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Digitalisation as a factor in the economic development of developing countries

Abstract. The relevance of this research arises from the need to assess the impact of digitalisation on the economic development of developing countries in the context of global challenges, such as economic inequality, limited access to modern technologies, uneven digital infrastructure, and low levels of digital literacy. The purpose of the article was to study the impact of digitalisation on the economic development of developing countries by identifying key digital indicators, analysing the clustering of countries by the level of digitalisation, and assessing the relationship between digital indicators and economic results. The research methods included cluster analysis to group countries by level of digital development, factor analysis to identify main drivers of digital transformation, and comparative analysis to identify key trends and features of digitalisation across countries. The analysis covered 90 countries with different levels of digital

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readiness and economic potential. The results of the study suggest that countries with a developed digital infrastructure, a high level of human capital and active government support demonstrate sustainable economic growth. It has been discovered that among main drivers of digital transformation are the following: access to high-speed Internet, digital education and the introduction of digital technologies in key sectors of the economy. Cluster analysis made it possible to identify four groups of countries that differ in the level of digitalisation, which helped to identify key priorities for each of them. The practical significance of the study is determined by the possibility of using the obtained results to develop recommendations for accelerating digital transformation in developing countries, taking into account their socio-economic conditions and potential

Keywords: cluster analysis; digital infrastructure; digital technologies; information and communications technology infrastructure; human capital

INTRODUCTION

Digitalisation is one of the key drivers of economic development, particularly for developing countries. The introduction of digital technologies contributes to increased productivity, improved business models, increased access to information and integration into global markets. Despite the overall benefits of digitalisation, developing countries face a number of challenges, including digital inequality, limited access to infrastructure and a low level of digital literacy. In the world where digital technologies play a key role in increasing competitiveness, attracting investment and ensuring sustainable development, middle- and low-income countries have the opportunity to reduce the economic gap considerably by implementing digital solutions. Ukraine, as a country with a significant potential for digital transformation, is also demonstrating progress in the implementation of digital technologies.

The digital transformation of national economies is no longer viewed merely as a technological innovation but rather as a strategic precondition for socio-economic growth. P. Winikoff (2024) focused on the operational dimension of digitalisation, defining it as the integration of digital technologies into business models to streamline processes, reduce transactional costs, and increase productivity. This interpretation grounds digitalisation firmly in corporate practice, presenting it as a functional tool for competitiveness rather than a holistic transformation of systems. In contrast, J. Clerck (2024) expanded the scope of the concept, arguing that digitalisation is a transitional phase on the path towards deep socio-economic reconfiguration. It was emphasised that digitalisation reshaped not only business processes but also cultural norms, institutional frameworks, and governance mechanisms. Together, these studies laid the theoretical groundwork for understanding digitalisation as a multilayered phenomenon with both technological and systemic implications.

Further empirical investigation into the link between digitalisation and economic performance has been provided by L.K. David *et al*. (2025). Their large-scale cross-country study quantifies the effect of digital readiness on economic growth by constructing a panel dataset covering indicators of information and communications technology (ICT) infrastructure, digital literacy, and e-government development across developing and emerging economies. The authors reported a statistically significant association between digital maturity and growth in sectors such as manufacturing, services, and education, concluding that digital investment yields long-term productivity gains and boosts national resilience to external shocks. Their work supports the idea that digitalisation plays a catalytic role in broader socio-economic dynamics. The relationship between digitalisation and GDP growth has also been rigorously examined by M. Sinha *et al*. (2025) in the context of South and Southeast Asia. Unlike previous macro-level studies, their approach incorporates institutional variables such as corruption control, bureaucratic quality, and legal effectiveness. The authors found that digitalisation alone does not guarantee economic improvement; rather, its positive effects materialise only in the presence of robust governance mechanisms. These findings highlighted that digital policy must be embedded in a stable institutional environment to generate sustainable development. This nuanced analysis contributes to the understanding that digitalisation is not a standalone driver, but one that is conditional on complementary policy frameworks.

The importance of institutional scaffolding is echoed in national-level studies conducted in Ukraine. H. Matviienko (2023) presented a case study on the interdependence between public-private collaboration and digital progress in Ukraine. It was argued that the development of the digital economy requires institutional commitment in the form of innovation grants, regulatory support, and public infrastructure investment. The study was based on an analysis of regional disparities and the impact of public procurement reforms on digital adoption. In a similar vein, N. Bobro (2024) analysed the structural coordination of Ukraine's digital policy, stressing the necessity for cross-sectoral integration to avoid fragmented implementation. A unified digital governance framework has been proposed to link ministries, local authorities and private organisations through shared performance metrics and interoperability standards. This recommendation is particularly relevant in the Ukrainian context, where overlapping mandates and institutional silos often hinder the scalability of digital initiatives.

A more geopolitical perspective is offered by S.V. Ivantsov (2024) who explored Ukraine's digital development within the framework of European integration. It outlined how alignment with EU digital standards – including the digital single market strategy – has prompted significant reforms in Ukrainian legislation, institutional design, and data protection policy. Modernisation was identified of ICT infrastructure and harmonisation of legal frameworks as two pillars that have facilitated Ukraine's integration into the European digital space. This study was especially valuable as it connects the technical aspects of digitalisation with the normative and legal standards that

define cross-border cooperation in the EU. Digitalisation under wartime conditions in Ukraine represents a unique dimension of this research field. Y. Pereguda *et al*. (2024) documented how the Russian invasion has catalysed the rapid deployment of digital tools in government and finance, particularly in areas such as cybersecurity, remote authentication, and blockchain-based registries. This case study showed that in extreme conditions, digitalisation becomes not only a development vector but a mechanism of survival and continuity. The authors provide detailed analysis of how national agencies adapted their operations to wartime constraints by digitising essential services and protecting data infrastructure.

The broader implications of wartime digital adaptation are analysed by V. Levytskyi *et al*. (2024), focused on the emergence of remote work infrastructure and digital logistics networks as critical resilience tools. It was argued that these technologies have enabled business continuity and minimised economic disruption, especially in export-oriented sectors. This work added to the growing body of literature that positions digitalisation as a core element of economic defence strategy. As a result, it was established that the aspect of quantitatively assessing the relationship between the level of digital maturity and macroeconomic indicators remains insufficiently explored. Therefore, the aim of this study was to develop an integrated Digital Integral Index, to conduct cluster and factor analysis for grouping countries by the level of digitalisation, and to identify the key digital and institutional factors that contribute to economic growth in national economies.

MATERIALS AND METHODS

A set of empirical, theoretical and general scientific research methods was used to study the level of digitalisation processes development on a regional scale and in national economies of developing countries, as well as to analyse this world-transforming process as a factor of economic development. The general scientific methods included the following: analysis and synthesis (studying the pace of digital transformation in leading developing countries by examining various aspects of economies' digitalisation), extrapolation (used to forecast the export of computer services by Ukraine), deduction (transitioning from the analysis of a region's digital development to the characteristics of individual countries), rating estimation using the average multidimensional method (was used to construct rankings of countries by the Digital Integral Index and the integral index of intellectual capital).

Correlation analysis as a statistical method was used to study the degree of relationship between random variables, while regression analysis was used to assess the relationship between a dependent variable (*Y*) and one or more independent variables (*X*) to model their behaviour in the future. For a more objective study of the impact of digitalisation on the economic development of developing countries, the analysis relied on the results of global indices. Global Knowledge Index (2023) assessed the potential of knowledge in key development areas. The Network Readiness Index (2023) analysed the ability of countries to exploit the opportunities of the information society. It examined innovation potential using data from corporate and academic partners. The Global Cybersecurity Index (n.d.) evaluated cybersecurity commitments across five domains: legal, technical, organisational, cooperation, and capacity development. The Digital Integral Index measured the availability of digital technologies, infrastructure, education, and regulatory policy based on 20 key indicators. The World Digital Competitiveness Ranking (2023) analysed the implementation of digital technologies that transform the economy and society. A parameter E-Participation Index was included in the study.

Figure 1 presents the structure of the Digital Integral Index, calculated by the authors for a more objective comprehensive study of the national economy and the level of its digitalisation. The index is based on five components: the subindex "ICT" of the Global Knowledge Index; the subindex "Human Capital and Research" of the Global Innovation Index; the subindex "People", "Government" and "Impact" of the Network Readiness Index. The significance of each component in the overall result is estimated at 20%. These components are selected to correspond to five strategically important dimensions of digitalisation, namely: infrastructure provision, intellectual potential, inclusion, government support and impact on the economy, society and the sustainable development goals. The authors assessed 84 developing countries, based on 2023 data.

