two multinationals, two local firms and two start-ups), carrying out a total of 23 interviews with business representatives, university experts and representatives of local authorities. Based on this analysis, the authors identified several key aspects. There are certain city-regions in Romania whose areas of activity (such as the ICT sector in the Cluj-Napoca city-region) are undergoing a transition toward an innovation-driven economy, even though Romania's overall economy is still factor-based economy. The region has strong external linkages, but the local network is underdeveloped. The return of IT specialists to the country has contributed to the heightened interest of ICT multinational companies in this region. Although the number of start-ups is high, the region has difficulties in providing them with long-term development opportunities. The authors also found that although the region is influenced by European institutions as well as national and local authorities, the interaction between the ICT sector and academia is not sufficiently capitalized. Consequently, the authors recommend strengthening local networks and improving support for start-ups with the objective of facilitating their sustainable growth.

Methodology

This paper uses the PREDICT 2023 dataset (Joint Research Centre, 2023) developed by the Joint Research Centre of the European Commission in 2023, which provides detailed information on the ICT sector in the EU member states (EU27) and 13 other advanced and emerging countries, as well as on research and development activities in this field, for the period 1995–2022. The indicators in this dataset refer to gross output (in Euro and PPS), employment, value added (in Euro and PPS), labor productivity, R&D expenditures made by ICT companies (in Euro and PPS), hours worked by employees of these companies and personnel involved in research and development activities in this sector.

The dataset has been subjected to initial pre-processing to facilitate comparative analysis. The methodology includes both descriptive and inferential statistics, supplemented by data visualizations. Due to the complexity and multi-faceted nature of the data, it is necessary to first conduct a data cleaning and transformation process. The aim of this stage is to filter out only the variables relevant to the ICT sector, with particular attention to gross output, value added, employment and R&D expenditures for Romania and the comparison countries (Bulgaria, EU27, Hungary and the United Kingdom). Thus, the following variables were selected: R&D expenditures of ICT companies in Euro and PPS (BERDEUR and BERDPPS), employment (EMP), gross output in Euro and PPS (GOEUR and GOPPS), gross value added in Euro and PPS (GVAEUR and GVAPPS), hours worked by employees of these companies (HEMP), the personnel involved in R&D activities (PERD) and the price index (PRICE).

Table 1 presents the mean, minimum, maximum and standard deviation values for the 10 key variables corresponding to Romania, highlighting the upward trend of the Romanian ICT sector.

To perform the scientifically analysis, a range of analytical techniques were employed: (1) descriptive statistics that provide a foundational understanding of the data and characterize the central tendency, dispersion and shape of Romania's ICT sector's distribution, (2) correlation matrices and heatmaps that are used to discern the relationships between key variables and (3) contour plots that are generated to explore the intricate relationships between economic output and employment in a multi-variable setting.

Results and discussion

Comparative analysis

To analyze Romania's ICT sector, six charts (Figures 2–7) were created using time series for six of the ten selected key variables, highlighting the evolution of these variables over the past decades. To facilitate a more nuanced understanding of Romania's position in the global context, a comparative analysis with Bulgaria and Hungary, countries located in Central and Eastern Europe, as well as with the EU27 and the United Kingdom (UK), was conducted.

As can be seen in Figure 2, the R&D expenditures of ICT companies in Romania are significantly lower compared to those in the UK and the cumulative value of the 27 EU countries. Additionally, it can be observed that these expenditures are characterized by an upward trend, especially after 2010, for the three countries analyzed on the right side of Figure 2 (Romania, Bulgaria and Hungary). While Hungary's expenditures show significant fluctuations, reaching multiple peak values, particularly in 2014, Romania and Bulgaria have had more steady and consistent increases over the last decade. This trend demonstrates the remarkable progress made by Romania in terms of ICT R&D investments.

Figure 3 emphasizes the employment in the ICT sector. Thus, the UK and the EU27 exhibit considerably higher levels of employment in the ICT sector than Romania. However, Romania leads significantly in the region, with the highest share of employees compared to Hungary and

Table 1. Key variables values for the Romanian ICT sector

Variable	Symbol	Unit of measure	Minim value	Maximum Value	Mean	Standard deviation
Business R&D Expenditure in Euro	BERDEUR	Millions of current euros	0.139	114.265	31.7	36.4
Business R&D Expenditure in PPS	BERDPPS	Millions of current euros PPS	0.373	216.327	61.91	69.37
Employment	EMP	1,000 persons employed	104.5	188.9	135.95	26.20
Gross Output in Euro	GOEUR	Millions of current euros	957.2	22563.8	9027.2	6545.16
Gross Output in PPS	GOPPS	Millions of current euros PPS	3453.380	42718.290	18449.25	11651.00
Gross Value Added in Euro	GVAEUR	Millions of current euros	623.6	14019.4	3646.31	3149.41
Gross Value Added in PPS	GVAPPS	Millions of current euros PPS	2249.820	26541.841	10828.96	6734.11
Hours Worked by Employees	HEMP	Millions of hours worked	212.594	339.22	258.62	41.93
Business R&D Personnel	PERD	Full Time Equivalent	48	2290	1,073.79	847.28
Price Index	PRICE	National currency	1.932	115.558	74.00	36.92

Source(s): Joint Research Centre (2023)

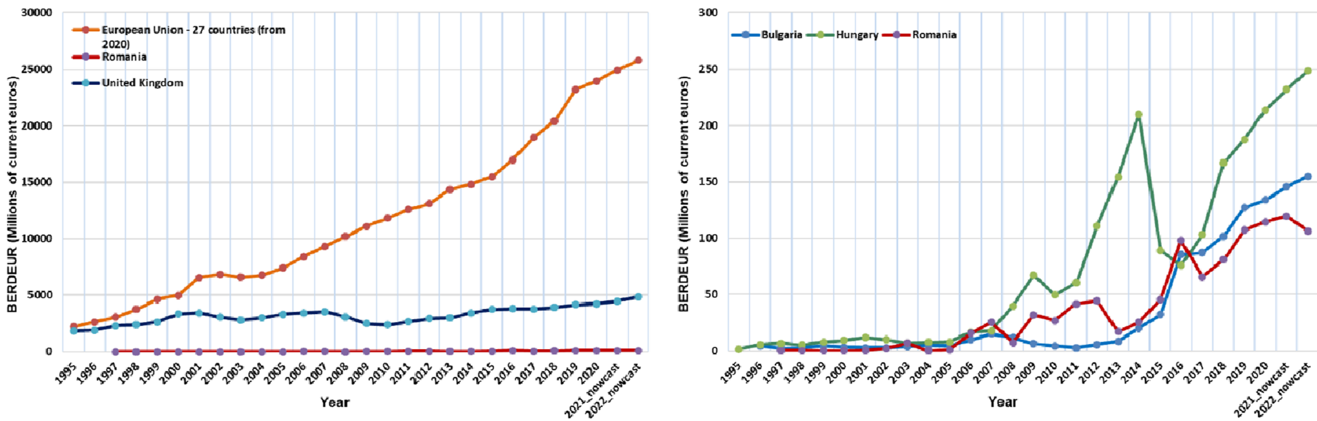

Figure 2. Comparative analysis of Business R&D Expenditures in the ICT Sector, in Euro. Source: Authors' own work based on European Commission data

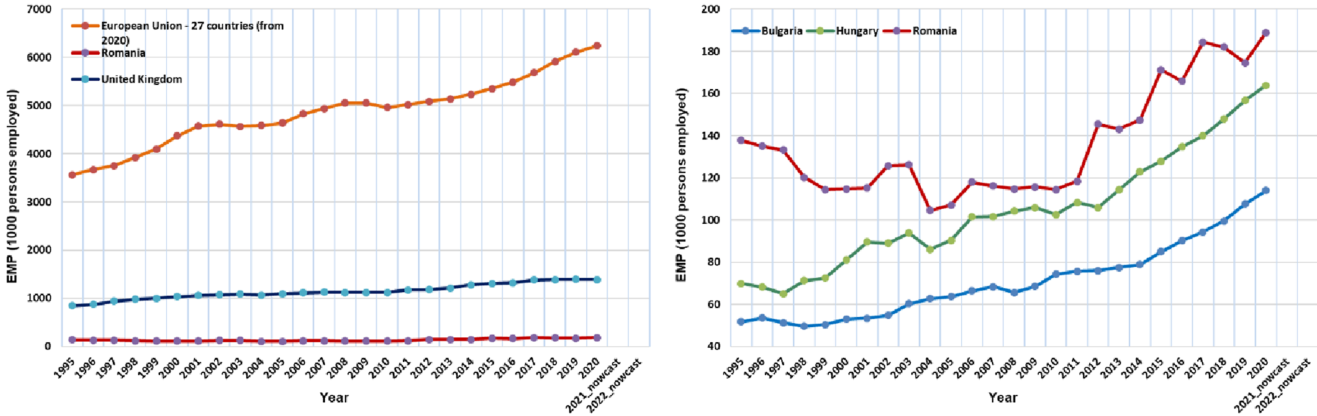

Figure 3. Comparative analysis of employment. Source: Authors' own work based on European Commission data

