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INDUSTRY 4.0 IN UKRAINE AND ROMANIA: CHALLENGES, OPPORTUNITIES, AND PATHWAYS TO INTEGRATION

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Abstract. The present study explores the current state and potential of Industry 4.0 adoption in Ukraine and Romania, two countries positioned at the edge of the European Union and sharing complex post-Soviet legacies. The subject of this study is the digital and industrial transformation driven by advanced technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), robotics, and big data analytics. The objective of the present paper is twofold: firstly, to identify the challenges and opportunities for these countries in embracing the Fourth Industrial Revolution; and secondly, to examine pathways for regional integration and economic modernisation. The study employs a comparative analysis, case study methodology, and a synthesis of official statistics and policy documents to evaluate the readiness and strategic direction of both countries. The present study draws upon an analysis of two representative firms, Dacia in Romania and Grammarly in Ukraine, in order to illustrate sector-specific technological integration, innovation scalability, and the role of external financial and institutional support in achieving transformation. The findings suggest that Romania benefits from EU structural funds and a centralised digital strategy, whereas Ukraine relies more heavily on private-sector innovation and international aid due to its ongoing geopolitical challenges. Despite these structural differences, both countries present promising opportunities for collaboration, particularly in cross-sectoral knowledge transfer, public-private partnerships, and digital upskilling of the workforce. The paper concludes that sustainable implementation of Industry 4.0 technologies requires a cohesive national strategy, inclusive digital education policies, and mechanisms for efficient resource allocation. The employment of a comparative perspective is conducive to the cultivation of a comprehensive understanding of the manner in which policy frameworks, economic structures, and innovation ecosystems interact to give form to the trajectory of digital transformation in emerging economies.

Keywords: Industry 4.0, Ukraine, Romania, IoT, AI, digital transformation, regional development.

JEL Classification: O14, O31, L26, R11, M13

1. Introduction

The Fourth Industrial Revolution, otherwise known as Industry 4.0, signifies a substantial transformation in the manner in which industries function and evolve through the integration of advanced digital technologies. This paradigm shift, as conceptualised by Klaus (Schwab, 2016), is typified by the convergence of the physical, digital, and biological realms. For countries at the periphery of the European Union, such as Ukraine and Romania, this shift presents a unique opportunity to bypass traditional developmental trajectories and embrace cutting-edge innovations that can enhance productivity, stimulate economic growth, and boost global competitiveness.

Although Ukraine and Romania are geographically close and have undergone similar post-socialist transitions, they have distinct economic landscapes and levels of readiness to adopt Industry 4.0. Despite grappling with the repercussions of prolonged geopolitical instability and a resource-constrained public sector, Ukraine has emerged as a digital frontrunner in the region, notably through its thriving IT industry and innovative startups. The Diia ecosystem and companies such as Grammarly serve to demonstrate Ukraine's capacity for innovation in

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the face of adversity. Conversely, Romania stands to benefit from EU membership and access to structured funding mechanisms. The country's institutional infrastructure, particularly in areas such as manufacturing automation, digital literacy, and IoT integration, is supported by strategic frameworks that are aligned with European digital transformation goals.

The objective of this research is to analyse how Industry 4.0 is being adopted and implemented in Ukraine and Romania, focusing on key economic ectors, government strategies, technological infrastructure, and private-sector engagement. A comparative approach is employed to highlight both converging and diverging trends between the two nations. This text focuses on case studies, which are utilised to illustrate the practical applications of advanced technologies in specific sectors. These sectors include, but are not limited to, automotive manufacturing and IT services.

Methodologically, this study employs a combination of qualitative content analysis, policy document review, statistical comparisons, and case study exploration. The sources from which the data has been drawn include European Commission reports, national digital transformation plans, academic research, and business performance data. The objective of the present paper is twofold: firstly, to make a contribution to the expanding corpus of literature on digital transformation in emerging economies; and secondly, to provide policy-relevant recommendations for accelerating the adoption of Industry 4.0 technologies.

