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LOW DIGITAL BUSINESS INTENSITY AS AN ENTREPRENEURIAL RISK FOR GREEN ENERGY STARTUPS IN THE EU

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Introduction. The European Union's ambitious climate targets under the Green Deal and REPowerEU plan have stimulated rapid growth in the renewable energy sector, positioning green energy startups as crucial agents of innovation and technological change. However, the capacity of these startups to develop, scale, and compete depends critically on the digital maturity of the business environment in which they operate. While considerable attention has been devoted to financial, regulatory, and technological risks facing green startups, the risk arising from the low digital intensity of the broader business ecosystem remains significantly underexplored in the academic literature (Jeffers et al., 2025; Jurgelevičius & Raišienė, 2025). Digital business intensity, measured by the adoption of cloud computing, big data analytics, artificial intelligence, e-commerce platforms, enterprise resource planning systems, and IoT-enabled processes across enterprises, constitutes a foundational element of the modern entrepreneurial ecosystem. The European Commission's Digital Economy and Society Index (DESI) provides comprehensive data on these dimensions across EU member states, revealing substantial cross-country variation that mirrors disparities in startup ecosystem performance (Kerner & Kitsing, 2023).

The purpose of this study is to examine low digital business intensity as a distinct category of entrepreneurial risk affecting the development of green energy startups within EU member states. The analysis draws on DESI indicators, Eurostat data on enterprise digitalisation, and startup density statistics from Dealroom and Crunchbase databases to identify patterns linking digital ecosystem weaknesses to startup formation and survival rates in the energy sector.

Data and Methods. The study is theoretical in nature and employs a combination of logical-structural analysis, comparative analysis, and systematic generalisation of the existing academic literature on digital transformation and green entrepreneurship. The research draws on the conceptual frameworks of ecosystem theory and institutional economics to analyse the channels through which low digital business intensity poses risks to green energy startups. The European Commission's DESI framework is used as a conceptual reference point for structuring the dimensions of digital intensity relevant to the energy startup ecosystem. The analysis synthesises findings from recent empirical studies on digitalisation and entrepreneurship to identify patterns and formulate propositions regarding the digital risk factors specific to the green energy sector.

Results. Theoretically, the relationship between digital business intensity and green startup development can be analysed through the lens of ecosystem theory and institutional economics. Digital technologies create network effects, reduce information asymmetries, and lower transaction costs within the entrepreneurial ecosystem, benefiting all participants, including startups, investors, corporate partners, and customers. When the broader business environment exhibits low digital adoption, these ecosystem-level benefits are diminished, creating a less fertile ground for technology-intensive ventures such as green energy startups (Meyer, 2024).

Evidence from cross-country comparisons indicates a statistically significant positive relationship between national digital business intensity scores and the density of clean energy startups. Countries in Southern and Eastern Europe, where enterprises lag in adopting advanced digital technologies, also demonstrate lower rates of startup creation in the green energy domain. Countries with advanced digital ecosystems, by contrast, combine high digital intensity with vibrant clean-tech startup sectors. This pattern persists even after controlling for differences in GDP per capita, venture capital availability, and support for renewable energy policy (Michalek, 2025; Sterea, 2023).

The risk of low digital intensity manifests through several interconnected channels. First, it weakens the startup ecosystem by limiting the network effects that digital platforms provide for knowledge sharing, talent acquisition, and market access. Startups in digitally lagging environments face higher costs for finding suppliers, customers, and collaboration partners, which directly impacts their burn rate and runway. Second, it reduces the digital readiness of potential corporate partners and customers, narrowing the addressable market for energy-tech solutions. Utilities and grid operators with low levels of digitalisation are less likely to adopt innovative digital energy solutions from startups, regardless of their technical merit (Miguel Olortegui-Alcalde & Cordova-Buiza, 2025).

Third, low digital intensity hampers the integration of distributed energy resources with smart grid infrastructure, which requires high interoperability and data exchange among market participants. Startups developing solutions for demand response, virtual power plants, peer-to-peer energy trading, or predictive maintenance rely on extensive digitalisation of the energy value chain. Where this digitalisation is absent, the entire category of digital energy business models becomes commercially unviable (Kolodiziev et al., 2024).

Fourth, low digital intensity creates an adverse selection effect: the most digitally ambitious founders may choose to locate their startups in digitally advanced countries, thereby reinforcing the innovation gap between EU member states. This brain and startup drain undermines the EU Green Deal's territorial cohesion objectives and exacerbates regional disparities in the energy transition. Empirical evidence from startup migration patterns confirms that founders in the energy-tech sector are significantly more likely to relocate to countries with stronger digital infrastructure.

The findings suggest that policymakers seeking to promote green energy startups should adopt complementary digital transformation strategies alongside traditional energy and innovation policies. Targeted interventions may include digital vouchers for SMEs in the energy value chain, public-private partnerships for building energy data platforms, investment in digital infrastructure in lagging regions, and cross-border digital innovation hubs. The EU's Digital Europe Program and Recovery and Resilience Facility offer financial instruments that could be strategically aligned with the promotion of green energy startups.

Furthermore, the study highlights the importance of measuring and monitoring digital business intensity as a component of startup ecosystem assessments. Current frameworks for evaluating green energy startup environments primarily focus on regulatory, financial, and human capital dimensions, with insufficient attention to digital readiness. Incorporating digital intensity metrics into ecosystem scorecards would enable more comprehensive risk assessment and more targeted policy interventions.

Conclusions. Low digital business intensity represents a systemic entrepreneurial risk that limits the formation, growth, and competitiveness of green energy startups across the European Union. Addressing this risk requires an integrated policy approach that bridges the digital and energy transitions, recognising that the success of green entrepreneurship is inextricably linked to the digital maturity of the broader economic environment. For EU member states in Central and Eastern Europe, including Ukraine as a prospective candidate country, closing the digital business intensity gap is a prerequisite for building competitive green energy startup ecosystems that can contribute to the continental energy transition.

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BIOBANKING OF GAMETES OF ENDANGERED ANIMAL SPECIES AS A PLATFORM FOR INNOVATION AND INTERNATIONAL COOPERATION IN THE FIELD OF ENVIRONMENTAL PROTECTION

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Introduction. Military hostilities on the territory of Ukraine have caused not only a large-scale humanitarian and economic crisis, but have also had a significant negative impact on protected natural areas and their biodiversity (Vincent et al., 2024). The destruction of zoos, farming and research parks, rehabilitation centers, and nature conservation facilities has resulted in the loss of, or critical threats to, populations of rare and endangered animal species, including those maintained *ex situ*. Under these conditions, gamete biobanking is gaining importance not only as a tool for preserving genetic material, but also as an innovative platform that integrates scientific research, biotechnological development, and state environmental policy (Kopeika et al., 2019). In accordance with the provisions of the Convention on Biological Diversity and the EU Biodiversity Strategy for 2030 (European Commission, 2020), the development of such platforms is considered a key mechanism for ensuring the long-term sustainability of biodiversity conservation programs in the context of global risks.

The aim of this study is to determine the role of animal gamete biobanking as an innovative interdisciplinary platform for biodiversity conservation under conditions of military and other global challenges, through the analysis of regulatory and legal frameworks, modern scientific approaches to the cryopreservation of reproductive material, and practical models of international biobank operation.

Data and Methods. The study is based on an interdisciplinary approach and includes analysis of international and European legal and regulatory act; a review of contemporary scientific publications addressing the cryopreservation of gametes and embryos in conservation programs for wild and semi-wild animals; a comparative analysis of European and international biobanks as infrastructural platforms for innovation and transnational cooperation.

Results. The analysis of regulatory and legal frameworks governing animal gamete biobanking in the context of biodiversity conservation under military risks revealed that, in accordance with Articles 8 and 9 of the Convention on Biological

Diversity (CBD, 1992), Parties are obliged to combine *in situ* and *ex situ* conservation measures, including the preservation of genetic resources. Although the CBD does not explicitly regulate gamete biobanking, it establishes a normative basis for the development of cryopreservation technologies as a legitimate tool for the long-term conservation of genetic material. In the context of armed conflicts, the Nagoya Protocol to the CBD plays a particularly important role by regulating access to genetic resources and the fair and equitable sharing of benefits. In cases of emergency collection and preservation of gametes from rare species in territories affected by military actions, a legal conflict arises between state sovereignty over genetic resources and the urgent need for their preservation. Current international law does not contain specific provisions addressing the biobanking of genetic resources in crisis or wartime conditions, indicating a significant regulatory gap. At the same time, CITES indirectly affects biobanking activities by regulating the cross-border movement of biological specimens. Gametes and embryos are only partially covered by the definition of "specimens," which creates practical difficulties in the international transport of cryopreserved material for conservation or population restoration purposes.

At the EU level, the EU Biodiversity Strategy for 2030 is a key strategic document that explicitly emphasizes the preservation of genetic diversity as the foundation of ecosystem resilience. Although the strategy does not detail specific biobanking instruments, it provides a political mandate for the development of genetic resource conservation infrastructures, including cryobanks. FAO guidelines on the conservation of animal genetic resources also play an important role, recognizing the cryopreservation of gametes and embryos as a core component of national and transnational conservation programs. These guidelines effectively legitimize biobanking as a standard practice, while leaving governance and management issues largely to national authorities. The European legal system currently lacks a unified regulatory framework that comprehensively governs the activities of animal reproductive material biobanks. Instead, regulation remains fragmented, dispersed across veterinary, biosafety, and transport legislation, and does not adequately address the specific needs of emergency situations, including armed conflicts.

Ukraine, as a Party to the CBD and other international environmental agreements, formally bears legal obligations to conserve biodiversity. However, current national legislation does not contain specific provisions regulating the establishment and operation of biobanks for gametes of wild or semi-wild animals.

We suppose that biobanks can operate as innovative platforms integrating scientific research in cryobiology, reproductive biology, and genetics; biotechnological development; transnational cooperation; and the implementation of state environmental policy. Gamete biobanking represents one of the most reliable tools for the long-term preservation of the genetic pool of endangered species. Unlike traditional ex situ animal maintenance, cryobanks are characterized by minimal dependence on physical infrastructure and the ability to operate under crisis conditions. Moreover, biobanks facilitate international exchange of genetic resources within existing legal frameworks, supporting joint research, restoration, and breeding programs. At the same time, the effective functioning of such platforms requires the identification of endangered species and breeds, systematic collection and cryopreservation of gametes and embryos, and their transfer to regional and national repositories. This activity is highly knowledge-intensive and resource-demanding, requiring highly qualified personnel, specialized equipment, and stable funding, thereby creating opportunities for engagement with the biotechnology sector and international investment programs. Integration of national biobanks into European networks strengthens interaction between science, public policy, and the innovation sector.

Conclusions. The biobanking of gametes from endangered animal species is not only an effective tool for biodiversity conservation under conditions of military threats, but also a strategic innovation platform that ensures synergy between science, business, and environmental policy. The development of such platforms is consistent with key European and international conventions and may serve as a foundation for shaping modern environmental policy oriented toward sustainable development and international cooperation which corresponds modern legal tendencies regarding the convergence and unification of Ukrainian and European legislation.

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THE INTERRELATIONSHIP BETWEEN DIGITAL MARKETING AND ENVIRONMENTAL EDUCATION: ECONOMIC ASPECTS AND CHALLENGES

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Introduction. Contemporary economic challenges associated with the war, namely the reduction of funding for environmental education in Ukraine due to the state budget deficit, the reorientation of international donors toward addressing humanitarian issues, and the decrease in revenues through fundraising platforms, require innovative approaches to educational outreach. Digital marketing, as a tool for the large-scale dissemination of environmental knowledge, becomes a key factor in overcoming budget constraints in the education sector. Thanks to this tool, the accessibility of environmental education increases despite budget constraints and other problems associated with the war. This study hypothesizes that digital marketing contributes to the development of environmental education by optimizing economic efficiency and overcoming financial barriers.

Data and Methods. The analysis of funding volumes for environmental education expenditures in Ukraine over the past five years is based on open data (state budget expenditures under budget classification code 0900 Education) (Ministry of Finance of Ukraine, n.d.); the open OECD CRS Database (under code 41081 Environmental education/training) (OECD, n.d.); and open data on project funding through the crowdfunding platforms Spilnokosht (Velyka Idea, n.d.) and Dobro.ua (Dobro.ua, n.d.) under the tags Education and Environment, as well as the findings of the report "Research on the Philanthropy Sector" (Zagoriy Foundation, 2025). A quantitative analysis method for expenditure time series, correlated with inflation indicators (Ministry of Finance of Ukraine, n.d.), was applied to the statistical data. The calculations were performed in an Excel spreadsheet.

A qualitative content analysis of 16 scholarly articles was conducted using the keywords "digital marketing environmental education," and the findings were consolidated into a separate table. The study also drew on data from the Digital 2026 Global Overview Report (Kemp, 2025), which served as the basis for systematizing key indicators, conducting a comparative analysis to identify trends, performing a correlation analysis of tendencies, and interpreting the data within the context of the research topic.

Results. In 2020–2025, nominal state budget expenditures on education (code 0900) demonstrated an upward trend. However, after adjusting for the Consumer Price Index, it was established that in 2022, real funding declined significantly (-20.4% compared to 2021), attributable to the inflationary shock (CPI 126.6%). Starting from 2023, a gradual recovery in real expenditures has been observed. Based on the correlation analysis, a moderate inverse relationship between the inflation rate and real expenditures on environmental education was established ($r \approx -0.61$). This indicates the sensitivity of environmental education funding to inflationary processes. The coefficient of determination ($R^2 \approx 0.37$) indicates that nearly half of the variation in real expenditures is explained by inflation dynamics. The calculations are presented in Table 1.

Table 1. Trends in State Budget Expenditures on Environmental Education in Ukraine, 2020–2025

Indicator	2020	2021	2022	2023	2024	2025
State Budget Expenditures (Education, code 0900), UAH million	52857,3	63837,1	58508,1	60452,2	64738	67260,8
Consumer Price Index (CPI)	105	110	126,6	105,1	112	108
Real State Budget Expenditures on Education (CPI-adjusted)	50340,3	58033,7	46214,9	57518,7	57801,8	62278,5
Real Expenditures on Environmental Education (1% of education expenditures)	503,4	580,3	462,1	575,2	578,0	622,8
Real Expenditure Growth Rate		115,28	79,63	124,46	100,49	107,74

The dynamics of international donors' expenditures on financing environmental education projects over 2020–2024 reveal a significant decline in the initial period (due to the reallocation of funds toward pandemic response) and a critical drop at the onset of the full-scale invasion. According to the findings of the "Research on the Philanthropy Sector" report for 2025 (Zagoriy Foundation, 2025), education projects account for 4% of total funding, while nature and ecology projects account for 4.7%. Based on the keywords "education" and "ecology" on the crowdfunding platforms under study (Spilnokosht and Dobro.ua), environmental education projects received a total of UAH 371 thousand in funding, which represents a low amount.

The results of the qualitative content analysis of 16 scholarly sources reveal a clear relationship between digital marketing and environmental education. Digital marketing channels, particularly social media, are increasingly being used to disseminate environmental knowledge and foster eco-conscious behavior. A significant portion of the analyzed works emphasizes their educational potential through the use of social networks, digital content, storytelling, and interactive communication formats. This enables the adaptation of complex environmental topics for a broad audience and enhances user engagement levels. Digital marketing acts as a catalyst for environmental education, accounting for up to 71.8% (Ibrahim, Amin, Shehloo, & Qadri, 2025) of the variation in sustainability awareness through interactive content and emotional campaigns. Studies confirm the high effectiveness of short-form videos (engagement rate 8–12%) (Bhikuning, Kusumawati, & Librado, 2025), which convert awareness into green practices through environmental literacy. An important aspect identified during the analysis is the phenomenon of digital greenwashing. A portion of the studies highlights the risks of manipulative use of digital marketing to create a false impression of the environmental friendliness of products or corporate activities. This poses a challenge for consumers and underscores the need to develop critical thinking within the framework of environmental education.

According to the Digital 2026 Global Overview Report (Kemp, 2025), an audience reach exceeding 6 billion internet users provides a scalability effect, reducing the marginal costs of distributing educational content and thereby enhancing the cost-effectiveness of environmental awareness campaigns. The dominance of video formats on platforms like YouTube and TikTok facilitates deeper audience engagement and drives behavioral change, which is crucial for promoting the principles of sustainable consumption. At the same time, the active integration of artificial intelligence technologies opens opportunities for personalizing environmental messages, yet is accompanied by risks of rising content production costs and potential manipulation, including the phenomenon of greenwashing.

Conclusions. The findings of the conducted research confirm the hypothesis that digital marketing is an effective tool for advancing environmental education under conditions of limited funding, particularly in the context of the wartime economic challenges facing Ukraine. It has been established that the decline in real budget expenditures on education, their sensitivity to inflationary processes ($r \approx -0.61$), and the reduction in international and charitable support create objective preconditions for seeking alternative, less costly channels of educational outreach. In this context, digital marketing provides economic advantages through scalability, reduced marginal communication costs, and high audience engagement effectiveness, as confirmed by both the results of the content analysis of scholarly sources and the data from the Digital 2026 Global Overview Report.

The scholarly contribution of the research lies in the comprehensive integration of macroeconomic analysis of environmental education funding with an assessment of digital marketing's potential as a compensatory mechanism under conditions of resource constraints.

At the same time, the study has certain limitations. First, the use of aggregated statistical data limits the ability to account for regional differences and the specific characteristics of individual target audiences. Second, the qualitative content analysis of scholarly sources involves an element of subjectivity in the interpretation of results. Third, the rapid dynamics of the digital environment, particularly the development of artificial intelligence technologies, may affect the relevance of certain conclusions in the long term. Furthermore, the impact of digital greenwashing on the effectiveness of environmental education and audience trust levels remains insufficiently studied.

Future research should be directed toward the quantitative assessment of the effectiveness of specific digital marketing tools in environmental education, the analysis of consumer behavioral changes under the influence of digital campaigns, and the examination of mechanisms for countering greenwashing and enhancing digital environmental literacy.

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BIG DATA ANALYTICS FOR MONITORING AND FORECASTING REGIONAL SUSTAINABLE DEVELOPMENT INDICATORS

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Introduction. Big Data analytics represents a shift from traditional, periodic statistical methods to a real-time, granular monitoring model, emphasizing the integration of high-frequency data for more sustainable and adaptive regional governance. As global regions face mounting environmental and social challenges, the utilization of Big Data – ranging from satellite imagery to IoT sensors – offers new pathways for achieving sustainable development goals through predictive intelligence. This is particularly relevant as local authorities seek to balance rapid economic progress with ecological responsibility and resource efficiency. The growing interest in digital monitoring reflects the need to reimagine regional systems that are not only data-driven but also socially and environmentally responsive. This paper investigates the question: How can Big Data analytics contribute to monitoring and forecasting regional sustainable development, and what are its primary benefits and limitations?

Data and Methods. This research is based on a structured literature review using sources from databases such as ResearchGate, Scopus, and Google Scholar, alongside reports from international organizations like the UN and CBAS. Keywords like "Big Data analytics," "SDGs," "regional monitoring," and "predictive intelligence" were used to identify relevant academic articles, conference papers, and industry reports. The selected literature was analyzed to explore current trends, recurring themes, and knowledge gaps related to the application of spatiotemporal intelligence and multi-modal fusion in sustainable development contexts. The goal was to synthesize current insights, highlight key themes, and identify gaps in existing research regarding the bridge of data gaps in regional indicators. This approach provides a broad understanding of the conceptual foundations and practical implications of the topic.

Results. The reviewed literature reveals a diverse range of perspectives on the integration of Big Data analytics within regional contexts, particularly in relation to sustainability. Rather than offering a single, unified view, existing studies highlight both the transformative potential and the practical challenges of implementing such analytical systems. To better understand this duality, the findings have been organized into advantages and limitations, reflecting the most frequently discussed themes in the current discourse. This structure allows for a balanced examination of how Big Data analytics is shaping – and being shaped by – sustainability goals in regional development.

The integration of Big Data with advanced forecasting models offers unprecedented opportunities for sustainable development. When regional authorities leverage large-scale datasets, they can enhance innovation by combining the computational power of "Big Earth Data" (satellite and terrestrial observations) with human intuition and contextual understanding. This complementary relationship enables more informed solutions to complex sustainability challenges; for instance, AI-based analytics can improve the accuracy of sustainability-related decisions by up to 60% through better pattern recognition and anomaly detection (Biswas et al., 2026). Furthermore, Big Data contributes to better resource optimization through "nowcasting" – the ability to model current conditions in real-time. Systems can analyze high-frequency data on energy consumption, air quality, and mobility patterns to support specific SDG indicators, such as SDG 11 (Sustainable Cities). When paired with human oversight, these insights lead to timely, responsible decisions that minimize waste and promote circular economy principles. Additionally, Big Data systems enhance agility in decision-making, particularly in climate-sensitive scenarios where the combined strength of data-driven analytics and human experience allows for rapid, adaptable responses to environmental shifts or resource shortages (CBAS, 2025; United Nations, 2025).

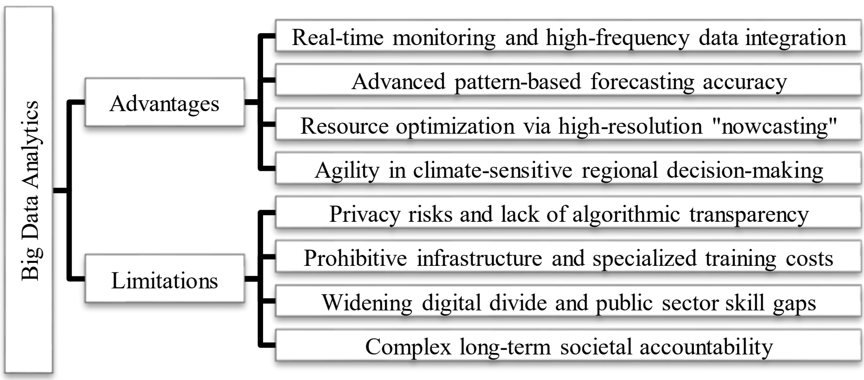

Figure 1. Advantages and limitations of Big Data Analytics for Regional Sustainable Development (based on CBAS, 2025; Biswas et al., 2026; SDSN, 2025; United Nations, 2025).

However, the implementation of Big Data frameworks also presents significant challenges (Figure 1). Ethical concerns, such as privacy risks, lack of transparency in "black-box" algorithms, and potential algorithmic bias, can undermine the social legitimacy of data-assisted decision-making. Without careful oversight, analytical systems may inadvertently reinforce existing inequalities or make unsustainable choices based on biased or incomplete datasets. Moreover, the costs associated with deploying such systems – both in terms of digital infrastructure and specialized human training – can be prohibitive, particularly for small and medium-sized regional centers, potentially widening the "digital divide" between regions. There is also the risk of creating an over-reliance on automated systems, which might erode critical human analytical skills while simultaneously requiring a level of digital literacy that is not yet widespread in the public sector workforce. Furthermore, the issue of accountability becomes complex in data-driven environments, especially when automated forecasts lead to decisions with long-term ecological or societal consequences. Clearly defined responsibilities and robust governance frameworks are essential to ensure that both technological tools and human decision-makers are held accountable for sustainable outcomes (Biswas et al., 2026; Sustainable Development Solutions Network, 2025).

Conclusions. Big Data analytics for regional monitoring shows strong potential to drive sustainable development by combining the strengths of high-frequency data systems with human analytical judgment and localized creativity. It enables smarter resource allocation, faster administrative decision-making, and more responsive regional governance practices. However, challenges such as data privacy ethics, high infrastructure implementation costs, and digital skill gaps remain significant barriers. Addressing these issues is crucial to fully realize the benefits of this data-driven transition. Future research should focus on empirical validation through regional case studies and the development of inclusive governance frameworks for responsible Big Data integration.