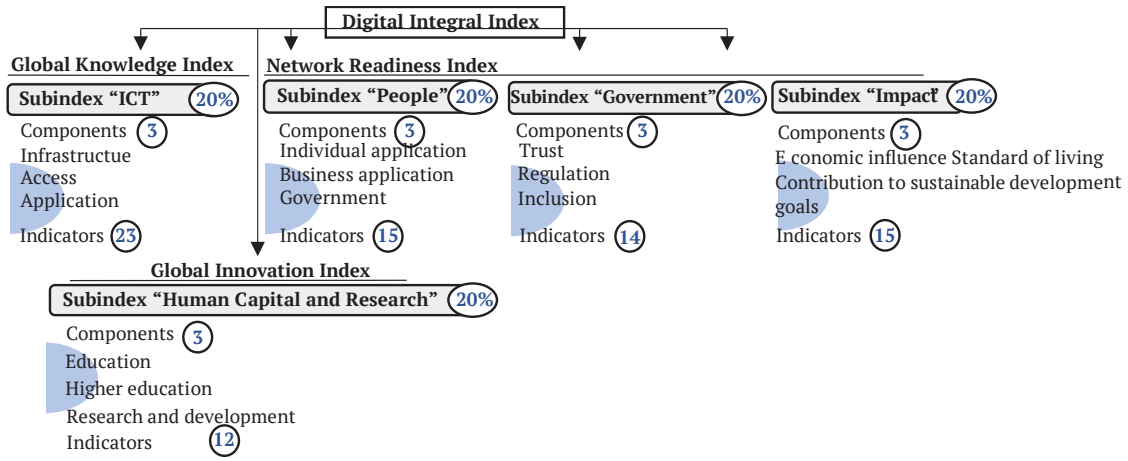

Figure 1. The structure of the Digital Integral Index

Source: prepared by the authors based on Global Knowledge Index (2023), Network Readiness Index (2023), Global Innovation Index (2023)

The calculation was based on the Human Development Index (n.d.) methodology with the following formula:

$$\text{Digital Integral Index} = \sqrt[5]{\bar{X}_1 \times \bar{X}_2 \times \bar{X}_3 \times \bar{X}_4 \times \bar{X}_5}, \quad (1)$$

where $\bar{X}$ – the share of a country's value, calculated by attributing the country's value in a subindex to the average total value for all countries in that subindex. It should be mentioned that China's Digital Integral Index score differs from that of any other 83 countries in the ranking. This is due to China's lack of a value in the ICT subindex, resulted in a slightly different formula used for the calculation:

$$\text{Digital Integral Index (for China)} = \sqrt[4]{\bar{X}_2 \times \bar{X}_3 \times \bar{X}_4 \times \bar{X}_5}. \quad (2)$$

Correlation analysis was applied to explore pairwise statistical relationships between selected digitalisation indicators and economic outcomes. In particular, Pearson's correlation coefficients were calculated between the Digital Integral Index and individual economic indicators, such as GDP per capita, high-tech exports, value added in industry, and public expenditure on education. This analysis enabled the identification of the strength and direction of linear dependencies between variables across the 90-country dataset. Regression analysis was used to assess the predictive relationship between economic performance and selected digital variables. The dependent variable (*Y*) in the regression model was GDP per capita, while the independent variables (*X)* included Internet usage rate, fixed broadband subscriptions, mobile cellular penetration, ICT exports, and Digital Integral Index scores. Multiple linear regression models were tested to evaluate the explanatory power of digitalisation for economic outcomes. The regression diagnostics included R^2 values and significance levels to validate the robustness of the results.

RESULTS

Based on the analysis carried out in 2023-2024, this research formulates guiding principles of digitalisation to be considered in digital strategies across all levels (enterprise, industry, region, state). Table 1 summarises these key principles.

Table 1. Universal principles of digitalisation

Principle	Essence
Inclusivity	The digital strategy should provide for and guarantee equal access to services, information and knowledge provided based on digital technologies
Integration	All components of the digital environment, both software products and physical objects that make the technology work, must be combined and operate smoothly as a single mechanism
Security	Digital tools and technologies must prioritise the security of systems and each citizen. This applies to the protection of personal and confidential data, privacy and user rights, etc.
Continuous improvement	A technology that is revolutionary today will inevitably be dominated by another technology at some point in the future. Therefore, the technological development of any system must be subject to continuous improvement, if it is to be viable
Transparency	Digital solutions should ensure transparency of operations and provide authorised persons with the ability to monitor, control, analyse and respond to processes in a timely manner

Source: compiled by the authors

Ignoring any of the above principles undermines the likelihood of achieving long-term strategic results. Regardless of how innovative a particular technology may be, insufficient digital skills among personnel or the emergence of social stratification and associated risks limits its positive impact. A relevant example is the challenge of integrating systems and digital products. In the case of Ukraine, the absence of a unified methodology and the failure to ensure seamless interaction among the information and telecommunication systems of various governmental institutions clearly illustrate this issue. Digital transformation in the broad sense – from the digitisation of data on physical media to a radical change in existing business models – is possible in any national economy. However, it is worth emphasising that the pace of such transformation and its quality will vary significantly in different economic systems. This is explained by the influence of various factors, which by their origin can be divided into: exogenous – to which the system will adapt quickly and endogenous, which are subject to influence and adjustments. Generally, they are represented by the following categories: political, economic, institutional and social, and specific digital factors (Fig. 2). The factors presented in Figure 2 include: financial issues of the ability to incorporate digital solutions, inclusiveness of institutions and population, legal regulation of relations in the country and in the digital sector in particular, state credit and tax policy, ideological and educational activities aimed at creating an innovation culture of the population and many other aspects. These factors should be considered comprehensively and necessarily in connection with others. Thus, it is possible to produce knowledge, innovations and technologies only under the condition of reliable and fair legislation on intellectual property rights, data protection, e-commerce, cybersecurity. Otherwise, representatives of the intellectual sphere have no guarantees that the results of their intellectual and creative activities will be protected in such a country. There is no point in financing research and development for either private national or foreign investors if there is no sufficient legislative regulation. The loopholes in the legislation or the lag of the existing regulatory framework from modern realities inevitably leads to distrust of the country's population in authorities, government and, as a result, any attempts to change something can have negative consequences. Increasing competitiveness and attractiveness for foreign investors and partners is out of question in a system characterised by such features.

The fourth category is characterised by specific prerequisites for digital development, expressed in the availability and degree of preparation of digital infrastructure. Accelerated digital development is possible in a system that is provided with information and telecommunication

networks, data centres, software and hardware, etc. It is worth mentioning that it is one thing when the digital infrastructure is available and quite another when the price for the internet connection allows households and business units to use the opportunities of the "digital time". The connection speed is acceptable, in other words, when the infrastructure support promotes the inclusion of users. Six leading countries were identified in the Digital Integral Index, China, which is not included in the ranking due to differences in the index calculation, and Ukraine, which is added for comparison. The parameters, according to which the study was conducted, have been systematised and grouped by the following areas: "inclusion", "government support", "intellectual potential" and "infrastructural support of the digital space". For a better visualisation of the obtained results, Figure 3 was constructed to present, which is presented below. Each axis represents a separate parameter (share of Internet users, employment in the ICT sector, share of mobile phone owners, etc.) and the country value corresponds to the symbol of the square painted in the corresponding colour. For most parameters, data by countries are given for the year 2022, except for the employment indicator in the ICT sector and in some cases where updated data is not available.