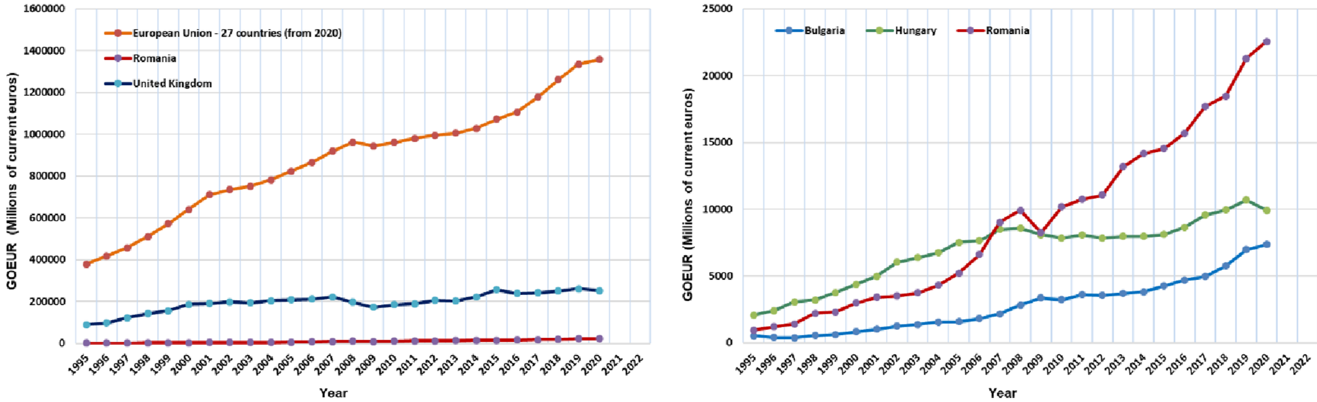

Figure 4. Comparative analysis of gross output, in Euro. Source: Authors' own work based on European Commission data

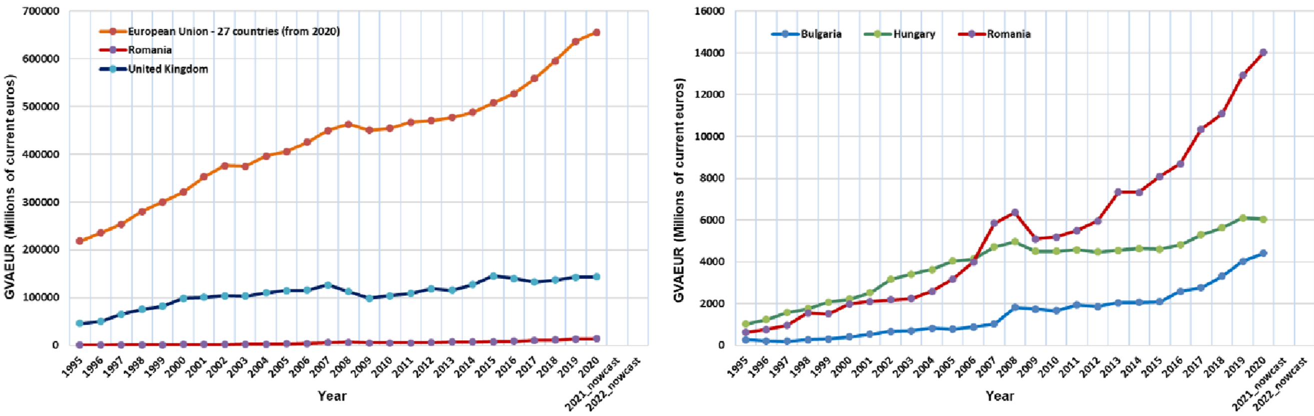

Figure 5. Comparative analysis of gross value added in euro. Source: Authors' own work based on European Commission data

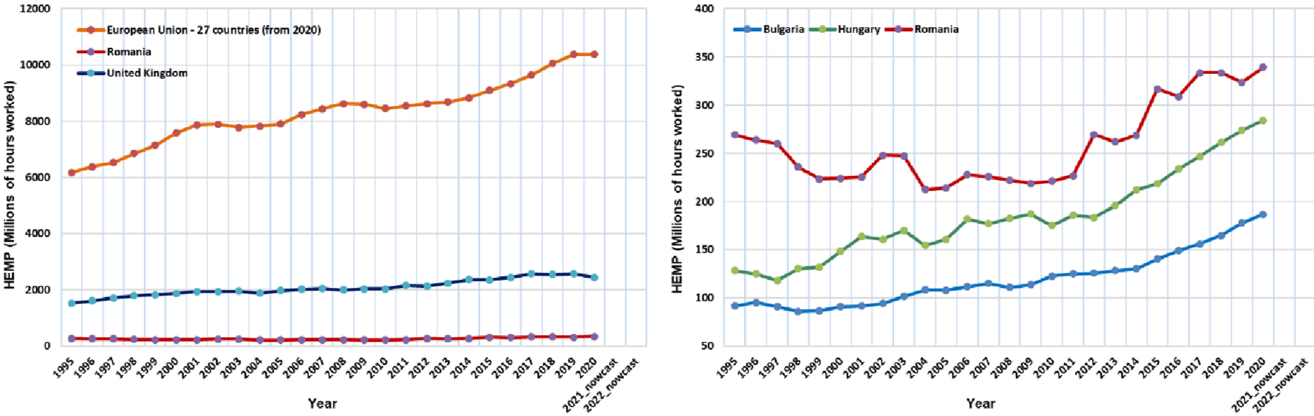

Figure 6. Comparative analysis of hours worked by employees. Source: Authors' own work based on European Commission data

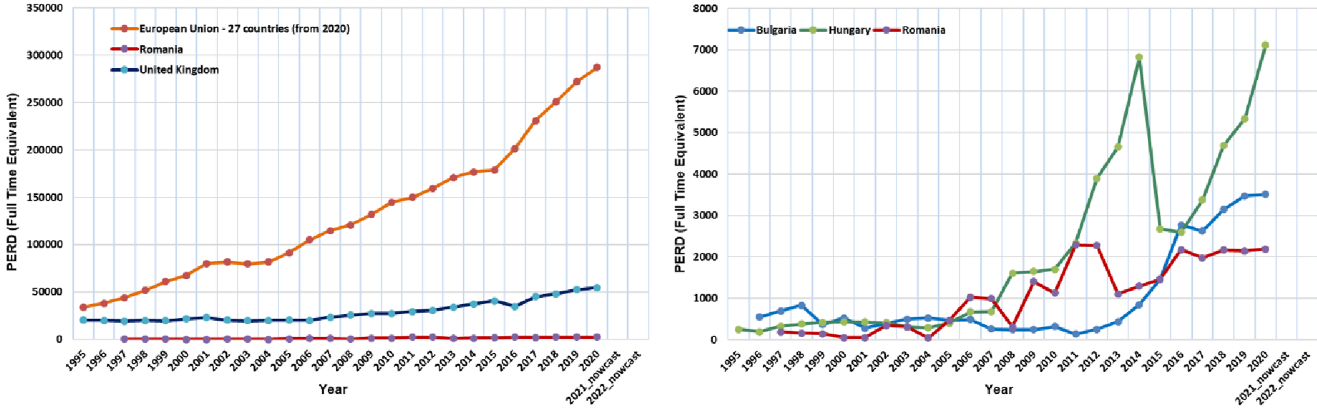

Figure 7. Comparative analysis of personnel involved in R&D activities. Source: Authors' own work based on European Commission data

Bulgaria. After a period of decline between 1995 and 2004, during which the number of employees decreased from 137.800 to 104.500 and a period of stagnation between 2004 and 2011, there is a significant increase in the number of employees in Romania, starting from 2011. This is explained by the development of ICT hubs in cities such as Bucharest, Cluj-Napoca, Iaşi and Timişoara. This difference between the two charts in Figure 3 underscores the need for Romania to invest further in human capital to strengthen its ICT sector.

Romania's gross output in the ICT sector is much lower than that of the UK and the EU27, but similar to its neighboring countries – Hungary and Bulgaria – it has shown a rising trend over the past decades (Figure 4). Additionally, this figure highlights that, unlike Hungary's output, which has remained relatively constant with minor fluctuations since 2009, or Bulgaria's output, which has experienced a small but steady increase, Romania's gross output reached a value 2.73 times higher in 2020 than in 2009.

With regard to the gross value added by this sector, Romania lags significantly behind both the UK and EU27. However, it should be noted that throughout the period under analysis, Romania has consistently outperformed Bulgaria. Moreover, since 2006, Romania has also surpassed Hungary (Figure 5). This indicator has shown a much more accelerated ascending trend since 2009 compared to the other two countries, which can be explained by the progress of the ICT sector driven by legislative changes and the growing demand for digitalization.

The variable representing the number of hours worked by employees in the ICT sector exhibits a similar behavior to that of ICT employment (Figure 6). The variable has considerably lower values for Romania in comparison to the UK and EU27, yet it is higher for both Hungary and Bulgaria.

Figure 7 presents the evolution of ICT sector personnel involved in R&D activities. The figure highlights the low values of Romania compared to UK and EU27, as well as the fluctuating trend of the variable for Romania, Hungary and Bulgaria. While in 2006, the value of the variable for Romania was higher than the values of Hungary and Bulgaria, by 2015, Romania had been surpassed by both countries. Thus, although the progress of Romania's ICT sector in the last decades is remarkable, the attention given to R&D activities and innovation in digitalization is still very low.

