DIGITAL TRANSFORMATION AND THE KNOWLEDGE ECONOMY: A FRAMEWORK FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT: *The knowledge economy has become a defining paradigm of contemporary economic development, emphasizing the strategic role of knowledge, innovation, digital transformation and human capital in generating competitiveness and sustainable growth. This paper aims to analyze the main dimensions of the knowledge economy and to highlight the relationship between knowledge-based resources and economic performance. The study focuses on four key pillars: human capital, innovation, digital economy and innovation output. By examining relevant indicators, the paper provides a multidimensional perspective on the transition toward knowledge-based development. This paper aims to analyze the main dimensions of the knowledge economy in selected Central and Eastern European countries and discusses the importance of digital transformation as an enabling factor for knowledge creation, dissemination and economic valorization. The findings suggest that economies investing consistently in education, innovation capacity and digital technologies are better positioned to enhance productivity, competitiveness and resilience. The paper concludes that the knowledge economy should be understood not only as a technological shift, but also as a structural transformation of economic systems, with significant implications for sustainable development and long-term competitiveness.*

Keywords: *Knowledge economy; Digital transformation; Innovation; Human capital; Sustainable development; Competitiveness.*

JEL Classification: *O31, J24, Q01.*

1. INTRODUCTION

Digital transformation and the knowledge-based economy constitute two of the main forces shaping contemporary economic development. The integration of digital technologies, the expanding use of information, and the growing importance of human capital are reshaping production processes, business models, and the relationships among institutions, enterprises, and society. In this context, innovation and the efficient utilization of knowledge can contribute to productivity growth, enhanced competitiveness, and the development of more sustainable economic solutions. Analyzing the interconnections between digitalization, knowledge, and

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sustainability is therefore essential for understanding the opportunities and challenges associated with the transition towards a resilient, inclusive, and future-oriented economy.

In the industrial economy, comparative advantages were primarily associated with access to raw materials, labor availability, and the accumulation of physical capital. In the knowledge-based economy, economic performance is determined to a great extent by a society's capacity to create, absorb, disseminate, and effectively utilize knowledge.

The development of information and communication technologies has accelerated the transition towards the knowledge-based economy. Digital infrastructure enables the rapid collection, processing, and transmission of large volumes of information, reduces coordination costs, and facilitates collaboration among firms, public institutions, universities, and individuals located in different geographical areas. Digital platforms, cloud computing services, artificial intelligence, automation, and data analytics are transforming both organizations' internal processes and their relationships with suppliers, consumers, and business partners (OECD, 2024).

However, the mere availability of digital technologies does not guarantee productivity growth. Their economic effects depend on the capacity of organizations and employees to integrate new technologies into routine activities and operational processes. For this reason, digital skills must be complemented by cognitive, analytical, managerial, and social competencies. Basic digital literacy enables access to and effective use of technology, whereas advanced skills, such as programming, data analysis, cybersecurity, the use of artificial intelligence, and digital systems management, support high-value-added activities. The OECD emphasizes that harnessing the benefits of digitalization requires coordinated policies in the areas of education, the labor market, research, innovation, and social protection, as well as opportunities for lifelong learning (OECD, 2024).

In this context, human capital becomes one of the principal forms of economic capital. Educational attainment, professional experience, adaptability, and a willingness to engage in continuous learning influence individual productivity as well as the performance of firms and national economies. Educational institutions are no longer expected merely to transmit a fixed body of knowledge; they must also develop individuals' capacity to identify relevant information, solve complex problems, and adapt to technologies and occupations that are undergoing continuous change. Consequently, education, vocational training, and reskilling should be regarded as economic investments rather than solely as social expenditures.

The knowledge-based economy is also closely linked to competitiveness. In a global environment characterized by rapid technological change, advantages based exclusively on low costs or access to resources tend to be vulnerable. Sustainable competitiveness requires the capacity to improve productivity, differentiate products, develop proprietary technologies, and participate in high-value-added segments of global value chains.