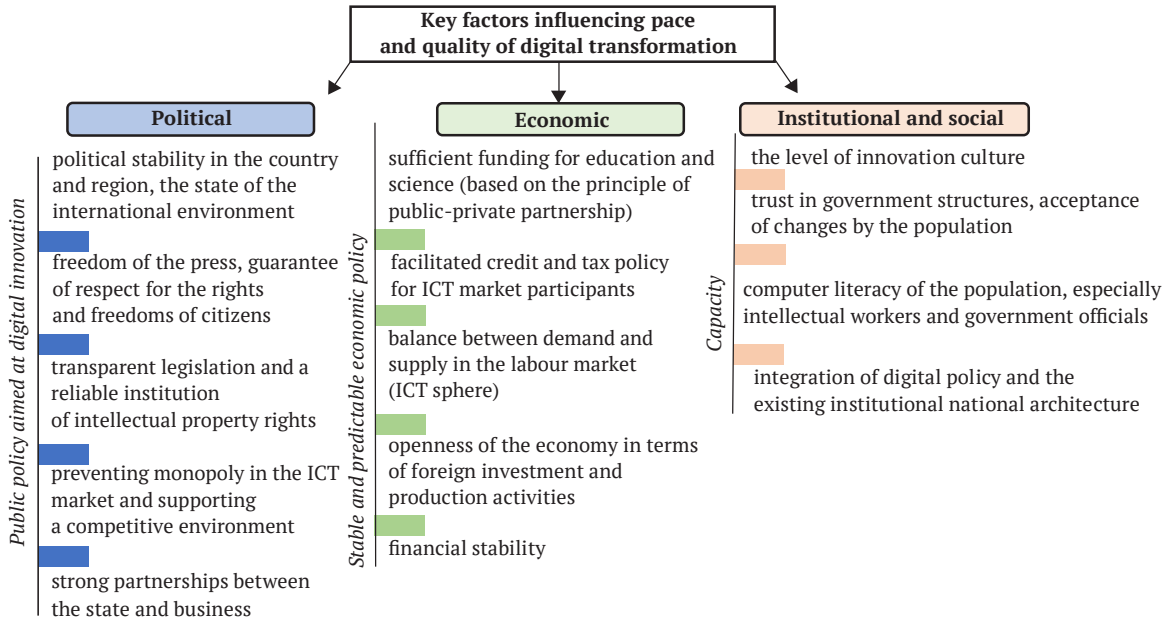

Figure 2. Key factors influencing digital transformation in the economic system
Source: prepared by the authors based on United Nations Development Programme (2022)

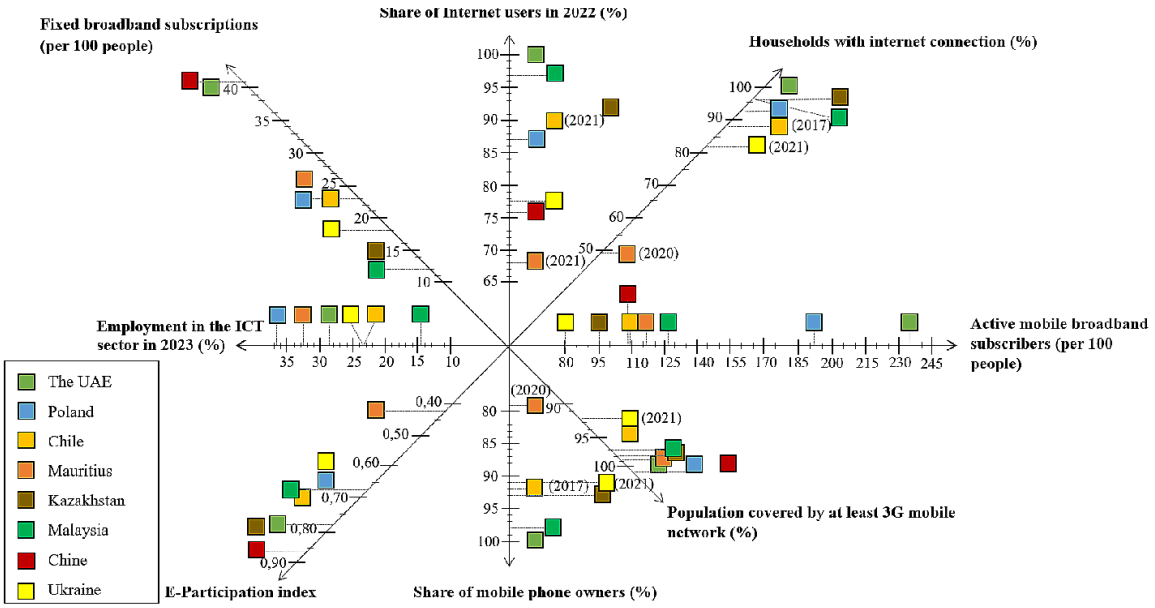

Figure 3. The values of the leading countries of the Digital Integral Index, China and Ukraine, in the area of "inclusion"
Source: prepared by the authors based on Global Knowledge Index (2023), Global Innovation Index (2023), United Nations E-Government Knowledge Base (2023), UN Trade and Development (UNKDAT) (2024)

As shown in Figure 3, all parameters assessed the degree of citizen involvement in digitalisation processes, including the availability of connection and communication, employment in the sector responsible for the digital transformation of the economy, and the E-Participation Index, which aimed to quantify how different countries utilised online tools to facilitate interaction between government and the population, as well as among citizens for the benefit of all (United Nations E-Government Knowledge Base, 2023). The values of the eight selected countries differ dramatically in several parameters, so it is expedient to analyse them in more detail. The shares of Internet users fluctuate in the range (68-100%) with the largest value in the UAE and, accordingly, the smallest in Mauritius (with the population of 1.27 million in 2021). These countries also have extremes in the parameter "share of households with the internet connection". It is logical that in order to use the Internet, a person must have both a connection and a mobile device. Figure 3 shows that countries with a higher number of mobile phone owners (the UAE, Malaysia, Kazakhstan) have both a higher share of Internet users and households with the internet connection. There was no doubt that the share of the active digital population was influenced by the price of internet connection. In Mauritius, the average monthly cost in 2023 amounted to 32.72 USD with a speed of 20.3 Mbps, whereas in the UAE it reached 98.84 USD, with an estimated average speed of 124.7 Mbps (BestBroadbandDeals, n.d.). In 2022, the percentage of Internet users in China and Ukraine was nearly identical; however, given the significant difference in population size, a substantial contrast in absolute user numbers was evident. Regarding the indicator "population covered by at least 3G mobile network," almost all of the analysed countries demonstrated acceptable levels, with values ranging from 92% to 100%, and the lowest level recorded in Ukraine.

Inclusion is evident in both the availability of a personal computer or smartphone and access to the Internet, as well as the effectiveness of its use. For this purpose, the parameter E-Participation Index was included in the study. The higher it is, the more the country's government is interested in using online tools to improve the efficiency of providing individual services, exchanging and accessing information, etc. In this case, the UAE lost the lead to China, which is actively promoting state strategies to increase the level of inclusion among its almost one and a half billion population. By most indicators, the only representative of the African continent, Mauritius, was among the outsiders, except for the parameter "employment in the ICT sector". This is explained by the international specialisation of the country and vectors outlined by the Mauritian government, in particular in the Mauritius National Export Strategy 2017-2021 (n.d.). Software development and arrangement of innovative approaches in all sectors of the national economy are among the key goals.

For digital transformation to occur not only at the level of individual enterprises but on a national scale, government support was essential. This included the adoption of comprehensive national digital strategies and the provision of adequate funding for sectors directly or indirectly related to the digital economy. In Figure 4, all parameters, with the exception of government spending on education, were provided for the year 2023. Since every citizen was expected to have at least a basic secondary education, the level of expenditure in this sector held significant strategic importance. A decline in education spending rendered the prospects for science and research development in the country increasingly unlikely. Among the analysed countries, the share of spending on education ranged from 3.9% to 5.7%. Notably, Ukraine recorded the highest share for this indicator, whereas the United Arab Emirates reported the lowest figure – 3.9%. According to the budget execution report, in absolute terms, the UAE Ministry of Education had spent AED 1.05 billion (USD 286.9 million) by 30 June 2021 (Ministry of Finance..., 2021).