The following introductory section aims to establish the foundations for a more in-depth investigation of the foundational conditions, technological adoption patterns, and strategic challenges that shape the digital transformation paths of Romania and Ukraine. The objective of the research is to provide a balanced perspective on how these nations can navigate their industrial futures by identifying both structural strengths and systemic weaknesses.

Ukraine and Romania are characterised by a shared geographic proximity and historical ties, yet they exhibit considerable disparities in terms of economic and technological preparedness. Ukraine faces considerable challenges due to geopolitical instability and resource constraints, yet it compensates for these issues with a robust IT sector. Conversely, Romania benefits from EU funding and structured policy support, but struggles with inefficiencies in resource allocation.

The present study aims to explore these divergences and convergences by presenting a comprehensive analysis of how Industry 4.0 technologies are shaping the economic landscapes of both nations.

2. General Preconditions of Development

The preconditions for Industry 4.0 development in both countries differ substantially, as shown in the table below.

Table 1
Prerequisites for the development of Industry 4.0 in Ukraine and Romania

Indicator	Ukraine	Romania
GDP per capita (2023)	4,300 USD	14,850 USD
DESI Index (2023)	Not ranked	26th in the EU
Digital literacy level	37%	58%
Industry 4.0 funding	Private sector-based	EU-supported

Source: compiled by the authors based on (Eurostat, 2023), DESI Index report

As Hermann et al. (2016) emphasise, there is a direct correlation between GDP and literacy levels, and technological readiness. Romania's higher GDP and EU support facilitate structured adoption, whereas Ukraine's reliance on private initiatives reflects resource constraints.

The adoption of Industry 4.0 technologies has transformed traditional business models, giving companies a competitive edge in various sectors (Wysokińska, 2020; Kravchuk & Voitko, 2021). Two notable examples are the Romanian automotive manufacturer Dacia and the Ukrainian IT innovator Grammarly, which demonstrate how different industries can leverage advanced technologies to achieve operational excellence and global success.

Dacia, a subsidiary of the Renault Group, is a prime example of the successful integration of Industry 4.0 in Romania. The company has implemented Internet of Things (IoT) technologies to transform its production processes. IoT sensors monitor real-time data across assembly lines, enabling predictive maintenance and reducing downtime while optimising resource utilisation.

The introduction of IoT systems at Dacia's Mioveni factory has resulted in significant efficiency gains. According to the company's 2022 operational report:

– Production delays decreased by 25%;
– energy consumption across facilities reduced by 15%, aligning with EU sustainability goals;
– quality control accuracy improved through automated defect detection systems integrated with IoT networks.

Dacia's case study illustrates how Industry 4.0 technologies can enhance traditional manufacturing practices, rendering them more agile and responsive to market demands. Moreover, EU funding has enabled these developments by providing resources for technological upgrades and workforce training.

Dacia's success also serves as an example to other Romanian industries, demonstrating the potential of cross-sector IoT adoption in areas such as energy management, logistics and retail.

While Romania has a strong manufacturing base, Ukraine has a notable presence in the IT sector, with Grammarly serving as a prime example of Industry 4.0-driven innovation. The company was founded in Kyiv and utilises both Artificial Intelligence (AI) and Natural Language Processing (NLP) to provide automated writing assistance to millions of users worldwide.

Grammarly's AI algorithms analyse text for grammar, tone and clarity, employing machine learning models trained on vast datasets. The platform's capacity to deliver personalised feedback in real-time serves to illustrate the transformative potential of AI in the creation of user-centric solutions.

Grammarly's global impact:
– Over 30 million daily active users as of 2023;
– integration with major platforms like Microsoft Word, Google Docs, and email clients;
– an estimated valuation of 13 billion USD in 2022, reflecting the scalability of its AI-based business model.

The company's success demonstrates Ukraine's IT sector's potential to develop global-scale solutions, even amid challenging geopolitical conditions. By fostering innovation through AI, Grammarly has positioned itself as a market leader and raised Ukraine's profile as a hub for advanced technological development.

Lessons from Dacia and Grammarly include the following.