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INVESTMENT MANAGEMENT OF ECO-INNOVATIONS IN THE CONTEXT OF PUBLIC-PRIVATE PARTNERSHIPS

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Introduction. In the context of global climate challenges and the transition to a circular economy, investment management of eco-innovations is becoming a fundamental tool for ensuring sustainable development. Environmental innovations require significant capital investments, are characterized by a high degree of uncertainty and a long payback period, which limits the private sector's ability to finance such projects independently. Public-private partnerships (PPP) emerge as a strategic model that allows for risk diversification and combines public resources with private capital and management expertise.

The research problem lies in the need to develop effective management mechanisms that would reconcile the financial interests of private investors with the social significance of environmental outcomes. The object of the study is investment management processes, and the goal is to analyze the role of PPPs as a catalyst for attracting investment in eco-innovations and to identify optimal models for managing such projects based on international experience.

Data and Methods. The methodological basis of the study is based on a comprehensive approach to the analysis of investment processes, combining qualitative and quantitative methods of assessing management strategies:

– systematic analysis of strategic reports by the European Commission and the OECD, which made it possible to identify priority areas for financing green projects and mechanisms for supporting sustainable eco-innovations in the context of the energy transition (European Commission, 2024; OECD, 2024);

– a critical review of scientific publications on translational approaches to eco-innovation management, which made it possible to identify the specifics of modern PPP models and their role in stimulating decentralized environmental initiatives (Habib et al., 2025; Podoinitsyn & Rudyk, 2025);

– financial analysis and modeling methods for comparative assessment of the effectiveness of capital expenditure (CAPEX) and operating expenditure (OPEX) allocation between public and private partners. This made it possible to determine the optimal capital structures for minimizing investment risks (World Bank, 2025);

– comparative analysis of functional partnership models (classic concessions, energy service contracts, asset management) to assess their adaptability to specific eco-innovation life cycles and ESG banking requirements (Baymuradova, 2025);

– econometric analysis and interpretation of World Bank analytical databases to identify global trends in financing environmental transformations and correlations between the level of PPP development and the pace of technological renewal in industry (World Bank, 2025).

This methodology allows for a comprehensive assessment of the financial, managerial, and socio-environmental aspects of investing in eco-innovations through PPPs.

Results. The study showed that effective investment management of eco-innovations within PPPs relies on the integration of financial incentives, including tax breaks, state guarantees, and co-financing mechanisms, which reduces barriers to entry for private capital. It has been established that financial incentives for environmental projects from the state are a key factor in minimizing investment risks in the early stages of the innovation life cycle. The most effective in international practice have been:

– concession agreements in the areas of resource processing and renewable energy, which ensure long-term stability of cash flows;

– energy service contracts with a clear distribution of risks and rewards between the state and private partners depending on the energy savings achieved.

A key component of modern management is the implementation of ESG criteria and non-financial performance indicators for monitoring investments (OECD, 2024). Integrating PPP models into strategic management allows environmental challenges to be transformed into financially attractive assets. The main barriers remain the complexity of long-term planning and the need to adapt the regulatory environment to the requirements of an innovative market. In addition, analysis of current management practices allows the following critical aspects to be identified:

– risks of information asymmetry: the lack of uniform standards for evaluating eco-innovative projects leads to increased transaction costs at the stage of preparing PPP agreements (World Bank, 2025). The use of intelligent systems for monitoring and verifying environmental results allows these risks to be mitigated, increasing the confidence of institutional investors (Habib et al., 2025; Baymuradova, 2025);

– financial stability mechanisms: it has been established that the viability of eco-projects directly depends on the transparency of state incentive algorithms. This involves not only direct subsidies, but also the creation of guarantee funds that cover the "first loss" risks for private partners (Podoinitsyn & Rudyk, 2025);

– institutional readiness: successfully transforming environmental challenges into assets is only possible if there is a shift from rigid contractual forms to flexible models of asset lifecycle management that take into account the rapid technological depreciation of eco-innovations (European Commission, 2024).

The systematization of the results obtained shows that investment management in the field of eco-innovation requires a hybrid approach: a combination of strict financial control over costs (CAPEX / OPEX) with flexible management of socio-environmental effects. This approach allows for the creation of "green" added value, which is the foundation for attracting international capital within the framework of post-war recovery and climate transition.

Conclusion. Investment management of eco-innovations in the context of PPP is a strategically important tool for transforming the national economy towards sustainable development. The study confirmed that the use of international practices not only ensures the stability of financial flows, but also significantly reduces investment risks through a mechanism of fair and transparent distribution between the public sector and private business.

The contribution of the study lies in substantiating the need to implement hybrid investment models that integrate socially significant environmental effects with the commercial viability of projects. It has been established that the successful implementation of such models depends on:

1. Institutional convergence: harmonization of environmental standards with financial regulations to stimulate green lending.
2. Managerial flexibility: the ability of PPP contractual structures to adapt to dynamic technological changes in the field of eco-innovation.
3. Transparency of monitoring: using ESG criteria as a basis for assessing the multiplier effect of investments.

The practical implementation of the proposed approaches will create a favorable environment for large-scale capital investment in eco-innovative modernization, which is critically important for Ukraine's post-war recovery and integration into the European economic space.

Areas for further research:

1. Development of a methodology for assessing the multiplier effect of eco-innovative PPP projects in conditions of instability.
2. Identification of priority sectors for accelerated investment modernization.
3. Analysis of the impact of digital management technologies on the effectiveness of partnerships.

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THE ARCHITECTURE OF SUSTAINABLE GROWTH IN THE EU: SMART SPECIALIZATION AND ECOSYSTEM GOVERNANCE

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Introduction. The architecture of sustainable growth in the European Union is being shaped under conditions of multidimensional transformations encompassing technological, environmental, and socio-economic domains. The deepening of digitalization, the implementation of the European Green Deal, and the intensification of global competition necessitate the development of new approaches to governance capable of ensuring long-term competitiveness and resilience of economic systems. In this context, the concepts of smart specialization and ecosystem governance are emerging not only as instruments of regional policy but also as an integrated framework for coordinating development, enabling synergy between innovation activity, institutional capacity, and resource efficiency.

Smart specialization, as a strategic approach, focuses on identifying and fostering the unique competitive advantages of regions through the concentration of resources on priority areas of innovation. Its foundation lies in the entrepreneurial discovery process, which ensures the involvement of business, academia, and public authorities in defining strategic priorities. At the same time, ecosystem governance expands this logic by integrating diverse actors into dynamic networks of value creation based on principles of open innovation and digital platforms. Consequently, the combination of these approaches forms a new architecture of sustainable growth grounded in the synergy of innovation, digital technologies, and institutional coordination. The relevance of this study is determined by the need for an in-depth analysis of the mechanisms integrating smart specialization and ecosystem governance within the transformation of EU economic systems. Despite a significant body of research on innovation policy, insufficient attention has been paid to the formation of a holistic architecture of sustainable development that reflects the multi-level nature of governance and the specificity of regional ecosystems. Accordingly, the research question is to determine how the integration of smart specialization strategies and ecosystem governance principles influences the effectiveness of sustainable growth in EU countries. The hypothesis assumes that the synergy of these approaches enhances the adaptability of economic systems, stimulates innovation activity, and ensures more efficient utilization of resources.

Data and Methods. The methodological framework of the study is based on an interdisciplinary approach combining tools of economic analysis, institutional theory, and the theory of innovation ecosystems. The empirical base includes analytical materials of the European Commission, particularly data from the Smart Specialisation Platform (S3 Platform), Eurostat statistical indicators, and national and regional smart specialization strategies of EU member states. Additionally, recent academic studies reflecting trends in innovation policy and regional ecosystem development are incorporated.

A comparative analysis method is employed to identify the specific features of smart specialization implementation across EU countries, taking into account their levels of economic development, institutional capacity, and technological potential. The case study method is used to examine the experiences of Germany, Finland, Spain, and the Netherlands as representative examples of different ecosystem governance models. Institutional analysis enables the assessment of the role of formal and informal institutions in ensuring the effectiveness of sustainable development policies. The analytical toolkit includes a structural-functional approach to evaluating the architecture of innovation ecosystems, as well as elements of network analysis to examine interactions among key actors. Particular attention is given to indicators such as innovation activity, intensity of cooperation among stakeholders, levels of investment in research and development, and the degree of digitalization. This approach provides a comprehensive understanding of the effectiveness of ecosystem-based governance in the context of sustainable growth (McCann et al., 2016; Nesterenko et al., 2024).

Results. The findings indicate that the architecture of sustainable growth in the EU is formed as an integrated system in which smart specialization provides strategic orientation, while ecosystem governance serves as the operational mechanism for realizing innovation potential. The key determinants of effectiveness include institutional coherence, the level of digital infrastructure, and the capacity for cross-sectoral collaboration. Germany demonstrates the effectiveness of integrating cluster policy into smart specialization strategies, enabling the development of high-tech innovation ecosystems. Regions such as Baden-Württemberg and Bavaria have concentrated on industrial automation, artificial intelligence, and green technologies, leading to increased productivity and enhanced export potential. A crucial factor is the strong collaboration between universities, research institutions, and industrial enterprises, which ensures effective knowledge transfer. Finland has implemented a model focused on digital transformation and the circular economy, resulting in the development of innovation ecosystems in bioeconomy, energy, and information technology sectors. A high level of trust among stakeholders and effective state support for innovation facilitate rapid technology adoption. Spain illustrates a differentiated approach, where regions such as Catalonia and the Basque Country adapt smart specialization strategies to their specific economic conditions, ensuring efficient utilization of local resources (Pinto et al., 2024). The Netherlands provides an example of advanced ecosystem governance, where digital innovation hubs act as integrative centers for stakeholders, ensuring a high level of coordination and enabling the development of new sustainable business models (European Commission, 2023). Overall, countries with more developed institutional frameworks and higher levels of digitalization demonstrate greater effectiveness in implementing smart specialization strategies (Foray et al., 2018; Kashchena et al., 2023).

At the same time, significant disparities among EU regions in terms of innovation ecosystem development have been identified, primarily due to differences in institutional quality and access to financial resources. These disparities pose challenges to the formation of a unified architecture of sustainable growth and necessitate the improvement of multi-level governance mechanisms.

Conclusions. The study concludes that the architecture of sustainable growth in the EU is based on the integration of smart specialization as a strategic framework and ecosystem governance as an operational mechanism, forming an innovation-driven development model. The synergy of these approaches enhances resource efficiency, strengthens innovation capacity, and improves the competitiveness of EU economies. However, limitations remain, particularly regarding uneven institutional development across regions, which complicates the implementation of a cohesive EU-wide policy. Future research should focus on developing methodologies for assessing the effectiveness of ecosystem governance and on identifying financial instruments to support smart specialization strategies. For Ukraine, the findings are particularly relevant in the context of European integration and post-war economic recovery. The implementation of smart specialization principles requires adaptation to national conditions, including structural imbalances and limited financial resources. Priority areas include the development of regional innovation ecosystems, strengthening digital infrastructure, and enhancing institutional capacity. Ensuring effective interaction between business, academia, and government is critical for creating the conditions necessary for sustainable economic growth. In this regard, the adoption of EU best practices in cluster development, digital platforms, and innovation support mechanisms is of strategic importance.

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ENVIRONMENTAL POLICY STRINGENCY IN THE ENERGY SECTOR AND ITS EFFECT ON GREEN STARTUP DEVELOPMENT

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Introduction. Environmental policy stringency (EPS) has become a central instrument in the global effort to decarbonise energy systems. Governments worldwide are tightening environmental regulations through carbon pricing mechanisms, emission trading schemes, renewable portfolio standards, and increasingly ambitious decarbonisation targets. While these measures are designed to redirect investment flows toward cleaner technologies, their impact on entrepreneurial activity in the green energy sector remains a subject of active scholarly debate. The dual nature of environmental regulation, simultaneously creating market opportunities and imposing compliance costs, makes the EPS-entrepreneurship nexus particularly complex (Streimikiene et al., 2024; Lyeonov et al., 2025).

The purpose of this study is to examine the effect of environmental policy stringency on the development of startups in the green energy sector, distinguishing between its role as a market-creating stimulus and its potential as a regulatory burden.

Data and Methods. The study relies on logical-structural analysis, comparative institutional analysis, and systematic generalisation of findings from the academic literature on environmental regulation and entrepreneurship. The OECD Environmental Policy Stringency framework serves as a conceptual basis for distinguishing between market-based and command-and-control instruments and analysing their differential effects on entrepreneurial activity. The theoretical analysis draws on the Porter Hypothesis and the compliance cost perspective as competing conceptual lenses, synthesising recent empirical evidence to assess the conditions under which environmental policy stringency stimulates or constrains green startup development. The role of institutional quality as a mediating factor is examined through the lens of institutional economics, drawing on the Worldwide Governance Indicators framework as a conceptual reference.

Results. Theoretical perspectives offer competing predictions regarding the EPS-startup nexus. The Porter Hypothesis, in its strong version, suggests that well-designed environmental regulations stimulate innovation and ultimately improve competitiveness by forcing firms to discover more efficient processes and products. For startups, stringent environmental policies create protected market niches, raise barriers for incumbent fossil fuel technologies, and generate demand for novel energy solutions. The induced innovation hypothesis further predicts that the direction of technological change responds to relative price signals created by environmental regulation (Sun et al., 2025).

Conversely, the compliance cost perspective warns that excessive regulatory stringency increases the administrative and financial burden on new ventures, potentially discouraging entry, particularly for capital-constrained startups operating in emerging markets. Startups, unlike large incumbents, lack dedicated compliance departments and regulatory expertise, leaving them disproportionately vulnerable to complex, costly regulatory requirements. It creates an asymmetric effect where environmental regulation may simultaneously benefit the clean energy sector at the aggregate level while imposing disproportionate costs on its smallest and most innovative participants (Bai et al., 2023).

The literature suggests a non-linear, inverted U-shaped relationship between EPS and green startup density. At moderate levels, increasing policy stringency is associated with higher rates of startup formation in clean energy sectors, as regulatory pressure creates market opportunities and investment incentives. However, beyond a certain threshold, additional stringency yields diminishing returns and may even deter entrepreneurial entry due to rising compliance complexity and regulatory uncertainty. This pattern is supported by evidence from multiple cross-country studies (Lee et al., 2025; Lyeonov et al., 2025).

The study further identifies that the composition of the EPS policy mix matters significantly. Market-based instruments, such as carbon taxes and emission trading schemes, show a stronger positive association with startup activity than command-and-control regulations, such as technology mandates and emission standards. Market-based instruments provide greater flexibility for entrepreneurs to develop innovative solutions, whereas prescriptive regulations tend to favor established firms with existing compliance infrastructure. This finding has important implications for the design of environmental policy packages intended to stimulate green entrepreneurship (AlNaqbi & Mohd Shamsudin, 2024).

Cross-country variation in the EPS-startup relationship is also shaped by institutional quality. In countries with transparent regulatory processes, strict rule of law, and predictable policy trajectories, environmental stringency operates primarily as a market stimulus. In contrast, where institutional frameworks are weak and policy implementation is inconsistent, such as in several Southern and Eastern European countries, the same level of stringency may generate uncertainty that deters entrepreneurial risk-taking. This institutional mediation effect highlights that environmental policy outcomes depend critically on the governance context in which they are implemented.

The temporal dimension of environmental policy also matters for startup development. Gradual, predictable policy escalation, combined with clear long-term targets and transition pathways, provides the planning certainty startups need for multi-year development cycles. Abrupt policy changes, retroactive modifications of support schemes, and political uncertainty about climate commitments, on the other hand, increase investment risk and discourage entrepreneurial entry into the sector (Zhang, 2023).

The findings carry important implications for policymakers designing environmental regulations in the energy sector. Effective green startup promotion requires not merely increasing regulatory stringency but ensuring that the policy design is innovation-friendly, predictable, and complemented by supportive institutional conditions. Specific recommendations include: prioritizing market-based instruments over command-and-control approaches; establishing long-term regulatory roadmaps; implementing regulatory sandboxes for innovative energy business models; and providing targeted compliance assistance for early-stage ventures.

Conclusions. For Ukraine, which is simultaneously pursuing EU approximation of its environmental legislation and post-war reconstruction of its energy system, these findings suggest that startup-friendly implementation mechanisms should accompany the transposition of EU environmental directives. A balanced approach that combines ambitious environmental targets with accessible compliance pathways and dedicated support for clean-tech entrepreneurs can maximise the entrepreneurial dividend of environmental policy stringency.

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THE GREEN ENERGY TRANSITION OF UKRAINE'S RESIDENTIAL SECTOR: MODELING THE IMPACT OF ENERGY EFFICIENCY AND RENEWABLES

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Introduction. The residential sector plays a critical role in shaping overall energy consumption and greenhouse gas emissions. In the context of the green energy transition and limited access to micro-level statistical data, the development and testing of macroeconomic decarbonization models are particularly important for building the evidence base for state and local energy policies. Therefore, the aim of the study is to conduct an econometric assessment of the impact of energy efficiency and the development of decentralized renewable energy sources (RES) on the reduction of CO_2 emissions, primarily in Ukraine's residential sector.

Data and Methods. The identification of decarbonization drivers was carried out using the ordinary least squares (OLS) method based on data from the State Statistics Service of Ukraine and the World Bank (2002–2021) [1-3]. Due to the lack of detailed data on the residential sector caused by the ongoing war in Ukraine, a system of proxy factor indicators was used: gross domestic product (GDP) per unit of energy use (energy efficiency), gross fixed capital formation (investment climate), the share of household expenditures on utility services (financial burden), the share of renewable energy in the structure of total electricity production (decentralized RES), and global crude oil prices (a benchmark for energy costs). The study was structured into two stages: the assessment of the general comprehensive model taking into account the impact of the green energy factor, including its development in the residential sector, and the isolated assessment of the impact of energy efficiency on decarbonization.

Results. The results of econometric modeling implemented in Stata 18.0 revealed a number of statistically significant patterns:

1) regarding price shocks and behavioral adaptation: a negative relationship was established between the financial burden on households and the level of emissions. An increase of 1% in household utility expenditures resulted in a decrease of 255 kg of CO_2 per capita per year. Concurrently, a 10 USD/bbl increase in world oil prices reduced emissions by 68 kg/capita. This proves that the rising cost of energy is a strong stimulus for its conservation and decarbonization in the residential sector;

2) regarding the critical role of energy efficiency: the isolated modeling demonstrated that an increase in GDP per unit of energy use by 1 USD (PPP) per 1 kg of oil equivalent lead to a massive reduction in emissions by 952 kg of CO_2 per

capita per year. Thus, reducing energy intensity is the most powerful decarbonization factor;

3) regarding the green energy effect: a 1% increase in the total share of RES in the electricity production structure reduced CO_2 emissions by 120 kg/capita per year, contributing to the achievement of national decarbonization goals, including in the residential sector;

4) regarding the carbon intensity of investments: a 1% increase in gross fixed capital formation (% of GDP) correlated with an increase in emissions by 136 kg per year. This indicates the historical orientation of the Ukrainian economy towards energy-intensive industries and housing stock, as well as the urgent need for the ecologization of investment flows.

The obtained empirical results indicate that technical instruments (energy efficiency) and technological ones (decentralized RES) in the residential sector generate a synergistic effect. However, their implementation requires a comprehensive energy policies at different management levels. The main recommendations include:

- institutional integration of thermal modernization programs and the development of decentralized "home" RES;
- introduction of mass energy auditing and building certification;
- launching effective financial incentive instruments (concessional lending, grants) for energy efficiency and green energy projects in the residential sector;
- fostering a culture of energy-saving behavior among the population.

It is important to note that the logic of the proposed model and the recommendations have a universal character. Variables reflecting investment activity and price signals can be adapted to the specifics of the municipal sector, where public sector buildings also require large-scale decarbonization.

Conclusions. Overall, increasing energy efficiency and developing decentralized generation based on RES are indispensable drivers of decarbonization. It has been proven that price incentives and energy intensity indicators directly shape behavioral patterns of energy conservation. Further emission reductions require shifting from fragmented projects to systematic state support for the green energy transition at the micro-level (in households and municipalities), thereby ensuring the long-term sustainability of Ukraine's energy system.

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SUSTAINABILITY: A MULTIDIMENSIONAL CONCEPT

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Introduction. Sustainability has progressively evolved from an ecological concern into a comprehensive framework for guiding socio-economic development. Since the late 20th century, key international milestones – including the Stockholm Conference (1972), the Brundtland Report (1987), and the Rio Summit (1992) – have contributed to conceptualizing sustainability as a multidimensional construct encompassing environmental, economic, social, and institutional dimensions. Despite this advancement, a persistent gap remains between policy commitments and tangible outcomes, as reflected in continued environmental degradation and widening social inequalities. This study addresses the question: How can sustainability be more effectively conceptualized and operationalized as a multidimensional framework to bridge the gap between policy intent and implementation?

Data and Methods. This research adopts a qualitative, conceptual methodology based on a historical and comparative analysis of key international policy documents and sustainability frameworks from 1970 onwards. Primary sources include global reports, institutional agreements, and governance initiatives. The analysis focuses on synthesizing theoretical and policy perspectives to examine the interaction of four core dimensions of sustainability—environmental, economic, social, and institutional. Particular attention is given to identifying structural inconsistencies and implementation challenges across these dimensions.

Results. The findings indicate that, although sustainability has been widely institutionalized, its practical implementation remains fragmented. Environmental indicators continue to deteriorate, with rising emissions and biodiversity loss persisting despite extensive policy frameworks. Economically, the dominance of private efficiency over social effectiveness constrains equitable development. Socially, inequalities endure, undermining both intra- and intergenerational justice. Institutionally, governance systems often lack integration, participation, and subsidiarity. The study highlights that insufficient recognition of sustainability's multidimensional nature, alongside the irreversibility of many socio-ecological processes, constitutes a central barrier to effective implementation.

Conclusions. The study concludes that achieving sustainability requires integrated, multidimensional approaches rather than isolated policy interventions. Emphasis is placed on the development of territorially sensitive indicators and iterative evaluation mechanisms to support decision-making, particularly at local scales where science–policy integration is more feasible. Limitations include the conceptual scope of the analysis and the absence of empirical validation. Future research should focus on operationalizing multidimensional frameworks through

localized metrics and examining governance models that better align policy commitments with measurable outcomes.

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ANALYSIS OF NEW SALES MARKETS FOR UKRAINIAN PRODUCTS IN AFRICA, ASIA AND LATIN AMERICA

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Introduction. The issue of finding new sales markets for Ukrainian products has become especially relevant under conditions of global economic transformation and decreasing dependence on traditional European markets. Although the European Union remains the main destination for Ukrainian agro-exports, its share declined from 52.1% to 47.5%, increasing the strategic importance of alternative regions such as Africa, Asia, and Latin America (African Hub). These regions demonstrate rapid population growth, increasing urbanization, and rising demand for food products, agricultural technologies, and industrial cooperation.

Africa has become a promising market because of food security challenges and growing imports of grain and oil products (Ukraine Opens). Asia remains the largest non-European market for Ukrainian agricultural exports, accounting for more than 30% of agro-export flows (Latin). At the same time, Latin America is considered an important geopolitical and economic partner due to its large population, growing economies, and interest in technological cooperation.

The main research question of this study is to determine how Ukraine can strengthen its export positions in Africa, Asia, and Latin America in 2026 through diversification strategies, logistics development, and expansion of value-added exports.

Data and Methods. The research is based on analytical materials, statistical reports, and publications from Ukrainian and international economic platforms, including Landlord, Ukrinform, AgroPortal, Kurkul.com, Latifundist, ITC TradeMap, and RBC-Ukraine. The study uses data related to export volumes, trade turnover, logistics routes, and market access agreements between Ukraine and countries of Africa, Asia, and Latin America.