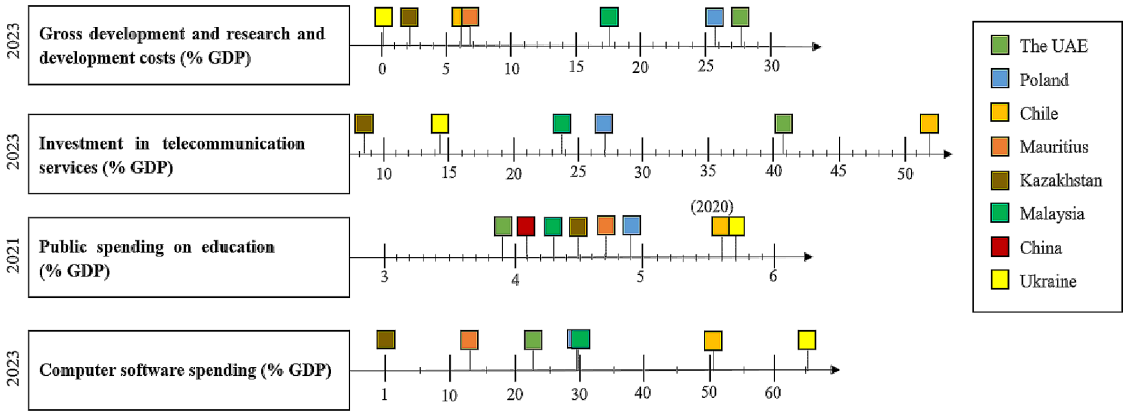

Figure 4. The values of the leading countries of the Digital Integral Index, China and Ukraine, in the area of "government support"

Source: prepared by the authors based on Global Knowledge Index (2023), World Bank Open Data (2024)

The telecommunications parameter is presented separately, since information is one of the national resources and constitutes the national wealth of the country. The informatisation of society and the digitalisation of sectors impose new requirements on the quality and efficiency of the telecommunications sector. The analysed countries took values in the range (8.5-51.9%) in 2023. Chile was identified as the regional leader in Latin America regarding the development of telecommunications infrastructure. Since the privatisation of the sector in the 1980s,

telecommunications had demonstrated continuous year-to-year growth. However, the Telecommunications Infrastructure Index (a component of the E-Government Development Index) in Chile reached 0.79990 in 2022, which remained lower than in Uruguay (0.8543), the subregional leader (United Nations E-Government Knowledgebase, 2024; International Telecommunication Union, 2024). The share of investment in telecommunications as a percentage of GDP amounted to 51.9% in 2023. Despite these achievements, the government of Chile expressed concern about the persistent digital divide and outlined plans to increase funding in this sector (Privacy Shield Framework, 2024).

An important area of analysis was "intellectual potential". The experience of developed countries such as Switzerland, Singapore, and the Republic of Korea demonstrated that knowledge could serve as a driver of economic transformation and facilitate the creation of a knowledge-based economy. A favourable national environment was required to enhance intellectual capital, particularly through government-led initiatives aimed at eliminating illiteracy and expanding access to education. According to the Chart of the day: Education level in China up over past 20 years (2023), the demographic dividend of a country depends on the size of its population; however, the quality of population is more important. The adult literacy rate in 2023 was one of the primary indicators used for comparative assessment (Fig. 5). The values ranged from 89.2% to 100%, with Mauritius reporting the lowest rate and Ukraine the highest (World Bank Open Data, 2024). The average number of years of education was also considered informative. The difference between the highest and lowest performing countries – Poland and China, respectively – amounted to 5.4 years. Recognising this disparity, the Chinese government included in its 14th Five-Year Plan (2021-2025) the objective that all Chinese people will have better opportunities for education and the average duration of education among the working-age population will increase to 11.3 years (Asian Development Bank, 2021).

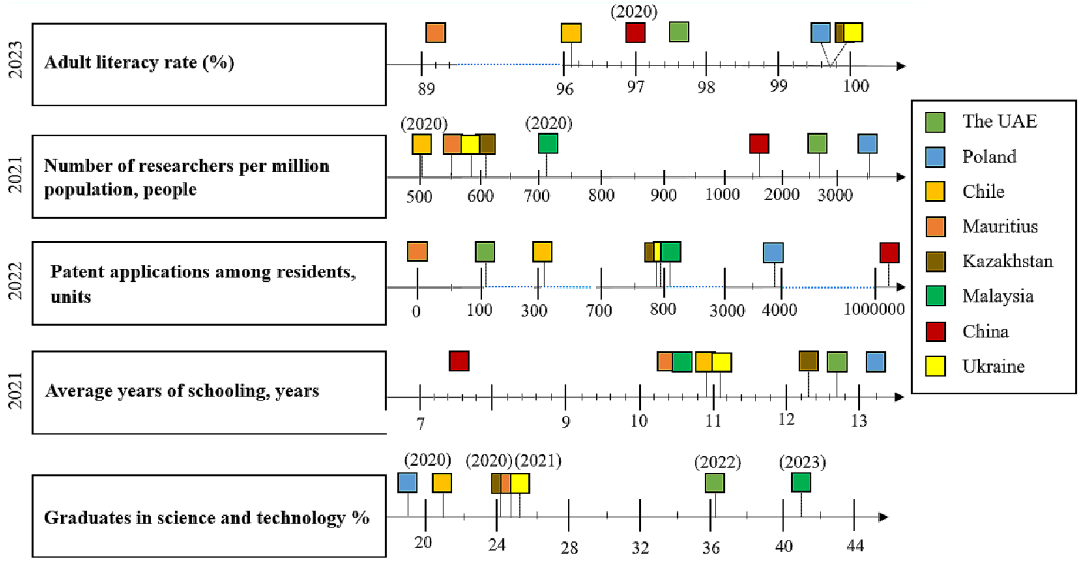

Figure 5. The values of the leading countries of the Digital Integral Index, China and Ukraine, in the area of "intellectual potential"

Source: prepared by the authors based on Global Knowledge Index (2023), World Bank Open Data (2024), UNESCO Institute for Statistics (2024)

Regarding the parameter "number of researchers per million population", a positive correlation was observed between the level of scientific engagement and factors such as the development of the education sector, legislative support, and adequate funding. In 2021, significant contrasts were identified across countries: Mauritius recorded 557 researchers per million people, while Poland reported 3,534 researchers (World Bank Open Data, 2024). For Mauritius, this figure was relatively high in proportion to its total population of 1.2 million. An analysis of the country's export commodity structure in 2021 indicated the dominance of low-tech sectors. Specifically, exports of foodstuffs amounted to USD 549 million and textiles to USD 600 million. In contrast, science-intensive sectors such as the chemical industry generated lower export volumes – USD 304 million (International Monetary Fund, 2024). Nevertheless, national research institutions, such as the Agritech Mauritius Research Centre (n.d.), highlighted the potential of digitalisation to transform the agribusiness sector. According to their projections, the adoption of digital technologies was expected to enhance competitiveness and increase the value-added component of agricultural products.

Regarding the number of patents granted to residents in 2022, Mauritius ranked the lowest, with no registered patented inventions, whereas China accounted for approximately 1.6 million patents (World Intellectual Property Organization, 2024). This result may have been linked to underdeveloped legal regulation in the field of intellectual property. As of 2022, Mauritius had not joined the Madrid Agreements Concerning the International Registration of Marks, the Hague Agreements Concerning the International Registration of Industrial Designs, or the Patent Cooperation Treaty. The respective accession treaties for

Mauritius entered into force on May 6, 2023, while the Patent Cooperation Treaty became effective on March 15, 2023 (World Intellectual Property Organization, 2024). In the final indicator included under the domain of "intellectual potential", Malaysia ranked highest, with 43.53% of university graduates in 2023 having specialised in science and engineering disciplines (World Intellectual Property Organization, 2023).

Infrastructure support of the digital sector is an important component of the digital transformation of countries around the world, covering a variety of aspects: the availability of hardware for the population (telephone, computer, etc.), databases, data centres and network capacity. One can wonder what the relationship between the localisation of infrastructure in the form of critical servers and computer subsystems and digital inclusion is. The relationship can be illustrated with the example of African countries, which need to solve the problem of affordability of internet connection in order to be included in digital processes or at least have access to the Internet. The most effective solution to guarantee the inclusion of each citizen is to have its own critical infrastructure with critical servers and computer systems with fully redundant subsystems. In 2023, Liquid Intelligent Technologies completed the Mauritius Telecom T3 submarine cable project, linking Mauritius and South Africa, thereby enhancing regional digital connectivity (South China Morning Post, 2023). In East, Southeast, and West Asia, China emerged as the regional leader in digital infrastructure development, actively competing with the world's most advanced economies. Technological advancement and cybersecurity were perceived by the Chinese government as key elements of national competitiveness and power. Consequently, substantial investments were directed towards national digital initiatives.

One of the most notable achievements in 2023 was the implementation of the Beijing-Wuhan-Guangzhou fibre-optic trunk line. This 3,000 km line, introduced under the national Future Internet Technology Infrastructure project, provided a data transmission speed of 1.2 terabits per second. According to South China Morning Post (2023), this speed equated to "the equivalent of 150 movies per second" and was approximately three times faster than that of the closest global competitor, the United States. Beyond national initiatives, China also engaged in international digital cooperation projects, particularly those focused on the development of digital infrastructure. In 2015, under the broader "One Belt, One Road" strategy, the "Digital Silk Road" initiative was launched. The framework of this project included partnerships aimed at enhancing terrestrial and submarine data transmission networks, exploring artificial intelligence, expanding the use of cloud computing, e-commerce, and mobile payment platforms, as well as developing surveillance technologies and satellite systems (South China Morning Post, 2023).