The relationship between the knowledge-based economy and sustainable development is equally significant. Innovation can promote the more efficient use of energy and raw materials, support the development of low-emission technologies, and optimize production and transport processes. Digitalization can enhance the monitoring of resource consumption and facilitate the adoption of circular business models. The knowledge economy should therefore be assessed not only in terms of the pace of innovation, but also in relation to the capacity of institutions to align technological progress with economic, social, and environmental objectives.

2. CONCEPTUAL FRAMEWORK OF THE KNOWLEDGE-BASED ECONOMY

The core principles of the knowledge-based economy highlight the strategic role of information, innovation, human capital, and technology in generating economic value and sustaining long-term competitiveness.

2.1. Concept of the Knowledge-Based Economy

The knowledge-based economy may be defined as an economic system in which the production, dissemination, and utilisation of knowledge and information constitute central mechanisms of value creation. The OECD and the World Bank associate this type of economy with the effective use of knowledge by enterprises, institutions, and individuals to support economic growth and enhance social well-being (OECD, 2023).

This definition should be interpreted with caution, since every form of economic activity relies on some type of knowledge. Traditional agriculture, craftsmanship, and industrial production have always drawn on experience, information, and skills. The distinctive feature of the contemporary economy is not the emergence of knowledge as an economic resource, but rather the intensification of its role and the increasing speed at which it is produced, transmitted, and superseded. Scientific progress, the expansion of education, and the development of digital technologies have shortened the time required to transform discoveries into economic applications and have strengthened the interdependencies among research, production, and the market.

Knowledge should not be conflated with information. Data consist of elementary observations or records, whereas information results from their organisation and interpretation within a relevant context. Knowledge involves the integration of information with the experience, competencies, and judgement of individuals or organisations. A database may contain valuable information, but economic value is generated only when economic actors possess the capabilities required to analyse that information and apply it in decision-making processes.

Intellectual property protection seeks to balance two objectives. On the one hand, innovators must be able to derive an economic return from their investments. On the other hand, excessive protection may restrict the circulation of knowledge and delay subsequent innovation. A well-functioning knowledge economy must therefore stimulate both the creation of new ideas and their diffusion throughout the economy.

Research and development constitute one of the principal institutionalised mechanisms for producing knowledge. Basic research expands the general scientific knowledge base, applied research seeks solutions to specific problems, and experimental development transforms research findings into commercially viable products, services, and processes. Research and development expenditure, however, does not automatically generate innovation. Outcomes depend on the quality of researchers, the available infrastructure, access to finance, cooperation among organisations, and the existence of demand for the products or solutions developed.

Education and vocational training complement this process. The education system develops the competencies required to generate and use knowledge, while vocational training facilitates the adaptation of skills to technological change. As the pace of change shortens the period during which certain skills remain relevant, lifelong learning becomes a structural component of the knowledge-based economy. Human capital cannot be regarded as a stock acquired exclusively at the beginning of an individual’s professional life, but rather as an asset requiring continuous investment and regular updating.

The framework developed by the World Bank groups the enabling conditions of the knowledge economy into four pillars: an education system capable of developing relevant skills, an effective innovation system, adequate information and communication technology infrastructure, and an economic and institutional regime that encourages entrepreneurship, investment, and the use of knowledge (World Bank, 2024). These four pillars are interdependent. Digital infrastructure makes only a limited contribution in the absence of appropriate skills, while skills cannot be used effectively without innovative enterprises, access to finance, and a predictable institutional framework.

2.2. The main factors of the knowledge-based economy

Human capital comprises the knowledge, skills, experience, and individual capabilities that contribute to economic activity. In the knowledge-based economy, the value of human capital derives not only from the volume of information possessed, but also from the capacity to learn, integrate knowledge from different fields, and solve novel problems. Investment in education can generate individual benefits by increasing productivity and expanding career opportunities, while also producing broader collective gains. Highly skilled employees facilitate technology adoption, contribute to the diffusion of best practices, and can support the creation of new enterprises. However, the quality of education is more significant than the mere quantitative expansion of participation in formal schooling. An economy may have a large number of graduates while simultaneously facing skills shortages when educational programmes are not aligned with technological developments and labour market demand. For this reason, curricula should integrate digital competencies with critical thinking, creativity, collaboration, and communication skills. Continuing vocational education and training performs a similar function. Automation does not merely eliminate certain occupations; it also changes the tasks performed within a wide range of professions. Employees must therefore be able to use emerging technologies and shift from repetitive activities towards tasks involving analysis, judgement, and human interaction. The OECD indicates that adaptation to digitalisation requires a combination of cognitive, digital, social, and emotional skills, supported through initial education, vocational training, and lifelong learning (OECD, 2019).