The methodological basis of the research includes comparative analysis, statistical analysis, and structural analysis of export flows. The study compares the dynamics of Ukrainian exports across regions and evaluates the role of different product categories, including grain, vegetable oils, meat products, and processed agricultural goods. Special attention is paid to the development of the "Middle Corridor" logistics route, export certification agreements, and regional cooperation projects.

Results. The African region demonstrates particularly high potential due to its demographic dynamics and growing demand for food security. According to the analyzed data, Africa currently accounts for approximately 10% of Ukraine's agro-export structure, with export volumes reaching nearly USD 2.6 billion in 2024 (TradeMap). Ukrainian exports to African countries mainly consist of grain crops, flour, sunflower oil, feed products, and other agricultural commodities. The study indicates that grain products continue to dominate the export structure, accounting for more than 70% of total food exports to the continent. Such a structure reflects the strong competitive advantages of Ukraine in agricultural production and grain logistics.

The largest African importers of Ukrainian agricultural products include Egypt, Nigeria, Kenya, Mozambique, and South Africa. Egypt remains one of the most strategically important partners due to its large-scale imports of Ukrainian grain and vegetable oil. Ukraine also supplies significant shares of critical agricultural imports to several African and Middle Eastern countries, including sunflower oil, barley, and corn (A Generation's).

One of the most important developments is the official opening of the Côte d'Ivoire market for Ukrainian meat exports in 2026 (Ukraine's. Historical, Ukraine Intensifies). Access toWest African markets provides opportunities for long-term trade agreements, expansion of food-processing exports, and increased competitiveness of Ukrainian producers. In addition, cooperation with South Africa, which remains the most industrially developed economy on the continent, strengthens Ukraine's access to regional distribution systems and industrial partnerships.

In 2025-026, Asia accounted for more than 30% of Ukrainian agro-export flows, reaching approximately USD 7 billion (Asia's). Singapore has become one of the most promising Asian markets for Ukrainian meat exports. The country is expected to fully open its market for Ukrainian pork products in 2026, while the Philippines has already included Ukraine in its priority list for veterinary certification procedures. In addition, Ukraine already possesses approved veterinary certificates for several categories of exports to Singapore, including poultry products, processed meat, eggs, and pet food (Asia's). This institutional progress significantly strengthens Ukraine's position within Asian food supply chains.

Turkey, India, and China remain among the largest importers of Ukrainian agricultural products. Turkey became one of the leading buyers of Ukrainian agro-products due to increasing imports of grain and oil products. However, fluctuations in demand from India and China influence overall export stability, emphasizing the importance of diversification across multiple Asian markets.

The research confirms that Latin America is gradually emerging as another strategically important region for Ukrainian economic expansion. The region consists of 33 countries with a combined population exceeding 660 million people and contributes approximately 8% of global GDP (Latin). Latin America possesses substantial demand for food imports, agricultural technologies, infrastructure development, machinery, energy cooperation, and digital modernization. These factors create favorable conditions for the development of long-term Ukrainian-Latin American trade relations.

Overall, the results of the research confirm that Africa, Asia, and Latin America represent strategically important and economically promising directions for the future expansion of Ukrainian exports. These regions provide opportunities not only for increasing export volumes but also for transforming the structure of Ukrainian exports toward higher value-added production, technological cooperation, and long-term industrial partnerships. The diversification of export geography, development of logistics infrastructure, and strengthening of international cooperation collectively contribute to the formation of a more resilient, competitive, and globally integrated Ukrainian export model.

Conclusions. The study confirms that Africa, Asia, and Latin America represent strategically important directions for the diversification of Ukrainian exports. Rapid demographic growth, increasing food demand, and expanding logistics opportunities create favorable conditions for strengthening Ukraine's economic presence in these regions. The development of new export routes, veterinary agreements, and agro-industrial partnerships contributes to reducing dependence on European markets and increasing the share of value-added exports.

At the same time, several limitations remain, including geopolitical instability, logistics risks, market volatility, and regulatory barriers in some regions. Future research should focus on long-term investment strategies, digital trade infrastructure, and mechanisms for increasing competitiveness of Ukrainian products in emerging markets.

Overall, the expansion of Ukrainian exports into Africa, Asia, and Latin America reflects a transition from a raw-material export model toward a diversified and innovation-oriented trade strategy capable of ensuring long-term economic resilience and global competitiveness.

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ADAPTIVE ENTERPRISES AND ARTIFICIAL INTELLIGENCE AGENTS IN THE SUSTAINABLE AND INCLUSIVE DEVELOPMENT OF REGIONAL SPACE UNDER POST-WAR RECOVERY

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The essence of an adaptive enterprise. The post-war recovery of Ukraine's regional space and the accompanying digital transformation require enterprises to rapidly reconfigure their business models to the conditions of an unstable environment. An adaptive enterprise is an organisational system capable of continuous reconfiguration of resources, processes, and management mechanisms on the basis of data and autonomous agent-based decisions. In such a logic, the advantage belongs not to individual digital tools but to the three-step management sequence "environmental signal → organisational response → strategy correction", in which software agents, human-centred practices, and analytics act as a single whole (Zincume & Maier, 2025).

The bibliometric analysis of the literature on digital transformation reveals a persistently high share of unsuccessful initiatives, attributed to the mismatch between the existing management models and the requirements of the digital environment (Oludapo et al., 2024). The key constraint on adaptability lies not in the absence of technologies but in the speed and quality of the management loop.

The methodology presented below extends the architecture proposed by the authors in their earlier work (four adaptability criteria, eight indicators, the OAI, and a three-level classification) and addresses the issue of binding an AI method to a specific management indicator.

Four adaptability criteria and the Organisational Adaptability Index. The enterprise's adaptability to digital transformation is operationalised through four interrelated criteria, each with two diagnostic indicators (Table 1).

Eight indicators with equal weighting coefficients are aggregated into an integral OAI on the interval (Wang, 2023) points.

Table 1 – Criteria and indicators of the Organisational Adaptability Index (OAI)

Criterion	Diagnostic indicators
Decision-making speed	Average time from problem identification to decision; number of approval levels
Quality of the feedback loop	Frequency of cross-functional communications; automated KPI monitoring
Degree of decentralisation of authority	Share of operational decisions; autonomy of working groups
Digital maturity of processes and competencies	Integration of digital technologies into business processes; level of digital competencies

Source: compiled by the authors based on earlier own developments.

Threshold values are computed as the product of the number of indicators and the qualitative anchor points of the Likert scale of an individual indicator: $8 \times 2.5 = 20$ points (lower threshold, median) and $8 \times 4.0 = 32$ points (upper threshold, "mostly formed"). Adaptability is accordingly classified as low (OAI < 20 points), moderate ($20 \leq \text{OAI} \leq 32$), or high (OAI > 32). Common digital maturity scales (DMM, Industry 4.0 maturity) focus on the availability of technologies and the formalisation of processes, while the Business Agility Index (Business, 2024) evaluates business flexibility on a ten-point range across five domains and 18 behavioural capabilities. The OAI instead emphasises the dynamics of the management cycle, which is critically important for operating under instability, in particular during post-war recovery (Berbyuk Lindström et al., 2024).

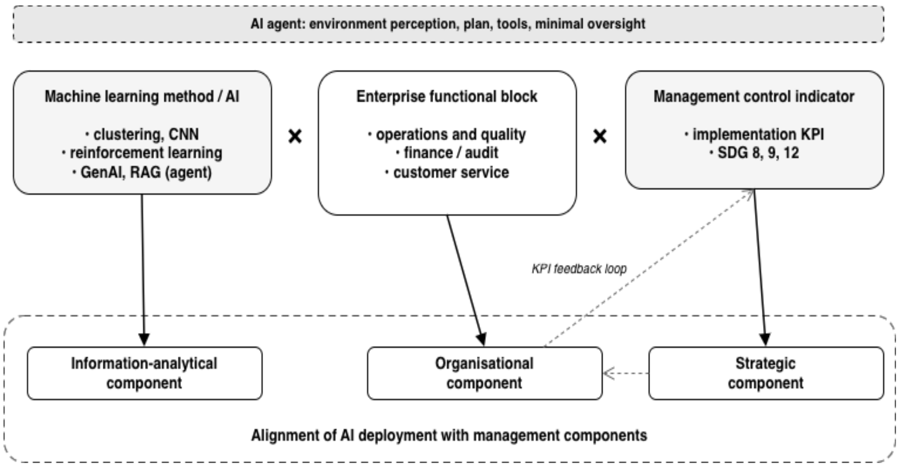
Evolution of AI: from tool to agent, and a three-level classification. In the classical definition, artificial intelligence is the study of agents that perceive their environment through percepts and take actions (Russell & Norvig, 2021). AI agents differ qualitatively from traditional robotic process automation (RPA) and generative models: they autonomously perceive the environment, formulate goals, plan multi-step actions, use external tools, and achieve specified results with minimal human intervention (Krishnan, 2025; Wang et al., 2023). A promising direction is multi-agent ecosystems, in which functionally specialised agents (from marketing and logistics to analytics and financial control) coordinate on the basis of policies and protocols (Sun et al., 2025).

On this basis, a three-level classification of management approaches by the depth of AI integration is proposed:

- *Level I (manual management):* AI is absent or minimal; decision speed is low (days–weeks); risks: human factor, concentration of decisions at the top level;
- *Level II (partial automation):* AI supports decisions; speed is moderate (hours–days); risks: data quality and bias, "blind trust" in recommendations;
- *Level III (agent-oriented models):* AI autonomously makes and executes decisions within policies; speed is high (minutes–hours); risks: ethical violations, LLM hallucinations, blurred accountability, attacks on agent chains.

Unlike dialogue bots that respond with single replies, a Level III agent builds a multi-step plan, retrieves data from corporate stores via retrieval-augmented generation (RAG), corrects execution, and may initiate actions in IT subsystems. Human oversight remains a mandatory link at all three levels.

The three-component AI-mechanism linkage. In the proposed approach, AI-based digital transformation rests on three interrelated elements: *machine learning method* × *enterprise functional block* × *management control indicator*. A generalised scheme of this triad, the role of the AI agent, and its anchoring to the strategic, organisational, and information-analytical components of management is shown in Fig. 1.



Source: developed by the authors.

Fig. 1 – The three-component AI-mechanism linkage of an adaptive enterprise

Without such anchoring, AI deployment remains an isolated IT project disconnected from management practice. Indicative control indicators for typical methods include: share of inquiries handled without escalation (supervised learning), share of true-positive detections (clustering), cumulative reward over a period (reinforcement learning), classification accuracy and defect rate (CNN-based defectoscopy). Each such pairing is simultaneously anchored to the Sustainable Development Goals (SDG 8, 9, 12), which provides the foundation for the inclusive recovery of the regional space in the post-war period.

According to McKinsey & Company (2024), 72 % of organisations already use AI in at least one business function, yet only a small share of organisations achieve a sustained managerial effect. This imbalance is explained by the absence of architectural integration: technologically successful pilots that lack a binding between the functional block and the control indicator remain one-off experiments.

Key implementation challenges

In the context of the post-war recovery of the regional space, the issue of the quality of the digital data infrastructure is particularly acute: the effectiveness of agent-based systems depends on access to structured, current, and integrated corporate data. Only about 24 % of large companies have successfully become data-driven, while 92 % cite culture, processes, and change management as the principal constraint (NewVantage, 2021).

Multi-agent AI chains expand the cyberattack surface: without access policies, invocation logs, and incident-response procedures, cyber risk grows disproportionately to the benefit. This makes AI Governance a central issue in Level III deployment.

EU Regulation 2024/1689 (the "AI Act") (European, 2024) and the NIST AI Risk Management Framework 1.0 (National, 2023) establish requirements for transparency, accountability, and the risk management of autonomous systems. At the enterprise level, compliance with these requires a redistribution of staff functions in favour of strategic, coordinating, and ethical-oversight tasks, which changes the very structure of managerial work (The future, 2023).

Conclusions

With the advent of AI agents, an enterprise's adaptability gains the practical instruments it had previously lacked. The novelty of this paper lies in the three-component linkage "method × function × indicator" and in its anchoring to the tasks of post-war recovery of the regional space; the OAI, the three-level classification, and the adaptability criteria originate from the authors' earlier own developments. The proposed methodological architecture transforms adaptability from a declarative category into a measurable management indicator. The four criteria unfold into eight diagnostic indicators that aggregate into the Organisational Adaptability Index (OAI). The OAI measures adaptability quantitatively, while a three-level classification of management approaches by the depth of AI integration operates in parallel. In this paper, both frames are augmented by the trinitarian formula "method × function × indicator". As a result, AI deployment ceases to be an isolated IT project and becomes simultaneously embedded in the enterprise's strategy, its organisational design, and its analytical function. The gap between the coverage of AI pilot projects and their integration into sustained management practice remains an open problem. Prospective directions for further research include industry-specific calibration of OAI weights and threshold values, the deepening of AI Governance mechanisms in accordance with EU Regulation 2024/1689, and the study of the relationship between organisational adaptability and the indicators of sustainable and inclusive development of the regional space under conditions of post-war recovery.

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UKRAINIAN BIOECONOMY IN THE CONTEXT OF EUROPEAN INTEGRATION

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In the context of current global challenges caused by war, climate change, the degradation of natural resources, and the need to ensure food security, the role of bioeconomy as one of the key directions of sustainable development is increasingly significant. Bioeconomy encompasses types of economic activity based on the efficient and responsible use of biological resources, the implementation of innovative technologies, the application of renewable raw materials, and the principles of a circular economy.

Cherevko I. and Cherevko H. consider this concept as a closed-loop transformation of natural resources in production processes, aimed at achieving economic benefits while taking environmental constraints into account [5].

According to Bugaychuk V. and Grabchuk I., bioeconomy represents a new direction in economic development, which, unlike previous models, promotes the repeated use and processing of secondary raw materials, including waste, creates conditions for multiple, cyclical use of resources, thereby increasing the gross domestic product and improving the overall socio-economic development of the country [2]. In the context of Ukraine's European integration, the development of bioeconomy is not only an environmental priority but also a strategic economic necessity [3].

In the European context, bioeconomy is understood as a system focused on the balanced use of biological resources in agriculture, forestry, fisheries, the food industry, energy, biotechnology, and waste management. It is an essential component for implementing the European Green Deal, which aims to achieve climate neutrality in the EU by 2050 [1]. At the same time, one of the EU's key priorities is the transition to a circular economy, where bioeconomic processes play a crucial role in creating new jobs, reducing emissions of pollutants into the atmosphere, and protecting the environment.

Ukraine's European integration course requires harmonizing national bioeconomy policies with EU approaches, as reflected in the provisions of the National Economic Strategy–2030, which identifies the development of green and bioeconomy sectors as a strategic priority.

Ukraine has significant potential for bioeconomy development due to its fertile soils, substantial agricultural production, scientific and technical capacity, and the possibility of utilizing agricultural sector waste as a raw material for the production of bioenergy, bioplastics, and other bioproducts. According to the Food and Agriculture Organization of the United Nations (FAO), Ukraine's bioenergy potential exceeds 20 million tons of oil equivalent per year, which could cover approximately 15–20% of the country's energy needs [4].

Current challenges for bioeconomy development in Ukraine include low levels of innovation activity, limited access to financing for green initiatives, fragmented legislation in the field of biotechnology, and the absence of a comprehensive national strategy for bioeconomy development [3]. At the same time, for full integration into the European bioeconomy space, Ukraine needs to modernize public policy instruments, strengthen support for scientific research, develop cooperation between business and academic institutions, and create a favorable environment for implementing innovations in agriculture and industry.

Thus, in the context of European integration, the bioeconomy should be considered a strategic mechanism for ensuring sustainable development, driving green transformation, and supporting Ukraine's post-war recovery. Its effective implementation requires a systemic approach, active government support, expanded international cooperation, and the engagement of business and the scientific community. In addition, fostering public awareness and promoting educational initiatives are essential to build societal understanding of bioeconomic principles. Strengthening research and innovation networks will further enhance the country's capacity to adopt sustainable technologies and integrate into the broader European bioeconomy space.

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DIGITAL TECHNOLOGIES AS THE INFRASTRUCTURE BASIS OF THE CIRCULAR ECONOMY

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The transition to a circular economy requires the development of new mechanisms for managing resource flows that enable the reuse, repair, refurbishment, remanufacturing, and recycling of products and materials throughout their entire life cycle. The implementation of such approaches is impossible without access to reliable information on product origin, composition, technical condition, location, and usage history. For this reason, digitalisation is now regarded as one of the key enablers of the transition from a linear to a circular economic model.

Industry 4.0 has become a major driver in the evolution of approaches to managing production and socio-economic systems, effectively initiating a new stage of profound digital transformation. The Industry 4.0 concept encompasses a broad range of technologies aimed at the digitalisation of production, the integration of physical and digital processes, and the management of the entire product life cycle. The academic and analytical literature identifies between nine and eleven core pillars of digital transformation (Haiston, 2025).

At the same time, a synthesis of existing classifications makes it possible to identify a core set of technologies that play a system-forming role in the digital and circular economy. Based on an analysis of recent studies, five key technologies have been identified: the Internet of Things (IoT), Artificial Intelligence (AI), blockchain, digital twins, and cloud computing. Together, these technologies constitute the fundamental digital infrastructure that supports the entire data lifecycle, from data collection and storage to analysis, verification, and practical application.

Within the context of the circular economy, these technologies create opportunities to track the movement of resources and products, predict the technical condition of assets, coordinate interactions among participants in value chains, and ensure information transparency throughout the product life cycle. Consequently, digital technologies provide the foundation for implementing circular economy principles and developing new circular business models.

The Internet of Things (IoT) represents an environment in which physical objects are capable of autonomously generating, transmitting, and analysing data in real time. The deployment of sensors and other technologies that connect physical objects to digital networks is currently expanding at an exponential rate. According to recent estimates, the number of connected IoT devices worldwide reached approximately 19.8–21.1 billion in 2025 and is projected to increase to around 39 billion by 2030 and more than 50 billion by 2035 (State, 2025; Bianes, 2025). At the same time, the total number of internet-connected devices, including smartphones, computers, and other digital devices, is already approaching 30 billion. This confirms the emergence of a globally hyperconnected environment.

Declining costs, miniaturisation, and the increasing intelligence of sensor technologies are driving their widespread adoption across diverse fields, ranging from households and wearable devices to urban infrastructure, transport systems, energy networks, and industrial production. This level of connectivity is fundamentally transforming the management of value chains by enabling the monitoring, analysis, and optimisation of processes in real time. In turn, this creates the conditions for improving resource efficiency and accelerating the transition towards a circular economy (Schwab, 2016).

While IoT is responsible for collecting vast amounts of real-time data, blockchain provides a robust infrastructure for their storage, verification, and secure exchange among value chain participants (Da Silva, 2025). Through its decentralised architecture and cryptographic security mechanisms, blockchain ensures data immutability, thereby preventing unauthorised alterations or falsification. As a result, blockchain creates a transparent and verifiable chain of events throughout the entire product life cycle (Karaduman et al., 2025; Centobelli et al., 2022).

The rapid development of Artificial Intelligence (AI) is one of the defining characteristics of the current stage of digital transformation and an essential component of the Industry 4.0 technological paradigm. According to the Digital 2026 Global Overview Report, more than one billion people worldwide already use AI tools on a regular basis, while actual estimates may reach 1.5 billion monthly users. Moreover, more than two billion people interact with AI every month through search engines (Kemp, 2025). Such levels of adoption indicate that AI has evolved from a niche technology into a mainstream instrument of the digital economy. Increasingly, AI is no longer viewed as a standalone technology but rather as a universal tool for processing, interpreting, and generating data.

Within the context of the circular economy, this transformation is of fundamental importance. Artificial intelligence converts vast datasets generated by the Internet of Things and verified through blockchain into actionable insights for optimisation and decision-making. Machine learning algorithms can predict product failures, optimise refurbishment processes, classify secondary materials, and model reverse logistics networks to minimise environmental impacts (Da Silva, 2025).

Digital twins constitute another key technology of Industry 4.0. Contemporary academic studies define a digital twin as a dynamic digital replica of a physical object that operates on the basis of real-time data and enables the monitoring, analysis, prediction, and optimisation of its behaviour (Kumbhar et al., 2023). According to analytical reports, approximately 80% of IoT platforms already incorporate digital twin functionality. Sensor data account for up to 60% of the information base of digital twins and underpin their ability to reflect the state of physical assets in real time (Eriksson, 2026; Digital Twin, 2026).

An important area of application is the use of digital twins in supporting the development of the circular economy. Digital twins make it possible to model scenarios, such as the effects of refurbishment or recycling strategies, before decisions are physically implemented. This capability enhances resource optimisation, extends asset lifespans, and accelerates the scaling of circular practices (Da Silva, 2025). In urban systems, for example, digital twins have the potential to reduce emissions and improve resource management efficiency by up to 20% (Eriksson, 2026).

Cloud computing has emerged as a key infrastructural foundation of the digital economy and an indispensable element of the Industry 4.0 technological ecosystem. It provides global capabilities for data storage, processing, and transmission, thereby creating the conditions necessary for the operation of artificial intelligence, the Internet of Things (IoT), Big Data, and digital platforms.

According to analytical reports published in 2025–2026, cloud platforms are characterised by rapid growth and near-universal adoption. More than 94% of enterprises worldwide already use cloud services, and around 80% of corporate workloads are processed in cloud environments (50 Cloud Usage, 2025). Moreover, approximately 90–95% of new digital solutions are developed directly on cloud infrastructures.

According to the Digital 2026 Global Overview Report (DataReportal), the global digital ecosystem is expanding rapidly. The number of internet users has exceeded six billion people, creating substantial demand for data processing, digital services, and the infrastructure required to support them. In this context, cloud platforms act as the "digital core" underpinning the functioning of global information flows and services.

Collectively, these technologies address three fundamental challenges of the circular economy:

- the lack of information on products and materials (IoT, blockchain, and digital twins);
- inefficiencies in resource-related decision-making (AI and digital twins);
- insufficient coordination among participants in circular value chains (blockchain and cloud computing).

Thus, digital technologies serve not merely as instruments for improving the efficiency of individual processes but as the system-forming foundation of the modern circular economy. They have provided a substantial impetus for the implementation of most contemporary circular strategies. Consequently, digitalisation should be viewed not as a separate tool of the circular economy but as its underlying informational and organisational foundation.

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ECOSYSTEM-INTEGRATED 10R HIERARCHY: JUSTIFICATION OF THE R10 "REGENERATE" STRATEGY AS THE APEX OF THE CIRCULAR ECONOMY

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Introduction. The classical 10R hierarchy (Haines-Young & Potschin-Young, 2018) is a powerful tool for managing material flows in the technosphere; however, its technocentric nature creates a significant gap: it lacks a strategy that directly addresses the state of natural ecosystems as the foundation of any economic activity. All ten strategies (from R0 Refuse to R9 Recover) are oriented toward products, materials, and waste—that is, toward what has already been created by humans. Meanwhile, ecosystems continue to degrade as a result of past economic activities. The classical 10R does not provide an answer to the question of how to restore lost natural capital. The highest strategy—R0 Refuse—only prevents further harm but does not remediate already inflicted damage. Achieving genuine sustainability requires an active restoration strategy—an analogue of regeneration in ecology.

The study aims to justify the need to supplement the classical 10R hierarchy with the R10 "Regenerate" strategy as its apex, as well as to propose approaches for operationalizing this strategy through a system of ecosystem service indicators.

Data and methods. The research is based on the analysis of secondary data. The theoretical foundation is formed by scientific publications, monographs, and reports of international organizations, including the Millennium Ecosystem Assessment (2005) and Konietzko, Bocken & Hultink (2020), which enabled a critical literature review and the construction of a conceptual research framework.

