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ORIGINAL SCIENTIFIC PAPER

Empowering Sustainable Growth Through Emerging Technologies in Serbia and North Macedonia

Kristina Velichkovska[1] | **Petar Mitić**[2*] | **Milena Kojić**[2]

[1] International Balkan University, Skopje, North Macedonia
[2] Institute of Economic Sciences, Environmental Economics Department, Belgrade, Serbia

ABSTRACT

This study explores the perceived economic, social, and environmental impacts of emerging technologies (including artificial intelligence, IoT, and big data) on sustainable growth in Serbia and North Macedonia. Drawing on survey responses from participants across professional sectors, the analysis employs descriptive statistics, Mann–Whitney U, and Kruskal–Wallis H tests to assess motivational factors, barriers to adoption, and sectoral differences. Findings indicate that innovation an competitiveness are dominant motivators, especially in North Macedonia, while high costs, skill shortages, and limited awareness remain key barriers. Economic benefits such as cost savings and operational efficiency are widely recognized, though environmental outcomes, particularly renewable energy adoption, are less developed. Sectoral comparisons reveal that business organizations lead in benefit realization, whereas government entities lag behind. The study highlights the need for context-specific policies and inclusive digital strategies to ensure that the adoption of emerging technologies supports long-term, sustainable development across varying institutional and sectoral environments.

Keywords: *emerging technologies, digital transformation, dustainable development, Innovation, Serbia, North Macedonia, technology adoption, environmental sustainability*

JEL Classification: O33, O38, O57, Q01

INTRODUCTION

In the era of fast-moving technological advances, enormous opportunities are opened for both economic and sustainable development. The growing uptake of emerging technologies, including 5G, the Internet of Things (IoT), artificial intelligence (AI), and data analytics, is revolutionizing industries, improving resource use, and enabling enhanced sustainability efforts. Businesses are increasingly accepting them as important in making efficient environmental changes: enterprises all over the world apply them to decrease their carbon emissions and put greener business practices into action. As found by a survey conducted by Ernst & Young, 76% of polled enterprises claimed that emerging technologies played a vital role in cutting their organization's carbon emissions, representing a significant move toward the integration of digital tools in corporate sustainability strategies (Baschnonga, 2023). Companies investing in 5G, IoT, and AI are already enjoying several benefits, such as “greater operational efficiency, improvement measurement capabilities, and the adoption of virtualized products and processes” (Baschnonga, 2023). Additionally, these technologies could enable companies to manage energy use and waste more

* Corresponding author, e-mail: petar.mitic@ien.bg.ac.rs

efficiently. According to the same survey, the polled enterprises consider reduced energy use to be the highest benefit from the deployment of digital technologies, followed by improved measurement and planning, as well as waste reduction in production. Digital tools are progressively taking center stage in corporate sustainability programs that have accelerated with the push toward virtual services and digital workforce solutions (Baschnonga, 2023). This is a trend that reflects digitalization as evolving from an efficiency tool to a critical part of environmental responsibility.

However, enterprises remain acutely aware of the risks and trade-offs posed by digital transformation. Of the businesses surveyed, 54% believe that emerging technological innovations can aid the growth of their sustainability agenda. Whereas another 41% regard such innovations as being largely positive but recognize them with some potential risks (Baschnonga, 2023). With a sense of caution, these sentiments broadly align with other research indicating that the information and communication technology (ICT) sector alone is responsible for anywhere between 1.8% and 2.8% of total global greenhouse gas emissions, plus a huge consumption of electricity (Baschnonga, 2023). Thus, digitalization does hold effective solutions; however, they should also pick up measures to reduce such impacts on the environment as well. By embedding emerging technologies into sustainability programs, companies can better measure and manage emissions, optimize resources in their processes, and be more circular and efficient in their operations.

This will be very much needed to make Serbia and North Macedonia change paradigms, where balancing economic growth against ecological responsibility remains a big task. Governments, the business community, and higher education institutions need to come together to demonstrate that digital transformation may not be mutually exclusive to long-term sustainability goals, but rather a conduit for technology-driven innovation that 1) generates an inclusive, 2) green, and 3) resilient economic development.

This paper looks at the relationship between the adoption of emerging technologies and sustainable economic growth in Serbia and North Macedonia. By analyzing industry trends and potential impacts, this study provides insights into how these economies can leverage technological advances in achieving sustainable and innovation-led growth.

THEORETICAL FRAMEWORK

For a long time, economic growth theories have recognized the role that technology has in driving productivity and economic growth. Neoclassical growth models, for example, suggest that technological progress enhances productivity and provides for long-term economic growth (Solow, 1956). Similarly, endogenous growth models, such as those by Romer (1990) and Lucas (1988), see human capital investment, innovation in technology, and knowledge accumulation as the basic forces underlying sustained economic growth. In this context, technological improvements, particularly in information and communication technology (ICT), serve as the means to promote efficiency gains and thus economic growth.

Over the past six decades, the world economy has witnessed a shift from the traditional labor-intensive production phase to the capital-intensive and ICT-driven phase. From the rise of modern computing in the 1990s, through the advent of the Internet, to the recent surge in the popularity of artificial intelligence (AI), the way goods are produced and companies operate has continuously evolved (Gonzales, 2023). Zeira (1998) elaborated an economic growth model that specifically addresses technological innovations that require reduced labor input but, at the same time, higher capital investment. This transition goes in line with empirical findings indicating that digitalization and emerging technologies inject economies of scale into their operations that reduce costs and raise efficiency (Nightingale, 2000; Wang et al., 2011; Nchake & Shuaibu, 2022).

Endogenous growth models are at the heart of the technology and economic growth literature. Arrow (1962) assumes that technical change, a product of knowledge and experience, gets embodied in new physical capital. It enters the production process, resulting in increased productive efficiency. The lines of thought in the technology and growth literature follow suit by assuming that technological change creates an increase in capital productivity. In the Schumpeterian tradition, Zeira (1998) presents a theoretical framework that has intermediate goods in production. The intensity of capital is increased with technology adoption, thus labor is substituted in the production process. Thereafter, technology is adopted when it increases output. Since some technologies require more capital inputs, some countries may not be able to continue on the technological frontier. Thus, the technology disparities between nations translate into differences in total output and productivity.

