The Implications of Emerging Technologies on The Sustainable Development Goals

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Abstract: *The paper investigates the relationship between emerging technologies and the progress of European Union Member States towards three goals of the 2030 Agenda: Goal 4 (Quality Education), Goal 8 (Decent Work and Economic Growth) and Goal 9 (Industry, Innovation and Infrastructure). The analysis follows how innovation, digital human capital and readiness for artificial intelligence are reflected in the social and economic performance of European countries. The research started from three research hypotheses: (1) countries with more advanced digital human capital have higher levels of basic digital skills; (2) innovation makes a significant contribution to economic performance; (3) investments in research and development strengthen a country's capacity to integrate artificial intelligence technologies. The methodology combines quantitative analysis (simple linear regressions) with qualitative analysis based on official data and reports published by Eurostat, the European Commission and Oxford Insights. The sample covers all 27 European Union States over the period 2021–2023. The results show a positive link between technological development and progress towards sustainable development goals 4, 8 and 9. The statistical models confirm the importance of digital skills, innovation, and AI readiness in supporting sustainable economic development. Even though emerging technologies have positive effects, some countries still face challenges related to the quality of employment, regional disparities, and unequal access to digital skills. Overall, emerging technologies can support the achievement of the goals when accompanied by inclusive policies, lifelong learning and investment in digital skills and connectivity.*

Keywords*:* Technological Change; Management of Technological Innovation and R&D; Macroeconomic Analyses of Economic Development, Economywide Country Studies

JEL: O11, O32, O33, O52

Introduction

In recent years, the global economy has changed rapidly with the development of technologies such as artificial intelligence, digitalization, the Internet of Things, and automation. These have brought economic growth and new business models but have also accentuated some inequalities and environmental problems. The transition to sustainable development has thus become essential for achieving the Sustainable Development Goals, especially through smart and innovative solutions. However, challenges such as cybersecurity, unequal access to technology and social polarization continue to slow down progress, particularly affecting less developed countries and vulnerable groups. Therefore, more and more governments are focusing their policies on reducing these differences and on the efficient use of available resources to support sustainable growth. This idea is the starting point for the 2030 Agenda and the 17 Sustainable Development Goals (SDGs). To respond to their complexity, integrated policies, clear regulations, and collaborations between the public and private sectors are needed. In this framework, the United Nations (UN) has established the 17 SDGs, which address social, economic, and environmental issues and aim to build a safer and more equitable future. An important element in advancing towards these goals is the integration of digital technologies and innovative solutions. Developed countries are already using these technologies on a large scale, and they are gradually being adopted in other regions of the world. These technological tools open new ways to address current challenges and find more effective solutions to existing problems.

1. Literature review

Recent research shows that digitalization, artificial intelligence, and automation can support sustainable development through greater efficiency, better use of resources and reduction of inequalities (Bocean, 2025; Camodeca & Almici, 2021). In particular, digital technologies can support environmental protection and the transition to circular models through resource saving, renewable energy, and cleaner production processes (Pînzaru et al., 2022). AI, data analytics and automation contribute to process efficiency, education, and resource management (Dionisio et al., 2023; Oprea, 2023). At the same time, solutions such as Cloud Computing and digitalization facilitate access to digital resources, collaboration, and innovation, helping to progress towards the SDGs (Kostoska & Kocarev, 2019; Oprea et al., 2025). However, the literature reports mixed effects: high energy consumption, carbon footprint, recycling difficulties and e-waste, but also risks related to the digital divide, system dependency, cybersecurity, privacy and information manipulation (Andriushchenko et al., 2020; Oprea et all., 2025). In this context, several studies call for the benefits to be accessible to all and show that emerging technologies can help even in times of global crisis and recovery (Perera et al., 2023).