Results. A critical analysis of the classical 10R hierarchy in the context of ecosystem services has revealed several critical limitations. The 10R hierarchy lacks a strategy for active regeneration of degraded ecosystems. It focuses on "what to do with products" but not on "what to do with ecosystems." It ignores the role of regulating (water purification, carbon sequestration, pollination) and supporting (nutrient cycling, soil formation) ecosystem services, which have no direct material expression but are critical for the functioning of any economy.

Exclusive reliance on technospheric indicators (waste, recycling, energy) creates the risk that improvement in one parameter is accompanied by deterioration in another related to ecosystems. For instance, increasing the share of biofuels (R2 or R9) may lead to deforestation and soil depletion, which is not captured by the classical hierarchy. The 10R does not answer the question: "A circular product is good, but is it at the same time environmentally safe?"

Furthermore, insufficient attention is paid to the geographic significance of ecosystem services and their temporal dimension. The 10R hierarchy assumes that strategies are mutually exclusive and can be ordered on a "better–worse" scale. However, ecosystem processes are often nonlinear: moderate biomass extraction from a forest (R2 Reduce) may be beneficial for maintaining biodiversity, while complete abandonment of use (R0 Refuse) in some cases may lead to negative environmental effects.

Based on the identified limitations, it is proposed to supplement the 10R hierarchy with the R10 "Regenerate" strategy, which should be placed at its apex. This approach finds support in the scientific literature: Konietzko, Bocken & Hultink (2020) and Fehrer, Kemper & Baker (2023) argue that the apex of the circular hierarchy should be not refusal (R0) but regeneration, as it ensures the long-term viability of the entire system.

R10 is defined as a circular economy strategy that involves active regeneration and improvement of the state of natural ecosystems to increase their capacity to provide ecosystem services (provisioning, regulating, supporting, cultural), which are the foundation for all other R-strategies and economic activity in general.

"Active regeneration" means that R10 is not limited to passive conservation, as in many cases degradation has progressed so far that natural succession would take hundreds of years or is entirely impossible. Active regeneration involves reintroduction of extinct species, restoration of hydrological regimes, removal of invasive species, tree planting, creation of constructed wetlands, and so on. "State improvement" implies not merely returning the ecosystem to a baseline state but, where possible, exceeding it—creating more resilient, biodiverse, and productive ecosystems than those that existed prior to degradation. This aligns with the concept of "net positive impact."

The placement of R10 above R0 can be justified by the fact that humanity has already degraded a significant portion of natural ecosystems, and ceasing further harm does not eliminate this legacy. All R-strategies (from R0 to R9) directly or indirectly depend on ecosystem services; therefore, R10, which restores the capacity of ecosystems to provide these services, creates conditions for the implementation of all other strategies. Moreover, the generations that benefited from ecosystem degradation bear a moral responsibility to future generations to restore this capital.

To operationalize R10, a system of indicators is proposed for each natural ecosystem that is the object of an R10 strategy: (1) baseline level of ecosystem services (current state); (2) target level of ecosystem services (state after regeneration); (3) R10 indicators—quantitatively measurable progress indicators. These indicators can be integrated into corporate reporting systems, as well as into payments for ecosystem services (PES) schemes and carbon markets.

Conclusions. The classical 10R hierarchy, despite its value for managing technospheric flows, is insufficient for addressing the problem of natural ecosystem degradation. Introducing the R10 "Regenerate" strategy at the apex of the hierarchy allows overcoming this gap by creating a biospheric foundation for all other R-strategies. R10 does not replace R0–R9 but complements them, transforming the circular economy from a "less harm" paradigm to an "active regeneration" paradigm. In practice, this means that the assessment of circularity of a product or business model should be based not only on technospheric indicators (share of recycled material, number of use cycles, etc.) but also on indicators of impact on ecosystem services. For example, "circular packaging" made of bioplastic may score high on the R8–R3 scale, but if its production leads to deforestation, it is not regenerative and cannot be considered fully circular in the sense of R10.

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THE ROLE OF DIGITAL TECHNOLOGIES IN THE DEVELOPMENT OF CIRCULAR BUSINESS MODELS

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Unlike traditional product sales models, circular business models require continuous access to information regarding a product's condition, location, intensity of use, and potential for reintroduction into the economic cycle. Digital technologies have, for the first time, provided the technical capability to collect and process such data in real time. This has created the conditions for the development of service-based, platform-based, and closed-loop business models that enable more efficient resource utilisation and reduce environmental pressures.

In particular, the Internet of Things (IoT) enables continuous monitoring of product conditions and control over product use throughout the life cycle, thereby providing the foundation for Product-as-a-Service, rental, leasing, pay-per-use, and predictive maintenance models.

Artificial Intelligence (AI) facilitates the analysis of large datasets, demand forecasting, and the optimisation of resource utilisation, thereby supporting the development of sharing platforms, reverse material flow management systems, product reuse models, and waste reduction strategies.

Blockchain technology enhances the transparency and traceability of value chains, supporting the operation of secondary resource trading platforms, product take-back systems, reuse and recycling models, and interaction mechanisms among participants within circular ecosystems.

Digital twins provide a digital representation of physical objects and processes throughout their entire life cycle, creating the conditions necessary for implementing repair, upgrade, refurbishment, and remanufacturing models.

Cloud computing enables data integration among manufacturers, consumers, repair organisations, and recycling companies, which is an essential prerequisite for the operation of digital platforms within the circular economy.

Digital technologies have acted as key drivers of the following groups of circular business models (Table 1):

- life-extension models (repair, upgrade, refurbishment, and remanufacturing);
- service-based models (Product-as-a-Service, pay-per-use, and leasing);
- platform-based models (the sharing economy, secondary resource marketplaces, and digital reverse logistics platforms).

Table 1. Circular business models enabled by digital technologies (Bressanelli et al., 2018; Kristoffersen et al., 2020; Centobelli et al., 2023; Pagoropoulos et al., 2022)

Digital technology	**Main capabilities**	**Circular business models**
Internet of Things (IoT)	• Real-time monitoring of product conditions • Collection of usage data • Remote management	• Product-as-a-Service (PaaS) • Rental and leasing models • Pay-per-use • Predictive maintenance • Product life extension
Artificial Intelligence (AI)	• Analysis of large datasets • Demand forecasting • Resource optimisation • Automated decision-making	• Sharing platforms • Predictive maintenance • Reverse logistics optimisation • Product reuse and recovery models • Dynamic pricing to reduce waste
Blockchain	• Traceability of materials and products • Supply chain transparency • Digital trust • Smart contracts	• Secondary resource trading platforms • Take-back systems • Reuse and recycling models • Peer-to-peer resource and energy exchange
Digital Twin	• Digital representation of the product life cycle • Prediction of technical conditions • Operational optimisation	• Product life-extension models • Repair and upgrade • Refurbishment • Remanufacturing • Circular supply chain management
Cloud Computing	• Storage and processing of large volumes of data • Integration of ecosystem participants • Scalability of digital services	• Digital sharing platforms • Product-as-a-Service • Secondary resource marketplaces • Product repair and reuse platforms
Integrated application of IoT, AI, Blockchain, Digital Twin & Cloud Computing	Creation of a unified digital environment for product management throughout the entire life cycle	• Circular ecosystems • Closed-loop supply chains • Digital Product Passports • Resource-as-a-Service

Digital technologies have created the conditions for a transition from traditional product sales models to business models based on service provision, asset sharing, product life extension, and the organisation of closed material loops. Collectively, these technologies form the foundation, or technological environment, for managing products throughout their entire life cycle. Their application enables the collection, processing, and transmission of vast amounts of product-related data, which constitutes a fundamental prerequisite for the development of the digital infrastructure of the economy.

At the same time, it should be recognised that digitalisation does not automatically guarantee sustainable development, as it may also be accompanied by increasing energy consumption and growing pressures on natural resources.

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ECOLOGICAL RHETORIC IN BRAND ADVERTISING COMMUNICATIONS: CONTENT ANALYSIS OF INSTAGRAM ACCOUNTS OF THE COCA-COLA COMPANY AND NESTLÉ

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Introduction. The growing environmental awareness of consumers has driven an intensification of "green" rhetoric in the marketing communications of global corporations. According to PwC (2023), 80% of consumers worldwide are willing to pay an average premium of 9.7% for products that meet environmental standards, while the adoption of corporate social responsibility practices increases company sales by 20%. However, alongside genuine environmental initiatives, the phenomenon of "greenwashing" has become widespread – defined as the manipulative construction of an environmental image without corresponding real actions (Oceana, 2022). Evidence of this manipulative image-building is the fact that Coca-Cola has topped the ranking of the world's largest plastic polluters for 6 consecutive years (Break Free From Plastic, 2024) while simultaneously positioning itself as an environmentally responsible company. The aim of this study is to identify the tools of ecological rhetoric in the Instagram communications of The Coca-Cola Company and Nestlé and to evaluate their "greenwashing" practices. The object of the study is the advertising and corporate Instagram publications of both companies, and the subject of the study is the characteristics of textual and visual elements in their ecology-related Instagram posts.

Materials and methods. The study employs the content analysis method. The sample was drawn from 1,127 publications from the Instagram accounts of The Coca-Cola Company (sub-accounts of the following brands: Coca-Cola, Fanta, Sprite, Fuze, Diet Coke, etc.) and Nestlé (sub-accounts: Nescafe, Nespresso, KitKat, etc.) for the period from October 2024 to October 2025. The developed category system encompasses eight blocks: specificity of eco-concepts (general, strategic, specific, industry-specific); thematic focus (plastics, water resources, sustainable agriculture, climate); tonality (positive, neutral, negative); presence of evidentiary support; subject of responsibility; and visual and audio components. In this study, ecological visual elements are understood as the dominance in publication design of colors that consumers associate with nature, purity, and sustainability: green (grass, leaves, vegetation, organic produce), blue (clean water, sky, ocean, freshness), and earthy shades of brown and beige (soil, natural raw materials, craft packaging).

Results. There are significant differences in the ecological rhetoric of the two companies (Table 1). Among The Coca-Cola Company's publications, only 2 out of 207 posts (0.97%) contained any ecological mentions (a Fuze Tea post featuring a recycling symbol). These messages addressed general eco-concepts in the context of packaging, appealed to consumers in a positive tone using emotional language, and were entirely lacking in evidentiary support. This result reflects the overall communication strategy of Coca-Cola Company's brands, which is focused on lifestyle identity rather than sustainability: Coca-Cola appeals to youth and fashion trends, Fanta showcases youth aesthetic culture and a summer mood, Sprite appeals to hip-hop culture, and Diet Coke targets glamorous Instagram fashion. Eco-themes are irrelevant in this context, as they require longer explanations and less visually striking content.

Table 1 – Comparative characteristics of company ecological rhetoric on Instagram (October 2024 – October 2025)

Indicator	The Coca-Cola Company	Nestlé
Number of publications analyzed	207	119
Share of eco-publications	0.97% (2 posts)	47.06% (56 posts)
Predominant thematic focus	General eco-concepts (packaging)	Strategic (55.36%), industry-specific (37.5%)
Tonality	Positive, no evidence	Positive – 78.57%, critical –1.79%
Evidentiary support	Absent	71.43% include references or data
Subject of responsibility	Appeal to consumer	Corporate responsibility (89.29%)
Ecological color palette	Absent (brand colors dominant)	Present in 60.71% of posts (green, blue, brown)

* Compiled by the authors based on a content analysis of Instagram publications.

47.06% of Nestlé's publications contain ecological rhetoric. The predominant messages (55.36%) address CSR topics, circular economy, supply chains, and efficient water use. Additionally, themes directly related to the company's field of activity are represented (37.5%): coffee, cocoa, and regenerative farming.

A notable feature of Nestlé's communication is the active use of an ecological color palette (green, blue, and brown-beige tones) in 60.71% of its environmental publications. This creates unconscious associations with nature and sustainability in the consumer's mind before they even read the text. At the same time, 71.43% of publications are supported by evidence or references to reports, yet only 26.79% include specific numerical indicators. Positive tonality is dominant in the messaging (78.57%), while critical content accounts for only 1.79% of all reviewed publications. Corporate responsibility is declared in 89.29% of eco-publications, yet calls to consumer action are recorded in only 1.79% of cases. Visually, images of processes and people predominate (58.93%).

In particular, the majority of the company's brands emphasize the sustainability of farming. For instance, Nescafe's communication focuses on regenerative farming, responsible sourcing of coffee beans, and producer support (76.92% of publications –

one of the highest figures among all sub-brands). Positive tonality (76.92%) and emotional language (76.92%) predominate, with images of people and processes leading visually (53.85%). Meanwhile, negative or critical mentions are entirely absent (0%), indicating an even more pronounced strategic avoidance of problematic discourse compared to the parent brand.

The vast majority of Nespresso content (92.57%) contains no broad ecological mentions: eco-narratives are used extremely selectively, only where they reinforce the image of a premium and technologically advanced brand (B Corp certification, capsules made from 80% recycled aluminium). Within KitKat's social media page, no eco-discourse was identified whatsoever. The brand focuses exclusively on product marketing, entertainment, and emotional branding, targeting a pop-culture communication format.

Conclusions. The ecological rhetoric of both brands functions primarily as an image-building tool rather than as a reflection of actual practices. In particular, Nestlé demonstrates a diversified eco-discourse across three levels of environmental issues (water, climate, farming). Coca-Cola doesn’t employ eco-communication at all. Nestlé systematically uses emotional imagery and language to construct an image of environmental leadership. The following indicators of "greenwashing" were identified in Nestlé: the dominance of declarative and emotional rhetoric over verifiable quantitative data; the complete absence of critical discourse regarding the company's own negative environmental impacts; and the positioning of the brand as a fully responsible actor without detailing systemic environmental problems. Prospects for further research include longitudinal analysis and comparative research across the regional accounts of both companies.

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CIRCULAR TRANSFORMATION OF INDUSTRIAL SYSTEMS: PRACTICAL ASPECTS AND IMPLEMENTATION MECHANISMS

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Introduction. Modern industry operates predominantly on a linear "take-make-dispose" model, leading to resource depletion, waste accumulation, and rising emissions. The transition to a circular economy, where waste becomes a resource, is a strategic imperative for achieving sustainable development. According to the Ellen MacArthur Foundation, circular approaches could reduce global greenhouse gas emissions by 39% and generate €1.8 trillion in economic benefits by 2030 (Circular, 2022).

Despite significant academic progress in the field of circular economy, practical implementation across industrial sectors remains uneven. Key barriers include high upfront investment costs, regulatory fragmentation, technological lock-in, and a lack of viable business models (The Circular, 2024).

Each industry has its own specific focus:

- Metallurgy emphasises scrap recycling and decarbonisation;
- Chemical industry operates at the molecular level, replacing fossil-based carbon with renewable sources;
- Machine building prioritises remanufacturing and product life extension;
- Construction and textiles develop cascading material use and chemical recycling.

The purpose of this study is to identify and systematise the practical mechanisms, tools, and challenges of circular transformations across key industrial sectors, drawing on international experience to formulate actionable recommendations for industrial policy.

Results. The analysis reveals that circular transformations are implemented through four interconnected strategic directions.

1. Transformation of the resource base – the shift from primary resource dependency to integrating secondary raw materials into production processes. Key mechanisms include:

- Industrial symbiosis – the exchange of waste and by-products between enterprises. The classic example is Kalundborg (Denmark), where a power plant, oil refinery, pharmaceutical company, and gypsum manufacturer systematically exchange heat, water, and materials (Jacobsen, 2006). Research confirms that such systems achieve efficiency gains of up to 30%.
- Urban mining – extracting valuable minerals from accumulated mining and metallurgical waste. The Re-Machine project (Germany) demonstrates the recovery

of critical materials with 90% lower energy consumption compared to primary extraction.

- Chemical recycling – processing complex waste streams (e.g., mixed plastics) at the molecular level. Plastic Energy's TAC™ pyrolysis technology converts plastic waste into TACOIL™, which serves as a replacement for conventional naphtha in existing petrochemical plants. An independent Life Cycle Assessment verified that TACOIL reduces CO_2 equivalent emissions by up to 78% compared to incineration with energy recovery (Chemical, 2025).

2. Improving resource and energy efficiency – reducing material intensity, energy consumption, and resource losses:

- RECP audits (Resource Efficient and Cleaner Production) identify 10-30% savings potential without significant capital expenditure. The UNIDO Global RECP Programme has been implemented in over 50 countries, demonstrating that resource-efficient and cleaner production approaches can significantly improve environmental and economic performance.
- Eco-industrial parks – industrial zones where enterprises jointly use resources, energy, and infrastructure. Research from the World Economic Forum indicates that industrial clusters applying circular principles achieve 20-35% energy reduction and 40-60% waste reduction.
- Digital twins and IoT monitoring enable real-time optimisation of resource flows, delivering 12-18% reduction in environmental impacts without increasing operational costs (State, 2024).

3. Greening and decarbonisation – reducing greenhouse gas emissions and environmental impact:

- CBAM (Carbon Border Adjustment Mechanism) and the EU Emissions Trading System (EU ETS) create economic incentives for emission reduction. Carbon prices exceeding €80/t CO_2 stimulate investment in cleaner technologies (State, 2024).
- Life Cycle Assessment (LCA) integrated with process simulation enables multi-criteria optimisation.
- EU Ecodesign for Sustainable Products Regulation (ESPR), which entered into force in July 2024, establishes a framework for setting ecodesign requirements on specific product groups, extending the scope to virtually all physical products (Ecodesign, 2024; Neramballi, 2024). The Regulation introduces Digital Product Passports (DPPs) – digital identity cards for products, components, and materials storing relevant information to support sustainability and circularity (Ecodesign, 2024).

4. Formation of closed-loop production cycles – extending product life, remanufacturing, and creating circular value chains:

- Remanufacturing preserves up to 80-85% of embedded energy and materials compared to new production. Caterpillar's CAT REMAN programme, which began in 1973, processes over 2 million components annually and has achieved reductions in water use by 93%, energy use by 86%, and waste sent to landfill by 99%.

- Digital Product Passports (DPP) ensure traceability of materials, repairability, and recyclability, enabling informed decisions at end-of-life (Ecodesign, 2024).
- Circular wood value chains – the SirkTRE project in Norway (budget NOK 181 million, 30+ partners) demonstrates systematic reuse of wood waste. Analysis shows over 50% of incoming recycled wood is of sufficient quality for reuse, and by 2030 the project aims to reuse 1 million m³ of wood waste annually, potentially reducing Norway's CO_2 emissions by 8% (Circular Wood, 2024).

Barriers to implementation. Despite proven effectiveness, scaling circular transformations is constrained by systemic obstacles: high initial capital costs, regulatory inconsistencies, lack of quality standards for secondary materials, and the need for trust-based collaboration across stakeholders (Durdyev, 2023; OECD, 2024). For example, the World Economic Forum highlights that while industrial clusters make exchange of resources more practical, "without regulatory alignment, shared classifications and data legibility for interoperability, any surplus stays stranded".

Conclusions. Practical circular transformations cannot be implemented using a one-size-fits-all approach – each industry requires its own strategies. Research on transformational processes in production industries confirms that "the implementation of industrial symbiosis, urban mining for the extraction of metals from urban waste, and the use of renewable materials" are key global trends.

- Metallurgy demonstrates the highest readiness for resource-base transformation through established scrap collection and recycling systems.
- Machine building leads in product life extension through remanufacturing and service-based models.
- Chemical industry requires technological breakthroughs in catalytic and biochemical conversion processes.
- Construction and textiles, which generate the largest waste volumes, require systemic product redesign and development of reverse logistics infrastructure.

The circular transition requires an integrated approach combining regulatory instruments (CBAM, Extended Producer Responsibility, Ecodesign), financial mechanisms (green bonds, tax incentives), digital infrastructure (Product Passports, symbiosis platforms), and industrial collaboration (eco-parks, waste exchange networks). For countries at early stages of circular transformation, priorities should include RECP audits at enterprises, pilot industrial symbiosis projects, and capacity building for circular design standards.

The economic case is increasingly compelling:

- remanufacturing delivers 70-90% material savings;
- industrial symbiosis improves efficiency by 30%;
- chemical recycling creates new value from waste streams with up to 78% CO_2 reduction (Chemical, 2025).

However, realising this potential at scale requires sustained policy commitment, cross-sectoral collaboration, and long-term investment in enabling circular infrastructure.

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INDICATORS OF THE FACTORS DEFINING TRANSACTION COST CATEGORIES IN THE IMPLEMENTATION OF ARTIFICIAL INTELLIGENCE AND INTERNET OF THINGS TECHNOLOGIES

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Introduction. The implementation of artificial intelligence (AI) and Internet of Things (IoT) technologies has become a defining feature of contemporary digital transformation. According to the OECD (2025), the average share of firms using AI technologies across OECD economies reached 20.2% in 2025, compared with 14.2% in 2024 and 8.7% in 2023, indicating that adoption has more than doubled within two years. A similar dynamic is observed in the European Union, where 20.0% of enterprises with ten or more employees used AI technologies in 2025, an increase of 6.5 percentage points from 13.5% in 2024 (20% of EU , 2025; Artificial, 2025). McKinsey & Company (2025) reports that 88% of organizations worldwide already use AI in at least one business function, while 62% are at least experimenting with AI agents and advanced analytical solutions. At the same time, organizations face increasing expenditures related to cybersecurity, legal compliance, supplier selection, algorithm verification, and governance mechanisms. These expenditures correspond to the concept of transaction costs, first introduced by Coase R. (1937) and systematically developed by Williamson O. (1985). The purpose of this study is to identify the categories of transaction costs arising in the implementation of AI and IoT technologies and to substantiate the indicators that characterize the factors shaping these categories.

Materials and methods. The study applies an approach based on comparative analysis, synthesis, and transaction cost economics. Secondary statistical information is collected from international analytical reports published during 2025 and 2026, including the OECD report on the adoption of artificial intelligence in firms (The Adoption, 2025), the Eurostat survey on ICT usage in enterprises (20% of EU, 2025), the McKinsey Global Survey on the state of AI (The state, 2025), the Deloitte study on generative AI in the enterprise (The State, 2026), the PwC Responsible AI Survey and AI Jobs Barometer (PwC, 2025; 2026 AI Global, 2026), and the IBM Cost of a Data Breach Report (Cost, 2025).

Results. Three transaction cost categories are identified based on the theoretical framework of Williamson O. (1985) and adapted to digital transformation processes: information costs associated with searching and selecting AI and IoT technologies, contractual costs related to negotiation, licensing, and legal protection, and monitoring costs connected with cybersecurity, algorithm auditing, and regulatory compliance.

The first category comprises information transaction costs arising before implementation. These costs include market intelligence, supplier evaluation, technological compatibility assessment, and feasibility studies. As more vendors enter the market, enterprises invest additional resources in identifying trustworthy suppliers, evaluating interoperability, and reducing information asymmetry. The scale of the search problem is illustrated by the pronounced sectoral differentiation of adoption. In the OECD area, the information and communication technology sector leads with 57.3% of firms using AI, while adoption in construction, hospitality, and agriculture remains below 10% (The Adoption, 2025). In the European Union, the information and communication sector recorded 62.5% of enterprises using AI technologies in 2025, followed by professional, scientific and technical service activities with 40.4% (Artificial, 2025). Such heterogeneity increases the cost of benchmarking, vendor comparison, and technology selection for enterprises in less digitalized sectors.

The second category consists of contractual transaction costs. These expenditures include legal negotiations, software licensing, intellectual property protection, contractual risk allocation, and compliance with emerging AI regulations. Enterprises allocate growing financial resources to legal consulting and compliance management. The relevance of this category is confirmed by governance gaps identified in recent studies. 63% of breached organizations either do not have an AI governance policy or are still developing one, and among those that have such policies only about one third perform regular audits for unsanctioned AI use (Cost, 2025).