At the same time, Acemoglu and Restrepo (2018) have constructed a "task-based" framework treating automation and the creation of new tasks as types of technological innovation. There are, in fact, technologies necessary to complement one another if output or productivity is to improve. Acemoglu and Restrepo (2018) first assumed that all tasks could actually be performed by labor, while "lower-indexed" tasks could automatically be automated; however, automation is capital-intensive, raising the share of capital and reducing the share of labor. But more sophisticated tasks are created, where labor has a comparative advantage. In the long run, there is stability and a balanced growth path along which the two innovations coexist and grow, allowing for the same rate of growth.

The above-mentioned theoretical works perform well to illustrate the relationship of modern science with developments in ICT and economic growth. Yet, there are still inadequacies in more recent forms of technological innovation brought by AI and machine learning. This can be due to the unavailability of data, both at the firm level and at the macro level, especially when analyzing long-run growth. However, this study is an attempt to address such literature gaps within the limits of data availability. The number of patents and scientific journals is commonly used as a measure of technological innovation in empirical studies. In the Schumpeterian sense, patent possession signifies monopoly rent accruing from the creation of a new technology. Firms, therefore, pursue rights to exclusivity over these monopoly rents; through invention and the generation of new technologies, they modify outdated infrastructure. This phenomenon is thus termed creative destruction. So, when new technologies are developed, they increase the productivity of firms by enabling them to achieve increasing returns to scale in the process. Consequently, patents may be interpreted, in this context, as a reflection of greater productivity in conjunction with the effort. Patents stand as a sign of higher production and, of course, higher national growth. In standard growth models, technological progress represents the arrival of knowledge, and knowledge is accumulated as a consequence of constant R&D endeavors. Using panel data estimation and data from Latin American economies, Kim and Lee (2015) found a negligible impact of scientific knowledge, with patents being significant and positively related to economic growth.

Numerous studies examining patents and growth generally reach similar conclusions (e.g., Lach 1995; Sinha 2008; Kim et al. 2012). Wong et al. (2005), modeling innovation and entrepreneurship alongside economic growth, showed that patent grants, used as an indicator of innovation, have a significant and positive effect on country growth rates. Yet, recent studies such as Sweet and Eterovic (2019) and Blind et al. (2022) have found no important effect of patents on economic growth. In another recent study, Nguyen and Doytch found a positive and significant effect of total patents on economic growth for high economies, while for lower economies, the effect of this variable related to technology diminishes. Additionally, ICT patents contribute to economic growth only in high-income economies. Also, they established that total patents in the long run are never significant in any area, while ICT patents stay positive and significant.

While growth theories provided the rationale for understanding technological progress, modern literature explores ways in which DT intertwines with sustainability. AI, IoT, and 5G have become increasingly recognized as sustainability enablers that facilitate business in optimizing resource utilization, enhancing operational functionality, and eventually transforming into virtualized processes that play into sustainability objectives. While these digital tools may have many other contributions, one aspect explored by many scholars is the transparency and accountability provided by digital transformation. Businesses are able to monitor their environmental footprint in real time through AI and IoT, thereby aligning operations with sustainability principles (Kristoffersen et al., 2020). Such integration specifically advocates for sustainable development goals (SDGs) by enhancing the efficient utilization of natural resources, minimizing waste, and fostering responsible consumption and production via digital technologies (Rejeb et al., 2022). Applying strategies of net-zero economy models by Stern and Valero (2021) signifies how digitalization can be engaged to ensure overall environmental and economic sustainability in the long run.

This paper approaches economic growth theoretically from a neoclassical and endogenous perspective, which seeks to explore the role of technological advancement as it propels productivity and economic growth. While traditional models link technology to growth, modern sustainability literature often frames the challenge using the Environmental Kuznets Curve (EKC) hypothesis, which posits that environmental degradation initially rises with economic growth before declining at higher income levels (Mitić, Kresoja, & Minović, 2019). This paper expands these theoretical frameworks since the study shows the importance of artificial intelligence and other digital innovations affecting economic, social, and environmental sustainability. By enhancing efficiencies, optimizing resource use, and boosting long-term resilience, emerging technologies contribute to sustainable economic growth and tackle broader sustainability challenges. Thus, this study aims to answer the following research questions:

1. How do emerging technologies influence sustainable economic growth?
2. What are the economic, social, and environmental impacts of emerging technologies?
3. To what extent do emerging technologies contribute to achieving long-term sustainability goals, including resource efficiency, carbon footprint reduction, and social inclusion?

LITERATURE REVIEW

The effect of emerging technologies on economic, social, and environmental sustainability has attracted increasing academic research. The existing literature investigates various dimensions of technological advancements and their implications for the broader foundational categories of sustainable development, focusing on artificial intelligence (AI), Internet of Things (IoT), blockchains, and big data analytics. In this section, major findings of the previous studies are synthesized under these three categorizations: economic sustainability, social sustainability, and environmental sustainability.

Emerging Technologies and Economic Sustainability

Economic sustainability refers to ways in which economies and businesses can maintain growth with continued long-term productivity and resilience. Traditional economic theory, explained by Solow (1956) and Romer (1990), established the fact that technological development has always been at the heart of economic growth. Recent empirical studies pinpoint that digital technologies have made significant contributions to improving economic efficiency and even encouraging invention.