Table 2. The values of the leading countries of the Digital Integral Index and China, the size of their GDP (billion USD) and the contribution of the ICT sector to GDP (%)

Place in the ranking	The DII 2023	GDP 2023	The ICT contribution
1. China	1.5950	17,700	55% (2021)
2. The UAE	1.5122	509.18	2.2% (2020)
3. Poland	1.4720	842.17	3.77% (2020)
5. Malaysia	1.4682	430.9	23% (2021)
12. Chile	1.4433	344.4	3% (2015)
21. Kazakhstan	1.4299	259.29	3% (2021)
33. Mauritius	1.4041	14.82	5.8% (2019)

Source: prepared by the authors based on Information Society Outlook (2020), Global Knowledge Index (2023), Global Innovation Index (2023), Network Readiness Index (2023), World Bank Open Data (2024)

Table 2 systematised the data for the leading countries from seven global regions, including their Digital Integral Index values for 2023, national market size (GDP), and the ICT sector's contribution to GDP. In absolute terms, China ranked first across all three indicators. Based on the results of the correlation analysis conducted between the Digital Integral Index and GDP size, a strong positive relationship was observed. For the seven countries under analysis, the Pearson correlation coefficient equalled 0.853, indicating a significant link between the scale of the national economy and the level of digital development in 2023.

Figure 6 shows the place of Ukraine and Poland in the main international digitalisation indices. Ukraine demonstrates positive dynamics in most indices, especially in increasing the rating in the Network Readiness Index. In particular, from 2019 to 2023, Ukraine rose from the 67th to 43rd place. At the same time, compared to Poland, the gap remains significant, especially in the Digital Competitiveness Index. The smallest gap between countries is observed in the E-Government Development Index, where Ukraine ranked 46th out of 193 countries and Poland ranked 34th in 2022. These results indicate Ukraine's achievements in certain aspects of digitalisation, whereas require further strengthening of reforms to narrow the gap with the leaders of the European region.

Analysing the dynamics of computer technology exports, the authors discovered that the trend line has an upward direction, suggesting a positive trend in the growth of computer services exports by Ukraine in the period 2007-2022 (Fig. 7).

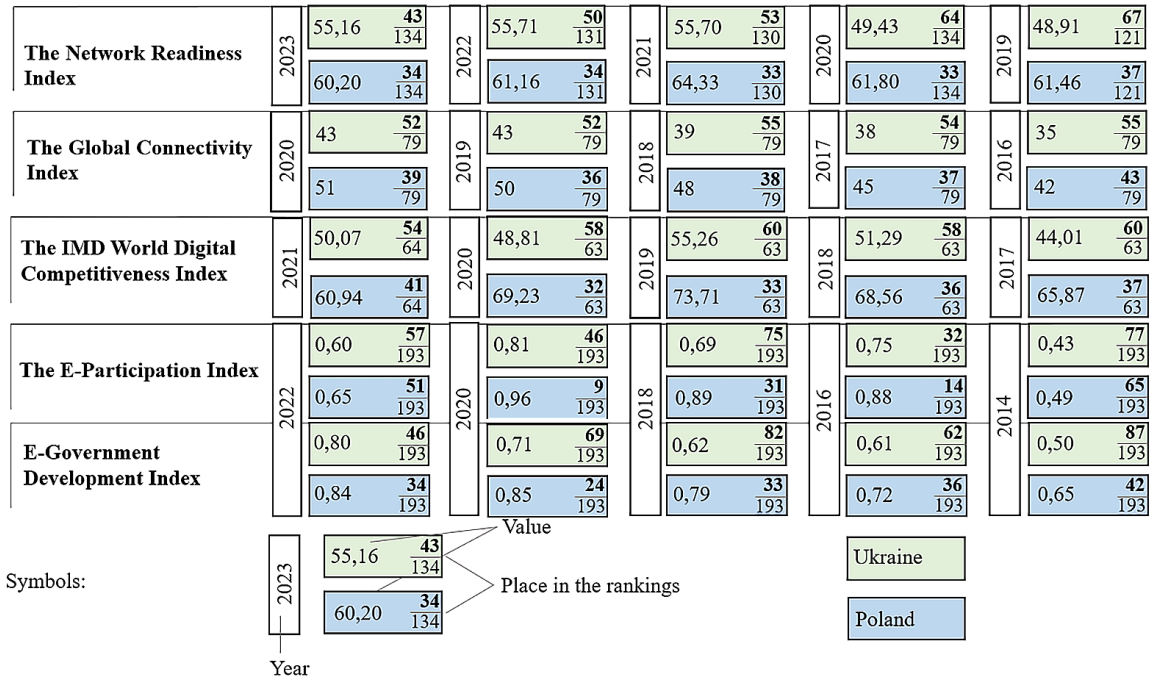

Figure 6. The values of Ukraine and Poland according to advanced indices in terms of digitalisation

Source: prepared by the authors based on Global Connectivity Index (2020), Network Readiness Index (2023), IMD World Digital Competitiveness Ranking (2024), E-Participation Index (2024), United Nations E-Government Knowledge Base (2024)

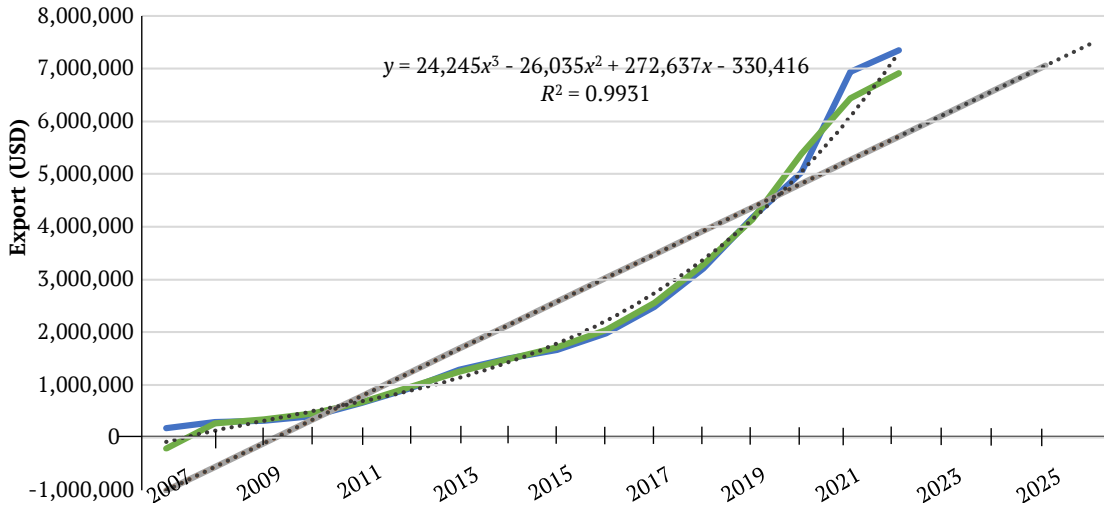

Figure 7. The dynamics of computer services export by Ukraine
(based on initial data and after smoothing the dynamic series) and a trend line

Source: prepared by the authors based on Trade Map (2024)

According to the data, export volumes demonstrate stable growth, despite the impact of crisis events, such as political instability in 2014-2015, the COVID-19 pandemic and the armed conflict in 2022. The conducted regression analysis indicates a high correlation between time and the increase in export volumes, which is proved by the coefficient of determination ($R^2 = 0.9931$). The constructed trend line suggests that the computer services sector in Ukraine is one of the key drivers of the economy, even during periods of turbulence. These data emphasise the importance of supporting and developing the IT sector in Ukraine, as it provides a significant contribution to national exports and remains one of the least vulnerable sectors during crises. The ICT sector was almost the only sector that gained even greater development during the period of full-scale invasion. The growing demand for remote services (medical, government, etc.), the need to track population movements, business online operations and many other factors have accelerated digitalisation in many sectors of the Ukrainian economy. Thus, digitalisation remains both a global trend and an effective rescue tool for citizens, business structures and the country itself. The result is presented in Table 3.