The third category represents monitoring transaction costs and has become the most significant component of transaction costs associated with AI implementation. IBM (2025) reports that the global average cost of a data breach declined to USD 4.44 million, a 9% decrease compared with USD 4.88 million in the previous year and the first decline in five years, driven primarily by faster identification and containment of incidents through AI-powered security tools. At the same time, incidents involving uncontrolled AI applications, known as shadow AI, generated additional losses. One in five organizations reported a breach linked to shadow AI (Cost, 2025). Moreover, 97% of organizations that experienced an AI-related security incident lacked proper AI access controls (Cost, 2025). These findings illustrate the growing importance of continuous monitoring, cybersecurity, algorithm auditing, and regulatory verification.

McKinsey & Company (2025) also reports that nearly two-thirds of organizations have not yet begun scaling AI across the enterprise, and only 39% attribute any measurable impact on earnings before interest and taxes (EBIT) to AI, in most cases below 5% of total EBIT. At the same time, 64% of respondents state that AI enables their innovation, and 80% set efficiency as an objective of their AI initiatives (The state, 2025). This indicates that implementation barriers are organizational and institutional.

The proposed classification demonstrates that transaction costs extend beyond traditional market exchanges and increasingly reflect the complexity of digital ecosystems. Information costs dominate the initial implementation stage, contractual costs become critical during technology acquisition and integration, whereas monitoring costs remain significant throughout the entire technology life cycle. Unlike traditional capital investments, transaction costs arise before, during, and after technology implementation and significantly influence project success.

Table 1 presents the principal indicators that characterize the factors defining the three proposed categories of transaction costs. For indicators available in comparable form for two consecutive years, the values for 2024 and 2025 are shown together with the absolute change. Indicators introduced into international surveys only in 2025 are marked as not available (n/a) for the previous year.

Table 1. Dynamics of indicators shaping transaction cost categories for AI and IoT implementation, 2024-2025

№	Indicator	2024, %	2025, %	Absolute growth, pp.	Transaction cost category
1	Enterprises using AI, OECD average (The Adoption, 2025)	14.2	20.2	6.0	Information costs
2	Enterprises using AI, EU average (20% of EU, 2025)	13.5	20.0	6.5	Information costs
3	ICT sector enterprises using AI, EU (20% of EU, 2025)	48.7	62.5	13.8	Information costs
4	Companies using AI in at least one business function (The state, 2025)	78	88	10.0	Information costs
5	Organizations at least experimenting with AI agents (The state, 2025)	n/a	62	-	Information costs
6	Organizations not yet scaling AI enterprise-wide (The state, 2025)	n/a	66	-	Monitoring costs
7	Companies reporting measurable EBIT impact from AI (The state, 2025)	n/a	39	-	Monitoring costs
8	Organizations reporting that AI enables their innovation (The state, 2025)	n/a	64	-	Monitoring costs
9	Companies setting efficiency as an objective of AI initiatives (The state, 2025)	n/a	80	-	Contractual costs
10	Breached organizations lacking AI governance policies (Cost, 2025)	n/a	63	-	Contractual costs

The dynamics presented in Table 1 allow the character of the observed changes to be assessed. The average share of firms using AI increased by 6.0 percentage points across the OECD and by 6.5 percentage points in the European Union, which corresponds to an increase of approximately 1.4 to 1.5 times within a single year (The Adoption, 2025; 20% of EU, 2025; Artificial, 2025). The ICT sector shows the largest absolute gain of 13.8 percentage points, which widens the sectoral gap and intensifies information asymmetry between digital leaders and laggard industries (20% of EU, 2025; Artificial, 2025). The share of companies using AI in at least one business function rose from 78% to 88%, indicating that adoption at the level of individual functions is approaching saturation (The state, 2025). Together these changes signal a growing volume of information transaction costs, since an expanding heterogeneous supplier market raises the cost of search, comparison, and selection.

The opposite direction of change is observed for the monetary indicator of monitoring costs. The average global cost of a data breach decreased by USD 0.44 million, or 9%, which represents the first decline in five years and is attributed to faster identification and containment of incidents through AI-powered security tools (Cost, 2025). This decrease is demonstrated that systematic investment in monitoring, governance, and AI-based security generates measurable returns.

The findings suggest that monitoring costs currently represent the most significant transaction cost component due to growing cybersecurity risks, algorithm verification requirements, and regulatory compliance obligations. Information costs remain essential because of increasing technological diversity. Contractual costs are expanding under new AI governance regulations.

Conclusions. The study confirms that transaction costs constitute an important determinant of AI and IoT implementation effectiveness. Information costs dominate the pre-implementation stage and reflect growing technological diversity and information asymmetry between vendors and adopters. Contractual costs expand under emerging AI governance regulations and require systematic investment in legal expertise and compliance management. Monitoring costs represent the largest and most persistent component throughout the technology life cycle. The gap between the 88% adoption rate and the 39% share of organizations reporting measurable EBIT impact indicates that institutional and organizational factors, rather than technological ones, constrain digital transformation.

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SUSTAINING UKRAINIAN HIGHER EDUCATION IN CHALLENGING TIMES

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Introduction. Since February 2022 the Ukrainian higher education system has been operating under difficult conditions that affect its functioning, stability and future development (Antoniuk, 2023). Universities located in frontline regions have had to adjust quickly in order to ensure the continuity of education, support students and staff, and maintain academic quality. In these circumstances, the concept of institutional resilience, understood as the ability of the system to cope with crises, adapt to change and recover, has gained particular significance (Lengnick-Hall et al., 2011). The purpose of this study is to examine how the current situation affects Ukrainian higher education institutions (HEIs) and to identify the adaptation strategies that help them sustain their activities.

Materials and methods. The study focuses on three universities located in frontline regions: Sumy State University, Zaporizhzhia National University and Kharkiv National Medical University. The empirical basis comprises 15 semi-structured interviews with representatives of these universities and eight interviews with experts from the wider higher education ecosystem, complemented by document analysis and on-site observation by the authors. The results are interpreted through the framework of educational resilience, organisational resilience (Lengnick-Hall et al., 2011) and complex adaptive systems theory (Mason, 2008).

Results. The crisis has affected all core dimensions of higher education. Between 2020 and 2024 the number of Ukrainian HEIs declined from 515 to 314 and the number of students decreased by over 16 percent. Universities in frontline regions saw their academic staff numbers fall by approximately 23 to 26%, reflecting broader patterns of migration and mobilisation (Antoniuk, 2023). The decline in international student enrolment proved financially significant. Research activities have also been affected, as prolonged stress reduces the concentration and productivity of researchers, while limited access to laboratories complicates experimental work. In response, scientific policy has shifted towards applied research, and Ukrainian enterprises have submitted a growing number of requests for research and development, particularly in engineering and medicine.

At the same time, HEIs demonstrated considerable adaptive capacity. They expanded digital and hybrid learning building on the experience of the COVID-19 pandemic, introduced flexible curricula, assessment formats, modular courses and micro-credentials, adapted their infrastructure, intensified international cooperation and strengthened the third mission of community engagement. Flexible approaches to assessment were introduced, including feedback-based formats without grades and group-based evaluation of collaborative student work. New courses and programmes reflecting current professional demands, such as clinical psychology, prosthetics and social work, have been launched.

Attention to the mental health and well-being of students and staff has become an integral element of institutional practice, although a policy framework in this area is still being developed. Classroom practices such as brief sensory engagement and the preservation of a regular schedule serve as psychological anchors that support a sense of normalcy and continuity.

Conclusions. Ukrainian frontline universities have maintained continuity and adapted to challenging circumstances, confirming the explanatory value of resilience and systems-based perspectives. Persistence, adaptation and transformation are all empirically observable. At the same time, certain vulnerabilities remain, particularly the outflow of human capital, financial dependence on the state and the limits of digital learning as a substitute for in-person interaction.

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DEVELOPMENT OF LOGISTICS SYSTEMS IN THE CONTEXT OF DIGITAL TRANSFORMATION OF THE ECONOMY

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Introduction. The digital transformation of logistics systems has emerged as a strategic driver of sustainable economic development, fundamentally reshaping supply chain management through the integration of advanced digital technologies. In the context of increasing environmental and energy challenges, digitalization enhances operational efficiency, reduces transaction and logistics costs, and strengthens coordination among supply chain stakeholders while supporting the transition toward climate-neutral and resource-efficient economic systems. Consequently, digital transformation serves as a critical enabler of the Green Deal objectives, energy transition strategies, and the implementation of the United Nations Sustainable Development Goals (SDGs).

Data and Methods. The study is based on the analysis and synthesis of international scientific literature and best practices concerning the digital transformation of logistics systems within the framework of green and energy transitions. Comparative analysis was applied to examine the implementation of digital technologies across different countries and industries, while a systems approach was employed to identify the interrelationships between digitalization, environmental sustainability, and logistics performance.

International experience demonstrates that both developed economies and emerging markets successfully employ digital technologies to improve the environmental and economic performance of logistics systems. The European Union, the United States, Japan, and other technologically advanced countries have actively implemented smart logistics systems integrating IoT, AI, blockchain, and big data analytics to create energy-efficient, low-carbon, and highly transparent supply chains [1]. These digital solutions optimize transport routes, minimize operational costs, improve energy management, and significantly reduce the environmental footprint of logistics operations.

Current research identifies several key directions in which digital technologies contribute to the development of sustainable logistics systems:

– Green logistics. Digital technologies enable continuous monitoring of fuel consumption, energy use, greenhouse gas emissions, traffic conditions, and vehicle performance.

– Supply chain transparency and traceability. Blockchain technology significantly improves the transparency, security, and traceability of logistics processes by ensuring immutable records across all stages of the supply chain.

– Collaborative supply chain management. Digital supply chain platforms improve coordination among manufacturers, logistics providers, suppliers, and customers by enabling real-time information exchange, collaborative planning, and integrated decision-making.

The international experience demonstrates that digital transformation represents one of the most effective mechanisms for integrating environmental sustainability with technological innovation. The deployment of renewable energy sources, intelligent transportation systems, digital logistics platforms, and energy-efficient technologies contributes to substantial reductions in CO_2 emissions, lower energy consumption, improved resource efficiency, and enhanced competitiveness of logistics enterprises [2].

Conclusions. The findings confirm that digital transformation has become a fundamental determinant of innovation and sustainable development in logistics systems. The integration of advanced digital technologies significantly improves operational efficiency through process automation, artificial intelligence, and data-driven decision-making, leading to lower operating costs, shorter delivery times, and increased productivity. Digital inventory management and transportation management systems enhance forecasting accuracy and optimize resource allocation, while blockchain and IoT technologies ensure end-to-end visibility, transparency, and traceability throughout supply chains.

From an environmental perspective, digital technologies contribute substantially to green and energy transitions by optimizing transportation routes, minimizing energy consumption, reducing greenhouse gas emissions, and improving the efficiency of resource utilization. At the organizational level, the successful implementation of digital transformation requires continuous investment in human capital, digital competencies, and innovation capabilities, fostering an organizational culture that supports sustainable technological development and long-term competitiveness.

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BEHAVIOURAL PATTERNS OF POPULATION HEALTH IN UKRAINE UNDER HEALTHCARE DIGITALISATION

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Introduction. Public health in Ukraine is defined by the simultaneous action of war shock and accelerated digitalisation of healthcare. The expansion of eHealth services, telemedicine and digital self-management tools proceeds against deteriorating population health indicators, which points to behavioural mechanisms mediating the link between digital infrastructure and health outcomes (Stoumpos, Kitsios, & Talias, 2023). The purpose of this study is to identify stable behavioural patterns of the population that emerge under healthcare digitalisation in crisis conditions and to propose a cluster typology suitable for targeting public health interventions.

Materials and methods. The study is based on a systematic literature review with elements of conceptual modeling. Behavioural factors are classified into destructive, resource-proactive and ambivalent groups and synthesised in the Digital Public Health Behaviour (D-PHB) model, which integrates six theoretical frameworks: the ecological model, social cognitive theory (Bandura, 1977), the health belief model, the theory of planned behaviour (Ajzen, 1991), conservation of resources theory (Hobfoll, 1989) and the transtheoretical model (Prochaska, DiClemente, & Norcross, 1992). In the model, eHealth literacy acts as the predictor, perceived risks and behavioural intention as the mediator, and psychological state and resilience as the moderator of health behaviour.

Results. The interaction of the three D-PHB dimensions generates two polar behavioural patterns and, at a finer resolution, four population clusters. The adaptive (pro-health) pattern combines active use of digital health services, willingness to seek medical and psychological help, treatment adherence and a positive attitude to prevention, including vaccination. The maladaptive (risk) pattern combines low use of eHealth tools, avoidance of professional help, heightened susceptibility to disinformation, institutional distrust and refusal of vaccination or treatment. Within these patterns, four clusters are distinguished. The first, digitally adaptive cluster (high eHealth literacy, high resilience), converts digital access into health outcomes and partially compensates treatment gaps through telemedicine and digital coping practices such as online volunteering and support communities. The second, fragile digital cluster (high literacy, low resilience), illustrates the moderating role of psychological state. Despite sufficient competence, exhaustion of material, social and psychological resources produces avoidant strategies, which is consistent with conservation of resources theory and with the observed gap between the 72 % of the population reporting anxiety or depression symptoms and the roughly 20 % who seek professional help (WHO EURO, 2026). The third, digitally excluded cluster (limited access or low literacy, about one third of the population without access to digital channels) is the zone where ambivalent factors switch to destructive outcomes. Self-treatment based on unreliable information and deepening health inequality. The fourth, resistant cluster (low literacy combined with institutional distrust) concentrates vaccination refusal driven by antivaccination content in messenger channels; with measles coverage below the 95 % herd immunity threshold, this cluster accounts for the rise of measles cases in the 2025 (WHO UNICEF, 2025). Destructive factors dominating the maladaptive clusters, namely interruption of NCD treatment (up to 80 percent of persons with NCDs unable to obtain medicines), refusal of vaccination and avoidance of psychological help, aggregate into a population-level health deficit that raises the load on the healthcare system and requires macro-level digital, financial and regulatory responses.

Conclusions. Behavioural patterns determine whether healthcare digitalisation reduces or amplifies health inequality. he same eHealth environment produces opposite outcomes across the four identified clusters. The cluster typology derived from the D-PHB model provides a targeting map for public health policy. Scaling telemedicine and digital reminders is effective for the adaptive and fragile clusters, whereas the excluded and resistant clusters require offline outreach, eHealth literacy programmes and trust-restoring communication before digital instruments can work. Priority interventions include behavioural nudge design in national eHealth platforms for NCD treatment persistence and vaccination, combined with the restoration of physical access to medicines and services, since digital solutions alone remain necessary but insufficient in the current crisis.

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ECONOMIC MECHANISM OF BEHAVIORAL DETERMINANTS OF PUBLIC HEALTH IN UKRAINE UNDER DIGITALIZATION[1]

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The digitalization of the healthcare system in Ukraine has created an information-analytical infrastructure that has simultaneously generated a new class of economic challenges: how to transform vast arrays of population behavioral data into mechanisms for changing that behavior in favor of health. Today, the Ukrainian eHealth system unites over 49,000 medical and pharmacy institutions, 475,000 medical and pharmaceutical professionals, and contains 5 billion medical records in the electronic patient chart [1]. The number of electronic medical records doubled in 2025 compared to 2023 [2]. Such infrastructure serves as a tool for building an economic mechanism for managing behavioral determinants of population health.

Behavioral economics proceeds from the concept of bounded rationality of the population regarding the ability to process information when making decisions about their own health [3]. The economic mechanism of behavioral health determinants under digitalization can be described through interrelated processes. First, digital platforms are used to influence activity in health applications and public services. At the same time, personalization through artificial intelligence and real-time behavior tracking increase the effectiveness of such interventions [5]. That is, the architecture of the e-prescription, e-referral, and the patient's personal account in the Electronic Healthcare System (EHS) is simultaneously a medical and a behavioral-economic tool. The system generates e-referrals and e-prescriptions [2], which record decision-making by both patient and physician, and can be used for targeted influence on treatment adherence.

Second, feedback processes that provide immediate information about health-related behavior enhance patient self-monitoring and self-correction [4]. The third group of processes comprises the application of telemedicine in healthcare, which entails a reduction in transaction costs when adjusting health behavior trajectories. In 2024, telemedicine services were included in 31 out of 41 medical service packages in Ukraine, almost three times more than in 2023 [6]. This reduced time and geographic barriers to seeking medical care, eliminating transaction costs as behavioral barriers to preventive activity. Furthermore, digitalization ex-ante allows reducing the burden on healthcare workers through the operation of electronic

[1] The paper is prepared in the framework of project “Modeling the impact of digitalization of the economy on the state of public health in Ukraine in the context of preserving human capital” (No. 0126U001085)

services, while administrative bodies gain tools for formulating evidence-based health policy [7].

Thus, the effectiveness of digital behavioral interventions in public health is determined by the technological maturity of the platform and the quality of the economic design of incentive mechanisms. Specifically, the processing speed of requests to the central EHS database increased by 20% in 2024 compared to 2023, while the system's uptime rate reached 99.8% [1], meaning the technological infrastructure has already achieved an effective level.

The behavioral intervention model entails evaluating effects at early stages of development. This involves using randomized controlled trials to test intervention options through digital health services.

A distinct structural challenge to realizing the potential of healthcare digitalization in Ukraine is the phenomenon of technological skepticism and active rejection of digital medical tools among certain population cohorts. According to Eurobarometer data [8], about 34% of citizens of EU countries with comparable levels of digital development express concerns about the security of personal medical data in electronic systems. In Ukraine, this factor is amplified by public fears regarding the use of EHS data by hostile intelligence services, which creates a psychological barrier to registration in the system and to providing medical information in digital format. Thus, the rejection of digitalization in healthcare is a rational response by the population to a security threat, which fundamentally distinguishes the Ukrainian situation from standard models of technological resistance described in the classical technology acceptance model [9].

Age and geographic differentiation in the rejection of digital medical services generate significant health inequality that risks becoming structurally entrenched. According to the Ministry of Health of Ukraine [7], over 33% of the population (predominantly older age groups, residents of rural and frontline areas) lack access to digital health channels, while the proportion of elderly patients among those with chronic non-communicable diseases requiring continuous treatment is the highest. The paradox of digital transformation is that it is most effective precisely for that segment of the population that uses it the least. That is, elderly people with chronic diseases, residents of de-occupied and frontline communities, and internally displaced persons without stable Internet connectivity cannot use digital health services. According to diffusion of innovations theory [10], these population groups correspond to the categories of "late majority" and "laggards," for whom transition to digital formats requires intermediaries capable of converting digital tools into familiar behavioral patterns of seeking help.

The economic consequence of rejecting digitalization is the so-called "analog medicine trap," whereby a portion of the population remains in the extra-systemic medical space, generating hidden costs that are not reflected in standard medical statistics. Individuals who refuse e-prescriptions, telemedicine, and electronic appointment booking are more likely to seek emergency care at later stages of illness, which increases treatment costs. Hospitalization costs are 19-32% higher compared to outpatient management costs [11]. In circumstances where healthcare financing in Ukraine is under significant pressure from military expenditures, the hidden cost of rejecting digitalization is an issue that requires targeted behavioral interventions (for example, trust-based marketing of digital medical services, incentive mechanisms within the National Health Service of Ukraine (NHSU) medical guarantees program, and others).

Thus, the combination of the eHealth digital infrastructure, behavioral economics principles, and telemedicine tools forms the foundation in Ukraine for creating an economic mechanism for managing behavioral determinants of public health. A promising direction is the development of a system of personalized digital motivation factors based on EHS data, their pilot testing within the NHSU medical guarantees program, and the scaling of the most effective solutions with economic evaluation of cost-effectiveness per each changed patient decision.

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METHODOLOGICAL FRAMEWORK FOR ASSESSING STRUCTURAL CHANGES IN INDUSTRY UNDER ARTIFICIAL INTELLIGENCE ADOPTION

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Introduction. Structural changes in industry are sustained shifts in the proportions of economic activities, technological levels of production and the spatial allocation of capacities driven by technological, market and institutional factors (Nelson & Winter, 1982). The diffusion of artificial intelligence can be interpreted as a component of the emerging sixth techno-economic paradigm, characterised by the convergence of digital, cognitive and autonomous systems (Perez, 2010). For economies exposed to external shocks, the key analytical problem is to separate technology-induced structural dynamics from shock-induced dynamics, since the two require fundamentally different policy responses. The purpose of this study is to develop a methodological framework for the quantitative assessment of structural changes in industry under AI adoption that performs three functions: diagnostic (measuring the scale and direction of transformation), attributive (isolating the contribution of AI diffusion against other factors) and prognostic (scenario modeling of the future structure as a basis for sectoral priorities).

Materials and methods. The framework rests on a typology of five kinds of structural changes, each with its own transmission mechanism and its own measurement instrument: sectoral shifts (redistribution of output between activities), technological shifts (changes in the ratio of low-, medium- and high-technology production), concentration shifts (strengthening or weakening of the dominance of particular industries), price-physical shifts (separation of nominal changes into a price component and a real volume component) and spatial shifts (redistribution of capacities between regions). The information base combines official statistics on the volume of sold industrial products by economic activity and producer price indices with international sources on AI adoption: Eurostat enterprise-level data, OECD evidence on firm-level adoption, and sectoral productivity differentials from the PwC Global AI Jobs Barometer. The methodological design follows the evolutionary premise that structural changes are cumulative and path-dependent, which requires comparison of states over time rather than a static snapshot.

Results. The developed framework comprises three blocks of indicators, an eight-step assessment algorithm and a normative interpretation scale. The first block describes the dynamics of the structure: shares of activity groups, their absolute changes in percentage points and relative changes reflecting the intensity of repositioning irrespective of group size. The second block contains integral measures: the mass of the structural shift, defined as half the sum of the moduli of share changes and showing what part of total output changed its sectoral affiliation; the speed of the shift per year; the Gatev and Szalai coefficients; the Ryabtsev index as the principal integral measure, since it is bounded between zero and one, independent of the number of groups and equipped with a normative interpretation scale; the Herfindahl-Hirschman index of concentration together with the effective number of groups; and the correlation between the vectors of share changes in adjacent periods, whose sign shows whether the trajectory continues or reverses. A mandatory methodological requirement is the decomposition of nominal changes into price and physical components through producer price deflation, since conclusions about real structural dynamics drawn from current-price shares risk misdiagnosing price divergence as physical restructuring.

The attributive function is implemented through scenario modeling of the AI-induced shift. AI diffusion is described by a logistic trajectory consistent with the Bass framework (Bass, 1969), calibrated to the latest observed adoption level. The annual productivity premium is time-varying and proportional to the current diffusion level, scaled to the empirical differential of revenue-per-worker growth between the most and least AI-exposed industries (PwC, 2026).

Sectoral AI exposure combines the Eurostat technological intensity classification with occupational exposure estimates and takes values between zero and one. The projected structure is obtained as a normalized accumulated product of annual group multipliers, and the AI-induced mass of the shift and the Ryabtsev index of the scenario structure are computed against the factual base-year structure, which makes modeled and observed shifts directly comparable. Interpretation proceeds in three dimensions: the scale of the shift is read against the normative scale and a decision scale for industrial policy (evolutionary dynamics, moderate shift, significant shift, shock transformation); the direction is read from the sign of the correlation between the actual and the AI-induced shift vectors, distinguishing reinforcement of the current trajectory from a compensatory potential of AI; concentration is read from the joint dynamics of the HHI and this correlation, signaling the risk of excessive specialization and the need for horizontal diffusion of AI into low-exposure industries. The same time scenario calculations isolate only the differential productivity effect of AI under ceteris paribus assumptions and are not a comprehensive forecast. Calibration parameters are subject to annual revision, and the sensitivity of results to their variation is to be tested within a defined range.