For example, Brynjolfsson and McAfee (2014) suggest that AI and automation boost productivity by optimizing workflows while lowering operational costs. AI contributes to economic growth through both the supply side (by automating work and enhancing labor productivity) and the demand side (by allowing for enhanced personalization and quality of goods and services) (Rao and Verweij, 2017). Thus, it is estimated that artificial intelligence will contribute about $15.7 trillion to the global economy by 2030. Lu (2021) further proposes a theoretical framing correlating AI to the growth of human capital. This framework is significant in demonstrating that AI can become a scalable production input due to its ability to learn and accumulate knowledge. Empirical studies investigating the economic effects of AI have been few in number, mainly due to the absence of data (Gonzales, 2023). Still, existing studies have pointed to a positive relationship between AI and growth. He (2019) examined the impact of AI on regional economic growth in China, using ICT investment as a proxy for AI adoption, while Fan and Liu (2021) confirmed the role of AI in advancing sustainable economic growth across Chinese provinces. Yang (2022), in a similar context, looked into productivity and employment at the firm level in Taiwan, demonstrating that both AI and non-AI patents contribute to total factor productivity. Interestingly, Yang discovered that AI technology has a comparatively larger impact on industrial capital than on labor productivity, confirming previous theoretical discussions on the same by Arrow (1962) and Zeira (1998).

However, this optimistic view has often been contrasted with the lack of empirical evidence explaining the contribution of ICT to economic growth, primarily in the case of developing countries. According to Niebel (2014), much of this uncertainty arises from the lack of high-quality micro and macro-level datasets on ICTs in these economies. The World Bank (2012) took an optimistic view: "Information and communication technologies (ICTs) have great promise to reduce poverty, increase productivity, [and] boost economic growth." However, there are compelling reasons for skepticism regarding the application of ICT that are valid a priori. Developing economies maintain limited absorption capacity, such as human capital and complementary factors like research and development (R&D) expenditures, which prevents them from harnessing ICT investments.

Conversely, some scholars suggest that emerging markets could leapfrog traditional development paths by registering digital solutions that circumvent traditional productivity-boosting methods (Steinmueller, 2001). In these contexts, ICT-related spillovers and network effects, which reduce transaction costs and accelerate the diffusion of knowledge, may yield greater results when a critical mass of firms in a specific region or industry adopts similar levels or types of ICT. Empirical studies conducted in developed economies have yielded equivocal results concerning the relationship between ICT and productivity. Stiroh (2002) originally found a negative output elasticity for ICT capital in U.S. manufacturing data from 1984 to 1999; however, later revisions (Stiroh, 2005), citing newer data, found positive ICT capital coefficients. Other studies by O'Mahony and Vecchi (2005) and Dimelis and Papaioannou (2011) confirmed a significant contribution of ICT capital to output growth in the UK and in the US. Dahl et al. (2011) enlarged the scope of the inquiry to eight European economies, using EU KLEMS data, contributing further to the argument that ICT investments would bring positive magazine performance.

Moreover, in a similar vein, Acemoglu and Restrepo (2018) unearth task displacement and task creation, showing that while automation obviates certain jobs, it creates economic opportunities and industries. As such, Saberi et al. (2019) demonstrate that the integration of blockchain technology in supply chains raises their economic effectiveness through improved transparency and decreased transaction costs. In addition, studies conducted by Wang et al. (2011) and Nchake & Shuaibu (2022) further highlight the achievement of economies of scale through the digitalization of firms.

As far as this topic is concerned in terms of Western Balkan countries, Levkov and Kitanovikj (2024) studied the level of digital, computer, and other skills in evaluating data, information, and digital content, comparing it with that of the EU region. In the WB context, Serbia has almost converged with the EU average in areas of computer skills, while North Macedonia was ahead in skills for evaluating data, information, and digital content. The results indicate that currently, the higher the level of digital skills in WB countries, the greater the labor productivity and GDP per capita. We explored the potential relation between the level of digital skills of the countries in WB and their economic performance, measured through labor productivity and GDP per capita for 2023. In this age of AI, a higher level of digital skills of the WB country's population suggests greater labor productivity value. They then investigated the relationship between the level of digital skills in WB countries and their economic performance, with GDP per capita as the measure for the year 2023. They also found a correlation (R2 = 0.74409) between digital skills and GDP per capita, akin to labor productivity.

Emerging Technologies and Social Sustainability

Social sustainability promotes fair and equal distribution of benefits from technological innovation, workforce flexibility, and digital inclusion. Studies show that integrating emerging technologies within the traditional scope of education, healthcare, and jobs can be transformative. While West (2018) states AI-enabled educational platforms enable personalized learning to greater access by diverse populations, Chui et al. (2016) found automated healthcare to improve service delivery, specifically by enhancing diagnostic accuracy and remotely monitoring patients. These trends witnessed a significant boom during the coverage of COVID-19, as AI-based telemedicine platforms helped to ease pressure on healthcare systems while allowing continuity of care (Topol, 2019). But mixed feelings arise regarding job displacement and digital inequality. Frey and Osborne (2017) elucidate that such increased automation may have disproportionate effects on low-skilled workers. This calls for targeted policies for workforce reskilling and digital literacy programs. Bessen (2019) draws attention to the necessity for governments and organizations to adopt the following substantive strategies to avert technological unemployment and promote inclusive growth.

Emerging Technologies and Environmental Sustainability

The environmental impact of emerging technologies is a critical area of study, with particular reference to energy efficiency, carbon emissions, and resource management. Emerging research shows both positive and negative effects. Kristoffersen et al. (2020) and Rejeb et al. (2022), for instance, point to AI, IoT, and data analytics, enabling companies to optimize energy consumption, reduce waste, and do predictive maintenance with, consequently, significant environmental benefits. The smart cities concept, driven by IoT and big data, attracts much interest as a model for sustainable urban development, as demonstrated in Batty et al. (2012) and Angelidou (2017). On the contrary, Koomey et al. (2011) inform that higher computing power for AI, blockchain, and cloud services means higher electricity consumption. Thus, the sustainability of digital transformation actually depends on transitioning to green computing practices and using energy-efficient technologies. Technology-related policies such as carbon pricing and investment in renewable energy are critical for decent progress in mitigating the environmental footprint of digitization, according to Stern and Valero (2021).

TECHNOLOGICAL LANDSCAPE IN SERBIA AND NORTH MACEDONIA

Over the last few years, advancements in technology have been one of the most important factors influencing global economic development, competitiveness, and innovation. Serbia and North Macedonia, two emerging economies in Southeast Europe, have made important progress in developing national technological ecosystems. This section provides a brief overview of each country's progress in key areas such as human capital, digital connectivity, government policy, infrastructure, and investment in research and innovation, with particular focus on the adoption of digital technologies.

