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Transformation of current trends in the development of marketing communications in the system of interaction between consumers and enterprises in the infrastructure of the contemporary market

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Abstract. Changes in the market structure and globalisation challenges necessitate the study of transformations in the field of marketing communications. The purpose of the study was to analyse the development of a contemporary marketing communications system, which is especially important in the context of increasing complexity of interaction between companies and various counterparties. This dynamic was compounded by shorter product life cycles, rapid changes in consumer preferences, and a decline in the effectiveness of conventional advertising methods. The paper focused on the method of epistemological analysis, which allowed establishing that marketing communications, being an organic component of the marketing complex, serve as a universal mechanism for influencing target audiences. Based on the analysis of statistical data, key trends in the development of marketing communications in the contemporary market were identified. The factors influencing the transformation of marketing communications tools were studied and ordered using the method of structural analysis of causal relationships. The results of the analysis helped to identify the stages of transformation of marketing communications tools within the levels of constructive changes: the level of emergence of new tools that co-exist with existing ones based on the principle of addition; the level of integration based on the unification, convergence, and interpenetration of various tools; the level of hybridisation of tools based on their multiplicity. It was established that these tools provide an opportunity to use the advantages of contemporary communication technologies and introduce innovative approaches. In addition, hybrid tools have contributed to improving the quality of interaction, and providing a higher level of mobility and adaptability of communication. The practical significance was to determine contemporary marketing communications, which is possible due to the emergence of the latest means of communication, which were integrated into interactive technologies, which helped not only to quickly obtain the necessary information,

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but also to analyse it, and compare it with other sources. The combination of conventional and innovative marketing communication tools ensured the company's effective operation in the market and helped attract new customers

Keywords: factors of influence; market environment; innovative marketing tools; hybrid tools; product promotion; advertising; target audience

Introduction

The rapid development of technologies and limited perception of digital information by consumers determine the need to create effective marketing impact formats. Despite the traditional emphasis on economic and statistical data, the transformation of communication tools also covers technological, psychological and informational aspects. In a dynamic market environment, the key factor of competitiveness is the introduction of current trends, in particular, the personalisation of interaction with customers. The use of the latest data collection technologies allows businesses to provide an individual approach and offer relevant solutions.

Leading Ukrainian researchers, studying the transformation of marketing communications in the context of digitalisation, pay special attention to the individualised approach as a tool for competitiveness. The study by S. Kovalchuk (2025) emphasised that personalisation is a key factor in creating a unique customer experience and keeping the audience in an environment of uncertainty, and analyses the transition from mass to personalised marketing and the use of digital channels for targeted impact on the consumer. N. Savytska (2022) considered the development of responsible communication and communication of personalised value to the client in conditions of war and global challenges. Research confirmed that communication has finally transformed from linear information to a complex interactive process, where personalisation was the foundation of trust and commercial success. Another notable trend is the integration of artificial intelligence (AI) into marketing. AI allows analysing large amounts of information, optimising advertising campaigns, and even predicting audience behaviour. This significantly improves the quality of customer interaction. Y. Makartseva & I. Lysenko (2025) considered the automation of marketing processes through conceptual approaches of artificial intelligence: substantiated the role of AI as a strategic tool for marketing automation, which ensured systematic growth of business competitiveness through hyperpersonalisation, predictive analytics, and optimisation of routine processes.

No less important is content marketing. High-quality, most useful and trusting content becomes the basis for building long-term relationships with the audience. Simultaneously, the focus is on video materials, live broadcasts, and exciting stories that attract attention and evoke emotions. Turkish researchers B. Mansour & M. Basal (2024) proved that successful digital content marketing not only increases sales, but also directly affects the development of ethical and environmentally responsible consumer behaviour, which is critical for sustainable business development. This is how the importance of environmental friendliness in marketing communications increases. Consumers are increasingly favouring brands that support sustainable values and demonstrate responsibility to society. When discussing trends, the dominance of social media cannot be ignored. Platforms are constantly evolving, offering new formats, and users are looking for authenticity and direct communication with brands. All this confirms the importance of a flexible approach to building marketing strategies. Tracking trends and applying them effectively allows businesses not only to adapt to changes, but also to stay ahead of their competitors. In their joint study, Z. Solodukha & S. Leonova (2025) examined the use of digital tools, specifically the Google Ads and Meta (Facebook/Instagram) platforms, for promoting marketing agencies, analysing their effectiveness and differences, thereby enabling agencies to position themselves more effectively and attract clients.

Thus, marketing communications remain a constantly evolving tool that gives businesses the opportunity not only to interact with their audience, but also to build long-term relationships, adapting approaches to the requirements of a dynamic market. Marketing communications in reality is not just a tool, but an integral part of the success of any company. There are several ways to analyse communication concepts. The technocratic approach focuses on the technical aspects and means of transmitting corporate messages in accordance with approach by A. Toffler (2022). However, this approach does not consider the motivation and opinions of the audience as recipients of information, which creates a problem that requires further research. The interaction approach treats the process of forming communications as the result of interaction, which implies a conscious and equal dialogue between the consumer of information and its producer. Representatives of this approach were P. Guddemi (2020) and C. Cooley (2024), who emphasised the importance of information exchange based on the active participation of both sides of the communication process. However, since the approach was based on subjective feedback and interpretation, there were no clear quantitative metrics for evaluating the effectiveness of communication.

As part of the psychological approach, researchers in the field of communication focus on the process of interaction between people, which includes the exchange of information, perception, and emotional aspects of relationships. One of the leading contemporary sociologists, M. Castells (2023), who specialises in information society theory, draws on the latest advances in neuroscience, particularly in the field of emotional intelligence research, in the concept of "communication power". This allows effectively applying methods such as framing, priming, cascade activation, and other techniques for influencing the audience –

viewers, listeners, or readers. However, the issues related to determining the areas of transformational changes in the marketing communications toolkit on an interdisciplinary basis and their substantiation at a qualitatively new level are still insufficiently investigated. This refers not only to individual markets or industries, as is often practised now, but also about the level of globalised information space formed through cross-border contacts and actions.

The implementation of the main goal requires a theoretical understanding of the evolution of the role of communications in the marketing complex. The development of marketing concepts from the classic 4P model to the contemporary Marketing 5.0 has transformed the role of communications in the marketing complex. Initially, communication was just a tool that informed consumers about the product, but over time it has become an important component of the product itself, especially in the service sector. The expansion to 7P highlighted the importance of integrating communication at every point of contact with the customer, breaking the linear logic of traditional advertising. Contemporary trends caused by digitalisation, the development of social media and changing consumer behaviour have turned communication into a dialogical, personalised and axiological element that forms brand values and competitive advantages. These factors caused changes in marketing communications, giving them new characteristics: integration into all elements of the complex, two-way, personalisation due to AI and Big Data, adaptation to the context of interaction, and the ability to convey brand values. The interaction of communication and consumer experience is combined in innovative Phygital environments and Live Shopping, which determines the current state and future research of the global media market. Thus, the purpose of the study was to provide theoretical substantiation and comprehensive analysis of transformation processes in the marketing communications system, which are caused by digitalisation of the market environment and the need to build multi-level interaction with consumers in the global information space.

Materials and Methods

The methodological basis of this study was based on an integrated approach that combines general scientific and special methods of cognition for a comprehensive analysis of the evolution of marketing communications in the context of global digitalisation. The design of the study was structured in such a way as to provide a transition from theoretical understanding of concepts to empirical analysis of market indicators and forecasting future trends. At the initial stage of the research, the method of epistemological analysis was applied, which allowed considering marketing communications not just as a set of promotion tools, but as a complex, organic mechanism for influencing target audiences within the marketing complex. Within the framework of this method, a critical review of three fundamental scientific approaches was carried out: technocratic approach: analysis of technical means of transmitting messages based on the studies by H. McLuhan (1962) and A. Toffler (2022). Interactive approach – the investigation of the dialogue between the producer and the consumer as equal participants – based on the papers by P. Guddemi (2020) and C. Cooley (2024). Psychological approach – the study of emotional aspects and neuroscience methods of influence (framing, cascade activation) – according to the concept of M. Castells (2023).

The methodological basis for interpreting empirical data in this section is the epistemological analysis applied at the initial stage of the study. Its theoretical result is a conceptual rethinking of the nature of marketing communications: they were considered not as a functional tool for promotion within the marketing complex, but as a system of constructing values that forms consumer experience and determines the behavioural responses of target audiences. The three scientific approaches – technocratic, interactive, and psychological – are not alternative theories, but successive stages in the evolution of the communicative paradigm, each of which is reflected in the corresponding segment of the contemporary media market: technocratic logic describes conventional media (TV, Print) that are steadily losing share; interactive – social media and content marketing with steady growth; psychological – GenAI Ads, Live Shopping, and Phygital practices as the most dynamic tools of the new generation. Thus, the statistics below are interpreted as empirical evidence for a deeper transformation: from a technical channel monologue – through a dialogue of equal actors – to interactive construction of a shared experience in real time.

At the second stage, the method of structural analysis of causal relationships was used to identify the factors that cause changes in the market infrastructure. This allowed classifying the factors of influence into six key groups: technological (automation drivers), socio-behavioural, economic, regulatory, globalisation, and concentration according to O. Yastremska (2025) and I. Ivanenko (2020). The focus was on analysing technology drivers such as artificial intelligence, machine learning, and Big Data that enable the transition from mass campaigns to hyper-personalised advertising trajectories. At the third stage, the empirical basis of the study was a statistical analysis of the dynamics of the global media market for the period 2020-2025, using forecast data for 2026. The sources were based on reports from leading analytical agencies: Statista (n.d.), Mordor Intelligence (n.d.), WPP Media (2024) and Dentsu (2025). The analysis of these data allowed investigating the dynamics of market volumes, the pace of changes in its key segments (Digital, TV, OOH, Print) and verifying the key stages of evolutionary transformation: from the pandemic leap to the era of algorithmic management.

In addition, by interpretive synthesis of diagnostic results and theoretical developments (Savytska, 2022; Kotler *et al.*, 2024; Kovalchuk, 2025), a conceptual model of the "Dominance Triad" of the contemporary market was formed. This allowed developing practical recommendations for improving the efficiency of business processes

through the introduction of innovative and hybrid communication tools. The choice of key elements of the "Dominance Triad" (AI, Social Media, Retail Media) was based on the use of a three-level logical filter, through which all identified trends in the media market passed. The main criteria for determining these elements as determinants were: the criterion of scalability and market share, the criterion of synergy and interdependence, the criterion of transformational potential. Scalability and market share determined the inclusion in the Triad of only those segments that were able to accumulate a critical mass of capital. Artificial intelligence algorithms became the basis for 80% of digital spending, and Social Media and Retail Media collectively covered more than 70% of the global advertising budget.

Synergy and interdependence allowed selecting elements based on the principle of forming a closed ecosystem. The applied logic filter eliminated isolated trends, such as conventional radio or the press, due to the lack of direct integration connection with the AI technological basis and the inability to provide instant conversion to sales. The transformational potential became the basis for identifying tools that ensure the transition from a linear to a cyclic communication model. Unlike classical media, which perform only the function of informing, the selected components of the Triad simultaneously implement personalisation, emotional engagement, and direct transaction. Thus, stable but static channels (for example, conventional OOH Out-of-Home advertising) did not pass through the logical filter, since they did not meet the criterion of full algorithmisation and were not autonomous sales ecosystems. A three-step data analysis procedure (2020-2026) was used to quantify the choice of AI, Social Media, and Retail Media as key dominants. This helped to transform the list of market trends into a conceptual model, where each element is confirmed by specific indicators of market capacity and cost dynamics. At the final stage, the method of comparative analysis was used to identify the stages of transformation of marketing communications tools within the levels of design changes: the level of addition, the level of integration, and the level of hybridisation. To illustrate these changes, the study analysed the use of digital tools, in particular, Google Ads and Meta platforms, and cases of Retail Media (Amazon, Walmart) and hybrid media (Programmatic DOOH, Shoppable TV).

Results and Discussion

In the context of global transformations, there is always a growing interest in trends and innovations in the field of marketing. And this is quite justified, because the analysis of innovations in digital marketing, technologies and platforms allows marketers to identify new opportunities. This not only helps to maintain the stability of the company, but also helps to stay ahead of the competition. That is why it is important to constantly monitor trends and innovations, especially in the context of digital marketing. Every year, the development of technology brings new tools for Internet marketing: some evolve, while others remain relevant for many years. Monitoring the capacity of the global media market aims to form a complete picture of the competitive environment and assess the level of capital concentration in the segments of contemporary communications. It was advisable to analyse the state of the global communication market, investigate the dynamics of its development for the period 2020-2025, considering the forecast data for 2026 and determine the key reasons for the changes that occurred (Table 1).

Table 1. Dynamics of the global media market development in 2020-2025

Tools of marketing communications	2020 billion USD	2021 billion USD	2021/2020, %	2022 billion USD	2022/2021, %	2023 billion USD	2023/2022, %	2024 billion USD	2024/2023, %	2025 billion USD	2025/2024, %	2026 billion USD	2026/2025, %
Digital advertising:	350.5	486.0	+38.7	567.5	+16.8	626.8	+10.5	721.2	+15.1	781.2	+8.3	860.5	+10.2
- *Search ads*	135.2	180.4	+33.4	212.1	+17.6	245.5	+15.7	315.4	+28.5	350.2	+11.0	390.8	+11.6
- *Social media*	102.5	148.6	+45.0	175.2	+17.9	198.4	+13.2	230.1	+16.0	255.4	+11.0	288.6	+13.0
- *Retail Media*	45.0	72.3	+60.7	98.4	+36.1	125.6	+27.6	154.2	+22.8	177.1	+14.8	210.5	+18.9
Television (Linear TV)	160.2	172.4	+7.6	168.3	-2.4	160.2	-4.8	158.4	-1.1	155.1	-2.1	152.4	-1.7
Out-of-home advertising (OOH)	30.5	34.2	+12.1	38.5	+12.6	42.1	+9.4	48.5	+15.2	52.0	+7.2	54.8	+5.4
Audio (Radio & Podcasts)	25.4	27.6	+8.7	28.1	+1.8	27.5	-2.1	26.8	-2.5	26.5	-1.1	26.2	-1.1
Print media	52.1	48.5	-6.9	45.2	-6.8	42.8	-5.3	46.5	+8.6	45.5	-2.2	42.3	-7.0
TOTAL	618.7	768.7	+24.2	847.6	+10.3	899.4	+6.1	1,001.4	+11.3	1,060.3	+5.9	1,136.2	+7.2

Source: compiled by the authors based on Statista (n.d.), Mordor Intelligence (n.d.)

Indicators and growth rates have a steady positive trend. In six years, the total market volume will almost double – from USD 618.7 billion in 2020, to the projected USD 1,136.2 billion until the end of 2026. According to WPP Media (2024), the turning point was 2024, when the market first exceeded the psychological mark of USD 1 trillion. Achieving this result was made possible by the combined impact of large-scale sporting events, such as the

Olympic Games and Euro 2024, and the rapid introduction of AI tools in the field of advertising. The average annual growth rate has reached a stable level after a sharp one-time jump of 24.2% in 2021. In the following years, the market develops at a rate of 6-11% annually, showing steady and steady growth. According to the data provided in Table 1 (Statista, n.d.; Mordor Intelligence, n.d.) the global media market is in a state of deep structural transformation, characterised by the gradual displacement of conventional media by digital tools.

Analysis of the dynamics of Linear TV shows a stable recession of this channel with an average annual reduction in coverage at the level of 2%. If in 2020 the share of television advertising was about 26% of the market, then according to the forecast indicators by 2026 it differentiates to 13%. Even more rapid degradation was observed in the print media segment. Despite the short-term stabilisation in 2024, volumes were projected to fall further by 7% by 2026, which indicates the transition of print advertising to highly specialised niche segments (Mordor Intelligence, n.d.). The digital advertising market is developing unevenly, which has contributed to the growth of several key areas. According to Table 1 (Retail Media), there were highest growth rates – from an impressive 60.7% to a stable 18.9% annually. This dynamic indicates a change in the strategy of brands that are increasingly investing in platforms such as Amazon, Walmart or Glovo, reducing the chain to the final purchase (Statista, n.d.).

Search advertising remains an important component of advertising budgets and is steadily growing by 11-15% annually. This is facilitated by the integration of generative artificial intelligence into search algorithms (Mordor Intelligence, n.d.). According to Statista (n.d.) out-of-home advertising (OOH) has demonstrated high adaptability. Despite a major downturn in 2020, the industry has recovered rapidly and is growing by 5-15% annually. A key role in this is played by digital out-of-home advertising (DOOH), which, due to the use of digital screens and purchasing programmes, provides greater efficiency and flexibility. Dynamic analysis of growth rates allowed identifying the "leading" market segments by calculating average annual indicators. The applied logical filter eliminated areas with growth below the average market level (6-11%), but verified Retail Media (growth to 60.7% in 2021 and stable 18.9% in 2026) and Social Media (11-13% annually) as key drivers of expansion. Market concentration analysis based on Statista data (n.d.) and WARC (n.d.) set the level of capital accumulation in segments. The defining criterion for inclusion in the "Triad" was the ability of the media channel to control a significant market share, which is confirmed by the concentration of more than 70% of advertising spending in the Alphabet, Meta, and Amazon ecosystems. A correlation analysis of technological impact has confirmed the role of artificial intelligence through the proportion of algorithmic (Programmatic) advertising within the digital advertising landscape. The forecast figure of 85% by 2026 served as empirical evidence that AI acts as a fundamental technological basis ("Vector A") for the entire contemporary media market. The study of trends in the development of the global advertising market for the period 2020-2026 demonstrated a significant transformation in the field of marketing communications. The market not only recovered from the effects of the pandemic, but also underwent drastic changes, moving from the concept of "digital support" to a full-fledged "digital-first" model.

Analysing structural changes in the media market and the redistribution of Statista influence (n.d.), key trends can be identified: Rapid expansion of digital channels (+19.1%) demonstrates the fastest growth in the history of the media market. Digital platforms have largely supplanted television and the press, and the Digital segment itself is undergoing a transformation from classic banner ads to integrated ecosystems. The growth of Retail Media's advertising power, according to Dentsu (2025), is turning marketplaces into one of the key market players. If in 2020 advertising within marketplaces was more of an additional tool (7.3%), then by 2026 it will become one of the three leading advertising forces, almost equal in impact to television. The crisis of traditional television (-12.5%) and a significant reduction in its market share indicate that this media channel has lost its status as the main tool for reaching the audience. Advertising budgets were actively moving to Connected TV (smart TVs) and social video platforms such as TikTok or YouTube, which are ranked in the Digital segment in this analysis. The stability of out-of-home advertising (OOH) allows this channel to maintain its share at the level of (~5%). The advantage of out-of-home advertising is that it organically complements mobile screens in real space, and does not compete with them. Conventional media such as television, radio, and the press are finally becoming additional tools for working with niche audiences or specific regional markets. Summary Table 2 illustrates the redistribution of global advertising budgets from conventional media to top three algorithmic ecosystems (2021-2026), reflecting their share in digital spending and the level of capital concentration.

Table 2. Structure of capital allocation of global advertising budgets between key ecosystems 2021-2026

Ecosystem (technology leader)	2021 % / billion USD	2022 % / billion USD	2023 % / billion USD	2024 % / billion USD	2025 % / billion USD	2026 % / billion USD	Role in the capital structure
Alphabet (Google)	22.1 % 147.6	22.8% 165.8	23.5% 189.4	24.0% 216.7	24.5% 243.1	25.0% 325.0	Dominance in search and AI algorithms
Meta (FB/Insta/ WhatsApp)	18.5% 123.6	16.4% 119.2	17.9% 144.3	19% 171.6	19.8% 196.4	20.0% 260.0	Monopoly on social capital and attention

Continued Table 2

Ecosystem (technology leader)	2021 % / billion USD	2022 % / billion USD	2023 % / billion USD	2024 % / billion USD	2025 % / billion USD	2026 % / billion USD	Role in the capital structure
Amazon (Retail Media)	8.2% 54.8	10.4% 75.6	11.2% 90.3	11.5% 103.8	11.8% 117.1	13.0% 169.0	Conversion to transactions and First-party data
Concentration coefficient (CR_3)	48.8% 326.0	49.6% 360.6	52.6% 424.0	54.5% 492.1	56.1% 556.6	58.0% 754.0	Level of market oligopolisation
Herfindahl-Hirschmann Index (HHI)	897.9	896.9	1,005.9	1,069.2	1,131.5	1,194.0	Moderate but increasing concentration
Other players (Microsoft, TikTok, Apple)	51.2% 342.0	50.4% 366.4	47.4% 382.0	45.5% 410.9	43.9% 435.6	42.0% 546.0	Fragmented segment of niche platforms
TOTAL (BigTech + Others)	100% 668.0	100% 727.0	100% 806.0	100% 903.0	100% 992.2	100% 1,300.0	Global Digital market

Source: compiled by the authors based on Statista (n.d.), WARC (n.d.)

The described dynamics of share redistribution between channels is only an external manifestation of a deep transformation of the ownership structure and control in the media market. To move from a descriptive analysis of market trends to a fundamental scientific assessment of the dominance of individual subjects, the study uses tools for quantitative analysis of capital concentration. Based on retrospective data from Statista (n.d.) and Dentsu's forecasts (2025), it is clear that this is not just a diversification of channels, but a critical consolidation of financial resources within a limited circle of global technology ecosystems. The methodological basis for verifying this dominance was the concentration coefficient (CR_3) and the Herfindahl-Hirschmann Index (HHI). The concentration ratio of the three firms, calculated as the arithmetic sum of the market shares of the three largest ecosystems (Alphabet, Meta, Amazon), shows a steady trend towards oligopolisation of the market. The combined share of these players in 2025-2026 reaches critical values: from 56.1% (USD 556.6 billion) in 2025 to the projected 58.0% (USD 754 billion) in 2026. An increase of 9.2 percentage points compared to 2021 (48.8%) mathematically confirmed that "top-3" absorbs more than half of the world's advertising capital, forming a market with a rigid oligopolistic structure. The analysis of the Herfindahl-Hirschmann Index (HHI) records a qualitative transition of the media market from the category of "low-concentrated" to "moderately concentrated". An increase in the index from 897.9 in 2021 to 1,194.0 in 2026 indicates overcoming the critical mark of 1,000 units in 2023, which, according to international anti-monopoly standards, signals the stabilisation of the oligopoly. The most significant contribution to the dynamics of HHI is provided by the expansion of Amazon, whose market share increased almost 1.6 times (from 8.2% to 13.0%). Since the index equation gives more mathematical weight to players with a higher share, strengthening the positions of the third participant in the top-3 is a key factor in the system stabilisation of the oligopolous model.

This transformation of market logic leads to the emergence of the phenomenon of "algorithmic rent", where advertisers are forced to pay not only for contact with the audience, but also for the right to priority bypass artificial intelligence filters. In these circumstances, First-party data ownership and the ability to adapt advertising content to the dynamic requirements of Big Tech software code become the only levers of influence on the effectiveness of communication. As a result, the strategic advantage in the 2026 market is shifting from creative agencies to technology integrators that can ensure seamless brand integration into the closed ecosystems of top-3. In addition, the displacement of independent players to the periphery of the media space (up to 42.0% of the market) radically narrows the field for experimental and niche strategies, as the algorithmic standards of Google, Meta, and Amazon establish unified rules of the game for the entire industry. Any market entity that does not comply with the technical protocols of the dominants actually becomes "invisible" to the consumer, regardless of the quality of its product or the ideological content of advertising. This completes the development of a "managed attention" model, where the boundaries of consumer experience are determined not by demand, but by the bandwidth and commercial priorities of three key algorithms. As a result of research by Dentsu (2025) and Statista (n.d.), by 2026, the advertising landscape will be transformed into a "Dominance Triad" format based on three defining segments. The first component is large-scale algorithmisation, according to which more than 80% of digital advertising costs will be carried out using artificial intelligence tools. The second area is associated with a steady increase in the popularity of social media, where the consumption of video content through Social Video and Connected TV provides double-digit growth rates (11-13%) against the background of a decrease in the share of conventional television. The third priority is the focus on efficiency, which is manifested in the dominance of the Retail Media segment, which provides direct conversion to sales and gradually displaces methods of mass audience reach. The conceptual model of transformation of the communication market is presented in Figure 1, which is based on the interdependence

between the technological basis (AI algorithms), the distribution environment (social media) and the final performance (Retail Media), which together form a closed ecosystem of effective marketing interaction.

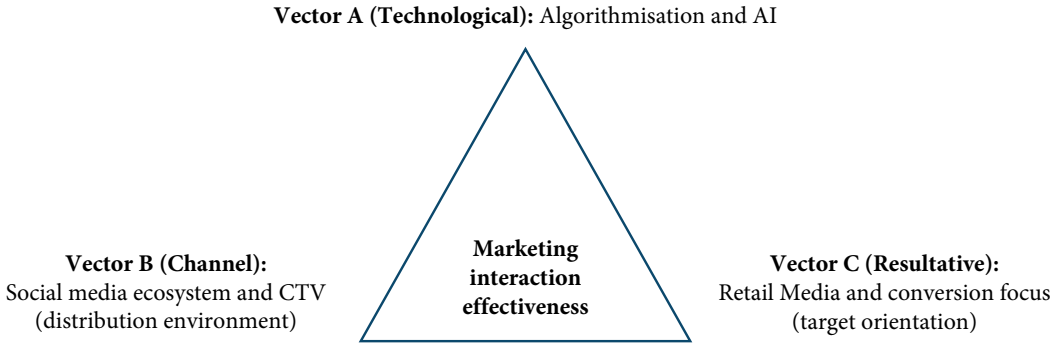

Figure 1. Conceptual model of the "Dominance Triad" of the advertising market
Source: compiled by the authors

The conceptual model is based on the synergy of three key dominants, where algorithmisation acts as a fundamental technological driver that ensures automation and accuracy of budget allocation. The relationship between algorithmisation and social media is implemented through video content personalisation mechanisms (TikTok, Reels, CTV), which allows transforming the emotional engagement of the audience into predictable reach.

In turn, the integration of social media with the retail media segment closes the communication cycle, ensuring the transition from the development of interest to the direct act of purchase (direct conversion). Thus, the priority of efficiency becomes an integration factor that forces companies to abandon mass coverage strategies in favour of tools based on Big Data processing and provide a measurable contribution to enterprise revenue. The presented model demonstrates the transition from a linear to a cyclical marketing communication system, where each element enhances the other: AI optimises costs, social networks generate traffic, and Retail Media monetises it in real time. The classic concept of the 4P marketing complex in the study by W. Perreault *et al.* (2021) assigned communications (Promotion) the role of the fourth, functionally subordinate element. The logic was simple: first, a Product is created, a Price is set, a sales channel (Place) is formed, and only after that a message about the finished value is developed. Communication in this model was the final link in the unidirectional chain: producer – message – consumer. Its job is to inform and convince, but not to create value on its own. The first impulse to rethink this role came with the development of the service sector. The 7P model based on research by V. Zeithaml *et al.* (2023), expanded the complex at the expense of People, Process and Physical Evidence, effectively recognising that in services, communication is inseparable from the product itself – each point of contact with the consumer is both an act of providing a service and a communication act. This destroyed the linear logic of 4P: communication no longer "serves" the product – it is partly a product.

Digitalisation has eliminated information asymmetry. In the industrial age, the manufacturer controlled information about the product – advertising was a mechanism for transmitting it to the consumer, who did not have alternative sources of verification. The Internet has radically changed this balance: the consumer has access to reviews, comparisons, and independent reviews. Consequence: classic advertising as a "product message" has lost its credibility. Communication was forced to evolve from conveying facts to forming context and meanings around the brand. This is what reflects according to Statista (n.d.) statistical reduction of traditional media (television – from 26% to 13% of the market in 2020-2026) and growth of content marketing and influence marketing as tools for building trust. The consumer's activation through social media has transformed them from a passive recipient of messages to an active participant in the communication process. Along with vertical communication "brand – consumer", a horizontal "consumer – consumer" was formed. UGC, ratings, and social media recommendations have become an independent communication channel that the brand does not control, but cannot ignore. Therefore, marketing communications have acquired a new feature – decentralisation: the brand is no longer the only source of self-message. This explains the dominance of Social Media in the structure of digital spending (USD 255.4 billion in 2025) and the growth of Retail Media, where a trust signal is generated directly at the place of purchase (Statista, n.d.).

Changing consumer identification behaviour. Post-industrial society has formed a new consumer logic: the product has ceased to be just a utilitarian object and has become a marker of identity, belonging to the community and a carrier of values. The study by M. Castells (2023) in the context of the "power of communications" show that the contemporary consumer chooses a brand not by product characteristics, but by what picture of the world this brand conveys. This trend is particularly pronounced in Generations Z and Alpha: according to J. Rude (2026), they shape

consumer priorities through digital ecosystems, where values are communicated through experience, not messages. The consequence is that communications acquire axiology – the ability to translate and form a value system as a competitive advantage of the brand. The combined effect of these factors led to the acquisition of qualitatively new characteristics by marketing communications, which fundamentally distinguish them from the classic Promotion in the 4P model. System-forming – communications permeate all elements of the marketing complex: they form the perception of a product even before its consumption, justify the price position through the value narrative, and are themselves part of the distribution experience (Shoppable TV, Retail Media). In the concept of Marketing 5.0 (Kotler *et al.*, 2021), communications actually become the platform on which the entire marketing complex is implemented. Two-way and dialogicity – instead of a brand monologue, there is a constant, non-linear exchange between the brand and the consumer, where the line between the sender and recipient of the message is blurred. Personalisation – transition from mass campaigns to individual communication trajectories due to Big Data and generative AI. Contextuality – message adapts to the situation, behaviour, and location of the consumer (Programmatic DOOH, targeted advertising). Axiological – communications translate and construct a brand value system as a determining factor of choice for the contemporary consumer. Integration into experience – the communication act and consumer experience have merged: Live Shopping, AR practices, and Phygital environments make the communication process itself an element of the product offering.

The evolution of marketing communications from the fourth element of 4P to the system-forming platform of the marketing complex is a natural reflection of deeper transformations: the disappearance of information asymmetry, consumer activation, and changes in the nature of consumer choice. It is this logic that explains why according to A. Nanji (2025), the concentration of more than 56% of advertising budgets in three technology ecosystems (Alphabet, Amazon, Meta) is not an anomaly, but a pattern: these platforms simultaneously provide all new features of communication – personalisation, contextuality, dialogicity, and integration into the consumer experience. Hybrid tools cover the entire path of the consumer (Full funnel) precisely because communication is no longer a separate phase of marketing – it is its continuous environment. The marketing communications market is a component of the economic system and develops in accordance with the basic laws of the market economy, meeting public demand for communication services. Considering the results of diagnostics of the global marketing communications market and summarising the research (Ivanenko, 2020; Kotler *et al.*, 2024; Yastremska, 2025), the factors that determine the vector of market development and determine the diversification of marketing communications tools can be divided into technological, social, economic, regulatory, globalisation, and concentration. Figure 2 illustrates a set of factors that determine the area of development and transformation of the tools of the contemporary marketing communications market.

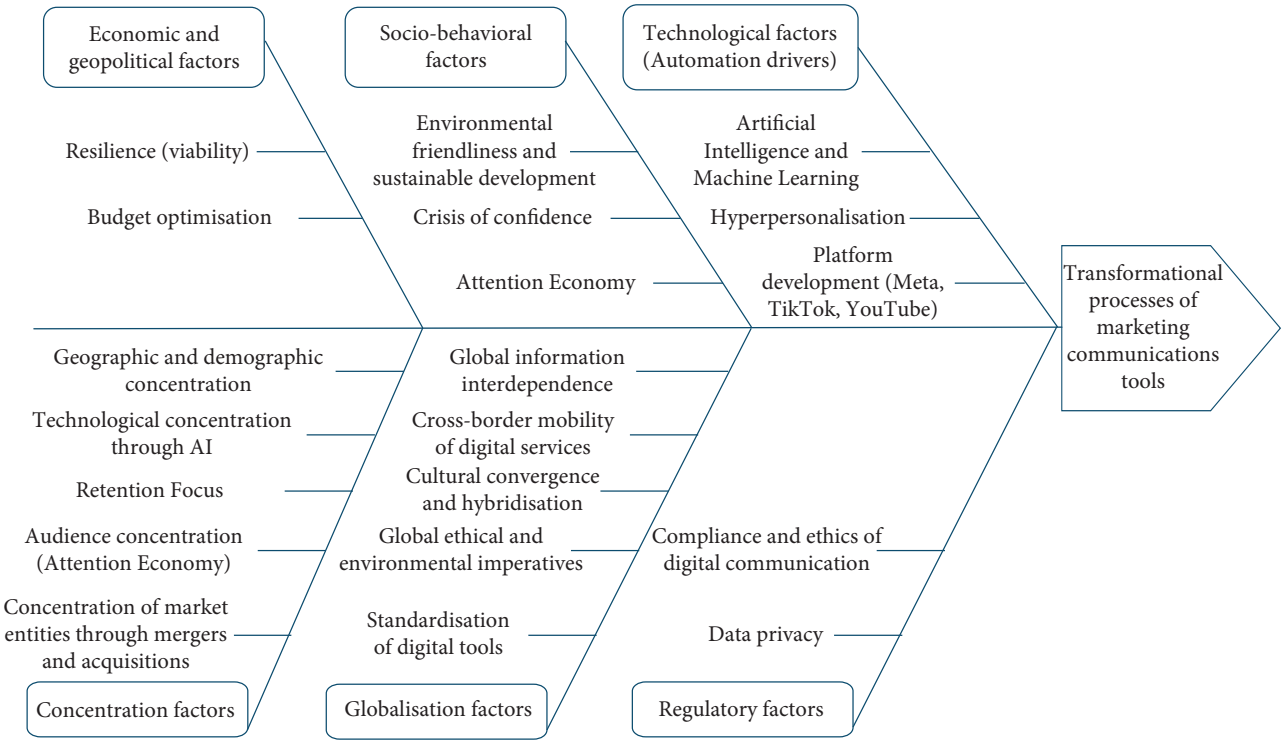

Figure 2. Generalisation of factors influencing the marketing communications market

Source: compiled by the authors

Thus, among the technological factors (automation drivers), it is necessary to note: artificial intelligence and machine learning (transition from static planning to dynamic content that adapts to the user in real time); hyperpersonalisation (the ability to process Big Data allows creating individual advertising trajectories instead of mass campaigns); development of Meta, TikTok, YouTube platforms (changing the algorithms for issuing content forces brands to switch from direct advertising to entertainment and information format (edutainment). Socio-behavioural factors include: environmental friendliness and sustainable development (consumers in 2026 prefer brands whose communications convey the values of environmental preservation and ethics); a crisis of trust (the growing importance of the "human face" of business, which encourages the development of influence marketing and content marketing as tools for building long-term relationships); the economy of attention (reducing user concentration time is a trend of short videos that requires maximum brevity and visual saturation from communications.

Economic and geopolitical factors cover several key aspects. Resilience. For Ukraine, this aspect is critically important, given the need to adapt communication systems to the conditions of war, energy blackouts, and changes in the demographic composition of the audience. Methods of rapid and effective adaptation ensure the stability of functioning against the background of serious shocks. Optimisation of budgets. This includes switching to tools with an increased return on investment (ROI), such as targeted advertising, and automated sales systems. Automated sales funnels are digital platforms that independently guide the customer through all stages – from getting acquainted with the product to making a purchase. Such systems act as a stand-alone marketing mechanism, replacing the manual work of managers: instead of phone calls to each potential client, they automatically send personalised messages, show current offers, discounts or advertising depending on user behaviour.

Regulatory factors cover a number of critical aspects. Special attention was paid to data privacy: strict rules for processing personal information (for example, the GDPR) force marketers to look for new communication methods that guarantee privacy protection. Simultaneously, the role of compliance and ethics in the digital space is growing. Increased control over the content of advertising is becoming a tool for combating disinformation, fakes and manipulative technologies, in particular deepfakes. This provides for the introduction of mandatory labelling of advertising materials, for example, in the content of bloggers, and identification of the use of artificial intelligence in creative processes. In addition, there are strict industry restrictions on advertising sensitive products and services, including gambling and pharmacy. The Ukrainian advertising legislation, updated in accordance with European standards, focuses on transparency of the sources of origin of advertising information as one of the key conditions for establishing audience trust.

These issues are particularly relevant in the context of digital transformation, as government regulators and large commercial platforms such as Meta and Google are becoming less tolerant of using "grey" promotion methods. This forces businesses to refocus on transparent white-hat marketing strategies based solely on ethical practices. Therefore, the main area of development is the evolution from a transactional communication model (focused on the direct sale of a product or service) to an interactive model. The latter was aimed at creating a dialogue and shared values between the brand and the consumer. In this process, artificial intelligence technologies play the role of a tool for scaling interaction and improving its effectiveness. In 2026, globalisation factors were becoming a powerful engine for the transformation of marketing communications, blurring the boundaries between local and international markets. Thus, globalisation factors of influence contain several key aspects. Standardisation of digital tools. Due to the dominance of global platforms such as Meta, Google, TikTok, and Amazon, the methods of promoting content in the world were unified. Marketing agencies in Ukraine used the same targeting algorithms as companies in the United States or Europe, which creates the need for specialists to work according to common international standards.

Global ethical and environmental imperatives. The global focus on sustainability forces companies to adapt their communications to the requirements of the global community. Environmental responsibility in marketing is becoming a prerequisite for entering international platforms. Cultural convergence and hybridisation. The spread of global content contributes to the development of universal consumer habits, such as the popularity of short video formats, but simultaneously there is a growing need for globalisation – adapting global strategies to the local cultural context without losing authenticity. Cross-border mobility of digital services. Crises – economic, military, or environmental – instantly become part of the global information field. This obliges brands to respond quickly and clearly to such events in their strategies, showing a high level of social responsibility. Thus, it can be stated that globalisation is transforming marketing communications into a universal business language. Those who integrate innovative technological standards faster, while remaining true to universal values and adhering to ethical standards, will be able to win here.

Concentration factors in marketing communications as of 2025-2026 determine the conditions under which market resources and consumer attention are focused within a limited range of platforms and channels of interaction. According to the leading research presented in reports by G. Crossan *et al.* (2025) and WARC (n.d.), there are several main factors that determine this trend. The concentration of market participants through mergers and acquisitions becomes critical. Corporate mergers allow companies to centralise budget spending on marketing, which is especially important in the oversaturated advertising environment of 2026. In this context, the dominance of Google (Search), Meta (Facebook/Instagram) and Amazon, which are set to account for over 70% of global advertising spend in the period 2025-2026, according to A. Nanji (2025),

significantly restricts the choice of channels for businesses. This, in turn, forces organisations to adapt their strategies in accordance with the algorithms of major players in the digital market. The audience's attention economy dictates new rules of the game. According to WARC (2025), consumers prefer to consume content in the short video format, which is typical for the TikTok, Instagram Reels, and YouTube Shorts platforms. This forces brands to develop content with maximum information saturation in the first seconds of interaction with the audience.

It becomes a priority to focus on loyalty (Retention Focus). In the context of the growing cost of attracting new consumers (Customer Acquisition Cost) during 2025-2026, companies are reorienting to invest in retaining an existing audience, actively using CRM communication tools. The next factor is related to technological concentration through AI. Automation of content marketing through AI-based models and the dominance of programmatic advertising is becoming a key trend. In particular, according to data by A. Guttmann (2025), programmatic advertising in 2026 will generate approximately 85% of the global digital advertising market's revenue, demonstrating the transition to algorithmic management. The last significant factor is the regional and demographic aspects of concentration. According to forecasts of J. Rude (2026), the Alpha generation will reach 24% of the world's population and actively integrate into digital ecosystems, including gaming platforms and meta-universes, which will shape their cultural and consumer priorities. The general conclusion for the business is that the combined influence of these factors leads to the development of the "winner gets everything" conditions. This means that brands that do not have sufficient resources to operate on leading platforms or do not use artificial intelligence and automation tools risk losing their competitiveness and visibility in the global and local information space.