Advanced visualizations

Correlation heatmaps were created to determine how the 10 variables are correlated with each other in each of the analyzed countries. For the correlation analysis between variables, the Pearson correlation coefficient method was used to assess the strength and direction of the linear relationship between two variables (Massaron and Boschetti, 2016; McKinney, 2022). The Pearson correlation coefficient (r) takes values in the range of -1 (indicating a perfect negative correlation between variables) and 1 (indicating a perfect positive correlation between variables). A value of 0 suggests that there is no correlation between the variables.

The correlation heatmaps shown in Figures 8 and 9 provide interesting insights into the interrelationships of the variables corresponding to the ICT sector in each country.

Regarding Romania's ICT sector (Figure 8), it can be observed that the variable related to R&D expenditures in Euro (BERDEUR) has a strong correlation with the following variables: gross output in Euro (GOEUR), gross output in PPS (GOPPS), gross value added in Euro (GVAEUR) and gross value added in PPS (GVAPPS), registering correlation coefficients (r) of 0.91, 0.92, 0.92 and 0.93, respectively. This can be explained by the fact that these expenditures directly influence both gross output and gross value added contributed by this sector. Additionally, there is an extremely strong correlation (0.99) between the variables gross value added in Euro and PPS and the variables gross output in Euro and PPS. Employment (EMP) and the hours worked by employees (HEMP) show a more moderate correlation with gross output and gross value added (0.75–0.81), suggesting that while they have an impact on the ICT sector, their effect is more limited compared to R&D investments.

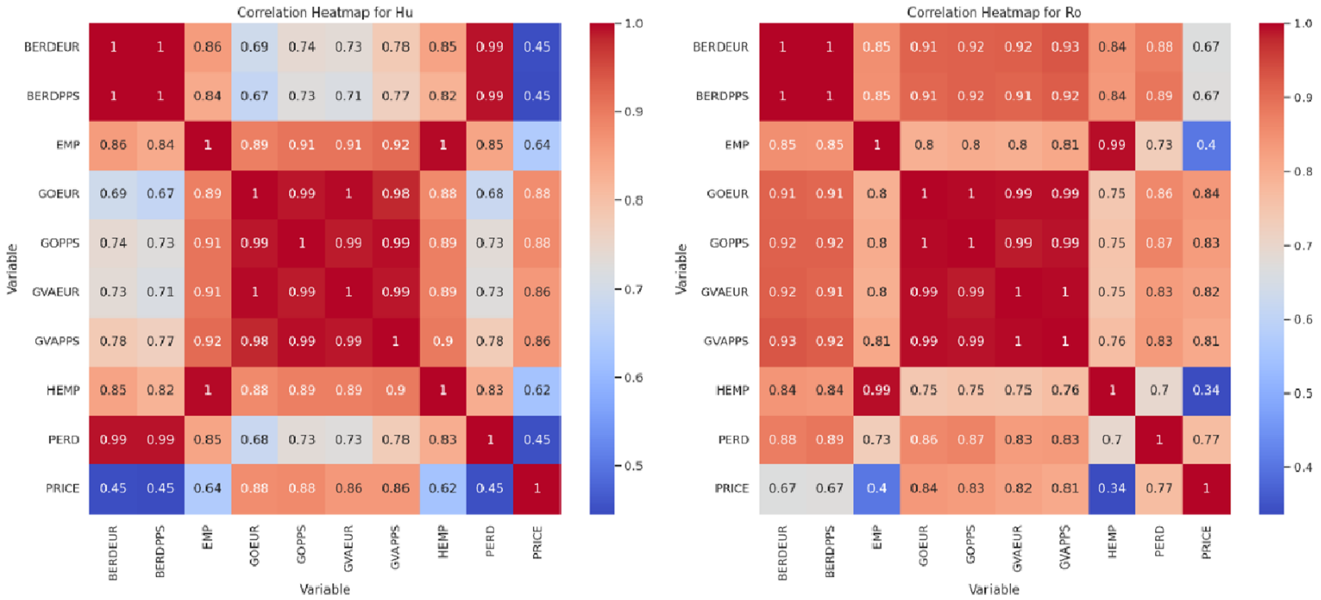

Figure 8. Correlation heatmap for Hungary and Romania. Source: Authors' own work based on European Commission data

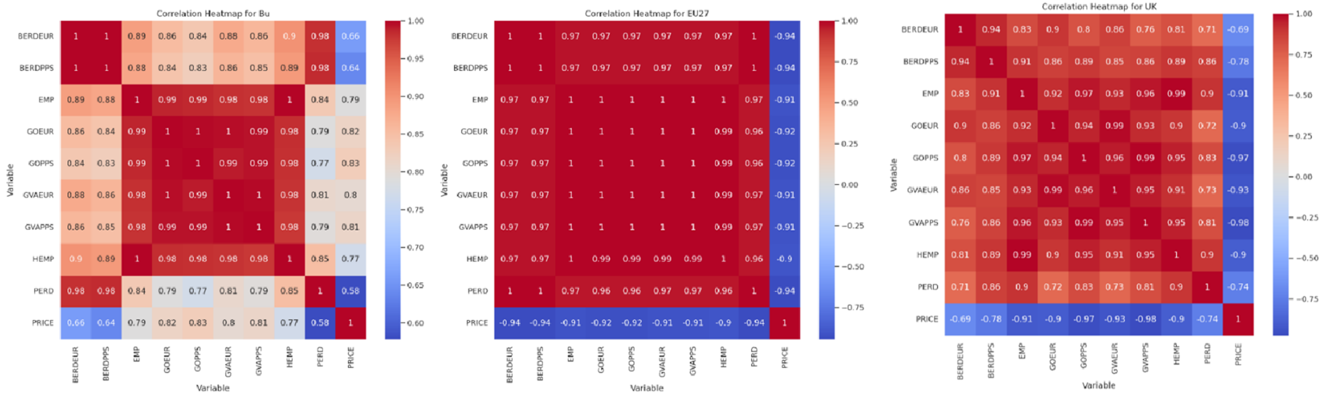

Figure 9. Correlation heatmap for Bulgaria, EU27 and UK. Source: Authors' own work based on European Commission data

According to Figure 9, which provides an analysis of the ICT sector in Bulgaria, there is a very strong correlation (0.98) between variable R&D expenditures (BERDEUR and BERDPPS) and the personnel involved in R&D activities (PERD). Additionally, a very strong correlation (0.98 and 0.99) is observed between the employment and the hours worked, on one hand, and gross output and gross value added, on the other hand. Unlike Romania's case, the number of employees and the hours they work have a direct and significant impact on the economic performance of this sector in Bulgaria. At the same time, R&D expenditures show a moderate to strong correlation (0.84–0.88) with gross output and gross value added, suggesting that these expenditures influence gross output, though the effect may be indirect. Similar to Romania's ICT sector, there is an almost perfect correlation (0.99 and 1) between gross value added variables (GVAEUR and GVAPPS) and gross output variables (GOEUR and GOPPS), which can be explained by the fact that value added is an essential component of gross output.

As in the case of Bulgaria, in the Hungarian ICT sector (Figure 8), there is a very strong correlation (0.99) between the personnel involved in R&D activity in this sector and the corresponding expenditures. Similarly, just like in Romania and Bulgaria, there is also a strong correlation between gross output and gross value added. Regarding the correlation between employment and the hours worked by employees, on one hand, and gross output and gross value added, on the other, Hungary is placed between Romania and Bulgaria, with the Pearson coefficient ranging between 0.88 and 0.92. Additionally, Figure 8 highlights that there is a moderate correlation (0.67–0.78) between R&D expenditures and both gross output and gross value added in this sector. This moderate correlation indicates that investments in R&D have a limited influence on the economic output of the sector.

The correlation heatmaps for the UK and EU27 (Figure 9) display strong positive correlations between almost all variables, emphasizing a mature and highly interdependent ICT ecosystem.

In order to conduct a meaningful comparative analysis between Romania, the UK and the EU27, considering the significant differences in population size, all key indicators were normalized on a per capita basis. The analysis focuses on 5 of the 10 indicators, which are considered to be the most salient to capture the sector's economic, employment and innovation dynamics (BERDEUR, EMP, GOEUR, GVAEUR and PERD).

The most recent five-year window with complete data for all three entities was selected, specifically the years 2018, 2019, 2020, 2021 (nowcast) and 2022 (nowcast). This approach mitigates the impact of missing data and short-term anomalies, providing a robust basis for cross-country comparison. For each country and variable, the mean value over the five-year window was calculated and then divided by the respective country's population (using 2020 estimates: Romania ∼19.3 million, UK ∼67 million and EU27 ∼447 million). This normalization enables meaningful comparison of sectoral intensity and performance across countries.

To investigate the structural relationships between ICT sector variables, Pearson correlation matrices were computed for each country using the five-year window of data. These matrices capture the strength and direction of linear associations between R&D expenditures, employment, gross output, gross value added and R&D personnel. The resulting correlation matrices were visualized as heatmaps (Figure 10), facilitating intuitive, side-by-side comparison of sectoral dynamics and interdependencies.