The diagnostic block of the framework has undergone a partial approbation on official data of the State Statistics Service of Ukraine (State, 2025; Minfin); the calculations cover sectoral shifts, the integral indices, concentration and the export dimension, while the price-physical decomposition, the assessment of technological and spatial shifts and the attributive scenario modeling of the AI-induced shift remain subjects of the full-scale validation. The structural dynamics of Ukrainian industry in 2014-2025 forms three regimes: evolutionary (2014-2019, Ryabtsev index 0.062, speed 1.05 percentage points per year), shock (2019-2022, 0.179 and 4.35 pp per year) and adaptive (2022-2025, 0.101 and 3.39 pp per year), with the cumulative shift of 16.11 pp formed by the war period by more than 90 %. The negative correlation between the shock and adaptive shift vectors (-0.461) qualifies the 2022-2025 phase as a partial structural reversal, in which machine building exceeded its pre-war share (8.98% against 7.58%) owing to the defence industry, while mining, coke and chemicals do not recover, so a new structure of industrial production is being formed rather than the pre-war one restored. Concentration peaked in 2022 (HHI 1,805) and partially declined to 1,702, remaining 19% above the pre-war level, which indicates a persistently narrowed production base. The export dimension records a change of the foreign-trade identity of industry: the agri-food complex replaced metallurgy as the export core (42.6% against 14.2% of industrial exports), while the new defence machine building, with an export intensity of only 13.1%, works for domestic government demand, so the current reindustrialization is import-substituting in character.

Conclusions. The proposed methodological framework provides a toolkit for diagnosing, attributing and forecasting structural changes in industry under AI adoption. Its distinctive features are the typology-based selection of indicators, the mandatory separation of price and physical components, the direct comparability of modeled AI-induced shifts with observed shifts, and the built-in translation of quantitative results into policy interpretation through normative and decision scales.

The partial approbation of the diagnostic block on Ukrainian data for 2014-2025 confirms that the framework distinguishes evolutionary, shock and adaptive regimes of structural dynamics and converts measurement into policy guidance: the optimal response is to consolidate recovery-driven diversification, to convert the capacities of the defence industry into exports, and to support the diffusion of technologies, including AI, into industry groups with low exposure. The full-scale validation of the attributive block, including the price-physical decomposition and the scenario modeling of the AI-induced shift against the war-induced one, constitutes the next stage of the research.

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METHODICAL FRAMEWORK FOR ASSESSING LOGISTICS READINESS FOR THE TRANSITION TO THE SIXTH TECHNOLOGICAL LRDER: DEVELOPMENT OF THE CASE INDEX

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Introduction. The transition to the sixth technological order (STO) is characterized by the convergence of digital, cognitive and energy technologies that fundamentally transform logistics systems. The logistics sector increasingly relies on technologies grouped within the CASE framework: Connected, Autonomous, Shared and Electric. Existing international indices, including the Logistics Performance Index, Digital Economy and Society Index and Global Connectivity Index, assess only particular aspects of technological development and do not provide a comprehensive measurement of logistics readiness for the STO transition. Consequently, there is a need for an integrated methodological instrument capable of measuring cross-country differences in technological preparedness and identifying structural barriers to diffusion. The purpose of this study is to develop a methodical framework and a composite CASE Index for assessing the readiness of logistics systems for the transition toward the sixth technological paradigm.

Materials and methods. The methodical framework is based on the CASE concept originally introduced in the automotive industry and adapted to logistics-specific conditions. The index consists of four equally weighted dimensions: Connected (digital connectivity and cybersecurity), Autonomous (robotization and artificial intelligence), Shared (platform logistics and shared mobility), and Electric (electrification and charging infrastructure). The empirical basis combines data from the International Telecommunication Union, OECD, International Energy Agency, KPMG Autonomous Vehicle Readiness Index, World Robotics Report, Eurostat and other international statistical databases.

The Connected component includes indicators of 5G penetration, IoT diffusion, connected vehicles, transport data traffic and cybersecurity readiness. The Autonomous component captures the density of autonomous mobile robots, AI adoption by logistics firms, autonomous delivery pilots and readiness for autonomous vehicles. The Shared dimension incorporates indicators of shared mobility and third-party logistics market development, while the Electric component reflects the diffusion of electric vehicles and charging infrastructure.

Normalization of indicators is conducted through the min-max approach, ensuring comparability across countries irrespective of measurement units. Sub-indices are calculated as weighted averages of normalized indicators, while the overall CASE Index is obtained as the arithmetic mean of the four dimensions.

Results. The proposed methodical framework comprises four analytical blocks, sixteen sub-indicators, a normalization procedure and an interpretation scale.

Empirical calculations for the United States, Japan, Germany, the EU-27 and Ukraine reveal significant asymmetries in logistics readiness for the STP transition.

The United States demonstrates the highest CASE Index value (0.786), reflecting mature digital ecosystems and strong platform integration. Germany achieves a value of 0.637 due to advanced electrification infrastructure and autonomous technologies. Japan and the EU-27 belong to the intermediate category characterized by coordinated transition mechanisms, while Ukraine records the lowest index value (0.063), indicating the initial stage of technological transformation.

The methodical novelty of the framework lies in combining technological indicators with institutional and strategic dimensions of transition. Furthermore, the CASE Index is integrated with game-theoretical interpretation through Nash equilibrium analysis. Countries with CASE values exceeding 0.60 demonstrate dominant equilibrium conditions favorable for autonomous technology adoption, while countries with values below 0.20 remain trapped in a non-adoption equilibrium because network effects are insufficient to stimulate investments.

The interpretation scale distinguishes five levels of transition: initial stage, adaptation, coordinated transition, platform integration and technological maturity. The framework therefore enables diagnostics of current technological readiness, and also identification of policy priorities required for overcoming coordination failures and accelerating technological diffusion.

Conclusions. The proposed CASE Index constitutes a new sectoral indicator for measuring logistics readiness for the transition toward the sixth technological paradigm. Its distinctive features include the integration of digital, autonomous, shared and electric dimensions into a unified assessment framework, cross-country comparability, and direct linkage with strategic decision-making mechanisms. The results indicate substantial technological divergence between countries and confirm that successful diffusion of STO technologies requires technological capabilities and institutional coordination, network effects.

BETWEEN FABRICATION AND EXPRESSION: LED TECHNOLOGIES, DIGITAL PRODUCTION, AND THE REORIENTATION OF SUSTAINABLE PRACTICE IN CONTEMPORARY VISUAL CULTURE

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Introduction. The global creative industries are undergoing a structural reconfiguration shaped by converging pressures from environmental accountability, digital fabrication capabilities, and shifting commercial expectations. This paper examines how LED-based production systems, CNC manufacturing, UV printing, and additive fabrication technologies are collectively reshaping the material, economic, and aesthetic conditions of contemporary art and commercial visual design.

The paper argues that the ecological and economic dimensions of these technologies are inseparable: that material efficiency, reduced energy consumption, and on-demand manufacturing simultaneously address environmental concerns and restructure the commercial logic of visual culture production. Rather than treating sustainability as a secondary ethical consideration, the paper positions it as a constitutive condition of contemporary fabrication practice – with implications for how visual environments are conceived, produced, and maintained across international creative industries.

Data and Methods. This paper approaches the question from a practitioner-research position, drawing on sustained engagement with LED art fabrication, commercial installation design, and hybrid visual production systems. The observations offered here are grounded in the specificity of production experience while reaching toward broader analytical claims about sustainability, material intelligence, and the evolving role of the artist-fabricator in international visual culture. The argument proceeds across several interconnected considerations: the structural advantages of LED technologies over traditional luminous systems; the role of digital fabrication in enabling adaptive, low-waste production; the economic reorientation that follows from sustainable material practices; and the interdisciplinary repositioning of the contemporary artist within commercial and spatial design fields.

Results. The conditions under which visual environments are produced have shifted considerably over the past two decades. What once required specialized industrial infrastructure, substantial material inventories, and complex supply chains can now be achieved through distributed fabrication workflows, digitally controlled manufacturing systems, and modular design architectures. This compression of

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production processes has altered the economics of commercial visual design and, with them, the conceptual possibilities available to practitioners working across art, architecture, and spatial communication.

From Glass to Light: The Structural Transition in Luminous Design. The shift from traditional glass neon to LED-based luminous systems represents one of the more consequential material transitions in recent visual design history – consequential not primarily because of its environmental metrics, but because it altered the conditions of production, transportation, installation, and authorship simultaneously.

Traditional neon fabrication is a craft-intensive process, and the energy consumption remains comparatively high across operational lifespans. LED neon systems do not simply replicate this aesthetic in a more efficient format. They reconfigure it. The material substrate changes from glass to flexible polymer or rigid acrylic; the production process shifts from manual glasswork to digital cutting and assembly; the energy profile contracts substantially; operational lifespan extends considerably. What is gained is durability, transportability, and adaptability. What is altered – and this deserves honest acknowledgment – is a particular textural warmth associated with traditional neon's analog character.

In commercial environments across hospitality, retail, entertainment, and branded spatial experiences, the transition has been largely absorbed without resistance. The visual legibility of illuminated lettering and graphic form remains intact; operational and maintenance costs fall; the installation tolerates handling and transit conditions that would compromise glass. From an ecological standpoint, reduced electricity consumption and extended product lifespan do contribute meaningfully to lower environmental impact across a product's operational life.

On-Demand Manufacturing and the Logic of Material Optimization. Digital fabrication technologies – CNC routing, UV flatbed printing, laser cutting, additive manufacturing – share a structural characteristic that distinguishes them from the industrial paradigms they are gradually displacing: they are inherently responsive rather than anticipatory. One of the most important benefit is that the overproduction – the quiet waste embedded in conventional manufacturing – disappears from the workflow.

When these technologies operate in combination – UV-printed acrylic panels assembled with CNC-cut structural components and integrated LED systems – the result is what might be described as a hybrid fabrication architecture: a production logic that is simultaneously digital and material, flexible and precise, visually ambitious and resource-conscious. The aesthetic character of work produced within this architecture is shaped as much by the properties of the tools as by the intentions of the practitioner. This is not unusual in art history; what is unusual is the speed at which the tools themselves are evolving, and the degree to which that evolution carries embedded environmental logic.

The Economic Reorientation of Sustainable Visual Practice. The discourse around sustainable design has long been structured around an implicit tension:

environmental responsibility as a cost to be absorbed, an ethical premium attached to ecologically sound choices. This framing is becoming analytically insufficient. Across commercial visual environments – hospitality, retail, entertainment, branded interior experiences – sustainability is operating less as a moral supplement and more as a structural condition of competitive practice.

Energy-efficient LED systems reduce operational expenditure over extended timeframes. Modular construction methodologies lower maintenance and replacement costs. On-demand manufacturing models reduce capital tied to inventory and unsold stock. These are not marginal savings; across the operational lifespans of commercial environments, they represent structural cost reductions that clients and commissioners are increasingly capable of quantifying and prioritizing.

This produces a productive alignment between the economics of sustainable fabrication and the commercial appetite for differentiated visual environments. On-demand production, local fabrication, and modular construction serve both the sustainability agenda and the client's desire for specificity. The artist or designer operating at this intersection occupies a position that is genuinely new in the history of visual production: neither the industrial supplier of standardized products nor the gallery artist producing work for contemplative audiences, but a practitioner whose expertise simultaneously spans fabrication, spatial design, material intelligence, and visual communication. In such a case the value proposition is irreducibly interdisciplinary – and that irreducibility is, increasingly, the point.

Conclusions. Contemporary art's expansion into fabrication-intensive, technology-mediated, and spatially complex forms of production is not a recent development – but the pace and depth of that expansion have accelerated considerably. The practitioner who works exclusively within a single medium, using a fixed set of tools and a stable relationship to materials, is far less characteristic of contemporary creative culture than the artist-designer who moves across disciplines, collaborates with engineers and architects, and produces work that occupies spaces between established categories.

Distributed fabrication systems, cross-border design workflows, and the increasing embeddedness of environmental accountability within commercial commissioning are collectively creating conditions in which the artist-fabricator's particular combination of competencies – technical precision, material knowledge, spatial sensibility, environmental literacy – carries substantive relevance across multiple sectors of the global creative economy.

RESEARCH AND POLICY AS AGENTS OF CHANGE IN THE GROWTH AND SUSTAINABILITY OF THE INDUSTRY: A CASE OF TELECOMMUNICATIONS INDUSTRY IN KENYA

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Introduction. The 17 Sustainable Development Goals (SDGs) are a call from the United Nations for all countries to achieve by 2030. The SDGs calls are backed up by 169 indicators including poverty, inequality, climate change, environmental degradation, prosperity, and peace and justice. These challenges relate to what lower-middle-income countries in Africa like Kenya are realizing in various sectors.

Research uptake and policy integration in social, political and economic ecosystem in the country has created an impact leading to progress in some sectors. This study focuses on how researches and policy guidelines are changing the industrial sector in Kenya which is experiencing push toward industrial growth to transform its economy from a lower-middle-income nation into a newly industrialized nation by 2030.

Data and Methods. While manufacturing's contribution to GDP has remained relatively low and fluctuating around 7%–8% in recent years, the government of Kenya is aggressively targeting an increase to 15% by 2027 and 20% by 2030, with major industrial sector being the telecommunications industry. Using mixed methods approach and targeting stakeholders in the telecommunication sector and their beneficiaries, the study are to investigate how research and policy guidelines has led to increased growth and transformation in the telecommunications sector in Kenya which is concerned as the leading and most dynamic sector in Kenya. The study also looked at how Safaricom PLC and Airtel Kenya, the two leading mobile providers in Kenya has benefited from research output targeting the industry and its influence in the sector.

Results. The study findings indicated that the telecommunication industry continue being the leading in Kenya due to its foundational role in driving digital transformation, innovation, near-universal mobile money penetration especially Mpesa mobile money transfer, massive investment in digital infrastructure and diversity in investment.

Conclusions. The industry is considered as the central backbone to Kenya economic growth as the countries moves towards industrialization and digital economy.

DIGITAL TWINS FOR SUSTAINABLE BUSINESS: DRIVING ENERGY EFFICIENCY AND GREEN INNOVATION

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Introduction. The simultaneous acceleration of the green and digital transitions is reshaping the foundations of corporate competitiveness and creating demand for technologies capable of reconciling economic performance with environmental sustainability. This challenge is particularly important in energy-intensive sectors: according to the International Energy Agency (IEA), industry accounted for nearly 40% of global final energy consumption in 2024, while roughly two-thirds of the increase in global final energy demand since 2019 has been concentrated in the industrial sector. At the same time, progress in global energy efficiency remains insufficient: the average annual improvement in primary energy intensity since 2019 has been approximately 1.3%, compared with the roughly 4% annual improvement required by 2030 under the ambition agreed at COP28 (IEA, 2024). Against this background, digital transformation provides businesses with new instruments for reducing the resource intensity of production without sacrificing productivity. Among these technologies, digital twins (DTs) – dynamic virtual representations of physical assets, processes or systems connected to their physical counterparts through data, are emerging as an important mechanism through which firms can simultaneously improve energy efficiency, reduce operating costs and strengthen their competitive position.

Methods and data. This study adopts a systematic literature review combined with a conceptual analysis to examine the role of digital twins in improving energy efficiency and strengthening competitive advantage within sustainable business models. The review follows the PRISMA framework to ensure a transparent and replicable selection process.

Results. Unlike conventional simulation models, digital twins can integrate operational and sensor data from physical systems and use this information to continuously monitor performance, forecast system behaviour and evaluate alternative operating scenarios (Tao & Qi, 2019). The economic significance of this functionality lies in its ability to transform previously fragmented operational information into a resource for optimizing business decisions. Digital twins can enable firms to experiment with changes in production processes, equipment parameters and resource allocation in a virtual environment before implementing potentially costly interventions in physical systems. They can also support predictive maintenance by detecting abnormal operating patterns and potential failures before breakdowns occur, thereby reducing unplanned downtime and extending asset lifetimes. Consequently, digital twins should not be regarded merely as another component of Industry 4.0 infrastructure but as an economic decision-support mechanism capable of influencing productivity, cost structures, capital utilization and ultimately firm competitiveness.

Energy efficiency represents one of the most direct channels through which this economic value can materialize. By continuously linking information on equipment condition, production requirements and energy consumption, digital twins make it possible to identify inefficient operating states and simulate interventions designed to minimize energy requirements. Empirical evidence already demonstrates substantial potential. A 2020 case study developed an energy digital twin for an industrial heating tunnel and reported reductions in energy consumption of up to 40%, alongside corresponding reductions in energy costs (Minerva et al., 2020). Another study of energy-intensive manufacturing enterprises found that implementing a digital-twin- and big-data-based energy management strategy reduced unit energy consumption and energy costs by at least 3% in one of the investigated companies (Tao et al., 2019). Although results vary considerably across applications and should not be generalized mechanically, these cases demonstrate that digital twins can convert improvements in information and optimization capabilities into measurable economic savings.

The implications of these improvements extend beyond reductions in firms' electricity bills. Greater energy efficiency can generate competitive advantage by lowering marginal production costs, reducing exposure to volatile energy prices, improving equipment reliability and enabling businesses to produce more output from a given resource base. Evidence from an IEA survey of 1,000 industrial firms across 14 countries supports this relationship: approximately 80% of surveyed companies considered energy efficiency important for maintaining their competitive edge, while respondents associated efficiency improvements with reductions in operational and maintenance costs and unplanned downtime (IEA, 2023). Moreover, nearly 40% identified energy efficiency as their first response to increasing energy costs.

Digital twins can furthermore contribute to the evolution of sustainable business models by changing how companies create, deliver and capture value. Their capacity to monitor assets throughout their lifecycle supports predictive maintenance, resource optimization, lifecycle management and more accurate assessment of environmental performance, while integration with renewable energy and demand-response systems can allow businesses to adapt production processes to changing energy-market conditions and the availability of renewable electricity. Recent research, for example, proposes combining digital twins with demand response so that manufacturing processes can adjust energy consumption in response to market signals while increasing the utilization of renewable energy at lower cost. Nevertheless, these benefits are not automatic (Jones et al., 2020).

Conclusion. In conclusion, digital twins represent a promising connection between digital transformation and the transition toward sustainable and competitive business models. Their economic relevance stems from their ability to translate real-time information, simulation and predictive analytics into lower energy consumption, reduced operating and maintenance costs, improved asset utilization, greater resilience and enhanced productivity. The emerging empirical evidence, including energy reductions reaching 40% in particular experimental applications, demonstrates the magnitude of potential efficiency gains while simultaneously emphasizing their context-dependent nature. At the macroeconomic level, the importance of exploiting such opportunities is reinforced by the fact that the global economy today generates approximately 36% more GDP per unit of energy than it did in 2000, illustrating the long-term economic value of improvements in energy productivity. Digital twins may accelerate this process at the firm level by making energy optimization continuous, predictive and embedded within strategic decision-making. Their contribution to sustainable business should therefore be evaluated not simply as technological innovation, but as a strategic capability through which energy efficiency can be converted into sustainable competitive advantage.

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ENERGY EFFICIENCY AS A WAY TO ENSURING UKRAINE'S ENERGY SECURITY

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Introduction. Energy efficiency is a key area for ensuring Ukraine's energy security, especially in times of war and post-war reconstruction. Reducing dependence on energy imports and increasing the resilience of the energy system are critically important tasks for ensuring the stable functioning of the economy and the social sphere. The introduction of energy-efficient technologies and energy management systems allows reducing energy costs, improving the environmental situation and stimulating innovation. Reducing dependence on energy imports and increasing the resilience of the energy system contributes to ensuring the country's energy security. The introduction of energy efficiency measures allows reducing energy costs, which is important for economic stability and development.

The purpose of the work is to study energy efficiency as a key area for ensuring Ukraine's energy security in wartime.

Data and Methods. The study draws on academic and statistical literature addressing energy efficiency as a key area for ensuring Ukraine's energy security. The analysis incorporates both classical theoretical works and recent studies published between 2022 and 2025. To

Results. The basic idea of energy efficiency is to achieve more useful work or services for the same amount of energy consumed. For this, energy-efficient technologies, control systems and process optimization are used, which allows reducing energy consumption without losing productivity or quality.

The amount of energy savings is the reduction in energy consumption, which is determined by the difference in energy consumption before and after the implementation of energy efficiency measures. This ensures the normalization of external and internal conditions that affect energy consumption. The principle of energy saving is focused on the overall reduction of energy consumption in a system, building or industry.

The main goal of energy saving is to reduce overall energy costs without necessarily increasing productivity or using more efficient technologies. This may include measures such as switching off electrical devices in standby mode, installing energy-efficient lighting, insulating buildings, etc. In contrast to simple energy saving, the principle of energy efficiency is more focused on optimizing energy use to achieve greater useful work. While the principle of energy saving focuses on the overall reduction of energy costs without necessarily changing productivity or quality.

The post-war energy infrastructure of Ukraine will necessarily include the capabilities of battery energy storage systems. The introduction of battery energy storage systems helps to improve the stability of the power grid, provides a backup source of energy in emergency situations, reduces infrastructure costs and increases the independence of energy supply. At the moment, the electricity tariff in Ukraine is on average 2.64 UAH per 1 kWh. If we analyze the cost of kWh in the countries of the European Union, we conclude that on average, according to Eurostat data, in 2022 it was 0.24 euros per 1 kWh, or approximately 9.6 UAH. In Ukraine, discussions have already been held on increasing the tariff to 5.5 UAH. per 1 kWh. Energy storage systems can significantly save costs. This is the main advantage of battery energy storage systems.

One of the newest ways to enhance the energy security of the power system is floating power plants (Powership). These are full-fledged floating power plants on ships or barges, located in coastal areas and ready to generate electricity. They can be quickly connected to the grid

Mini-power plants are an innovative solution for providing electricity to enterprises and their production needs. These systems can be used in cases where the enterprise needs an additional or temporary source of electricity, or as a backup power system during emergencies, accidents or planned outages. Such stations can be equipped with various energy sources, such as diesel generators, solar panels or batteries, depending on the availability and requirements for electricity supply.

Conclusion. The introduction of energy-efficient technologies and energy management systems allows to reduce dependence on imported energy resources, reduce energy costs, improve the environmental situation and stimulate innovation. Analysis of the legislative framework shows that the implementation of European directives contributes to increasing energy efficiency and sustainability of the energy system. The practical value of the study lies in identifying specific measures and recommendations for increasing energy efficiency, which can be used in state policy and at enterprises.

Further research should include studying the harmonization of national legislation with European directives, the introduction of innovative technologies such as small modular nuclear reactors and battery energy storage systems, and the conduct of energy audits and information campaigns.

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STARTUP ECOSYSTEM IN TIMES OF WAR: CHALLENGES, TRENDS, AND DEVELOPMENT PROSPECTS[3]

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Introduction. In today's global digital transformation, startups are one of the key drivers of innovative economic development, contributing to the creation of new technologies, commercialization of scientific research results, the creation of high-tech jobs, and increasing the competitiveness of national economies. Developed startup ecosystems accelerate the structural modernization of the economy, stimulate entrepreneurial activity, and are an important factor in attracting investment resources. In this regard, the development of startups is considered one of the priority areas for the formation of an innovative model of economic growth in most countries of the world.

Data and Methods. Over the past decade, Ukraine has formed one of the most dynamic startup ecosystems in Central and Eastern Europe. This was facilitated by the high level of technical education of the population, the rapid development of the IT sector, the active implementation of digital technologies in business processes, and the emergence of a large number of entrepreneurial initiatives in the field of high technology. A feature of the Ukrainian model of startup development was the combination of a strong human resource potential with an orientation towards global markets, which allowed many companies to successfully compete internationally.

Let's look at the dynamics of the number of Ukrainian startups entering the global market during 2021–2024 (Fig. 1). In 2021, about 150 startups began international expansion. This period was marked by a peak in startup activity, when many Ukrainian companies entered the international market. However, in 2022, their number decreased to about 100, due to the beginning of a full-scale war and its impact on investment and operational opportunities. However, as companies quickly adapted to new realities and used the advantages of remote work and digital tools to reach a global audience, as of 2023, about 120 startups had already entered international markets. Thus, in 2024, the number of startups entering international markets increased to over 150, which indicates a strong recovery and growth in international interest in Ukrainian innovations.