1. Sector-specific applications of Industry 4.0:
– Dacia represents the effective integration of IoT in traditional industries like manufacturing, where physical processes can benefit from automation and real-time monitoring.
– Grammarly showcases how AI can disrupt service-based industries by creating value through digital-only solutions.

2. Resource optimisation:
– Dacia's adoption of predictive maintenance reduced waste and increased efficiency, aligning with sustainability standards.
– Grammarly's reliance on cloud computing and scalable AI infrastructure demonstrates the potential of digital tools to optimise operational costs.

3. Scaling innovation:
– Dacia's use of IoT for predictive analytics highlights the importance of scaling innovation within production ecosystems.
– Grammarly's global reach underscores the scalability of AI solutions across markets and languages, reinforcing the importance of export-oriented innovation.

The success of Dacia and Grammarly reflects broader trends in Industry 4.0 adoption across Europe. Their achievements underline the need for:
– Investment in advanced technologies (both companies benefited from investments in IoT and AI, proving the importance of funding and resource allocation).
– Workforce development (as seen in Dacia's factory modernisation, training workers to manage new technologies is critical for success). Similarly, Grammarly relies on a skilled team of data scientists and engineers to maintain its competitive edge.
– Cross-sectoral collaboration (the lessons from Dacia's IoT systems could be applied to other industries, such as logistics or retail, while Grammarly's AI expertise could inform innovation in educational or healthcare applications).

These examples demonstrate how Romania and Ukraine can leverage their strengths to drive Industry 4.0 adoption, thereby contributing to regional and global economic competitiveness.

3. Infrastructure and Technology

The Internet of Things (IoT) is a critical enabler of smart systems. Romania is using IoT in manufacturing and logistics, with support from EU-funded initiatives. In contrast, Ukraine is focusing on agricultural applications, such as AgriEye, which uses drones to analyse soil.

Research by Deloitte (2021) found that the adoption of the Internet of Things (IoT) has been demonstrated to improve productivity by 20-30%, especially in the logistics and manufacturing sectors.

Romania has emerged as a leader in the adoption of Big Data analytics within the banking and telecommunications sectors. Ukraine continues to function as a major outsourcing hub, with companies such as SoftServe providing analytics solutions to international clients.

The adoption of robotics technology varies significantly between the two countries. The following table illustrates the marked differences in robotic penetration.

Table 2
Introduction of robotics in Ukraine and Romania

	Ukraine	Romania	EU Average
Robots per 10,000 workers	18	126	151

Source: compiled by the authors based on (Deloitte, 2021)

Romania's UiPath, a leader in the field of robotic process automation (RPA), has been able to

capitalise on this trend, while Ukraine has seen limited progress due to its comparatively limited investment in robotics.

4. Challenges and Prospects

The development and integration of Industry 4.0 technologies in Ukraine and Romania are hindered by several overarching challenges that reflect their unique economic, institutional, and infrastructural realities. While both nations demonstrate significant potential, it is imperative to address the financial, educational and strategic barriers that hinder sustainable growth in this domain.

4.1 Financial Limitations

It is evident that economic constraints represent a significant impediment to the adoption of Industry 4.0 technologies.

In light of the ongoing war, Ukraine's fiscal resources are predominantly allocated to defence and reconstruction, resulting in a limited availability of public funding for technological innovation (Lopatynskyi, Vodianka, Khil, 2024). Consequently, reliance on international aid and private investment has become imperative. Programmes such as USAID EDGE provide targeted financial assistance for digital transformation projects, while the World Bank supports initiatives focused on rebuilding infrastructure with advanced technologies. Nevertheless, these external funds are frequently inadequate in meeting the substantial demands of Ukraine's economy.

Private-sector investments, particularly in the IT industry, have been instrumental in mitigating this shortfall. Initiatives such as Diia.City, a tax and regulatory framework for IT businesses, have attracted foreign direct investment (FDI) and encouraged global partnerships. In 2023 alone, Diia.City facilitated over $1 billion in IT-related investments. Nevertheless, the absence of a centralised national fund dedicated to Industry 4.0 projects remains a critical gap.