The per capita averages and correlation structures were interpreted to assess both the absolute and relative performance of the ICT sector in each country. Special attention was given to identifying patterns of integration, efficiency and innovation, as well as highlighting structural differences between Romania (as an emerging ICT economy) and the more mature ICT ecosystems of the UK and EU27.

As it can be seen in Figure 10, in Romania's ICT sector during the period 2018–2022, there is a perfect positive correlation (1.0) between R&D expenditures (BERDEUR) and gross output in Euro (GOEUR), suggesting that increases in R&D expenditures are directly and immediately reflected in output. This may indicate a small, highly responsive sector, or it could be a statistical artifact due to the limited data points. Additionally, there is a very strong

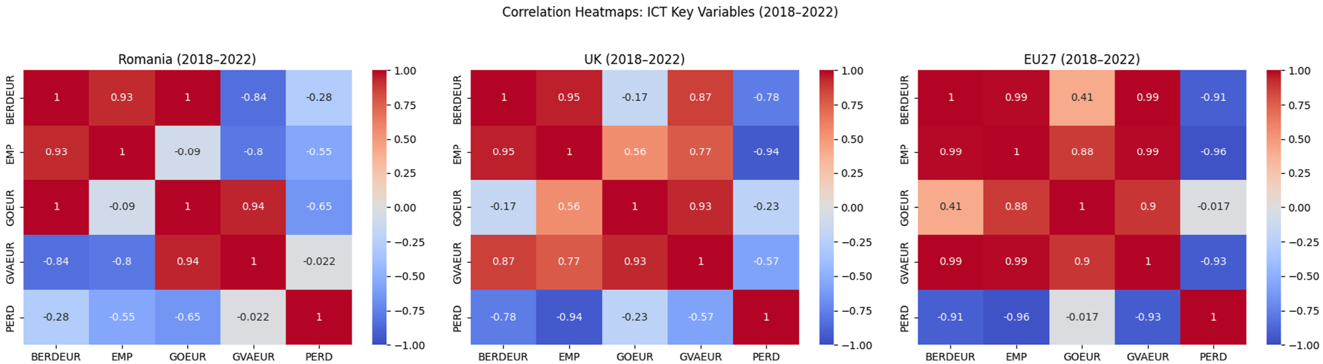

Figure 10. Correlation heatmap for Romania, UK and EU27, per capita basis. Source: Authors' own work based on European Commission data

correlation (0.93) between employment (EMP) and R&D expenditures (BERDEUR), meaning that as R&D expenditures increases, employment also rises. This suggests that R&D investment in Romania is labor-intensive, reflecting a focus on expanding the workforce rather than investing in capital or advanced technologies. At the same time, there is a strong negative correlation between gross value added in Euro (GVAEUR) and employment (EMP) and a strong positive correlation between gross value added in Euro (GVAEUR) and gross output in Euro (GOEUR). This may indicate that while more is being spent and more people are employed, the efficiency or productivity is not increasing at the same rate. The negative correlations between the personnel involved in R&D activities and the other indicators suggest that the number of employees involved in R&D is not closely tied to spending, output or employment levels. Romania's ICT sector appears to be in a phase where R&D and employment are tightly linked, but these do not always translate into higher value added or efficient use of R&D personnel. The sector may still be maturing, with room to improve productivity and the effectiveness of R&D investment.

In the case of the UK, there is a strong positive correlation (0.95) between R&D expenditures of ICT companies (BERDEUR) and employment (EMP), similar to Romania. However, there is only a moderate negative correlation (−0.17) between R&D expenditures and gross output in EUR (GOEUR). As in any mature economy, there is a strong positive correlation between gross output (GOEUR) and gross value added (GVAEUR). The strong negative correlation (−0.78) between R&D expenditures (BERDEUR) and the personnel involved in R&D activities (PERD) indicates that as the sector becomes more capital- or technology-intensive, fewer personnel are needed to achieve the same or even greater output, reflecting efficiency gains. The UK's ICT sector is more mature, with strong links between R&D, employment and value creation. The negative correlation with R&D staff suggests a shift toward higher productivity per worker, possibly due to automation, better technology, or more efficient processes.

The mature ICT ecosystem of the EU27 is indicated by the perfect positive correlations between R&D expenditures of ICT companies (BERDEUR), employment (EMP) and gross value added (GVAEUR). Additionally, the strong negative correlations between the personnel involved in R&D activities and the other indicators – except for gross output – reflect a broader EU trend of increasing output and value added with fewer personnel, indicating technological advancement and improved efficiency. The EU27's ICT sector is highly efficient and integrated. Growth in R&D, employment and value added is closely linked, and the sector is likely benefiting from economies of scale, advanced technology and effective policy frameworks. The negative correlation with R&D staff suggests that productivity improvements are allowing for more output and value with fewer personnel.

For Romania, the focus should be on improving the productivity of R&D investment and workforce, possibly through better training, technology adoption and innovation policy, moving toward the more integrated and efficient model seen in the UK and EU27.

The varying patterns in the heatmaps reflect the different economic, social and policy contexts within each country. These differences can be attributed to a multitude of factors, including but not limited to: *maturity of the ICT sector, R&D investment, policy framework, skilled workforce, globalization and external factors*, as well as *data availability and quality.* More *mature* economies like the UK and the EU27 often have a more integrated and developed ICT ecosystem, reflected in higher correlations across multiple metrics. The level and consistency of *investment in ICT* can significantly influence the relationships between variables like R&D investment, employment and economic output. Countries with coherent *long-term policies* for the ICT sector may show more stable and predictable correlations among various indicators. The availability of a *skilled workforce* can influence the interplay between employment and economic output metrics. Countries more integrated into the global ICT market might exhibit different correlation patterns, owing to influences like foreign direct investment, global market demand and international collaborations. Finally, the *extent and quality of data available* can also influence the observed correlations. Sparse or inconsistent data can lead to misleading or counterintuitive patterns. Thus, the different patterns in the correlation heatmaps encapsulate the complexity and uniqueness of the ICT landscape in each country, making them a rich source for nuanced analysis and interpretation.

Contour plots is an advanced visualization technique used to illustrate the relationships between three numerical variables in a two-dimensional space. The two independent variables are represented on the axes *x* and *y*, while the third variable, *z*, determines the contour levels, which are displayed as curves in varying colors (Vo *et al.*, 2017; Yim *et al.*, 2018).

Contour plots offer a valuable avenue for highlighting complex relationships between multiple variables and enable readers to discern patterns or gradients that may not be immediately obvious through conventional visualizations. Specifically, the contour lines and color gradients can be interpreted to understand zones of high or low activity, as well as how the two independent variables contribute to these zones. The areas with tightly packed contour lines indicate regions of high data density, while sparse contour lines signify less frequent combinations of the three variables. The direction and curvature of the contour lines can provide insights into the rate of change between the variables.

Figures 11 and 12 show contour plots that provide a nuanced understanding of how gross output and employment interact to influence a hypothetical outcome, acting as a proxy for sectoral productivity.

Comparing the contour plots for the ICT sector in Romania, Bulgaria and Hungary, it is evident that Romania has the highest level of gross output and employment in this sector. At the same time, Romania exhibits the highest "outcome" values, indicating a strong correlation between gross output and employment. These clear advantages in favor of Romania can be explained by the high investments in R&D within the ICT sector, a robust digital infrastructure and economic policies that support this industry.

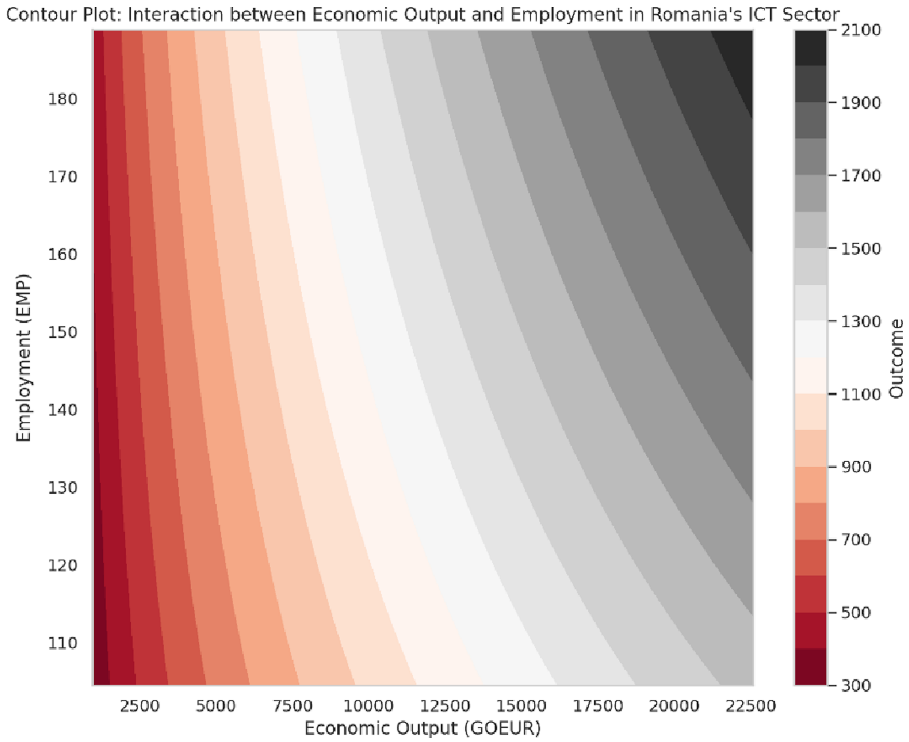

Figure 11. Interaction between gross output and employment in Romania's ICT sector. Source: Authors' own work based on European Commission data