Human Capital and Digital Skills

Serbia and North Macedonia understand the role of human capital in facilitating technological change. Serbia has a fairly well-established ICT workforce of about 80,000 people, while North Macedonia has been steadily increasing its digital talent pool. Having skilled professionals in information and communication technologies (ICT) is the result of investments in education and the workforce. Universities and vocational training centers in both countries provide specialized programs in software development, data science, and cybersecurity. This is a response to the increasing demand for digital savvy experts. Senior professionals are now helping young people to broaden their experience and assist in start-up & other projects owing to the increase in incubators and hubs. Serbia's 'Digital Serbia Initiative' and North Macedonia's 'Smart Specialization Strategy' are improving digital skills and boosting investigations into new 'emerging' technologies.

Digital Connectivity and Integration of Digital Technology

Both countries have taken significant steps towards strengthening digital connectivity. The Internet penetration in Serbia is greater than 80%, closely followed by North Macedonia at approximately 79%. High-speed broadband penetration has increased, supported by infrastructure investments and regulatory reforms. Both Serbia and North Macedonia widely use 4G networks and are now preparing for 5G deployment. Many businesses and consumers are more frequently using digital tools, e-commerce, and fintech, which is making the digital economy more vibrant. Yet, the rural areas of both countries are struggling with connectivity issues which must be resolved.

The use of digital technology is at the center of economic transformation in both countries. In North Macedonia (NM), the use of big data stands at 13%, which is higher than the Western Balkans (WB) average. On the other hand, 10% use cloud and AI. However, only 26% of SMEs have a basic level of digital intensity, below the WB average of 35%. The level of e-commerce is notably low, with only 9% of SMEs selling online and 1% engaging in cross-border e-commerce. National strategies such as the Economic Reform Program (2021-2023) or the Strategic Plan of the Ministry of Information Society and Administration (2021-2023) incorporate the digital transformation agenda. Though long-term strategic documents like the ICT Strategy (2021-2026) have not yet been adopted and the National Strategy for Artificial Intelligence is being developed (Tintor et al., 2022).

Though Serbia has made some progress in the digital front, it still faces challenges regarding digital adoption. Only 22% of businesses use enterprise resource planning (ERP) systems for the electronic exchange of information, and 16% do so on social media (both below WB averages). Advanced digital technology uptake is low, as just 1% of enterprises use AI and 4% make use of big data. Cloud computing is adopted more readily than before. The percentage of enterprises using cloud solutions is 22%. This is higher than 16% which is the WB average. Almost 50% of Serbian SMEs reach at least a basic level of digital intensity, indicating that they are more digitally intensive than their competitors. E-commerce uptake is also more advanced, as 26% of SMEs sell online, although e-cross-border commerce is still very limited to 3 percent (Tintor et al., 2022).

Serbia has started using various strategic policies to speed up its digital transformation. The goal of the Industrial Policy Strategy (2021-2030) is to utilize the available means and resources for industrial digitalization, financial incentives, and education programs (for digital skills). North Macedonia, on the other hand, developed a National Strategy for SMEs (2018-2023) and, in turn, put forward key digital laws that would facilitate e-governance and online services.

Government Policies and Strategic Initiatives

Both the governments in Serbia and North Macedonia have taken steps to enable digital transformation. While North Macedonia has its own 'National Strategy for Digital Transformation' focusing on e-governance and cybersecurity, Serbia wants its 'Strategy for the Development of Artificial Intelligence 2020-2025' to position itself as a leader in artificial intelligence research and applications. Strategies at the national level pertaining to digitalization, e-governance, and cybersecurity have been devised to enhance the efficiency and security of public administration and the private sector. Reforms to facilitate business registration and tax administration, as well as e-government services, have improved the ease of doing business. Further, there are tax concessions and grants for foreign direct investment (FDI) in the technology sector. This focus is critical, as a high quality of government, specifically the Rule of Law and political stability, has been proven to significantly and positively influence the attraction of foreign direct investments in Southeastern European countries including Serbia and North Macedonia (Jovanović, Domazet, & Marjanović, 2023). Government officials are also prioritizing the digitization of educational and health facilities for the citizens.

Infrastructure Development

Infrastructure investment has been a priority for enhancing digital and technological capabilities in the two countries. Serbia is strongly investing in its National Broadband Plan, which aims to enable high-speed internet access for all households by 2025. Similarly, North Macedonia has invested in fiber-optic networks to promote digital inclusion as well as in the upgrade of fiber-optic networks, data centers, and cloud computing services. Smart city projects and digital public services have also been developed. However, investment should continue in order to outpace the urban-rural digital divide and scale up cybersecurity measures. Both governments are looking to partner with the private sector to enhance 5G roll-out and build digital infrastructure even further.

Investment in Research, Innovation, and Digitalization

Serbia and North Macedonia have been investing in research and innovations with the help of national governments and international organizations. Serbia invests about 0.9 percent of its GDP in R&D, while North Macedonia invests 0.4 percent. There was an opportunity for innovation and science and technology thanks to innovation funds, research grants and cooperation with the EU's Horizon programs. Tech startups and research facilities in areas like AI, Blockchain and Biotech are emerging, creating a more innovative ecosystem. However, we must boost private participation in research and industry-academy cooperation efforts. The key industries (manufacturing, logistics, agriculture, etc.) are undergoing digitalization, which is improving, but further investment is needed to fully utilize Industry 4.0 technologies. Although these technologies can significantly raise productivity and competitiveness, the rates of adoption of automation, IoT applications, and AI growth vary across sectors. More financial incentives and policy support will be crucial to ensure that the digital transformation of the economy reaches all sectors.

DATA AND METHODOLOGY

The research employed a quantitative survey-based design to investigate the adoption of emerging technologies and their associated economic, social, and environmental impacts across sectors in Serbia and North Macedonia. The study was based on responses from 81 participants, following data cleaning procedures applied to the initial sample. Data were collected through an online structured questionnaire targeting ICT professionals, academics, policymakers, and other relevant stakeholders, over the period from 15 December 2024 to 31 January 2025.