Table 3. Determined clusters and their composition

Cluster No. 1	Cluster No. 2	Cluster No. 3	Cluster No. 4
Malaysia, Vietnam, Philippines, China	The UAE, Saudi Arabia, Qatar, Bahrain, Kuwait, Brunei	Turkey, Iran, Tunisia, Thailand, Argentina, Brazil, Colombia, Costa Rica, Mexico, Panama, El Salvador, Trinidad and Tobago, Uruguay, Chile, India, Kazakhstan, Uzbekistan, Sri Lanka, Mauritius, Armenia, Bulgaria, Bosnia and Herzegovina, Georgia, Moldova, North Macedonia, Poland, Romania, Russian Federation, Serbia, Hungary, Ukraine, Montenegro, Belarus	Jordan, Egypt, Algeria, Iraq, Sudan, Indonesia, Cambodia, Mongolia, Azerbaijan, Guatemala, Honduras, Dominican Republic, Ecuador, Paraguay, Peru, Jamaica, Bangladesh, Pakistan, Angola, Benin, Botswana, Burundi, Ghana, Eswatini, Ethiopia, Zambia, Zimbabwe, Cabo Verde, Cameroon, Kenya, Democratic Republic of the Congo, Côte d'Ivoire, Lesotho, Madagascar, Mali, Mozambique, Namibia, Nigeria, South Africa, Rwanda, Senegal, Tanzania, Uganda, Albania, Gabon, Nicaragua, Togo

Source: prepared by the authors

It is necessary to pay attention to the fact that although the countries were systematised into groups based on the principle of similarity, the objects are characterised by inhomogeneity, which is visually proved by the clustering tree (Fig. 8).

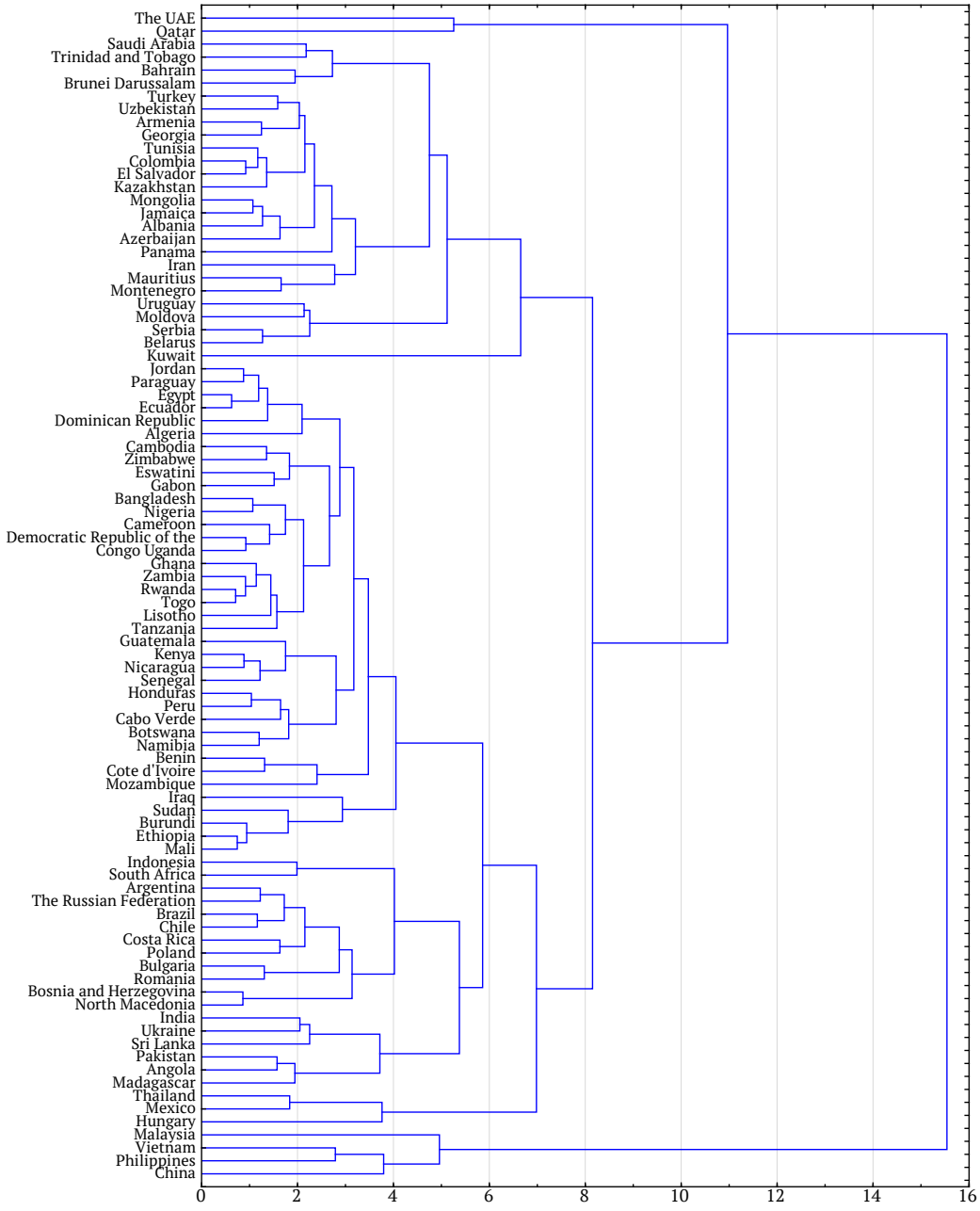

Figure 8. Clustering tree for developing countries by studied parameters

Source: prepared by the authors

Cluster No. 1 includes 4 countries of Southeast Asia (Malaysia, Vietnam, Philippines) and East Asia (China). In this group, the countries' GDP per capita fluctuates in the range from 3,500 to 12,800 USD. This cluster is a leader in terms of average share of high-tech exports from total sales (10.9%). All countries are competitors in terms of high-tech products, although Malaysia remains the flagship of the group (46.9%). Malaysia (0.75) and China (0.77) are the most distant from the centre of cluster No. 1. Cluster No. 2 grouped 6 Arab countries of the Middle East. Among all other clusters, this one stands out with an average value of 5.2 for GDP per capita, however the dispersion index within the group is quite low – 2.9. Although Brunei surpasses Saudi Arabia and Bahrain in terms of GDP per capita, the country is the last in terms of population (449,002 people). The greatest distance from the centre of cluster No. 2 is observed for the UAE and Bahrain. Cluster No. 3 includes 33 countries and is of a great interest to us, due to Ukraine's presence there. The objects of this group contrast in terms of the level of economic development, the GDP per capita of Uruguay (20,795 USD) is 9.2 times higher than that of Uzbekistan (2,255 USD). Hungary, Romania and Armenia are located further from the cluster centroid. Cluster No. 4 is characterised by the greatest contrast in terms of economic development and population number. In terms of GDP per capita, the Dominican Republic (10,111 USD) is 39 times ahead of Burundi (259 USD) and the difference between the population of Cabo Verde (593,149 people) and Bangladesh (171.2 million people) is significantly greater. Cluster No. 4 includes countries from almost all regions of the world: the average values in the cluster differ most in the share of public spending on education and gross fixed capital formation (1.02). Sudan, Burundi, South Africa and Indonesia are the most distant from the centre of cluster No. 4. Cluster average values in Figure 9 allow to compare the studied clusters across the entire set of parameters.

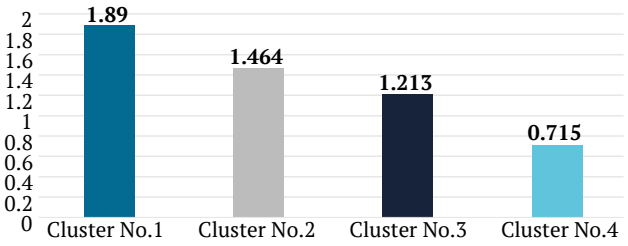

Figure 9. Average values across clusters for all parameters
Source: prepared by the authors

In addition, it can be assumed that each cluster is characterised by a corresponding level of digital development: Industry 2.0 and Industry 3.0, as well as two transition zones, referred to as Industry 2.5 and 3.5 in Figure 10.