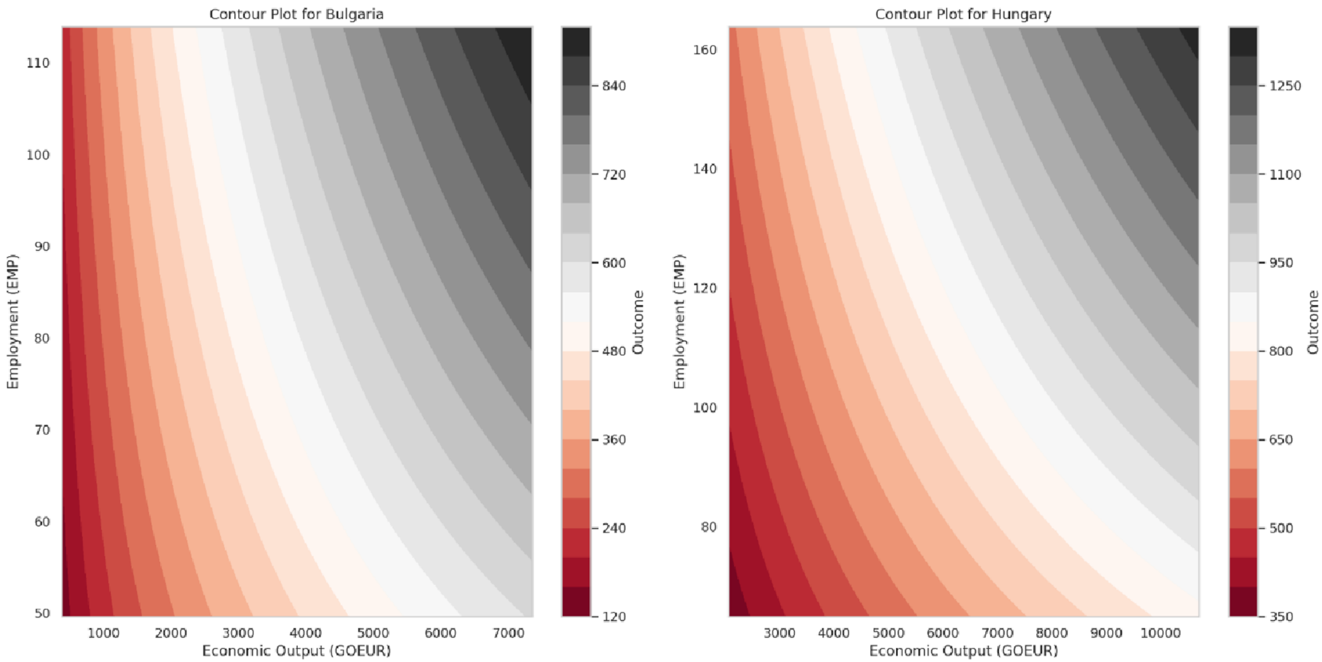

Figure 12. Interaction between gross output and employment in the Bulgarian and Hungarian ICT sector. Source: Authors' own work based on European Commission data

To explore further the multidimensional structure and temporal evolution of Romania's ICT sector, PCA and K-means clustering were applied to the full time series (1995–2022) of the 10 key indicators.

PCA can serve as a powerful tool to simplify the complexity of the data by reducing its dimensionality (Vo *et al.*, 2017; Yim *et al.*, 2018). It could allow the visualization of the evolution of the Romanian ICT sector over time in a two- or three-dimensional space, making it easier to identify trends or outliers.

Applying clustering algorithms, like K-means, could provide insights into different phases in the development of Romania's ICT sector. By identifying clusters or groups of years with similar characteristics in terms of gross output, employment and R&D investment, the analysis can provide a better understanding of the sector's trajectory and highlight periods that may be considered turning points of particular significance.

The analysis was conducted through the following steps: data standardization, PCA, K-means clustering and visualization.

In the data standardization stage, all variables were standardized (zero mean, unit variance) to ensure comparability and to prevent scale differences from biasing the analysis.

PCA was performed to reduce the dimensionality of the dataset and to identify the main axes of variation. The first three principal components were retained, as they explained over 99% of the total variance (PC1 – 65.1%, PC2 – 26.5% and PC3 – 7.8%).

The loadings of each variable on the principal components (Table 2) were examined to interpret the underlying economic dimensions (e.g. sector size, efficiency and innovation capacity).

As can be seen in Table 2, PC1 is most strongly influenced by GOEUR, GVAEUR, GVAPPS, GOPPS and PRICE (all positive) and negatively by EMP and HEMP. PC2 is dominated by R&D variables (BERDEUR, BERDPPS and PERD), while PC3 is most influenced by EMP and HEMP (both positive).

K-means clustering ($k = 3$) was applied to the time series of Romania's ICT sector, projected onto the first three principal components. This unsupervised learning technique grouped years into distinct "phases" or "eras" based on their multivariate profiles, revealing periods of structural change or stability in the sector's development.

The three development phases (clusters) correspond to the following years:

(1) Cluster 2 (Early Pre-Transition phase): 1995, 1996;

(2) Cluster 0 (Transition/Restructuring phase): 1997–2005;

(3) Cluster 1 (Modernization phase): 2006–2020.

In Table 3, the clusters' summary statistics are presented, and the cluster centroids in PCA space are listed in Table 4.

Table 2. PCA loadings to each principal component

Variable	PC1	PC2	PC3
BERDEUR	−0.089	0.594	−0.095
BERDPPS	−0.174	0.546	−0.121
EMP	−0.340	0.004	0.565
GOEUR	0.372	0.149	0.215
GOPPS	0.352	0.211	0.285
GVAEUR	0.369	0.143	0.253
GVAPPS	0.355	0.186	0.329
HEMP	−0.341	−0.007	0.557
PERD	−0.242	0.476	−0.124
PRICE	0.384	0.034	−0.177

Table 3. Cluster summary statistics

Variable	Cluster 0	Cluster 1	Cluster 2
BERDEUR	13.74	41.67	181.22
BERDPPS	37.03	80.76	669.51
EMP	404.44	231.03	478.99
GOEUR	4584.41	9,750.17	3097.98
GOPPS	12165.62	18919.37	11475.42
GVAEUR	2307.08	4963.85	1,413.27
GVAPPS	6,107.40	9,621.56	5231.28
HEMP	769.12	429.16	901.85
PERD	1,634.73	888.00	43690.00
PRICE	36.67	97.55	2.65

Table 4. Cluster centroids in PCA Space

Cluster	PC1	PC2	PC3
0	−1.983	−1.369	0.382
1	1.888	0.229	−0.179
2	−5.234	4.446	−0.381

The results were visualized using 2D (Figure 13) and 3D (Figure 14) scatter plots of the principal component scores, with years annotated and colored by cluster assignment. This allowed for intuitive interpretation of the sector's trajectory and the identification of key transition points.

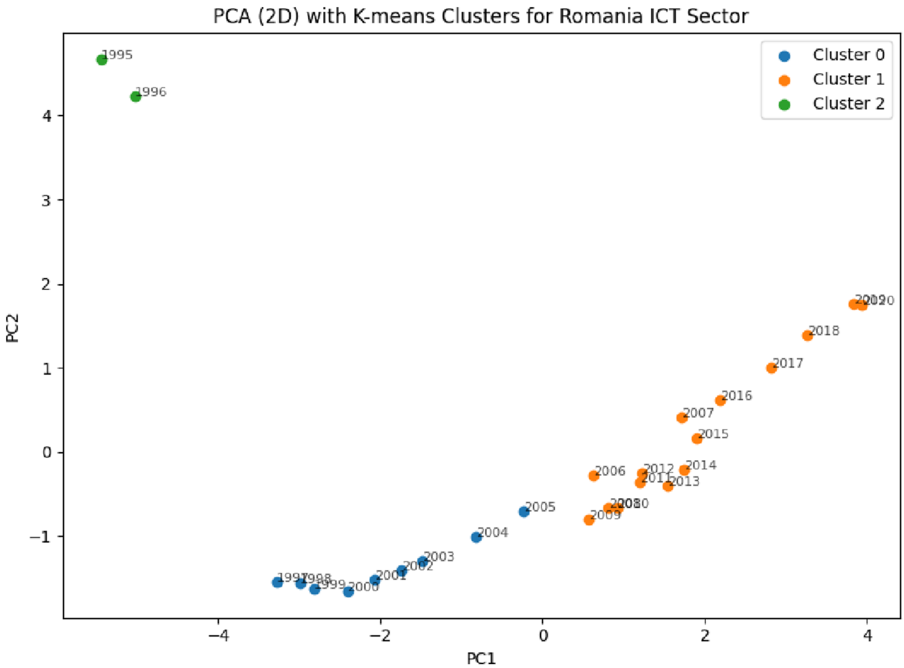

Figure 13. 2D PCA plot with K-means clusters. Source: Authors' own work based on European Commission data

Figure 13 shows how Romania's ICT sector evolved over time, with each year colored by its development phase (cluster).