Innovation constitutes the mechanism through which knowledge is transformed into economic and social value. It may take the form of new products, more efficient production methods, alternative business models, or organisational change. Innovation should not be confined to high-technology sectors. Agriculture, the food industry, construction, transport, and public services can also make use of advanced knowledge and generate substantial productivity gains.

Digital infrastructure encompasses communication networks, data centres, cloud services, information systems, and the security solutions required for economic activity. It facilitates market access, reduces transaction costs, and enables firms to coordinate complex operations. For small enterprises, digital technologies can lower certain barriers to entry and broaden access to customers, suppliers, and specialised services. The effects of digital infrastructure are contingent upon the level of available skills. Basic competencies enable the use of common digital tools, whereas advanced capabilities support the development and management of technologies. Between these two levels lie occupation-specific digital skills, such as an accountant’s ability to use integrated information systems, an engineer’s capacity to work with digital simulations, or a manager’s ability to interpret indicators generated through data analytics. Digital policy cannot therefore be reduced to investment in equipment and connectivity. It must be integrated with education policy, employment policy, and innovation strategy. The European Commission regards digital skills as a central component of digital transformation and of efforts to reduce disparities in access, while the OECD distinguishes among foundational skills, basic digital competencies, and the advanced capabilities required to develop and use digital technologies (European Commission, 2026; OECD, 2024).

Knowledge generates economic effects when it circulates among individuals and organisations. Such transfer may occur through education, labour mobility, foreign investment, commercial relationships, licensing, consultancy, participation in professional networks, and collaborative research projects. In many cases, knowledge transfer does not involve the mere replication of an existing solution, but rather its adaptation to a different organisational, sectoral, or regional context.

Institutions shape the way knowledge is produced, protected, and commercially exploited. Macroeconomic stability, regulatory quality, the protection of property rights, competition, and access to finance influence the willingness of economic actors to invest in innovative projects. In an environment characterised by legal uncertainty or excessive administrative barriers, firms may favour low-risk, short-term investments at the expense of research and innovation.

At the same time, public institutions should avoid providing permanent protection to unproductive enterprises. The knowledge-based economy requires a balance between supporting innovation and preserving competitive pressures. Competition encourages firms to invest in improving products and processes, while temporary intellectual property protection may enable innovators to recover research and development costs.

2.3. The Relationship Between the Knowledge-Based Economy and Competitiveness.

Economic competitiveness may be understood as the capacity of an economy to generate productivity, income, and employment opportunities within an open international environment. It should not be reduced to maintaining low labour costs or increasing exports. A competitive economy is capable of using available resources productively, adapting to change, and improving living standards over the long term.

The first mechanism through which knowledge influences competitiveness is productivity growth. Technology enables the automation of repetitive tasks, the reduction of errors, the optimisation of resource use, and the improvement of decision-making. However, productivity gains arise only when technological investment is accompanied by organisational restructuring and skills development. The implementation of an information system without corresponding changes to organisational processes may generate additional costs without producing significant benefits.

The second mechanism is product and service innovation. Firms that invest in research, design, and knowledge of consumer preferences can develop differentiated products and avoid competing exclusively on price. Intellectual property, reputation, databases, software, and organisational capabilities constitute intangible assets that can strengthen firms' competitive positions.

The third mechanism concerns integration into high-value-added segments of global value chains. Economies that primarily undertake standardised assembly activities remain vulnerable to the relocation of production to lower-cost regions. The development of research, design, software, marketing, and specialised service activities enables economies to retain a larger share of the value created. Economic policy should therefore focus not only on attracting investment, but also on strengthening the capacity of domestic firms to learn, become specialised suppliers, and develop proprietary technologies.