The analysis was conducted using both descriptive and inferential statistical methods. Descriptive statistics included frequencies and percentage distributions to capture the demographic and professional profiles of respondents. Inferential statistics were applied to assess variations in technology-related perceptions and motivations. Specifically, the Mann–Whitney U test was used to compare economic, social, and environmental motivations and barriers across groups, while the Kruskal–Wallis H test was employed to examine differences in perceived benefits of emerging technologies across various sectors. All statistical processing and visualization were conducted using Microsoft Excel and the R programming environment.

The collected data were analyzed using appropriate nonparametric statistical methods based on variable characteristics and distribution patterns. Categorical variables were presented as frequencies and percentages.

For comparing two independent groups, the Mann-Whitney U test was employed as it effectively evaluates distribution differences without requiring normality assumptions. The Kruskal-Wallis H test, extending this rank-based approach to multiple groups, was utilized when comparing three or more independent groups, assessing significant distribution differences without assuming normal distribution or variance homogeneity.

Associations between categorical variables were examined using the Chi-square test of independence, which evaluates significant relationships by comparing observed frequencies against those expected under independence assumptions.

It must be noted that, while the sample of this survey offered insightful findings into sectoral differences, it does not completely reflect the population at large. Most of the respondents came from an academic and urban context, which may limit the generalizability of the findings to other sectors and experiences in rural areas. Therefore, caution should be taken when applying findings to the national level. Future research should strive to have a larger and broader sample to improve external validity and offer more perspectives.

RESULTS AND DISCUSSION

Table 1 presents the demographic and professional profile of the 113 survey respondents. The majority of participants were between 25 and 54 years of age, with the largest group aged 25–34. Most respondents were from North Macedonia (54%) and held postgraduate qualifications, with nearly half holding a PhD. Gender representation was balanced, with a slight majority of female participants. A large proportion of respondents (79%) had personally adopted emerging technologies, while 51% indicated their organization had done so. Most were employed in medium-sized organizations and in urban areas. The academic and research sector accounted for the largest share (49%), followed by the ICT sector (27%). Since the majority of respondents were based in urban areas, and almost half of all respondents were connected to academic or research institutions, responses may have been impacted by this composition, especially in regards to awareness, motivation, and perceptions of sustainability-related outcomes, which may have varied in samples that were more focused on the government or industry.

Table 1. Descriptive statistics

Dimension	**Summary**
Age	18–24 (6%); 25–34 (33%); 35–44 (22%); 45–54 (25%); 55–64 (11%); 65 and above (3%)
Country	MK (54%); RS (46%)
Education	High School (9%); Bachelor's Degree (20%); Master's Degree (25%); PhD candidate (1%); Doctorate (PhD) (44%); Post-Doctoral (1%)
Gender	Female (52%); Male (44%); Prefer not to say (4%)
Org Tech Adoption	Organization adopted (51%)
Organization Size	Micro (<10) (15%); Small (<50) (17%); Medium (50–250) (48%); Large (>250) (20%)
Personal Tech Adoption	Personally adopted (79%)
Residential Area	Urban (88%); Rural (12%)
Sector	Academic/Research (49%); Business organization (1%); Government (12%); ICT Sector (27%); NGO (11%)
Specific Tech Adoption	Artificial Intelligence (AI) (88%); Internet of Things (IoT) (51%); 5G (37%); Big Data (35%); Blockchain (10%); Smart Farm Implementation (2%)

Dimension	Summary
Tech Adoption Awareness	Yes (59%); No (19%); Not aware (22%)
Work Experience	<1 year (1%); 1–5 years (38%); 6–10 years (22%); 11–15 years (14%); 16–20 years (11%); 21–25 years (6%); >26 years (8%)

Source: Authors` calculation.

Artificial Intelligence (88%) was the most commonly adopted technology, while awareness of emerging technologies was relatively high (59%). Work experience was well distributed, with the largest group having between 1 and 5 years of experience.

Overall, 59.3% of respondents indicated personal awareness of emerging technologies, while 18.5% reported no awareness, and an additional 22.2% expressed varying degrees of unfamiliarity (18.5% unaware of adopted technologies and 3.7% unaware of any emerging technologies). When comparing countries, awareness was higher among respondents from Serbia, where 67.6% stated they were personally aware of emerging technologies, compared to 52.3% in North Macedonia. Conversely, a higher proportion of respondents in North Macedonia (25.0%) reported no awareness, compared to 10.8% in Serbia, see Figure 1. Despite these differences, the Chi-square test indicated that the association between country and awareness was not statistically significant ($\chi^2 = 3.169$, $p = 0.366$). These results suggest that while there are observable differences in awareness levels between the two countries, they are not strong enough to infer a significant association statistically.