A comprehensive analysis of the dynamics of the global media market and the determinants of the impact on the marketing communications system allows verifying the key stages of their evolutionary transformation in the context of digitalisation of the economic space. 2020-2021 (pandemic jump): Lockdowns caused a sharp transition of budgets to online. According to Oberlo (n.d.) in 2021 alone, total digital advertising spending increased by 30%. 2022-2023 (correction and stabilisation): the market has adapted to the new data privacy conditions. Social networks and search advertising have consolidated the status of the main channels. 2024-2025 (era of algorithms and AI): marketing has become hyper-personalised due to generative AI. The main drivers were video content (TikTok, Reels) and Retail Media (advertising directly on marketplaces like Amazon). The transformational paradigm of the global media market in 2025-2026 is determined by four dominant vectors. High level of market concentration: development of an oligopolistic capital distribution structure, where according to A. Nanji (2025), more than 56% of global advertising budgets are accumulated in the ecosystems of technology leaders (Alphabet, Amazon, Meta), which determines the dependence of marketing strategies on the algorithmic standards of these platforms. Mobile-first dominant (mobile marketing): the final consolidation of the mobile segment as a priority communication channel (according to Statista (2026) more than 70% of total digital spending), which requires adapting content to the specifics of mobile consumption. Multimedia format transformation: the dominance of short-form video as the most relevant tool for converting and attracting an audience, reflecting changes in cognitive patterns of information perception.

The modern evolution of marketing tools is characterised by blurring the boundaries between traditional and digital channels, which leads to the emergence of hybrid media and autonomous intelligent systems (Emerging Tech). The first category includes converged solutions such as Programmatic DOOH, which transforms out-of-home advertising into an adaptive system based on real data (traffic, geo-positioning), and Shoppable TV (Connected TV), which provides direct integration of e-commerce into TV content, combining emotional reach with instant transaction. A special place is occupied by Phygital-practices where augmented reality (AR) technologies create additional value for a physical product through digital interactivity. In parallel with hybridisation, there is the emergence of a new generation of autonomous tools: Retail Media Networks (RMN), which function as closed ecosystems with unprecedented accuracy of consumer data; GenAI Content Engines, which implement the transition from mass targeting to algorithmic hyper-personalisation of creatives in real time; and Social Commerce (Live Shopping), where entertainment content is directly converted into the act of purchase. The synergy of these tools forms a new marketing communication architecture focused on the continuity of the customer experience and maximum automation of the decision-making process. Thus, based on the analysis of market dynamics in 2020-2026, the emergence and consolidation of new marketing tools can be distinguished. They emerged at the intersection of technology (AI, Big Data) and changing consumer behaviour. A special place is occupied by hybrid tools that blur the boundaries between the online and offline environment (Table 3).

Table 3. Comparative table of characteristics of new key tools

Tool	Type	Key advantage	Role in sales growth
Retail Media	Digital	Access to real transaction data	Lower part (Sale)
Programmatic DOOH	Hybrid	Flexibility and contextuality in offline mode	Upper part (Coverage)
Shoppable TV	Hybrid	Direct transition from view to receipt	Full funnel
GenAI Ads	Technological	Infinite variety of creatives	Middle part (Interest)

Source: compiled by the authors

The conclusion of the presented study on the transition to the "digital-first" model and the growth of the share of digital advertising from 56.6% in 2020 to the projected 75.7% of the market in 2026 was confirmed by a systematic review of M. Cioppi *et al.* (2023), which covered 117 articles and found that digital transformation changes marketing processes simultaneously in three dimensions: the expansion of ICT communication channels, the ability to interact with customers in real time, and the development of new relationships between producers and consumers. This study is methodologically close to the conducted research: both applied a review of scientific literature and an analysis of statistical trends. However, there is a significant difference: the above-mentioned review covered publications in 2014-2020 and captured the initial stage of the digital transition, while this study documented a qualitatively new stage – 2020-2026 – with the transition to algorithmic control and AI dominance, that is, it is a chronological continuation and deepening of this review. A similar position was occupied by V. Nesterenko *et al.* (2023), where the researchers recorded a decrease in the effectiveness of conventional mass marketing and the growth of personalised digital formats, which directly confirmed the identified statistical trend of reducing the share of television from 26% to 13% of the market. However, researchers focused mainly on the qualitative description of the phenomenon, while the conducted research verified it quantitatively through the analysis of the dynamics of the media market in 2020-2026 and offered a conceptual model ("Dominance Triad") to explain the identified patterns.

The central thesis of the presented study on hyper-personalisation as a key technological trend is consistent with the results of B.B. Gao *et al.* (2023), who systematised the role of AI in advertising in four areas: targeting, personalisation, content generation, and ad optimisation. The researchers proved that it is personalised recommendation systems that have become an indispensable tool for Internet platforms, which confirms the conclusion about the dominance of algorithmic purchases (more than 85% of digital advertising revenue in 2026 is programmatic). Simultaneously, the researchers focus on the technical aspect of AI advertising systems, while the outlined study considered algorithmisation in the broader context of the transformation of the marketing complex from 4P to Marketing 5.0, linking the technological trend with the change in the very nature of communication.

V. Shankar *et al.* (2022) conducted a large-scale review of digital marketing communications in global marketplaces and found that the effectiveness of digital tools significantly depends on the degree of inter-channel data integration. This finding correlates with the concept of the "Dominance Triad" presented in the study: algorithmisation, social media, and retail media are complementary forces, not competing. The difference is that researchers were limited to the horizon until 2021, while this study covered 2022-2026 and recorded the emergence of fundamentally new hybrid formats – Shoppable TV and Programmatic DOOH – that were not considered before. T. Teepapal (2025) investigated the impact of AI personalisation on consumers' perception of social media and found that value and trust are key mediators between personalised content and purchasing intentions. The study confirms the thesis about the axiological function of contemporary communications: consumers react not to product characteristics, but to the semantic context that forms the brand. Simultaneously, the researcher considered only the level of individual psychological dynamics, while the presented study offered a broader market perspective – explained why psychological mechanisms determine the concentration of 56% of budgets in three ecosystems.

The trend of dominance of short video content (TikTok, Reels, Shorts) and its double-digit growth rate (11-13% annually) revealed was confirmed by X. Shen & J. Wang (2024). The researchers found that the user's personal identification with the content author through shared values is a key mediator between video perception and purchasing intentions, which empirically confirms in the study the theoretical thesis about the axiological function of contemporary marketing communications. P. Yin *et al.* (2024) examined consumer behaviour in social commerce video streams and found that atmospheric (emotion, social presence) and capital (quality and quantity of information) characteristics of the platform shape purchasing intentions through affective and rational ways simultaneously. This conclusion complements the proposed concept: hybrid tools (Live Shopping, Shoppable TV) are effective precisely because they affect both channels of decision-making – which is a practical confirmation of the psychological approach (M. Castells), declared in the methodology of the presented study.

W. Jiang & H.-L. Chen (2025) analysed the impact of short videos on consumer behaviour through the use and gratification theory and social presence theory, and found that digital dependence mediates the relationship between content value and purchasing intent. It is noteworthy that the researchers attribute the growth of dependence to algorithmic personalisation of TikTok, which directly confirms the conclusion that algorithmisation is the first and defining component of the "Dominance Triad". Z. Huang *et al.* (2024) found that social presence in Live Shopping positively affects customer satisfaction and well-being and is a mediator between the stream's atmosphere and repeat shopping intentions. This conclusion concretises the content of the concept of hybrid tools under study: Shoppable TV and Live Shopping are effective precisely because of the combination of emotional involvement with direct transaction, implementing a psychological approach in practice. In contrast to the above-mentioned study, which focuses on the individual well-being of the consumer, the outlined study considered Live Shopping as a systemic market phenomenon – a component of hybridisation of tools at the level of the global media market.

The concentration of more than 70% of global advertising budgets in three ecosystems (Alphabet, Amazon, Meta) was confirmed by data from WARC (2025), and O. Yastremska (2025), who investigated marketing tools as factors of adaptability of enterprises to crisis changes in the external environment. The researcher found that in conditions of instability, companies are reorienting to tools with increased ROI and direct conversion – which is a theoretical explanation for the rapid growth of Retail Media recorded in the study (starting from USD 45 billion in 2020, to USD 210.5 billion in 2026). The difference lies in the focus: the researcher analysed adaptation at the level of an individual enterprise, while the conducted study examined structural changes at the level of the global market. It is necessary to note the limitations of the concentration model, which was highlighted by G. Crossan *et al.* (2025) in the TMT Predictions report: over-reliance on tech giant ecosystems creates structural risks for small and medium-sized businesses. This aspect is an important caveat to the conclusions of this study: the "digital-first" strategy with a focus on leading platforms is optimal for large players, but for small and medium-sized businesses it is necessary to develop alternative communication strategies, which may become the subject of separate further research. Comparison of the results with the considered publications allows clearly determining the specific contribution of the presented study, and evaluating the opinions of other authors. Most of the analysed studies consider individual tools or market segments, while the conducted research suggests an integrated three-level transformation model (complement – integration – hybridisation) and a conceptual model of the "Dominance Triad" covering the market as a whole. Unlike the available reviews that describe "what" is happening, the outlined study, through epistemological analysis, explains "why" – linking market trends to the evolution of the communication paradigm from technocratic to psychological. None of the considered studies analysed the transformation in the chronological range of 2020-2026 in combination with forecast data, which makes the presented study more relevant from the point of view of practical application. A promising area is to investigate the specifics of these transformations for the Ukrainian market of marketing communications in wartime conditions as a special context of adaptation to global trends.

Conclusions

The analysis of the development of the global communication market for 2020-2026 indicates the final approval of the "digital-first" paradigm. Statistics show a doubling of the market volume (more than USD 1 trillion in 2024) against the background of a reduction in the share of conventional media from 26% to the projected 13% in 2026. The technological core of this transformation was artificial intelligence (AI) and machine learning (ML), which provided algorithmisation of 80% of digital advertising costs and the transition to dynamic hyperpersonalisation in real time. The structural architecture of the modern market is defined by the "Dominance Triad": algorithmisation, expansion of short video formats (TikTok, Reels) and rapid growth of Retail Media Networks (growth of up to 60% annually). Epistemological analysis revealed that marketing communications have gone from a subordinate element of 4P to a system-forming factor in the Marketing 5.0 concept. This evolution was caused by the elimination of information asymmetry, consumer activation, and changes in the identification behaviour of the Z and Alpha generations. In contrast to purely statistical descriptions, this study proves that the contemporary communicative paradigm is fundamentally different from the classical "Promotion" in such features as axiological (value), contextuality, and integration into the consumer experience.

For practical implementation, priority tools were identified: hybrid systems (Programmatic DOOH, Shoppable TV, AR technologies); intelligent nodes (GenAI Content Engines, Retail Media); social-centric formats (Live Shopping and short video). The oligopolistic nature of the market, where more than 56% of budgets are controlled by BigTech giants (Alphabet, Amazon, Meta), requires brands to switch to "white-hat" marketing strategies, transparency and radical resilience, which is especially critical for Ukrainian enterprises in wartime conditions. Prospects for further research are to explore the ethical limits of using neural networks in manipulative framing and analyse the risks of "cognitive isolation" of the consumer due to excessive algorithmic personalisation. An urgent task is to develop ethical protocols for using generative artificial intelligence (GenAI) to prevent a crisis of trust in the digital environment. Special attention should be paid to the study of emotional brand value in the "experience economy", where conventional metrics (KPI) should be supplemented with neuromarketing tools to measure deep cognitive resonance. A separate research vector should be the development of adaptive resilience strategies for local markets, in particular Ukrainian ones, in the context of post-crisis recovery and global digital expansion. This will allow forming a methodological basis for building inclusive and value-oriented communication ecosystems that can withstand the turbulence of the globalised information space. Ultimately, the analysis of the convergence of marketing with the "Internet of Things" (IoT) and meta-universes is promising, which will require a qualitatively new epistemological understanding of the role of consumer virtual identity.

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Conflict of Interest

None.

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Трансформація актуальних трендів розвитку маркетингових комунікацій у системі взаємодії споживачів та підприємства в інфраструктурі сучасного ринку

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Анотація. Зміни ринкової структури та глобалізаційні виклики зумовлюють необхідність дослідження трансформацій у сфері маркетингових комунікацій. Метою статті був аналіз становлення сучасної системи маркетингових комунікацій, що особливо актуально в умовах зростаючої складності взаємодії компаній із різноманітними контрагентами. Ця динаміка посилювалась скороченням життєвих циклів продукції, швидкими змінами у споживчих вподобаннях та зниженням ефективності традиційних рекламних методів. Стаття зосереджена на методі гносеологічного аналізу, який дозволив встановити, що маркетингові комунікації, будучи органічною складовою маркетингового комплексу, слугують універсальним механізмом впливу на цільові аудиторії. На підставі аналізу статистичних даних визначено ключові тенденції розвитку маркетингових комунікацій на сучасному ринку. Досліджено та впорядковано фактори, що впливають на трансформацію інструментарію маркетингових комунікацій, із застосуванням методу структурного аналізу причинно-наслідкових зв'язків. Результати проведеного аналізу дозволили ідентифікувати етапи трансформації інструментів маркетингових комунікацій у межах рівнів конструктивних змін: рівень появи нових інструментів, які співіснують з існуючими на основі принципу доповнення; рівень інтеграції, що базується на об'єднанні, зближенні та взаємопроникненні різних інструментів; рівень гібридизації інструментів, яка ґрунтується на їх множинності. Встановлено, що ці інструменти забезпечують можливість використання переваг сучасних комунікаційних технологій і впровадження інноваційних підходів. Крім того, гібридні інструменти сприяли підвищенню якості взаємодії, а також забезпечують вищий рівень мобільності та адаптивності комунікацій. Практична цінність полягала у визначенні сучасних маркетингових комунікацій, що можливе завдяки появі новітніх засобів зв'язку, які інтегрувалися в інтерактивні технології, що дозволило не лише швидко отримати необхідну інформацію, а й проаналізувати її, порівнювати з іншими джерелами. Поєднання традиційних та інноваційних інструментів маркетингових комунікацій забезпечило ефективну діяльність підприємства на ринку та сприяло залученню нових клієнтів

Ключові слова: фактори впливу; ринкове середовище; інноваційні маркетингові інструменти; гібридні інструменти; просування товарів; реклама; цільова аудиторія

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The development of small and medium enterprises in Tanzania: The role of entrepreneurial skills

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Abstract. Entrepreneurial skills increasingly became a critical driving force for economic growth and are widely recognised as essential for economic dynamism. This study aimed to assess the importance of the skills available for the development of small and medium enterprises in Tanzania, specifically focusing on participants who are owners of small and medium-scale businesses within the Coast Region. Specifically, the study examined three key skills: communication, business management, and creativity/innovation. A quantitative research approach was adopted, using structured questionnaires distributed to 168 respondents. Descriptive and regression analyses were employed to examine respondent characteristics and test the hypothesised relationships among variables. The results indicated that communication skills have a positive and statistically significant effect on small and medium enterprises development ($B = 0.196$, $\beta = 0.195$, $t = 3.708$, $p < 0.001$, 95% CI [0.092, 0.301]). Creativity and innovation skills exhibited a stronger and highly significant influence ($B = 0.748$, $\beta = 0.763$, $t = 17.229$, $p < 0.001$, 95% CI [0.662, 0.833]). In contrast, business management skills showed a weak and statistically insignificant effect ($B = 0.035$, $\beta = 0.032$, $t = 0.844$, $p = 0.400$, 95% CI [-0.047, 0.116]). The regression model was statistically significant and explained a substantial proportion of variance in small and medium enterprises development ($R^2 = 0.941$, Adjusted $R^2 = 0.940$, $F(3,164) = 873.998$, $p < 0.001$), with no evidence of autocorrelation (Durbin-Watson = 1.984). The study concluded that communication, creativity, and innovation were key determinants of small and medium enterprises development, while business management skills played a limited role. These findings provide important implications for policymakers, educators, and development practitioners in designing targeted interventions to promote sustainable small and medium enterprises growth in Tanzania

Keywords: creativity; business; opportunities; formal employment; financial institutions

Introduction

Small and medium enterprises (SMEs) are often referred to as the backbone of many economies, and Tanzania is no exception. These enterprises not only provide jobs but also stimulate local economies and foster innovation. Despite their significant contributions, SMEs in Tanzania face numerous obstacles that hinder their growth and sustainability. One of the most pressing issues is the limited level of entrepreneurial skills among business owners, which can severely restrict their ability to navigate the complexities of the market. This skills gap weakens the ability of entrepreneurs to effectively manage and expand their enterprises in an increasingly competitive business environment, as underscored by I.J. Ismail (2022) and D.F. Matari (2024) that individuals enter business out of necessity rather than opportunity, which results in inadequate preparation and limited experience. Although the Tanzanian government and development partners have introduced various support initiatives, such as access to finance, training programs, and policy reforms, their impact has been inconsistent. While these programs are relatively widespread, there remains a disconnect between training provision and the actual application of entrepreneurial skills. H.E. Inegbedion *et al.* (2024) and A. Chshelokovskiy (2025) demonstrate that the connectivity between entrepreneurial support initiatives and the actual impact raises a concern about the relevance, accessibility, and effectiveness in addressing real entrepreneurial needs.

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Technological advancement has transformed the business landscape, creating both opportunities and challenges for SMEs. Gunartin *et al.* (2023) and E. Barkley & O. Jokonya (2024) underline that entrepreneurs are now required to adopt innovative and digital business models, which demand advanced technical and adaptive skills. Without these competencies, Tanzanian SMEs can lose competitiveness in both local and global markets. Additionally, F. Alfazzi (2023) and N. Viswarajan (2024) highlight the need to better understand how entrepreneurial skills are developed and their contribution to long-term business sustainability. Strengthening entrepreneurial skills also has broader socio-economic implications. The growth of SMEs can increase employment opportunities and reduce poverty. As emphasised by J. Amoah *et al.* (2022), as Tanzania aspires toward industrialisation, enhancing entrepreneurial skills becomes a critical component in achieving this national objective.

From a global job-creation perspective, H.E. Inegbedion *et al.* (2024) argue that SMEs are recognised as key drivers of economic growth, especially in developing countries, due to their role in job creation and income generation. However, their development is often constrained by financial limitations. Based on Tanzania SMEs' resource outlook, D.F. Matari (2024) claims that many SMEs in Tanzania remain stagnant due to limited access to resources and inadequate skills. A significant portion of SME activity occurs within the informal sector, which is dominated by vulnerable groups such as women, youth, and retirees. As stated by R. Lambin & M. Nyyssola (2022), the informal sector comprises a significant portion of SMEs that face structural barriers that limit access to formal employment. Access to finance remains another critical challenge. B. Nguyen & N.P Canh (2021) identify that many SMEs struggle to secure funding from formal institutions, but they rely on informal sources like family and friends. The financial challenges to SMEs are linked to poor entrepreneurial skills. This is articulated by I.J. Ismail (2022) that SMEs face challenges in securing formal financing, which are closely linked to weak entrepreneurial skills. Empirical studies such as D.B. Audretsch & M. Belitski (2021) and Gunartin *et al.* (2023) have emphasised the importance of diverse entrepreneurial skills, pinpointing managerial, relational, conceptual, behavioural, resilience, and effective management practices in improving SME performance. These skills are central to navigating complex business environments. Additionally, E. Barkley & O. Jokonya (2024) and Gunartin *et al.* (2023) stressed the importance of digital literacy and limited technological capabilities that hinder SME growth, highlighting the importance of IT and management skills.

However, this study demonstrates that creativity, innovation, and communication skills collectively play a vital role in equipping entrepreneurs to transform creative ideas into practical, valuable applications. Recognising the significance of these competencies, this study aimed to examine the role of entrepreneurial skills in the development of SMEs. The study is guided by Schumpeter's Innovation Theory (SIT) and the Competence-Based Theory of Entrepreneurship (CBTE), both of which highlight the critical importance of skills and innovation in driving business success. Drawing from the conceptual framework presented in this study, the following hypotheses are proposed: (1) communication skills have a positive effect on the development of SMEs; (2) business management skills have a positive effect on the development of SMEs; (3) innovative and creative skills have a positive effect on the development of SMEs; (4) communication, business management, and innovative/creative skills collectively have a positive influence on the development of SMEs.

Materials and Methods

This study examined the role of entrepreneurial skills in SME development by identifying key competencies necessary for business success. To strengthen its theoretical foundation, the study was guided by SIT and CBTE. SIT, introduced in 1911 and later expanded, emphasises innovation as central to entrepreneurship and business growth (Fig. 1).

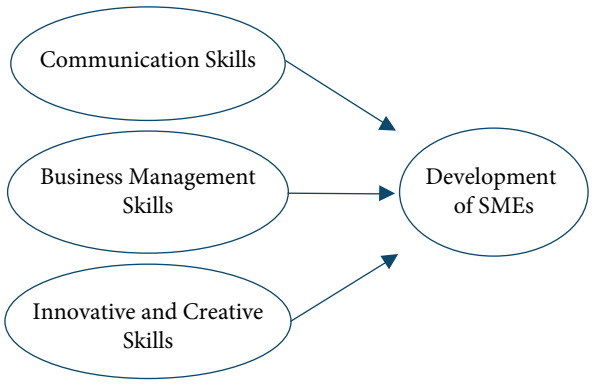

Figure 1. Conceptual model
Source: conceptualised by the author from literature and theories (Schumpeter's Innovation Theory)

This study adopted a survey research design to facilitate the systematic collection of both quantitative and qualitative data from a relatively large group of respondents. The survey approach was considered appropriate due to its scalability and its effectiveness in generating standardised information that can be used for research, professional analysis, and policy-related purposes. The design enabled the researcher to capture diverse perspectives from SMEs while maintaining consistency in data collection. The study was conducted among SMEs located in Kibaha Town Centre in the Coast Region. The target population comprised 290 SMEs operating within this area. From this population, a sample of 168 respondents was selected to participate in the study. The sample size was determined using Slovin's formula, which is suiTable when the population size is known but variability within the population is not clearly established. The formula is expressed as:

$$n = N/(1 + Ne^2), \quad (1)$$

where n – sample size; N – population size; e – margin of error. Using a confidence level of 95% and a margin of error of 0.05, the calculation yielded a sample size of 168 respondents. To ensure fairness and reduce selection bias, a fishbowl random sampling technique was employed, giving each SME an equal chance of being included in the study. Ethical consideration was addressed by observing the code of ethics of research as per the guidelines, principles, and procedures, as informed consent is crucial in making voluntary participation of the respondents (Horstkötter & de Wert, 2020; ICC/ESOMAR international code…, 2025). Informed consent for this study was of great significance and was obtained by ensuring that participants were given sufficient and necessary information about the study's intention, the opportunity to fill out the questionnaire without any force, and the freedom to decide whether to take part in the study or not. To ensure privacy, anonymity, and confidentiality, consent forms were distributed and collected separately from the questionnaire; the respondents were asked to provide neither their names nor their identification. The participants were also assured of the confidentiality of their information, as the data obtained were for academic purposes.

Data were collected using a structured questionnaire designed to align with the objectives of the study. The development of a semi-structured questionnaire for this study was adopted from previous empirical studies but improved to complement the variables, objectives, and hypotheses of this study (Mashuri *et al*., 2022). During the development of the questionnaire, the English language was used because the respondents were familiar with the language. Two methods were used to distribute the questionnaire: a physical and a mailed questionnaire. In total, four weeks (28 days) were used to collect information from the distributed questionnaires. The questionnaire consisted of closed-ended questions formulated under a deterministic philosophical approach, ensuring that responses could be quantified and analysed statistically. A five-point Likert scale was used to measure respondents' perceptions and attitudes, with equal intervals ranging from strongly disagree to strongly agree. This scaling technique enhanced the measurability of variables and facilitated quantitative analysis. In addition to primary data collection, a systematic review of empirical literature was conducted to provide a theoretical and contextual foundation for the study. This review helped in identifying knowledge gaps and refining the variables under investigation, namely: Development of SMEs (DoS), Communication Skills (CS), Creativity and Innovation (CR and INN), Business Management Skills (BMS).

Data analysis was carried out using both descriptive and inferential statistical methods. Descriptive statistics were employed to summarise and organise the data, including the use of frequency distributions and tabular presentations. In inferential statistics, statistical methods such as Pearson correlation analysis were used to assess the strength and direction of the linear relationship between two continuous variables. Multiple linear regression was employed to model the relationship between one dependent variable and two or more independent variables. The goal was to predict the dependent variable based on the values of the independent variables. The Variance Inflation Factor (VIF) is a diagnostic tool used to detect multicollinearity. It quantifies how much the variance of a regression coefficient is inflated due to multicollinearity. In regression analysis, the presence of autocorrelation can violate the assumption that residuals are independent, leading to inefficient estimates. Therefore, for this study, the Durbin-Watson statistic was used to test for autocorrelation in the residuals of a regression model. In this study, being one of the social science studies, a 0.05 significance level was used as a threshold for determining whether a result is statistically significant. A common choice of 0.05, which implies that there is a 5% risk of concluding that a difference exists when there is no actual difference (Type I error). When conducting hypothesis tests, if the p-value obtained from the analysis is less than 0.05, researchers typically reject the null hypothesis, suggesting that the observed effect is statistically significant. Conversely, if the p-value is greater than 0.05, the null hypothesis is not rejected, indicating insufficient evidence to support the alternative hypothesis. All data analyses were performed using the Statistical Package for the Social Sciences (SPSS) software, version 31. The use of this software ensured accuracy, consistency, and efficiency in data processing. Inferential analysis was particularly important in accounting for potential sampling error and enabling generalisation of findings from the sample to the broader population.

Results

Socio-demographic results outline the profiles of the study respondents in their area of specialisation. The respondents' profile includes the gender of the business owners, the age of the respondents, their education level, and the duration of conducting their businesses (Table 1).

Table 1. Social demographic results (gender, age, education level, and years in business)

Variable	Category	Frequency	Percent (%)	Valid percent (%)	Cumulative percent (%)
Gender	Male	143	85.1		85.1
	Female	25	14.9	15.5	100.0
	Total	168	100.0	100.0	
Age	18-25	26	15.5	15.5	
	26-35	109	64.9	64.9	80.4
	36-45	22	13.1	13.1	93.5
	46+	11	6.5	6.5	100.0

Continued Table 1

Variable	Category	Frequency	Percent (%)	Valid percent (%)	Cumulative percent (%)
	Total	168	100.0	100.0	
Education Level	Secondary	22	13.1	13.1	13.1
	Primary	2	1.2	1.2	14.3
	Degree	138	82.1	82.1	96.4
	Other	6	3.6	3.6	100.0
	Total	168	100.0	100.0	
Years in business	Less than 1	36	21.4	21.4	21.4
	1-3	129	76.8	76.8	98.2
	4-6	3	1.8	1.8	100.0
	Total	168	100.0	100.0	

Source: created by the author

The results in Table 1 show that the sample is predominantly dominated by males (85.1%), with females representing only 14.9%. This reflects a persistent gender gap in SME participation, often linked to structural barriers such as limited access to finance, markets, and entrepreneurial support systems for women. The underrepresentation of women reduces the inclusiveness of SME development and limits overall economic productivity, as female-led enterprises are an important source of income diversification and poverty reduction. The World Bank (2022) highlights ongoing gender disparities in entrepreneurship and access to finance. The International Labour Organization (2023) also indicates the barriers to women's participation in SMEs in developing economies.

The findings on age indicate that the majority of respondents (64.9%) fall within the 26-35 age group, followed by 15.5% aged 18-25. This indicates that SMEs are largely driven by young entrepreneurs, suggesting entrepreneurship is a key employment pathway for youth. Youth-led SMEs contribute to economic dynamism, innovation, and labour market participation, although they may face constraints such as limited experience and capital. The Global Entrepreneurship Monitor (2023) reports that high entrepreneurial activity occurs among younger age groups. OECD (2022) also highlights the role of youth entrepreneurship in economic recovery and growth. A significant majority (82.1%) of respondents possess a university degree. This suggests that SME ownership is increasingly knowledge-driven, with educated individuals entering entrepreneurship, possibly due to limited formal employment opportunities. Higher education enhances managerial capacity, innovation potential, and productivity, contributing to more competitive and sustainable enterprises. The World Bank (2021) elaborates on linking higher education to improved firm performance and innovation, and UNESCO (2022) emphasises the role of education in fostering entrepreneurial skills.

Most respondents are in early-stage businesses: 76.8% have operated for 1-3 years, and 21.4% for less than one year. This reflects a high concentration of young firms, indicating strong entrepreneurial entry but limited business maturity. While new firms stimulate economic activity and competition, they are also more vulnerable to failure due to limited experience, financial constraints, and market uncertainties. OECD (2021) denotes that young firms are key drivers of job creation but face high failure rates, and the World Bank (2022) narrates on the challenges faced by early-stage SMEs in developing economies. Young entrepreneurs (especially 26-35 years) are typically more technologically adaptable, more willing to take risks and experiment, and responsive to changing market conditions. Technological adaptability and willingness to take risks impact on SMEs, increasing innovation and creativity, rapid adoption of digital tools and platforms, and enhancing adaptability to economic slumps. The capability of young entrepreneurs to changing environment is in support with Global Entrepreneurship Monitor (2023), which signifies that youth entrepreneurs are more innovation-oriented and opportunity-driven.

Highly Educated Entrepreneurs bring about advanced analytical and managerial skills, better financial literacy, planning ability, and greater access to networks and information. Entrepreneurs with a high level of education have a positive effect on improved efficiency and productivity. According to UNESCO (2022), education enhances innovation and entrepreneurial effectiveness. A dominance of both young and educated entrepreneurs led to innovation-driven entrepreneurs, knowledge based economic, and flexible and adaptive business models. However, limited experience of SMEs may affect long-term sustainability, and new firms may struggle with access to finance and markets. From an employment, income growth, and poverty reduction perspective, SMEs are major contributors to employment. Youth-led SMEs reduce unemployment, and new firms generate net job opportunities. The report from the World Bank (2022) states that SMEs account for the majority of jobs globally. SMEs provide income-generating opportunities and contribute to higher productivity and earnings (International Labour Organization, 2023). Overall, the findings reveal that the young, highly educated, and early-stage SME sector promotes innovation, adaptability, and economic dynamism, and supports job creation and income generation. The results in Table 2 indicate the mean, standard deviation, and the sample size of the studied population.

Table 2. Mean, standard deviation, and sample size

Variables	Mean	Std. Deviation	N
Development of SMEs	4.3869	0.86810	168
Communication skills have improved business	4.3869	0.86118	168
Creativity and innovation have increased competitive advantage	4.3690	0.88608	168
Business management skills helped in expanding business	4.2560	0.81157	168

Source: created by the author

The high mean scores for communication (4.3869), creativity/innovation (4.3690), and business management (4.2560) suggest that most SME owners/managers perceive these competencies as highly impactful. Communication skills improve coordination within teams and enhance relationships with customers and suppliers. Creativity and innovation enable SMEs to differentiate their products/services and Support adaptation to changing market demands. Because the standard deviations are relatively low (~0.81-0.88), this agreement is consistent across the sample, strengthening the argument that these are not isolated opinions but broadly shared experiences. Overall, SMEs with stronger communication and innovation capabilities are likely to operate more efficiently and position themselves better against competitors.

Innovation is not just a personal trait; it functions as a system-level economic driver. When many SMEs exhibit high innovation capacity, new products and services enter the market. Additionally, job creation increases, and market competition improves efficiency across sectors. The results of innovation within SMEs contribute to structural economic transformation, not just firm-level success. SMEs act as engines of growth, especially in developing economies, where they make up a large share of employment. In conclusion, high innovation scores suggest that SMEs are actively contributing to broader economic dynamism, not merely improving their internal operations. The high values across all indicators strongly suggest a positive outlook for sustainability (Innovative SMEs can respond better to shocks (market changes, crises) and Strong management and communication support scaling operations and sustainability of SMEs. The relationship between variables is presented by a correlation matrix (Table 3).

Table 3. Correlation matrix (Pearson correlation coefficients)

Variables		DoS	CS	CR and INN	BMS
Pearson Correlation	DoS	1.000	0.912	0.965	0.819
	CS	0.912	1.000	0.903	0.868
	CR and INN	0.965	0.903	1.000	0.809
	BMS	0.819	0.868	0.809	1.000

Source: created by the author

The results indicate strong and positive relationships across all variables, suggesting that these factors tend to improve simultaneously within SME environments. The very high correlation between DoS, CR, and INN (r = 0.965) highlights the central economic role of innovation in SME development. This implies that firms engaging in creative processes, product development, and innovation-driven practices are significantly more likely to experience growth. Economically, this reflects the principle that innovation enhances productivity, efficiency, and market competitiveness, making it the most direct contributor to firm expansion and sustainability.

The strong correlation between DoS and CS (r = 0.912) suggests that effective communication both internally (management employees) and externally (customers, suppliers, investors) is also critical for SME growth. From an economic standpoint, communication reduces transaction costs, improves coordination, and strengthens market relationships, thereby supporting business performance. Additionally, the high correlation between CS, CR, and INN (r = 0.903) indicates that communication skills facilitate innovation processes. Firms with strong communication capabilities are better positioned to share knowledge, collaborate, and implement new ideas, reinforcing the complementary relationship between these variables. Although BMS is positively correlated with DoS (r = 0.819) and other variables, its relatively lower coefficients suggest a less dominant direct effect. This helps explain its statistical insignificance in regression analysis, which can be justified on several grounds:

- indirect influence – business management skills often operate through other variables, such as enabling better communication or supporting innovation, rather than directly driving growth;
- multicollinearity – the relatively high correlations between BMS and other predictors (e.g., CS = 0.868) indicate shared explanatory power, which reduces its independent statistical contribution;
- contextual factors in SMEs – in many SME settings, especially in developing economies, practical innovation and adaptive strategies may outweigh formal management

expertise, making innovation a more immediate determinant of success.

Overall, the matrix suggests that while all factors are important, creativity and innovation emerge as the dominant drivers of SME development, supported by communication, with management skills playing a complementary role. The high correlations observed in the matrix imply the presence of multicollinearity, which is typically reflected in high VIF values. High VIF indicates that independent variables are strongly interrelated, leading to reduced reliability of individual coefficient estimates and inflated standard errors, which can render some variables (e.g., BMS) statistically insignificant despite meaningful relationships. Thus, while the model may remain useful for explaining overall trends, its internal stability is weakened, and coefficient interpretations should be treated with caution.

At the same time, the high R^2 value indicates that the model explains a large proportion of variation in SME development. This suggests strong goodness of fit, but also raises concerns about overfitting, where the model captures sample-specific patterns rather than general relationships. This situation limits the generalisability, particularly across different regions, industries, or economic conditions. Therefore, although the model is highly explanatory within the sample, its predictive performance in other contexts may be less robust.

The findings have important implications for the wider economy and align closely with the journal's thematic focus on SMEs and innovation. The dominant role of innovation supports the idea that SMEs contribute to economic growth through productivity improvements and technological advancement. Innovative SMEs enhance efficiency and create new markets, driving overall economic expansion. SMEs are major sources of employment, and innovation-driven firms are more likely to expand operations and generate jobs. Moreover, innovation tends to increase demand for skilled labour, contributing to human capital development. Firms with strong innovation capacity are more attractive to investors due to their higher growth potential and competitive advantage. This encourages both domestic and foreign investment, strengthening the business ecosystem. The results reinforce the view that SMEs are key agents of structural transformation. Their ability to innovate, adapt, and respond to market changes positions them as central players in modern, knowledge-based economies.

The relative insignificance of management skills suggests that policymakers and development programs should prioritise innovation support systems (e.g., access to technology, R&D incentives), strengthen communication and knowledge-sharing platforms, and encourage entrepreneurial experimentation and creativity. In summary, the correlation analysis demonstrates that creativity and innovation are the most influential determinants of SME development, supported by communication skills, while business management skills play a secondary, indirect role. However, the presence of high VIF and R^2 values indicates potential multicollinearity and limits to generalisability, suggesting the need for cautious interpretation and possibly more advanced modelling techniques in future research. The estimated regression coefficients, their statistical significance, and the level of multicollinearity are presented in Table 4.

Table 4. Coefficients, t-statistics, significance, and collinearity level

Model	Unstandardised Coefficients		Standardised Coefficients	t	Sig.	95.0% Confidence Interval for B		Collinearity Statistics	
	B	Std. Error	Beta			Lower Bound	Upper Bound	Tolerance	VIF
(Constant)	0.11	0.090		1.224	0.223	-0.068	0.288		
CS	0.196	0.053	0.195	3.708	0.000	0.092	0.301	0.130	7.693
CR and INN	0.748	0.043	0.763	17.229	0.000	0.662	0.833	0.183	5.467
BMS	0.035	0.041	0.032	0.844	0.400	-0.047	0.116	0.242	4.125

Source: created by the author

The findings in Table 4 show that communication skills have a positive and significant effect on the development of SMEs (B = 0.196; p = 0.000; t = 3.708. That means for each one unit increase in communication skills improvement will influence the development of SMEs by 19.6 per cent. Additionally, creativity and innovation have a strong positive effect on the development of SMEs (B = 0.748; p = 0.000; t = 17.229). A unit increase in the level of creativity and innovation will almost have a total improvement in SMEs by 74.8 per cent. Business management skills have a positive effect on the development of SMEs, but this effect is not statistically significant. The overall model performance and goodness-of-fit indicators are presented in Table 5.

Table 5. Model summary

R Square	Adjusted R-Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
			R Square Change	F Change	df1	df2	Sig. F Change	
0.941	0.940	0.21254	0.941	873.998	3	164	0.000	1.984

Note: predictors: (constant), business management skills helped in expanding business, creativity and innovation have increased competitive advantage, communication skills have improved business; dependent variable: development of SMEs

Source: created by the author

The results in Table 5 show the model summary of the regression analysis. A coefficient of determination of $R^2 = 0.941$ indicates that approximately 94.1% of the variance in the dependent variable is explained by the predictors included in the model. On the surface, this suggests an excellent model fit. The very small gap between R^2 and adjusted R^2 (0.941 vs. 0.940) further implies that the included predictors contribute meaningfully and that the model is not excessively penalised when adjusting for the number of variables. This typically signals that the explanatory variables are relevant and not merely inflating the fit by chance. However, such a high R^2 also warrants scrutiny. One possible explanation is multicollinearity**,** where independent variables are highly correlated with each other. In this situation, predictors may collectively explain a large portion of the variance, thereby inflating R^2, even though their individual contributions are not clearly distinguishable. Multicollinearity does not reduce predictive power per se, but it undermines the stability and interpretability of regression coefficients. Small changes in the data can lead to large swings in estimated parameters.

Another consideration is model overfitting. Although the Adjusted R^2 is nearly identical to R^2, suggesting a limited penalty for model complexity, overfitting can still occur if the model is too closely tailored to the sample data. This is especially relevant if the dataset is relatively small or if the model has been iteratively refined without validation. Overfitted models tend to perform exceptionally well on training data (hence the high R^2) but may generalise poorly to new data. The F-statistic (873.998, $p < 0.001$) confirms that the model as a whole is statistically significant, meaning the predictors jointly explain a significant portion of variance in the outcome variable. The large F value aligns with the high R^2, reinforcing the overall strength of the model. The standard error of the estimate (0.21254) indicates that the residuals (prediction errors) are relatively small, suggesting good predictive accuracy. Meanwhile, the Durbin-Watson statistic (1.984) is very close to 2, indicating no serious autocorrelation in the residuals an important assumption for regression validity. Therefore, the results point to a model that fits the observed data extremely well, but this strength should be interpreted with caution.