The fourth mechanism relates to adaptability and resilience. An economy with a diversified skills base and well-developed research institutions can respond more rapidly to technological change, supply-chain disruptions, and shifts in demand. Human capital facilitates the reallocation of resources towards new activities, while digital infrastructure supports the reorganisation of production and the remote delivery of services. Resilience depends not only on the availability of advanced technologies, but also on the capacity of economic actors to learn and cooperate.

The importance of innovation for competitiveness is also reflected in international assessment frameworks. Indicators used by the OECD and the World Intellectual Property Organization encompass dimensions such as human capital, research and development, infrastructure, patents, collaboration, and technological outputs. This approach highlights that innovation performance cannot be explained by a single factor, but results from the functioning of a complex economic and institutional system (OECD, 2026; World Intellectual Property Organization, 2025).

The relationship between knowledge and competitiveness is neither automatic nor uniform. Investment in education may produce limited effects when the economy fails to generate suitable employment opportunities, potentially resulting in the underutilisation of skills or the migration of qualified personnel. Similarly, investment in research may yield few commercial outcomes when links between universities and enterprises are weak. Digital infrastructure may also intensify economic concentration when only large firms possess the resources required to exploit data and advanced technologies.

The knowledge-based economy may also generate regional disparities. Innovative activities tend to concentrate in areas that already benefit from universities, infrastructure, capital, and a diversified labour market. Although this concentration creates positive externalities, it may also widen the gap between urban centres and peripheral regions. Cohesion policies should therefore combine the expansion of digital infrastructure with the development of local institutions for education, training, and entrepreneurial support.

Knowledge-based competitiveness must also be aligned with social inclusion. Digitalisation can create new professional and entrepreneurial opportunities, but it may exclude individuals who lack the necessary skills, equipment, or connectivity. Public policies should facilitate access to training and reskilling, particularly for workers exposed to automation and for groups with low labour-market participation. In the absence of such measures, productivity growth may be accompanied by increasing disparities in income and access to economic opportunities.

The competitiveness of a knowledge-based economy arises from the complementarity among technology, skills, innovation, and institutions. None of these factors is sufficient in isolation. Technology may remain underutilised without adequate human capital; education without corresponding economic opportunities may lead to skills migration; and research without effective transfer mechanisms may have only a limited impact on productivity. Economies that successfully integrate these components are better positioned to create value, adapt to change, and sustain long-term economic growth.

3. ROMANIA'S POSITION IN THE KNOWLEDGE-BASED ECONOMY

An economy’s capacity to generate, integrate, and leverage knowledge depends on several resources that operate simultaneously: the level of human capital, the intensity of research and development activities, the population’s digital skills, and the ability of the economic system to convert these resources into productivity gains and added value.

To provide a concise comparison between Romania, the European Union average, and a group of Central and Eastern European countries, an experimental composite index, termed the Knowledge Economy Composite Index (KEI), was developed. The index incorporates four dimensions considered essential to the functioning of a knowledge-based economy: human capital, innovation, digitalization, and economic performance.

KEI = Human capital + Innovation + Digitalization + Economic performance

The KEI is not an official indicator of the European Union and should not be confused with the identically named index previously developed by the World Bank. Rather, it is proposed as an analytical tool designed to provide a concise, transparent, and easily replicable measure of the knowledge economy, based on comparable Eurostat indicators and a transparent normalization procedure.

Each of the four dimensions is represented by a single indicator. This approach reduces computational complexity and facilitates the interpretation of the results; however, it inevitably simplifies the multidimensional nature of the knowledge economy. The implications of this methodological choice are discussed in the section addressing the study's methodological limitations.

Table 1. Dimensions and indicators included in the KEI

Dimension	Indicator	Unit of measure	Reference year
Human Capital	Persons aged 25–34 with tertiary educational attainment	%	2025
Innovation	Gross domestic expenditure on research and development (GERD)	% GDP	2024
Digitalization	Persons aged 16–74 with at least basic digital skills	%	2025
Economic performance	Gross domestic product (GDP) per capita expressed in purchasing power standards (PPS)	UE-27 = 100	2025

Source: Author's own compilation based on Eurostat indicators.