Several Sustainable Development Goals are directly linked to the responsible adoption of digital technologies, but this paper focuses on SDGs 4, 8 and 9, as developments in digitalisation, innovation and artificial intelligence clearly impact education, the economy and technological infrastructure. SDG 4 aims for quality education, and emerging technologies can expand access to digital resources and reduce learning gaps. SDG 8 targets economic growth and decent work, areas where emerging technologies can increase productivity and competitiveness, but also the need for reskilling programmes. SDG 9 focuses on innovation and sustainable infrastructure and highlights the role of digital technologies in supporting economic development (Argyroudis et al., 2022). Together, these three goals provide a coherent picture of how emerging technologies can support sustainable development in the EU. However, these technologies also come with risks: high energy consumption, increased e-waste, digital divide, and vulnerabilities related to security and privacy (Vasile & Manta, 2025; Jula & Jula, 2023). To achieve sustainable results, investments in digital skills, connectivity, active labour market policies, clear regulations and ethical standards are needed (Martínez-Peláez et al., 2024). Given these challenges and mixed results in the literature, this paper aims to provide an integrated analysis of how emerging technologies influence SDGs 4, 8 and 9, by correlating digitalization indicators with specific sustainable development indicators and to fill a gap in the literature. The study examines the differences between EU countries, how they adopt emerging technologies and the impact on education, labour market, and infrastructure. The analysis is guided by three hypotheses regarding the relationship between digital human capital, innovation and investment in research and development, and the capacity to adopt artificial intelligence.

The hypotheses formulated are: Hypothesis 1 (H1): A higher level of digital human capital is correlated with the development of more advanced digital skills; Hypothesis 2 (H2): A higher degree of innovation is associated with superior economic performance; Hypothesis 3 (H3): Increased investment in research and development is linked to a greater capacity to adopt artificial intelligence.

The results can contribute to the formulation of public policies aimed at reducing gaps and ensuring a fair distribution of the benefits of digitalization. The paper is organized into four sections. The first section presents the theoretical context and the foundations of the topic. The second section describes the data used and the methodology applied in the analysis. The third section presents the results and their associated discussions, and the last section includes the conclusions, limitations of the study and future research directions.

2. Research methodology

To analyse the influence of emerging technologies on sustainability, the paper uses a mixed methodology. The quantitative part includes simple linear regression models, used to test the link between technological indicators and those of sustainable development. This is complemented by a qualitative, descriptive-comparative analysis, based on secondary data from international reports. Choosing a mixed method is useful because the phenomenon studied is complex and allows for the observation of differences between countries and recent developments.

The indicators were selected based on theoretical relevance, their use in the specialized literature and the availability of comparable official data at EU level. The sample includes all 27 Member States of the European Union, and the analysis period 2021-2023 reflects the common reporting interval. The data used are exclusively secondary data, taken from official international sources such as the European Commission, Eurostat, Oxford Insights, the UN and the OECD and were processed in four stages: collection, selection, harmonisation in a unitary database and checking for outliers (e.g. GDP/capita in Ireland and Luxembourg). Hypotheses H1–H3 are tested by simple linear regression models (OLS – Method of Least Squares), checked by the overall model significance (F test / ANOVA), the significance of the regression coefficient (t test), coefficient of determination (R^2 and adjusted R^2), and the graphic residual diagnostics.

The research is exploratory in nature, and the results should be interpreted considering limitations such as the gaps between reporting years, the sample restricted to the EU and the influence of extreme values of GDP/capita for some countries. These limitations indicate future research directions, as well as the use of panel models, multiple regressions, and additional indicators.

3. Results and discussions

The analysis is structured in three sections corresponding to the three research hypotheses, each tested by a simple linear regression model, which examines the relationship between a technological indicator and one associated with SDGs 4, 8 and 9. The results are presented both numerically (tables) and graphically to facilitate comparison between domains.

3.1. Digital human capital and the share of individuals with basic digital skills.

Hypothesis H1 examines whether the level of digital human capital is associated with a higher proportion of the population possessing basic digital skills (SDG 4 – Quality Education). Based on the estimated model, the regression equation obtained is:

Basic Digital Skills = 16.551 + 1.8775 × DESI Human Capital

The slope coefficient ($\beta = 1.8775$; $p \approx 0.00035$) indicates a positive and statistically significant relationship: for every one point increase in the DESI Human Capital score, the share of the population with basic digital skills increases, on average, by approximately 1.88 percentage points. Table 1 presents the model's coefficients and statistical indicators, while $R^2 = 0.406$ shows that the model explains about 41% of the variation in basic digital skills across EU member states.

Table 1: Results of the linear regression: DESI Human Capital (X – Score 0–100) and Basic Digital Skills (Y – Percentage of individuals 0–100%), 2021, EU Member States.