This study tested four hypotheses concerning the role of entrepreneurial skills (communication skills, business management skills, and creativity/innovation) on the development of SMEs. Through rigorous correlation and regression analyses, the study reveals significant insights into how these skills contribute to SME growth. The results indicate that while communication and innovative skills have a strong positive effect on SME development, business management skills show a more nuanced relationship. The collective influence of these skills is also examined, highlighting their combined importance in fostering SME success.

Hypothesis 1 (H1) posited that communication skills positively affect SME development, which was supported by a strong correlation ($r = 0.912$) and a statistically significant regression result ($B = 0.196$, $p < 0.001$). Hypothesis 2 (H2) suggested that business management skills would positively influence SME development; however, this was only partially supported as the relationship was not statistically significant ($B = 0.035$, $p = 0.400$). Hypothesis 3 (H3) claimed that creativity and innovation would have a significant positive effect on SME growth, which was strongly supported with a high correlation ($r = 0.965$) and a robust regression result ($B = 0.748$, $p < 0.001$). Finally, Hypothesis 4 (H4) examined the collective influence of these skills, which was supported by a significant overall regression model ($F = 873.998$, $p < 0.001$), indicating that these skills together substantially impact SME development.

Discussion

This study examined the influence of entrepreneurial skills, specifically communication, creative and innovative, and business management skills, on the development of SMEs. The findings reveal that communication skills have a strong and direct positive effect on SME development, underscoring their central role in driving business growth. Furthermore, the study highlights how these skills enhance decision-making, foster stakeholder relationships, and improve adaptability in competitive markets, thereby enabling SMEs to sustain performance, seize emerging opportunities, and navigate challenges effectively while contributing to broader economic development and employment creation across diverse industry contexts and supporting inclusive, sustainable growth.

The prominent role of communication skills identified in this study is consistent with prior research. P.N. Shillie & N.N. Nachang (2023) found that communication significantly enhances organisational effectiveness by improving coordination, enabling timely decision-making, and strengthening relationships with both customers and employees. Similarly, A.A.M. Medhekar *et al.* (2022) argued that clear and purposeful communication allows entrepreneurs to translate business ideas into actionable strategies, leading to improved service delivery and higher customer satisfaction. In support of this, W.K. Kong (2025), in a study of Malaysian SMEs, highlighted that communication-related competencies, including negotiation ability, trust-building, and customer engagement, positively influence competitiveness and growth. Collectively, these studies affirm that communication is not merely a supportive skill but a core entrepreneurial competency essential for SME development. Additionally, the findings show that entrepreneurs who maintain strong communication with customers are more likely to achieve business growth. This aligns with customer relationship management theories, which emphasise the importance of continuous interaction and feedback in fostering customer loyalty and responsiveness to market demands. P.N. Shillie & N.N. Nchang (2023) and M.M. Kuruchumila (2025) maintain that communication skills are especially critical, as they enable entrepreneurs to articulate ideas, build relationships, and attract investment. Strong communication fosters trust, networking, and collaboration, all of which are vital for business success. It

also enhances the integration of business operations and adaptability to changing environments, and influences performance within SMEs. While communication skills have been widely recognised as important, there is still a need to examine a broader range of entrepreneurial skills and identify specific skill gaps affecting SME growth in the context of Tanzania. It is also important to consider sector-specific skill requirements, as different industries demand different capabilities. For instance, digital businesses require technological adaptability, while manufacturing firms depend on operational efficiency and supply chain management.

However, this finding differs somewhat from D. Bashulula (2025), who emphasised the dominant role of strategic management, accounting, sales, and marketing skills in driving small business growth. This variation suggests that SME development is multidimensional, requiring a combination of skills that may vary in importance depending on context. In this regard, communication skills can be viewed as integrative, enhancing the effectiveness of other competencies such as marketing and strategic planning. Beyond communication, the study also found that creative and innovative skills significantly contribute to SME development. This is strongly supported by existing literature, which consistently identifies innovation as a key driver of firm growth and competitiveness. A.A. Nwankwo & C.V. Ezeibe (2021) argued that creativity enhances entrepreneurs' capacity to identify opportunities, solve problems, and adapt to changing business environments. Similarly, M.S. Alosani & H.S. Al-Dhaafri (2021) found that innovation-oriented capabilities improve organisational performance by promoting adaptability and continuous improvement. S. Darwish *et al.* (2024) further reinforced that innovation and creativity are essential for sustaining SME growth, particularly in dynamic and competitive markets. These findings are also aligned with SIT, which views innovation as the engine of economic development and entrepreneurial success. According to this perspective, entrepreneurs who introduce new products, processes, or business models can gain competitive advantages that drive firm growth.

However, an important finding of this study is that business management skills were not perceived as a primary determinant of SME development in the Tanzanian context. This contrasts with R. Mugambi & P. Katobu (2024), who argued that managerial competencies, technological adoption, and innovation significantly enhance SME performance. Similarly, M. Rubio-Andrés *et al.* (2025) emphasised the importance of talent management and organisational learning in transforming human capital into improved business outcomes. The discrepancy may be explained by contextual factors such as the dominance of informal business practices, limited access to formal training, and a stronger reliance on practical and relational skills among Tanzanian entrepreneurs.

Furthermore, R. Cahyaningati *et al.* (2026) highlighted that innovation serves as a strategic link between knowledge resources and corporate social responsibility, ultimately improving business sustainability. Their findings suggest that SMEs should adopt innovation-driven strategies supported by both intellectual and social capital. This complements the present study by indicating that innovation is part of a broader system of capabilities necessary for sustained SME success. However, international studies present some divergence, with scholars in highly industrialised contexts arguing that innovation alone is insufficient without strong institutional support and access to finance, thereby revealing tensions in how innovation translates into performance across different environments.

Therefore, as contended by E. Hosseini *et al.* (2021), entrepreneurial skills encompass a blend of technical, managerial, and personal abilities necessary for establishing and growing businesses. These skills are essential for identifying opportunities, managing risks, fostering innovation, and enhancing performance. Nonetheless, debates persist regarding which skill sets are most critical, with some studies prioritising digital competencies while others emphasise soft skills such as adaptability and networking.

Importantly, this study contributes to the existing body of knowledge by providing empirical evidence from Tanzania, a context that has been relatively underexplored in prior research. Much of the literature has focused on emerging economies, often emphasising leadership, technological advancement, and organisational learning. In contrast, this study demonstrates that entrepreneurial skills, particularly communication and creativity, play a more immediate and visible role in influencing SME development, thereby challenging dominant narratives that privilege technology-centric growth models. Overall, the findings indicate that SME growth depends on a combination of entrepreneurial skills. Therefore, promoting a holistic approach to entrepreneurial skill development, integrating communication, innovation, and management competencies, is essential for achieving sustainable SME growth, while also reconciling ongoing scholarly disagreements that have been provided on context-specific drivers of success.

Conclusions

The regression results indicate that the model has very strong explanatory power. With an R-Square of 0.941 and an adjusted R-Square of 0.940, this suggests that the model is not overfitted and that the explanatory variables are largely relevant. Furthermore, the overall model is statistically significant, as indicated by a high F-statistic ($F = 873.998$, $p < 0.001$), confirming that the predictors jointly have a meaningful effect on the dependent variable. The Durbin-Watson statistic of 1.984 is very close to 2, indicating no serious autocorrelation in the residuals, and thus supporting the reliability of the regression estimates.

An examination of the individual regression coefficients reveals that CR and INN are the most influential predictors in the model. It has a large positive coefficient ($B = 0.748$) and a very high standardised beta ($\beta = 0.763$), with a statistically significant p-value ($p < 0.001$). This implies that CR and INN contribute the most to changes in

the dependent variable and are the primary drivers of the model's explanatory power. Similarly, CS also shows a positive and statistically significant relationship with the dependent variable ($B = 0.196$, $\beta = 0.195$, $p < 0.001$), although its effect size is notably smaller compared to CR and INN. In contrast, BMS has a very small coefficient ($B = 0.035$) and is not statistically significant ($p = 0.400$), indicating that it does not have a meaningful impact on the dependent variable within this model. Finally, the collinearity diagnostics indicate the presence of moderate multicollinearity among the independent variables. VIF values 7.693 for CS, 5.467 for both CR and INN, and 4.125 for BMS exceed commonly accepted thresholds, particularly for CS, suggesting that some predictors are correlated. Although this does not invalidate the model, it may affect the stability and interpretation of the estimated coefficients.

Overall, the model demonstrates strong explanatory power with respect to the dependent variable, with CR and INN emerging as the most influential predictors, CS contributing moderately, and BMS showing no significant effect. Nevertheless, these findings should be interpreted with caution due to the observed multicollinearity. The results suggest that entrepreneurial skills (communication skills, innovation, creativity, and business management skills) are crucial for the growth of SMEs. In conclusion, given the increasing importance of self-employment, this study highlights the need for future research to identify and validate the key factors required for the initiation of SMEs, as well as to assess their relevance in fostering the growth of entrepreneurial ventures.

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Conflict of Interest

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Розвиток малих та середніх підприємств у Танзанії: роль підприємницьких навичок

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Анотація. Підприємницькі навички дедалі більше стають критично важливою рушійною силою економічного зростання та широко визнаються необхідними для економічного динамізму. Метою цього дослідження було оцінити значення наявних навичок для розвитку малих та середніх підприємств у Танзанії, з особливим акцентом на учасниках, які є власниками малого та середнього бізнесу в Прибережному регіоні. Зокрема, у дослідженні розглянуто три ключові навички: комунікацію, управління бізнесом і креативність/інноваційність. Було застосовано кількісний дослідницький підхід із використанням структурованих анкет, розповсюджених серед 168 респондентів. Для аналізу характеристик респондентів і перевірки гіпотетичних взаємозв'язків між змінними було використано описовий і регресійний аналіз. Результати показали, що комунікаційні навички мають позитивний і статистично значущий вплив на розвиток малих та середніх підприємств ($B = 0{,}196$, $\beta = 0{,}195$, $t = 3{,}708$, $p < 0{,}001$, 95 % ДІ [0,092, 0,301]). Навички креативності та інноваційності продемонстрували сильніший і високозначущий вплив ($B = 0{,}748$, $\beta = 0{,}763$, $t = 17{,}229$, $p < 0{,}001$, 95 % ДІ [0,662, 0,833]). Натомість навички управління бізнесом показали слабкий і статистично незначущий вплив ($B = 0{,}035$, $\beta = 0{,}032$, $t = 0{,}844$, $p = 0{,}400$, 95 % ДІ [-0,047, 0,116]). Регресійна модель була статистично значущою та пояснювала значну частку дисперсії розвитку малих та середніх підприємств ($R^2 = 0{,}941$, скоригований $R^2 = 0{,}940$, $F(3{,}164) = 873{,}998$, $p < 0{,}001$), без ознак автокореляції (Durbin-Watson = 1,984). У дослідженні зроблено висновок, що комунікація, креативність та інноваційність є ключовими детермінантами розвитку малих та середніх підприємств, тоді як навички управління бізнесом відіграють обмежену роль. Ці результати мають важливе значення для політиків, освітян і фахівців у сфері розвитку під час розроблення цільових заходів, спрямованих на сприяння сталому зростанню малих та середніх підприємств у Танзанії

Ключові слова: креативність; бізнес; можливості; офіційна зайнятість; фінансові установи

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Risk-oriented product management of AI-based solutions in the energy sector

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Abstract. AI-related innovation initiatives in the energy sector have traditionally been viewed as sources of organisational complexity and potential vulnerability. The study aimed to analyse the interplay between energy security and the resilience of energy systems, to explore emerging risks associated with digitalisation and the implementation of intelligent systems, and to evaluate the managerial and policy measures necessary for the effective integration of AI into energy infrastructure. To achieve the stated objectives, open-access sources were utilised and an integrated approach was applied, combining general scientific and specialised research methods, with particular emphasis on advanced analytical, monitoring and automated technologies. The findings underscored the importance of investing in technological, human, and regulatory capacities to fully leverage the potential of AI. At the same time, the role of AI-driven tools in modern energy systems is increasing due to their contributions to digital resilience, operational stability, predictive maintenance, cybersecurity, and strategic decision-making. However, these developments are accompanied by corresponding risks. That is why the modern management system must evolve from an administrative and control-oriented function to an

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intelligent, analytical mechanism that integrates human expertise with algorithmic decision-making. In this way, digital resilience extends the concept of system resilience by integrating information technologies and AI-driven analytics to anticipate, absorb, and recover from disruptions, whether caused by physical, technological, or cyber incidents. This integration reduces subjectivity, enhances the accuracy of operational decisions, and ensures a transparent, adaptive, and scientifically grounded approach to strategic coordination. By combining advanced analytics, AI-driven automation, and proactive risk management, energy systems can achieve enhanced stability, operational reliability, and cybersecurity resilience in increasingly complex and digitally interconnected environments. Furthermore, leveraging global best practices and fostering cross-border collaboration in AI innovation and cybersecurity can accelerate the transformation of energy enterprises toward sustainable, intelligent, and resilient infrastructures

Keywords: digital environment; cyber risks; investments; product management; strategic planning; project management; operational risk

Introduction

The growing number of AI-related innovation projects and the increasing role of AI-driven tools in modern energy systems are accompanied by newly emerging operational risks, including cyberattacks, and therefore require advanced approaches to risk management and system resilience. Accordingly, digital resilience extends the state of the art within resilience theory and, in this context, becomes an essential feature of any modern energy system. Given the foundational role of energy in supporting economic stability and long-term development, these components constitute priority areas for innovation and sustainability.

The studies by O. Trofymenko *et al.* (2021), H. Pudycheva (2021), and Yu. Kravchyk (2025) explored methodological approaches to the design of renewable energy infrastructure and assessed the prospects for further sustainable development in Ukraine and the European Union. Growing digitalisation simultaneously expands the cyber threat surface, creating systemic vulnerabilities that require coordinated resilience strategies. M.A. Alomari *et al.* (2025) emphasised the global importance of strengthening legislative and regulatory frameworks to enhance cybersecurity and operational resilience within the electricity sector. S. Horbachenko & O. Savratsky (2025) analysed strategies for proactively increasing resilience, including infrastructure redundancy, the implementation of cybersecurity frameworks, the diversification of energy resources, and the development of international cooperation aimed at strengthening the reliability and continuity of energy systems. Cybersecurity solutions provide mechanisms for detecting, preventing, and responding to cyber threats, thereby enhancing the resilience and operational stability of critical infrastructure.

A study by M. Florkowski *et al.* (2024) examined the functioning of the energy sector as a critical infrastructure for modern society, which relies heavily on the reliability of digital systems. The authors emphasise that the digitalisation of the energy sector, the introduction of automated solutions, and remote-control technologies are leading to increased complexity and vulnerability of energy systems. The study places particular emphasis on the role of AI technologies in improving the efficiency and resilience of energy systems, as well as new risks associated with cybersecurity, data integrity, and algorithmic decision-making. It is noted that disruptions in AI-driven energy systems can lead not only to economic losses but also to large-scale social risks.

S. Shandilya *et al.* (2024) examined the concept of system resilience in the context of digital transformation. Their research emphasises that different systems demonstrate varying capacities to withstand risks of diverse origins, adapt to environmental changes, and ensure rapid recovery while returning to a stable operational state. These capabilities are collectively conceptualised as resilience. The authors further argue that when such properties are achieved or enhanced through the adoption, implementation, and advancement of digital technologies, they can be defined as digital resilience, highlighting the critical role of digital tools and infrastructures in strengthening the adaptive and recovery capacities of modern systems.

Accelerating globalisation in the world economy, along with the liberalisation and integration of energy markets, increases the importance of research into mechanisms for ensuring energy security and supporting sustainable development in the energy sector. These processes create new challenges and interdependencies that require systematic analysis and coordinated action. In such conditions, the role of innovation management as a key tool for adapting energy systems to dynamic changes in the external environment is growing. Effective innovation management ensures the implementation of advanced technologies, in particular digital solutions, AI and cybersecurity systems, which contribute to increasing the resilience of energy infrastructure. Introduction of innovations is traditionally accompanied by uncertainty, but AI as a technological innovation has a qualitatively different risk profile.

Despite the growing body of research on cybersecurity, resilience, and digital transformation in the energy sector, several important aspects remain insufficiently explored. Existing studies primarily focus on the development of renewable energy infrastructure, regulatory frameworks, and cybersecurity strategies for protecting critical infrastructure. However, the specific mechanisms for integrating digital resilience principles into risk management processes in AI-related projects remain limited in the current literature. Therefore, the current research aimed to analyse the interplay between energy security and resilience of energy systems, explore the emerging risks associated with

digitalisation and implementation of intelligent systems, and evaluate managerial and policy measures necessary for the effective integration of AI in energy infrastructure.

Materials and Methods

The theoretical and methodological foundation of this study was grounded in the fundamental principles of economic theory and practice, as well as in a combination of general scientific and specialised methods for the analysis of economic phenomena. The methodological framework was based on an integrated approach that enables a comprehensive investigation of digital resilience and risk management in projects involving the application of AI within the energy sector. A set of general scientific methods, including scientific abstraction, analysis, and synthesis, was employed to conceptualise the research problem and to structure the theoretical framework. These methods facilitated the identification of key categories, relationships, and patterns associated with digital resilience, cybersecurity risks, and the integration of AI technologies into energy systems. In addition, historical and comparative analysis were applied to examine the evolution of approaches to resilience and energy security.

Comparative and logical analysis were specifically used to investigate the interrelationship between energy security and system resilience. The application of these methods enabled the alignment and critical evaluation of existing theoretical approaches and justified the need for their integration into modern risk management frameworks. A systems approach was adopted to consider digital resilience as an integral component of complex energy infrastructures. This approach allowed energy systems to be analysed as multi-level structures incorporating technological, organisational, and informational elements, thereby identifying the role of AI in enhancing system adaptability and recovery capacity. Economic and statistical methods were utilised to assess trends in the development of cyber threats and investments in cybersecurity. The empirical analysis was based on open-access statistical data, including materials from the State Service of Special Communications and Information Protection of Ukraine (n.d.), which were used to examine the dynamics of cyber incidents targeting the energy sector. Additionally, analytical reports from the Kyiv School of Economics (2024) and DTEK (2024) were employed to evaluate the economic losses and structural vulnerabilities of the Ukrainian energy system.

Trend analysis and graphical modelling were applied to visualise changes in the frequency of cyber incidents. Python-based data processing tools were used to construct time series and identify patterns and tendencies in the evolution of cyber threats. The use of these methods was justified by the need for quantitative validation of observed processes and for enhancing the analytical rigor of the study. Furthermore, the monographic method and thematic analysis were employed to examine a wide range of domestic and international scientific publications. A frequency-based content analysis of scholarly sources was conducted to identify dominant research themes, methodological approaches, and gaps in the existing literature on digital resilience, AI, and cybersecurity in energy systems. These sources formed the theoretical basis for the study and supported the development of the conceptual framework. Methods of induction, deduction, and synthesis were used to generalise the findings, formulate theoretical conclusions, and develop conceptual approaches to risk management in AI-related projects. The empirical basis of the study was represented by the energy sector of Ukraine, which is considered as a case study under conditions of heightened risk and wartime disruptions. This context provided a unique opportunity to analyse the functioning of critical infrastructure in crisis environments and to evaluate the role of digital technologies in ensuring system resilience. The research was conducted in several stages, including: analysis of theoretical approaches; collection and processing of statistical data; trend modelling and visualisation; and synthesis of results and development of a conceptual model of digital resilience.

Results and Discussion

AI-related innovation initiatives have traditionally been regarded as drivers of organisational complexity and potential vulnerability. This evolving understanding is encapsulated in the notion of digital resilience, which extends the classical concept of resilience – defined as a system's ability to absorb shocks, adapt to changing conditions, and recover from disruptions – by emphasising the enabling role of digital technologies and information systems within highly interconnected environments. Simultaneously, the ongoing digital transformation of critical infrastructures is fundamentally redefining governance and management paradigms, particularly in the energy sector. Digital resilience denotes the capability of energy systems to sustain stable and continuous operations under conditions of disruption, including cyber incidents, technological failures, and large-scale crisis events. The attainment of such resilience increasingly depends on the deployment of advanced analytical, monitoring, and automation technologies, with AI occupying a central role.

However, the integration of intelligent systems simultaneously generates new layers of operational, technological, and cybersecurity risk. These emerging risk profiles necessitate the implementation of structured and proactive risk management frameworks. Accordingly, effective governance of AI-related innovation projects requires the systematic alignment of AI capabilities with comprehensive risk assessment procedures, mitigation mechanisms, and resilience-oriented system architecture. Such an integrated approach is essential to ensuring the secure, reliable, and sustainable functioning of critical energy infrastructure in digitally transformed environments.

Innovation implementation is inherently associated with uncertainty and risk. AI represents a distinct class of innovation with risk characteristics. These risks include algorithmic opacity, data dependency, and ethical concerns.

Innovation implementation is inherently associated with uncertainty and risk, and AI represents a distinct class of innovation characterised by specific risk factors. Algorithmic opacity limits the interpretability of AI systems, data dependency makes their performance sensitive to the quality and completeness of datasets, and ethical concerns relate to fairness, privacy, and potential bias in automated decision-making. Together, these risks increase uncertainty in AI adoption and require careful governance to ensure responsible and reliable implementation. In innovation management, this necessitates the adaptation of classical risk management mechanisms. At the idea screening stage, additional evaluation criteria must be applied. These include data quality, model transparency, and potential societal impact. During the planning phase, technology readiness assessment becomes critical. This mechanism ensures alignment between AI solutions and organisational capabilities. In the development stage, agile methodologies enable iterative validation and risk reduction. Portfolio management mechanisms support risk diversification across AI projects. At the commercialisation stage, stakeholder management becomes essential due to regulatory and reputational risks. Continuous monitoring and post-implementation review ensure adaptive risk control.

The concept of energy security is closely linked to the notions of resilience and risk, both of which are fundamental to the stable and reliable operation of critical energy systems. The case of Ukraine between 2014 and 2021 illustrates a persistent imbalance between these dimensions. In 2014, the country exhibited moderate to high levels of risk alongside medium to low levels of resilience, a situation that showed little improvement over the subsequent six years. A significant external risk factor remained the country's dependence on energy imports, as four out of five major energy sources were imported. This dependency was further exacerbated by a high concentration of supplier power, stemming from limited diversification and the potential for politically motivated actions by exporting countries. At the same time, resilience factors were insufficient to offset these risks. Structural weaknesses – including underdeveloped infrastructure, outdated technologies, and inefficient, wasteful patterns of energy consumption – constrained the system's capacity to absorb and respond to external shocks (Chaika, 2023). Thus, in contemporary energy systems, resilience refers to the broader capacity of the system to anticipate, absorb, and recover from disruptions, including those arising from cyber threats. In this regard, resilience complements the concept of energy security by extending beyond the mere continuity of supply to encompass the system's ability to adapt and sustain functionality under adverse conditions.

The cybersecurity ecosystem in the energy sector encompasses a diverse set of stakeholders, including electric utilities, oil and gas corporations, renewable energy operators, transmission system operators, industrial automation vendors, cybersecurity solution providers, and national security agencies. Renewable energy operators, particularly those managing large-scale wind and solar installations, increasingly integrate cybersecurity measures to safeguard inverter technologies, distributed control systems, and remote monitoring platforms. This is crucial for maintaining the resilience of low-carbon energy systems and supporting the transition to sustainable energy models. The emergence of virtual power plants and peer-to-peer energy trading platforms further expands the cyber threat landscape, introducing new risks associated with decentralised and consumer-oriented infrastructures. Additionally, energy trading platforms and market participants are exposed to phishing, fraud, and insider threats, necessitating the implementation of advanced, finance-grade cybersecurity protocols. In the context of sustainable development, robust cybersecurity practices contribute to the stability, reliability, and trustworthiness of energy systems. Therefore, cybersecurity can be considered a foundational element of digital resilience, enabling the secure and sustainable evolution of modern energy ecosystems.

The cybersecurity ecosystem in the energy sector includes utilities, transmission system operators, technology vendors, cybersecurity providers, and government agencies, each performing roles in system operation, protection, regulation, and incident response while coordinating through shared platforms and protocols. The most common cyber threats include attacks on SCADA systems, malware, phishing, supply chain compromises, and vulnerabilities in distributed and decentralised energy infrastructures (Ige *et al.*, 2024). Practical cases have shown that cyberattacks can lead to power outages, disruption of fuel supply chains, and financial losses in energy markets. To mitigate these risks, organisations apply network segmentation, zero-trust approaches, continuous monitoring systems, and strict access control mechanisms. Altogether, these measures enhance digital resilience and ensure the stability and sustainability of modern energy systems.

Unprecedented missile strikes targeting key facilities of the electric power sector have resulted in widespread emergency power outages, the consequences of which have been mitigated through the extensive efforts of transmission system operators. Deliberate attacks on critical infrastructure, including power plants, substations, and transmission networks, have significantly undermined the stability and reliability of electricity supply. Despite these challenges, the energy sector has demonstrated a remarkable level of resilience, characterised by rapid resource mobilisation and the ability to restore system functionality under extreme conditions.

Emergency restoration mechanisms for electricity supply have been successfully implemented, enabling the gradual stabilisation of the power system. A historic milestone was achieved in 2022 with the synchronisation of the Ukrainian power system with the European electricity network. This integration strengthened energy security and created new opportunities for electricity trade. In addition, Ukraine expanded electricity exports to the European Union, thereby enhancing the country's position within the regional energy market (DTEK, 2024). Large-scale

disruptions to the power system required the deployment of structured resilience mechanisms combining technical recovery, coordinated system management, and adaptive infrastructure solutions. Restoration processes were organised in stages, including immediate fault isolation, activation of emergency protection schemes, and phased grid re-energisation, with priority given to critical facilities; in many cases, essential services were restored within one to three days. The transmission system operator Ukrenergo ensured continuous real-time coordination, balancing supply and demand, implementing controlled load shedding, and maintaining frequency stability under stressed conditions. Integration with ENTSO-E enabled cross-border electricity flows, with emergency imports reaching up to approximately 1-2 GW and covering a notable share of demand deficits during peak disruptions. Infrastructure resilience was further supported through the deployment of mobile substations, reserve generating capacities, and network reconfiguration, which contributed to the recovery of a substantial proportion of damaged assets and the stabilisation of overall system performance yberthreat-landscape-2024 (ENTSO-E strategic roadmap, n.d.).

The longitudinal analysis of cyber incidents targeting Ukraine's energy sector reveals a critical escalation in early 2024, where a sharp increase to 124 incidents (+138%) indicates the presence of a significant external destabilising factor or a shift in the monitoring paradigm that enhanced event detection. While the data reached a peak of 127 incidents in the second half of 2024, the subsequent stabilisation at 120 incidents in early 2025 suggests a transition toward a high-intensity plateau; consequently, a comparison of empirical data with the trend line indicates that, in the short-term perspective, incident frequency is projected to remain within the range of 115-125 cases per semi-annual period absent the implementation of further robust preventive measures (Fig. 1).

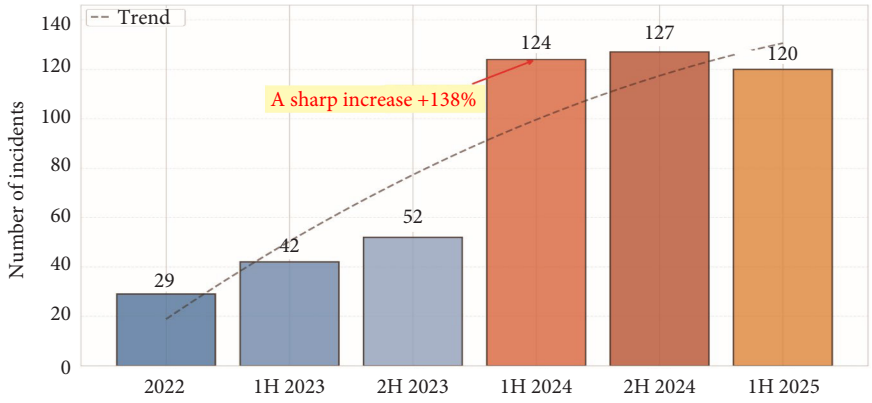

Figure 1. Trends in the number of cyber incidents targeting the energy infrastructure in Ukraine, 2022-2025
Source: prepared by the authors based on State Service of Special Communications and Information Protection of Ukraine (n.d.)

Between October 2022 and September 2024, the Russian Federation carried out more than 1000 attacks on Ukraine's energy infrastructure, damaging or destroying the majority of the country's major thermal and hydroelectric power plants. As a consequence of occupation and sustained military strikes during 2022-2023, the Ukrainian power system lost nearly 21 GW of generation capacity. In 2024 alone, the losses resulting from missile and drone attacks are estimated to exceed 9 GW (Kyiv School of Economics, 2024). In addition to generation facilities, repeated strikes have targeted critical nodes of the electricity transmission network, further increasing operational risks and placing additional pressure on the stability of the national energy system. One of the most significant applications of AI in energy resilience is predictive analytics for demand forecasting and operational planning. Machine learning models analyse historical consumption data, weather conditions, and economic indicators to forecast fluctuations in electricity demand. Such predictive capabilities allow system operators to optimise generation schedules and prevent overloads or shortages in energy supply. As a result, predictive analytics contributes to improved stability and efficiency in energy system operations. AI tools supporting digital resilience in energy systems are presented in Table 1.

Table 1. AI tools supporting digital resilience in energy systems

AI tool	Application in energy systems	Contribution to digital resilience
Predictive Analytics	Forecasting electricity demand and optimising generation planning	Improves system stability and prevents supply disruptions
Predictive Maintenance	Monitoring equipment condition using sensor data and AI models	Reduces equipment failures and unplanned outages
Anomaly Detection Systems	Identifying abnormal network behaviour and operational irregularities	Enhances cybersecurity and early threat detection
Decision Support Systems (AI-based)	Assisting operators in real-time operational and strategic decisions	Improves response speed and decision accuracy

Continued Table 1

AI tool	Application in energy systems	Contribution to digital resilience
Digital Twins	Creating virtual models of energy infrastructure for simulation	Enables risk modelling and scenario testing
Smart Grid Optimisation Algorithms	Managing distributed energy resources and balancing loads	Enhances grid flexibility and operational efficiency
Renewable Energy Forecasting Models	Predicting solar and wind generation levels	Supports integration of renewable energy sources
Automated Control Systems	Real-time adjustment of energy flows and grid parameters	Ensures rapid adaptation to system disturbances

Source: prepared by the authors based on F. Bertone *et al.* (2020), J. Holmström (2022), A. Sulaiman *et al.* (2023), J. Ruan *et al.* (2023), P. Koundouri *et al.* (2025), S.C. Vetrivel *et al.* (2025), H. Dui *et al.* (2025), M.F. Khaleel & Z.M. Abdulkareem (2025)

Another critical area of AI application is predictive maintenance of energy infrastructure. Intelligent algorithms process large volumes of sensor data collected from turbines, transformers, and transmission lines to detect early signs of equipment degradation or malfunction. By identifying potential failures before they occur, AI systems allow energy companies to implement preventive maintenance strategies and reduce the risk of unexpected outages. This approach enhances operational reliability while simultaneously lowering maintenance costs and extending the lifespan of critical assets.

AI also plays an essential role in strengthening the cybersecurity and operational monitoring of digitalised energy systems. Advanced anomaly detection algorithms continuously analyse network activity and system performance to identify irregular patterns that may indicate cyber intrusions or technical faults. Through real-time monitoring and automated alerts, these systems enable rapid response to potential threats and help prevent cascading failures within interconnected energy networks. Furthermore, AI-driven decision support systems and digital twin technologies provide advanced tools for modelling, simulation, and strategic planning in the energy sector. Digital twins create virtual representations of physical energy infrastructure, allowing operators to simulate various operational scenarios and evaluate potential risks. Combined with AI-based decision support systems, these tools improve situational awareness and facilitate data-driven decision-making. Consequently, the integration of AI technologies significantly contributes to the development of resilient, adaptive, and secure energy systems.

Cyber risks in the energy sector range from malware and ransomware to sophisticated state-sponsored attacks targeting operational technology and industrial control systems. The consequences of such attacks may include power outages, equipment damage, financial losses, and reduced public trust in energy providers. The integration of renewable energy sources and smart grid technologies further increases the complexity of the system, creating new potential attack vectors. Effective mitigation requires a combination of robust cybersecurity strategies, continuous monitoring, staff training, and the adoption of advanced technologies such as AI for threat detection and predictive maintenance.

The global cybersecurity market in the energy sector generated approximately USD 8.6 billion in revenue in 2021. This market is expected to experience substantial growth over the coming decade as the digitalisation of energy infrastructure accelerates and cyber threats continue to intensify. According to current projections, the market volume is anticipated to reach nearly USD 21.8 billion by 2031. This growth corresponds to an average annual growth rate of approximately 11.3% during the period from 2022 to 2031 (Allied Market Research, n.d.). The expansion of cybersecurity investments reflects the increasing priority placed on protecting critical energy infrastructure and ensuring the stability and resilience of modern power systems.

It is emphasised that it is necessary to help managers and other decision-makers make informed investment decisions to effectively ensure IT security. The study addresses issues such as lack of transparency in IT security costs, staff shortages and difficulties in resource planning. A sample calculation shows the financial impact of IT security measures using the Return on Security Investment (RoSI) model (Deutsche Energie-Agentur, n.d.). The RoSI cost estimate shows that the investment is already profitable for important companies in the first year, and for particularly important ones – from the second year. The sample calculation illustrates that the investment is profitable even with low damage compensation costs.

The development of national strategies for the digital transformation of the energy sector, alongside the implementation of industry standards and regulatory frameworks for the safe and ethical use of AI, facilitates the formalisation of digital processes. Such regulatory support also encompasses the establishment of quality control mechanisms, certification of innovative products, licensing of AI-based solutions, and assurance of consumer data protection. Financial and investment incentives are critical for fostering the adoption of innovative solutions by energy companies. These mechanisms include government subsidies, grants, concessional loans, and tax incentives aimed at encouraging investment in digital modernisation. An essential component of this approach is the promotion of public-private partnerships, which enable the pooling of resources from governmental bodies, private enterprises, and research institutions to implement large-scale technological initiatives.

The investment feasibility of cybersecurity solutions based on AI is determined by their capacity to enhance digital resilience. AI-driven systems enable proactive

threat detection and real-time response. This reduces the expected losses from cyber incidents. In the framework of innovation management, such investments should be evaluated using risk-adjusted performance metrics. Traditional cost-benefit analysis is insufficient for AI-based cybersecurity solutions. It should be complemented by scenario analysis and probabilistic risk assessment. The incorporation of AI improves the accuracy of threat intelligence and forecasting models. This increases the effectiveness of resource allocation in cybersecurity strategies. However, investment decisions must account for implementation risks, including model bias and data vulnerabilities. Regulatory compliance and ethical considerations also influence the overall investment attractiveness. Therefore, a comprehensive evaluation approach is required to ensure sustainable and resilient AI-driven cybersecurity investments.

In the energy sector, several factors act as barriers to technological change. A conservative approach to adopting new technologies is often driven by concerns regarding their effectiveness and potential impact on existing business models. Additionally, digital transformation initiatives in many energy companies remain incomplete, necessitating further investment and the restructuring of management practices. Management is evolving from a primarily administrative and control-oriented function into an intelligent, analytical mechanism for strategic coordination, which integrates human expertise with algorithmic analytics. The ultimate objective is to establish an effective, adaptive, and transparent decision-making framework that combines human experience with the capabilities of analytical algorithms through a comprehensive controlling system.

The human factor continues to represent one of the primary challenges for energy enterprises, as the resilience of operational technology systems and energy networks depends largely on employee actions in mitigating both external and internal cyber threats. Currently, there is a pronounced shortage of cybersecurity specialists, which poses a significant challenge for the sector. The Figure 2 illustrates the key challenges associated with the implementation of AI, including regulatory gaps, transparency issues, hybrid threats, and human-factor risks. It also presents sustainability strategies such as AI-blockchain synergy, structured threat taxonomies, and safety culture, which support the development of digital resilience and effective risk management in AI-related projects.

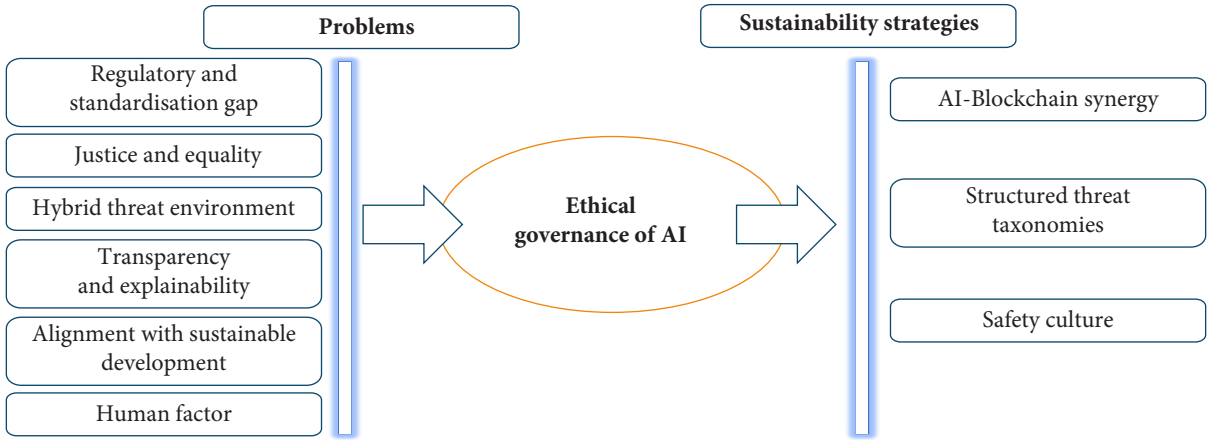

Figure 2. Conceptual framework of ethical AI governance for digital resilience and risk management in AI-related projects

Source: prepared by the authors

Scientific, educational, and workforce development further ensure the creation of a professional foundation for the effective utilisation of AI tools within the energy sector. Supporting specialised educational programs in digital technologies, particularly those focused on energy systems, is essential for preparing qualified personnel. Moreover, initiatives should promote the retraining of existing energy sector employees and the establishment of research centres and laboratories dedicated to the development and implementation of AI solutions for energy infrastructure. The deployment of comprehensive cybersecurity solutions across energy infrastructure requires substantial financial investment, reflecting the critical importance of safeguarding complex and digitally integrated energy systems. Building on the challenges and strategies highlighted in the figure, Table 2 provides a detailed overview of the economic effects of AI applications in the energy sector. It summarises key application areas, the mechanisms through which AI generates value, and the expected outcomes for operational efficiency, cost reduction, and strategic decision-making. The Table 2 summarises key AI application areas, the associated economic effects, the mechanisms through which AI generates value, and the expected outcomes for energy systems, including cost reduction, improved efficiency, risk mitigation, and enhanced decision-making. Ukraine demonstrates considerable development potential due to its unique experience in countering cyber warfare, the rapid pace of digital trans-

formation, and the strong support of international partners. At the same time, the sector remains vulnerable due to market fragmentation, insufficient systemic financing, and the lack of comprehensive regulatory and legal standards for businesses operating in the digital environment. Nevertheless, the growing demand for cybersecurity solutions, the diversification of technological capabilities, and the potential for exporting digital technologies create favourable conditions for Ukraine to evolve into a regional leader in this domain.