Human capital. The share of the population aged 25–34 with tertiary educational attainment is used as a proxy for the stock of advanced human capital among younger cohorts. Although this indicator does not directly capture the quality of education or the extent to which graduates' skills match labor market demand, it provides a meaningful measure of the education system's capacity to produce highly qualified graduates. In 2025, the proportion reached 44.8% in the EU-27, compared with 23.0% in Romania (Eurostat, 2026a).

Innovation. Research and development intensity is measured by gross domestic expenditure on research and development (GERD) as a percentage of GDP. This indicator reflects the financial resources devoted to knowledge creation, technological development, and innovation. In 2024, GERD amounted to 2.24% of GDP in the EU-27, compared with only 0.46% in Romania. For several of the countries included in the analysis, the 2024 figures are preliminary or provisional; consequently, marginal differences should be interpreted with caution (Eurostat, 2026b).

Digitalization. The digital dimension is approximated by the share of persons aged 16–74 with at least basic digital skills. The Eurostat indicator encompasses five domains: information and data literacy, communication and collaboration, digital content creation, problem solving, and safety. As it is derived from respondents' self-reported digital activities, the indicator provides a proxy for the digital skills applied in practice. In 2025, 60.39% of the

EU-27 population possessed at least basic digital skills, compared with 31.84% in Romania (Eurostat, 2026c).

Economic performance. GDP per capita expressed in purchasing power standards (PPS) largely adjusts for differences in national price levels, thereby enabling more meaningful cross-country comparisons of living standards and economic productivity. The EU-27 average is set equal to 100; thus, a value of 78 indicates a GDP per capita approximately 22% below the EU average. As the estimates for 2025 are preliminary or provisional and remain subject to revision, the economic component of the index should be interpreted accordingly (Eurostat, 2026d).

Table 2. Raw values of the indicators included in the KEI

Country	Persons aged 25–34 with tertiary educational attainment (%)	Gross domestic expenditure on research and development (GERD) (% GDP)	Persons aged 16–74 with at least basic digital skills (%)	GDP per capita PPS, UE=100
EU-27	44.8	2.24	60.39	100
Bulgaria	41.2	0.77	38.26	68.00
Czechia	36.0	1.82	70.45	92.4
Hungary	32.6	1.31	57.33	76.2
Poland	45.2	1.41	50.42	81.2
Romania	23.0	0.46	31.84	77.7
Slovakia	36.3	0.98	53.56	74.8
Slovenia	42.8	2.16	46.50	90.5

Source: Author's own compilation based on Eurostat indicators.

The selected indicators are expressed in different units of measurement and therefore cannot be aggregated in their original form. To ensure comparability, each indicator was normalized relative to the EU-27 average, which was set as the benchmark equal to 100. This normalization approach offers two main advantages. First, the results are straightforward to interpret, as all components are expressed relative to the same reference value. Second, a country's score remains unaffected by the inclusion or exclusion of other countries from the sample, unlike the min–max normalization method, where the range of observations directly influences the resulting scores.

For the construction of the KEI, equal weights were assigned to the four dimensions. This weighting scheme does not imply that each dimension contributes equally, in objective terms, to economic development. Rather, it represents a transparent normative assumption under which human capital, innovation, digitalization, and economic performance are treated as equally important components of the composite index

Table 3. Normalized scores, KEI values, and regional ranking

Country	Human capital	Innovation	Digitalization	Economic performance	KEI	Ranking
EU-27	100.00	100.00	100.00	100.00	100.00	Reper
Bulgaria	91.96	34.38	63.35	68.00	64.42	6
Czechia	80.36	81.25	116.66	92.40	92.67	1

Country	Human capital	Innovation	Digitalization	Economic performance	KEI	Ranking
Hungary	72.77	58.48	94.93	76.20	75.60	4
Poland	100.89	62.95	83.49	81.20	82.13	3
Romania	51.34	20.54	52.72	77.70	50.57	7
Slovakia	81.03	43.75	88.69	74.80	72.07	5
Slovenia	95.54	96.43	77.00	90.50	89.87	2