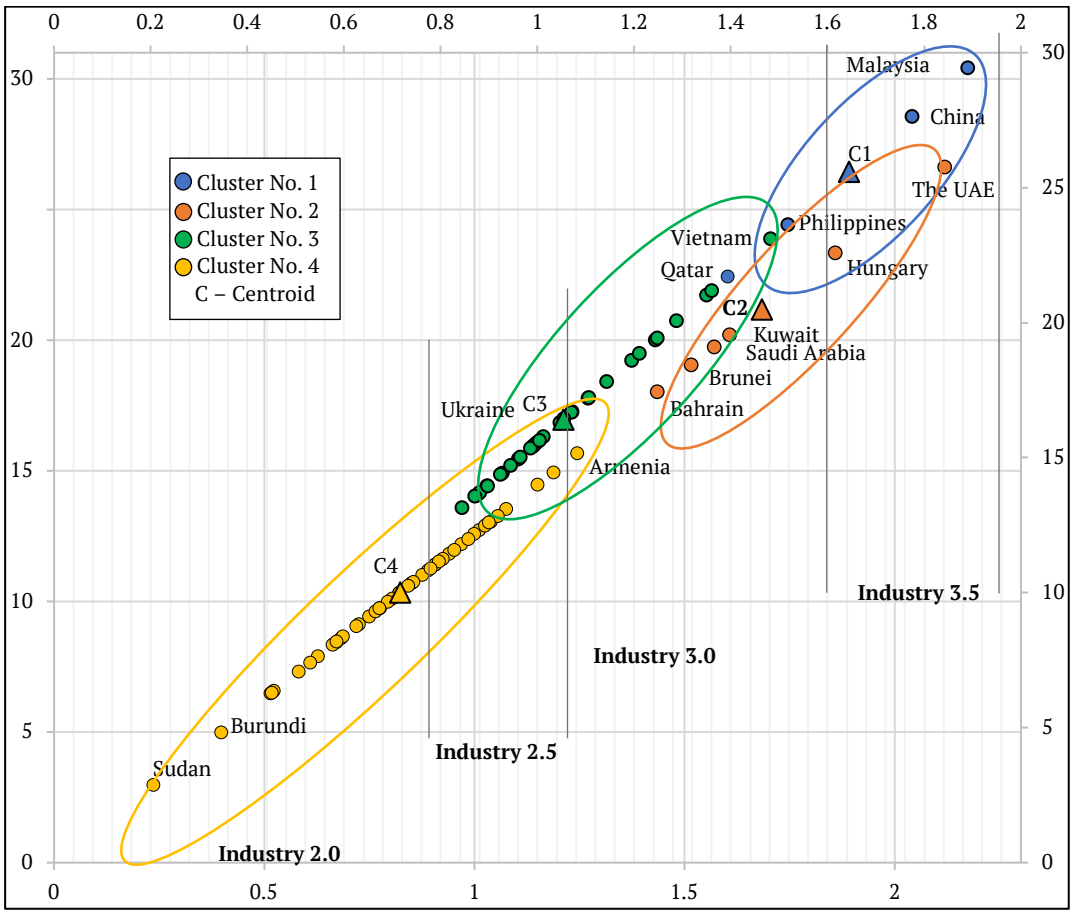

Figure 10. Cluster scatter diagram by average values for the studied parameters
Source: prepared by the authors

Malaysia, China and the UAE have already left the third technological revolution, which is characterised by robotic systems, total computerisation, the development of microelectronics, and are actively moving towards the next level of digital Industry 4.0. Ukraine is a vivid "transit" representative of Industry 2.5, characterised by a hybrid state of innovative and technical development. Despite experimental digital solutions in the form of government services digitisation and state registers, most industrial enterprises in the post-war period belonged to mechatronic systems. The latter refers to the synergistic combination of precision mechanics with electronic components, providing for reducing the workload on employees and increasing their productivity. Digital "experiments" should fit into the existing institutional environment, be accompanied by the creation of formal institutions and should not confront informal institutions that exist in society (corruptibility, traditions and people's perceptions, values, etc.).

Although Ukraine is well represented in the ranking of developing countries according to the parameters studied, the number of fixed broadband Internet subscriptions or the share of Internet users do not provide a qualitative assessment of the economy digitalisation level. Ukraine has experience in implementing successful digital projects only in certain high-tech sectors of the economy: telecommunications, IT or the production of electrical equipment and computer equipment. Similar to Ukraine, several other developing countries have achieved notable success through targeted digital policies and inclusive technology deployment. Recent studies suggest that digitalisation contributes to narrowing the development gap between countries and enhances economic resilience and growth (UN Trade and Development, 2024; World Bank Open Data, 2024). India, for instance, has emerged as a global leader in IT services by investing heavily in digital education and broadband infrastructure (Financial Times, 2024). Kenya's widespread adoption of the M-Pesa mobile payment system significantly improved access to financial services, particularly in underserved regions (GSMA, 2023). Such examples can serve as valuable references for Ukraine's digital trajectory. The "Diia" project, recognised internationally for its innovation in digital governance, reflects Ukraine's potential to apply best practices and accelerate its transformation (European Investment Bank, 2023).

The results of each country were formed under the specific circumstances of place, time and the ratio of resources to achieve the current level of digital development. For this reason, it is strategically important for the authority of Ukraine to work comprehensively with the economic system, which would cover both digital technologies and issues of infrastructure, the level of social institutions development and many other aspects. However, it is impossible to assign a certain level of digital development to each of the resulting clusters, since for a more substantive analysis it is necessary to increase the set of digitalisation indicators, including quantitative indicators of artificial intelligence application in economic systems, the volume of digital economy and the volume of the e-commerce market, whereas for most of the studied countries such data are absent, as well as a qualitative calculation methodology.

Digital technologies, which are used in combination with the most modern means of production, increase efficiency the most. Systems will have a radically different effect when digitalisation is combined with equipment and technologies, which physical properties are significantly limited in comparison with the best new models. Therefore, if different or even similar innovative and technological systems dominate within the studied clusters and different digital tools are applied, economic development in cluster countries will be different. As a result of the conducted factor analysis, which supplemented the cluster analysis findings, the percentage distribution between the two groups of factors was obtained (Fig. 11), namely, the percentage distribution between the two groups of factors.

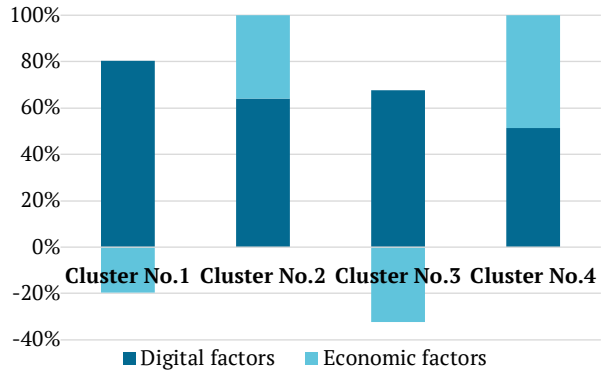

Figure 11. Percentage ratio of digital and economic factors by clusters

Source: prepared by the authors

In all cases, it was observed that the total factor loadings for digital variables are higher than for similar economic variables. The biggest difference is in clusters No. 1 and No. 3 – here digital factors reach 80%, the factor volume in cluster No. 2 is almost twice as large and in the last group it is almost balanced. These calculations statistically prove the statement that digitalisation is an influential factor in the economic development of developing countries, especially in the group characterised by the features of Industry 3.0. The findings of this study confirmed that digitalisation had a significant and multifactorial influence on the economic development of developing countries. These effects became most evident when digital transformation was supported by investments in infrastructure, human capital, effective institutions, and inclusive policies.

DISCUSSION

One of the most critical enablers of successful digital transformation was the availability and quality of digital infrastructure. S. Lin *et al*. (2025) used panel data from Chinese provinces and demonstrated that broadband infrastructure not only reduced regional disparities but also promoted industrial diversification and investment in less-developed areas. A consistency was observed between these findings and the cluster analysis results, where strong ICT infrastructure was identified as a key attribute of high-performing economies. At the firm level, evidence from X. Zhao & F. Dong (2025) indicated that infrastructure development under China's national broadband strategy resulted in improved innovation performance among non-state companies, thereby reinforcing the relationship

between digital access and competitiveness. From a regulatory standpoint, E.J. Oughton *et al*. (2021) noted that broadband affordability continued to pose a significant policy challenge. To mitigate digital exclusion, particularly in low-income countries – a concern highly relevant to countries included in Cluster No. 4 – subsidies and price regulation mechanisms were recommended.

Alongside infrastructure, human capital was recognised as a fundamental component in translating digitalisation into sustainable growth. In particular, K. Bibi *et al*. (2025) demonstrated that digital transformation yielded the highest results when accompanied by strategic investment in education, which enhanced the capacity to absorb and apply technological solutions. This conclusion was supported by the findings of N. Xholo *et al*. (2025), who showed that digitalisation had a positive effect not only on income levels but also on innovation and economic complexity, particularly when supported by intellectual and technological development. These perspectives aligned with the results of the factor analysis, in which human capital was identified as a key component of the constructed Digital Integral Index.