Table 2. Economic effects of AI applications in the energy sector, their value creation mechanisms, and expected outcomes

AI application area	Economic effect	Mechanism of value creation	Expected outcome
Predictive Maintenance	Reduction of maintenance costs	Early detection of equipment failures through data analytics	Decreased downtime, extended asset lifetime
Demand Forecasting	Optimisation of energy production costs	Accurate prediction of consumption patterns using machine learning models	Reduced imbalance costs and improved planning efficiency
Smart Grid Management	Improved operational efficiency	Real-time load balancing and automation of grid operations	Lower transmission losses and increased system stability
Cybersecurity (AI-based)	Risk cost reduction	Early detection of cyber threats and automated response	Prevention of financial losses from cyber incidents
Renewable Energy Optimisation	Increased return on investment (ROI)	Forecasting of renewable generation and integration into energy systems	Higher utilisation of renewable sources and reduced curtailment
Energy Management Systems	Cost savings in energy consumption	AI-driven optimisation of industrial and commercial energy use	Reduced energy expenses and improved efficiency
Decision Support Systems	Improved investment decision quality	Data-driven analysis of scenarios and risks	More efficient capital allocation and reduced uncertainty
Digital Twins	Cost reduction in system testing and planning	Simulation of operational scenarios and risk modelling	Lower costs of errors and improved infrastructure planning

Source: prepared by the authors

Overcoming these structural barriers requires the coordinated integration of education, business, and public policy into a unified system aimed at strengthening national cyber resilience. However, alongside these opportunities, new challenges are emerging. The widespread adoption of digital technologies and AI raises critical questions regarding ethical governance, the development of transparent and accountable algorithmic decision-making systems, and the fair allocation of responsibility among technology developers, system operators, and regulatory authorities. These challenges are particularly acute in sectors that have experienced the most significant physical and cyber impacts in recent years, most notably the Ukrainian energy sector. Ensuring the resilience of this sector requires the implementation of innovative protection strategies, continuous professional development of specialised personnel, and the cultivation of a culture of digital responsibility among all stakeholders involved in the energy ecosystem.

Overall, the analysis of the reviewed studies demonstrated a strong and growing consensus regarding the critical role of artificial intelligence and cybersecurity in enhancing the resilience of modern energy systems. The existing literature confirmed that increasing digitalisation, while enabling significant efficiency gains, simultaneously introduced new layers of complexity and vulnerability. The technological dimension of resilience was explored in detail in several studies. Specifically, M. Shadabfar *et al.* (2022) highlighted the importance of resilience-oriented design frameworks incorporating computational models and simulation tools to anticipate and withstand disruptions. The findings of the study aligned with this conclusion regarding the need for proactive modelling; however, this perspective was expanded in the current study by demonstrating that such technological frameworks must be an integral part of a comprehensive risk management system. Similarly, I. Alhamrouni *et al.* (2024) emphasised the role of artificial intelligence in enhancing system stability through real-time control, fault detection, and adaptive protection mechanisms. Conclusions fully corroborated the effectiveness of AI tools for monitoring and predictive analytics, but additionally indicated that technical robustness must be supported by organisational adaptability. Furthermore, B. Ozpineci (2022) examined the integration of AI and machine learning techniques directly into power electronics and cybersecurity architectures. Current results coincided with the author's vision regarding the formation of the technological core of resilient energy systems; nevertheless, the necessity of combining these architectures with institutional governance mechanisms was emphasised.

However, a purely technological approach appeared insufficient to fully capture the complexity of the contemporary energy environment. The research by S.M. Stezhko & V.M. Fitsa (2021) highlighted the institutional and regulatory dimensions, arguing that the effectiveness of cybersecurity measures depended on national policies and legal frameworks. The conclusions of current study agreed with this assertion, as regulatory compliance and stakeholder coordination were also considered as mandatory

components of the proposed integrated model of digital resilience. Along the same lines, A. Ige *et al.* (2024) demonstrated that the implementation of cyber risk defence strategies required the alignment of technical solutions with organisational processes and human resource capabilities. This conclusion completely coincided with the results obtained, which confirmed the necessity of a systemic approach wherein technological innovations were supported by managerial mechanisms.

Recent empirical data also pointed to a critical gap between theoretical advancements and practical implementation. M. Nachaat *et al.* (2023) noted that energy enterprises faced barriers such as high implementation costs, a lack of technical expertise, and organisational inertia. Results fully aligned with these observations, confirming that the transition from the technological potential of AI to its practical application was significantly constrained by structural and managerial factors. Similarly, O. Degtiareva *et al.* (2024) highlighted the limited integration of AI-based cybersecurity tools into operational processes, particularly in regions with economic constraints. The findings of the study coincided with this position; however, a specific mechanism to overcome this issue through the implementation of a comprehensive risk management framework was also proposed.

Despite the alignment of results with the conclusions of the aforementioned scholars in specific aspects, the comparative analysis revealed a fundamental limitation in the existing literature. Most prior studies tended to examine technological, infrastructural, or policy-related aspects in isolation, without adequately addressing their interdependencies. In contrast to this fragmented approach, the results of current research substantiated the need for an integrated analytical framework. The model extended existing approaches by explicitly linking AI capabilities with structured risk management processes (including risk identification, assessment, mitigation, and continuous monitoring) within a unified conceptual model of digital resilience. Thus, the results of this work confirmed that the future development of energy systems required a paradigm shift from isolated technological solutions toward comprehensive, risk-oriented management models that balanced innovation, institutional governance, and human capital development in the face of hybrid threats.

Conclusions

The study demonstrates that the sustainable development of modern energy systems is fundamentally dependent on minimising operational and systemic risks associated with cyber threats. Any destabilisation of critical energy infrastructure significantly reduces both the environmental and economic efficiency of the sector, thereby confirming that cybersecurity has become an integral component of sustainable energy governance. The research results indicate that the implementation of intelligent technologies, particularly AI-based systems, plays a key role in strengthening innovation-driven management in the energy sector. At the same time, the increasing digitalisation of energy infrastructure leads to higher exposure of information and communication systems to a wide range of cyberattacks. Once deployed, such systems remain continuously vulnerable to external interference, which makes resilience and survivability essential characteristics of modern energy information systems. It has been established that ensuring the stable functioning of energy infrastructure under adverse and uncertain conditions requires a systemic approach to digital resilience management. This approach integrates technological, organisational, and strategic components into a unified governance framework. Effective cybersecurity governance must clearly define responsibilities across all management levels, ensuring coordination in cybersecurity operations, business continuity planning, and incident response mechanisms.

The study highlights the importance of combining continuous monitoring, real-time threat detection, and predictive analytics with structured risk assessments and scenario-based testing. Such integration enhances the adaptive capacity and robustness of energy systems. Additionally, human-centred measures, including training, awareness programs, and adaptive operational procedures, significantly reduce vulnerabilities caused by human factors. Empirical evidence from Ukraine confirms that the combined application of technological solutions, organisational coordination, and strategic management enables energy systems to maintain functionality even under extreme conditions. In this context, AI-based tools for anomaly detection and predictive control further strengthen proactive risk management within energy enterprises. Future development of energy systems should be based on an integrated resilience-oriented approach, where digital security is embedded into overall sustainability strategies. The formation of a resilience ecosystem, supported by standardised indicators, AI-driven mitigation mechanisms, and international cooperation frameworks, is essential for ensuring the stability and security of interconnected global energy networks.

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Conflict of Interest

None.

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Ризик-орієнтоване управління продуктовими AI-рішеннями в енергетичній галузі

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Анотація. Інноваційні ініціативи, пов'язані зі штучним інтелектом, в енергетичному секторі традиційно розглядалися як джерела організаційної складності та потенційної вразливості. Метою дослідження було проаналізувати взаємодію між енергетичною безпекою та стійкістю енергетичних систем, дослідити нові ризики, пов'язані з цифровізацією та впровадженням інтелектуальних систем, а також оцінити управлінські та політичні заходи, необхідні для ефективної інтеграції штучного інтелекту в енергетичну інфраструктуру. Для досягнення поставлених цілей використано джерела з відкритим доступом та застосовано інтегрований підхід, що поєднує загальнонаукові й спеціалізовані методи дослідження з акцентом на передові аналітичні, моніторингові та автоматизовані технології. Результати дослідження підкреслюють важливість інвестування в технологічний, людський та регуляторний потенціал для повного використання потенціалу штучного інтелекту. Водночас роль інструментів на базі штучного інтелекту в сучасних енергетичних системах зростає завдяки їхньому внеску в

цифрову стійкість, операційну стабільність, прогнозне обслуговування, кібербезпеку та прийняття стратегічних рішень. Однак ці розробки супроводжуються відповідними ризиками. Саме тому сучасна система управління повинна еволюціонувати від адміністративної та контрольно-орієнтованої функції до інтелектуального аналітичного механізму, який інтегрує людський досвід з алгоритмічним прийняттям рішень. Таким чином, цифрова стійкість розширює концепцію стійкості системи, інтегруючи інформаційні технології та аналітику на основі штучного інтелекту для передбачення, поглинання та відновлення після збоїв, спричинених фізичними, технологічними чи кіберінцидентами. Ця інтеграція зменшує суб'єктивність, підвищує точність операційних рішень та забезпечує прозорий, адаптивний та науково обґрунтований підхід до стратегічної координації. Поєднуючи передову аналітику, автоматизацію на основі штучного інтелекту та проактивне управління ризиками, енергетичні системи можуть досягти підвищеної стабільності, експлуатаційної надійності та стійкості до кібербезпеки у все більш складних та цифрово взаємопов'язаних середовищах. Крім того, використання передового світового досвіду та сприяння транскордонній співпраці в галузі інновацій у сфері штучного інтелекту та кібербезпеки може прискорити трансформацію енергетичних підприємств у напрямку стійких, інтелектуальних та стійких інфраструктур

Ключові слова: цифрове середовище; кіберризики; інвестиції; продакт менеджмент; стратегічне планування; управління проектами; операційний ризик

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The use of Open Data for strategic planning of machine-building enterprises in the context of innovative and sustainable development

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Abstract. The relevance was determined by the increasing importance of the machine-building industry in promoting innovative development, strengthening national economic competitiveness, and supporting integration into global value chains. Under conditions of digital transformation and the transition toward sustainable development during 2020-2025, the use of openly accessible data emerged as an important instrument for improving the effectiveness of strategic planning at industrial enterprises. The aim was to investigate the potential of openly accessible data for increasing the effectiveness of strategic planning in machine-building enterprises under conditions of innovation and sustainable development. The study was based on statistical and analytical data from the State Statistics Service of Ukraine, Eurostat, the World Bank, the OECD, UN Comtrade, and WIOD. The methodological framework included general scientific and specialised methods, namely analysis and synthesis, comparative and statistical analysis, systemic and structural-logical approaches, economic and analytical methods, as well as strategic assessment instruments for evaluating political, economic, social, technological, strengths, weaknesses, opportunities, and threats factors. The results demonstrated that the use of openly accessible data significantly improved the informational support of strategic decision-making and contributed to greater adaptability of enterprises to changing market conditions. An algorithm for strategic planning of machine-building enterprises based on data integration and analytical processing was developed and substantiated. A strategic development map for the industry was designed, reflecting interconnections among financial, production, innovation, customer-oriented, and environmental priorities. The study also assessed the development indicators and structural characteristics of Ukraine's machine-building industry in 2020-2025 and identified its development prospects in the context of European integration and digital modernisation. In addition, the findings confirmed that integrating external data resources into enterprise management strengthened forecasting capabilities, supported evidence-based planning, and increased long-term sustainability and competitiveness. The practical significance of the study consisted in providing methodological and analytical support for managers and policymakers to improve strategic decision-making and enhance the resilience and innovative capacity of machine-building enterprises

Keywords: industrial management; publicly available datasets; evidence-based decision-making; technological modernisation; enterprise competitiveness; digital economy; industrial innovation

Introduction

The machine-building industry continues to be one of the key sectors shaping economic development in the period of industrial and technological transformation of 2020-2025 at both global and national levels. It plays a crucial role in ensuring the production of technological equipment, fostering industrial innovation, and supporting the modernisation of nearly all sectors of the economy. During 2020-2025, its importance increased significantly due to intensifying global competition, rapid digitalisation, and the growing emphasis on sustainable development principles. At the same time, the industry operates under a number of challenges, particularly those related to improving production efficiency,

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adopting advanced technologies, and meeting environmental standards. As noted in recent studies, the manufacturing sector is among the major contributors to environmental impact, which makes the transition to sustainable production models and the integration of Industry 4.0 concepts especially relevant (Kannan *et al.*, 2023).

Under these conditions, machine-building enterprises need to reconsider traditional approaches to strategic planning. Effective strategic planning, aligned with current economic trends, allows firms to achieve long-term competitive advantages, respond more flexibly to external changes, and improve resource utilisation. Moreover, as J. Dhlamini (2025) argued, strategic planning continues to be a critical management tool even in highly dynamic environments, as it supports not only strategy formulation but also its practical implementation. In the context of digital transformation, strategic planning is increasingly becoming data-driven. This shift significantly enhances the quality and validity of managerial decisions. In particular, the use of Open Data is gaining growing attention as a valuable source for analytics and forecasting. Open Data provide access to large volumes of information that can improve transparency, stimulate innovation, and increase organisational efficiency. C. Pascu & J.-C. Burgelman (2022) emphasised that Open Data form the foundation of modern scientific and innovation systems, contributing to knowledge creation, research reproducibility, and the integration of artificial intelligence into decision-making processes. Therefore, Open Data can be considered an essential element in the development of data-driven management approaches.

A review of academic literature published in 2021-2025 shows a steady increase in interest in the role of data in strategic management within machine-building enterprises. For instance, A. Romsdal *et al.* (2025) analysed data quality issues in production planning and demonstrated that, despite the widespread use of ERP systems, companies often rely on additional tools such as spreadsheets to maintain flexibility. Their findings suggest that insufficient data quality and delayed updates can significantly reduce the effectiveness of both strategic and tactical planning, highlighting the need for more robust data management practices. Similarly, M. Tahiduzzaman *et al.* (2025) explored the application of Open Data in optimising production processes. Their results indicated that the use of Open Datasets can improve the accuracy of optimisation models and enhance overall production performance. At the same time, the authors point out that the limited availability of structured Open Data remains a significant barrier to the broader adoption of data-driven approaches in the industry. This issue underlines the importance of developing appropriate Open Data infrastructures for industrial applications. Further insights are provided by J. Baecker *et al.* (2025), who focused on the formation of data strategies in modern enterprises. They identify key types of value creation based on data, including efficiency improvement, innovation development, new product creation, and market control. Their analysis shows that the strategic use of data not only strengthens competitive positions but also supports adaptation to rapidly changing market conditions.

In addition, M.F. Mubarak *et al.* (2025) examined the role of strategic foresight and knowledge management in fostering open innovation. Their empirical findings suggest that integrating external data and knowledge into internal processes can significantly improve the effectiveness of new product development. This confirms the growing importance of open information sources as a driver of innovation and competitiveness. B.M. Rodrigues (2025) also highlighted the impact of data analytics and digital technologies on production planning within the framework of data-driven manufacturing management. The study demonstrates that the use of integrated data systems, predictive analytics, and digital platforms contributes to better alignment between strategic and operational goals, while also reducing costs and improving efficiency. Overall, the findings indicate that adopting a data-driven approach is no longer optional but a necessary condition for maintaining competitiveness.

Thus, the analysis of studies published in 2021-2025 suggests that the use of Open Data represents a promising direction for improving strategic planning in machine-building enterprises. However, several issues remain unresolved, particularly those related to data accessibility, quality, and integration, which require further investigation. The aim of this article is to explore the potential of Open Data in enhancing the effectiveness of strategic planning in machine-building enterprises under conditions of innovation and sustainable development. To achieve this aim, the study addressed the following objectives: to assess the current state and development trends of the machine-building industry using open statistical and analytical datasets; to identify the methodological foundations and key stages of strategic planning in industrial enterprises through the application of systemic and comparative analysis; to determine the analytical potential of Open Data for supporting managerial decision-making at different stages of strategic planning; and to develop and substantiate a practical framework for integrating Open Data into the strategic management process of machine-building enterprises, including environmental assessment, strategy formulation, implementation, monitoring, and adaptation. The accomplishment of these objectives enabled the development of a strategic planning algorithm and the identification of practical directions for applying data-based approaches to improve enterprise competitiveness and long-term sustainability.

Materials and Methods

The methodological framework of this study was based on an interdisciplinary approach integrating the principles of strategic management, digital transformation, data-informed managerial decision-making, and sustainable development. The application of a comprehensive methodological approach ensured the scientific validity, analytical consistency, and reproducibility of the research outcomes and complied with contemporary academic standards.

The empirical basis of the study was formed using open statistical and analytical data from national and international organisations. The research relied on publicly available datasets obtained from the State Statistics Service of Ukraine (n.d.), Eurostat (n.d.), the World Bank (n.d.), the OECD (n.d.), the United Nations (2021), and the World input-output database (n.d.). These sources were selected because they provide standardised, internationally comparable, and regularly updated indicators necessary for assessing macroeconomic conditions, industrial performance, foreign trade, and participation in global value chains. The use of open datasets corresponded to the principles of transparency and reproducibility in scientific research (OECD, 2023; Pascu & Burgelman, 2022).

The study covered the period from 2020 to 2025. This time horizon was selected because it allowed capturing several consecutive stages of industrial transformation: the effects of post-pandemic recovery beginning in 2020, structural disruptions caused by geopolitical challenges and military impacts in 2022-2023, and the early phase of economic stabilisation and recovery expected for 2024-2025. Such a period enabled the assessment of both short-term fluctuations and medium-term strategic changes affecting machine-building enterprises. The information base included statistical databases, analytical reports of international organisations, official government portals, and scientific publications. To ensure the reliability and comparability of open data, a triangulation procedure was applied through cross-verification of indicators obtained from multiple independent sources. Data consistency was checked using harmonised statistical classifications and methodological descriptions provided by official institutions. Indicators measured in different units were standardised into relative indicators, growth rates, indices, and percentage values to ensure comparability across countries and periods.

The methodological framework combined general scientific and specialised research methods. Methods of analysis and synthesis were applied to systematise theoretical approaches to strategic planning and to identify the role of open data in enterprise management (Bryson, 2017; Grant, 2021). Comparative analysis was employed to benchmark Ukraine's machine-building industry against selected European Union countries, while statistical analysis was used to assess macroeconomic and sectoral dynamics based on open datasets. The comparative analysis included Germany, Poland, Czechia as reference countries due to their different levels of industrial specialisation, technological intensity, export orientation, and relevance for Ukraine's economic integration processes. The comparison was conducted according to the following criteria: the share of machine-building in industrial production, the share of high-technology manufacturing, research and development expenditure as a percentage of gross domestic product, export orientation of production, and indicators reflecting digital transformation and industrial modernisation.

The systemic approach ensured a comprehensive examination of relationships among economic, technological, social, and environmental factors influencing the development of machine-building enterprises. The structural-logical method was used to organise the sequence of strategic planning stages and to substantiate the integration of open data into managerial processes. Economic and analytical methods supported the interpretation of quantitative indicators and facilitated the formulation of evidence-based managerial conclusions. Strategic analysis tools occupied a central place in the study. Political, Economic, Social, and Technological analysis was applied to assess external conditions affecting machine-building development. The political dimension included indicators related to industrial policy, regulatory changes, state support measures, and European integration processes based on data from the OECD (n.d.) and the European Commission (2023). Economic factors were evaluated using gross domestic product growth, inflation, foreign direct investment, industrial production, and export indicators derived from the World Bank (n.d.), Eurostat (n.d.), and the State Statistics Service of Ukraine (n.d.). Social factors included employment levels, laubor market indicators, demographic trends, and workforce qualifications obtained from Eurostat (n.d.) and the OECD (n.d.). Technological factors were assessed using indicators of digitalisation, innovation activity, research and development expenditures, and technology implementation derived from Eurostat (n.d.), the OECD (n.d.), and McKinsey & Company (2022).

SWOT analysis was performed to integrate external and internal assessment results. Internal factors (strengths and weaknesses) were selected according to production performance, export capacity, innovation activity, technological readiness, labour productivity, and resource efficiency indicators. External factors (opportunities and threats) were identified through the analysis of macroeconomic trends, digital transformation processes, environmental requirements, international market conditions, and geopolitical challenges. Factor selection was conducted according to three criteria: strategic relevance for machine-building enterprises, statistical support from open data sources, and consistency across at least two independent datasets.

Trend analysis and forecasting methods were additionally employed to estimate development prospects for the period 2024-2025. Forecasting was performed using trend extrapolation based on historical indicator dynamics for 2020-2024 and scenario analysis involving baseline, recovery, and optimistic scenarios. The forecast considered changes in industrial production, exports, investment activity, and macroeconomic conditions and was additionally compared with projections from international analytical sources. Methods of generalisation and data visualisation were applied to structure statistical information and facilitate the interpretation of analytical findings. Their application was intended to support the identification of development tendencies, improve the clarity of analytical interpretation, and strengthen the methodological basis for strategic assessment. Data processing and analytical procedures were conducted using Microsoft Excel for statistical

calculations and database integration, Microsoft Power BI for visualisation and dashboard construction, and open analytical platforms and official statistical portals for data verification and comparative assessment. The use of digital analytical tools contributed to increasing transparency in data processing and supporting evidence-based analysis within the research framework. Thus, the selected materials and methods ensured a comprehensive and systematic investigation of the use of Open Data in strategic planning and created methodological conditions for evaluating their applicability in supporting innovative and sustainable development of machine-building enterprises under digital transformation conditions.

Results and Discussion

Strategic planning during the period of industrial transformation in 2020-2025 is one of the key prerequisites for ensuring the long-term competitiveness of machine-building enterprises in the context of economic system transformation, intensifying global competition, and the growing role of innovation (Bryson, 2017). The strategic planning process of a machine-building enterprise is a systematic process of defining long-term objectives, developing the means to achieve them, and ensuring the efficient use of resources in a dynamic market environment (Grant, 2021). The specificity of the machine-building industry is determined by its high capital intensity, long innovation cycles, complexity of technological processes, and significant dependence on macroeconomic and political factors (European Commission, 2023).

In the context of sustainable development, strategic planning at machine-building enterprises involves the integration of economic, environmental, and social dimensions (United Nations, 2021). This implies that, alongside traditional objectives such as profitability and market expansion, it is necessary to consider resource efficiency, reduction of environmental impact, human capital development, and social responsibility. The effectiveness of strategic planning largely depends on the quality of information support used in managerial decision-making (McKinsey & Company, 2022). One of the key sources of such information is Open Data – data that are freely available for use, processing, and dissemination. For machine-building enterprises, Open Data serve as an important source of information for analysing market trends, assessing the competitive environment, identifying investment opportunities, monitoring public policy, and evaluating environmental risks. The strategic planning process involves the implementation of interrelated stages, among which the key ones include environmental analysis, goal setting, and strategy selection (Grant, 2021). The use of Open Data at the analysis stage makes it possible to obtain up-to-date information on markets, competitors, and technological trends (OECD, 2023). Based on the results of the analysis, strategic objectives are formulated, which should meet the criteria of measurability, achievability, relevance, and time-boundedness (Project Management Institute, 2021). The final stage involves the development of strategic alternatives and the selection of the optimal development strategy for the enterprise. Figure 1 presents the algorithm of strategic planning at machine-building enterprises under the conditions of Open Data utilisation.

Open Data play an important role in shaping industrial policy by providing access to information on industry conditions, innovation activity, and environmental performance (OECD, 2023). This contributes to more informed decision-making and better coordination between government and business. The figure presents a step-by-step algorithm for the formation and implementation of enterprise strategic decisions based on data. The first stage involves data acquisition and integration, including the collection of Open Data from external sources (government registers, statistical databases, international platforms) as well as internal enterprise data. At this stage, data are harmonised and integrated into a unified data management system, forming the informational foundation for further analysis.

The second stage focuses on data analytics and environmental assessment. Modern analytical tools (SWOT, PEST), business intelligence systems, and predictive models are applied to identify trends, patterns, and potential changes. Based on this analysis, strategic challenges and opportunities are determined, including the identification of market trends, technological drivers, risk assessment, and the formulation of strategic goals in accordance with the SMART approach. The subsequent stages involve the development of strategic alternatives and the selection of the optimal strategy. Various development options (innovation, diversification, digital transformation, sustainability) are generated and evaluated using economic indicators (NPV, ROI), as well as risk and feasibility assessments. The selection of the most appropriate alternative is carried out using multi-criteria decision-making methods and is grounded in an evidence-based, data-driven approach. The final stages cover strategy implementation as well as monitoring, evaluation, and adaptation. Action plans, programs, and projects are developed; resources are allocated; and key performance indicators (KPIs) are established. In addition, digital monitoring of implementation processes is ensured. A feedback loop enables continuous strategy adjustment based on updated data, ensuring flexibility and adaptability in a dynamic environment.

The proposed approach ensures comprehensiveness and integrates data-driven management with strategic planning. Unlike classical models, the proposed algorithm combines the processes of collecting large volumes of open and internal data with analytical tools and decision-making mechanisms within a unified, closed-loop system. Its novelty also consists in incorporating continuous digital monitoring and an adaptive feedback loop, which enables not only the formulation of strategy but also its dynamic adjustment under conditions of uncertainty and rapid environmental change. This approach enhances the validity of managerial decisions and contributes to achieving long-term enterprise sustainability. The Use of Open Data in

strategic planning of machine-building enterprises involves the integration of national and international information resources, providing access to up-to-date macroeconomic, sectoral, and structural indicators (State Statistics Service of Ukraine, n.d.; Eurostat, n.d.; World Bank, n.d.). Global value chain databases, such as OECD TiVA (OECD, n.d.), UN Comtrade, and the WOID (World input-output database, n.d.), also play a significant role.

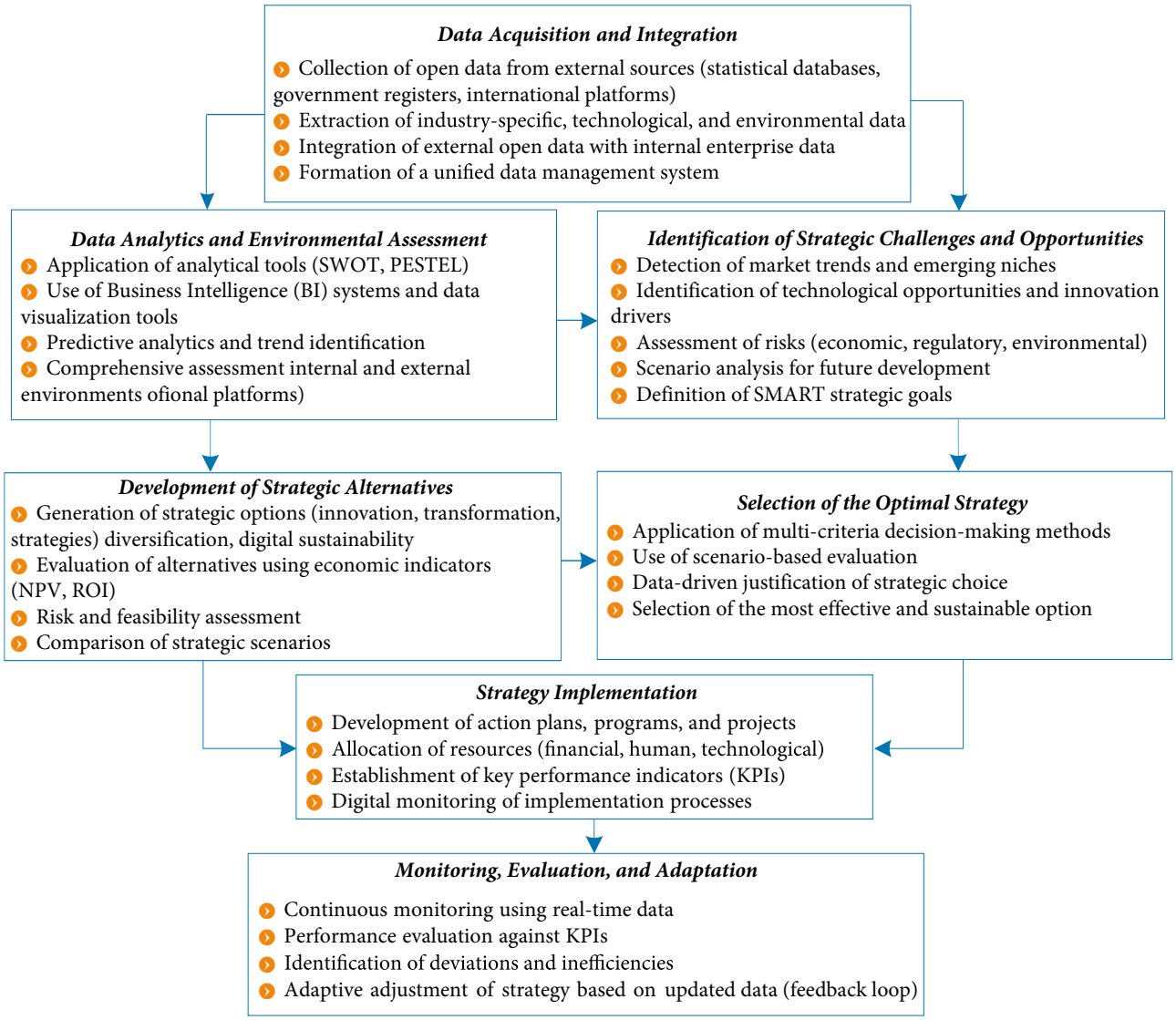

Figure 1. Algorithm of strategic planning at machine-building enterprises under conditions of Open Data utilisation
Source: developed by the author

National statistical resources provide the fundamental informational basis for assessing the state of the machine-building sector in Ukraine. Data from the State Statistics Service of Ukraine cover industrial production indicators, product sales volumes, exports, the number of enterprises, and employment levels. Using data from the State Statistics Service of Ukraine in strategic planning enables the assessment of domestic market capacity, its structural characteristics, market saturation levels, and growth potential. Analysis of key indicator dynamics allows for understanding production cycles, technological structure changes, and enterprise innovation activity. These data also facilitate competitive environment analysis, including the evaluation of the number of market participants, market concentration, and positions of key players. Additionally, they form a basis for economic forecasting and scenario modelling, increasing the validity of strategic decisions in a dynamic external environment.

Particularly relevant in the context of European integration is the possibility of conducting comparative analyses of Ukraine's machine-building development relative to selected European Union countries and aggregated EU averages using Eurostat (n.d.) data. In this study, the comparison was conducted with Germany, Poland, Czechia, and the EU average indicators, as these countries represent different models of industrial development and varying

levels of integration into European manufacturing value chains. Germany was selected as the benchmark of high-tech industrial leadership in Europe; Poland and Czechia were included due to their comparable industrial specialisation, historical transformation trajectories, and active participation in regional manufacturing networks. Such a comparative approach makes it possible not only to identify quantitative differences in industrial structure and innovation activity but also to determine strategic gaps and opportunities for Ukraine's machine-building sector. The use of standardised Eurostat indicators ensures methodological comparability of results and strengthens the analytical validity of cross-country benchmarking within the strategic planning framework.

The macroeconomic environment, shaped in particular by analytical and statistical data from the World Bank (n.d.), plays a significant role in shaping the strategic priorities of mechanical engineering enterprises. The systematic use of open macroeconomic indicators-covering GDP dynamics, inflation trends, investment activity, employment levels, and external economic parameters-provides a comprehensive informational basis for understanding broader economic trends. This, in turn, enables enterprises to more accurately identify potential risks and opportunities, assess the degree of macroeconomic instability, and take into account the cyclical nature of economic development. Moreover, the use of such data supports the development of alternative growth scenarios that consider various changes in the external environment, which is particularly important under conditions of uncertainty and global challenges. The integration of Open Data into strategic planning processes also enhances the validity of managerial decisions, ensuring their adaptability and alignment with the long-term goals of sustainable enterprise development.

Critically important Open Data sources are international databases reflecting global value chains. These allow enterprises to assess not only domestic production structures but also integration into international economic processes. Resources such as OECD TiVA (OECD, n.d.), UN Comtrade, and WIOD enable analysis of component composition, geographical distribution, and dependence on imported inputs, which is especially relevant for high-tech industry segments. Information from global databases allows enterprises to: identify bottlenecks and supply chain risks, e.g., dependency on certain suppliers or countries affecting production stability and costs; plan supplier diversification and production localisation, using global trade flow analyses to strategically relocate production capacities and reduce disruption risks; identify new markets and partnerships, leveraging export-import data to forecast product demand, develop partnerships, and integrate into international manufacturing networks; enhance competitiveness in high-tech segments, by evaluating opportunities to enter high value-added and innovative sectors.

Global Data is particularly significant for transitioning to Industry 4.0 and data-driven production, providing the information foundation for predictive analytics, logistics optimisation, inventory management, and strategic selection of technological solutions. For Ukrainian enterprises gradually integrating into European and global production networks, access to Open Data on supply chains becomes a key tool to reduce dependency on imported components and improve production efficiency. The further development of strategic planning for machine-building enterprises under the conditions of active use of Open Data requires the formation of a systematic methodology for their analytical processing. Such an approach should be based on the integration of modern strategic analysis tools that ensure the transformation of Open Data sets into relevant managerial decisions (OECD, 2023; European Commission, 2023). The use of Open Data in strategic planning should be implemented through the step-by-step application of a set of analytical tools, among which PEST analysis, SWOT analysis, trend and forecasting analysis, and data visualisation methods occupy a central position. The initial stage involves conducting a PEST analysis, which enables a comprehensive assessment of the impact of external environmental factors on the functioning of machine-building enterprises based on Open Data sources.

Within the political dimension (P – political), Open Data provides opportunities to analyse industrial policy, the regulatory environment, innovation support programs, and integration processes with the European Union. In particular, the use of governmental portals and international data resources ensures monitoring of changes in the regulatory framework that determine industry conditions (European Commission, 2023). The economic dimension (E – economic) is based on the analysis of macroeconomic indicators, including GDP dynamics, inflation processes, investment activity, and foreign trade indicators. The use of Open Data from international organisations allows enterprises to identify the phase of the economic cycle and assess the level of effective demand and investment attractiveness of the industry (World Bank, n.d.). Social factors (S – social) include the analysis of the labour market, employment levels, workforce qualifications, and demographic trends. The use of Open Data in this context contributes to assessing the availability and quality of human capital, which is critically important for high-tech production (OECD, 2023). The technological dimension (T – technological) involves assessing the level of digitalisation, innovation activity, R&D expenditures, and the implementation of Industry 4.0 technologies. Based on international Open Databases, enterprises can identify global technological trends and evaluate their competitive positions (McKinsey & Company, 2023).

At the same time, the technological component should not be interpreted solely as a set of production upgrades or isolated digital initiatives. In the context of contemporary machine-building development, technology acts as a systemic factor that determines the adaptability of enterprises to external economic turbulence and the speed of integration into global value chains. Open Data sources provide an opportunity not only to monitor technological indicators

but also to identify structural changes in industrial development patterns, shifts in investment priorities, and emerging technological niches with high growth potential. For the Ukrainian machine-building industry, technological transformation acquires strategic importance due to the necessity of increasing production flexibility, reducing resource intensity, and improving resilience under conditions of heightened uncertainty. The analysis of open international databases enables enterprises to compare their technological maturity with international benchmarks, identify critical gaps in automation, robotics, digital infrastructure, and engineering capabilities, and determine priority directions for modernisation.

An authorial interpretation of the technological factor suggests considering technological development as a multidimensional category that combines not only innovation capacity but also the ability of enterprises to absorb and scale external knowledge. In this context, digital transformation becomes an instrument for strengthening competitive sustainability rather than an end in itself. The implementation of cloud technologies, industrial analytics, predictive maintenance systems, artificial intelligence solutions, and integrated production management platforms creates conditions for increasing operational efficiency and improving decision-making quality. Furthermore, the use of Open Data significantly expands the analytical capabilities of enterprises by enabling continuous monitoring of patent activity, technological investments, industrial productivity, export specialisation, and innovation ecosystems across countries and regions. Such an approach supports a transition from reactive management practices toward predictive and evidence-based strategic planning. Consequently, the technological dimension within the PEST framework serves not only as a diagnostic element but also as a foundation for forming long-term development trajectories of machine-building enterprises. The results of the PEST analysis of the machine-building industry of Ukraine are summarised in Figure 2.

P	*E*	*S*	*T*
◦ Martial law and geopolitical leading to destruction instability the production capacities and disruption of supply chains; ◦ Active government support for the defense-industrial complex, stimulating the growth of specific machine-building segments; ◦ Ukraine's European integration course, providing access to EU markets and financial support in struments; ◦ Strengthening of the state's role in demand formation (public procurement as a key industry driver).	◦ Economic recovery after the 2022 crisis, albeit at a moderate GDP growth in 2025); of pace (approximately 2% ◦ Low level of investment (6-8% of GDP), insufficient for industry modernization; ◦ Increase in the share of machine building in industry to approximately 9.1% in 2025; ◦ High dependence on imports of technological components.	◦ Reduction in labor resources (employment decreased by to migration and approximately 20% due mobilization); ◦ Shortage of qualified engineering personnel; ◦ Increasing importance of human capital in high-tech segments.	◦ Accelerate d implementation Industry of 4.0 seg ments; technologies in certain ◦ Development of defense and dual-use technologies; ◦ Low level of R&D funding compared to the EU; ◦ Digitalization of production processes and logistics

Figure 2. Results of the PEST analysis of the machine-building industry of Ukraine based on Open Data
Source: developed by the authors

The obtained results demonstrate that external environmental factors exert a differentiated influence on the development of machine-building enterprises and require integrated interpretation rather than isolated assessment. Political and regulatory conditions shape the institutional framework for industrial activity, economic factors determine investment capacity and market dynamics, social changes influence labour potential and demand structure, while technological factors define opportunities for modernisation and long-term competitiveness. Therefore, the practical value of PEST analysis lies not only in identifying key trends but also in revealing interdependencies between external drivers that collectively influence strategic decisions. From the author's perspective, the application of Open Data in conducting PEST analysis increases the objectivity and reproducibility of analytical conclusions, reducing dependence on subjective expert judgments. Unlike traditional approaches, the integration of publicly available international and national datasets enables dynamic updating of assessments and supports continuous strategic monitoring. This is particularly relevant for the Ukrainian machine-building sector, where rapid changes in external conditions require flexible analytical instruments and regular revision of development priorities. The next stage involves conducting a SWOT analysis based on Open Data, which ensures the integration of external and internal environmental analysis results. The summarised results of the analytical procedures are presented in Figure 3.

Strengths	*Weaknesses*
◦ High adaptive capacity of the industry: in 2023, production increased by 57.6% following the decline in 2022; ◦ Development of defense machine building . (production increased several-fold); ◦ Availability of a strong engineering school. and established production competencies; ◦ Integration into alobal value chains.	◦ High depreciation of fixed assets; ◦ Low levels of investment and innovation; ◦ Dependence on imported components (imports reached up to $16 billion in 2022); ◦ Logistical constraints and destruction of infrastructure
Opportunities	***Threats***
◦ Integration into the EU market; ◦ Development of defense and high-tech manufacturing; ◦ Attraction of international financial assistance; ◦ Development of digital manufacturing platforms.	◦ Prolonged war and security risks; ◦ High level of global competition; ◦ Instability of the investment environment; ◦ Outflow of human capital.

Figure 3. Results of the SWOT analysis of the machine-building industry of Ukraine based on Open Data
Source: developed by the author

The synthesis of PEST and SWOT analysis results makes it possible to form a comprehensive vision of the current state and development prospects of the machine-building industry in Ukraine. The study indicates that the industry is in a phase of structural transformation, combining recovery processes with technological modernisation. Despite significant external risks, existing internal capacities and opportunities create preconditions for further development. At the same time, achieving sustainable economic growth requires overcoming internal constraints, primarily through intensifying investment activities, fostering innovation, and developing human capital. In this context, the use of Open Data serves as an important tool for improving the validity of strategic management decisions and shaping an effective model for industry development (OECD, 2023).