Source: Author's calculations based on Eurostat data (2026a–d).
Note: Component scores are expressed relative to the EU-27 average, set equal to 100

Romania records a KEI score of 50.57, the lowest among the seven countries included in the analysis. This value should not be interpreted as indicating that the Romanian economy is "50.57% knowledge based." Rather, it signifies that Romania's average performance across the four selected dimensions reaches 50.57% of the EU-27 benchmark. The gap relative to the EU average amounts to 49.43 points, while the difference compared with Bulgaria (the country ranked immediately above Romania) is 13.85 points. Relative to Slovakia, the gap widens to 21.50 points.

Romania's performance profile reveals a marked imbalance between economic convergence and the structural factors that underpin the long-term generation and utilization of knowledge. The economic performance component reaches 77.70 points, whereas the scores for digital skills and human capital are substantially lower, at 52.72 and 51.34 points, respectively. Innovation constitutes the weakest dimension, with a score of only 20.54 points.

These findings indicate that Romania's GDP per capita has converged towards the EU average considerably faster than the indicators related to education, digital skills, and research and development. This pattern suggests that the country's process of economic convergence is not yet supported by a comparable convergence in the core drivers of a knowledge-based economy.

The most pronounced deficit is observed in the field of innovation. Gross domestic expenditure on research and development, amounting to 0.46% of GDP, represents only about one-fifth of the EU-27 average, corresponding to an absolute gap of 1.78 percentage points of GDP. Human capital constitutes the second major structural constraint, as the share of the population aged 25–34 with tertiary educational attainment is 21.8 percentage points below the EU average. The gap is even wider with respect to basic digital skills, reaching approximately 28.6 percentage points.

Czechia ranks first, with a KEI score of 92.67. Its strongest comparative advantage lies in digitalization: a digital skills score of 116.66 indicates that the share of individuals possessing at least basic digital skills exceeds the EU-27 benchmark by 16.66%. This strong performance is further supported by relatively high R&D intensity and GDP per capita close to the EU average.

Slovenia occupies second place, with a score of 89.87. Its performance profile is more balanced, with human capital, research and development, and economic performance all approaching the EU-27 benchmark. The country's comparatively weaker dimension is digital skills, which records a score of 77.00.

Poland ranks third, achieving 82.13 points. It is the only country in the group where the share of the population aged 25–34 with tertiary educational attainment slightly exceeds the EU-27 average. Nevertheless, its overall performance is constrained by lower R&D intensity and a GDP per capita that remains below the European benchmark.

Hungary and Slovakia occupy the middle positions in the ranking, with scores of 75.60 and 72.07, respectively. Hungary performs relatively well in digital skills, approaching the EU average, but continues to lag in human capital, research and development, and economic performance. Slovakia displays a comparatively balanced profile in terms of human capital and digitalization; however, its R&D expenditure remains below half of the EU-27 level.

Bulgaria records a KEI score of 64.42. Although it exhibits a relatively high share of young adults with tertiary educational attainment, this advantage is offset by comparatively weak performance in research and development, digital skills, and GDP per capita. Romania outperforms Bulgaria only in the economic performance component, while remaining substantially behind in human capital and recording lower scores in both innovation and digitalization.

Limitations of the analysis. The first limitation arises from the representation of each dimension by a single indicator. Human capital cannot be fully captured by tertiary educational attainment alone, innovation extends beyond expenditure on research and development, and digitalization encompasses a broader range of capabilities than basic individual digital skills.

A second limitation concerns the lack of complete temporal alignment across the indicators. Owing to differences in reporting schedules, the variables refer to different reference years. Consequently, the KEI reflects the most recent data available for each dimension rather than the performance of all dimensions within a single reference year.

A third limitation stems from the use of the arithmetic mean, which assumes full compensability among the index components. Under this approach, a relatively high level of GDP per capita can mathematically offset a very low level of research and development expenditure, even though these two configurations are not structurally equivalent from the perspective of a knowledge-based economy.