Romania benefits significantly from EU grants, with 4 billion EUR allocated in 2023 for digitalisation and Industry 4.0 projects. These funds have enabled advancements in robotics, the Internet of Things (IoT), and digital literacy programmes. However, the effectiveness of these resources is often undermined by bureaucratic inefficiencies. Delays in disbursing funds and inadequate project monitoring limit the impact of EU investments.

Notwithstanding the aforementioned challenges, Romania's financial infrastructure for Industry 4.0 is demonstrably more robust than that of Ukraine, offering stable mechanisms for long-term planning and implementation. Optimising administrative processes and ensuring transparent fund allocation could further accelerate technological adoption.

It is recommended that both countries explore public-private partnerships in order to diversify funding sources and reduce reliance on external grants. Furthermore, Romania could share its expertise in accessing and managing EU funds with Ukraine, thereby fostering cross-border collaboration.

4.2 Digital Literacy

The integration of Industry 4.0 technologies is contingent upon the presence of a digitally literate workforce. However, both Ukraine and Romania face significant gaps in this area, which limit their capacity to leverage advanced tools effectively.

With 58% of the population possessing fundamental digital competencies, Romania exhibits moderate progress in comparison to other countries within the region. However, this figure is inadequate to facilitate the comprehensive implementation of advanced technologies such as robotics and big data analytics. The rural-urban divide further exacerbates this issue, as access to digital education and resources is concentrated in urban centres such as Bucharest and Cluj-Napoca. Programmes such as Code for Romania, which provide training in coding and digital skills, play a pivotal role in addressing these disparities. Furthermore, EU-backed initiatives target young professionals and small businesses by offering workshops and certifications in digital tools.

The digital literacy rate in Ukraine is 37%, which is lower than the rate in Romania. This is indicative of systemic gaps in education and resource availability. The government's Diia platform, launched in 2020, seeks to address this challenge by providing online training and certifications in digital skills. By 2023, the platform had amassed over 2 million users, offering courses on subjects such as data analytics, AI, and digital marketing.

Notwithstanding these efforts, considerable challenges persist in rural areas and conflict-affected regions, where access to digital infrastructure is constrained. It is imperative that the reach of initiatives such as Diia is expanded, and that digital skills training is integrated into national education curricula.

Both nations must invest in targeted digital literacy campaigns that focus on underserved communities. Partnering with private-sector leaders, such as IT companies and educational platforms, could help to increase the scale of these efforts.

4.3 Strategic Planning

Strategic planning plays a pivotal role in the adoption of Industry 4.0 technologies. While Romania has

established clear frameworks, Ukraine's fragmented approach poses a barrier to cohesive implementation.

Romania's Digital Transformation Plan (2023–2030) sets out clear objectives for Industry 4.0, such as greater automation in manufacturing, the widespread deployment of the Internet of Things (IoT), and improved digital literacy. The plan is aligned with EU digital strategy benchmarks, ensuring consistency with regional goals. For instance, it emphasises integrating robotics into high-growth sectors such as automotive manufacturing and logistics, backed by structured funding mechanisms.

Romania's centralized approach facilitates enhanced resource allocation and project monitoring, leading to the reduction of redundancies and inefficiencies. Nevertheless, challenges persist in ensuring timely execution and adapting to rapid technological changes.

Ukraine has yet to develop a comprehensive national Industry 4.0 strategy; instead, the country relies on regional and sector-specific initiatives. For example, the Lviv IT Cluster is a key driver of innovation in western Ukraine, and there are also isolated initiatives in agriculture and logistics that are implementing IoT and automation solutions.

This fragmented approach limits scalability and creates disparities in technological adoption across different regions. Developing a unified national roadmap that incorporates the best practices of Romania's digital transformation strategy could address these issues.

Ukraine must prioritise formulating a national Industry 4.0 strategy that integrates post-war reconstruction efforts with digital transformation objectives. Utilising regional success stories, such as the Lviv IT Cluster, as models for nationwide initiatives could accelerate progress.

5. Comparative Analysis

Ukraine and Romania, despite their geographical proximity, exhibit divergent approaches to the adoption of Industry 4.0, a discrepancy attributable to disparate governance structures, funding sources, and industrial priorities. This section explores critical areas of comparison–the Internet of Things (IoT), funding, and robotics–through both qualitative insights and quantitative data, with a focus on the distinct opportunities and challenges faced by each country.