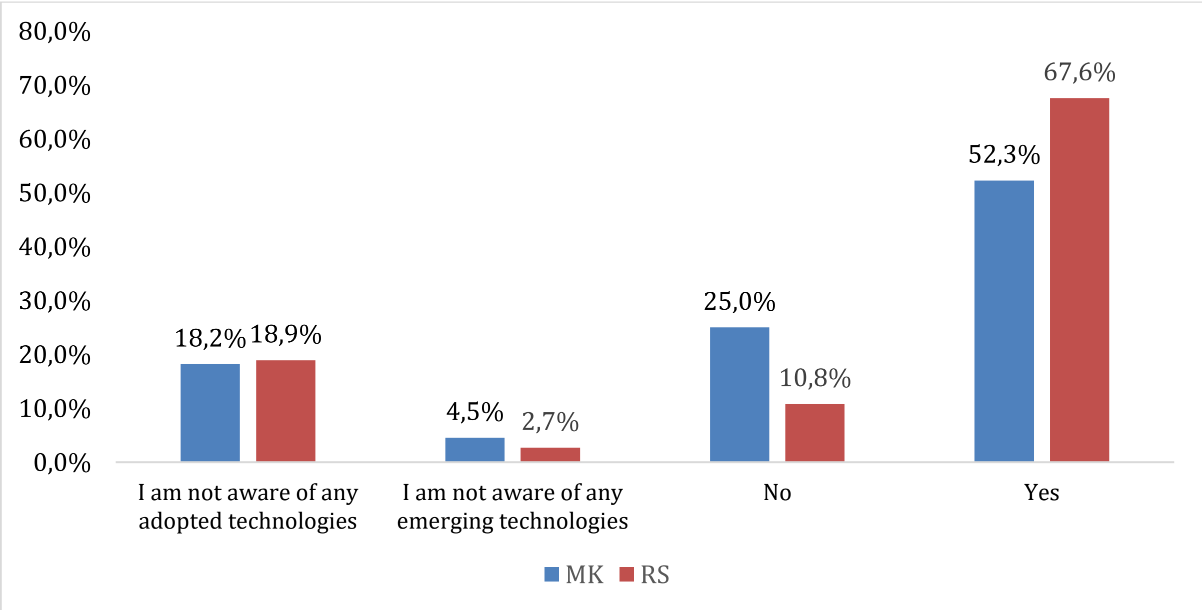

Figure 1. Have you personally, or the organization you work for, adopted any emerging technologies? (e.g., AI, Blockchain, IoT, 5G, Big Data, etc.)

Motivation and Challenge Ratings

The distribution of motivation ratings (Table 2) reveals that the strongest drivers for the adoption of emerging technologies among respondents are related to driving innovation and digital transformation (44% rating "5 – very motivated"), gaining a competitive edge in the market (38%), and complying with sustainability-related regulations (42%). These findings suggest that market and innovation pressures represent more immediate incentives for engagement with new technologies than altruistic or long-term environmental goals. By contrast, motivations such as promoting social sustainability and advancing environmental sustainability received the lowest proportion of "very motivated" responses (both at 12%). This may reflect either the perceived difficulty in measuring these benefits or a lower prioritization of non-economic outcomes in respondents' operational settings.

Table 2. Distribution of Motivation Ratings

Rating	Enhancing economic sustainability	Promoting social sustainability	Advancing environmental sustainability	Gaining a competitive edge in the market	Driving innovation and digital transformation	Complying with sustainability-related regulations or policies	Complying with sustainability-related regulations or policies
1	6%	10%	16%	10%	4%	8%	16%
2	8%	14%	12%	10%	8%	6%	16%
3	22%	26%	36%	22%	22%	22%	28%
4	36%	38%	24%	20%	22%	22%	26%
5	28%	12%	12%	38%	44%	42%	14%

Source: Authors` calculation.

To test for differences in motivation between Serbia and North Macedonia, Mann–Whitney U tests were conducted across all motivation categories. The analysis revealed two statistically significant differences: gaining a competitive edge in the market ($p = 0.036$) and driving innovation and digital transformation ($p = 0.020$). In both cases, the results indicate higher motivation levels among respondents from North Macedonia compared to their Serbian counterparts. These results suggest a stronger market-driven and innovation-oriented technology adoption context in North Macedonia, potentially reflecting national policy incentives, sectoral dynamics, or institutional support systems. A third variable - supporting research, education, and knowledge - approached significance ($p = 0.051$), suggesting a marginal difference that may become statistically significant with a larger sample size or longitudinal data.

Table 3. Mann–Whitney U Test Results for Motivation Ratings

Motivation Category	Mann-Whitney U	p-Value	Significance
Enhancing economic sustainability	267.5	0.383	Not significant
Promoting social sustainability	308.5	0.968	Not significant
Advancing environmental sustainability	232.5	0.116	Not significant
Gaining a competitive edge in the market	207	0.036	Significant
Driving innovation and digital transformation	197.5	0.020	Significant
Supporting research, education, knowledge	215	0.051	Marginal
Complying with sustainability-related policies	242.5	0.174	Not significant

Source: Authors` calculation.

Conversely, there were no significant cross-country differences for motivations related to enhancing economic, social, or environmental sustainability, nor for complying with sustainability-related regulations. These findings indicate a shared baseline appreciation for sustainability as a value, but one that is not strongly differentiated by national context. The data suggest that competitive positioning and innovation ecosystems are the most differentiating forces in technology adoption between Serbia and North Macedonia. Meanwhile, motivations linked to sustainability, though present, are more evenly distributed, implying a common normative recognition rather than a context-specific strategic driver.

The distribution of challenge ratings (Table 4) indicates that the most prominent barriers to adopting emerging technologies are related to human capital limitations and financial costs. Specifically, the highest shares of "very significant challenge" responses were recorded for lack of skilled personnel (24%), limited understanding of potential benefits (22%), and high costs (20%). Conversely, the lowest ratings were observed for resistance to organizational change (12%), lack of infrastructure or technological support (16%), and regulatory or compliance issues (14%). These findings suggest that respondents perceive cognitive and capability-related barriers as more pressing than structural or institutional ones—possibly reflecting a degree of organizational readiness or a stable regulatory environment.

Table 4. Distribution of Challenge Ratings

Rating	High costs	Lack of skilled personnel	Resistance to change within the organization	Lack of infrastructure or technolo-gical support	Regulatory or compliance issues	Limited understanding of potential benefits
1	10%	6%	16%	8%	16%	18%
2	20%	18%	18%	22%	24%	18%
3	34%	30%	30%	26%	40%	22%
4	16%	22%	24%	28%	6%	20%
5	20%	24%	12%	16%	14%	22%

Source: Authors` calculation.

Mann–Whitney U test results (Table 5) revealed statistically significant differences between Serbia and North Macedonia for two challenges: high costs ($p = 0.017$) and limited understanding of potential benefits ($p = 0.038$). In both cases, further interpretation of the rankings indicates that respondents in North Macedonia experience these barriers more acutely. This likely reflects different levels of institutional support, financial resources, or exposure to innovation ecosystems. In addition, lack of infrastructure or technological support showed a marginally significant difference ($p = 0.063$), suggesting this may also represent a more prominent constraint in North Macedonia.