[3] The paper is prepared within the scientific research project "Digital transformations to ensure civil protection and post-war economic recovery in the face of environmental and social challenges" (No. 0124U000549) and "Digital Economy and Renewable Energy: Building Sustainable Business Models for Ukraine's Post-War Reconstruction " (No. 0126U000877).

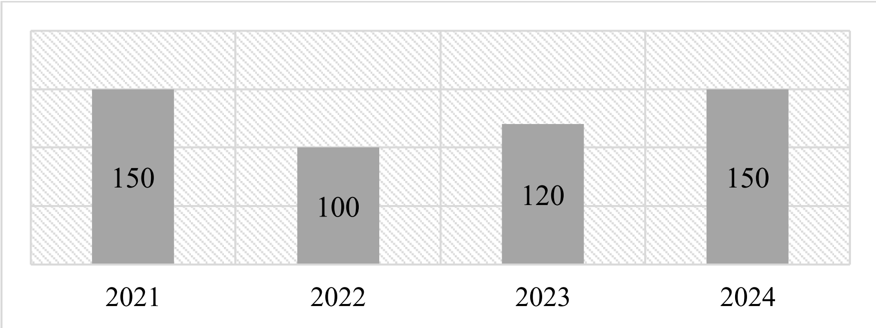

Figure 1 – Number of Ukrainian startups that entered the global market during 2021–2024 [1]

Results. For a more comprehensive assessment of the state of the startup ecosystem in Ukraine, it is advisable to analyze not only the number of startups entering international markets, but also the dynamics of Ukraine's positions in international rankings, the number of active startups, and the amount of funding raised. This allows us to assess the level of competitiveness of the national startup ecosystem in the global innovation environment and identify the main trends in its development. The main quantitative characteristics of the development of the startup ecosystem in Ukraine are given in Table 1.

Table 1 – Dynamics of development of the startup ecosystem of Ukraine in 2021–2025

Indicator	**2021**	**2022**	**2023**	**2024**	**2025**
Ukraine's place in the Global Startup Ecosystem Index (StartupBlink)	34	50	49	46	42
Position in Eastern Europe	7	11	10	9	8
Number of startups in the StartupBlink database	–	–	600+	633	874
Annual growth rate of the ecosystem, %	–	–	+6.8	+9.2	+26.2
Volume of investments attracted by Ukrainian startups, million USD	–	–	–	13.9	–

Source: summarized by the authors based on data [2-5]

The data in Table 1 indicate the mixed nature of the development of the Ukrainian startup ecosystem in wartime. After a significant deterioration in the positions in the global StartupBlink ranking in 2022, caused by a full-scale invasion and a sharp increase in investment risks, a gradual recovery of Ukraine's competitive positions is observed during 2023–2025. In particular, in 2025, Ukraine rose to 42nd place in the Global Startup Ecosystem Index, improving its result by four positions compared to the previous year.

Another positive trend is the increase in the number of active startups and the acceleration of the ecosystem development. According to StartupBlink, in 2025 Ukraine demonstrated one of the highest growth rates among the countries included in the group of 50 leading startup ecosystems in the world. This indicates the high adaptability of Ukrainian entrepreneurs to crisis conditions, the preservation of innovative activity and the gradual strengthening of the international competitiveness of the national startup ecosystem.

Conclusions. The modern Ukrainian startup ecosystem is at a stage of deep transformation, caused by the simultaneous impact of military challenges, digitalization of the economy, changes in the structure of global demand for innovation, and increased international integration. Unlike the pre-war period, when the majority of Ukrainian startups were focused on software development, outsourcing solutions, and e-commerce, today there is a gradual diversification of innovation activities and the formation of new high-tech sectors.

One of the key trends in recent years has been the rapid growth of the Defense Tech segment. The war significantly increased the demand for innovative solutions in the field of defense and security, which stimulated the development of startups related to unmanned aerial vehicles, robotic systems, electronic warfare, digital command and control systems, satellite technologies and software solutions for data analysis. A feature of this area is its high innovative activity and significant potential for commercialization in international markets after the end of the war.

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DIGITAL DEVELOPMENT OF UKRAINE IN THE LIGHT OF THE GLOBAL INNOVATION INDEX

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Introduction. Determining the level of digitalization allows us to assess the country's place in the global market of innovative and digital technologies, which is the basis for understanding the country's problems and advantages in development. That is why international ratings and indices are becoming an important source of information about the potential and dynamics of development of countries in the ICT sphere, and serve as an indicator of opportunities for increasing the competitive advantages of the economy.

The purpose of this work is to determine Ukraine's place among European countries in terms of innovation in the context of digital development.

Data and Methods. The study draws on academic and statistical literature addressing digitalization of Ukraine and the EU. The analysis incorporates both classical theoretical works and recent studies published between 2022 and 2025. Data on digitalization are contained in many sources with varying visibility and accessibility. A search was conducted for reports and statistical databases published by authoritative international organizations that contain data on Ukraine. These analytical materials allow us to assess Ukraine's positioning relative to other European countries in terms of the state of the economy, business development, and digital technologies.

Results. Overall, there is a significant difference in the level of development between different EU countries, but many of them have the potential for further growth and improvement in all aspects.

Based on statistical calculations, countries were divided into five clusters according to their distances from other countries in the parameter space. Here is a description of each cluster based on the 2021 results.

1. Cluster 1 (Ukraine). This cluster contains only Ukraine. It is the most distant among the countries according to the parameters used for clustering. This may indicate a unique situation or characteristics of Ukraine compared to the EU countries considered.
2. Cluster 2 (Austria, Belgium, Estonia, Ireland, Cyprus, Slovenia, France, Czech Republic). This cluster consists of several countries that have a high level of development in most of the aspects considered. Although they may differ in certain parameters, such as the level of infrastructure or business development, they still have a more similar profile compared to the other clusters.
3. Cluster 3 (Denmark, Netherlands, Germany, Finland, Sweden). This cluster includes countries that have a very high level of development in many aspects, including institutions, human capital, infrastructure, market and business

development, as well as knowledge and technological inventions. These countries are leaders in many areas and have one of the highest levels of relevant development in the EU.

4. Cluster 4 (Luxembourg, Malta). This cluster consists of countries that have lower indicators compared to other countries, but still have a good level of development of institutions, infrastructure and other aspects.

5. Cluster 5 (Bulgaria, Greece, Spain, Italy, Latvia, Lithuania, Poland, Portugal, Romania, Slovakia, Hungary, Croatia). This cluster includes countries that have lower indicators in most aspects compared to other countries. These countries can be recommended to improve in many areas to achieve their higher level of development.

Ukraine's indicator in the "Human" component Capital and Research ” is also lower than in many EU countries (Figure 4). This indicates the need for investment in education and research to increase innovation potential.

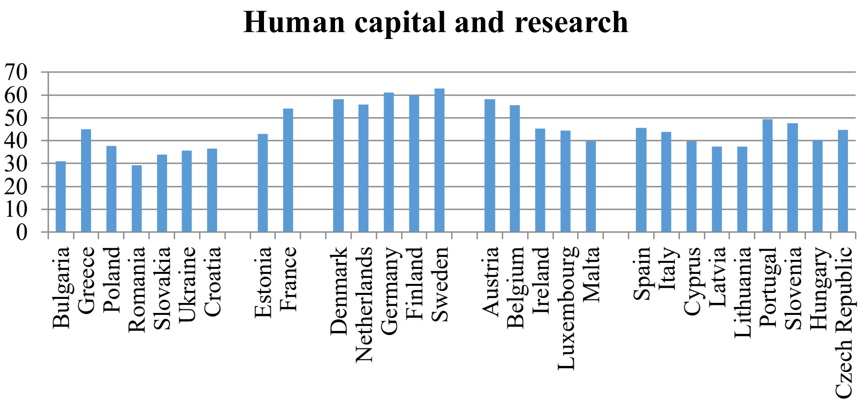

Fig. 1. The meaning of the components of "Human" capital and research » from «GII» indicators

Conclusion. To effectively use Ukraine's potential for innovative development in order to achieve political stability and sustainable economic growth, it is recommended to pursue a policy of encouraging innovation and the development of education and science; to expand the country's integration into global economic chains and innovation networks; to implement at the state level the search for and attraction of talents, the policy of retaining a qualified workforce in the country; to balance technological integration and investment in human capital.

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UKRAINE'S TRANSITION TO "GREEN" ENERGY IN THE CONDITIONS OF MARTIAL LAW

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Introduction. Traditional energy, based on the use of coal, oil and gas, remains vulnerable to military attacks and disruptions of logistical chains. At the same time, Ukraine has significant potential for the development of renewable energy, which will not only strengthen the country's energy independence, but also reduce the environmental burden. However, the introduction of "green" energy is complicated by the conditions of martial law, the destruction of infrastructure, economic and social challenges.

The purpose of this article is to study the challenges of the transition from traditional energy to renewable energy sources under martial law.

Data and Methods. The study draws on academic and statistical literature addressing Ukraine's transition to " green " energy in the conditions of martial law. The analysis incorporates both classical theoretical works and recent studies published between 2022 and 2025. The research methodology is based on monographic methods: analysis of available sources, scientific publications that highlight the issues of "brown" energy and the transition to "green" in Ukraine, as well as qualitative aspects of "green" energy under martial law, collection and analysis of statistical and other data to study the current prerequisites for the transformation of the energy sector of Ukraine.

Results. Clean energy is generally considered better for the environment than traditional fossil fuel-based resources and generally results in less air and water pollution than combustible fuels such as coal, natural gas and oil. Energy produced using renewable sources such as wind, water and sunlight does not create harmful carbon dioxide emissions that lead to climate change, which causes drought, wildfires, floods, poverty, health risks, biodiversity loss and more.

Although both renewable and non-renewable energy sources require land for infrastructure, renewable energy systems often have a smaller footprint. For example, solar panels can be installed on existing structures, and wind turbines are well suited for agricultural land without displacing crops. Legislative framework for the transition to "green" energy in Ukraine. Legislative regulation is a key tool for implementing the strategy of transition to "green" energy in Ukraine, which is aimed at reducing dependence on fossil fuels and integrating renewable energy sources into the country's energy system.

The legal framework for this process is multifaceted and covers both national initiatives and international obligations aimed at reducing greenhouse gas emissions and improving the environmental situation.

One of the main legal documents defining the legal framework for the development of "green" energy in Ukraine is the Law of Ukraine "On Alternative Energy Sources". An important segment of renewable energy is small hydroelectric power plants, the capacity of which has increased from 87 MW in 2015 to 121 MW in 2023. Although this growth looks more modest compared to wind and solar energy, it still shows that the sector has potential for further development.

We cannot ignore biomass, the sector of which is also developing quite dynamically today. This segment requires more attention and investment, as the use of biomass can significantly contribute to the country's energy independence.

Overall, the share of renewable energy sources in Ukraine increased from 3.9% in 2014 to 9.19% in 2020. This indicator is evidence that the country is actively moving towards environmental sustainability.

In the context of modern global challenges, in particular climate change and dependence on fossil fuels, the transition to "green" energy has become an urgent task for many countries, including Ukraine. However, the ongoing war in the country significantly complicates this process, posing new challenges for society, but at the same time opening up new opportunities.

Equally important is raising public awareness of the importance of the transition to "green" energy. In wartime, when society is faced with numerous difficulties, the population may focus on survival issues. However, awareness of the need to transition to environmentally friendly energy sources can contribute to the formation of support for such initiatives. This may include the implementation of training programs that will reveal the potential of renewable energy sources and their benefits for society.

Conclusion. In times of war, renewable energy sources can be an important step in ensuring energy security and stability. Raising public awareness of the importance of switching to environmentally friendly energy sources is also of great importance for building support for such initiatives. Thus, the transition to "green" energy is not only an environmental necessity, but also an economically and socially justified step to ensure the sustainable development of the country in the future.

Acknowledgment. *The paper is prepared within the scientific research project «Drivers and barriers this human capital transformation for a circular and green economy» (No. 0126U001080).*

DISRUPTIVE TECHNOLOGIES AS DRIVERS OF GREEN TRANSITION: EVIDENCE FROM THE EU

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Introduction. The European Union has placed the twin green and digital transition at the center of its long-term development strategy through the European Green Deal, the Digital Decade, and the Net-Zero Industry Act. Disruptive technologies, including artificial intelligence (AI), the Internet of Things (IoT), blockchain, digital twins, big data analytics, and cloud computing, are increasingly recognized as key enablers of decarbonization, resource efficiency, and sustainable economic growth. According to the IEA, achieving the EU's climate objectives requires a smarter and more digitalized energy system capable of integrating rapidly expanding renewable energy sources. Electricity consumption is expected to increase by approximately 60% by 2030, while installed wind and solar capacity must expand from around 400 GW in 2022 to at least 1,000 GW by 2030, requiring advanced digital solutions for system flexibility and grid management (IEA, 2025).

Methods and data. This study employs a systematic literature review and conceptual analysis to examine the contribution of disruptive technologies to the green transition within the European Union. The review follows peer-reviewed publications indexed in Scopus and Web of Science Core Collection, together with reports published by the European Commission, the European Environment Agency (EEA), and the International Energy Agency (IEA). Scientific publications published between 2018 and 2025 are selected using keywords including artificial intelligence, digital twins, Internet of Things, blockchain, green transition, renewable energy, energy efficiency, and European Union. Bibliometric mapping and qualitative content analysis are employed to identify major research trends, technological applications, and the principal economic mechanisms linking digital innovation with environmental sustainability.

Results. The review demonstrates that disruptive technologies accelerate the green transition by improving energy efficiency, enabling real-time monitoring of energy systems, facilitating predictive maintenance, and supporting data-driven decision-making (IEA, 2025). Artificial intelligence improves renewable energy forecasting and electricity demand prediction, while IoT technologies provide continuous monitoring of industrial equipment and smart buildings. Digital twins enable simulation and optimization of complex energy systems, reducing operational costs and improving asset utilization. Blockchain facilitates decentralized electricity markets and peer-to-peer energy trading, enhancing transparency and consumer participation (Nambisan et al., 2017). The European Environment Agency emphasizes that AI, IoT, advanced analytics, and digital twins significantly strengthen environmental monitoring, improve climate-risk assessment, and support more efficient integration of renewable energy into European electricity systems.

The analysis further indicates that disruptive technologies contribute to sustainable economic development through several complementary channels. They reduce production costs by improving resource efficiency, enhance firms' competitiveness through process optimization, and strengthen energy security by increasing system flexibility (Schwab, 2017). At the policy level, the European Commission identifies digital technologies, including smart meters, cloud-edge computing, AI, IoT, and digital twins, as critical components of a decentralized and interactive energy system capable of supporting the EU target of reducing greenhouse gas emissions by 55% by 2030 while increasing renewable energy deployment (Vial, 2019). Nevertheless, significant barriers remain, including high investment costs, cybersecurity risks, fragmented data governance, interoperability challenges, and shortages of advanced digital skills. Recent research also highlight the importance of regional innovation ecosystems and stronger integration between digital and green technologies to maximize the benefits of the EU's twin transition.

Conclusions. Disruptive technologies have become fundamental drivers of the European Union's green transition by enhancing energy efficiency, accelerating renewable energy integration, and supporting the development of sustainable business models. Their economic impact extends beyond technological modernization, creating opportunities for productivity growth, innovation, and long-term competitive advantage while contributing to climate neutrality objectives. Future research should complement conceptual evidence with empirical analyses investigating how the adoption of AI, digital twins, IoT, and other disruptive technologies influences environmental performance, firm productivity, and green innovation across EU member states and industrial sectors.

Acknowledgment. *The paper is prepared within the scientific research project "Digital Economy and Renewable Energy: Building Sustainable Business Models for Ukraine's Post-War Reconstruction" (No. 0126U000877)*

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DIGITAL TRANSFORMATIONS FOR THE SAFETY OF INDUSTRIAL PERSONAL

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Introduction. The relevance of the study lies in the awareness of the growing importance of digital technologies in the modern world and their potential for increasing personnel safety in emergency situations. In particular, the growing threat of natural disasters, military operations, shelling and other dangers requires the development of new approaches to ensuring security. One of such approaches is the use of digital innovations, which is becoming an important scientific and practical task. This article aims to study the possibilities of using digital technologies to increase personnel safety in case of emergency circumstances.

The purpose of this article is to investigate the impact of digital transformations on the safety of industrial personal.

Data and Methods. The study draws on academic and statistical literature addressing digitalization of Ukraine. The analysis incorporates both classical theoretical works and recent studies.

Results. Digital solutions in the management initiative help in the development and implementation of emergency plans, as well as in ensuring the readiness of personnel to detect and resolve problems in emergency situations. Digital platforms provide the ability to create and store emergency plans electronically. This facilitates access to documentation and updating plans in real time. Electronic systems allow managers to easily update and edit plans, taking into account new risks and emergency scenarios. With the help of digital tools, virtual scenarios can be created for personnel training. Electronic simulators allow employees to experience the realism of situations and acquire the necessary skills. Virtual simulators can cover various aspects, including evacuation, first aid, communication and strategies in emergency situations.

Creating backup supplies and protective equipment. Providing the enterprise with backup supplies and protective equipment, such as first aid, fire extinguishers, emergency lighting, and others, is an important element of occupational safety and emergency preparedness. It is necessary to develop an emergency preparedness plan that determines what backup supplies and protective equipment are needed for different emergency scenarios. Such backup supplies should include first aid kits in visible and accessible places in the office or workplace; fire extinguishers and other fire extinguishing equipment in visible and accessible places; an emergency lighting system to provide lighting during a power outage; the possibility of installing a generator or other backup power supply to provide electricity during outages; clear marking of evacuation routes and exits.

Creating an effective system of backup supplies and protective equipment, regularly checking them and replacing faulty equipment in a timely manner. All these measures will help the enterprise effectively deal with emergencies and ensure the safety of personnel.

Digital solutions play a key role in creating and managing backup stocks and protective equipment, which is an important aspect of occupational safety and emergency preparedness. Electronic inventory management involves the use of digital platforms to automate inventory management and allows for effective tracking of the quantity and condition of backup stocks. Automatic replenishment systems can be configured to automatically order backup stocks when a certain minimum level is reached, ensuring the constant availability of necessary materials and tools.

Digital monitoring systems allow for real-time monitoring of the status of backup stocks and protective equipment, providing operational information to management. Analytical tools can help determine optimal stock levels and develop strategies for effective inventory management. Digital platforms can be used to create detailed emergency preparedness plans, including inventorying backup stocks and protective equipment. Electronic audit systems can regularly check the status of reserves, their compliance with safety standards and effectiveness.

Conclusion. Digital technologies effectively coordinate personnel actions, resource allocation and crisis management. An important component is the ability to quickly and effectively communicate with personnel and influential structures, which allows for prompt information support and decision-making. These technological solutions can significantly reduce risks for personnel and help in crisis management, increasing the overall level of security in organizations and communities. Thus, the integration of digital transformations is an integral part of security strategies in the modern world.

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ENERGY SECURITY OF UKRAINE IN THE CONTEXT OF MODERN CHALLENGES

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Introduction. World experience shows that effective implementation of RES requires balancing between state support and market mechanisms. For example, in Germany, a gradual transition from a fixed "green" tariff to an auction system has allowed to reduce the price of electricity from RES and reduce the debt burden on the energy market. In Denmark, the state stimulates the development of RES through long-term lending and simplified permitting procedures for small generation. Analysis of these approaches can become the basis for improving the Ukrainian model of "green" tariff. One of the main challenges for Ukraine's energy independence is the vulnerability of the centralized power system to attacks and technical failures.

Decentralization of generation through the development of local microgrids and autonomous energy storage systems can significantly increase the resilience of the energy infrastructure. In addition, the development of small RES generation among the population and enterprises will allow avoiding large-scale power outages in the event of crisis situations.

The purpose of this article is to investigate energy security of Ukraine in the context of modern challenges.

Data and Methods. The study draws on academic and statistical literature addressing the energy system of Ukraine. The analysis incorporates both classical theoretical works and recent studies.

Results. It is worth encouraging enterprises that are not based on electricity generation to use partially autonomous RES and use the "green" tariff. This will allow the enterprise to reduce the costs of purchasing electricity on the market and will enable autonomous activity even in blackouts when using the appropriate equipment, namely its own substation and batteries. For Ukraine, such actions of the enterprise will allow increasing the total generation capacity of the state and will allow releasing electricity for more profitable sales agreements. These restrictions on the capacity of solar power plants and wind power plants should be increased at least twice. This approach will allow in the future to loop several such generating capacities into a partially autonomous system, which in the event of a power outage in the central system will automatically disconnect from it and close the local system and, accordingly, will ensure autonomy and will support itself through the use of batteries, and if necessary, an additional substation, which will normalize the voltage in the system. This equipment is quite expensive and, accordingly, this initiative should be implemented by the state at the expense of funds released from optimizing the "green" tariff system.

Possible scenarios for the development of the Ukrainian energy sector are:

1. Baseline scenario. This is the preservation of the existing system of support for renewable energy, which will lead to further accumulation of debt and market instability.
2. Reformist scenario. This is a gradual transition to an auction system for large generation and the preservation of the "green" tariff only for small producers.
3. Innovation scenario. This is the widespread implementation of distributed generation, where small businesses and households receive incentives for autonomous electricity generation and storage.

As the war has shown, the Ukrainian power system is not sufficiently autonomous in the operation of its infrastructure elements. However, at the moment, the implementation of any plan to improve this situation is impossible due to the shortage of public funds. Therefore, the measures listed below are more focused on the long-term perspective.

The main goal is to create autonomous closed systems of electricity generation capacity in a centralized system. That is, if the central power supply system is interrupted, the generation capacities operate in an autonomous mode, ensuring the operation of the corresponding closed sector. This measure can be implemented only by building local systems, which, in the event of damage to the central system, switch to operation in an autonomous mode and can be controlled both manually and automatically. That is why it is necessary to increase the maximum permitted generation capacity for private households so that in the future it is possible to use the above mechanism more effectively.

Conclusion. Ensuring Ukraine's energy independence is possible only with a rational state policy aimed primarily at increasing its own renewable energy generation capacity. However, due to the problem of a deficit of public funds and colossal debts in the energy market, achieving this goal is quite difficult. It can be achieved only if the "green" tariff system is reviewed and changed.

Acknowledgment. *The paper is prepared within the scientific research project «Digital transformations this ensure civil protection and post- war economy recovery in the face of environmental and social challenges» (No. 0124U000549)*

LEADERSHIP SKILLS DEVELOPMENT IN RESPONSE TO CURRENT GLOBAL AND LOCAL CHALLENGES

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Introduction. The relevance of the study of leadership skills is due to the need to rethink the role of the manager in conditions of prolonged uncertainty, increasing psychological burden on personnel and transformation of labor relations. A modern leader increasingly acts not only as carriers of managerial decisions, but also as a subject of trust formation, capable of combining a strategic vision with a human-centric approach. This actualizes the need to systematize the evolution of leadership skills in time, taking into account changes in the external environment, managerial challenges and technological shifts.

The purpose of this article is to study leadership skills development in response this current global and local challenges.

Data and Methods. The study draws on academic and statistical literature addressing leadership skills development in response these current global and local challenges. The analysis incorporates both classical theoretical works and recent studies.

Results. The transition from pre-crisis stability to adaptation in conditions of constant instability was accompanied not only by an increase in the complexity of management tasks, but also by a significant transformation of the very nature of leadership activity. If at the initial stage the focus on efficiency, process management and predictability of decisions prevailed, then subsequent periods required managers to be able to act in conditions of uncertainty, maintain the psychological stability of teams, ensure the ethics of management decisions and maintain the trust of personnel. In parallel, the role of digital technologies was strengthened, namely from tools for supporting management decisions to the systemic integration of digital platforms and elements of artificial intelligence into management processes. Taken together, these changes led to the evolution of requirements for leadership skills, in particular, the growth of the importance of communication, value and motivational competencies, which creates the basis for further analysis of their transformation in accordance with each of the identified periods.