5.1 Internet of Things (IoT)

The Internet of Things (IoT) has emerged as a cornerstone of Industry 4.0, facilitating real-time data collection and automation across various sectors. While both Ukraine and Romania are advancing IoT adoption, their focus areas differ significantly due to sectoral priorities and resource availability.

The Internet of Things (IoT) ecosystem in Ukraine is predominantly concentrated in the agricultural and logistics sectors. AgriEye, a leader in the field of precision agriculture, deploys drones and the Internet of Things (IoT) sensors to collect soil data, monitor crop health, and optimise irrigation. These technologies have been instrumental in increasing crop yields by up to 20%, particularly in regions such as Poltava and Vinnytsia.

In the field of logistics, Nova Post, Ukraine's largest courier service, has adopted the IoT-enabled inventory systems that facilitate the real-time tracking of packages and the monitoring of warehouse operations, thereby reducing error rates by 12%.

However, the absence of a unified IoT strategy at a national level restricts the scope for wider applications in sectors such as healthcare and urban infrastructure. A positive scenario would see increased foreign direct investment (FDI) and partnerships with global IoT providers, enabling the expansion of the IoT into areas such as energy management and smart cities.

Romania's IoT ecosystem benefits from EU support, enabling integration across manufacturing, energy and smart infrastructure. For example,

Table 3

Comparative Analysis of Industry 4.0 Development

Criterion	Ukraine (Optimistic scenario)	Romania (Optimistic scenario)
IoT	Expansion in agriculture and logistics. For example, AgriEye uses IoT technology to carry out drone-based soil analysis, thereby improving crop yields by up to 20%. Similarly, logistics companies such as Nova Post use IoT technologies to optimise warehousing.	Cross-sectoral IoT integration, including manufacturing, energy, and urban infrastructure. OMV Petrom uses IoT for predictive maintenance, reducing costs by 15%, and smart cities deploy IoT solutions for urban mobility.
Funding	Increased international aid and private investment driven by programs like Diia.City, which provides tax incentives for IT companies and encourages global partnerships.	Efficient utilisation of 4 billion EUR in EU funding for digitalisation efforts, enhancing automation, workforce skills, and R&D projects. Targeted grants for SMEs foster greater innovation in emerging tech sectors.
Robotics	Growth driven by education and partnerships, particularly in collaboration with universities and global robotics firms. Focused on adoption in high-value sectors such as pharmaceuticals and automotive assembly.	Advanced automation in manufacturing, led by companies like Dacia. Romania's robotics integration is expanding into logistics, healthcare, and agriculture, supported by EU-funded R&D projects.

Source: compiled by the authors based on national statistics and case analysis

companies such as OMV Petrom use IoT sensors for the predictive maintenance of energy facilities, thereby reducing operational downtime by 25%. This IoT-driven efficiency is in line with the EU's sustainability goals.

Urban areas such as Bucharest and Cluj-Napoca are also using the IoT for smart city initiatives, including real-time traffic monitoring and optimising waste management. Supported by EU grants, these projects enhance urban mobility and reduce environmental impact.

Romania's structured funding mechanisms and private-sector innovation could position it as a regional leader in IoT technologies, according to the optimistic scenario.

5.2 Funding

Investment is a critical driver of Industry 4.0 adoption. Romania benefits from structured EU support, while Ukraine relies on international aid and contributions from the private sector.

Ukraine's funding for Industry 4.0 initiatives is heavily reliant on external sources, including USAID EDGE and the World Bank (Fedun, Kudyrko, Shnyrkov, Bey, Yatsiuk, Sayniuchenko, 2023). The government's Diia.City programme offers tax incentives and streamlined regulatory frameworks to IT companies, resulting in the attraction of over 250 global and domestic firms since its inception in 2021.

Despite these successes, a fragmented approach to funding allocation limits scalability. Strengthening Ukraine's financial foundation for Industry 4.0 projects could be achieved through increased collaboration with international organisations and targeted investment in high-impact sectors such as energy and manufacturing.