Figure 14 gives a more nuanced view, showing how the sector's trajectory moves through "phases" in three principal dimensions.

Cluster 2 (1995–1996), "Early Post-Transition" phase, is characterized by very high R&D personnel and expenditures, but low output, value added and price index. These years likely reflect the legacy of the pre-market economy, with inflated R&D staff numbers (possibly due to state employment), but low efficiency and market output. The sector was not yet restructured for market realities.

Cluster 0 (1997–2005), "Transitional/Restructuring" phase, has moderate R&D, high employment and hours worked, but still relatively low output and value added. Price index is rising, but it is not yet high. This phase marks the restructuring of the ICT sector. Employment remains high (possibly due to slow labor market adjustment), but output and value added are only starting to grow. R&D is moderate, reflecting both legacy and new investments. The sector is adapting to market conditions, with gradual improvements in productivity.

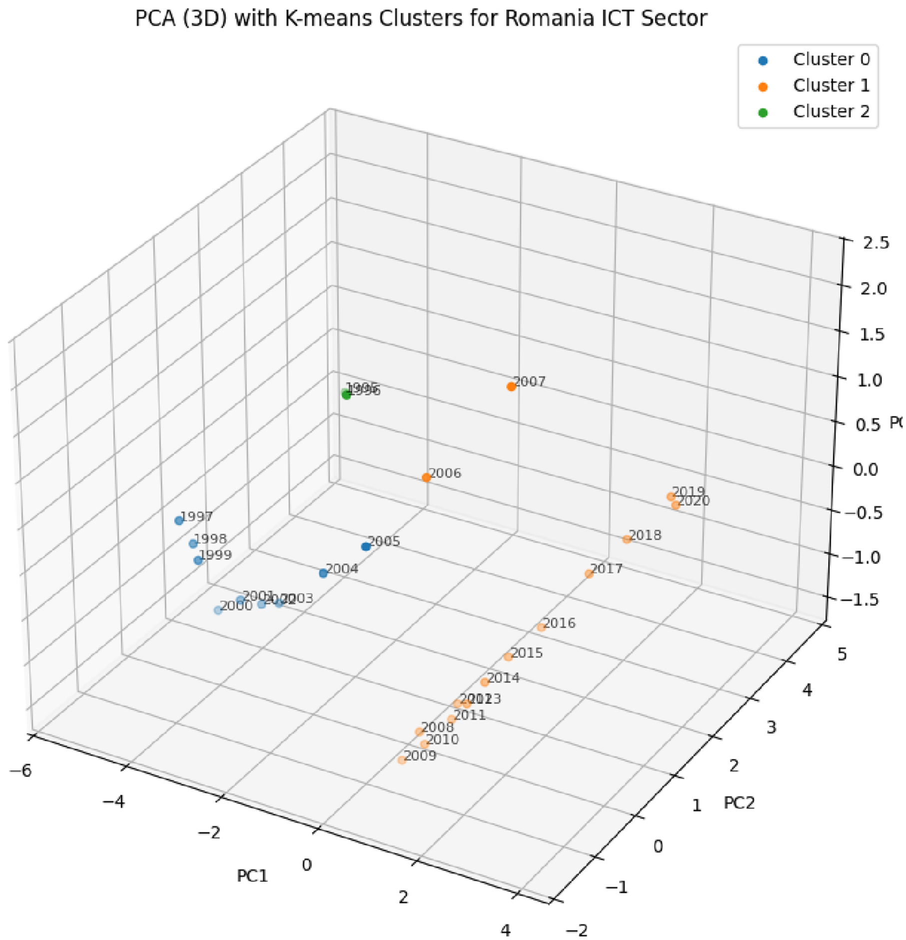

Figure 14. 3D PCA plot with K-means clusters. Source: Authors' own work based on European Commission data

Cluster 1 (2006–2020), "Growth and Modernization" phase, is defined by high output, value added and R&D expenditures. Employment and hours worked are lower (reflecting efficiency gains), and the price index is much higher. This is the "modernization" phase, where the sector is competitive, productive and innovation-driven. Output and value added rise sharply, R&D investment increases, and the sector becomes more efficient (less labor-intensive, more value per worker). The high price index reflects both inflation and the higher value of ICT products/services. This phase aligns with Romania's EU accession and integration into global ICT markets.

Conclusion

The study provides a comprehensive analysis of Romania's ICT sector, revealing its strengths and areas requiring attention. The advanced visualizations employed offer a multidimensional perspective. Initial exploration involved generating correlation heatmaps to identify relationships between key variables. The heatmaps highlighted different correlation patterns among countries, with Romania exhibiting moderate to strong correlations between employment and hours worked, on one hand, and gross output, on the other hand. The contour plots can serve as a sophisticated tool for policymakers, researchers and industry stakeholders seeking to understand the nuanced interplay between key metrics in Romania's ICT sector. Both PCA and contour plots can be used as robust techniques for understanding multivariate relationships. While PCA aims to capture the maximum variance in the data by transforming the original variables into a new set of uncorrelated variables (principal components), contour plots provide a visual representation of three-dimensional data in two dimensions through contour lines.

The 3D PCA plot, integrated with K-means clustering and year annotations, provided robust visual tools for understanding complex economic phenomena in Romania's ICT sector. The principal components were interpreted as capturing the overall "health," "efficiency" and "innovative capacity" of the sector. The identified clusters could represent different "eras" or "phases" in the development of Romania's ICT sector, with the annotated years offering a temporal lens for better understanding the sector's evolution.

In the context of the ICT sector, Romania presents a unique case study, particularly when juxtaposed against a broader international backdrop. The country has been experiencing a notable uptick in its ICT capabilities, driven by a combination of factors including governmental policies, foreign investments and a burgeoning start-up ecosystem. The main strengths are talent pool, cost competitiveness and strategic location. Romania boasts a strong educational system in the fields of engineering and computer science, generating a skilled workforce that is increasingly attractive to both domestic and international employers. Lower operational and labor costs compared to Western European countries make Romania an attractive destination for ICT outsourcing and shared service centers. Romania's geographical location, at the crossroads between Eastern and Western Europe, makes it an ideal hub for companies looking to expand their operations across the continent.

Digitalization has had a transformative impact on business processes, management and organizational frameworks. The impact of digitalization on business processes has multiple faces, like automation and efficiency, data-driven decision-making, supply chain optimization and customer experience. Technologies like Robotic Process Automation (RPA) and AI reduce manual effort, speed up processes and minimize errors, while real-time analytics and big data allow businesses to monitor performance, predict trends and make informed decisions faster. Internet of Things (IoTs) and blockchain technologies improve transparency, tracking and logistics efficiency. Digital tools enhance interactions through chatbots, personalized marketing and omnichannel service delivery. In the digital transition, organizational frameworks are improved by different shifts. Traditional top-down structures are giving way to more collaborative and cross-functional teams, and organizations are adopting frameworks like Agile, Scrum or Design Thinking to foster innovation and respond quickly to change. Businesses are more interconnected through digital platforms, leading to the rise of ecosystems, partnerships and platform-based models, and a specific focus on continuous learning, adaptability and digital literacy is becoming central to organizational culture. The use of digital tools has metamorphis managerial approaches and expectations with remote and agile work. Cloud computing, collaboration platforms (Slack, Microsoft Teams) and project management tools (Trello, Asana) have enabled remote work and agile practices. Performance Monitoring is improved because managers now have access to dashboards and KPIs that offer real-time insights into employee productivity and business metrics. In addition, Recruitment and HR processes have become more data-driven, using AI for candidate screening, digital onboarding and learning platforms (Aquilani *et al*., 2016; Dominici, 2021; Vătămănescu and Bratianu, 2021; Cubillas-Para *et al*., 2024).

Taking into account the results of this analysis, some opportunities were identified – R&D investment and high-skilled employment. This initial data analysis showed a positive trend in R&D expenditures (BERDEUR), suggesting an increasing focus on innovation. This is a key area where Romania could gain a competitive edge. The correlation heatmap revealed a moderate to strong relationship between employment (EMP) and hours worked (HEMP), on one hand, and gross output (GOEUR) and gross value added, on the other, suggesting that they do have an impact on the ICT sector, but their effect is more limited compared to R&D investment.

Besides the opportunities, the main challenge is international competition. While Romania has many strengths, it faces stiff competition from other countries in the region, like Hungary and Bulgaria, as well as from more developed ICT ecosystems like the UK and the broader EU. Romania's ICT sector is at a critical juncture, with significant opportunities for growth and innovation. However, realizing this potential will require concerted efforts in terms of policy formulation, investment in human capital and industry-academia collaboration. The challenges in data completeness and compatibility encountered in this study underscore the need for robust data governance, which could serve as a foundation for evidence-based policymaking. The findings suggest that while Romania has made significant progress in economic output and employment within the ICT sector, there is a pressing need to focus on R&D investment to sustain long-term growth and competitiveness.