Table 5. Mann–Whitney U Test Results for Challenge Ratings

Challenge	Mann-Whitney U	p-Value	Significance
High Costs	191.5	0.017	Significant
Lack of Skilled Personnel	264.5	0.356	Not significant
Resistance to Change	269.5	0.412	Not significant
Lack of Infrastructure	218.5	0.063	Marginal
Regulatory/Compliance Issues	283	0.576	Not significant
Limited Understanding of Benefits	206	0.038	Significant

Source: Authors` calculation.

In contrast, there were no statistically significant differences between countries regarding the perceived challenge of a lack of skilled personnel, resistance to change, or regulatory and compliance issues. This suggests that these are shared barriers across national contexts, possibly rooted in broader regional trends in workforce development, organizational culture, or institutional capacity.

Overall, the findings imply that tailored policy approaches may be warranted. In North Macedonia, targeted interventions such as subsidies, awareness campaigns, and workforce training could help overcome financial and knowledge-related obstacles. In Serbia, the emphasis may need to shift toward upskilling initiatives and long-term investment strategies to sustain digital transformation momentum.

Perceived Economic, Social, and Environmental Benefits of Emerging Technology Adoption

The results in Table 6 indicate that respondents widely recognized and experienced economic benefits from the adoption of emerging technologies, particularly in areas related to operational efficiency, cost reduction, and customer satisfaction.

Table 6. Economic benefits from adopting emerging technologies

Benefit	Do not know	Not at all	Slightly	Moderately	Extensively
Improved operational efficiency or faster processes (e.g., automated tasks, quicker decision-making)	18%	10%	14%	32%	26%
Reduced operational costs (e.g., reduced paper usage, energy costs, or staffing needs)	6%	6%	22%	34%	32%
Increased funding or revenue opportunities (e.g., new grants, funding from donors, or service fees)	12%	10%	20%	32%	26%
Enhanced ability to innovate or stay competitive (e.g., staying ahead of industry trends, developing	16%	10%	24%	28%	22%
Improved customer or stakeholder satisfaction and retention	10%	2%	20%	32%	36%
Better resource allocation or optimization (e.g., better use of time, materials, or funds)	16%	6%	10%	32%	36%
Streamlined reporting or administrative processes (e.g., automated forms, digital records management	12%	8%	18%	36%	26%
Improved financial planning and forecasting through data analysis tools	16%	8%	22%	36%	18%

Source: Authors` calculation.

The most extensively realized benefits include improved customer or stakeholder satisfaction (36%), better resource allocation or optimization (36%), and reduced operational costs (32% moderately, 32% extensively). These findings suggest that tangible, efficiency-driven improvements are the most visible and valued outcomes of technology integration. In contrast, benefits such as enhanced innovation capacity and improved financial planning were less frequently reported as extensively achieved, with only 22% and 18% of respondents respectively selecting the highest rating. This disparity points to potential barriers in leveraging technologies for strategic functions, such as innovation and predictive analytics, which may require more advanced capabilities, longer timeframes, or greater organizational maturity.

The data show that social benefits related to employee well-being are the most widely experienced outcomes of emerging technology adoption (Table 7).

Table 7. Social benefits from adopting emerging technologies

Benefit	Do not know	Not at all	Slightly	Moderately	Extensively
Enhanced support for employees (e.g., flexible work schedules, professional development opportunities)	10%	6%	16%	32%	36%
Improved accessibility or inclusivity (e.g., tools for remote work, features supporting individuals with disabilities)	8%	6%	28%	36%	22%
Strengthened relationships with external communities or stakeholders (e.g., engagement with local communities, collaboration with partner organizations)	12%	8%	20%	36%	24%
Expanded access to education, training, or public services (e.g., online platforms, e-learning tools, digital service delivery)	18%	6%	20%	28%	28%
Increased employee satisfaction or morale (e.g., greater job satisfaction from improved tools or work processes)	8%	4%	16%	36%	36%
Improved internal collaboration (e.g., enhanced teamwork through digital communication tools and virtual platforms)	12%	8%	20%	42%	18%
Greater transparency and accountability (e.g., improved progress tracking, clearer reporting of operations and goals)	8%	14%	22%	28%	28%
Empowerment of underrepresented groups (e.g., increased opportunities for women, minorities, or marginalized communities)	12%	20%	24%	24%	20%

Source: Authors` calculation.

Specifically, enhanced employee support and increased employee satisfaction or morale both received the highest share of "extensively experienced" responses (36%), indicating strong recognition of technology's role in improving job conditions and satisfaction. Other benefits, such as improved accessibility or inclusivity and strengthened relationships with external communities, were also commonly reported, though to a slightly lesser extent. Notably, internal collaboration tools were frequently cited as moderately beneficial (42%), yet fewer respondents rated them as extensively impactful (18%), suggesting only partial realization of their potential. Meanwhile, transparency and accountability and expanded access to education or public services showed moderate uptake, with balanced distributions across response categories. Empowerment of underrepresented groups received the lowest scores, with only 20% indicating extensive benefits, reflecting that diversity-focused outcomes may be underdeveloped or deprioritized. Overall, while social benefits tied to internal human resources are well established, broader inclusion, transparency, and external collaboration remain areas with room for strategic enhancement and future investment.

The findings on environmental benefits from emerging technology adoption (Table 8) suggest that resource efficiency and logistics optimization are the most consistently recognized outcomes.

Table 8. Environmental benefits from adopting emerging technologies

Benefit	Do not know	Not at all	Slightly	Moderately	Extensively
Reduced physical resource use in operations (e.g., less paper, materials, or energy consumption)	8%	11%	25%	38%	18%
Lower energy consumption from efficient processes or remote work	15%	11%	32%	36%	6%
Reduced carbon emissions (e.g., from reduced commuting, automation, or clean energy transitions)	18%	18%	22%	32%	10%
Adopted renewable energy sources (e.g., solar or wind energy for offices or data centers)	14%	40%	14%	24%	8%
Optimized logistics or transportation processes (e.g., fewer physical deliveries, better route optimization)	18%	27%	8%	32%	15%
Improved waste management efficiency (e.g., better recycling practices, digital waste monitoring)	19%	18%	23%	30%	10%
Implemented circular economy practices (e.g., material reuse, extending product lifecycle)	18%	19%	18%	30%	15%

Source: Authors` calculation.