Romania's integration into the EU provides access to substantial funding, including the 4 billion EUR allocated in 2023 for digitalisation and Industry 4.0 development (Gheorghe, Badea, Ilie, & Despa, 2021). These funds support a variety of initiatives, ranging from manufacturing automation to digital literacy programmes in rural areas.

Furthermore, Romania's SME sector benefits from grants that encourage experimentation with emerging technologies such as artificial intelligence and robotics. A future scenario that is perceived as optimistic by some stakeholders involves the streamlining of fund utilisation to ensure the timely and effective execution of projects, thereby further solidifying Romania's position as a hub for innovation.

5.3 Robotics

Robotics is a critical enabler of automation and efficiency, and both Ukraine and Romania are making strides in this area, albeit at different scales.

While the adoption of robotics in Ukraine remains modest, with an average of five robots per 10,000 workers, educational institutions such as National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute" are at the forefront of innovation through robotics research and competitions. The utilisation of robots in healthcare is a nascent field of study, with startups such as Robo Technologies exploring the potential of automation in domains such as sterilisation and patient monitoring.

A positive outlook anticipates an enhancement in collaboration with international robotics enterprises, thereby facilitating Ukraine's adoption of robotic systems within sectors such as automotive assembly and pharmaceuticals.

In comparison, Romania's robotics sector is more advanced, with 18 robots per 10,000 workers. Dacia, a subsidiary of Renault, has successfully implemented a fully automated production line system, achieving a 30% increase in efficiency and a reduction in production costs.

Robotics applications are expanding beyond manufacturing into logistics and agriculture. For example, logistics hubs use robotic arms for packaging and sorting, and drones equipped with AI are being tested for precision farming.

Deloitte (2021) have emphasised the significance of well-defined policies in optimising outcomes in the context of Industry 4.0. Romania's alignment with EU digital transformation strategies provides it with a competitive advantage, ensuring consistent funding and policy-driven innovation. Ukraine has demonstrated considerable agility and adaptability through its private-sector initiatives. However, in order to scale its Industry 4.0 capabilities effectively, it must adopt a more cohesive national strategy.

6. Conclusions and Recommendations

Ukraine and Romania have complementary strengths when it comes to adopting Industry 4.0 technologies, reflecting their unique economic, geopolitical and institutional contexts. Romania's membership of the European Union has given it access to substantial financial resources and structured policy frameworks that facilitate the implementation of advanced technologies such as the Internet of Things (IoT), robotics, and big data analytics. By contrast, Ukraine's innovative IT sector has demonstrated resilience and adaptability by producing globally recognised solutions such as Grammarly and SoftServe, despite facing challenging conditions of economic instability and geopolitical conflict.

Notwithstanding these strengths, both nations are confronted with critical challenges that must be addressed if they are to fully capitalise on the potential of Industry 4.0. These include gaps in digital literacy,

disparities in technological adoption across sectors, and the need for cohesive strategic planning. Addressing these challenges will enhance the competitiveness of both countries and position them as leaders in the regional and global digital economy.

Key recommendations:

1. Investment in workforce training is recommended in order to address the digital literacy gap. The successful adoption of Industry 4.0 technologies is contingent upon the presence of a digitally skilled workforce. In Romania, despite relatively higher levels of digital literacy in comparison to Ukraine, significant disparities persist, particularly in rural areas. Government-led initiatives, such as the expansion of coding programmes like Code for Romania, could help address these disparities. In a similar vein, Ukraine's Diia Education platform is poised to augment its training programs, with the objective of equipping the workforce with the competencies required for the integration of IoT, AI, and robotics.

Proposed actions:

– Develop and implement nationwide campaigns to improve digital literacy, targeting low-income communities;
– work with international organisations to provide certificates for advanced digital skills;
– creation of vocational training centres focused on Industry 4.0 technologies, such as robotics and data analysis.