During the pre-crisis stability phase (2019-early 2020), leadership began to gradually shift from a traditional management approach to a more comprehensive model combining managerial, social, and technological skills. This transition required leaders to be able to support team interaction, motivate staff, make decisions, and effectively use digital management tools.

According to the OECD report Skills Strategy 2019, leadership skills must respond to global trends such as digitalization, population aging and economic interdependence, which are shaping new demand for competencies.

The need to develop skills throughout the life cycle of an individual, including continuous adult learning, was also emphasized. This document emphasizes the importance of applying skills in a professional environment to ensure innovation and social well-being. Forbes (2019) identifies six competencies for leaders of the future: creativity, innovation, active listening, emotional intelligence and perseverance. For example, according to IBM, creativity is the most common requirement among 1,500 global executives, which emphasizes the priority of innovative and socio-emotional skills in the work of a leader. In practical terms, NASP (2019) identifies 10 skills, including emotional intelligence, critical thinking, conflict resolution, communication, stress and change management, creativity, and negotiation skills, that enable leaders to effectively interact with teams, make informed decisions, and maintain a productive work environment. Thus, it can be argued that in 2019, leadership skills already combined technical and "soft" competencies. At the stage of pre-crisis stability, a trend is emerging towards the integration of technology, the human factor, and strategic thinking in the profile of a modern leader, which creates the basis for the further transformation of leadership skills.

The transformation of leadership skills in 2019-2025 took place under the influence of a consistent change in socio-economic, technological and security conditions, which significantly complicated the management environment. Each of the identified periods formed a specific set of management challenges that led to a change in emphasis in leadership activities, namely from an orientation towards efficiency and control to a strengthening of the role of human-centric and value-based approaches.

Conclusion. The increasing importance of the socio-emotional characteristics of the leader indicates a shift in attention to creating an environment of trust, psychological safety, and a shared vision of development. Leadership acquires the features of social influence, based on values, ethical responsibility, and the ability to maintain people's resilience in difficult conditions.

The technological dimension of modern management enhances the role of the human in the organization. The use of digital tools and artificial intelligence requires the manager not only technical literacy, but also the ability to maintain a balance between innovation and humanistic principles of interaction. Accordingly, the competitiveness of organizations increasingly depends on how harmoniously technological capabilities and human potential are combined.

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FACTORS INFLUENCING THE COST OF STEEL PRODUCTION IN UKRAINE

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Introduction. The cost of production is a basic structural element of the price of metal products. It is the level and structure of costs that determine the lower price limit beyond which production becomes unprofitable, and the enterprise is forced to either raise prices or reduce production. Analysis of the cost structure in wartime conditions allows us to identify key areas of price pressure.

Materials and methods. The methodological basis of the study is a systematic approach to analyzing the impact of production and logistics costs on the formation of metal product prices. The information base comprises analytical materials from the metallurgical enterprises Metinvest and ArcelorMittal Kryvyi Rih, industry reports, and open statistical sources for 2021–2023 [1-3].

The study used comparative and structural analysis to assess changes in the cost structure, and an economic and mathematical method to assess the impact of cost growth on the financial stability of metallurgical enterprises. The results of the study are summarized using graphical methods.

Results. *Energy component.* After the start of large-scale shelling of Ukraine's energy infrastructure in October 2022, metallurgical enterprises faced an acute shortage of electricity and gas, as well as supply disruptions. To maintain production processes, enterprises were forced to install backup generators, purchase electricity at higher peak-hour tariffs, and reduce or shut down individual capacities at the most critical moments. According to industry analysts, electricity costs per ton of production increased in 2022–2023 by 30–45% compared to 2021 [1].

Raw material component. A significant share of coking coal, previously supplied from mines in the Donetsk and Luhansk regions, was completely lost after 2014, especially after 2022, due to the occupation. Enterprises were forced to switch to more expensive suppliers from Poland, the USA, Australia, and Mongolia. This led to an increase in the cost of coking coal in the cost structure. At the same time, ArcelorMittal Kryvyi Rih and Metinvest have their own iron ore mining operations in the Kryvyi Rih iron ore basin, which partially offset the increase in costs for this item.

Logistics component. The costs of transporting metal products to the end consumer or to the port increased most significantly. Railway tariffs at Ukrzaliznytsia increased, routes became longer due to the need to bypass frontline areas, and the workload at border crossings increased. The cost of delivering metal products to EU ports via railway crossings increased by approximately $40–80/t compared to sea freight at the pre-war level (Fig. 1) [2].

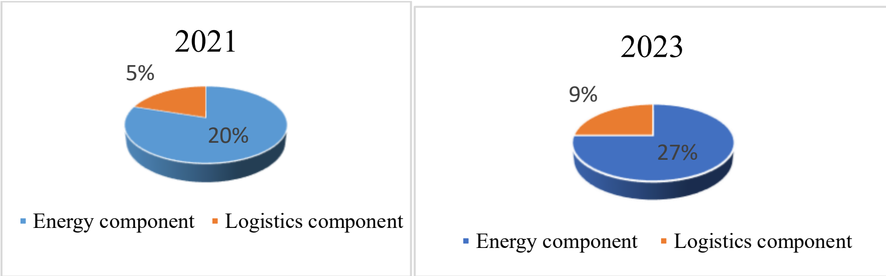

Fig. 1. Cost structure of steel reinforcement production in Ukraine in 2021 and 2023 (comparative chart)

Conclusions. The increase in production costs in 2022–2023 was the key driver of higher prices for metal products in Ukraine's domestic market. At the same time, in the foreign market, the impact of rising production costs is limited by the need to focus on competitors' prices, which requires enterprises to find cost savings or enter higher-premium markets.

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THE EU TRANSITION TO A SUSTAINABLE INNOVATION POLICY

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Introduction. If, in the 20th century, the main focus of the EU's innovation policy was to ensure economic growth and increase competitiveness, then in the 21st century, it has taken on a more comprehensive character, aimed at solving social, environmental, and cultural problems. Thus, the EU is moving toward a sustainable innovation policy model (Sustainable Innovation Policy), which combines economic goals with the tasks of sustainable development and improving the quality of life for the population [1].

Materials and methods. The methodological basis of the study is a systematic approach to analyzing the evolution of the European Union's innovation policy and its modern mechanisms. The information base comprises EU regulatory acts, materials from the Horizon 2020 and Horizon Europe framework programs, scientific publications, analytical reports, and official statistical sources.

The study uses historical and comparative methods to analyze the development of EU innovation policy, the generalization method to systematize its main tools and principles, and the structural-logical method to characterize the innovation mechanism and its components. The results of the study are presented in tabular and graphical forms.

Results. The European Union's transition to a sustainable innovation policy marks a profound transformation in its approaches – from a technology-oriented model to a humanistic-ecological one, centered on people, knowledge, culture, and sustainable development. Such experience is a valuable reference point for Ukraine, which seeks to integrate into the European innovation space and build its own model of balanced innovative growth. The main difference between traditional and sustainable innovation policy lies in their respective development goals. If the classical model is aimed primarily at economic growth, increasing labor productivity, and competitiveness, then the modern one is aimed at achieving social well-being, ecological balance, and sustainable development of society. The need to transition to a new model of innovation policy arises because traditional approaches no longer meet modern challenges. Despite sustained economic growth, many EU countries have not achieved a significant increase in the population's standard of living, while social inequalities and environmental problems have continued to deepen. These circumstances have highlighted the need to rethink the role of innovation in achieving sustainable development, strengthening social cohesion, and fostering an inclusive society.

The modern EU innovation policy emphasizes the development of human potential - education, vocational training, building social capital, ensuring stability and cohesion of communities. This approach turns innovation into a tool not only for economic, but also for socio-cultural progress, reflecting a new humanistic paradigm of development. Appendix A provides indicators (and ratings) that characterize the relevant directions of development of EU countries. Note that Finland, Sweden, Denmark, Germany, and Austria are among the ten leading EU countries in all indicators [2]. The experience of the last two decades shows a consistent shift in the priorities of European innovation policy towards sustainability. This is manifested in the integration of social and environmental objectives into the framework programs, the expansion of their thematic coverage, and the consideration of the needs of local communities and social groups. Each new EU program includes more areas related to climate change, environmental safety, and social inclusion, forming a steady trend towards the integration of all components of sustainable development. Thus, the European Union's modern innovation policy has evolved from a traditional, economically oriented model to a sustainable innovation approach that combines economic efficiency, social progress, and environmental responsibility, creating a holistic, balanced system of development.

Conclusions. The European Union Innovation Mechanism has been formed as a multi-level system that combines institutional, financial, legal, and organizational tools to support scientific and technological development. Its evolution from a traditional to a sustainable model of innovation policy reflects the transition from an orientation towards economic growth to a comprehensive provision of sustainable development, social well-being, and environmental safety. Thanks to framework programs, a system of grants, and the development of digital innovation centers and research infrastructures, the EU ensures coherence among science, business, and society. The modern model of innovative development in Europe is based on the principles of openness, regional specialization, and partnership, which allows strengthening the competitiveness and technological independence of the Union. European experience demonstrates the effectiveness of a systemic approach to innovation management, which can serve as a guideline for the development of innovation policy in Ukraine.

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SUSTAINABLE BUSINESS MODELS IN ENERGY SECTOR

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Introduction. The global transition toward climate neutrality has fundamentally transformed the energy sector, compelling companies to redesign traditional business models in response to decarbonization, digitalization, and changing consumer expectations. According to the International Energy Agency (IEA), global investment in clean energy is projected to exceed USD 2 trillion in 2025, almost twice the level of investment in fossil fuels (IEA, 2025). Simultaneously, renewable energy sources accounted for approximately one-third of global electricity generation in 2024, with solar photovoltaics representing the fastest-growing source of new electricity capacity. These trends demonstrate that sustainable business models have become a strategic necessity rather than a voluntary environmental initiative. Modern energy companies increasingly create value through decentralized energy systems, digital platforms, energy storage, smart grids, and customer-oriented services, replacing conventional commodity-based approaches with integrated, sustainability-driven business strategies.

Methods and Data. This research employs a systematic literature review and conceptual analysis to investigate the evolution of sustainable business models in the energy sector. Peer-reviewed publications published between 2018 and 2025 are retrieved from the Scopus and Web of Science Core Collection databases using combinations of keywords including *sustainable business model*, *energy sector*, *renewable energy*, *digitalization*, *energy transition*, and *business model innovation*. The selected studies are analyzed using bibliometric mapping and qualitative content analysis to identify dominant research themes, emerging technological drivers, and the economic mechanisms through which sustainability-oriented business models generate competitive advantage and long-term value creation.

Results. The literature demonstrates that sustainable business models in the energy sector increasingly rely on the integration of renewable energy technologies with digital innovations such as artificial intelligence, Internet of Things (IoT), digital twins, blockchain, and advanced data analytics (Szczepaniuk and Szczepaniuk, 2022). These technologies enable real-time monitoring of energy systems, predictive maintenance, demand-response management, and optimization of electricity generation and consumption. As a result, firms can reduce operational costs, improve resource efficiency, increase asset utilization, and strengthen system reliability (Geissdoerfer et al., 2018). Furthermore, the transition from centralized electricity production toward decentralized and customer-oriented energy ecosystems has facilitated the emergence of innovative business models, including Energy-as-a-Service, peer-to-peer electricity trading, virtual power plants, and prosumer-based energy communities. These models create new revenue streams while supporting environmental sustainability and increasing market flexibility.

The review further indicates that sustainable business models contribute to competitive advantage through multiple economic channels. Improved energy efficiency lowers production costs and reduces firms' exposure to energy price volatility, while digital technologies enhance operational resilience and decision-making capabilities (UN, 2015). Companies adopting sustainability-oriented business models also benefit from stronger ESG performance, improved access to green finance, enhanced corporate reputation, and greater investor confidence. Nevertheless, several barriers continue to constrain large-scale implementation, including high initial investment costs, insufficient digital infrastructure, cybersecurity risks, regulatory uncertainty, and shortages of digital skills (Teece, 2018). The findings suggest that successful business model transformation requires not only technological innovation but also organizational change, supportive public policies, and effective collaboration among firms, governments, technology providers, and consumers.

Conclusions. Sustainable business models are becoming a key source of long-term competitiveness in the energy sector by integrating renewable energy, digital technologies, and innovative value-creation mechanisms. The literature indicates that digitalization significantly enhances the economic viability of renewable energy deployment by improving operational efficiency, reducing costs, and increasing organizational flexibility. Future research should move beyond conceptual analyses toward empirical assessments of how different digital technologies influence firm performance, business model innovation, and sustainability outcomes across countries and energy subsectors. Such evidence will contribute to the development of effective corporate strategies and public policies supporting the twin transition toward a low-carbon and digitally enabled economy.

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HUMAN RESOURCES OR HUMAN CAPITAL? RETHINKING THE ROLE OF PEOPLE IN CONTEMPORARY ORGANIZATIONS

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Introduction. In the context of organizational transformation and the digitalization of business processes, the importance of people as a source of organizational value is increasing. In academic discourse, the concepts of “human resources” and “human capital” are often used interchangeably, although they reflect different dimensions of people's roles within an organization. The lack of a clear conceptual distinction between these concepts may lead to ambiguity in approaches to employee development and the assessment of their contribution to organizational performance. Contemporary changes in the organization of work and the development of the knowledge economy reinforce the need to move beyond viewing employees solely as a resource and to consider their knowledge, skills, competencies, experience, and capacity to create value. Therefore, distinguishing between human resources and human capital is essential for clearly defining their respective roles and understanding the relationship between employee management and the development of employees' productive potential.

The aim of the study is to identify and systematize the conceptual differences between human capital and human resources and to substantiate the nature of their relationship in contemporary management.

Data and Methods. The study draws on academic literature addressing human capital theory and human resource management. The analysis incorporates both classical theoretical works and recent studies published between 2022 and 2025. To achieve the research objective, a systematic literature review, content analysis, and comparative analysis were employed. The main approaches to conceptualizing human resources and human capital were identified, and criteria for their comparison were established. The findings were synthesized to determine the relationship between human resource management and human capital development.

Results. The analysis demonstrated that human resources and human capital share a common subject – people - but differ in their conceptual focus. Human resources are primarily considered from the perspective of managing employees, whereas human capital refers to the qualitative characteristics of individuals and their potential to create value. This distinction is consistent with the development of a strategic approach to human capital, within which employees’ knowledge, skills, and abilities are regarded as a potential source of organizational competitive advantage (Barney & Wright, 1998; Becker, 1964). The main differences between the two concepts are summarized in Table 1.

Table 1. Conceptual distinction between human resources and human capital

Criterion	Human Resources	Human Capital
Primary focus	Management of employees and their engagement in achieving organizational goals	Employees' qualitative characteristics and their potential to create value
Primary object	Employees as participants in organizational activities	Knowledge, skills, competencies, experience, and abilities embodied in people
Role of people	A resource necessary for the functioning and development of the organization	A carrier of productive potential and a source of organizational value creation
Key components	Workforce size, workforce structure, employment, occupational composition, and other workforce-related characteristics	Knowledge, skills, competencies, experience, abilities, and other characteristics that determine productive potential
Value creation	Through the effective engagement, utilization, and management of employees	Through the application of knowledge, skills, competencies, and other human characteristics

Source: developed by the author based on Ray et al. (2023), Zhang et al. (2023), Andersén & Jansson (2024), Kim (2024), Zerrad & Schechter (2025)

Human resources is considered primarily in terms of managing people and ensuring the organization has the employees required to perform its activities. Human capital, in contrast, focuses on the qualitative characteristics of employees and their capacity to generate economic and organizational value. This approach is consistent with the contemporary understanding of human capital resources as a set of employee characteristics that can contribute to organizational outcomes (Ray et al., 2023). Within the human resources concept, employees are viewed as participants in organizational activities, whereas the human capital concept places greater emphasis on employees' knowledge, skills, competencies, experience, and abilities (Zhang et al., 2023). From a human resources perspective, people are regarded as a resource necessary for carrying out organizational processes. In contrast, from a human capital perspective, employees are viewed as carriers of knowledge, skills, and other characteristics that can create value (Andersén & Jansson, 2024). For human resources, key characteristics include workforce size, structure, employment, occupational composition, and other workforce-related attributes. Human capital, in turn, encompasses knowledge, skills, competencies, experience, abilities, and other characteristics that determine employees' productive potential (Kim, 2023). Human resources create conditions for the effective utilization of labor through appropriate management practices, whereas human capital creates value through the application of employees' knowledge, skills, competencies, and other characteristics (Zerrad & Schechter, 2025). These concepts should not be viewed as opposing categories, as they are directly interconnected.

Recent studies confirm that HRM practices can serve as mechanisms for developing and strengthening human capital (Otoo et al., 2022; Jo et al., 2024). Human capital may mediate the relationship between HRM practices and organizational performance. This indicates that management practices directed at employees can affect organizational outcomes not only directly but also through the development of human capital. Investments in employee development, competency formation, and the effective utilization of human potential can therefore be regarded as components of human capital management. This further highlights the distinction between managing people as a resource and managing the characteristics that determine their capacity to create value. Accordingly, human resources and human capital should be regarded as interconnected but conceptually distinct categories.

Thus, human resources primarily addresses who an organization employs and how employees are managed, whereas human capital addresses what knowledge, skills, competencies, and potential people possess and what value they can create.

Conclusion. The study confirmed that the concepts of human resources and human capital are interrelated but conceptually distinct. Human resources primarily characterize people as a component of the organizational system and as an object of management, whereas human capital refers to the set of characteristics embodied in people that can create value. For contemporary organizations, this implies the need to combine the management of existing human resources with the targeted development of employees' knowledge, competencies, and other characteristics that determine their capacity to generate results. Such an approach helps create conditions for the development and effective use of their potential.

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NON-FINANCIAL REPORTING AS A TOOL FOR HUMAN CAPITAL ASSESSMENT

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Introduction. In the contemporary knowledge-based economy, human capital is increasingly recognized as an important source of organizational value and competitive advantage. The growing importance of knowledge, skills, competencies, and experience of employees has changed the perception of people in organizations from a traditional labor resource toward a strategic source of value creation. Human capital resources include characteristics embodied in employees that can contribute to organizational outcomes and therefore require appropriate approaches to their identification and measurement (Ray et al., 2022; Zhang et al., 2023).

At the same time, traditional financial reporting provides limited information about the qualitative characteristics of employees. Personnel-related expenditures are generally reflected as costs, whereas knowledge, competencies, experience, commitment, and development potential are not directly recognized as organizational assets. This creates a need for complementary information that enables stakeholders to understand how organizations develop and utilize their human potential.

Non-financial reporting provides an opportunity to disclose information about employees and their development that cannot be adequately represented through financial indicators alone. Such information can include workforce characteristics, employee development, training, competencies, commitment, and other characteristics related to the organization’s human capital. The importance of employee commitment as a characteristic connected with human capital resources is also emphasized in recent research (Andersén & Jansson, 2024).

The aim of the study is to substantiate the role of non-financial reporting in human capital assessment and to identify the main groups of indicators that can be used to characterize human capital.

Data and Methods. The study is based on a review of recent academic literature on human capital resources and their measurement. The theoretical basis is formed by the studies of Ray et al. (2022), Zhang et al. (2023), and Andersén and Jansson (2024), which examine the conceptualization, measurement, and characteristics of human capital resources.

A systematic literature review and comparative analysis were used to identify the main characteristics of human capital and to determine their potential representation through non-financial reporting. The analysis focused on three dimensions: the characteristics embodied in employees, approaches to human capital measurement, and organizational factors associated with the development and utilization of human capital.

Results. The analysis demonstrates that human capital should be considered as a multidimensional concept that cannot be adequately assessed through a single quantitative indicator. Zhang et al. (2023) emphasize the importance of clearly defining and measuring human capital resources and demonstrate that the concept includes a range of employee characteristics relevant to organizational performance. Ray et al. (2022) similarly conceptualize human capital resources as employee characteristics that may contribute to organizational outcomes.

Based on these approaches, the information relevant to human capital assessment through non-financial reporting can be grouped into several dimensions.

Table 1. Main dimensions of human capital assessment through non-financial reporting

Dimension	Examples of indicators	Human capital characteristic
Workforce characteristics	Number and structure of employees, occupational composition	Human capital base
Knowledge and education	Education level, qualifications, professional knowledge	Knowledge
Skills and competencies	Professional and organizational competencies, skill development	Productive capabilities
Employee development	Training, professional development, career development	Human capital accumulation
Experience	Length of service, professional experience	Accumulated knowledge
Commitment and engagement	Employee commitment, engagement, retention	Relational and motivational characteristics

Source: developed by the author based on Ray et al. (2022), Zhang et al. (2023), Andersén & Jansson (2024).

The first important dimension concerns the characteristics of the workforce. Information about the number and structure of employees provides a basic description of the organization’s human resources. However, such quantitative characteristics alone cannot represent human capital. Human capital assessment requires consideration of the knowledge, skills, competencies, and other characteristics embodied in employees (Ray et al., 2022; Zhang et al., 2023).

Knowledge and skills represent core components of human capital. The measurement of these characteristics is important because employees with different levels and combinations of knowledge and competencies may have substantially different productive potential. Consequently, non-financial reporting can provide information about employee education, professional qualifications, competencies, and opportunities for their further development.

Employee development is another important dimension. Investments in training and professional development can contribute to the accumulation and renewal of human capital. From this perspective, information about employee development is relevant not only as an indicator of organizational expenditure but also as evidence of the organization's efforts to strengthen the productive potential of its workforce.

An additional dimension is employee commitment. Andersén and Jansson (2024) emphasize the relationship between organizational commitment and human capital resources and introduce the concept of commitment capital as a way of connecting these dimensions. This suggests that employee commitment may be considered an important characteristic when assessing the capacity of human capital to contribute to organizational outcomes.

The analysis therefore indicates that non-financial reporting can provide information about both the **quantity** and **quality** of human capital. Quantitative indicators describe the size and structure of the workforce, while qualitative indicators provide information about knowledge, skills, competencies, experience, development, and commitment. The combination of these dimensions provides a more comprehensive understanding of the organization's human capital.

However, the assessment of human capital through non-financial reporting remains methodologically challenging. Human capital is multidimensional, and different organizations may use different indicators and measurement approaches. Zhang et al. (2023) emphasize the importance of conceptual clarity and appropriate measurement of human capital resources, which is particularly relevant for ensuring comparability between organizations.

Another challenge is establishing the relationship between human capital indicators and organizational outcomes. The presence of highly qualified employees does not automatically guarantee higher performance. The value of human capital depends on how employees' characteristics are utilized within organizational processes. Therefore, non-financial reporting should ideally provide not only information about the characteristics of employees but also information that allows stakeholders to understand how these characteristics are developed and utilized.

Conclusion. The study confirms that non-financial reporting can serve as an important source of information for human capital assessment. Its main advantage is the possibility of complementing financial information with qualitative characteristics of employees that are not directly reflected in traditional financial statements.

Human capital assessment should combine indicators describing workforce characteristics with information about knowledge, skills, competencies, experience, employee development, and commitment. Such an approach corresponds to contemporary research, which considers human capital resources as employee characteristics that can contribute to organizational outcomes (Ray et al., 2022; Zhang et al., 2023).

Therefore, non-financial reporting can contribute to a more comprehensive understanding of the organization's human capital and its potential for value creation. Further research should focus on developing an integrated system of indicators that would improve the comparability of human capital information and strengthen the connection between human capital characteristics and organizational performance.

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Наукове видання

"ECONOMICS FOR ECOLOGY"

(“Science for sustainable and innovative Europe”)

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Друкується в авторській редакції

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