Institutional quality also played a determining role in shaping the outcomes of digital transformation. In a study focused on the MENA region, M. Touitou & Y. Laib (2025) found that the effectiveness of digitalisation depended on political stability and the quality of governance. This observation correlated with the tendency of countries possessing strong institutions to be grouped in the same digital development clusters and to demonstrate higher levels of economic performance. Similarly, O.P. Olofin (2023) identified transparency and regulatory stability as essential prerequisites for leveraging the benefits of the digital economy in African and Asian contexts. The importance of institutional capacity was further underlined in the research of S. Shabnam & H.C. Rakibul (2025), where confirmed that the implementation of digital public services contributed to greater citizen trust and improved administrative efficiency. This provided empirical support for including platforms such as Ukraine's Diia as illustrative examples of institutional digitalisation. Beyond economic and institutional dimensions, the social implications of digital transformation were extensively addressed in recent literature. A study by S. Nosratabadi *et al*. (2023), based on data from EU-27 countries, demonstrated that inclusive digitalisation strategies improved labour market outcomes and reduced socio-economic inequality. Conversely, S. Qureshi (2023) emphasised the potential for digitalisation to reinforce existing inequalities if inclusive policy frameworks were not in place. These perspectives underscored the necessity of incorporating principles of equity and accessibility into national digital strategies, especially in developing contexts.

At the macro level, further empirical validation of the identified relationships between digitalisation and economic development was provided. According to H.Q. Vu *et al*. (2025), digital transformation in Vietnam had a significant positive impact on GDP growth, particularly in the manufacturing and services sectors. This finding corresponded to observations made in the case of Ukraine, where the expansion of ICT exports was linked to enhanced economic resilience. In a broader cross-country study, H. Asma *et al*. (2024) employed panel ARDL modelling for 78 developing economies and identified both short-term and long-term growth benefits of digitalisation, thereby supporting the inclusion of dynamic effects in national digital strategies. Additionally, a global comparative study by N. Mahikala *et al*. (2022) covering seven world regions confirmed a generally positive relationship between digitalisation and GDP, though the effects were weaker in areas with underdeveloped infrastructure. This pattern reinforced the differentiation established by the cluster analysis regarding digital readiness levels.

Environmental dimensions of digitalisation were addressed in the study by R. Li *et al*. (2025) who explored the intersection of digitalisation, human capital, and carbon efficiency in China. Using regional data and structural equation modelling, they show that investment in digital infrastructure and education correlates with improved energy productivity and reduced emissions intensity. Their findings suggest that digitalisation not only drives growth but can also align with environmental sustainability – a point that adds complexity to policy considerations in developing countries. O.Ya. Yurchyshyn *et al*. (2023) evaluated the territorial disparities of digital transformation in Ukraine. Through a regional comparative analysis, significant inequalities in broadband access, digital literacy, and institutional readiness across regions were identified. It was concluded that unless national policy is adjusted to address these imbalances, digitalisation risks deepening existing socio-economic divides. This recommendation focussed on targeted regional investment, digital capacity-building programmes, and multi-level governance mechanisms to foster inclusion. An important contribution to the discourse on national models of digital transformation is made by R. Ouyang *et al*. (2024), where an in-depth analysis of China's digital economy strategy was provided. The authors examined the structure and implementation of digital development under conditions of centralised political governance, noting that China's top-down approach enables rapid mobilisation of resources and large-scale investment in digital infrastructure. It was highlighted the strategic role of the state in initiating nationwide projects such as fibre-optic networks, cloud infrastructure, and 5G expansion, which have significantly boosted connectivity and technological capacity across provinces.

Given the growing relevance of digitalisation as a key determinant of economic development, recent academic discourse increasingly focuses on the relationship between digital readiness, infrastructure, and socio-economic outcomes in developing countries. Numerous studies highlighted the need to assess this impact within the broader context of global challenges – economic inequality, uneven technological access, and the accelerated pace of innovation. The findings of the study are supported by a growing body of international research across key dimensions such as infrastructure development, education and skills, institutional governance, social inclusion, and macroeconomic growth. A common conclusion emerges: digitalisation functions as a key enabler of sustainable development, provided it is supported by a favourable policy and social environment. The applied cluster and factor analysis, along with the proposed Digital Integral Index, contribute to this discussion by offering a structured analytical framework for assessing digital readiness and transformation capacity in developing countries.

CONCLUSIONS

The study confirmed that the introduction of digital technologies contributed to increased productivity, enhanced business process efficiency, and the integration of economies into global markets. To assess the level of digital transformation, the authors developed the Digital Integral Index, which incorporated five key components: infrastructure, intellectual potential, government support, inclusion, and the socio-economic impact of digitalisation. Based on the 2023 data, China (Index score: 0.772), Malaysia (0.754), and the UAE (0.749) demonstrated the highest levels of digital development among developing countries. In contrast, Ukraine's index score amounted to 0.589, indicating positive dynamics in digital readiness and inclusion, yet still revealing a considerable gap compared to European leaders such as Poland (0.702) and Romania (0.694).

The Global Knowledge Index, Network Readiness Index, and Global Innovation Index all pointed to the decisive role of access to knowledge, human capital development, and infrastructure availability as fundamental drivers of digital transformation. For instance, in 2023, Malaysia reported 43.53% of graduates in science and engineering, while Poland recorded 3,534 researchers per million people, reflecting strong intellectual capital. The cluster and factor analyses confirmed that countries with advanced digital infrastructure and active digital policy demonstrated greater prospects for sustainable economic growth. Specifically, Clusters No. 1 and No. 2, which included countries such as China, Malaysia, and the UAE, were characterised by a high share of ICT exports (up to 10.9%), broad 4G coverage (over 95%), and Internet penetration exceeding 90%. Conversely, Ukraine, assigned to Cluster No. 3, exhibited moderate digitalisation levels and required increased public investment and policy reforms.

Despite Ukraine's upward trend in indicators such as Network Readiness Index rank (from 67th in 2019 to 43rd in 2023) and growth in ICT service exports, significant challenges remained. These included underdeveloped digital infrastructure in rural regions, insufficient funding for ICT education, and low levels of digital literacy among older age groups. The findings thus indicated that further government support, enhancement of infrastructure, and comprehensive digital skills development were essential for bridging the digital divide. Further research could be aimed at analysing the impact of specific digital tools on the development of economic sectors such as agriculture, healthcare and education, as well as developing strategies for adapting successful international practices to Ukrainian conditions.

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CONFLICT OF INTEREST

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Цифровізація як чинник економічного розвитку країн, що розвиваються

Анотація. Актуальність дослідження зумовлена необхідністю оцінки впливу цифровізації на економічний розвиток країн, що розвиваються, в умовах глобальних викликів, таких як економічна нерівність, обмежений доступ до сучасних технологій, нерівномірність цифрової інфраструктури та низький рівень цифрової грамотності. Метою статті було дослідити вплив цифровізації на економічний розвиток країн, що розвиваються, шляхом визначення ключових цифрових індикаторів, аналізу кластеризації країн за рівнем цифровізації та оцінки взаємозв'язку між цифровими індикаторами та економічними результатами. Методи дослідження включали кластерний аналіз для групування країн за рівнем цифрового розвитку, факторний аналіз для визначення основних факторів цифрової трансформації та порівняльний аналіз для виявлення ключових тенденцій та особливостей цифровізації в різних країнах. Аналіз охопив 90 країн із різним рівнем цифрової готовності та економічного потенціалу. Результати дослідження засвідчили, що країни з розвиненою цифровою інфраструктурою, високим рівнем людського капіталу та активною державною підтримкою демонструють стійке економічне зростання. Виявлено, що серед основних драйверів цифрової трансформації є такі: доступ до швидкісного інтернету, цифрова освіта та впровадження цифрових технологій у ключових секторах економіки. Кластерний аналіз дозволив виділити чотири групи країн, які відрізняються за рівнем цифровізації, що допомогло визначити ключові пріоритети для кожної з них. Практичне значення дослідження визначається можливістю використання отриманих результатів для розробки рекомендацій щодо прискорення цифрової трансформації в країнах, що розвиваються, з урахуванням їх соціально-економічних умов та потенціалу

Ключові слова: кластерний аналіз; цифрова інфраструктура; цифрові технології; інфраструктура інформаційно-комунікаційних технологій; людський капітал