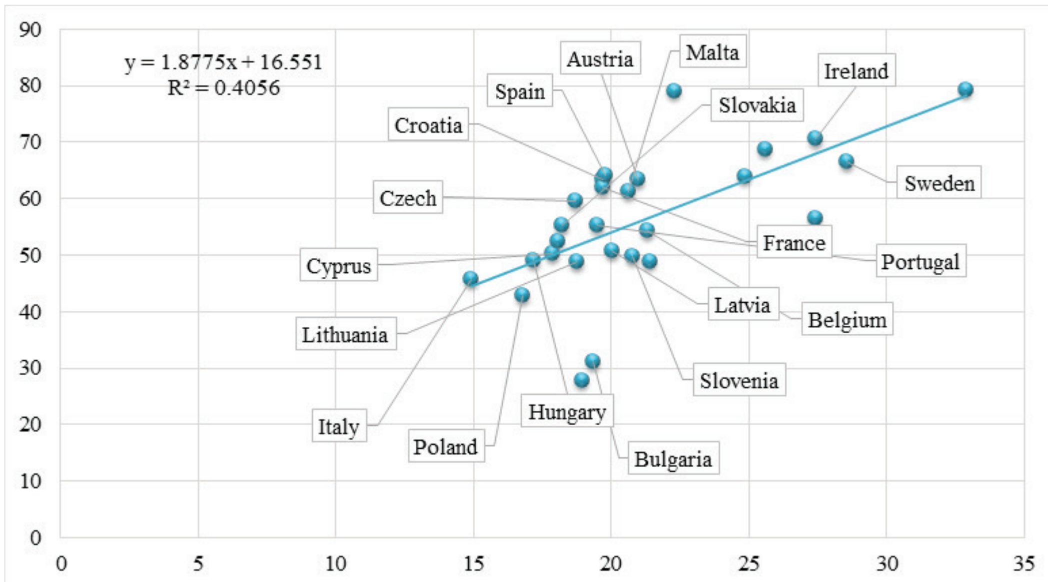
	Coefficient	Std. Error	t Stat	P-value	IC 95% (min)	IC 95% (max)
Intercept	16.5506	9.7955	1.6896	0.1035	-3.6236	36.725
DESI – Human capital 2021	1.8775	0.4545	4.1304	0.00035	0.9413	2.8136

Statistics regression	
Multiple R	0.6368
R Square	0.4056
Adjusted R-Square	0.3818
Standard Error	9.5188
Observations	27

Source: author's calculations (Ordinary Least Squares – OLS) based on DESI "Human Capital" data (European Commission, 2021) and Eurostat – Basic Digital Skills (2021).

The regression plot (Figure 1) visually confirms the positive relationship, and the trend line equation matches the OLS estimation.

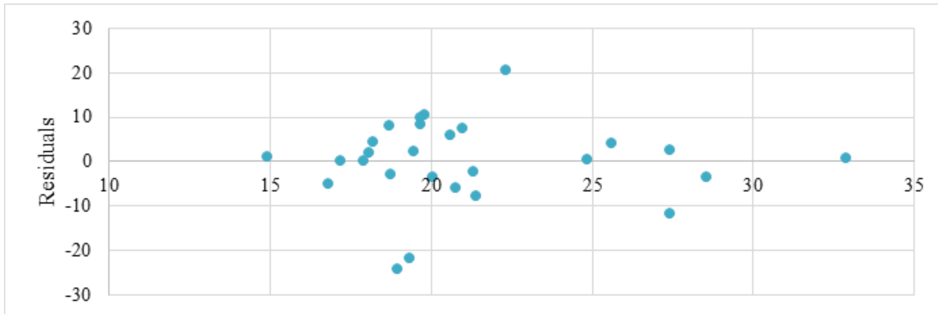
Figure 1: Scatter plot of DESI Human Capital (X) vs. Basic Digital Skills (Y)



Source: author's calculations (OLS) based on data from the European Commission – DESI, Human Capital component (2021), and Eurostat – Individuals with Basic Digital Skills (2021). Note: Trend line = OLS estimate. Labels indicate EU Member States. The equation and R^2 are displayed in the plot panel.