Table 1 presents the dynamics of the main indicators of Ukraine's machine-building industry for the period 2020-2025. Analysis of the dynamics indicates that the machine-building industry in Ukraine experienced significant fluctuations due to macroeconomic and geopolitical factors. A particularly sharp decline occurred in 2022, associated with war-related risks and destruction of production capacities. Data for 2024-2025 indicate gradual sectoral recovery, with positive trends in industrial production indices and export growth, reflecting enterprises' adaptation to new operational conditions (State Statistics Service of Ukraine, n.d.). To improve the transparency and analytical validity of the obtained results, the forecast values for 2024-2025 were generated using trend extrapolation combined with scenario-based assessment. The baseline period included statistical observations for 2020-2023 obtained from the State Statistics Service of Ukraine and complemented by analytical estimates of recovery dynamics. Forecast ranges were formed considering three groups of factors: macroeconomic stabilisation indicators, expected export recovery, and gradual adaptation of production systems to wartime and post-war conditions. Instead of deterministic values, interval estimates were applied in order to reflect uncertainty and possible deviations in recovery trajectories. The projected indicators therefore should not be interpreted as exact values but as analytical scenarios illustrating potential directions of industry development under current institutional and economic conditions.

Table 1. Dynamics of indicators of machine-building in Ukraine

Indicator	2020	2021	2022	2023	2024	2025
Industrial production index, %	96.8	107.1	62.4	85-90	95-102	103-108
Share of machine-building in industry, %	10.2	10.8	8.5	9.0	9.5	10.0
Export of machine-building products, USD billion	5.4	6.2	3.8	4.5	5.2-5.6	5.8-6.3
Number of enterprises, in thousands	11.5	11.8	10.2	10.5	10.8	11.0

Note: 2023 – estimates based on open statistical and analytical data; 2024 – preliminary aggregated estimates (recovery trends); 2025 – forecast values based on recovery trends
Source: compiled by the authors based on State Statistics Service of Ukraine (n.d.)

The increase in the number of enterprises in 2024-2025 may indicate the activation of small and medium-sized businesses, the relocation of production, and the emergence of new production capacities. Collectively, these trends lay the groundwork for structural modernisation of the sector, based on digitalisation, innovation, and integration into global value chains. The obtained results demonstrate not only quantitative recovery but also qualitative structural transformation within the industry. Although industrial output and export volumes show positive dynamics in 2024-2025, the recovery process remains uneven and largely dependent on external financing, logistics resilience, and access to technological resources. The slower restoration of the machine-building share in industry compared with production growth may indicate persistent structural imbalances and insufficient expansion of high value-added segments. From the perspective of strategic planning, these findings suggest that future competitiveness should rely not exclusively on restoring production capacities but on accelerating technological modernisation, digital transformation, and deeper integration into European industrial ecosystems. Consequently, Open Data becomes not merely an informational instrument but a strategic resource for continuous monitoring and adaptive managerial decision-making. In EU countries, machine-building is characterised by a high share in GDP (up to 15-20% of industrial production), significant innovation components, and a high level of digitalisation (Industry 4.0). Table 2 presents comparative machine-building indicators (Ukraine vs EU).

Table 2. Comparative machine-building indicators (Ukraine vs EU)

Indicator	Ukraine	EU (average)
Share in industry, %	8-10	15-20
Share of high-tech production, %	5	15-25
R&D expenditure, % of GDP	0.4	2.0-3.0
Export orientation, % of production	50	70-80

Source: compiled by the author on Eurostat (n.d.)

Comparative analysis based on Eurostat data and selected benchmark countries (Germany, Poland, and Czechia) reveals substantial structural differences between Ukraine's machine-building industry and European industrial models. The values presented in Table 2 reflect aggregated EU averages and therefore serve as a generalised benchmark rather than indicators of individual countries. The comparison demonstrates that the gap is particularly visible in technological intensity and innovation investment. While European enterprises maintain higher levels of R&D expenditure and produce a larger share of high-tech output, Ukrainian machine-building remains concentrated in medium- and low-technology production segments. This situation limits productivity growth and constrains integration into high-value global production networks. At the same time, Ukraine's relatively strong export orientation indicates the presence of adaptation potential and opportunities for strengthening international industrial cooperation. Therefore, strategic priorities should focus not only on increasing production volumes but also on improving technological complexity, expanding domestic innovation capacity, and creating institutional conditions for industrial upgrading.

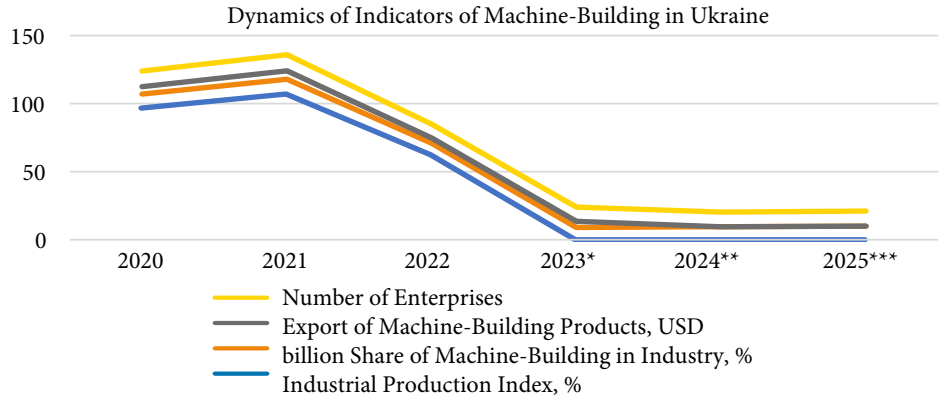

Figure 4. Dynamics of indicators of machine-building in Ukraine

Source: developed by the author based on State Statistics Service of Ukraine (n.d.)

The dynamics presented in Figure 4 indicate that the development trajectory of Ukraine's machine-building industry during 2020-2025 is characterised not only by cyclical fluctuations but also by structural adaptation processes. The sharp decline observed in 2022 reflects the impact of military, logistical, and investment constraints; however, subsequent recovery tendencies suggest increasing resilience and gradual restoration of industrial activity. At the same

time, the uneven pace of recovery across indicators demonstrates that quantitative growth does not automatically imply qualitative modernisation. In particular, the restoration of production volumes and export activity remains accompanied by a relatively slow recovery of the industry's structural position within total industrial output. This indicates the need for strategic reorientation toward technological upgrading and increasing value added. Therefore, the next stage of analysis involves comparing Ukraine's performance with European benchmarks in order to identify development gaps and determine strategic priorities for further integration into European industrial systems.

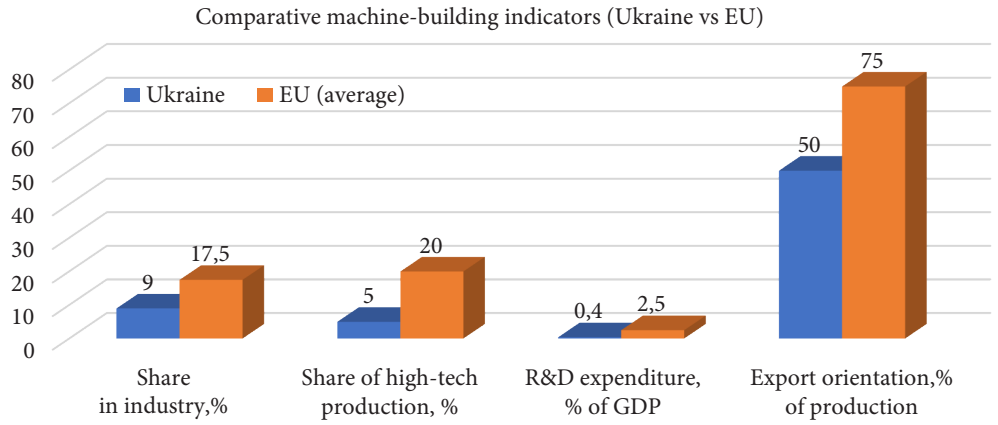

Figure 5. Comparative machine-building indicators (Ukraine vs EU)
Source: Developed by the author on World input-output database (n.d.)

GDP recovery, declining inflation, and increased foreign direct investment in 2023–2025 create favourable conditions for stimulating business activity and modernising machine-building enterprises (Table 3).

Table 3. Macroeconomic Indicators of Ukraine

Indicator	2020	2021	2022	2023	2024	2025
GDP growth, %	-4.0	3.4	-29.1	5.3	4	5
Inflation, %	5.0	10.0	26.6	12-13	8-10	6-8
Foreign direct investment, USD billion	0.2	6.7	-0.2	4.0	4.5-5.5	5.5-7.0
Export of goods and services, % of GDP	40	41	35	38	39-40	40-42

Note: 2024 – preliminary estimates; 2025 – forecast values
Source: compiled by the author based on World input-output database (n.d.)

The indicators reflect the severe economic crisis in 2022, marked by sharp GDP decline, rising inflation, and reduced investment activity. In 2023-2025, gradual macroeconomic stabilisation is observed, including positive economic growth, reduced inflationary pressure, restoration of foreign investment inflows, and stabilisation of foreign trade activity. The identified macroeconomic trends have direct implications for strategic planning in machine-building enterprises. Positive GDP dynamics and investment recovery increase the feasibility of implementing modernisation projects and expanding production capacities. At the same time, the persistence of inflationary pressures and uncertainty in external markets require enterprises to apply flexible planning instruments and scenario-based strategic management. The results also indicate that macroeconomic recovery alone does not automatically ensure industrial competitiveness. Sustainable growth of machine-building enterprises depends on their ability to transform external economic opportunities into internal technological capabilities through investment in innovation, digital infrastructure, and human capital development (Fig. 6). Accordingly, the next stage of the study involves forming a comprehensive vision for the development prospects of the machine-building industry through the design of a strategic map that reflects the key directions of its transformation under conditions of innovative and sustainable development. Such a map serves as an effective strategic management tool, as it ensures a logical interconnection between goals, resources, instruments, and the expected performance outcomes of enterprises. The strategic map for the development of Ukraine's machine-building industry, based on the use of open data, relies on the concept of balanced development and integrates the principles of data-driven management, digital transformation, and sustainable production. It reflects the interdependence among financial, production, innovation, customer, and socio-environmental aspects of enterprise performance, in line with the modern requirements of the global economy and European standards. Figure 7 presents the strategic map for the

development of Ukraine's machine-building industry in the context of Open Data utilisation. The proposed map envisages the transformation of information resources into competitive advantages, thereby enhancing the effectiveness of managerial decision-making and ensuring the long-term sustainability of machine-building enterprises.

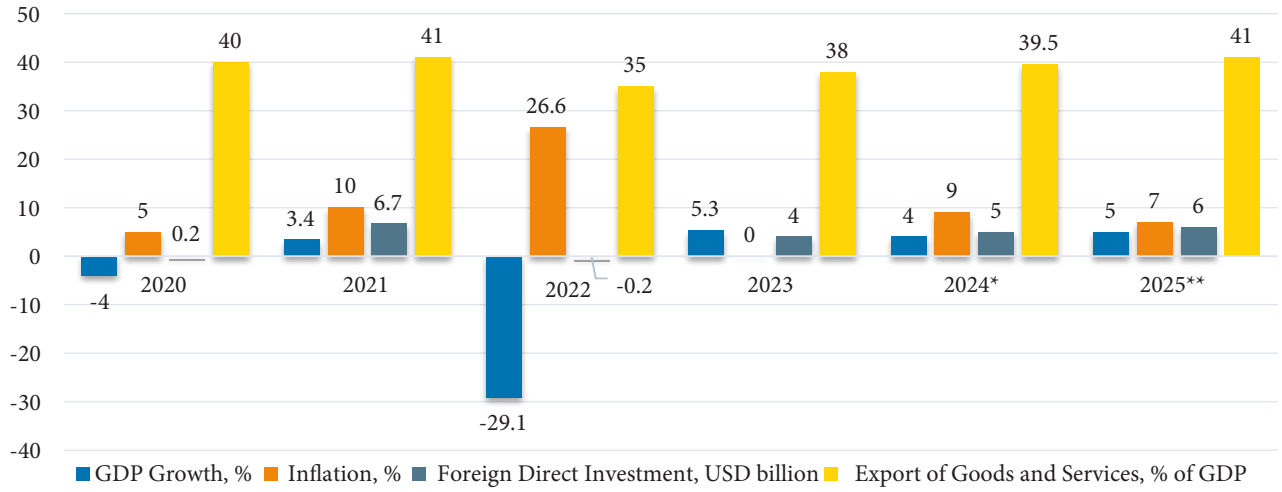

Figure 6. Macroeconomic Indicators of Ukraine
Source: developed by the author based on World input-output database (n.d.)

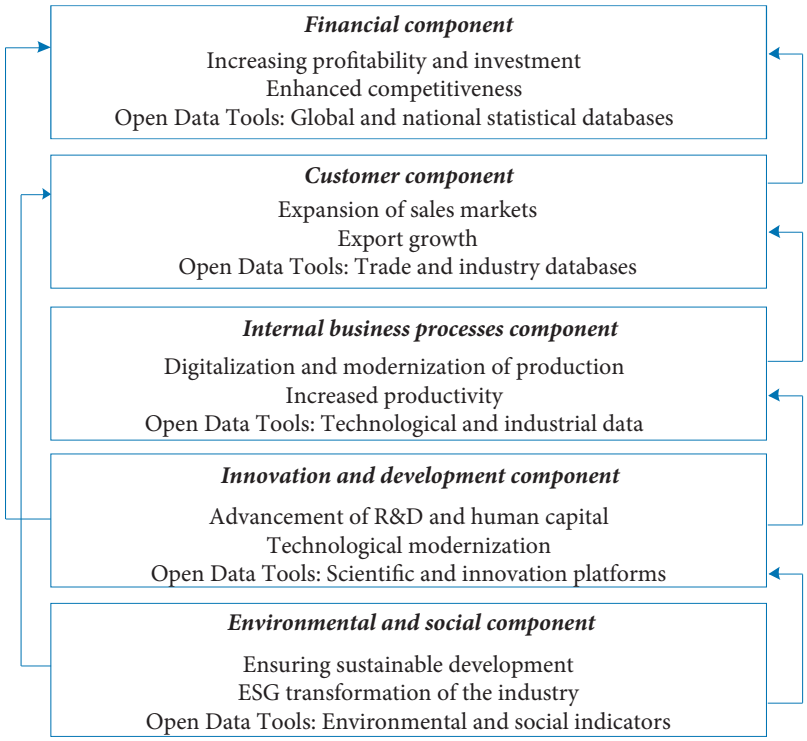

Figure 6. Strategic map for the development of Ukraine's machine-building industry using Open Data
Source: developed by the author

The financial perspective determines the ultimate outcomes of strategy implementation and aims to ensure the economic stability and competitiveness of machine-building enterprises. The primary strategic objectives include increasing profitability, enhancing investment attractiveness, and expanding the export potential of the industry. Accordingly, key strategic priorities involve increasing production and sales volumes, improving profitability, attracting foreign investment, expanding international market presence, and integrating into global value chains. The customer perspective reflects enterprises' orientation toward meeting consumer needs and enhancing product competitiveness in both domestic and international markets. Its key strategic objectives include improving product

quality and technological sophistication, expanding the range of high-tech products, strengthening positions in the European Union market, fostering partnerships and international cooperation, and increasing customer orientation. The internal business processes perspective focuses on improving the efficiency of production and management processes through the implementation of innovations and digital technologies. Key strategic directions include the modernisation of production facilities, the adoption of Industry 4.0 technologies, the digitalisation of manufacturing and logistics, the optimisation of supply chains, the enhancement of energy and resource efficiency, and the implementation of quality management systems.

The innovation and learning perspectives constitute the foundation for the long-term competitiveness of machine-building enterprises. This dimension of the strategic map defines the potential for creating new knowledge and technologies and encourages enterprises to develop research and development (R&D), enhance the digital competencies of personnel, stimulate innovation activity, strengthen cooperation with universities and research institutions, implement artificial intelligence and big data analytics, and utilise open scientific and technological data. In accordance with the principles of sustainable development, the ESG perspective also provides for the integration of ESG principles into the activities of machine-building enterprises. This includes reducing environmental impact, implementing environmentally friendly technologies, improving energy efficiency, promoting the circular economy, ensuring safe working conditions, and enhancing corporate social responsibility. The results of the conducted study confirm the pivotal role of the machine-building industry in fostering innovative development and strengthening economic competitiveness under conditions of digital transformation and sustainable development. The obtained findings demonstrated that the integration of Open Data into strategic planning created additional opportunities for improving environmental assessment, increasing the validity of managerial decisions, and strengthening enterprise adaptability under conditions of uncertainty.

The obtained conclusions correspond with the theoretical position proposed by D.J. Teece (2025), who argued that dynamic capabilities determine the ability of enterprises to respond to environmental changes and maintain sustainable competitive advantages. The findings of the present study extend this argument by demonstrating that the integration of external information resources into strategic planning enhances not only organisational adaptability but also the analytical capacity required for long-term strategic development. The significance of digital transformation for strategic management is also confirmed by P.C. Verhoef *et al.* (2021), who emphasised that digital technologies reshape managerial processes and stimulate the emergence of new business models. Similar conclusions were obtained by K. Schwertner (2017), who demonstrated that digital transformation contributes to higher managerial efficiency and supports organisational sustainability. In the context of the present research, these conclusions were further developed through substantiating the practical role of Open Data as an instrument supporting strategic planning procedures.

The findings are consistent with the conclusions of S. Kraus *et al.* (2022), who identified digital transformation as a critical determinant of industrial sustainability and innovation capacity. Their research primarily focused on organisational readiness for digital change, whereas the present study concentrated on the practical incorporation of open information resources into strategic planning mechanisms and demonstrated their applicability for improving strategic responsiveness. The strategic role of data resources was also emphasised by G. George *et al.* (2021), who characterised data as an important driver of innovation and managerial renewal. Similar observations were made by R. Dubey *et al.* (2020), whose research demonstrated that data analytics positively influences operational performance and resource allocation. Unlike previous studies focused mainly on operational outcomes, the present research showed that Open Data may support not only production efficiency but also strategic forecasting and long-term managerial decision-making.

Comparable conclusions were obtained by S. Wamba *et al.* (2018), who demonstrated that data-oriented management contributes to improving competitiveness and operational effectiveness. The results of this study additionally indicate that the use of external open datasets improves strategic flexibility and facilitates adaptation to changing macroeconomic conditions. The role of external information ecosystems was further examined by S. Nambisan *et al.* (2019), who emphasised that digital platforms and open information exchange create favourable conditions for innovation and strategic renewal. The findings of this research support these conclusions and demonstrate that publicly available international databases can become an important source for strengthening analytical capabilities in industrial enterprises.

The importance of Open Data for innovation systems was also highlighted by C. Pascu & J.-C. Burgelman (2022), who argued that open information environments support knowledge creation and improve decision-making transparency. In comparison with their conceptual approach, the present study focused on practical managerial implementation and proposed a structured algorithm for integrating Open Data into enterprise strategic planning. Recent empirical studies additionally support the relevance of the obtained findings. A. Romsdal *et al.* (2025) demonstrated that insufficient data quality and delayed information updates reduce planning effectiveness in manufacturing systems. The present study complements this conclusion by showing that combining verified external information with internal enterprise data improves strategic assessment and reduces informational uncertainty.

Similarly, J. Baecker *et al.* (2025) identified organisational data strategies as a mechanism for generating competitive advantages and enhancing enterprise performance. The strategic planning algorithm proposed in this

study extends this perspective by integrating Open Data throughout the full strategic cycle, including environmental analysis, strategy formulation, implementation, and monitoring. B.M. Rodrigues (2025) also emphasised that data-driven manufacturing management enables stronger coordination between strategic and operational objectives. The results obtained in this study support these findings and additionally demonstrate that the integration of forecasting procedures and strategic analytics enhances long-term industrial resilience.

Additional support for the obtained conclusions is provided by recent studies on industrial digital maturity. M.P. Hetmanczyk (2024) proposed a methodology for evaluating the maturity of production process automation and demonstrated that sustainable industrial transformation requires not only technological modernisation but also systematic integration of data into managerial processes. These findings reinforce the conclusions of the present study concerning the necessity of combining strategic planning with analytical support mechanisms. Related conclusions were obtained by A.E. Öberg *et al.* (2024), who argued that manufacturing enterprises achieve higher digital readiness when strategic decisions are supported by structured analytical frameworks and continuous assessment of technological capabilities. Overall, the comparison with contemporary scientific literature demonstrated that most previous studies investigated digital transformation, data analytics, and industrial modernisation separately. In contrast, the present study proposed an integrated managerial approach combining Open Data, strategic planning instruments, forecasting procedures, environmental assessment, and strategic mapping within a unified decision-making framework. Such integration contributes to increasing enterprise resilience, supporting sustainable industrial development, and strengthening competitiveness under dynamic economic conditions.

Conclusions

The conducted study confirmed that the machine-building industry remains one of the key sectors influencing innovative development and strengthening the competitiveness of the national economy. It was established that under conditions of globalisation, digital transformation, and increasing attention to sustainable development, the effectiveness of enterprise management increasingly depended on the modernisation of strategic planning approaches and the systematic use of open information resources. The research expanded the theoretical and methodological understanding of strategic planning in machine-building enterprises by substantiating the role of Open Data as an analytical basis for managerial decision-making. Based on the analysis of national and international information resources a comprehensive assessment of industry development conditions and structural changes during 2020-2025 was conducted.

The obtained results demonstrated that the integration of Open Data into strategic planning improved the quality of environmental analysis, increased the validity of strategic decisions, and strengthened the adaptability of enterprises to external changes. In particular, an algorithm for strategic planning of machine-building enterprises under conditions of Open Data utilisation was developed. The proposed algorithm incorporated sequential stages of data collection and integration, analytical processing, environmental assessment, formation of strategic alternatives, implementation of strategic initiatives, and continuous monitoring with feedback mechanisms. The conducted PEST analysis and SWOT analysis identified the main factors influencing the development of Ukraine's machine-building industry and revealed existing structural constraints together with opportunities related to digital transformation and European integration. Comparative analysis with selected European Union countries demonstrated a lower share of high-technology production, lower research and development intensity, and weaker integration into international production chains, which indicated the necessity of technological modernisation and investment support.

A strategic map for industry development was proposed, integrating financial, production, innovation, customer-oriented, and environmental priorities and demonstrating practical directions for applying Open Data at different stages of strategic planning. The practical significance of the study consisted in creating methodological support for managers and policymakers aimed at improving evidence-based decision-making and increasing enterprise resilience. Prospects for further research include the development of quantitative models for evaluating the effectiveness of Open Data implementation in strategic management, the application of artificial intelligence instruments in industrial forecasting, and the assessment of digital maturity and data governance mechanisms in machine-building enterprises under conditions of post-war economic recovery.

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Використання Open Data для стратегічного планування підприємств машинобудування в умовах інноваційного та сталого розвитку

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Анотація. Актуальність була зумовлена зростанням ролі машинобудівної галузі у забезпеченні інноваційного розвитку, підвищенні конкурентоспроможності національної економіки та інтеграції у глобальні виробничі ланцюги. В умовах цифрової трансформації та переходу до сталого розвитку у 2020-2025 роках використання відкритих даних набуло особливого значення як інструмент підвищення ефективності стратегічного планування промислових підприємств. Метою статті було дослідження потенціалу відкритих даних для підвищення ефективності стратегічного планування підприємств машинобудування в умовах інноваційного та сталого розвитку. Дослідження ґрунтувалося на статистичних та аналітичних даних Держстату України, Eurostat, Світового банку, OECD, UN Comtrade та WIOD. Методологічну основу становили загальнонаукові та спеціальні методи дослідження, зокрема аналіз і синтез, порівняльний та статистичний аналіз, системний і структурно-логічний підходи, економіко-аналітичні методи, а також інструменти стратегічного оцінювання політичних, економічних, соціальних і технологічних чинників та аналізу сильних і слабких сторін, можливостей і загроз. Результати дослідження засвідчили, що використання відкритих даних суттєво покращило інформаційне забезпечення стратегічних управлінських рішень і сприяло підвищенню адаптивності підприємств до змін ринкового середовища. Було розроблено та обґрунтовано алгоритм стратегічного планування підприємств машинобудування, заснований на інтеграції даних та їх аналітичному опрацюванні. Сформовано стратегічну карту розвитку галузі, що відображала взаємозв'язки між фінансовими, виробничими, інноваційними, клієнтоорієнтованими та екологічними пріоритетами. Також здійснено оцінювання тенденцій розвитку та структурних характеристик машинобудівної галузі України у 2020-2025 роках та визначено перспективи її розвитку в умовах європейської інтеграції та цифрової модернізації. Крім того, встановлено, що інтеграція зовнішніх інформаційних ресурсів у систему управління підприємствами посилила можливості прогнозування, сприяла прийняттю обґрунтованих рішень та підвищила довгострокову стійкість і конкурентоспроможність підприємств. Практичне значення дослідження полягало у формуванні методичного та аналітичного забезпечення для керівників підприємств і органів державного управління з метою підвищення якості стратегічних рішень та посилення стійкості й інноваційного потенціалу підприємств машинобудування

Ключові слова: промислове управління; загальнодоступні набори даних; обґрунтоване прийняття рішень; технологічна модернізація; конкурентоспроможність підприємств; цифрова економіка; промислові інновації

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The impact of energy-efficient architecture as a driver of economic innovation and fiscal resilience in Ghana

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Abstract. This study aimed to investigate energy-efficient architectural design as a strategic instrument of economic policy and innovation, repositioning it to address Ghana's energy crisis by driving economic innovation and fiscal resilience within the building sector. The survey of 120 registered architects in Ghana (quantitative survey) produced 72 valid responses (60.0% response rate). The methods applied included descriptive statistics, Pearson correlation, multiple linear regression and principal component analysis. Factor analysis indicated that there were two main innovation themes Building Envelope/Orientation (64.4% of variance) and Site Condition decisions (9.2% more variance) with good scale reliability (Cronbachs 0.90). The multi-dimensional outcome construct was confirmed with energy performance items loading on one factor, which explained 80.5% of variance. Five predictors of energy performance were identified by regression, which accounted 81.7% of the variance of energy performance; with passive solar (β = 0.510), natural ventilation (β=0.373), site temperature (β=0.315), daylighting (β=0.284), and site shading (β= =0.175) for a standardised regression coefficient. The main barriers are economic and informational: absence of public knowledge (mean = 3.20/4), and client budget (mean = 3.00/4), which are considered to be high barriers. Key conclusions showed that design innovations have the potential to save 25-50 per cent of energy loads in buildings and are also related to productivity of labour, 5-15 per cent. Scenario analysis projected that, with widespread implementation, annual economic benefits would reach 150-300 million dollars, comprising direct fiscal savings (25-50 million), productivity enhancement (15-30 million), green construction investment mobilised (100-200 million), and reduced fuel imports (10-20 million) offsetting 7-13 per cent of the yearly energy deficit

Keywords: sustainable development; productivity gains; green investment; climate-responsive planning; fiscal policy

Introduction

Ghana's persistent and deepening energy crisis represents one of the most significant threats to national economic stability, manifesting not merely as a technical shortfall i n generation capacity but, more fundamentally, as a structural impediment to productivity, public expenditure management, and long-term development. Consequently,

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the cyclical nature of power outages, colloquially termed "dumsor" has disrupted industrial activity, undermined business confidence, and imposed recurrent fiscal burdens on an already strained public budget. In response, policy responses have historically concentrated on expanding supply-side infrastructure, investing heavily in thermal generation and pursuing renewable energy targets; however, these efforts have consistently lagged behind escalating demand, thereby exposing the limitations of a purely supply-oriented approach. Within this context, the building sector emerges as a critical yet underutilised point of intervention.

The ongoing energy crisis in Ghana is causing instability in the economic condition of the country, not as a technical inadequacy, but as a structural hindrance to productivity and fiscal governance. It has led to the existence of electricity sector debt in excess of GH 80 billion (US 5.6 billion) estimated to rise to over US 9 billion by 2026 with cyclical power outages (dumsor) disrupting most industries, undermining business confidence, and plunging the country into recurrent fiscal burdens (Asmah, 2025; Lighting up Accra…, 2025). Nevertheless, the responses have been on supply-side infrastructure expansion but this has failed to keep pace with the rising demand revealing the shortcomings of supply-only-oriented policy. Nevertheless, the building sector as a large electricity user, presents a very important, yet under-tapped demand-side intervention. According to the estimates of the World Bank Group (2025), every dollar spent on energy efficiency will give the US government a return of US 3-5, saving their money. But this potential has not been exploited due to disjointed regulations, inadequate technical integration, and the view of efficiency as an engineering, but not a strategic, economic issue. There are no enforced efficiency requirements in building regulations, so architectural design choices, which shape the long-term energy use, are rarely considered in macroeconomic terms (Built environment critical…, 2024). This alienation of technical practice and economic policy is the main issue: the systematic underestimation of energy-efficient architecture as a source of fiscal resiliency.

Ministry of Finance of Ghana (2025) promoted changes in demand without reasoning to the construction of buildings. G. Tettey *et al.* (2025) also found policy incoherence in renewable transition, but did not consider building codes. Clean Air Task Force (2025), once emphasised the demand-side urgency without quantifying the level of building-level efficiency input. S. Owusu-Mante (2025) analysed the landscape of Ghana's renewable energy transition, concentrating on the creation of the Ministry of Energy and Green Transition as a policy signal. The scientist concluded that institutional coordination remains weak, with disjointed efforts across ministries and limited integration of green skills development, local material supply chains, and building regulations into a coherent strategy. Greater focus was on renewable barriers, as G. James *et al.* (2025) analysed them, and the Energy Commission (2025) demanded increased enforcement of efficiency. The International Energy Agency (2025) worldwide affirmed that efficiency programmes have economic benefits. E. Ochedi & A. Taki (2022) developed a framework approach to energy-efficient residential building design in Nigeria, identifying passive solar strategies, natural ventilation, and site-responsive design as critical interventions in tropical climates. The authors concluded that systematic application of these principles can yield significant reductions in cooling loads and operational energy consumption. J. Allen *et al.* (2022) associated indoor quality with a 5-15% productivity increase but in high-income nations only. The fact that the Ghana has created the Ministry of Energy & Green Transition indicates that this connection has been acknowledged within its policies.

Nevertheless, there is a very big discrepancy between the technical architectural solutions and their expression in the form of conscious economic policy. To empirically determine and measure the effect of architect's design decisions that are energy-efficient (EED) on the energy performance (EP) of buildings in Ghana, and to re-conceptualise these technical results as sources of economic innovation. Practically translate evidences of economic innovation sustainability into coherent policy, industry structure to decrease national energy demand, reduce public sector expenditures and spur green investment to support national energy security, and sustainable development objectives (Tettey *et al.*, 2025). Consequently, an existing large gap is the connection between particular architectural design decisions, and building energy performance that has not been empirically assessed in the Ghanaian professional setting, or converted into economic frameworks involving the correlation of design with minimised government expenditure, increased productivity, and green market stimulation. The purpose of the study was to empirically determine the effect of energy-conscious design on building energy performance in Ghana and redefines these results as quantifiable aspects of fiscal stability, which gives an innovation evidence base of incorporating architectural practice in the national energy policy.

Materials and Methods

The research design used was a quantitative, and cross-sectional survey design to understand the correlation between design decisions of architects, and building energy performance in Ghana. The statistical tools applied include descriptive statistics, Pearson correlation, multiple linear regression, and principal component analysis. Principal Component Analysis (PCA) with Varimax rotation using SPSS. Scale reliability was excellent (Cronbach's $\alpha = 0.90$). The study population was registered architects with good standing registered by the Architects Registration Council of Ghana (ARCG). Out of 850 registered architects on their sample frame; 120 practicing architects were used

for the study, as it was determined by R. Krejcie & D. Morgan (1970) sample size determination table, being recommended by L. Kish (1965) for conducting surveys on the professionals. Data cleaning resulted in the retention of 72 complete and valid responses to be analysed and the response rate was 60. They used stratified sampling depending on years of experience (0-5, 6-15, 16 or more years), and primary practice sector (public, private, and academia). The major metropolitan centres with very high, and more constructional projects were used to draw the participants in Accra, Kumasi, and Takoradi.

The work of N. Ahmad *et al.* (2019) was used to develop a structured questionnaire which was piloted on 15 architects to evaluate their clarity, relevance and length. Pilot feedback was taken into consideration with minor wording changes, and the consent of the appropriate respondents was taken, in accordance with the ethical principles of the American Sociological Association (2018), and used solely for academic purposes, and no name was required. The questionnaire included four parts: Section 1 that covered demographic and professional information with six questions: years of experience, sector of practice, highest educational level, type of typical project (residential, commercial, institutional, or mixed use), the number of efficient projects completed with respect to building energy codes, and knowledge of Ghana building energy codes. Section 2 quantified the frequency and priority of 13 individual energy efficient design (EED) decisions rated where 1 = Never Used to 5 = Always Used. These were divided into two: Building Envelope/Orientation Innovations (eight items: building orientation, window to wall ratio, external shading devices, wall insulation, roof insulation, glazing type, building compactness, and thermal mass) and Site Condition Innovations (five items: prevailing wind utilisation, landscaping for shading, vegetation placement, topography adaptation and rainwater harvesting integration). Section 3 measured perceived building energy performance based on five statements with a 5-point Likert scale (1 = Strongly Disagree to 5 = Strongly Agree). They were as follows: Buildings that I design consume less energy than conventional designs, occupants report lower energy costs, thermal comfort is always well achieved without excessive mechanical cooling, indoor environmental quality (air quality, daylight, acoustics) is just as high as occupant expectations, and post occupancy evaluations indicate high occupant satisfaction with energy performance. Section 4 enumerated 5 possible obstacles to the implementation of energy efficient design on a 4-point scale (1 = Not a Barrier to 4 = Severe Barrier): absence of client demand, increased cost of upfront costs, limited technical expertise of design teams, no enforcement of building energy codes, and no availability of energy efficient materials in the immediate area.

The data were collected within eight weeks by utilising both electronic (Google Forms) and paper-based data, which was gathered at the professional association meetings as well as direct visit to architectural firms in Accra, Kumasi, and Takoradi. A set of information was given to the participants in an information sheet that contained the purpose of this study, and all respondents were informed to give consent. There were anonymity and confidentiality. The results were analysed in SPSS version 26. Three descriptive statistics (means, standard deviations, frequencies) were calculated of respondent characteristics, and design priorities. Pearson product moment correlation coefficients were used to examine bivariate associations between EED decisions, and energy performance. This was followed by multiple linear regression (stepwise entry) to determine the most important predictors of the energy performance with standardised beta coefficients used to determine the relative contribution of each predictor. Before the regression, the assumptions of linearity, normality, homoscedasticity, and multicollinearity were tested with the help of the residual plot and variance inflation factor. All statistical tests were two tailed and the level of significance was 0.05. design. This study has a number of limitations. To begin with, the sample of 72, which is used in this study, is sufficient to perform its statistical analysis, but does not allow generalising it to the whole profession. Once again, the use of self-reported performance of energy instead of quantitative consumption data presents a possibility of response bias. The cross-sectional design, however, only captures associations, but not causality. Research in the future must also include the actual energy consumption in buildings built with the known EED strategies to confirm the self-reported performance indicators.

Results and Discussion

Ghana's energy crisis and the underutilised potential of building energy efficiency

The Energy Crisis in Ghana and the argument in favour of constructing energy efficiency. The power industry in Ghana is in a structural crisis that is spiralling out of control with increasing debt, inefficiencies in operations, and financial burdens that are unsustainable. Clean Air Task Force (2025) asserts that, the energy crisis of Ghana is a debt/inefficiency spiral: the accrued debts of the sector are over GH80 billion (about US5.8 billion), and the amount of money needed to fund it annually is estimated to be US2.23 billion. Combined with S. Owusu-Mante (2025) stated that, performance of Electricity Company of Ghana (ECG) is a major bottleneck, which contributes to Aggregate Technical, Commercial and Collection (ATC&C) losses of up to 40% leading to a monthly shortfall in revenue of US 25.8 million. This leakage in the budget, he argues, is a budget killer to other important investments in the state. The power generation mix of Ghana in the year 2023-2025 is shown in Table 1. Most of the generation is thermal.

Table 1. Ghana's power generation mix: 2023-2025 (GWh)

Source	2023 (Actual)	2024 (Actual)	2025 (Projected)
Hydro	9,187	9,893	10,200
Thermal	14,930	14,524	15,200
Other renewable sources	147	181	250
Total	**24,264**	**25,550**	**25,650**

Source: Ghana renewable electricity: % of total electricity generation (2024), Global Legal Insights (2025) for 2023 data, Electricity Monitor Ghana (2025), M. Afful (2025) and author's projections based on Energy Commission (2025) outlook

Moreover, according to Electricity Monitor Ghana (2025), since 2016, electricity generation has been dominated by thermal power, and its output has been increasing steadily to reach its peak of 14,930 GWh in 2023 and then slightly declines to 14,524 GWh in 2024. This means that, hydropower, which controlled Ghana generation rates between 2000 and 2015 with a share of between 51 and 92%, has been surpassed by thermal over the past few years. According to the International Trade Administration (2025), a significant portion of power generation in Ghana is based on thermal generation (66%), hydro (33%), and renewable sources (1%). Ghana has had limited success in the integration of renewable energy, although its ambitious policy targets have been terribly derailed by the continued failures in implementing them. S. Owusu-Mante (2025) highlighted that, the renewable energy transition states that there is a broader implementation gap: though policy objectives indicate that the non-hydro renewables should take more than 20% of installed capacity, they occupy less than 2%. G. Tettey *et al.* (2025) stated that the absence of effective policy streams hinders development of Ghana, which is aggravated by financing mechanism, and institutional barriers pattern, which the Danish Institute of International Studies (2025) also notes.

Although the need to promote energy efficiency in buildings has been a long-established idea in the global discourse as a pillar of sustainable development, its potential as an economic innovation driver has been little tapped in Ghana. According to A. Salmi *et al.* (2022) building energy efficiency is viewed internationally as one of the keys to sustainable economic development because buildings are a long-term capital infrastructure that lowers operational expenses. Sustainable development as a concept of economic and environmental objectives was put forward by the World Commission on Environment and Development (1987). E. Ochedi & A. Taki (2022) presented major strategies for energy efficiency in buildings and economic innovation, comprising either Building Envelope/Orientation Innovations (e.g., passive solar, natural ventilation) or Site Condition Innovations (e.g., climatic analysis, shading), which is consistent with R. Crawford (2011). However, empirical research from Ghana quantifying the impact of specific energyefficient design (EED) decisions and directly linking them to macroeconomic outcomes is lacking.

Conceptual frameworks:

Design-based performance-based economic innovation

The combination of whole building design approach has turned out to be one of the fundamental principles of sustainable construction operationalisation (Ochedi & Taki, 2022). M. Kashef (2025), the bifurcation of EED decisions is in line with contemporary building science, inspired by holism, and biophilic approach to bioclimatic performance optimisation. According to E. Ohene *et al.* (2024), the above strategies are considered by the existing literature on tropical architecture to be critical resilience to make buildings more tolerant to temperature and power outages, which are also validated by Y. Yang *et al.* (2023). The shift of slender energy metrics to a more socio technological notion of efficiency, connected to occupant wellbeing, and cognitive output is found in the International Energy Agency (2025), The human dimension… (2020), and Y. Yu *et al.* (2024).

Based on modern political economy explanations of the nexus of constraints in Ghana, that deter efficiency expenditures (Clean Air Task Force, 2025; World Bank Group, 2025). Also, EEDs are innovations in a sophisticated construction innovation system, observable in the Global Alliance for Buildings, and Construction (2024). E. Ohene *et al.* (2024) on the contrary confirm the relationship between performance, and economic returns with life cycle cost models, which is that low levelised costs of efficient structures in tropical climates. J. Allen *et al.* (2022) further present strong evidence for the relationship between cognitive functioning, and indoor air quality, as well as thermal comfort based on controlled studies. S. Owusu Mante (2025), and G. Tettey *et al.* (2025) proved the necessity to design green skills, and resources that can motivate local entrepreneurs as an opportunity with a future in the current strategy in Ghana. In the context of the basis of the circular economy and decoupling, P. Albrecht & M. Gravesen (2025) and Ministry of Finance of Ghana (2025) discussed the vulnerability of the fiscal and trade sector in Ghana. The conceptual framework of energy efficient building design strategies, and energy performance of public buildings in Ghana, as shown in Figure 1 reflects Building Envelope/Orientation Innovations, and Site Condition Innovations as the main sources of energy performance in the national context.