Specifically, reduced physical resource use and lower energy consumption through efficient processes were among the most commonly reported benefits, with 38% and 36% of respondents respectively, rating them as experienced "moderately." However, extensive recognition remains limited, with only 18% or fewer respondents selecting the highest rating for any single environmental benefit. This indicates that while progress is evident, full realization of environmental outcomes remains in development. Notably, renewable energy adoption lags significantly behind other areas, with 40% of respondents reporting they have not experienced it at all, suggesting either limited infrastructure, financial constraints, or low prioritization of clean energy transitions. Similarly, benefits such as carbon emissions reduction, waste management efficiency, and circular economy practices were moderately acknowledged but rarely rated as extensively achieved, pointing to a potential gap between environmental aspirations and practical implementation. These results emphasize the need for stronger incentives and institutional support to translate technological capabilities into a more comprehensive environmental impact.

While these findings align with much of the existing international literature that has emphasized the positive economic and operational efficiency benefits of transformative digital organizational development (Brynjolfsson & McAfee, 2014; Song, 2025), they shed some doubt on the findings of other researchers who have found more neutral or even negative results regarding the aforementioned issues. Such studies, like Koomey et al. (2011) and Stern and Valero (2021), express concern that increasing energy consumption of new technology, ranging from AI to blockchain to cloud computing, may displace sustainability benefits without real commitment to a future green energy transition. Frey and Osborne (2017) and Bessen (2019) also highlight that technology-enabled automation may worsen job polarization and inequality in low digital inclusion and low retraining economies. In this sense, this study highlights a broader challenge in achieving environmental and inclusivity-related benefits within a rapidly growing digital transformation sector, highlighting the need for policy to integrate considerations of a green transition, promote equitable access to emerging opportunities across all sectors, and the responsibility of ensuring that innovation does not lead to permanent job loss in any economy.

Sector-Specific Impact of Technology Adoption

The Kruskal–Wallis H test results (Table 9) indicate statistically significant differences across sectors for both economic ($p = 0.016$) and social ($p = 0.021$) benefits derived from emerging technology adoption, with environmental benefits showing a marginally significant variation ($p = 0.097$). These findings confirm that the perceived impacts of technological adoption are not uniformly distributed but are influenced by the sectoral context.

Table 9. Kruskal-Wallis H Test Results

Dimension	Chi square	p-Value	Significance
Economic	12.120	0.016	Significant
Social	11.559	0.021	Significant
Environmental	7.846	0.097	Marginally

Source: Authors` calculation.

Descriptive statistics further clarify these differences (Table 10). Business organizations reported the highest levels of benefit across all three dimensions—economic (32.00), social (32.00), and environmental (28.00)—highlighting a broad and impactful engagement with emerging technologies in the private sector. In contrast, academia and research institutions showed strong outcomes in the social (23.58) and environmental (15.67) dimensions, while maintaining moderate levels of economic benefit (22.88). This pattern suggests that research-driven environments may prioritize long-term societal and sustainability goals more than immediate financial gains.

Table 10. Descriptive Statistics by Sector

Sector	Economic	Social	Environmental
Business Org.	32.00	32.00	28.00
Academia/Research	22.88	23.58	15.67
ICT Sector	20.25	19.06	13.69
NGO	16.20	16.00	11.20
Government	7.75	9.00	7.00
Overall Mean	20.34	20.38	14.14

Source: Authors` calculation.

The ICT sector demonstrated a relatively balanced focus, with moderate economic (20.25) and social (19.06) benefits, but a lower score on environmental outcomes (13.69), implying potential for further engagement in green digital strategies. NGOs placed emphasis on social sustainability (16.00) but recorded the lowest economic (16.20) and environmental (11.20) benefit levels outside of the government sector, reflecting their mission-driven focus and resource constraints.

Finally, government institutions consistently ranked lowest across all dimensions, particularly in economic (7.75) and environmental (7.00) domains, indicating limited realization of technological benefits. These findings highlight the need for targeted strategies and policy support to foster more equitable and effective adoption of technologies across different sectors.

CONCLUSION

This study highlights how emerging technologies are perceived to contribute to sustainable growth across different sectors and national contexts in Serbia and North Macedonia. The findings reveal that while economic benefits, such as cost reduction and operational efficiency, are broadly recognized, social and especially environmental impacts remain underdeveloped in practice. Innovation and competitive positioning drive adoption more strongly than normative sustainability goals, with significant cross-country differences suggesting that national policy frameworks and institutional support systems matter.

Barriers such as limited skills, high costs, and knowledge gaps remain persistent, particularly in North Macedonia, where financial constraints and lower organizational readiness were more frequently reported. Meanwhile, Serbia shows a stronger need for long-term investment and capacity building. Sectoral analysis confirms unequal realization of benefits: business organizations lead in impact realization, while government sectors lag significantly. This disparity underscores the importance of targeted policy design that reflects sector-specific conditions and national readiness.

To fully leverage the sustainability potential of digital transformation, both countries must reinforce cross-sector collaboration, support innovation ecosystems, and promote inclusive access to digital capabilities. Investments in skills development, renewable energy integration, and smarter regulation are essential to ensure emerging technologies become enablers—not obstacles—of a resilient and sustainable future.

This analysis raises a number of open questions for future study. Why are the environmental benefits from emerging technologies so much more under-realized, particularly in relation to public institutions and less digitally mature sectors, compared to the economic ones? How would we design inclusive and environmentally sound digital approaches to ensure that social and environmental benefits line up with economic ones? Answering these questions would require larger, longitudinal, and cross-institutional studies that would help us identify the mechanisms through which equitable and sustainable technological transformation occurs in different national and institutional contexts.

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