The analysis of the residuals (Figure 2) shows a relatively uniform distribution around the zero axis and a close linear relationship, indicating a good fit of the model. Positive residuals are particularly evident in countries such as Finland and the Netherlands, where digital skills are above the level predicted by the DESI score, probably due to early investments in digital education and continuing training. Negative residuals are found in Southern and Central Eastern Europe (Italy, Hungary, Bulgaria, Poland), where internal disparities and limited digital literacy programs explain the lower performance.

Figure 2: Regression plot of DESI Human Capital vs. Basic Digital Skills (2021)



Source: author's calculations (OLS) based on data from the European Commission – DESI, Human Capital component (2021), and Eurostat – Individuals with Basic Digital Skills (2021).

Overall, the residual plot shows that the model works well: the relationship is close to linear, and the points are distributed relatively evenly around the zero axis. Although there are a few outliers, these do not significantly change the main conclusion of the analysis.

3.2. The Innovation Index and Real GDP per Capita.

The analysis examines the relationship between the level of innovation and economic performance in the context of SDG 8, testing hypothesis H2: countries with higher levels of innovation tend to have a higher real GDP per capita. The model used is a simple linear regression, with the Innovation Index (2023) as the independent variable and real GDP per capita (2023) as the dependent variable:

GDP per capita = –16,080.41 + 481.17 × Innovation Index

The slope coefficient ($\beta = 481.17$; $p < 0.001$) is positive and statistically significant, indicating that each additional point in the Innovation Index is associated, on average, with an increase of approximately €481 in real GDP per capita. Thus, a 10 point difference in innovation corresponds to an estimated increase of about €4,800 per person. The intercept is not statistically significant and is used only to position the regression line.

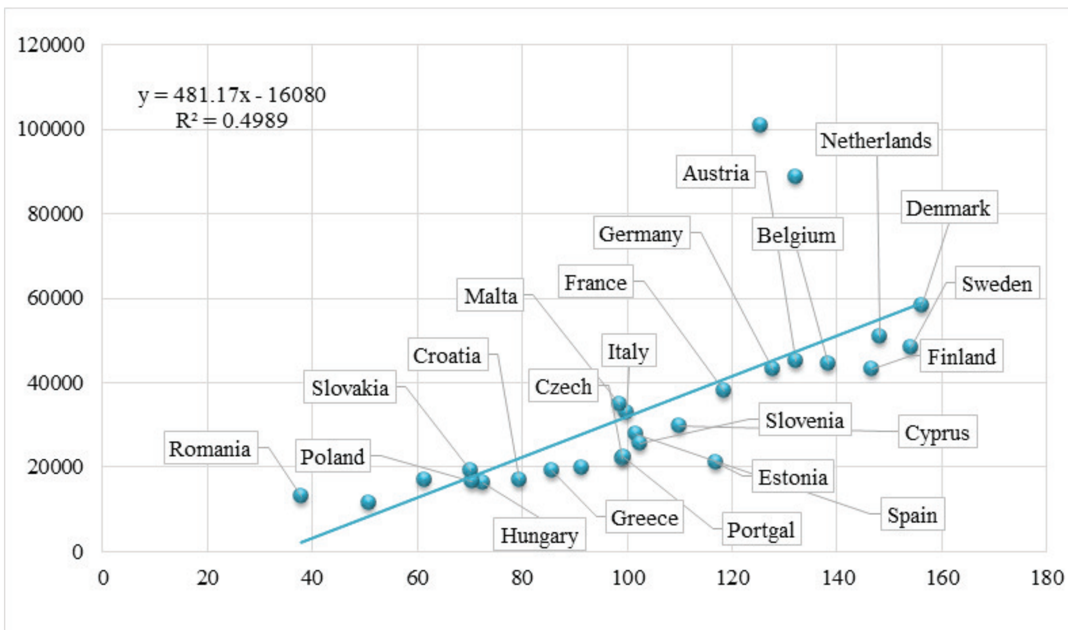
	Coefficient	Std. Error	t Stat	P-value	IC 95% (min)	IC 95% (max)
Intercept	-16080.41	10539.2	-1.5257	0.1396	-37786.3	5625.478
DESI – Human capital 2023	481.172	96.4396	4.9893	0.0004	282.551	679.794

Regression statistics	
Multiple R	0.7063
R Square	0.4989
Adjusted R-Square	0.4788
Std. Error	15727
Observations	27

Source: author's calculations (Ordinary Least Squares – OLS) based on Innovation Index data (European Commission, 2023) and Eurostat – Real GDP per capita (2023).