Finally, the proposed index primarily captures input variables and intermediate outcomes. It does not incorporate other important dimensions, such as institutional quality, scientific output, patent activity, export complexity, the adoption of digital technologies by firms, or the regional distribution of human capital. In addition, some of the values for research and development expenditure and GDP per capita are preliminary or provisional and may be revised in subsequent releases of the Eurostat database.

4. CONCLUSIONS

The knowledge-based economy is reshaping the traditional sources of competitiveness by shifting the emphasis from material resources and low costs towards information, innovation, human capital, and technology. Economic performance increasingly depends on societies' capacity to create, disseminate, and use knowledge effectively.

Digitalisation can enhance productivity, reduce costs, and facilitate cooperation, but its effects depend on the availability of appropriate skills and the adaptation of organisational processes. Education, vocational training, reskilling, and lifelong learning therefore become essential forms of economic investment. Innovation transforms knowledge into value-added products, services, processes, and business models. Its outcomes depend on the quality of research, access to finance, cooperation between universities and enterprises, digital infrastructure, and the stability of the institutional framework.

Knowledge-based competitiveness requires productivity growth, the development of proprietary technologies, and integration into higher-value-added segments of global value chains. However, digitalisation may widen social and regional disparities when access to skills, infrastructure, and economic opportunities remains unequal.

A high-performing knowledge-based economy requires complementarity among technology, human capital, innovation, and institutions. The coherent integration of these components can support long-term economic growth, resilience, social inclusion, and sustainable development.

The proposed composite index provides a concise assessment of Romania's position relative to the EU-27 average and to the selected economies of Central and Eastern Europe. With a KEI score of 50.57, Romania ranks last among the countries included in the analysis, remaining at a considerable distance from both the European benchmark and the other countries in the sample.

The most important finding is not merely the magnitude of this gap but its underlying structure. Romania has experienced faster economic convergence than convergence in the key structural drivers of a knowledge-based economy, namely human capital, innovation capacity, and digital skills. While GDP per capita has reached approximately 78% of the EU-27 average, relative performance remains at only 51–53% in human capital and digital skills and declines to 20.54% in research and development.

These findings suggest that the long-term sustainability of Romania's economic convergence will depend on a transition from a development model based primarily on capital accumulation, cost advantages, and the adoption of externally developed technologies towards one in which advanced education, research, digital capabilities, and domestic innovation make a substantially greater contribution to productivity growth and value creation.

The results point to the need for a coherent policy strategy aimed at narrowing the gap between GDP per capita convergence and the three structural dimensions that continue to lag: research and development, human capital, and digital skills.

The first policy priority is to increase the intensity of research and development activities. Although higher public investment is essential, it is unlikely to be sufficient on its own. It should be complemented by stronger incentives for private-sector R&D investment, enhanced collaboration between universities and businesses, more effective utilization of research infrastructure, and institutional mechanisms that facilitate the translation of scientific knowledge into innovative products, services, and production processes.

A second priority concerns the expansion and modernization of human capital. The relatively low share of young adults with tertiary educational attainment constrains both the supply of researchers and highly skilled professionals and the capacity of firms to adopt advanced technologies. Expanding access to tertiary education should therefore be accompanied by improvements in educational quality, measures to reduce university dropout rates, and closer alignment between academic programmers, technological change, and labor market demand.

The third priority relates to the enhancement of digital skills across the population. Investment in digital infrastructure alone cannot eliminate the existing gap. Comprehensive adult training programmers, the systematic integration of digital competencies into formal education, and targeted interventions addressing groups at greater risk of digital exclusion, particularly rural populations, older adults, and individuals with lower levels of educational attainment, are all required.

Ultimately, the effectiveness of public policy will depend on strengthening the complementarities among the four pillars of the knowledge economy. Investments in education are likely to generate greater economic returns when graduates are successfully integrated into research activities and innovative enterprises. Likewise, investment in research is more likely to translate into sustained economic benefits when firms and the workforce possess the digital capabilities required to adopt, diffuse, and further develop new technologies.

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