Based on this study, several recommendations can be formulated for policymakers, concerning four key aspects: investments in R&D activities within the ICT sector, personnel training, university–industry partnerships and innovation-friendly policies. Accordingly, the recommendations derived from the study's findings are presented in the following lines. The first recommendation is to increase funds for R&D in the ICT sector. The ICT sector is one of the most important drivers of innovation and economic growth, with a cross-cutting impact on other industrial sectors and society as a whole. Investments in R&D in this sector lead to increased productivity, the generation of new technologies and services, the creation of well-paid jobs and increased global competitiveness. A second recommendation is prioritizing innovative projects with an impact on economic growth that involve focusing resources, policies and support on initiatives within the ICT sector that significantly drive productivity, competitiveness and long-term national development. These projects should act as catalysts for structural transformation by creating sustainable value across industries and society. Third, supporting the continuous training of employees in the ICT sector is essential for maintaining technological competitiveness, fostering innovation and enhancing organizational performance. This support can be structured through comprehensive programs that respond to the fast-paced evolution of ICT technologies and the diverse needs of employees. In addition, facilitating partnerships between universities and ICT companies can be a strategic approach to foster innovation, knowledge transfer and technological advancement. Such collaborations leverage the complementary strengths of academia and industry, driving research commercialization and improving economic competitiveness. Romania's ICT sector is a key contributor to its GDP and economic development, yet the recent elimination of income tax exemptions for IT employees has increased labor costs and posed challenges for competitiveness. Finally, reintroducing or designing new fiscal incentives that directly target innovation activities is essential to offset these challenges, foster R&D and keep the sector attractive for talent and investment. So, (re)introducing fiscal incentives for innovation in the ICT sector in Romania is crucial to stimulate growth, competitiveness and technological advancement, especially following the removal of previous tax breaks for IT employees in 2025. A modernized and targeted incentive framework can help attract investments and support startups and established firms focused on digital transformation.

Given the scope and findings of this study, several directions for future research have been identified from different perspectives – longitudinal analysis, policy impact assessment, sectoral decomposition, international comparison, advanced econometric modeling and social and environmental impacts. The current study encompasses data until 2022, so a longitudinal extension of this research could provide more dynamic insights into the evolution of Romania's ICT sector and how it responds to global economic changes. Further research could focus on the correlation between policy changes and shifts in PCA or contour plot patterns. This would offer a deeper understanding of how governmental decisions influence the sector's stability, efficiency and innovation. The ICT sector comprises various sub-sectors such as software development, hardware manufacturing and telecommunications. A more granular analysis could reveal nuanced patterns and trends within these sub-sectors. While this study has compared Romania's ICT sector to that of Bulgaria, Hungary, UK and the EU27, future research could expand this to include additional countries, providing a more comprehensive global context. Combining quantitative findings with qualitative insights from industry experts, surveys or case studies could provide a more comprehensive view of the sector. Given the fast-paced evolution of technology, subsequent studies could explore how emerging technologies like Artificial Intelligence, IoTs and Blockchain are influencing Romania's ICT sector. The introduction of econometric models like Vector Autoregressive (VAR) models or structural equation modeling could add another layer of sophistication, allowing for the prediction of future trends based on past data. Incorporating machine-learning algorithms like Random Forest or Neural Networks could offer predictive insights and identify non-linear relationships between variables, which traditional statistical methods might not capture. Future research could also consider the social and environmental impacts of the ICT sector's growth, such as its role in job creation, income inequality and carbon footprint. By building upon the methodological and analytical frameworks established in this study, these future directions could offer even more comprehensive and nuanced insights into Romania's ICT sector, thereby contributing to the body of academic research on this subject.

References

Akkaya, B., Apostu, S.A., Hysa, E. and Panait, M. (2023), *Digitalization, Sustainable Development, and Industry 5.0: an Organizational Model for Twin Transitions*, Emerald Publishing, Leeds.

Aquilani, B., Abbate, T. and Dominici, G. (2016), "Choosing open innovation intermediaries through their web-based platforms", *International Journal of Digital Accounting Research*, Vol. 16, doi: 10.4192/1577-8517-v16_2.

Bahrini, R. and Qaffas, A.A. (2019), "Impact of information and communication technology on economic growth: evidence from developing countries", *Economies*, Vol. 7 No. 1, p. 21, doi: 10.3390/ECONOMIES7010021.

Bakari, S. (2022), "The impact of digitalization and patent on economic growth in Romania", *Journal of Research, Innovation and Technologies*, Vol. 1 No. 1, pp. 49-61, doi: 10.57017/jorit.v1.1(1).05.

Bălăcescu, A., Pătraşcu, A. and Tănăsescu, A. (2023), "Analysis of disparities in internet purchases by individuals at the EU state level", *Electronics*, Vol. 12 No. 4, p. 982, doi: 10.3390/electronics12040982.

Bhandari, A. and Burroway, R. (2023), "Hold the phone! A cross-national analysis of Women's education, mobile phones, and HIV infections in low-and middle-income countries, 1990-2018", *Social Science and Medicine*, Vol. 334, 116217, doi: 10.1016/j.socscimed.2023.116217.

Binsfeld, N., Pugalis, L. and Whalley, J. (2015), "ICT ecosystems in small countries: an analysis of Luxembourg", [Online], available at: https://www.econstor.eu/handle/10419/127127 (accessed May 2024).

Chmielarz, G. (2024), "Data management in Polish SMEs in the era of AI–threats and benefits of AI-based tools", *Procedia Computer Science*, Vol. 246, pp. 5439-5447, doi: 10.1016/j.procs.2024.09.681.

Cubillas-Para, C., Cegarra-Navarro, J.G. and Vătămănescu, E.M. (2024), "Gliding from regenerative unlearning toward digital transformation via collaboration with customers and organisational agility", *Journal of Business Research*, Vol. 177, 114637, doi: 10.1016/j.jbusres.2024.114637.

Danileţ, A.M. (2022), "All aboard: towards digitalisation. Romania and its ICT sector", *Proceedings of the 5th International Conference on Economics and Social Sciences*, pp. 367-377, doi: 10.2478/9788367405072-033.

Dominici, G. (2021), "Socio-economic ecosystems: challenges for sustainable development in the digital era", *Kybernetes*, Vol. 50 No. 10, pp. 2697-2700, doi: 10.1108/K-10-2021-914.

Dubyna, M., Kholiavko, N., Zhavoronok, A., Safonov, Y., Krylov, D. and Tochylina, Y. (2022), "The ICT sector in economic development of the countries of eastern Europe: a comparative analysis", *WSEAS Transactions on Business and Economics*, Vol. 19, pp. 169-185, doi: 10.37394/23207.2022.19.18.

Erkmen, T., Günsel, A. and Altindağ, E. (2020), "The role of innovative climate in the relationship between sustainable IT capability and firm performance", *Sustainability*, Vol. 12 No. 10, p. 4058, doi: 10.3390/SU12104058.

ETAG (2023), "Overview of the Estonian ICT sector", [Online], available at: https://etag.ee/wp-content/uploads/2022/07/Overview-of-the-Estonian-ICT-sector-_2023.pdf (accessed June 2025).

Fainshmidt, S., Wenger, L., Pezeshkan, A. and Mallon, M.R. (2019), "When do dynamic capabilities lead to competitive advantage? The importance of strategic fit", *Journal of Management Studies*, Vol. 56 No. 4, pp. 758-787, doi: 10.1111/joms.12415.

Fan, P., Urs, N. and Hamlin, R.E. (2019), "Rising innovative city-regions in a transitional economy: a case study of ICT industry in Cluj-Napoca, Romania", *Technology in Society*, Vol. 58, 101139, doi: 10.1016/j.techsoc.2019.05.003.

Filip, A., Kmen, M. and Tisler, O. (2022), "Digital challengers on the next Frontier: perspective on Romania", [Online], available at: https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/digital-challengers-on-the-next-frontier-perspective-on-romania (accessed April 2024).

Gabor, E., Oancea, M. and Pripp, V. (2023), "Regional evolution of the ICT sector in the European Union: insights and trends", *Revista de Ştiințe Politice. Revue des Sciences Politiques*, Vol. 80, pp. 129-146.

Gebre-Mariam, M. and Bygstad, B. (2019), "Digitalization mechanisms of health management information systems in developing countries", *Information and Organization*, Vol. 29 No. 1, pp. 1-22, doi: 10.1016/j.infoandorg.2018.12.002.

Hallikas, J. and Lättilä, L. (2012), "Firm positioning and performance in ICT industry sectors", *Journal of the Knowledge Economy*, Vol. 3 No. 4, pp. 406-420, doi: 10.1007/S13132-011-0061-8/TABLES/7.

Hayes, N. and Westrup, C. (2012), "Context and the processes of ICT for development", *Information and Organization*, Vol. 22 No. 1, pp. 23-36, doi: 10.1016/j.infoandorg.2011.10.001.

Heeks, R. (2010), "Do information and communication technologies (ICTs) contribute to development?", *Journal of International Development*, Vol. 22 No. 5, pp. 625-640, doi: 10.1002/jid.1716.