The model explains approximately 50% of the variation in real GDP per capita across EU countries ($R^2 \approx 0.50$), which represents a moderate fit in a cross-sectional analysis. The F-test ($p < 0.001$) confirms the overall relevance of the model. The graphical representation (Figure 3) shows a clearly positive linear relationship, consistent with the OLS estimates.

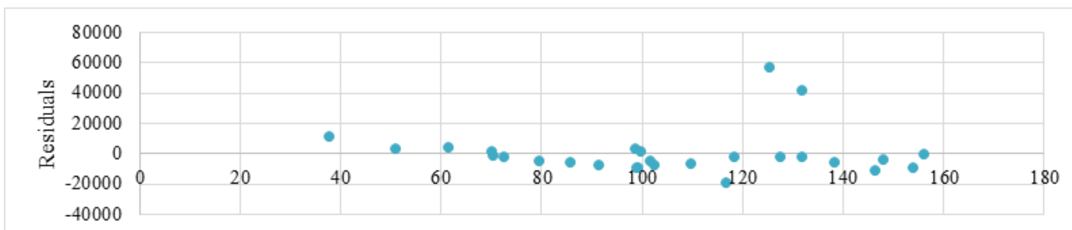
Figure 3: Scatter plot of Real GDP per capita (X) vs. the Innovation Index (Y)



Source: author's calculations (OLS) based on data from the European Commission – Innovation Index (2023) and Eurostat – Real GDP per capita (2023). Note: Trend line = OLS estimate. Labels indicate EU Member States. The equation and R² are displayed in the plot panel.

The analysis of the residuals shows that countries with positive values (GDP/capita above estimates) may benefit from additional factors such as the quality of institutions, the structure of the economy or foreign capital. Negative residuals suggest difficulties in transforming innovation into economic growth – for example, low productivity or a lack of qualified human resources. Luxembourg and Ireland appear as outliers, due to the structure of their economies, but this does not affect the basic conclusion: the Innovation Index is an important predictor of economic performance, even if it does not fully explain the differences between countries.

Figure 4: Regression plot of Real GDP per capita vs. the Innovation Index (2003)



Source: author's calculations (Ordinary Least Squares – OLS) based on Innovation Index data (European Commission, 2023) and Eurostat – Real GDP per capita (2023).

Overall, the analysis confirms that the level of innovation is an important determinant of economic performance, and the model consistently captures the positive relationship between the Innovation Index and real GDP per capita, even if it does not fully explain the differences between EU member states.

3.3. AI Readiness and National Expenditure on Research and Development

The analysis is situated within the framework of SDG 9 and examines how technological maturity (AI Readiness) correlates with the intensity of research and development investment (GERD), testing hypothesis H3: countries that are more advanced in adopting AI tend to invest more in R&D. The estimated OLS model is:

GERD = –4.179 + 0.0903 × AI Readiness

The slope coefficient ($\beta = 0.0903$; $p < 0.001$) is positive and statistically significant, indicating that each additional point in AI Readiness is associated with an increase of approximately 0.09 percentage points in R&D expenditure as a share of GDP. A 10 point difference in AI Readiness corresponds to an estimated increase of about 0.9 percentage points in investment intensity. The intercept does not have a direct economic interpretation.

Table 3: Linear regression results: GERD as a percentage of GDP (Y – % of GDP) and the AI Readiness Index (X – Score 0–100), 2023, EU Member State