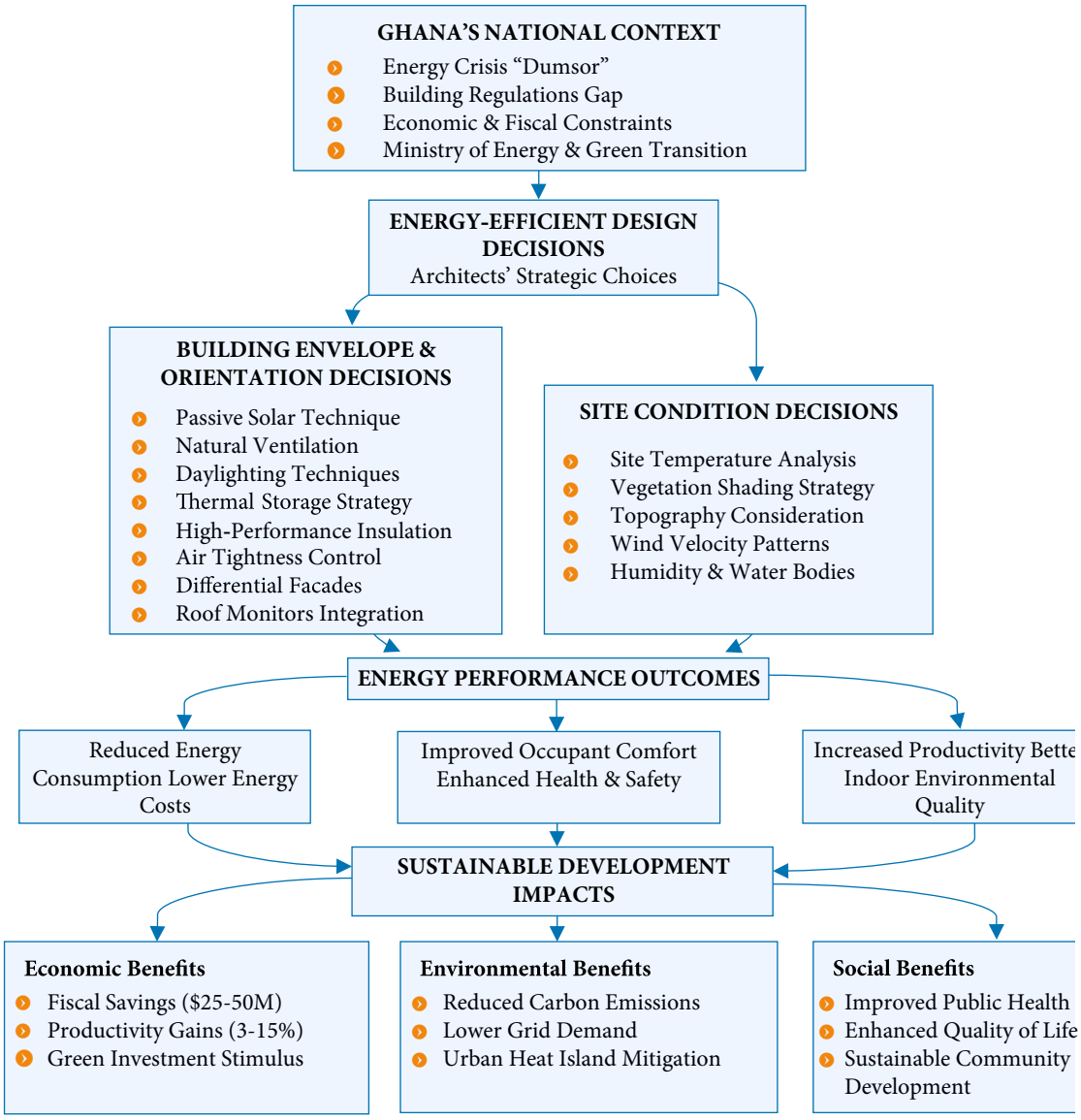

Figure 1. Conceptual framework: Energy efficient design strategies and energy performance
Source: author's elaboration

Figure 2 shows the economic innovation pathway of energyefficient building design in Ghana. The diagram illustrates EEDs leading to energy performance, which bifurcates into Productivity & Fiscal Benefits and Green Market Stimulus, converging on Macroeconomic Resilience.

The Ghana Green Building Code based policy framework of energy efficient building design in Ghana and the EDGE certification system have been shifted to be a regulated market-driven mechanism rather than a voluntary niche approach (Kumar, 2025). According to S. Asuamah Yeboah (2024), it is stipulated that the Government incentives towards sustainable construction in developing countries: Catalysts for change. Drivers of change: Government incentives to promote sustainable construction in developing countries; the evidence shows that this framework successfully transfers environmental targets into economic results that can be measured: Ghana has already achieved one million square metres of EDGE-certified space by 2025 (up from just 40,000 m^2 in 2017). The 100% EDGE certification of the Greenville District Housing Programme which is mandatory is another indication that the regulators have now come to the realisation that green building is a prerequisite towards the provision of public housing.

More importantly, the integration of the framework with local financing that has been epitomised by the SUNREF Ghana programme that deployed the equivalent of the US$30 million in credit lines offered by the Agence Française de Developpement (AFD) as well as the equivalent of the US$2 million in technical assistance offered by the EU Africa Infrastructure Trust Fund which has executed over US $20 million in green energy projects. As it generates an estimated annual reduction of about 139,020 tonnes of CO_2 (SUNREF Ghana Programme ends, advances climate finance and green investment, and low carbon

materials, such as the 139,020 tonnes of CO_2 in the world largest Limestone Calcined Clay Cement (LC_3) plant commissioned in Tema with a US $110 million investment which replaces up to 40 percent of traditional clinker and reduces carbon emissions by as much as 40% (Afful, 2025), creates its own reinforcing loop: regulation attracts demand, demand attracts investment, and investment lowers technology costs. Accordingly, some of the main lessons of this analysis are that obligatory certification targets, rather than voluntary guidelines, have triggered market expansion, requiring that codes be coupled with accessible EDGE certification reduces compliance costs incurred by developers, and making codes conditional on their being coupled with accessible EDGE certification further lowers compliance expenses. In the absence of such alignment and ongoing public-private coordination, this framework risks remaining a mere blueprint rather than becoming a lived reality.

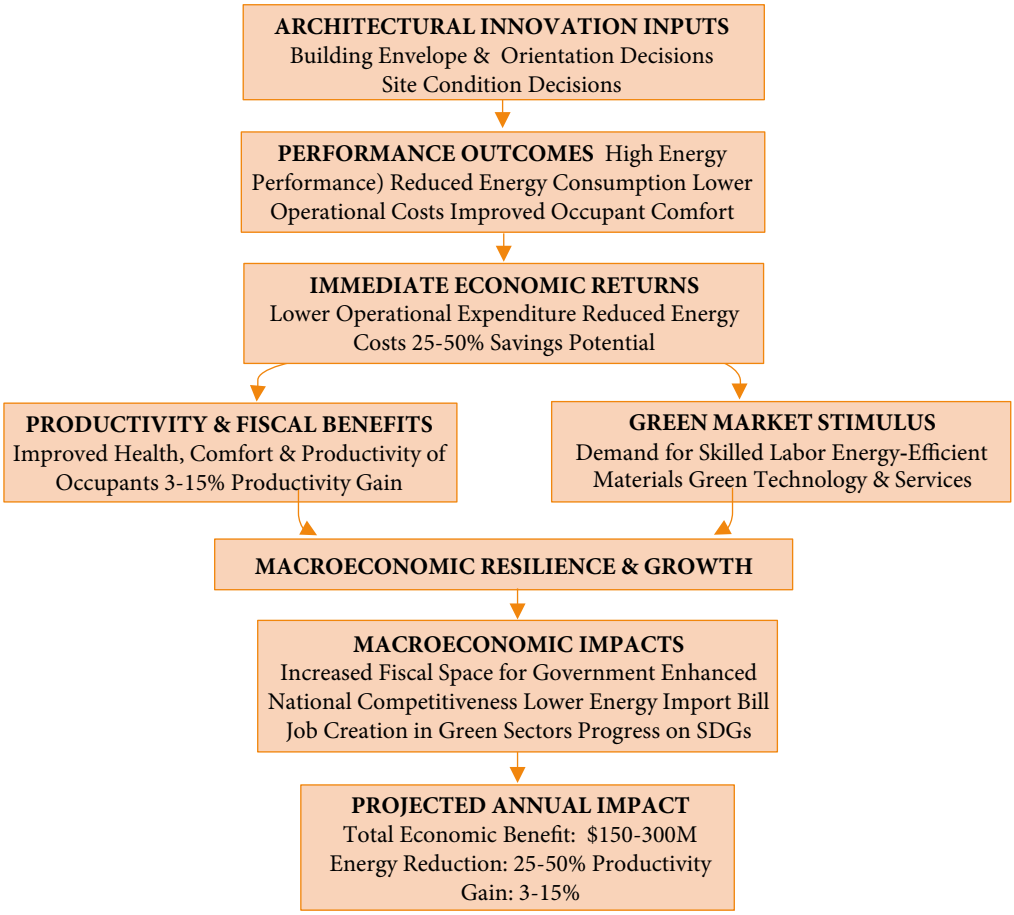

Figure 2. Economic innovation pathway of energy-efficient building design in Ghana
Source: author's elaboration

Results sample characteristics and response rate

A total of 72 valid responses were obtained out of the 120 questionnaires sent out which is a response rate of 60.0. The sample included architects of the following experience levels: 25.0% of 0-5 years, 41.7% had 6-15 years, and 33.3% had 16+ years. In terms of sector, 58.3, 25.0 and 16.7% were in the private practice, the public sector and academia respectively. Principal Component Analysis of energy efficient design decisions. The 13 EED items were subjected to a Principal Component Analysis (PCA) with varimax rotation. The Kaiser Meyer Olkin measure of sampling adequacy = 0.814, and the Test of Sphericity was significant ($\chi^2 = 684.237$, n = 78, p = 0.001). The PCA reduced the 13 EEDs to two components that accounted 73.6% variance. The factor loadings are shown in Table 2.

Table 2. Principal component analysis of energy-efficient design decisions

Component and design decisions	Factor loadings	Variance explained
Component 1: Building Envelope/Orientation (BE/O) Decisions		64.4%
Passive solar technique	0.832	
Provision of natural ventilation	0.815	

Continued Table 2

Component and design decisions	Factor loadings	Variance explained
Daylighting techniques	0.808	
Thermal storage strategy	0.797	
High-performance insulation	0.767	
Air tightness / Infiltration control	0.733	
Differential facades technique	0.695	
Integration of roof monitors	0.641	
Component 2: Site condition (SLC) decisions		9.2%
Temperature of the building site	0.923	
Site shading by vegetation	0.858	
Topography of the building site	0.576	
Wind velocity at the building site	0.597	
Humidity and presence of water bodies	0.539	
Total variance explained		**73.6%**

Source: author's computation

The average scores of the single EED items indicated that, site temperature analysis (mean = 4.64) and passive solar technique (mean = 4.58) and natural ventilation (mean = 4.56) were the most common design innovations used. Nonetheless, Table 3 shows the reliability analysis results of the Cronbach alpha coefficients of the scales (Cronbach's alpha >0.9).

The alpha coefficients of the Cronbach coefficients in Table 3 range between 0.905 and 0.943, which are far greater than the more traditional acceptable test value of 0.70 and the more stringent test value of 0.80 as a good reliability test. These values imply a very high degree of internal consistency of each of the three scales. In particular, the scale of Performance (5 items; $\alpha = 0.943$) has an excellent internal consistency; that is, the five items covary with each other as well as are reliable in measuring a single construct. The "BE/O" scale (8 items; $\alpha = 0.932$) and the "SLC" scale (5 items; $\alpha = 0.905$) also show excellent reliability, with α values above 0.90. Such coefficients are not only acceptable in the context of this study, but are also indicative of very reliable measurement instruments.

These findings warrant considering that each of the scale's measures consistently its intended latent variable without undue measurement error. Further the high alphas, along with the factor loadings obtained elsewhere (as in Table 5), is strong evidence that the scales are both reliable and unidimensional in nature. There is no need to revise the scale or to remove items based on the theory of internal consistency. Table 4 shows Multiple regression analysis, with stepwise multiple regression analysis conducted to identify predictors of energy performance. The model was significant ($F(5,66) = 159.144$, $p < 0.001$), explaining 81.7% of the variance in energy performance (Adjusted $R^2 = 0.817$).

Table 3. Reliability and scale validation test results

Scale	Number of scale items	Cronbach's alpha coefficient
BE/O	8	0.932
SLC	5	0.905
Performance	5	0.943

Source: author's computation

Table 4. Multiple regression results for EEDs predicting energy performance

Predictor variable	Beta (β)	t-value	p-value
Passive solar technique	0.510	7.128	< 0.001
Natural ventilation	0.373	6.595	< 0.001
Site temperature consideration	0.315	4.521	< 0.001
Daylighting technique	0.284	3.885	< 0.001
Site shading strategy	0.175	3.572	< 0.001

Source: author's computation

Again, the Principal Component Analysis for energy performance (PCA) revealed five energy performance items with unidimensional structure, with a single factor explaining 80.524% of the variance (KMO = 0.792, Bartlett's Test = 389.781, $p < 0.001$). Table 5 shows the factor loadings.

Table 5. Principal component analysis for energy performance

Item	Factor loading
Reduced energy consumption	0.945
Less energy cost	0.936
Improves the comfort of occupants	0.922
Improves health and safety of occupants	0.880
Improves the productivity of occupants	0.818

Source: author's computation

The implications of these results to the structure of the scale are quite numerous. The highest loading (0.945) indicates that the item with the highest loading in the factor is Reduced energy consumption, which is also the most central and defining item of the factor, and the lowest loading (0.818) still comfortably exceeds the 0.70 benchmark, demonstrating that it makes a meaningful contribution, which is statistically significant. Importantly, it does not have weak or negative or cross- loadings. The consistently high loadings, therefore, offer strong empirical support of a unidimensional scale format. Such a pattern of results is reliably indicative to show that all the five items converge to measure one single, cohesive latent construct, which can be interpreted as the perceived benefits of energy-efficient design. Thus, it can be safely assumed that the scale can be used as a unidimensional scale with no subscales or items should be deleted. The Constraints to implementation as shown in Table 6 presents mean ratings for five barriers to incorporating EEDs, measured on a 4point scale (1 = Not a Barrier to 4 = Severe Barrier).

Table 6. Constraints to incorporating energy-efficient design decisions

Constraint	Mean rating	Level of barrier
Lack of public awareness of benefits	3.20	High
Client's budget constraints	3.00	High
Lack of skilled labour	2.91	MediumHigh
Lack of access to energyefficient materials	2.82	Medium
Lack of enforcement of compliance during construction	2.77	Medium

Source: author's computation

The primary barriers to energy-efficient construction are not purely technical but are rooted in economic, informational, and regulatory gaps. The highest-rated constraints suggest that demand-side intervention is critical, as overcoming the lack of public awareness and clients' budget constraints requires policies aimed at stakeholder education and strengthening the financial case, for example through incentives, green financing, or lifecycle cost analysis. At the same time, the presence of medium-high to medium barriers related to skills, materials, and enforcement indicates the need for supply chain and workforce development, including investments in training, the expansion of local material supply chains, and the strengthening of oversight mechanisms to ensure that design intentions are properly implemented during construction. Table 7 projects the economic mechanisms, and outcomes associated with each highperformance design innovation.

Table 7. Projected economic potential of high-performance design innovations

Innovation (predictor)	Primary economic mechanism	Shortterm economic outcome	Longterm macroeconomic benefit
Passive solar technique (β = 0.510)	Displacement of purchased electricity for lighting/heating	~ 2540% reduction in lighting/AC load; reduced utility bills	Fiscal space creation; energy security (reduced peak demand)
Natural ventilation (β = 0.373)	Elimination/reduction of mechanical cooling demand	~ 3050% savings on cooling costs; lower HVAC maintenance	Labour productivity gain (515% from improved IAQ); reduced healthcare burden
Site temperature & shading (β = 0.315 & 0.175)	Microclimate moderation to reduce heat island effect and cooling loads	~ 1020% lower cooling energy; extended building lifespan	Urban resilience; ecosystem value (carbon sequestration, biodiversity)
Daylighting technique (β = 0.284)	Direct displacement of artificial lighting	~ 1530% savings on lighting electricity; enhanced visual amenity	Productivity & health (310% improvement in occupant wellbeing and cognitive performance)

Source: author's computation based on beta coefficients and benchmarks from R. Pacheco et al. (2012) and International Energy Agency (2025)

The results substantiate EEDs as powerful economic innovations. The great explanatory power of the model shows that investments in the identified EEDs give significantly predictable returns. The high predictive value of the passive solar (0.510) and the natural ventilation (0.373) highlights the value of climate responsive design as a direct measure of financial savings and productivity increase in government buildings. These innovations provide the space that a government badly needs so that it can more effectively address the existing $2 billion annual energy deficit, and also create a more competent workforce in the government. Table 8 presents a scenario analysis estimating the annual economic benefits of a national public building energy efficiency program.

Table 8. Estimated macroeconomic benefits of a national public building energy efficiency program

Impact category	Key metric	Conservative estimate (annual)	Rationale
Direct fiscal savings	Reduced government energy expenditure	$2550 million	30% energy use reduction across 20% of public building stock
Productivity enhancement	Value of increased public sector output	$1530 million	3% productivity gain from improved comfort/ health
Investment & GDP stimulus	Green construction investment mobilised	$100200 million	Initial capital for retrofits flowing into local sectors
Energy sector & trade	Reduced fuel imports & grid stress	$1020 million	Lowered thermal generation demand
Total potential annual economic benefit	Combined direct & indirect impact	$150300 million	Demandside contribution to mitigating US$2.23 billion annual energy shortfall (Clean Air Task Force, 2025)

Source: author's computation based on Ministry of Finance of Ghana (2025) and Clean Air Task Force (2025)

Table 8 summarises the estimated annual macroeconomic benefits of a national public building energy efficiency program, and disaggregated into the four key impact categories. All estimates are given as lower limits and the overall combined annual benefits have been estimated to be between 150 million and 300 million. The biggest direct fiscal gain is through reduced government spending on energy (25-50 million per year), based on a modelled 3% productivity gain between occupants of the public sector as a result of increased thermal comfort, lighting, and indoor air quality parameters empirically related to higher work output. The largest macroeconomic lever mobilised green construction investment. Mobilised green construction investment (100-200 million yearly) is the most significant macroeconomic lever. This capital inflow is invested in local supply chains (materials, labour, engineering services) providing multiplier effects in terms of GDP and employment.

Moreover, there were decreased fuel imports and gridstess (100-200 million annually). Combined, the total economic benefit of 150- 300million annually, as a demand-side contribution, will help reduce this US 2.23 billion annual energy short fall identified by the Clean Air Task Force (2025). It is noteworthy that all the estimates are characterised as conservative, which means that the actual benefits might be higher, in case a larger percentage of the building stock is retrofitted or energy prices increase. Policy-wise, Table 8 shows that a public building energy efficiency program would yield returns in more than one channel fiscal, productivity, investment, and trade among macroeconomic channels rather than just reducing utility bills. The range format (X-Y million) is the only format that appropriately takes into account uncertainty in uptake rates, energy price volatility, and productivity measurement, but still provides an actionable order-of-magnitude direction to be taken in cost-benefit analysis. The programme has the potential to generate US$150-300 million yearly. Green construction investment (US$100-200 million) is the greatest benefit followed by direct fiscal savings (US$25-50 million), productivity gains (US$15-30 million), and reduced fuel imports (US$10-20 million). These, combined, can help overcome the US 2.23 billion annual energy deficit in Ghana, which is a macroeconomic demand side strategy with positive fiscal, productivity and trade impacts.

The output of PCA empirically confirms the theoretical bifurcation of the conceptual framework (Fig. 1), as the EED decisions of architects in Ghana concentrate around Building Envelope/Orientation Innovations and Site Condition Innovations. This total variance explained (73.6) is high implying that these two types have most systematic difference in EED practices. Comparison of possible savings on the international and regional level. The projected energy savings in this study (25-50 reduction of building loads) are in line with the results of similar tropical settings. In Tanzania, it was found out that, green buildings are capable of saving between 8 to 57 per cent of the annual energy (Islam *et al.*, 2024). E. Ohene *et al.* (2024) found that, in Ghana alone, passive design strategies had the potential to save 34-35% of energy in different climates against baseline conditions.

A. Khalid & M. Okitasari (2023) also found that, government related barriers are still a serious impediment to the uptake of green building technologies in Ghana. The results find correlation with the regression results of the current study that assigned passive solar technique (0.510), and natural ventilation (0.373) as the most effective predictors of the energy performance. The current study however contrasts the relative economic contribution of each design

innovation unlike the past studies, which mainly concentrated on technical feasibility only. Multipliers and creation of employment. Table 8 estimates of economic benefits of between 150-300 million a year are well supported by recent global analysis. The World Bank Group (2025) discovered that, on an investment of one dollar in energy efficiency, can provide a payoff of between 3 and 5 dollars, and can save future energy supply investments by up to $11.6 billion in power savings to an average middle-income nation by 2050. Notably, the report says that, in 2022, energy efficiency generated the largest number of jobs throughout the energy industry, with nearly 11 million individuals in global companies' workplace in respect of manufacturing, construction, installation, and support services.

For Ghana, this implies that, a national EED program could generate significant formal employment in the construction, and retrofit sectors for dimension which is absents from previous Ghanaian studies. Partnership for Energy efficiency in Buildings (2025) supports this perception by stating that, 80% of the buildings that will be constructed in Africa by the year 2050, will have a one-time chance of generating employment, lessening the use of energy, and enhancing the security of energy by green building. The current researches predicted that mobilised green construction investment in the range of 100-200 million dollars (Table 8) would be directly related to such employment results. Obstacles to adoption: Multiple studies agree. The conclusion that, economic (Primary barriers) and informational (Table 6) are the main obstacles is strongly backed by the latest literature.

In a doctoral thesis on net zero carbon buildings in Ghana, E. Ohene (2024) found a greater initial investment cost to be the greatest obstacle, then unavailability of skilled labour, inadequate regulations, and policies, and public awareness. Similar results were reached by A. Khalid & M. Okitasari (2023), who assert that, government related obstacles are significant that, an efficient communication approaches, regulations backed by the mass, and standards are crucial promotion techniques. Meanwhile, thematic analysis of the green certification barriers in Ghana revealed that, built environment professionals repeatedly mention cost, insufficient awareness, and inadequate enforcement as the barriers to the implementation. This paper concurs with the above authors that, the main challenges are not technical, but informational and economic. This is the agreement of numerous studies with significantly different methodologies, which enhances the argument of specific policy interventions. Economic innovation pathway (Fig. 2).

The regression results empirically support the entire chain illustrated in Figure 2. Figure 2 shows that, EEDs lead to improved energy performance, which then splits into (a) Productivity & Fiscal Benefits and (b) Green Market Stimulus, finally converging on Macroeconomic Resilience. The strong predictive power of passive solar ($\beta = 0.510$), and natural ventilation ($\beta = 0.373$) directly feeds the fiscal savings leg: a 25-50% load reduction translates into lower government utility bills, creating fiscal space. Meanwhile, improved indoor environmental quality supports the 5-15% labour productivity gains documented by the International Energy Agency (2025) and J. Allen *et al.* (2022). The Green Market Stimulus leg is evidenced by estimated $100-200 million in mobilised green construction investment (Table 8), which would stimulate demand for local materials, skilled labour, and efficient technologies. Thus, Figure 2 is not merely a diagram, it is an empirically grounded causal chain where each link is quantified by the beta coefficients and projected outcomes. The productivity pathway itself is supported by emerging Ghanaian evidence.

An importance-performance analysis of an EDGE-certified office building in Ghana found that, occupants prioritise temperature, air quality, and humidity exactly the IEQ factors improved by passive solar and natural ventilation (Zhong *et al.*, 2023). A.-M. Sadick (2020) found significant differences in job satisfaction and self-reported productivity based on IEQ factors among university employees in a tropical African climate. These findings extend J. Allen *et al.* (2022) controlled-study evidence from high-income countries to Ghana, suggesting similar mechanisms operate across different economic contexts. Finally, the scenario analysis (Table 8) projects annual benefits of $150-300 million, which would offset 7-13% of Ghana's US$2.23 billion annual energy sector deficit reported by Clean Air Task Force (2025). This demonstrates that, demand-side efficiency can meaningfully complement supply-side expansions. However, the study acknowledges with G. Tettey *et al.* (2025), and P. Albrecht & M. Gravesen (2023) that, an implementation gap persists: policy goals exist, but are not realised due to weak coordination, fragmented regulations, and insufficient enforcement. The disconnect between technical feasibility and policy implementation mirrors broader regional patterns. In this context, the present study provides the empirical basis quantified beta coefficients and projected macroeconomic benefits to elevate energy-efficient architecture from a technical specialism to a central pillar of national fiscal policy.

Conclusions

The research found that the response rate of 60.0% (72 valid responses out of 120 distributed questionnaires) is reasonable to conduct a professional survey of registered architects in Ghana. They discovered that, the decisions in energy efficient design by the architects are clustered around two empirically validated innovation themes, Building Envelope/Orientation Innovations (explaining 64.4% of the variance) and Site Condition Innovations (explaining another 9.2% of the variance of design strategies). The research determined that, there are five design choices that are statistically significant predictors of building energy performance.

The total amount of variance in the energy performance attributed to passive solar technique ($\beta = 0.510$), natural ventilation ($\beta = 0.373$), site temperature consideration ($\beta = 0.315$), daylighting technique ($\beta = 0.284$), and site shading strategy ($\beta = 0.175$) was 81.7%. The most commonly

used design innovations were site temperature analysis (mean = 4.64), passive solar technique (mean = 4.58) and natural ventilation (mean = 4.56). It was further discovered that, the major barriers to adoption are economic, and informational: lack of public awareness (mean = 3.20), and client budget constraints (mean = 3.00) are high barriers, and skilled labour (2.91), material access (2.82), and enforcement (2.77) are medium to medium high. The Scenario analysis estimated that, a national public building energy efficiency programme would result in economic savings of between 150-300 million per annum, in compensation of the estimated 7-13% of the estimated 2.23 billion per annum of the Ghanaian energy sector deficit.

Future research opportunities consist of: more cost benefit analysis in the five most popular design strategies in various building types (schools, hospitals, offices); macroeconomic modelling of the nationwide retrofit programmes using computable general equilibrium models; exploring new financing models like the Energy Service Company, green bonds, and public private partnerships; longitudinal studies of actual energy performance, and productivity results; and cross country research on West Africa to determine the sensitivity of policy and market contexts.

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Conflict of Interest
None.

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Вплив енергоефективної архітектури як рушія економічних інновацій та фіскальної стійкості в Гані

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Анотація. Метою цього дослідження було вивчення енергоефективного архітектурного проектування як стратегічного інструменту економічної політики та інновацій, з метою його використання для подолання енергетичної кризи в Гані шляхом стимулювання економічних інновацій та фіскальної стійкості у будівельному секторі. Опитування 120 зареєстрованих архітекторів у Гані (кількісне дослідження) дало 72 дійсні відповіді (рівень відгуку 60,0 %). Використані методи включали описову статистику, кореляцію Пірсона, множинну лінійну регресію та факторний аналіз головних компонентів. Факторний аналіз показав наявність двох основних інноваційних тем: будівельна оболонка/орієнтація (64,4 % дисперсії) та рішення щодо умов майданчика (ще 9,2 % дисперсії) із високою надійністю шкали (Кронбах $\alpha = 0{,}90$). Багатовимірна конструкція результатів була підтверджена, причому показники енергетичної ефективності завантажувалися на один фактор, який пояснював 80,5 % дисперсії. Регресійний аналіз виявив п'ять предикторів енергетичної ефективності, які пояснювали 81,7 % дисперсії: пасивне сонячне опалення ($\beta = 0{,}510$), природна вентиляція ($\beta = 0{,}373$), температура на майданчику ($\beta = 0{,}315$), денне освітлення ($\beta = 0{,}284$) та затінення майданчика ($\beta = 0{,}175$) за стандартизованим коефіцієнтом регресії. Основними бар'єрами виявились економічні та інформаційні: відсутність знань у громадськості (середнє = 3,20/4) та бюджет клієнта (середнє = 3,00/4), що вважаються значними перешкодами. Ключові висновки показують, що інновації у проєктуванні можуть забезпечити економію 25-50 % енергоспоживання будівель, а також пов'язані з продуктивністю праці на 5-15 %. Сценарний аналіз прогнозує, що при широкому впровадженні річні економічні вигоди можуть досягти 150-300 мільйонів доларів, включаючи прямі фіскальні заощадження (25-50 млн), підвищення продуктивності (15-30 млн), залучення інвестицій у зелене будівництво (100-200 млн) та зменшення імпорту палива (10-20 млн), що компенсує 7-13 % річного енергетичного дефіциту

Ключові слова: сталий розвиток; підвищення продуктивності; зелені інвестиції; клімато-адаптивне планування; фіскальна політика

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The role of digital transformation in the formation and development of intellectual capital in telecommunications companies

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Abstract. The study aimed to determine how the introduction of digital technologies changes the components of telecommunications companies' intellectual capital and affects their efficiency and economic performance. To study the digital transformation of telecommunications companies, data analysis methods, integration of analytical and artificial intelligence platforms, assessment of the impact of the Internet of Things, cloud services and digital ecosystems on the efficiency of business processes, personalisation of services and development of intellectual capital were used. The study determined that in 2025, the number of Internet users worldwide reached about 6 billion people (72% of the population), while in Ukraine, this figure was 31.5 million people (82.4% of the population). The study determined that the structural capital of telecom operators has strengthened thanks to process automation, the introduction of cloud platforms and data analytics; 85% of operators consider digitalisation critical to growth, 70% reported increased network productivity, and operating costs fell by 15-20%. The study also found that customer capital has been transformed through service personalisation, self-service platforms, and the integration of the Internet of Things. The study determined that Kyivstar increased service efficiency with digital revenue in 2025 increased 4.7 times to USD 124 million (a 4.9-fold increase to UAH 5.2 billion) and reached 10.7% of total revenue. In the fourth quarter of 2025, revenue from digital services grew 6.1 times to USD 50 million (a 6.4-fold increase to UAH 2.1 billion) and accounted for 15.7% of total revenue. The share of multiplay users increased 18.0% year-on-year to 7.3 million, representing 35.0% of active monthly mobile subscribers. The study showed that Vodafone invested more than UAH 6 billion in network modernisation and deployed 7,252 LTE stations. The study determined that Lifecell increased Internet speed by 20-30%These changes strengthened human, structural, and customer capital and supported the innovative development of telecom operators. The practical significance of the study is determined by the applicability of the results in the development of effective strategies for the digital transformation of telecommunications companies and improving the effective management of their intellectual capital

Keywords: cloud technologies; automation; innovation; personalisation; productivity; subscriber loyalty

Introduction

Telecommunications companies operate in a rapidly changing technological environment, where the implementation of digital solutions is becoming a key factor in development. Digital tools enable companies to optimise their operations, improve process efficiency and create new services for users. In such conditions, intellectual capital becomes a strategic resource that ensures a company's ability to innovate, adapt to change and maintain competitiveness in the market.

Research shows that the digital transformation of the telecommunications industry has a multi-vector impact that encompasses the technological base, staff competencies, approaches to customer service, and the strategic sustainability of business models. A. Jafor *et al.* (2024) emphasised that the key driver of these changes is the transition to cloud technologies. Cloud solutions not only optimise internal infrastructure but also ensure high scalability and operational efficiency in resource management. Thus,

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cloud computing is becoming a basic structural element on which other digital solutions are built. In turn, the effectiveness of this infrastructure largely depends on the level of staff training. J. Stofkova *et al.* (2022) emphasised that the development of employees' digital skills stimulates innovation and increases companies' ability to adapt to market changes. Staff with new competencies interact much better with digital platforms, operate large data sets and can initiate process improvements. This means that human capital becomes not just a resource for servicing technical systems, but an active agent of digital transformation. M. Celestin *et al.* (2024) proved that personalised services and self-service platforms significantly increase customer loyalty. Analytical tools can be used to repurpose data on user behaviour to generate individualised offers and recommendations. This transforms customer interactions from transactional to long-term and value-oriented. Thus, digital services become a mechanism for forming a stable consumer base and increasing the value of the customer portfolio.

Digitalisation not only increases loyalty but also significantly improves the cost and operational model of the business. L. Xia *et al.* (2024) demonstrated that the introduction of digital tools provides simultaneous revenue growth and cost reduction through the automation of routine operations. Automated processes are faster and more accurate, which reduces errors and lightens the workload on staff. This is consistent with the research of M.V. Vasylkivskyi *et al.* (2024), emphasising that network automation and virtualisation can significantly reduce service time, optimise infrastructure capacity utilisation, and accelerate the deployment of new services. In other words, the structural capital of companies, including their networks, technologies, and architecture, becomes more productive and focused on rapid scalability. The range of digital solutions is expanding thanks to the Internet of Things (IoT), which, according to Z. Rehman *et al.* (2023), can be used to manage resources more efficiently and create smart services with a high level of accuracy and automation. IoT technologies generate large data flows that can be used to monitor infrastructure, predict loads and improve service quality. This helps companies not only optimise costs but also strengthen their competitive position by offering more innovative and adaptive services. Notably, the development of IoT and other digital technologies is impossible without a high level of digital competence among staff. Therefore, T. Ciarli *et al.* (2021) emphasised that training employees in digital and information technologies provides the basis for creating innovative solutions and strengthens human capital. New skills facilitate the faster implementation of digital initiatives, which accelerates the company's adaptation to technological trends and sharpens its innovative potential.

At the same time, according to H. Ji *et al.* (2022), the digitalisation of corporate processes significantly increases the adaptability of companies to dynamic changes in the external environment. The integration of digital platforms accelerates the analysis of existing trends, updates business processes, and responds to market challenges. As a result, companies become more flexible, reduce decision-making time, and better maintain their competitive positions in conditions of high uncertainty. The formation of a sustainable business model largely depends on effective data management. F. Xiong *et al.* (2022) proved that competent data processing increases the value of a company's intangible assets. Analytical tools can be used by companies to predict customer behaviour, develop new approaches to customer service and improve service quality. As a result, customer capital becomes not only broader but also more valuable, as it is based on an accurate determination of user needs. A study by L. Melnyk *et al.* (2024) emphasised that digital transformation creates a synergy effect between human, structural and customer capital. The development of staff competencies ensures the effective use of technology; structural innovations form the infrastructure for flexible management; and improving the quality of customer interaction strengthens loyalty and long-term business stability. Thanks to the interaction of these components, companies not only increase productivity but also strengthen their strategic positions, making digitalisation a fundamental factor in their competitiveness.

The results of these studies have shown that digital transformations significantly increase the effectiveness of various components of telecommunications companies' intellectual capital and contribute to improving their productivity and economic performance. However, it remains insufficiently studied which specific digital strategies and practices ensure maximum synergy between human, structural and customer capital, which requires further research. The study aimed to investigate the impact of digital transformations on the development of the components of intellectual capital of telecommunications companies and their contribution to improving competitiveness and financial results. The study goals included: to examine the specific features of the impact of digital transformation on the human, structural and customer capital of companies, to assess the relationship between the development of intellectual capital and the performance of telecommunications operators, to analyse digitalisation practices using the example of leading telecommunications companies in Ukraine, such as Kyivstar, Vodafone Ukraine and Lifecell.

Materials and Methods

The study included a comprehensive analysis of the transformation of telecommunications companies' intellectual capital under the influence of digital technologies. To assess the digital transformation of telecommunications companies, data on the global growth in the number of Internet users worldwide from 2005 to 2025, provided by TVTechnology (2025), was used to analyse the impact of digital solutions on customer service efficiency and internal process optimisation. Human capital research was conducted by analysing the transformation of employees' professional skills in the areas of artificial intelligence (AI), cyber security, 5G networks, IoT and Big Data

(Alamuri *et al.*, 2025). The following methods were used to assess the effectiveness of staff development: studying corporate training programmes (internal and external training in digital technologies and cybersecurity), analysing retraining programmes aimed at mastering AI, Big Data and cloud platforms, and analysis of employee participation in practical technology projects and mentoring, which increases the innovative potential of personnel (Ewim *et al.*, 2021). The role of creativity and innovation capacity was assessed through an analysis of corporate practices for stimulating the generation of new ideas and non-standard solutions (Gui *et al.*, 2022). Methods of adapting human resource policies to global competition for talented specialists were also studied, in particular, the creation of attractive working conditions and human capital development programmes (Erkkilä *et al.*, 2023).

To determine the impact of structural capital on the development of telecom operators, data from Gitnux (Linder, 2025) was used to assess changes in network performance, company productivity, and financial results. Operational activities were studied by analysing the integration of automated resource management platforms and evaluating the use of analytical platforms and AI solutions to forecast demand for services and optimise network load. Digital ecosystem implementation practices were assessed through the analysis of the integration of IoT, Smart City, and Industry 4.0 services, which provide centralised data management and interaction between digital products. Data security methods were examined by analysing multi-level cyber protection systems, network monitoring and backup to support the reliability of the information infrastructure and the stability of business processes.

To assess the role of structural and customer capital, statistical analysis of the WifiTalents Team (2025) data was used, which showed the share of telecom companies that have implemented or strengthened digital transformation initiatives, invested in data analytics, integrated IoT platforms, and automated operational processes. Service personalisation methods included analysis of machine learning algorithms and intelligent customer interaction systems, which can be used to predict the needs of different user categories and forming individual offers. Approaches to integrating digital self-service platforms, mobile applications, and online chats that provide customers with round-the-clock access to services were also evaluated. To improve service quality, methods for monitoring service quality, ensuring network connection stability, and automated user support systems were studied. Lastly, to assess the effectiveness of partner ecosystems, an analysis was conducted of the integration of IoT solutions, digital platforms, and third-party services, which enables comprehensive B2B and B2C customer service and increases the value of customer capital.

For practical analysis, the study covered the activities of Ukrainian telecom operators Kyivstar, Vodafone Ukraine, and Lifecell. These companies were selected for practical analysis due to their leading position in the Ukrainian market, active implementation of digital technologies, and diverse experience in transforming intellectual capital. Their implementation of IoT solutions, cloud services, digital customer engagement platforms, AI, and cybersecurity systems was studied. This was used to illustrate the real mechanisms of digital transformation and assess their impact on the development of human, structural, and customer capital.

The study included an analysis of the benefits of digitalisation, such as accelerating technological innovation, developing new services for corporate clients (B2B) and end consumers (B2C), strengthening cyber security, optimising costs and increasing revenues. It also examined the challenges of digital transformation, including the shortage of highly skilled professionals, the need for significant capital investment, the growth of cybersecurity risks, and the need to change corporate culture. Studying these aspects provided a comprehensive overview of digital transformation processes and laid the groundwork for further analysis of the economic and strategic impact on telecommunications companies.

Results

The number of Internet users worldwide is constantly growing, reflecting the gradual global digitisation of the population and the increasing integration of digital technologies into everyday life. The increase in the number of users reflects not only the expansion of access to the network, but also changes in the ways people communicate, work, learn and do business. This growth contributes to the development of e-commerce, digital services and online platforms, stimulates innovation in information technology and increases the importance of the internet as a tool for sharing information and providing services. At the same time, the proportion of the population using the internet is growing, indicating the gradual inclusion of different regions of the world in the global digital economy and the creation of conditions for greater integration of information resources into social and economic processes (Table 1).