Heeks, R. (2017), *Information and Communication Technology for Development (ICT4D)*, Routledge, London.

Hysa, E., Manta, O., Ailincă, A.G., Piciu, G.C. and Yue, X.G. (2024), "Digitalization as an instrument in support of covering the circularity gap in the European Union economy", *Environment, Development and Sustainability*, pp. 1-21, doi: 10.1007/s10668-024-04772-6.

Joint Research Centre (2023), [Online], available at: https://joint-research-centre.ec.europa.eu/predict/ict-sector-analysis-2023/data-and-metadata_en (accessed May 2024).

Karim, M.S., Nahar, S. and Demirbag, M. (2022), "Resource-based perspective on ICT use and firm performance: a meta-analysis investigating the moderating role of cross-country ICT development status", *Technological Forecasting and Social Change*, Vol. 179, 121626, doi: 10.1016/j.techfore.2022.121626.

Khalil, S. and Belitski, M. (2020), "Dynamic capabilities for firm performance under the information technology governance framework", *European Business Review*, Vol. 32 No. 2, pp. 129-157, doi: 10.1108/EBR-05-2018-0102.

Kim, Y., Jung, S. and Kim, C. (2023), "The impact of capital structure on the profitability performance of ICT firms", *Processes*, Vol. 11 No. 2, p. 635, doi: 10.3390/PR11020635.

Kupis-Fijałkowska, A. and Misztal, M. (2023), "ICT usage in enterprises in the years 2010-2019– Poland in comparison with other European Union countries", *Acta Universitatis Lodziensis. Folia Oeconomica*, Vol. 4 No. 361, pp. 22-57, doi: 10.18778/0208-6018.361.02.

Li, Z., Akouatcha, H.G., Akram, U. and Anaba, O.A. (2021), "Information and communication technology and organizational performance during COVID-19 pandemic: the role of organizational commitment, growth mindset, and entrepreneurial orientation", *Frontiers in Psychology*, Vol. 12, 752193, doi: 10.3389/fpsyg.2021.752193.

Lin, J. and Tao, J. (2024), "Digital resilience: a multiple case study of Taobao village in rural China", *Telematics and Informatics*, Vol. 86, 102072, doi: 10.1016/j.tele.2023.102072.

Massaron, L. and Boschetti, A. (2016), *Regression Analysis with Python*, Packt Publishing, Birmingham.

Mazurencu-Marinescu, M. and TraianPele, D. (2012), "Modelling the strategic success factors of the Romanian ICT based companies", *Procedia – Social and Behavioral Sciences*, Vol. 58, pp. 1111-1120, doi: 10.1016/j.sbspro.2012.09.1092.

McKinney, W. (2022), *Python for Data Analysis*, O'Reilly Media, Sebastopol, CA.

Murphy, M. (2002), "Organisational change and firm performance", [Online], available at: https://www.oecd-ilibrary.org/science-and-technology/organisational-change-and-firm-performance_615168153531 (accessed June 2024).

Ober, J. (2022), "Open innovation in the ICT industry: substantiation from Poland", *Journal of Open Innovation: Technology, Market, and Complexity*, Vol. 8 No. 3, p. 158, doi: 10.3390/joitmc8030158.

Ojo, T. (2016), "Global agenda and ICT4D in Africa: constraints of localizing 'universal norm'", *Telecommunications Policy*, Vol. 40 No. 7, pp. 704-713, doi: 10.1016/j.telpol.2016.05.002.

PARP (2023), "The IT/ICT sector in Poland – report 2023", [Online], available at: https://www.parp.gov.pl/storage/publications/pdf/3_RAPORT_IT_2023_PARP_14_08_2023.pdf (accessed June 2025).

Parthiban, R., Sun, R., Qureshi, I. and Bandyopadhyay, S. (2024), "Empowering rural micro-entrepreneurs through technoficing: a process model for mobilizing and developing indigenous knowledge", *The Journal of Strategic Information Systems*, Vol. 33 No. 2, 101836, doi: 10.1016/j.jsis.2024.101836.

Pawełoszek, I., Wieczorkowski, J. and Czarnacka-Chrobot, B. (2023), "Digital transformation of Polish micro-enterprises: lessons from the COVID-19 era", *Procedia Computer Science*, Vol. 225, pp. 1572-1581, doi: 10.1016/j.procs.2023.10.146.

Radovici, C. (2023), "To be or not to be digital? The paradox of Romanian ICT systems – 3 seas Europe", [Online], available at: https://3seaseurope.com/digital-romania-ict-systems/(accessed May 2024).

Salumaa-Lepik, K. and Nisu, N. (2024), "European values, artificial intellligence and e-governance in Estonia and EU", *Internet of Things*, Vol. 28, 101278, doi: 10.1016/j.iot.2024.101278.

Sein, M.K. and Harindranath, G. (2004), "Conceptualizing the ICT artifact: toward understanding the role of ICT in national development", *The Information Society*, Vol. 20 No. 1, pp. 15-24, doi: 10.1080/01972240490269942.

Suciningtias, S.A., Sudarsono, H., Anik, S. and Widhyasti, S.A. (2022), "Impact of dynamic capabilities and ICT utilization on performance of SMEs and moderating role of agile leadership: a case study for Indonesia", in Barolli, L. and Miwa, H. (Eds), *Advances in Intelligent Networking and Collaborative Systems. Incos 2022. Lecture Notes in Networks and Systems*, Springer, Cham, Vol. 527, pp. 339-349, doi: 10.1007/978-3-031-14627-5_34.

Teece, D.J., Pisano, G. and Shuen, A. (1997), "Dynamic capabilities and strategic management", *Strategic Management Journal*, Vol. 18 No. 7, pp. 509-533, doi: 10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z.

Thanh Nhon, H., Van Phuong, N., Quang Trung, N. and Quang Thong, B. (2020), "Exploring the mediating role of dynamic capabilities in the relationship between intellectual capital and performance of information and communications technology firms", *Cogent Business and Management*, Vol. 7 No. 1, 1831724, doi: 10.1080/23311975.2020.1831724.

Thapa, D., Sein, M.K. and Sæbø, Ø. (2012), "Building collective capabilities through ICT in a mountain region of Nepal: where social capital leads to collective action", *Information Technology for Development*, Vol. 18 No. 1, pp. 5-22, doi: 10.1080/02681102.2011.643205.

Toader, E., Firtescu, B.N., Roman, A. and Anton, S.G. (2018), "Impact of information and communication technology infrastructure on economic growth: an empirical assessment for the EU countries", *Sustainability*, Vol. 10 No. 10, p. 3750, doi: 10.3390/SU10103750.

UNCSTD (1997), *Report of the Working Group on Information and Communication Technologies for Development*, UN Commission on Science and Technology for Development, Geneva.

U.S. Department of Commerce (2024), "Romania – Information and communications technology (ICT)", [Online], available at: https://www.trade.gov/country-commercial-guides/romania-information-communications-technology-ict (accessed March 2024).

Vargas, V.M., Nita, S.C. and Hoinaru, R. (2022), "Study regarding the impact of ICT development on Romania's economic growth", in Busu, M. (Ed.), *Digital Economy and New Value Creation. ICBE 2021. Springer Proceedings in Business and Economics*, Cham, Springer International Publishing, pp. 1-10, doi: 10.1007/978-3-031-07265-9_1.

Vătămănescu, E.M. and Bratianu, C. (2021), "Challenges for sustainable development in the digital era", *Systems Research and Behavioral Science*, Vol. 38 No. 3, pp. 275-278, doi: 10.1002/sres.2781.

Vo, T.H.P., Czygan, M., Kumar, A. and Raman, K. (2017), *Python: Data Analytics and Visualization*, Packt Publishing, Birmingham.

Walsham, G. (2012), "A better world with ICTs? Response to the commentaries", *Journal of Information Technology*, Vol. 27 No. 3, pp. 255-257, doi: 10.1057/jit.2012.16.

Walsham, G. (2017), "ICT4D research: reflections on history and future agenda", *Information Technology for Development*, Vol. 23 No. 1, pp. 18-41, doi: 10.1080/02681102.2016.1246406.

Walsham, G. (2020), "South-south and triangular cooperation in ICT4D", *The Electronic Journal on Information Systems in Developing Countries*, Vol. 86 No. 4, e12130, doi: 10.1002/isd2.12130.

Wiechetek, Ł. and Gola, A. (2023), "Development of Polish ICT sector: education, governmental policy, employment and future trends", in Bukalska, E., Kijek, T. and Sergi, B.S. (Eds), *Modeling Economic Growth in Contemporary Poland*, Emerald Publishing, pp. 221-233, doi: 10.1108/978-1-83753-654-220231017.

Yim, A., Chung, C. and Yu, A. (2018), *Matplotlib for Python Developers: Effective Techniques for Data Visualization with Python*, Packt Publishing, Birmingham.

Zheng, Y., Hatakka, M., Sahay, S. and Andersson, A. (2018), "Conceptualizing development in information and communication technology for development (ICT4D)", *Information Technology for Development*, Vol. 24 No. 1, pp. 1-14, doi: 10.1080/02681102.2017.1396020.

Corresponding author
Mirela Panait can be contacted at: mirela.matei@upg-ploiesti.ro