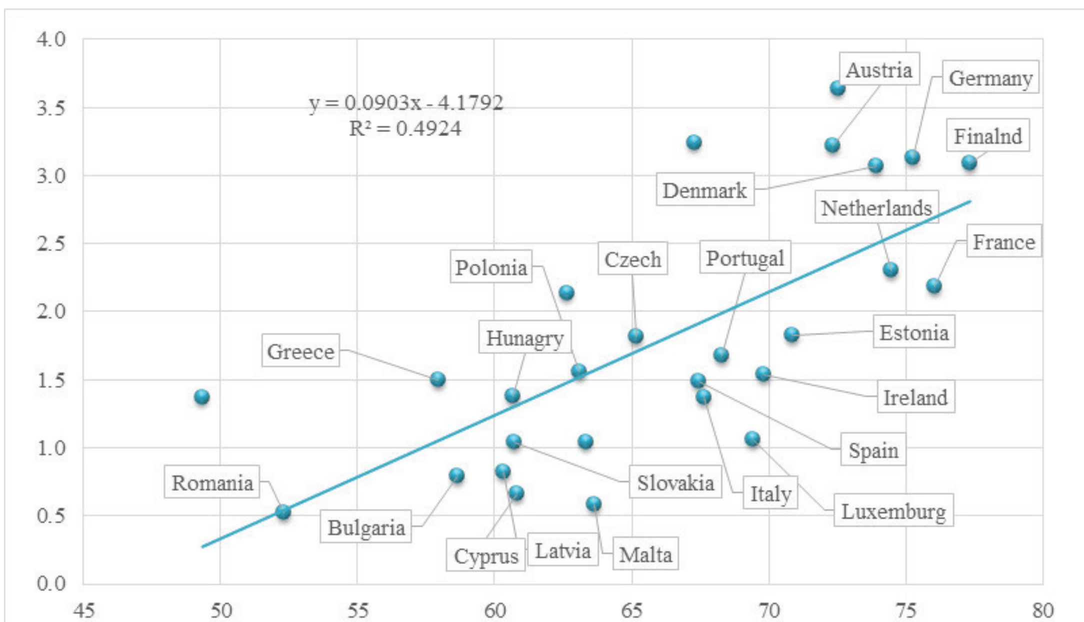
	Coefficient	Std. Error	t Stat	P-value	IC 95% (min)	IC 95% (max)
Intercept	-4.1791	1.2167	-3.434	0.00207	-6.6851	-1.6732
AI Readiness	0.0903	0.0183	4.925	4.5269	0.0525	0.128

Regression statistics	
Multiple R	0.702
R Square	0.492
Adjusted R-Square	0.472
Std. Error	0.668
Observations	27

Source: author's calculations (Ordinary Least Squares – OLS) based on AI Readiness Index data (Oxford Insights, 2023) and Eurostat – GERD as a percentage of GDP (2023).

The model explains approximately 49% of the variation in R&D investment across EU countries ($R^2 \approx 0.49$), indicating a moderate fit. The graphical representation (Figure 5) reproduces the identified positive linear relationship, and the standard error of the regression (~0.67 p.p.) reflects typical deviations from the observed values.

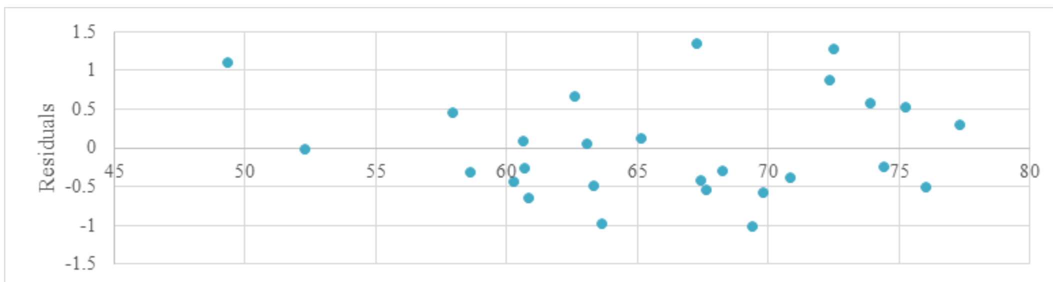
Figure 5: Scatter plot with regression line for AI Readiness (Y) and GERD (X)



Source: author's calculations (Ordinary Least Squares – OLS) based on AI Readiness Index data (Oxford Insights, 2023) and Eurostat – GERD as a percentage of GDP (2023). Note: Trend line = OLS estimate. Labels indicate EU Member States. The equation and R² are displayed in the plot panel.

The residual analysis (Figure 6) shows that some countries invest above the level estimated by the model, due to strong national innovation strategies or large private investments. Negative residuals mark situations where, despite high AI Readiness, investments remain below expectations—an aspect associated with institutional constraints, low productivity, or dependence on imported technologies. The outliers observed at very high levels of AI Readiness reflect structural factors influencing the model.