Table 1. Number of Internet users worldwide (2005-2025)

Year	Number of users (billion)	Population percentage (%)
2005	~1	~15%
2006	~1.1	~17%
2007	~1.2	~18%
2008	~1.4	~20%
2009	~1.7	~23%
2010	~2	~27%

Continued Table 1

Year	Number of users (billion)	Population percentage (%)
2011	~2.1	~29%
2012	~2.3	~31%
2013	~2.5	~34%
2014	~2.7	~37%
2015	~3	~40%
2016	~3.3	~44%
2017	~3.5	~47%
2018	~3.8	~50%
2019	~4.2	~54%
2020	~4.7	~58%
2021	~5	~61%
2022	~5.3	~64%
2023	~5.5	~67%
2024	~5.8	~69%
2025	~6	~72%

Source: compiled by the author based on TVTechnology (2025)

Between 2005 and 2025, there was steady and significant growth in the number of Internet users worldwide, indicating a gradual global digitalisation of the population. In 2005, the number of users was approximately one billion, corresponding to approximately 15% of the world's population, while by 2015 this figure had grown to three billion, or approximately 40%. The trend continued in the following years: by 2020, the number of users exceeded 4.7 billion, covering 58% of the population, and by 2025, the number of users is expected to reach six billion, accounting for about 72% of the world's population. This dynamic demonstrates not only the expansion of internet access, but also the increasing role of digital technologies in everyday life and economic activity, stimulating the development of online services, e-commerce and digital infrastructure around the world.

Technologies require new competencies in cybersecurity, big data processing, cloud technologies, AI management, and 5G and 6G network operation. Presence of such skills not only maintains existing systems among staff but can also be used to create new services, improve operational efficiency, and provide additional value to the enterprise. Employees become active participants in digital transformations, and their competence forms the basis for the company's competitive advantages in the telecommunications market (Alamuri *et al.*, 2025).

To adapt to digital changes, companies actively encourage continuous learning and retraining of staff. This includes corporate training, participation in internal and external educational programmes, practical projects, and mentoring. This approach can be used by employees to master new technologies, including AI, blockchain, and automation, as well as develop key professional skills: digital literacy, data analytics, cybersecurity, and adaptability to new technologies. In addition, soft skills such as creativity, problem-solving and emotional intelligence are becoming increasingly relevant as people collaborate with AI systems. Continuous learning creates the conditions for a flexible and motivated workforce that can respond quickly to changes in technology and the market, increasing productivity and reducing the risk of the company falling behind its competitors. Successful strategies include partnerships with educational institutions, internal training programmes, and the integration of flexible work cultures, which ensure the effective transformation of work functions and prepare staff for the future digital environment (Ewim *et al.*, 2021).

Employees who can generate new ideas and find unconventional solutions become key assets of the company. The development of innovative thinking contributes not only to improving the quality of products and services, but also to strengthening intangible assets such as patents, copyrighted developments and intellectual systems, which directly increases the productivity of individual companies and the efficiency of the division of labour between them. The study established that companies that invest heavily in intangible assets, especially young and small ones, benefit significantly from easier financing, particularly through bank loans, shareholder financing and government support. This creates favourable conditions for the rapid launch of new technological solutions and support for the company's innovation strategy in the market, as well as partially offsetting the financial barriers that hinder the development of innovative enterprises (Gui *et al.*, 2022).

Competition for talented specialists in the global labour market is forcing companies to adapt their HR policies. Companies strive to provide their employees with attractive working conditions: opportunities for professional development, participation in strategic projects, the use of advanced technologies, flexible schedules and remote work. This focus on personnel helps to increase employee loyalty, reduce staff turnover and build stable human capital capable of supporting and accelerating digital transformation processes. According to international rankings such as the Global Competitiveness Index, Global Innovation Index,

Global Talent Competitiveness Index, and Global Power City Index, countries and cities with high competitiveness and innovation scores demonstrate a greater ability to attract and retain talented professionals, underscoring the strategic importance of effective human capital management for companies (Erkkilä *et al.*, 2023).

Thus, digital transformations are changing human capital in telecommunications companies, making it a central factor in development and innovation. Investments in skills upgrading, creativity development and adaptation to new technologies are becoming strategic for achieving competitive advantages. Highly skilled and innovative staff form the basis for companies' economic growth and ensure their sustainability in a rapidly changing digital environment. Digital transformations have significantly influenced the development of structural capital, which encompasses digital infrastructure, information systems, corporate standards, databases, and internal business processes (Table 2).

Table 2. The effects of digitalisation on operational efficiency and structural capital

Metric/change	Value/percentage
Percentage of telecoms companies that consider digital transformation critical to growth	85%
Percentage of operators reporting increased network performance or efficiency after DT	70%
Reducing operating costs through digital initiatives	-1520%
Growth in revenue per user (ARPU/revenue per subscriber)	+12%
Percentage of operators who used Big Data/analytics for personalisation or forecasting	7480%

Note: DT – digital transformation; ARPU – average revenue per user
Source: compiled by the author based on J. Linder (2025)

The data shows specific economic benefits of digitalisation for telecom operators. For example, a 12% increase in ARPU and a 70% increase in network efficiency among operators demonstrate the direct impact of digital technologies on revenue and productivity. The simultaneous reduction of operating costs by 15-20% and the widespread adoption of Big Data and analytics (74-80% of operators) underscore the strengthening of structural capital through process optimisation, the use of cloud platforms and network virtualisation, which can be used for rapid service scaling and the implementation of new business models.

Automation of internal processes has reduced the time required to perform routine operations, improved data accuracy, and reduced management costs. The use of cloud platforms has enabled centralised storage and processing of information, as well as simplified service scaling; 58% of smart city projects use cloud platforms, and edge computing is used in 35% of cases for local data processing. Big Data analytics has made it possible to evaluate process efficiency in real time, predict network load, and make informed management decisions; AI technologies have been implemented in 26% of projects to optimise traffic, energy consumption, and maintenance. In addition, digital innovations such as personalisation, self-service and behavioural pricing have significantly impacted the customer experience: the use of self-service platforms has increased customers' sense of influence and control, and IoT solutions for energy and waste management have been implemented in more than 45% of cities. As a result, telecommunications companies have been able to improve productivity, adaptability and resource management quality, while balancing the efficiency of digitalisation with the preservation of human contact to maintain long-term customer trust (Industry Research, 2025).

The introduction of new products and business models has become a key factor in strengthening structural capital. The growth of population density in cities and the need to improve the quality of urban services have stimulated the widespread adoption of digital technologies: in the last decade alone, the number of digital devices such as sensors, actuators, smartphones and smart appliances has grown significantly, creating the basis for the development of the IoT. This foundation has shaped the concept of Smart City, which uses information and communication technologies to improve the efficiency of urban operations and the quality of interaction with the population. IoT services, Smart City solutions and Industry 4.0 approaches have made it possible to integrate various digital services into a single ecosystem, providing companies with new sources of revenue and promoting the development of innovative areas of activity. New business models involve the use of data as a strategic resource, enabling the creation of personalised products and strengthening interaction with customers and partners, while the expansion of digital capabilities supports long-term development and competitiveness. The development of digital infrastructure has become one of the central elements of structural capital. The deployment of 5G networks, the introduction of virtualised Software-Defined Networking (SDN) and Network Function Virtualisation (NFV), as well as edge computing, have significantly increased data processing speed and service scalability. Such technologies enable high data transfer speeds comparable to LTE (up to 300 Mbit/s for reception and 75 Mbit/s for transmission), ensure low latency, and improve the integration of IoT devices into smart city infrastructures compared to Wi-Fi, Bluetooth, Zigbee and Z-wave (Nassereddine & Khang, 2024).

Research into the implementation of integrated SDN-NFV architecture showed that upgrading the network infrastructure, in particular replacing standard virtual switches with DPDK and SR-IOV-based solutions, increased throughput to 200 Mbit/s at the server level and up to 1.6 Gbit/s at the edge nodes, while reducing latency to 12 ms and 17 ms, respectively. In addition, optimised

network management reduced operation execution time by 9-22 minutes, depending on the scenario (Surantha & Putra, 2022). This increase in performance has enabled companies to launch new products faster, improve service availability for corporate and private users, and manage network resources efficiently. Digital infrastructure has become the foundation for the development of new technologies, including automated control systems, AI solutions, and analytics platforms.

Fifth-generation technologies, together with IoT, create substantial infrastructure capable of connecting billions of devices with high speed, reliability and availability. At the same time, the integration of 5G-IoT has not yet been sufficiently studied in terms of security and management, which leads to a lack of practical solutions. The use of these technologies increases the efficiency, flexibility, scalability and simplicity of data analysis, but at the same time requires a number of issues to be addressed, including architecture design, coordination of interaction between devices, and ensuring confidentiality and cybersecurity. One promising approach is to ensure the compatibility of all operating systems and implement open standards for seamless data exchange, which improves security through intelligent identification and authorisation mechanisms. Such solutions guarantee users a constant and secure connection, improving the user experience, while the implementation of the full potential of 5G requires an in-depth study of technical challenges and coordination of efforts at the industry level (Ahmed *et al.*, 2024).

Thus, digital transformations have turned structural capital into an integrated system of technologies, processes, and standards that ensures management efficiency, business scaling, and innovation development. Investments in automation, cloud platforms such as Amazon Web Services, Microsoft Azure and Google Cloud Platform, infrastructure development and cyber security enable companies to increase productivity, create additional economic value and strengthen their competitive position in the telecommunications market. Digital transformations have changed telecommunications companies' approach to customer capital management, defining the value of interactions with subscribers and corporate customers (Table 3).

Table 3. The impact of digital initiatives on customer capital and subscriber engagement

Metric/change	Value/percentage or trend
Percentage of telecoms companies that have stepped up their digital transformation initiatives since 2020	75%
Improved operational efficiency in companies that have implemented DT	+30%
Percentage of operators that increased investment in data analytics	70%
Percentage of operators that have integrated IoT platforms into their digital infrastructure	60%
Percentage of companies that see DT as key to future development of 6G/new networks	more than 80%

Source: compiled by the author based on the WifiTalents Team (2025)

The data shows how digital initiatives increase the value of customer capital by expanding opportunities for interaction with subscribers through mobile applications, IoT platforms, and personalised services. The high proportion of companies that perceive digital transformation as key to the development of 5G, 6G, and new networks indicates strategic planning and a focus on long-term customer loyalty. The results emphasise the significance of combining technological solutions and engagement strategies to enhance the effectiveness of B2B and B2C services and strengthen competitive positions in the market.

The transition to customer-oriented digital platforms, self-service services, and mobile applications has enabled companies to provide more convenient, faster, and more accessible services to various categories of users. Customers gained the ability to independently manage services, connect new tariffs and services, pay bills, and receive online support without having to visit offices in person. The introduction of cloud computing into digital platforms has made it possible to efficiently manage large amounts of data in real time, increase the speed of information processing, and improve the accuracy of consumer and operational data analysis. The use of parallel data processing models such as Hadoop, Spark, and Storm has ensured the flexibility and scalability of systems, ensuring quick response to changes in demand and load. The integration of cloud solutions has significantly improved the performance of digital services and the stability of platforms, providing users with more timely and reliable access to services (Al-Jumaili *et al.*, 2023). Personalisation of services has become a key element in strengthening customer capital. The use of Big Data analytics, intelligent customer interaction systems, and machine learning algorithms has made it possible to offer users personalised services, optimise communication, and predict customer needs. These approaches have contributed to an increase in average revenue per user, greater loyalty, and a reduced risk of subscriber churn. Companies were able to plan marketing campaigns more effectively, create targeted offers, and form deeper relationships with customers, which contributed to an increase in long-term customer value (Talebkhah *et al.*, 2023).

Network technologies such as IoT, SDN, NFV, Docker containers, cloud computing, edge computing, and AI-based networking enable companies to efficiently collect, process, and analyse large amounts of data in real time. The implementation of deterministic and time-sensitive network solutions and advanced 5G/6G mobile technologies provides high data transfer speeds of up to 10 Gbit/s and low latency, less than 1 millisecond, which is critical

for services with high-quality service requirements, such as industrial automation systems, autonomous vehicles, and augmented reality applications. These innovations enable the creation of personalised, scalable and integrated digital services, improving service efficiency and user satisfaction (Beshley *et al.*, 2023). The development of partner ecosystems has become a substantial factor in supporting customers in both the B2B and B2C segments. The integration of IoT solutions, digital platforms, and partner services has enabled companies to offer comprehensive products and services covering various aspects of digital interaction. For business customers, this resulted in increased operational efficiency, process automation, and rapid technology integration, while private users gained access to innovative services and personalised digital solutions. This approach expanded the range of services offered by companies, increased the economic value of customer capital, and helped strengthen long-term partnerships (Saeed *et al.*, 2023). Thus, the introduction of customer-centric digital platforms, self-service and mobile applications, the use of cloud computing, Big Data analytics, intelligent systems and advanced network technologies (IoT, SDN, NFV, Edge Computing, 5G/6G) has enabled telecommunications companies to provide fast and personalised service, optimise real-time data processing, predict user needs and create targeted offers.

Digital transformation is a key factor in the development of telecommunications companies in Ukraine, strengthening various components of intellectual capital: human, structural and customer. The country's leading operators are actively integrating digital technologies into their business processes, which contributes to increased efficiency, expanded services, and strengthened competitive positions in the market (Table 4).

Table 4. Comparison of digital transformation practices of leading telecommunications companies in Ukraine and their impact on capital and financial results

Company	Key DT priority	Impact on human capital	Impact on structural capital	Impact on client capital	Key financial/operational result
Kyivstar	AI, Smart services, My Kyivstar, cybersecurity, digital infrastructure development	The development of skills in working with AI and analytical platforms, improving staff efficiency	Optimisation of request processing, integration of digital platforms	Expanded digital services, improved network resilience Broadened access to essential connectivity, enhanced service reliability Growth in the share of digital sales and improved quality of experience	Digital revenue in 2025 increased 4.7 times to USD 124 million (a 4.9-fold increase to UAH 5.2 billion) and reached 10.7% of total revenue. In the fourth quarter of 2025, revenue from digital services grew 6.1 times to USD 50 million (a 6.4-fold increase to UAH 2.1 billion) and accounted for 15.7% of total revenue. The share of multiplay users rose 18.0% year on year to 7.3 million, representing 35.0% of active monthly mobile subscribers
Vodafone Ukraine	IoT, cloud services, Big Data	Improved staff skills in cloud technologies and analytics	Optimisation of internal processes, scaling of the network and digital products	Improved accessibility and speed of service, enhanced service quality	Investments in network and digital systems >6 billion UAH; increased network performance and stability
Lifecell	eSIM, digital identification, service automation	Improved staff skills, rapid adaptation to new technologies	Optimisation of internal processes, reduction of customer service time	Growth in the share of digital sales, increased availability and speed of digital services	increase in internet speedservice continuity and increased network performance

Source: compiled by the author

Kyivstar (2026b) actively uses AI, Smart services, the My Kyivstar platform, and cybersecurity services, which are used to personalise services, automate request processing, and improve service quality. These initiatives have contributed to ARPU growth, an increase in the share of multi-service subscribers, and a reduction in customer churn, with digital revenue in 2025 increased 4.7 times, reaching USD 124 million strengthening the company's customer and structural capital.

Vodafone Ukraine is focusing its digital transformation on IoT, cloud services, and Big Data analytics, which improves the efficiency of working with corporate customers. Significant investments in technological infrastructure (UAH 6.215 billion in 2024) and network modernisation have made it possible to increase the speed and reliability of data processing, restore more than 1,000 base stations and deploy 7,252 LTE stations, strengthening structural capital, enabling service scaling and supporting the launch of new digital products (Kabachinsky, 2026).

In the fourth quarter of 2025, Kyivstar showed revenue growth of 28.4% to USD 321 million (by 30.1% YoY to UAH 13.5 billion), reflecting the consistent implementation of the converged services and digital transformation strategy. Mobile ARPU increased by 18.2% YoY to USD 3.8, and the share of users who switched to 4G tariffs increased by another 5.9 pp. Revenue from digital services

increased by 6.1 times YoY to USD 50 million (6.4 times to UAH 2.1 billion), reaching 15.7% of total revenue, of which Uklon's contribution amounted to USD 34 million (UAH 1.4 billion). The number of multiplay users – those who simultaneously use voice services, 4G Internet and at least one digital application – increased by 18.0% YoY to 7.3 million, which is 35.0% of active mobile subscribers for the month. The expansion of Kyivstar's portfolio of services is increasingly integrating the company into the daily life of customers.

EBITDA increased by 21.7% to USD 172 million (by 23.1% to UAH 7.2 billion) in the fourth quarter of 2025, driven by revenue growth and disciplined cost control. EBITDA margin decreased by 2.9 pp YoY to 53.5%, which is in line with Kyivstar's previously announced targets, while the intensity of capital investments increased to 36% of revenue against the backdrop of seasonal factors and investments in network and energy sustainability.

The Kyivstar (2026c) expanded its digital healthcare services by acquiring Tabletki.ua in February – Ukraine's leading online marketplace for medicines and health products – for USD 160 million. Kyivstar (2026a) has extended Starlink Direct to Cell services to all its 4G users, and nearly 5 million subscribers have already used the basic text-messaging capabilities. The launch of voice services and low-bandwidth data transmission is planned for later in 2026.

In December, the Kyivstar (2025) acquired LLC "SANVIN 11", the owner of a 12.9 MW solar power plant. This investment enables Kyivstar to diversify its energy sources and reduce risks related to energy supply. In February 2026, Kyivstar also announced the acquisition of the internet provider "Shtorm", expanding the Group's share in the highly fragmented fixed broadband market.

Lifecell (n.d.) is implementing eSIM, service automation and digital identification, which reduces service time and increases the share of digital sales. Digital initiatives contribute to the development of staff competencies and increase the productivity of internal processes. Thanks to 4G modernisation and a stable network infrastructure the average mobile internet speed has increased by 20-30%, which improves the company's flexibility, efficiency and competitive position.

Thus, the digital transformation of Ukraine's three leading mobile operators demonstrates the systematic strengthening of their customer, structural and human capital through the large-scale implementation of innovative technologies. The development of AI solutions, cloud platforms, smart services, IoT infrastructure, eSIM and digital identification ensures revenue growth, increased productivity of internal processes, expansion of multi-service capabilities and improved quality of subscriber service. Significant investments in network modernisation, management automation and infrastructure resilience enable operators to maintain a high level of technological readiness, ensure communication stability even in crisis conditions and maintain service continuity. As a result, digital initiatives create a sustainable competitive advantage in the market, contribute to the financial growth of companies, and lay the foundation for further innovation in Ukraine's telecom sector.

As of early 2025, approximately 31.5 million people in Ukraine used the internet, and the network penetration rate reached approximately 82.4%, indicating a high level of digitalisation among the population and active use of digital services, including telecommunications services. 94.1% of mobile connections in Ukraine were broadband (3G/4G/5G), which is a relevant component of the digital transformation of the telecom industry (Zinchenko, 2025). Digital transformations contribute to the acceleration of technological development. Cloud platforms, Big Data analytics, AI, and 5G/6G networks are used by telecom operators to quickly adapt to changes in the tech environment, introduce new services, and make internal processes more efficient. Thanks to AI technologies such as machine learning and deep learning, systems can automate, analyse data, gain predictive insights and adapt to new conditions.

The number of connected wireless devices worldwide has grown from 11.5 billion in 2020 to 31.6 billion in 2023, illustrating the scale of traffic growth and the need for network automation. AI enables the next generation of wireless networks to automatically exchange information between "smart" applications, significantly improving network performance. 5G networks provide high data transfer speeds and low end-to-end latency, while URLLC services guarantee latency of less than 1 ms, which is critical for controlling smart devices, remote medicine, and industrial robots. This approach reduces time to market, increases responsiveness to customer needs, and strengthens the company's position among competitors (Alhammadi *et al.*, 2024).

The increase in the value of intangible assets is a significant outcome of digital transformation. Data, software solutions, digital platforms, intelligent management systems, and patents are becoming strategic resources that support business development. Strengthening intellectual property protection has a positive impact on the process of data capitalisation: an analysis of a long-term panel sample of Chinese companies for 2011-2022 showed that effective IP protection increases both the resources for data capitalisation and the willingness of companies to use them. The greatest effect is observed in private companies, high-tech industries, and regions with developed digital infrastructure. Thus, intangible assets form the basis for new business models and create additional economic value for the company, which directly affects its financial results and investment attractiveness (Wang & Dong, 2025).

Expanding the competencies and creative capabilities of staff contributes to increased productivity and human capital development. Employees acquire new skills in cybersecurity, big data processing, AI management, and digital networks, which increases their ability to generate innovative solutions. Research confirms that the systematic strengthening of human resource competencies, combined with the active use of technology and

diversification of activities, significantly increases the productivity of enterprises: for example, analysis of small and medium-sized businesses has shown that the combination of these factors has a positive and statistically significant impact on their sustainable operations, with a coefficient of determination of 72.3%. In addition, effective personnel development and support from public policy are fundamental in ensuring the stability and growth of enterprises. This ensures quick adaptation to change, efficient resource utilisation, and the maintenance of high intellectual value (Hernita *et al.*, 2021).

Digitalisation enables companies to optimise operating costs and improve key financial indicators. Studies show that companies that actively implement digital technologies can reduce operating costs by approximately 30%, increase ARPU by 20%, increase earnings before interest, taxes, depreciation and amortisation (EBITDA) by 25% and improve return on assets by 15% compared to less digitised companies, indicating significant economic benefits from the implementation of digital solutions (according to a business process optimisation model using AI and big data analytics) (Liao *et al.*, 2025). This confirms that process automation, analytics and cloud technology implementation directly impact the financial performance and economic sustainability of companies, contributing to increased productivity and reduced costs. These trends are reflected in studies on digital business transformation, which indicate the positive impact of digital solutions on the performance and competitiveness of enterprises. Thus, digital transformation comprehensively strengthens the intellectual capital of telecom companies, increasing business flexibility, service quality and financial results. The integration of AI, Big Data and cloud solutions contributes to the creation of new sources of value and the formation of effective business models. This strengthens the market position of operators and ensures stable long-term development.

In the process of digital transformation, telecommunications companies face several systemic constraints that slow down modernisation and affect the effectiveness of innovation implementation. Despite the active introduction of AI, big data, automation and cloud solutions, the industry needs more developed organisational, human resource and financial prerequisites. Therefore, the ability of companies to identify and remove internal and external barriers that hinder the formation of a sustainable digital ecosystem is becoming a key condition for successful transformation (Mahboub & Sadok, 2024). One of the main constraints is the shortage of highly qualified personnel. The effective implementation of technologies such as AI, Big Data analytics, cloud platforms and 5G/6G networks requires employees with specialised knowledge and experience. A study of digital literacy among higher education students (N = 324) showed that the level of training of future specialists is uneven: the lowest scores were in working with digital information, particularly in the ability to assess data quality and identify source bias. The highest results, on the other hand, were in social digital literacy, such as the skills of proper online communication. Although the difference between the studies was insignificant, experience and length of study had a positive impact on the level of digital competence. These results indicate that the modern level of training does not fully meet market requirements, which creates competition for specialists and complicates the formation of strong human capital and the development of innovative projects (Morgan *et al.*, 2022).

The implementation of digital technologies requires significant financial resources. Investments in infrastructure development, the purchase of licensed software, and the implementation of cloud platforms and cybersecurity systems create high capital expenditures, which increase OPEX. Research on the digitalisation of small professional service firms shows that even organisations with limited resources recognise both the opportunities and risks of digital transformation, but the complexity of the technological environment and the instability of the innovation landscape often led to organisational tensions and inhibit decision-making. Such firms tend to adopt a "selective digitalisation" approach, where investments in technology are made selectively depending on the innovation orientation of management and staff. At the same time, expanding cooperation with technology providers and partners creates additional costs for coordination and network management. Therefore, telecommunications companies should carefully plan financial policies and ensure the efficient use of resources to benefit from the economic effects of digitalisation and avoid overspending (Cardinali *et al.*, 2023).

Increased cyber risks are another significant challenge. The expansion of digital platforms, growth in data volumes and integration of IoT solutions create additional vulnerabilities for cybersecurity. Research on sustainable digitalisation emphasises that cyber threats can undermine environmental, social and economic sustainability, as privacy breaches, data leaks or digital system failures can have significant socio-economic consequences. Therefore, cybersecurity must be considered an integral part of sustainable digitalisation, requiring flexible policies and regulations that can adapt to the rapid changes in the digital environment. Experts also emphasise the importance of a multi-stakeholder approach involving the state, business and users for effective risk management. The implementation of comprehensive data protection systems, network monitoring and backup procedures is critical to minimising the risks of information loss, financial loss or reputational damage (Goswami *et al.*, 2023).

Equally relevant is the transformation of corporate culture and the adaptation of business processes. The introduction of new technologies requires a change in management approaches, greater openness to innovation, flexibility, and the ability to make quick decisions. Research based on the theory of innovation adoption and a systematic review of the literature for 2011-2024 shows that organisational culture is a key factor in the successful implementation of Business Process Management. Companies with a culture focused on innovation, collaboration and continuous

improvement have a significantly higher level of acceptance of Business Process Management, while barriers such as resistance to change and risk aversion significantly reduce the effectiveness of digital transformations and employee satisfaction. This highlights the need to create an adaptive and innovative environment in which companies encourage staff training, implement cross-functional teams and change internal processes to effectively integrate digital tools (Lima *et al.*, 2025).

Thus, overcoming personnel, financial, cybersecurity, and cultural barriers is a fundamental condition for the successful digital evolution of telecom companies. By building strong human capital, ensuring cyber security, optimising investments and creating an innovation-oriented corporate culture, companies can significantly improve the efficiency of their business processes. This not only minimises risks but also ensures strategic stability, rapid scaling of digital services and long-term growth in competitiveness in the context of dynamic market changes.

Discussion

The analysis of the results showed that digital transformations had a significant impact on the development of human capital in telecommunications companies. The introduction of continuous learning programmes and internal training ensured quick adaptation of staff to new technologies, increasing creativity and innovative potential, which was reflected in productivity and the ability to create added value for the company. This issue was also studied by P. Ueasangkomsate & T. Soodsom (2024), confirming that telecom companies need employees who possess relevant digital skills and can utilise innovative technologies. Developing such competencies contributes to increased productivity, efficiency, and business competitiveness. Investments in human capital ensure the sustainable growth of companies and their ability to quickly adapt to technological changes. A. Arini & H. Respatiningsih (2024) also showed that the digital economy requires constant updating of knowledge and professional skills. Training and retraining help staff respond effectively to new challenges and master new tools. Supporting innovation within the team stimulates a creative approach to work and contributes to the formation of the company's competitive advantages. Analysis of the results shows that effective development of digital competencies requires a systematic approach that includes both technical training and the development of analytical thinking and communication skills. Telecom companies must provide access to learning platforms, practical training, and opportunities for professional growth. In addition, it is necessary to create a corporate culture prioritising innovation and continuous learning, which will ensure a smooth transition for employees adapting to rapid technological changes.

The study showed that structural capital also underwent significant changes under the influence of digitalisation. The study determined that process automation, cloud management systems and the use of big data analytics increase the efficiency of internal operations. In addition, the introduction of IoT services, Smart City and Industry 4.0 solutions created new sources of revenue and contributed to the development of innovative products. The expansion of digital infrastructure, including 5G, virtualised networks and edge computing, increased the scalability of services and the speed of launching new services. L. Broccardo *et al.* (2024) concluded that business process automation enables telecom companies to reduce costs, accelerate customer service, and improve service quality. The development of high-speed networks and the introduction of cloud platforms form the basis for scaling digital services and creating new products. Such modernisation strengthens the structural capital of enterprises and ensures stable development in the context of technological competition. A study by V. Stocker & G. Knieps (2021) determined that the expansion of digital infrastructure requires the transformation of organisational management models and the introduction of more flexible approaches to planning. Telecom companies are actively integrating innovative solutions such as AI and IoT technologies to optimise their operations. These changes contribute to the formation of telecommunications ecosystems capable of responding quickly to market and customer needs. These results confirm the above study, as they demonstrate a close link between the digital transformation of structural capital and the growth in efficiency of telecommunications companies. The introduction of automated systems and the latest technological solutions ensures the optimisation of internal processes and improved service quality. Thus, the modernisation of digital infrastructure is becoming a key factor in strengthening companies' competitive positions in the market.

Digital transformations were found to have a significant impact on customer capital. Companies implemented customer-centric digital platforms and self-service services, which increased the accessibility of services and simplified subscriber interaction with the company. Personalisation of services through big data analysis and IoT integration made it possible to predict user needs and increase ARPU, which strengthened customer loyalty and reduced churn. It is worth highlighting the study by J. Oumaima & S. Lamari (2024), demonstrating that personalisation of services improves awareness of the needs of their users and offer solutions that best meet their expectations. Digital platforms provide more convenient communication and self-service channels, which increase subscriber satisfaction. High-quality interaction with customers helps build trust in the company and strengthen its reputation in the market. In turn, M. Pereira *et al.* (2025) concluded that the use of digital tools not only expands the capabilities of the service but also creates an individual experience for each user. Analytics systems help predict customer behaviour and respond to their requests in a timely manner. As a result, higher loyalty and long-term customer capital value are formed, which has a positive impact on the financial performance of telecom companies. These data

correspond to the theses presented in the previous section, as they confirm the importance of digital tools for increasing subscriber satisfaction and engagement. Thanks to personalised services and convenient platforms, companies can form stronger and longer-lasting relationships with their customers. This, in turn, ensures sustainable growth in customer capital and strengthens the competitive advantages of telecom operators.

In addition, the study demonstrated the benefits of digital transformation for intellectual capital. The study determined that innovative approaches contributed to the growth of companies' intangible assets, increased staff competence and improved financial performance. Companies that effectively integrated digital technologies into all aspects of their operations achieved better adaptability to technological changes and gained competitive advantages in the market. Notably, R. Trequattrini *et al.* (2022) conducted a study, the results of which confirmed that digital transformation stimulates the development of innovative products and services, ensuring a quick response to market changes. It increases the adaptability of organisations by ensuring the rapid introduction of new technologies and processes. In addition, investments in digital solutions strengthen the intangible assets of enterprises, in particular their brand, reputation and staff knowledge. H. Halim *et al.* (2023) showed that a digital transformation strategy aimed at optimising the company's performance can be used for the improvement of operational processes and increased productivity. The use of data analytics, automation, and digital platforms contributes to more informed management decisions. This ensures increased competitiveness and sustainable long-term development of the company. Comparing the data obtained during the research, it is possible to argue that digital transformation directly affects the growth of the innovative potential and flexibility of telecom companies. It contributes to the accumulation of intangible assets, such as staff knowledge, brand and technological expertise, which increases the overall value of the enterprise. Therefore, investments in digital solutions are strategically relevant for strengthening the company's position in the dynamic communications market.

At the same time, the study revealed significant challenges faced by telecommunications companies. The main problems were a shortage of highly qualified personnel, high investment and operating costs, and increased cyber risks. In addition, companies were forced to transform their corporate culture to more effectively implement innovative processes and ensure organisational flexibility. Based on the results of the study, K. Uzule & N.Verina (2023) concluded that the digital transition of telecom companies faces staffing challenges related to a shortage of specialists capable of working with the latest technologies. Financial constraints can delay the implementation of digital platforms and network modernisation, limiting the scale of transformation. In addition, technological and security risks, including cyber threats and the complexity of integrating new systems, create additional barriers to an effective transition to digital models. Data from Y. Niu *et al.* (2023) show that the implementation of innovative technologies is often hampered by organisational inertia and staff resistance to change. A lack of financial resources and difficulties in integrating new systems can significantly slow down the pace of digital transformation. As a result, companies risk losing ground to competitors and missing opportunities to create new services and improve business process efficiency. An analysis of the study results revealed that the main threats to digital transition significantly affect the speed and efficiency of telecom companies' transformation. Personnel and financial constraints, as well as technological challenges and security risks, require a systematic approach to planning and managing digital projects. Only a comprehensive strategy that addresses these factors can minimise negative consequences and ensure the successful integration of innovations into business operations.

Based on the data obtained, it is possible to conclude that digital transformations played a key role in strengthening the intellectual capital of telecommunications companies. They simultaneously influenced human, structural and customer capital, ensuring increased productivity, the development of new services and the economic stability of companies. The results of the study emphasise the need for a comprehensive approach to the integration of digital technologies to achieve strategic competitive advantages in the market.

Conclusions

The study showed that the digital transformation of telecommunications companies has a significant impact on the development of human, structural and customer capital, increasing productivity and competitiveness. As of 2025, the number of Internet users worldwide reached ~6 billion people, or 72% of the population, and in Ukraine, about 31.5 million people used the Internet, which is 82.4% of the population. The growth in the number of users is accompanied by an increase in staff competence in the areas of AI, big data analytics, cybersecurity and 5G/6G networks, which is a key factor in successful digitalisation. The structural capital of companies has been strengthened through process automation, cloud platforms and analytical solutions: routine operations have been reduced by 30-40%, and 85% of operators consider digitalisation critical to development. 70% of companies report increased network productivity, and cost optimisation was 15-20%. The use of Big Data and IoT platforms has improved the accuracy of forecasts and the efficiency of resource management.

Customer capital was transformed through service personalisation, self-service platforms, and IoT ecosystem integration. Kyivstar revenue in Q4 2025 increased 28.4% to USD 321 million; mobile ARPU rose 18.2% year-on-year; digitalservices revenue grew 6.1× to USD 50 million (15.7% of total, including USD 34 million from Uklon); multiplay users increased 18% to 7.3 million; EBITDA rose 21.7% to USD 172 million with a 53.5% margin; capex

intensity reached 36% of revenue. Vodafone invested over UAH 6 billion, deploying 7,252 LTE stations, which improved network stability, while Lifecell increased internet speeds by 20-30%.

The results of the study confirmed the key benefits of digital transformation: increased innovation and creative potential of staff, accelerated adaptation to technological changes, growth in the value of intangible assets, process optimisation and improved economic efficiency. At the same time, the main challenges were identified, high investment costs, increased cyber risks, and the need to change corporate culture for rapid innovation implementation.

Thus, digital transformations have become a catalyst for strengthening the intellectual capital of telecommunications companies, creating conditions for sustainable development, increasing competitiveness, and achieving strategic advantages in the market. The limitation of the study is that the analysis was based on open data and reports from individual Ukrainian telecom operators, which may not fully reflect the situation in the global market. Prospects for further research include a detailed study of the impact of digital transformations on the long-term sustainability of intellectual capital and its relationship with the financial and non-financial performance indicators of telecommunications companies.

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None.

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Роль цифрової трансформації у формуванні та розвитку інтелектуального капіталу телекомунікаційних підприємств

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Анотація. За мету ставилося визначення того, як впровадження цифрових технологій змінює складові інтелектуального капіталу телекомунікаційних компаній та впливає на їхню ефективність і економічні результати. Для дослідження цифрової трансформації телекомунікаційних компаній використовувалися методи аналізу даних, інтеграції аналітичних та платформ штучного інтелекту, оцінки впливу Інтернету речей, хмарних сервісів та цифрових екосистем на ефективність бізнес-процесів, персоналізацію сервісів та розвиток інтелектуального капіталу. Було встановлено, що у 2025 році кількість інтернет-користувачів у світі досягла близько 6 мільярдів осіб (72 % населення), тоді як в Україні цей показник становив 31,5 мільйона осіб (82,4 % населення). Визначено, що структурний капітал телеком-операторів посилився завдяки автоматизації процесів, впровадженню хмарних платформ та аналітики даних; 85 % операторів вважають цифровізацію критичною для зростання, 70 % повідомили про підвищення продуктивності мереж, а операційні витрати знизилися на 15-20 %. Також встановлено, що клієнтський капітал трансформувався завдяки персоналізації сервісів, платформам самообслуговування та інтеграції Інтернету речей. Було з'ясовано, що Kyivstar підвищила ефективність обслуговування, цифрова виручка у 2025 році зросла у 4,7 раза – до 124 млн дол США (у 4,9 раза – до 5,2 млрд грн) і досягла 10,7 % у структурі виручки. У четвертому кварталі 2025 року дохід від цифрових сервісів у 2025 році зріс у 6,1 раза – до 50 млн дол. США (у 6,4 раза – до 2,1 млрд грн) і склав 15,7 % від загальної виручки. Частка користувачів пакетних послуг (multiplay-користувачів) зросла на 18,0 % р/р – до 7,3 млн, що становить 35,0 % активних мобільних абонентів за місяць. Дослідження показало, що Vodafone інвестувала понад 6 мільярдів гривень у модернізацію мережі та розгорнула 7252 LTE станції. Було визначено, що Lifecell підвищила швидкість інтернету на 20-30 %. Ці зміни зміцнили людський, структурний та клієнтський капітал і підтримали інноваційний розвиток телеком-операторів. Практичне значення дослідження полягає у тому, що його результати можуть бути використані для розробки ефективних стратегій цифрової трансформації телекомунікаційних підприємств та підвищення ефективного управління їх інтелектуальним капіталом

Ключові слова: хмарні технології; автоматизація; інновації; персоналізація; продуктивність; лояльність абонентів

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The agility approach as an accelerator for developing an organisation's dynamic resilience in ecosystem-based innovation management

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Abstract. The purpose of the study was to substantiate the role of agility practices as a catalyst for strengthening the dynamic sustainability of enterprises within the framework of ecosystem innovation management. The research methodology was based on the use of system structural and comparative analysis to identify the architectonics of agility processes, and logical modelling methods to assess their impact on the iterativeness of innovative development. It was accepted that in conditions of high market volatility, the agility approach is a key driver that ensures the speed of resource reconfiguration and the viability of business models. Conceptual parameters of flexible management (strategic lability, operational iterativeness, network coherence) and their role in the transition from static to dynamic stability models were considered. The level of integration of agility tools into the activities of contemporary Ukrainian enterprises in 2023-2025 was analysed, which allowed establishing a direct correlation between the speed of managerial decision-making and the organisation's resilience to external shocks. It was revealed that the main destabilising factors that restrain the effect of sustainability acceleration are the inertia of organisational structures, low digital capacity, and weak synergy of participants in the innovation ecosystem. Analysis of secondary data showed that ignoring these factors leads to a drop in innovation productivity by 25-30% and increases the time of adaptation to market changes by 35-40%, while gaps in network interaction reduce the level of ecosystem synergy by 20-25 %, which minimises the effectiveness of implementing agility tools. Based on the results of the study, a five-stage mechanism for deploying agility practices and a matrix of their functional role (from operational to cognitive levels) in ensuring the vitality of enterprises within open innovation ecosystems were proposed. It was proved that only the convergence of flexible management methods with strategic vectors of ecosystem interaction allows forming long-term dynamic stability and competitiveness of the enterprise

Keywords: acceleration of innovations; business models; strategic resilience; enterprise vitality; flexible management

Introduction

The current stage of development of enterprises is characterised by a radical complication of the operating conditions, which is manifested in the high variability of the external environment, non-linearity of economic processes, and the growing role of inter-organisational interaction in creating innovative value. In such circumstances, traditional management approaches lose their effectiveness, giving way to concepts focused on speed of response, flexibility of decision-making, and the ability to constantly update. One of these approaches is agility, which is increasingly considered not as a set of tools, but as a holistic management logic that determines new parameters of enterprise functioning

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in innovative ecosystems. The relevance of the study is conditioned by the fact that the introduction of innovations within ecosystems is accompanied by both expanding access to resources and increasing dependence on external participants, which increases the level of uncertainty and risks. Under such conditions, it is the agility approach that can serve as an accelerator, providing acceleration of the processes of adaptation, coordination, and transformation of business processes. Its practical implementation is complicated by a number of factors, including insufficient consistency of strategic and operational levels of management, limited organisational flexibility, and fragmented integration into innovation ecosystems.