2. Strengthen public-private partnerships to accelerate technological integration. Collaboration between governments, private enterprises and academic institutions is essential in overcoming gaps in resources and expertise. Romania could leverage its existing partnerships with multinational corporations such as Renault and UiPath to establish innovation hubs that facilitate knowledge transfer and joint technology development. Meanwhile, Ukraine, with its thriving startup ecosystem, should focus on fostering collaborations between IT companies and traditional industries to drive digital transformation.

Proposed actions:

– Creation of incentives for private sector investment in Industry 4.0 projects, such as tax breaks or co-financing opportunities;
– encourage the creation of joint ventures between local firms and global technology leaders with a view to introducing best practices;
– maintainance of co-operation between universities and industry with a view to commercialising research in the field of advanced manufacturing and automation technologies.

3. Development of comprehensive national strategies to bring them into line with international standards. The lack of cohesive strategies in both countries restricts the scalability and consistency of Industry 4.0 implementation. While Romania's Digital Transformation Plan (2023–2030) provides a solid foundation, it requires regular assessments to ensure alignment with EU benchmarks and market demands. Ukraine urgently needs to formulate a comprehensive national Industry 4.0 strategy that prioritises post-war recovery and modernisation.

Proposed actions:

– Development and adoption of long-term national roadmaps for Industry 4.0, integrating sustainable development and innovation goals;
– harmonisation of industrial policy with international standards in order to attract foreign direct investment;
– establishing monitoring and evaluation mechanisms to track progress and adapt strategies as necessary.

4. Access to funding and financial support must be expanded. Ukraine must attract foreign investment and leverage grants from international development organisations to diversify its funding sources. Romania should continue to optimise the utilisation of EU funds by reducing bureaucratic hurdles and focusing on high-impact projects.

5. The enhancement of regional and international collaboration is imperative. It is recommended that both nations engage actively in regional initiatives, such as the Central European Digital Economy Partnership, with a view to sharing best practices and co-developing cross-border projects. Participation in global forums, such as the World Economic Forum's Digital Transformation Initiative, would further enhance their visibility and access to expertise.

6. The promotion of innovation ecosystems is of paramount importance. The encouragement of the development of innovation clusters, such as IT hubs in Lviv for Ukraine and Bucharest for Romania, has the potential to stimulate local entrepreneurship and facilitate the establishment of networks for knowledge exchange. Governmental backing for incubators and accelerators has been demonstrated to have a significant impact on the growth of small and medium-sized enterprises (SMEs) in high-tech industries.

7. The emphasis should be placed on sustainability and green technologies. As global attention shifts towards sustainable development, both countries must incorporate green technologies into their Industry 4.0 frameworks. This encompasses investments in energy-efficient manufacturing processes, smart grids, and renewable energy systems. Romania's experience with the Internet of Things (IoT)-enabled energy management can serve as a model for Ukraine's post-war reconstruction efforts.

It is submitted that, by addressing these key areas, Ukraine and Romania can achieve more balanced and sustainable progress in Industry 4.0 adoption.

Romania has the opportunity to position itself as a regional leader in manufacturing automation, while Ukraine's IT sector has the potential to drive innovation in AI and software solutions. It is submitted that both countries can serve as exemplars for other emerging economies seeking to navigate the complexities of digital transformation.

This strategic alignment will not only serve to strengthen their economic resilience but also contribute to broader regional stability and integration into the global digital economy.

Conflict of Interest Statement

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References:

Meghișan-Toma, G. M., Puiu, S., Florea, N., Meghișan, F., Bădîrcea, R., & Manta, A. (2022). Sustainable Transformation of Romanian Companies through Industry 4.0, Green Production and Environment Commitment. *Amfiteatru Economic,* 24(59), 46–60. DOI: https://doi.org/10.24818/EA/2022/59/46

Deloitte Insights (2021). Digital Transformation in Emerging Markets. Available at: https://www2.deloitte.com/us/en/insights/topics/digital-transformation/digital-transformation-approach.html

Digital competitiveness worldwide. Available at: https://www.statista.com/statistics/1042743/worldwide-digital-competitiveness-rankingsbycountry