Figure 6: Regression plot of AI Readiness and GERD (2023)



Source: author's calculations (Ordinary Least Squares – OLS) based on AI Readiness Index (Oxford Insights, 2023) și Eurostat – GERD % PIB (2023).

Overall, the analysis confirms that a high level of AI readiness is an important predictor of investment in R&D, although the relationship only partially explains the differences between Member States, suggesting the influence of additional economic and institutional factors. The results of the analysis show that investment in innovation, digital skills and AI readiness have direct effects on economic development and the quality of the workforce. At the level of SDG 8, progress is visible, but the countries analysed remain below the EU average. Sustainable growth is limited by insufficient investment in the modernisation of the economy and by the uneven quality of jobs, which reduces productivity potential and the capacity to adapt to technological transformation.

For SDG 9, investment in research and development is starting from a low level and readiness for emerging technologies is still modest. Although digitalisation is steadily advancing, the pace is slower than the European average and technological infrastructure is unevenly developed. Dependence on external capital and the orientation towards traditional industries delay the adoption of advanced technologies, although European funds and industrial support programmes can accelerate the recovery of gaps.

Regarding SDG 4, the digital skills of the population remain below the EU average. Generational differences, urban-rural disparities and youth migration affect the availability of human capital needed for technological sectors. Progress is there, but it is slow and requires co-ordinated and long-term interventions. Current EU policies are aligned with these findings: digitalisation, innovation and skills development are considered essential for competitiveness and sustainable growth.

The analysis has some limitations that need to be taken into account. Some data sets come from different years (e.g. DESI 2021 vs. economic indicators 2023), which may generate small misalignments in interpretation. The sample is limited to the 27 EU states, so the generalization of the results outside the European space is restricted. In some cases, GDP/capita values are influenced by economic particularities (Ireland, Luxembourg), which may affect their positioning in regressions and comparative analyses. The models used are simple linear regressions, which capture only bivariate relationships and do not include other relevant factors such as economic structure, demography, quality of institutions or sectoral mix. For a more detailed analysis, multilateral models, panel models or time series can be used, to better capture the dynamics, lagged effects and possible causal relationships. Thus, future studies can provide a deeper understanding of how emerging technologies contribute to reducing regional gaps and accelerating progress towards sustainable development goals.

Conclusions

This paper analysed how innovation, digital human capital and readiness for artificial intelligence influence the progress of European Union countries in achieving SDG 4 (Education), SDG 8 (Jobs and Growth) and SDG 9 (Industry and Innovation).

Performance in SDG 4, SDG 8 and SDG 9 is closely linked to the level of digitalization, investment in research and development and the quality of human capital. Countries that consistently invest in digital education, innovation and technological infrastructure manage to maintain stable labour markets, high productivity, and a rapid adoption of emerging technologies. Regional differences – North vs. South, West vs. East – remain pronounced, which underlines the decisive role of cohesion policies in reducing these gaps. Northern and western countries are leading by a long way, while many Central and Eastern European countries are in a process of recovery, with increasing investment, but still insufficient to rapidly transform the economy. Taken together, these results show that countries that consistently invest in digitalization, skills, and innovation advance faster in achieving the Sustainable Development Goals.

The paper offers relevant contributions: comparative analysis between technological indicators and SDG indicators for all EU countries; three regression models explaining the relationship between innovation, digital human capital, AI readiness and progress on the SDGs; economic interpretation of the results, with implications for public policies, companies and education. For public policies, these conclusions highlight the need to expand digital infrastructure, vocational training programs – both basic and advanced – and support technological transition in all regions. For the business environment, the conclusions suggest accelerating the adoption of emerging technologies, especially in low-productivity sectors, but also continued investment in developing employee skills. The education system needs to update the curriculum, strengthen digital literacy programs for adults and reduce disparities between regions and generations.

The paper shows that emerging technologies have an important role in the economic and social transformation of EU Member States. Investments in innovation, digital human capital and technological infrastructure are essential for a competitive and resilient economy. Although there are still differences between countries, the general direction is positive, and European policies support a progressive transition towards a more balanced digital society. The results can form the basis for future analyses and public and organizational strategies oriented towards sustainable development.

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