European Commission Joint Research Centre (2019). Digitally-enabled Development for a Sustainable Future in Eastern Europe. JRC Science for Policy Report. Available at: https://unece.org/housing-and-land-management/events/digitally-enabled-development-sustainable-future-eastern-europe

Eurostat. (2023). Digital Economy and Society Index (DESI) Report. Available at: https://digital-strategy.ec.europa.eu/en/policies/desi

Fedun, I., Kudyrko, L., Shnyrkov, O., Bey, R., Yatsiuk, M., & Sayniuchenko, A. (2023). Economic and Political Challenges of Development in Ukraine Industry 4.0. In *Digitalisation: Opportunities and Challenges for Business* (pp. 453–467). DOI: https://doi.org/10.1007/978-3-031-26953-0_42

Gheorghe, G., Badea, S.-I., Ilie, I., & Despa, V. (2021). Is Romania Ready for the Development of Smart Industry 4.0? In *Innovations in Industrial Engineering* (pp. 293–304). DOI: https://doi.org/10.1007/978-3-030-78170-5_26

Hermann, M., Pentek, T., & Otto, B. (2016). Design Principles for Industrie 4.0 Scenarios. Proceedings of 49th Hawaii International Conference on System Sciences HICSS, Koloa, 5-8 January 2016, p. 3928–3937. DOI: https://doi.org/10.1109/HICSS.2016.488

Iastremska, O., Stashkevych, O., & Mehdizade, M. M. (2021). Benefits and Risks of Digital Business Transformation: The Example of Eastern European Countries. *Journal of Eastern European and Central Asian Research* (JEECAR), 9(2), 234–245. DOI: http://dx.doi.org/10.15549/jeecar.9i2.910

Ivanova, M., & Putintseva, N. (2021). Approaches to Evaluation of Digital Transformation of Government: Comparative Analysis of Indicators in the Central and Eastern European Countries. *Regional Statistics,* 11(1), 1–20. DOI: https://doi.org/10.1145/3444465.3444508

Kravchuk, Y., & Voitko, S. (2021). Formation and implementation of industry 4.0 development strategies in the international context. *Ekonomika ta derzhava,* 12, 48–53. DOI: https://doi.org/10.32702/2306-6806.2021.12.48

Meghișan-Toma, G.M., Puiu, S., Florea, N., Meghișan, F., Bădîrcea, R. & Manta, A., (2022). Sustainable Transformation of Romanian Companies through Industry 4.0, Green Production and Environment Commitment. *Amfiteatru Economic,* 24(59), 46–60. DOI: https://doi.org/10.24818/EA/2022/59/46

Manyika, J. et al. (2018). Unlocking Big Data Potential in Emerging Economies. P. 156.

Nikitin, Y., & Kulchytskyy, O. (2019). Strategy of the development of Industry 4.0 in Ukraine: evaluation of the representatives of various organizations and companies of Ukraine. *Technology Audit and Production Reserves,* 4(4(48), 25–29. DOI: https://doi.org/10.15587/2312-8372.2019.176907

Schwab, K. (2016). The Fourth Industrial Revolution. World Economic Forum, p. 184. Available at: https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab

Velychko, V., Voinova, S., Granyak, V., Ivanova, L., Kotlyk, S., & Kudriashova, A. (2023). New Information Technologies, Simulation and Automation. P. 727.

Lopatynskyi, Yu., Vodianka, L., & Khil, R. (2024). Development of the Startup Ecosystem in Ukraine: A Case Study of Chernivtsi Region. *Investments: Practice and Experience,* 3, 37–42. DOI: https://doi.org/10.32702/23066814.2024.3.37

Nedelcu, M.-R. (2023). Industry 4.0 in Central and Eastern Europe: Is Romania Ready for the New Industrial Revolution? *Proceedings of the International Conference on Business Excellence,* 17 (1), 41–60. DOI: https://doi.org/10.2478/picbe-2023-0058

Wysokińska, Z. (2020). A Review of the Impact of the Digital Transformation on the Global and European Economy. *Comparative Economic Research. Central and Eastern Europe,* 23(4), 27–43. DOI: https://doi.org/10.18778/1508-2008.24.22

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