A significant number of studies are devoted to the investigation of theoretical and practical aspects of implementing agility technologies and mechanisms of ecosystem innovation management. The fundamental principles of functioning of business accelerators and their role in technological transfer in the framework of systems scientific reviews were investigated by J.P. Hausberg & S. Corre (2020), emphasising the importance of co-quoting and networking for the success of startup ecosystems. The issue of functional specifics and operational gaps in the activity of contemporary accelerators was analysed in detail by J. Aljalhama & J. Slough (2022), which helps to better understand the mechanisms of stimulating innovation activity. M. Shkilniak & O. Tymkiv (2026) considered the conceptual framework for using agile technologies to improve the change management system in enterprises. The researchers analysed in detail the potential of flexible methods to increase the adaptability of management structures and identified the systemic advantages of switching from rigid hierarchies to iterative models. K. Bellavitis *et al.* (2024) paid particular attention to strategic changes in deep technologies and team management in conditions of high uncertainty; their findings confirmed the need for flexible reconfiguration of resources to maintain competitiveness. Further, A. Revenko *et al.* (2026) explored agile as a managerial innovation in project management. The researchers concluded that the effectiveness of a flexible approach depends on minimising the risks of simulated implementation, which is essential for ensuring real, rather than declarative, dynamic stability at the micro level.

N. Kotvytska *et al.* (2026) analysed the role of digital innovation as a driver of development and adaptive capacity of enterprises in a turbulent economic environment. They stressed that digital solutions are crucial for strengthening the viability of organisations through mechanisms for rapid reconfiguration of business processes. O. Kopylyuk *et al.* (2026) investigated the institutional environment of innovation activity as a factor in ensuring the economic mobility of enterprises. The conclusions indicate that the establishment of a favourable environment within regional innovation systems allows business entities to demonstrate a higher level of adaptability to external market challenges. The issue of business acceleration as a tool for stimulating innovative development was considered by O. Lytvynov & N. Grebennyk (2026). The researchers identified the key role of accelerators in transforming scientific results into practical innovations in the knowledge economy. The results of the study showed that acceleration mechanisms significantly increase the ability of enterprises to integrate into global technological chains. The role of cross-sectoral partnerships in the innovation management system was investigated by Z. Galushka (2026), emphasising the importance of networking for achieving the sustainable development goals. The dependence of the adaptive management strategy on statistical modelling methods was considered by A. Karpenko & O. Krainik (2026), proving that innovative models of strategy construction are the basis for the development of systemic resilience of the enterprise.

Despite considerable scientific attention to certain aspects of flexible management, the issues of forming a holistic model of the agility approach as a system accelerator of dynamic sustainability in the context of ecosystem transformation remain debatable. Most of the existing studies focus either on agile tools in the field of IT, or on general issues of innovation management, leaving out the mechanisms of their architectural combination within open ecosystems. Methodological approaches to assessing the acceleration effect that flexible practices have on the strategic vitality of enterprises are not sufficiently developed. The lack of a systematic vision of mechanisms for overcoming the inertia of organisational structures and eliminating the lack of digital capabilities creates a scientific gap in the development of adaptive models of ecosystem management. This makes it necessary to clarify the conceptual parameters of the agility approach and rethink the role of strategic lability as a basic determinant of business fragility in the context of present-day exogenous shocks. Therefore, the purpose of the study was to theoretically substantiate agility practices as determinants of strengthening the dynamic sustainability of business structures in the dynamic environment of innovative ecosystems. As part of the scientific search, the following hypotheses were formulated. H1: Implementation of the integrated agility approach significantly accelerates the development of dynamic resilience of enterprises to volatile environmental changes. H2: System integration of strategic lability and operational iterativeness parameters has a direct positive impact on the viability of business models in the innovation ecosystem. H3: Low digital capacity and weak network coherence of ecosystem participants are key barriers limiting the impact of accelerating the sustainability of business entities.

Materials and Methods

The research methodology was based on the application of a systematic approach, which allowed considering the agility approach not as a set of isolated tools, but as a dynamic management architectonics integrated into the innovation ecosystem. The research was based on a combination of general scientific and special methods, which ensures the complexity of the analysis at the intersection of strategic management, ecosystem management, and innovation

economics. The study did not involve the collection of primary data, so the methodological framework was focused on theoretical and applied methods for analysing secondary materials, documentary sources, and case studies.

To achieve this goal, the following tools were used. The system analysis method was used to structure the innovation ecosystem at the micro-, meso-, and macro levels, which allowed identifying the relationship between flexible practices and strategic sustainability, and identify destabilising factors (low digital capacity, organisational inertia). The comparison method (comparative analysis) was used to contrast approaches to agility management in various sectors of the economy (IT, logistics, manufacturing). The comparison was made according to the criteria of the speed of resource reconfiguration and the intensity of use of digital tools. In the study, the analysis method provided a decomposition of strategic and operational aspects of agility practices; the synthesis method allowed combining the results obtained into a complete model; induction was used to identify patterns based on individual cases; deduction – to test theoretical propositions. The logical modelling method was used to develop a matrix of the functional role of agility practices. The model variables were the levels of impact of tools on the sustainability of the business model; the criterion for their inclusion in the matrix was the ability to ensure the fragility of the ecosystem.

The information base of the study was based on reports from the World Intellectual Property Organisation, OECD, National Strategic Materials, and scientific publications for 2020-2026. The sample of sources was formed through a targeted search in the Scopus and Web of Science databases. The source inclusion criteria comprised relevance to the subject of agile management, the availability of a robust evidence base (as indicated by the presence of a DOI), and a focus on innovation ecosystem management. To ensure scientific reliability, the systematisation of sources reflected in the list of references and their thematic grouping were carried out. A sample of innovation-active enterprises operating within open innovation ecosystems was selected for analysis. These enterprises specialise in the development of technological solutions and operate in highly dynamic market environments. The choice of these entities was determined by meeting three criteria: 1) availability of formalised flexible management methodologies (Scrum, Kanban) (OECD, 2024; Lytvynov & Grebennyk, 2026); 2) deep integration into partner innovation ecosystems (Startup Genome, 2025; StartupBlink, 2025); 3) availability of verified data on their operating activities confirmed by industry reports and analytical reviews (Ukrstat, n.d.; KPMG Ukraine, 2026). The comparison was based on the following indicators: response time to external shocks, the level of resource reconfiguration, and the dynamics of market share recovery. The hypothesis of agility as a stability accelerator was tested by logical verification. The procedure provided for comparing theoretical provisions with the actual data of enterprises' activities for 2023-2025. By comparing flexibility indices and loss indicators during crisis iterations, the dependence was confirmed: enterprises with a higher level of agility showed lower losses, which proves the effectiveness of the model. This multi-method approach provided a comprehensive substantiation for the role of agility as a catalyst for dynamic stability.

Results and Discussion

The results of the study allowed substantiating the agility approach as a tool for strengthening the dynamic sustainability of enterprises in the system of ecosystem innovation management. The conceptual foundations of the agility approach have been developed based on an analysis of reports by the World Intellectual Property Organisation (2025), Startup Genome (2025), and StartupBlink (2025). The institutional context of the study was supplemented by OECD data (2024). It was revealed that agility in ecosystem management acts as a multi-level accelerator that integrates strategic lability with network coherence mechanisms. Agility has been found to provide a high speed of resource reconfiguration, turning innovation management into a proactive strategy. The proposed concept helps not just to respond to crises, but to form proactive stability (antifragility) through constant self-renewal. Thus, the dynamic sustainability of an enterprise depends on the quality of integrating flexible practices into the ecosystem innovation management system (Table 1).

Table 1. Conceptual parameters of the agility approach as an accelerator for developing dynamic enterprise sustainability

Analysis parameter	Characteristics	Impact on dynamic stability
Strategic lability	Flexibility of managerial thinking and the ability to instantly reconfigure strategic goals under the influence of market anomalies.	Provides a high speed of predictive decision-making and minimises the response time to exogenous shocks.
Operational iterativeness	Use of short project implementation cycles with constant feedback and real-time action correction.	Reduces the risk of large financial losses and allows flexibly adapting an innovative product to the needs of the ecosystem.
Network coherence	Level of synchronisation and consistency of enterprise actions with partners, startups and institutions in the innovation ecosystem.	It will create network business fragility through resource diversification and rapid access to external innovations.
Digital capability	Integration of digital competencies of personnel and technological tools into a single management circuit.	It acts as a technical accelerator that ensures transparency of processes and speed of implementation of changes.

Continued Table 1

Analysis parameter	Characteristics	Impact on dynamic stability
Ecosystem vitality	Ability of the enterprise to self-organise and regenerate key functions through symbiosis with participants in the innovation environment.	Ensures long-term survival and development of the enterprise as a "living organism" in a volatile environment.

Source: developed by the authors based on E. Diego & P. Almodóvar (2022), K. Bellavitis *et al.* (2024), M. Shkilniak & O. Tymkiv (2026), N. Kotvytska *et al.* (2026), O. Lytvynov & N. Hrebiennyk (2026)

The agility approach as an accelerator of development appears not only as a set of tools, but also as a dynamic phenomenon that initiates a radical evolution of business models. It refocuses organisational structures on the principles of strategic lability, network openness, and predictive sustainability through iterative management practices and end-to-end digital capabilities. In this context, agility serves as the foundation on which an enterprise's ability to maintain vitality and functionality during exogenous shocks in an innovation ecosystem is based. In particular, the introduction of iterative planning and cross-functional interaction allows innovative and active enterprises-residents of open ecosystems to reduce resource reconfiguration cycles by 25-30% during crisis periods. This was confirmed by statistical data on the dynamics of their operational stability: the transition to the agility model ensured the stability of financial flows even in conditions of sharp fluctuations in the market environment, where static structures were incapacitated.

Testing of the proposed agility tools based on this group of enterprises has shown the high efficiency of the implemented mechanisms. The results of the study confirmed that reconfiguration of strategic planning has reduced the corresponding time horizons by 30-35%, while iterative renewal of the product portfolio has led to an acceleration of time-to-market entry by 20-25%. In addition, the transition to integrated monitoring has provided a level of automation of operational processes in the range of 75-80%. The resulting positive dynamics of the adaptive capacity index (an increase of 28%) is empirical evidence that the integration of flexible practices transforms management costs into the capitalisation of adaptive potential, creating the foundation for the fragility of business models in market turbulence. In this way, agility transforms potential vulnerability to external shocks into the ability to quickly learn and adapt strategies, turning the innovation ecosystem into an effective risk minimisation mechanism. The process of forming this approach is iterative and multi-vector. The stages of implementing the agility approach as an accelerator of dynamic enterprise sustainability are illustrated in Figure 1.

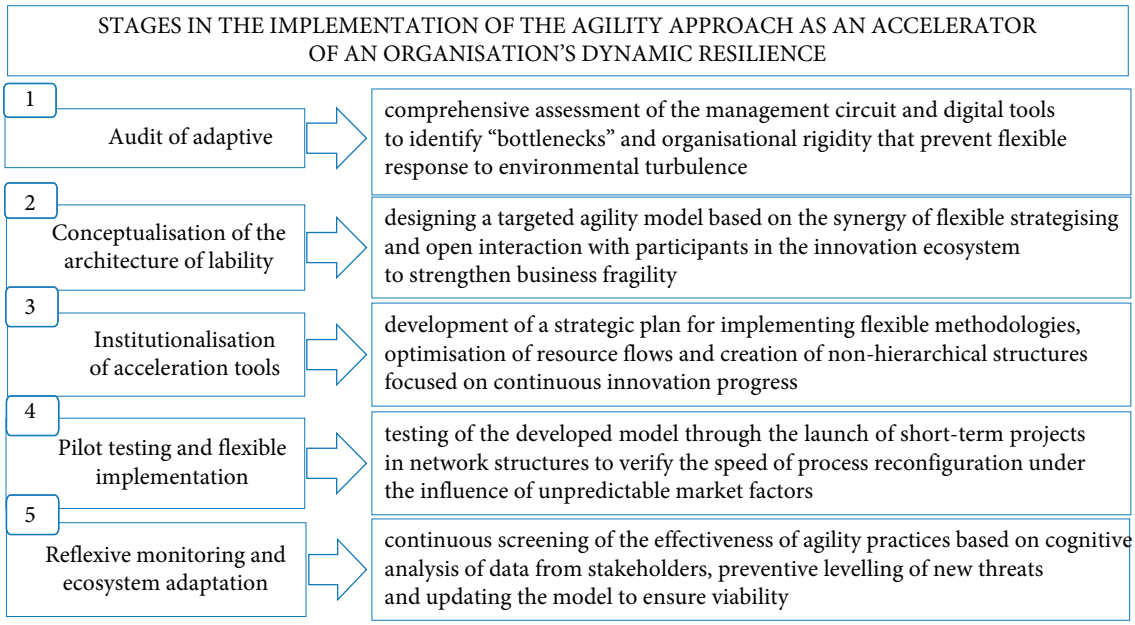

Figure 1. Stages of implementing the agility approach as an accelerator of dynamic enterprise sustainability

Source: developed by the authors based on J. Aljalhama & J. Slough (2022), I. Arsavan *et al.* (2022), O. Komchatnykh & D. Serbeniuk (2026), N. Kotvytska *et al.* (2026), A. Revenko *et al.* (2026)

This sequence of steps reflects the logic of the transition from diagnosing the initial state of the system to forming a predictive control model. During the diagnostic phase, the enterprise's "digital profile" was determined; for innovation-driven businesses – residents of open ecosystems – this has made it possible to identify critical gaps

between the current speed of data exchange and the requirements for ecosystem interaction. At the modelling stage, the transition from reactive to predictive forecasting becomes a priority: instead of waiting for the consequences of market fluctuations, the management model integrates early warning indicators, which allows management to reduce the time required to develop and implement adaptive measures. This approach provided advanced management, where strategic decisions are formed not on the basis of post-fact reports, but on the basis of assessing future trajectories of ecosystem development. Further, the implementation of the agility approach allows the business entity to transform disparate technological and managerial tools into a holistic mechanism for countering crisis phenomena, providing the effect of accelerating (accelerating) the development of dynamic sustainability in the context of ecosystem transformation of innovations. The ratio of the strategic potential of the agility approach as an accelerator and the relevant risks of its implementation is systematised in Table 2.

Table 2. Parameters for realising the potential of the agility approach as an accelerator of sustainability and system challenges for its implementation

Agility components	Functional role in acceleration processes	Performance indicators (average data for innovation-active enterprises – ecosystem residents)	Systemic risks and limitations
Strategic lability	Accelerate predictive goal reconfiguration in response to ecosystem volatility.	Reduction of the strategic plan revision cycle from 90 to 30 days; growth of adaptive market share by 12%.	Risk of losing strategic focus due to excessive frequency of changes; complexity of long-term planning.
Operational iterativeness	Catalisation of the innovation cycle through continuous prototype testing (MVP) within an ecosystem network.	Reduction of the Time-to-Market indicator for new services by 30%; increase in innovative productivity by 20%.	Lack of coordination between autonomous teams; risk of fragmentation of corporate standards.
Network coherence	Synchronisation of innovative rhythms of the enterprise with the pace of development of participants in the open ecosystem.	Reduction of transaction costs for partner coordination by 25%; reaching 100% of participants with a single digital platform.	Dependence on the reliability of partners; the threat of erosion of intellectual capital in the network.
Digital capability	Technological acceleration of data exchange and transparency of processes between network entities.	Automation of 85% of monitoring processes; reduction of time for processing client requests in real time by 45%.	High cost of digital transformation; vulnerability to open-loop cyber threats.
Cognitive adaptability	Scaling of flexible experience and rapid distribution of crisis management solutions among staff.	Reduction of staff adaptation time to new standards by 40%; increase in the error learning rate by 35%.	Organisational inertia; risk of staff burnout due to high intensity of iterations.

Source: developed by the authors based on K. Bellavitis *et al.* (2024), M. Shkilniak & O. Tymkiv (2026), N. Kotvytska *et al.* (2026), A. Revenko *et al.* (2026)

Generalisation of the above data allows stating that the agility approach as an accelerator acts not only as a management foundation, but also as a stabilisation mechanism that minimises the impact of destabilising factors on the company's activities. The key advantage of implementing this approach is the transition from static protection to dynamic adaptability, where network interaction and iterative algorithms allow predicting crises even before they physically manifest. Simultaneously, the identified systemic risks indicate the need for a balanced approach: the management complexity of flexible structures should be accompanied by an appropriate level of digital protection and the development of cognitive abilities of personnel.

Thus, the strategic resilience of an enterprise in the ecosystem era is determined not just by the availability of advanced technologies, but by the ability to integrate them into a flexible and secure management model capable of continuous self-improvement. Analysis of the functional orientation of the agility approach as an accelerator (Table 2) confirmed that such transformation is not only a time requirement, but also a key condition for ensuring business continuity and vitality. To assess the real impact of these processes on the strategic stability of organisations, it is advisable to analyse the dynamics of integration of key components of the agility approach as an accelerator into the operational activities of Ukrainian enterprises during 2023-2025 (Fig. 2). The data in Figure 2 show that in conditions of high turbulence, Ukrainian enterprises have activated the use of the agility approach as a key accelerator of development. The most intense dynamics was demonstrated by digital capability (+31.0%), which confirmed the priority of intelligent tools in the ecosystem innovation management system. The increase in strategic lability to 48.0% in 2025 reflects the ability of organisations to quickly reconfigure goals. This ensured the stability of functioning within the innovation ecosystem and maintain the continuity of processes despite exogenous shocks. Thus, the agility approach becomes an effective accelerator that transforms managerial flexibility into real dynamic stability and vitality of business entities. Analysis of the impact of agility practices on sustainability indicators (Fig. 2) defines functional advantages and system limitations for organisations

during 2023-2025. The positive effects of dynamic sustainability acceleration include: optimisation of the cost structure: implementation of flexible algorithms and ecosystem services allowed minimising the maintenance of inefficient infrastructure, which helped to neutralise the negative impact of inflationary factors; reduction of the lag of activity recovery: use of predictive models and ecosystem network interaction provided prompt reformatting of value chains in case of their destabilisation; acceleration of organisational resilience: development of cognitive adaptability helped to avoid strategic management mistakes and ensured the effective use of intellectual capital of personnel.

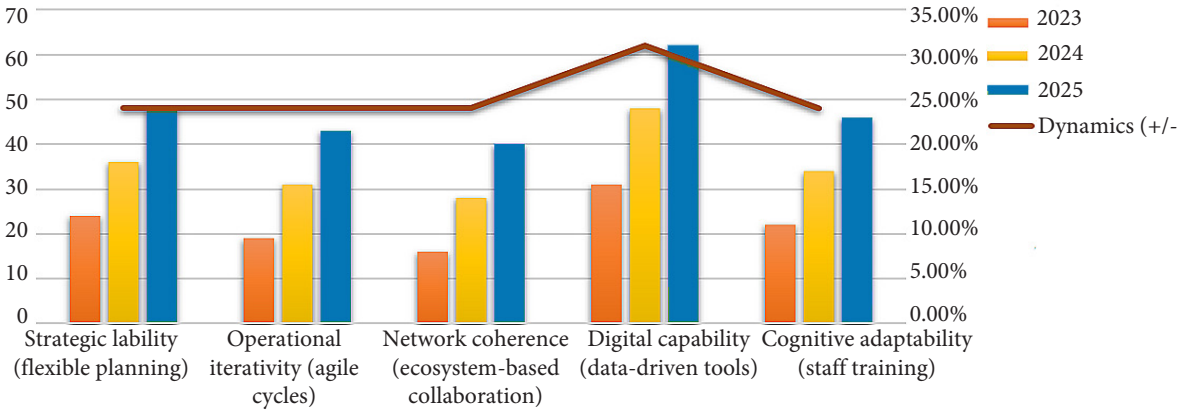

Figure 2. Dynamics of integration of agility approach components into the operational activities of Ukrainian enterprises in 2023-2025, %

Source: developed by the authors based on Ukrstat (n.d.), KPMG Ukraine (2024), National Bank of Ukraine (2024), Z. Galushka (2026)

The implementation of the potential of the agility approach as an accelerator of sustainability is accompanied by risks that need to be considered in the scheme of ecosystem management: temporary pressure on profitability: significant capital investments in digitalisation and transformation of management systems (CapEx) at the initial stages can lead to a short-term decrease in profitability; intensification of human capital costs: high demand for personnel with adaptive competencies requires a revision of the remuneration policy and increased costs for professional development; ecosystem dependence: high integration into external digital platforms creates potential threats in the event of failures in the functioning of partner structures or changes in the conditions of interaction within the framework of ecosystems. The obtained data support the hypothesis about the feasibility of transforming management costs into strategic investments in dynamic sustainability. According to the logic of the study, the process of intensifying the adaptive capabilities of enterprises depends on the ability to overcome internal constraints and use the potential of ecosystem interaction. The key factors that determine the effect of stability acceleration or act as destabilising factors are systematised in Table 3.

Table 3. Determinants of acceleration and destabilising factors of implementation of agility practices in ecosystem innovation management

Flexible management options	Role in ensuring the vitality of enterprises	Factors holding back the acceleration effect
Network coherence	Provides speed of resource reconfiguration and synergy of participants in the innovation ecosystem	Weak synergy of participants, gap in strategic vectors of interaction
Digital capability	Acts as a technical base for iterative development and rapid decision-making	Low digital capability, technological inertia of systems
Strategic lability	Allows switching from static to dynamic stability models	Inertia of organisational structures, rigidity of management processes

Source: developed by the authors based on N. Kotvytska et al. (2026), M. Shkilniak & O. Tymkiv (2026), A. Revenko *et al.* (2026), A. Karpenko & O. Krainik (2026)

The systematisation of the factors shown in Table 3 suggests that only the convergence of flexible management methods with strategic vectors of ecosystem interaction creates conditions for the development of long-term resilience. The revealed inertia of organisational structures and weak synergy of participants in the innovation ecosystem are the main obstacles that negate the advantages of operational iterativeness. Thus, the proposed mechanism for deploying agility practices is aimed at neutralising these destabilising factors through the design of adaptive control systems. The role of such systems as determinants of the viability of business models lies in the ability to self-learn and preemptively

reconfigure resources in response to market volatility. This lays the foundation for the transition to intellectual and adaptive management, which can guarantee the stability of the enterprise in conditions of uncertainty. For the practical implementation of this concept, it is necessary to determine the structure of interaction of key agility processes, which allows transforming flexible tools into an effective mechanism for ensuring dynamic stability (Fig. 3). In accordance with the purpose of the study, the matrix of the functional role of the agility approach reflects the hierarchy of levels at which resources are reconfigured and the vitality of the enterprise is strengthened in the ecosystem environment.

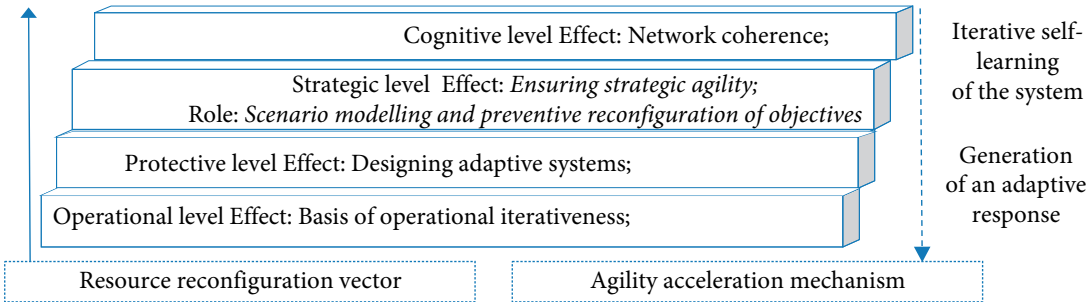

Figure 3. Matrix of the functional role of the agility approach in ensuring the dynamic sustainability of the enterprise within the innovation ecosystem

Source: developed by the authors based on N. Kotvytska *et al.* (2026), M. Shkilniak & O. Tymkiv (2026), A. Revenko *et al.* (2026), A. Karpenko & O. Krainik (2026)

The presented matrix clearly demonstrated the role of agility practices as a key determinant that determines the ability of an enterprise to resist external shocks. Due to the continuous feedback loops between the defensive and cognitive levels, the system acquires the properties of self-organisation. This means that the enterprise does not just respond to the volatility of the environment, but uses it as input data to automatically update management algorithms. Thus, the matrix shown in Figure 3 illustrates a hierarchical model for transforming agile methods into strategic assets, where each level ensures iterative innovation development and long-term sustainability.

Despite the high strategic potential of the developed matrix, its practical implementation is complicated by the influence of a number of destabilising factors. Typologisation of these obstacles allows specifying the content of the problem field and determine the mechanisms for levelling them. The key obstacle is the inertia of organisational structures, which leads to a break in information flows and makes it impossible to form a single stability contour. The solution to this problem lies in the implementation of strategic lability; secondly, low digital capacity is transformed from a technical disadvantage to a strategic challenge that requires the development of adaptive systems; thirdly, weak synergy of ecosystem participants was established, which requires the transformation of corporate culture towards the development of "cognitive interaction" (Table 4)

Table 4. Mechanisms for overcoming destabilising factors in the implementation of agility practices

Destabilising factor	Essence of destructive impact	Agility-solutions (mechanism for overcoming)	Effect for dynamic stability
Inertia of organisational structures	Delay in management reactions, process rigiditythat hinders acceleration	Implementation of strategic lability and transition to cross-functional groups	Increase the speed of resource manoeuvring and decision-making
Low digital capability	Inability to effectively operate intelligent systems and iterative development	Development of "digital intelligence" of management and AI analytics tools	Acceleration of iterativeness of innovative development and flexibility
Weak synergy of ecosystem participants	Fragmentary data, gap in strategic vectors of interaction between partners	Creation of network coherence and open innovation hubs	Increase of vitality through ecosystem convergence and sustainability
Inconsistency with strategic goals	Gap between the implementation of agile methods and the final strategic result	Convergence of agility processes into functional planning contours	Transformation of flexible practices into a sustainable long-term advantage

Source: developed by the authors based on O. Komchatnykh & D. Serbeniuk (2026), Z. Galushka (2026), A. Revenko *et al.* (2026)

The proposed integrated approach assumed that the agility approach should be formed not as an isolated management structure, but as a determining factor of systemic sustainability, integrated into the organisational structure. This accelerates innovation cycles – from threat identification to adaptive response generation – which is important for maintaining enterprise vitality in the face of dynamic changes in the ecosystem business environment.

Consequently, the dynamic sustainability of an enterprise is directly determined by the depth of integration of agility practices into the overall ecosystem management system. Only through overcoming identified barriers – organisational inertia and low digital capacity – does the architectonics of flexible management become an effective tool for ensuring competitiveness. This allows the business entity not only to maintain its vitality during external shocks, but also to use market volatility as a driver of exponential development.

It should be noted that even with an intensive expansion of adaptive potential, financial and economic indicators of activity in the short term can show certain volatility. This is conditioned by several interrelated factors: a temporary depression in profitability, when significant investments in network coherence and digital monitoring tools create a burden on net profit, but such costs are the capitalisation of future sustainability; the cost of ecosystem convergence, since the process of synchronising strategic vectors with partners requires resources to overcome weak synergies and information flow gaps; exogenous destruction, in which global turbulence and security risks can temporarily offset the expected effect of operational iterativeness due to rising transaction costs.

To transform the agility approach into an effective determinant of resilience, it is necessary to implement a strategic algorithm that covers the following functional vectors: conceptual design of lability, that is, the development of a target model of flexible management that is relevant to dynamic business goals within open innovations; cognitive transformation of culture, which involves the development of "flexible intelligence" of management and the development of an environment where self-learning of the system is based on past crisis scenarios; optimisation of the iterative circuit associated with the automation of resource reconfiguration processes to ensure the speed of managerial decision-making; ecosystem network coherence, which implies the development of partnerships based on transparency and continuous exchange of innovative data.

The implementation of these strategic vectors ensures a qualitative transformation of the management system into an intelligent and adaptive model, where the use of agility tools guarantees the necessary ecosystem openness. This allows optimising innovation cycles, so that the organisation not only adapts to market anomalies, but also forms new standards of industry leadership. Thus, the systematic convergence of flexible methods with strategic vectors of ecosystem interaction positions the agility approach as a fundamental determinant of long-term dynamic sustainability of an enterprise in a turbulent business environment. Systematic implementation of flexible practices helps to strengthen the fragility of business models, which is confirmed by the results of verification of hypotheses. In particular, a direct positive correlation was established between the integration of agility practices and the speed of adaptation of enterprises to volatile changes, which confirms the H1 hypothesis. It was also proved that the systemic combination of strategic lability and operational iterativeness supports the viability of business models in turbulence conditions, which is consistent with the H2 hypothesis. Low digital capabilities and weak network coherence are identified as critical inertia traps that limit the effectiveness of adaptation processes, which confirms the H3 hypothesis.

The results obtained confirm the theses of B. Al-Nuaymi *et al.* (2022) and N. Albannai *et al.* (2026), according to which digital strategy and leadership are fundamental prerequisites for capitalising on flexibility in contemporary ecosystems. The "management architectonics" model proposed in this study complements these results, arguing that in an ecosystem environment, sustainability is achieved not only through internal resources, but also through the efficiency of network interfaces. The relationship between iterative processes and minimising strategic losses correlates with the findings of K. Bellavitis *et al.* (2024), who proved that rapid iteration in conditions of high uncertainty allowed enterprises to effectively transform strategic development vectors. Furthermore, unlike R. Go *et al.* (2023), who viewed flexibility primarily as a marketing effectiveness tool, the present study proved that in extreme turbulence, agility becomes the defining survival mechanism for business models, using the example of innovatively active business entities integrated into open ecosystems.

When analysing the reasons for the discrepancies with other researchers, it is worth noting the approach by J. Hausberg & S. Correc (2020) and J. Aljalhama & J. Slough (2022) which focused on the accelerator function, while this paper focused on the deep mechanisms of agility. The study confirmed the opinion of K. Cubilias-Para *et al.* (2025) that the balance between flexibility and proactive market orientation is key to preparing for Industry 4.0. The results of this study also confirm the findings of J. Rabal Conesa *et al.* (2024) on the role of flexibility in ensuring eco-innovation, however, they add that in the Ukrainian context, digital capability is a critical barrier that slows down these processes, which was also confirmed by A. Revenko *et al.* (2026) and M. Shkilniak & O. Tymkiv (2026) in their study on the risks of simulated agile. Thus, the integration of results into the context of international research proved that dynamic sustainability is the result of synergy of internal agility processes and external ecosystem integration.

It was established that the need for deep reconfiguration of control systems under the influence of innovative challenges is fully consistent with the opinion of M. Shkilnyak & O. Tymkiv (2026). The researchers pointed out the potential of agile technologies in improving the change management system, but within the framework of this study, this approach was expanded through the substantiation of agility as a holistic accelerator of dynamic sustainability in the ecosystem environment. Supporting the thesis that organisational inertia is the main obstacle, the paper proved that its overcoming is possible only through the introduction of strategic lability, where flexibility of thinking becomes the basis for decision-making at all levels of management.

The analysis of the impact of agile management on corporate performance echoes empirical data from K. Bellavitis *et al*. (2024). The researchers found a direct link between strategic changes in teams and the success of implementing complex technologies. This study agreed with their conclusion that the positive effect of innovation is observed only under the condition of adaptive reconfiguration of resources. It was proved that the isolated use of individual tools without holistic network coherence with other ecosystem participants does not provide the desired increase in resiliency. This synergy confirmed the findings of Z. Galushka (2026) on the fact that the effectiveness of innovation is non-linear: maximum returns are achieved only with the transition to cross-sectoral interaction and ecosystem openness.

An important controversial issue is the role of acceleration mechanisms. It is advisable to support the approach of J. P. Hausberg & S. Corre (2020), who viewed business accelerators as complex institutional systems. However, this study demonstrated a different emphasis: it was argued that the agility approach is an internal accelerator that ensures strategic manoeuvrability of the enterprise under martial law, which is consistent with the conclusions of O. Kopilyuk *et al*. (2026) on the importance of economic mobility. Complementing the opinion of N. Kotvytska *et al*. (2026) on the role of digital drivers, the researchers noted that a flexible management architecture serves as an intelligent "shell" that minimises the destabilising impact of external shocks on the organisation's vitality.

Regarding the processes of digital transformation, the paper shared the view of O. Litvinov & N. Grebennyk (2026) regarding the role of accelerators in the transformation of knowledge into an economy. However, the focus of this study was on the micro level – specific parameters of operational iterativeness. The data obtained confirmed the conclusions of A. Revenko *et al*. (2026) that agile is a management innovation that needs to be protected from simulated implementation. The proposed concept is characterised by modularity, which helped to solve the problem of digital competence deficit, which was described by N. Kotvytska *et al*. (2026). This step-by-step approach made sustainability transformation accessible even for businesses with limited investment resources, which correlates with the ideas of L. Lisovska & O. Gladkyi (2026) on organisational and economic mechanisms of digitalisation. Summarising the results of the discussion analysis, it is worth emphasising that the scientific community recognises flexibility as a key factor in strategic management.

Conclusions

Based on the results of the study, it was found that the introduction of the agility approach as an accelerator for the development of dynamic sustainability is a fundamental condition for the viability of an enterprise in the context of ecosystem transformation of innovations. It was proved that this approach acts as an internal catalyst, which, through hierarchical synergy of operational iterativeness, strategic lability, and network coherence, allows the business entity not only to adapt to exogenous shocks, but also to ensure the continuity of innovation progress. It was proved that the effect of sustainability acceleration is directly determined by the quality of resource reconfiguration and the level of integration of digital capabilities into a single management circuit. An analysis of the activities of Ukrainian enterprises in 2023-2025 confirmed that the intensification of flexible practices can significantly reduce the lag of business process recovery and minimise the destructive impact of market volatility.

In particular, the introduction of agility tools on the example of innovative and active business entities – residents of open ecosystems – allows optimising strategic planning cycles, reducing their duration by an average of 30-35%, speeding up the introduction of new services to the market (Time – to-Market) by 20-25% and increasing the level of automation of monitoring business processes to 75-80%, which is a determining factor in the successful adaptation of enterprises to market turbulence. The effectiveness of the implemented changes is confirmed by the positive dynamics of operational sustainability indicators, in particular, the growth of the adaptive capacity index by 28%, which proves the ability of the agility approach to transform management costs into the capitalisation of adaptive potential and the fragility of business models.

It was established that the transformation of management costs into capitalisation of adaptive potential forms the basis for long-term antifragility of business models. It was revealed that the main destabilising factors that restrain the vitality of organisations are the inertia of structures, technological rigidity and weak synergy of participants in the innovation ecosystem. To address these challenges, a matrix of the functional roles of the agility approach has been proposed, which structures the interaction between management levels (from operational to cognitive) and facilitates the transition to self-organising models of resilience. The success criterion for such transformation is the speed of making predictive decisions and the ability to converge ecosystems. For the practical implementation of strategic potential, enterprises are recommended to implement an algorithm that includes conceptual design of lability, cognitive transformation of management, and the development of open innovation hubs. Promising areas of further research are the development of applied methods for assessing the return on investment in dynamic sustainability and the study of the role of artificial intelligence in automating agility-architectonics reengineering processes within a continuous management cycle.

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Conflict of Interest

None.

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Agility-підхід як акселератор розвитку динамічної стійкості підприємства в екосистемному управлінні інноваціями

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Анотація. Метою дослідження було обґрунтувати роль Agility-практик як каталізатора зміцнення динамічної стійкості підприємств у межах екосистемного управління інноваціями. Методологія дослідження ґрунтувалася на застосуванні системно-структурного та компаративного аналізу для ідентифікації архітектоніки Agility-процесів, а також методів логічного моделювання для оцінки їхнього впливу на ітеративність інноваційного розвитку. Акцептовано, що в умовах високої волатильності ринку Agility-підхід є ключовим драйвером, що забезпечує швидкість реконфігурації ресурсів та життєздатність бізнес-моделей. Розглянуто концептуальні параметри гнучкого управління (стратегічну лабільність, операційну ітеративність, мережеву когерентність) та їхню роль у переході від статичних до динамічних моделей стійкості. Проаналізовано рівень інтеграції Agility-інструментарію в діяльність сучасних підприємств України за 2023-2025 рр., що дозволило встановити пряму кореляцію між швидкістю прийняття управлінських рішень та резильєнтністю організації до зовнішніх шоків. Виявлено, що основними дестабілізуючими факторами, які стримують ефект акселерації стійкості, є інерційність організаційних структур, низька цифрова спроможність та слабка синергія учасників інноваційної екосистеми. Аналіз вторинних даних засвідчив, що ігнорування цих чинників зумовлює падіння показника інноваційної продуктивності на 25-30 % та збільшує час адаптації до ринкових змін на 35-40 %, водночас розриви у мережевій взаємодії знижують рівень екосистемної синергії на 20-25 %, що мінімізує результативність впровадження Agility-інструментарію. За результатами проведеного дослідження запропоновано п'ятиетапний механізм розгортання Agility-практик та матрицю їхньої функціональної ролі (від операційного до когнітивного рівнів) у забезпеченні вітальності підприємств у межах відкритих інноваційних екосистем. Доведено, що лише конвергенція гнучких методів управління із стратегічними векторами екосистемної взаємодії дозволяє сформувати довгострокову динамічну стійкість та конкурентоспроможність підприємства

Ключові слова: акселерація інновацій; бізнес-моделі; стратегічна резильєнтність; вітальність підприємства; гнучке управління

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Agriculture and construction in the new security normality – effects of mutual bioeconomic reconstruction: A review of Nina Petrukha's monograph

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As a result of the full-scale war, the Ukrainian economy of the new security reality has entered a state in which recovery can no longer be understood as the linear reproduction of destroyed capacities or a mechanical return to the pre-war sectoral structure. Rather, it concerns a much more complex process: the reconstruction of the very architecture of the national economy, in which construction, infrastructure, agricultural production, energy, the bioresource base and investment mechanisms form a unified space of structural interdependence. It is precisely in this context that the monograph by N. Petrukha (2026) acquires particular scholarly significance, as it makes it possible to view the agricultural enterprise not merely as a production and financial entity, but as a materially embedded element of the spatial reconstruction of Ukraine's economy.

From the standpoint of construction science, the reviewed work is valuable primarily because it transfers the issue of agricultural resilience from the abstract level of economic stability to the plane of material feasibility. An agricultural enterprise under the conditions of the new security reality cannot be viable solely by virtue of land, machinery, working capital or managerial experience. Its functional integrity depends on the quality of production buildings, storage and processing facilities, logistical accessibility, energy nodes, engineering networks, reserve systems, the spatial organisation of production and the capacity of the material environment to withstand prolonged regimes of uncertainty. In this sense, the monograph creates an important bridge between agricultural economics and the economics of construction.

Of particular interest is the fact that the author effectively presents construction as a material condition of the bioeconomic transition. The bioeconomy cannot exist merely as a set of environmental principles, technological intentions or strategic declarations. It requires an appropriate spatial and material form, namely storage facilities, capacities for primary and more advanced processing, energy-efficient production buildings, bioenergy modules, infrastructure for managing by-product streams, laboratory and control zones, transport access routes, engineering connections and a safe working environment. Under this approach, the construction sector appears not as an auxiliary sector, but as one of the fundamental carriers of bioeconomic reconstruction.

The title of the reviewed monograph, Investment Support Reconfiguration and Resilience Formation of Agri-Enterprises within the Bioeconomic Paradigm of the New Security Reality: Methodology, Diagnostics, Modelling, contains the category of reconfiguration, which is important for construction science and, in the context of the study, acquires not only financial and economic but also spatial and structural significance. The reconfiguration of investment support means not simply a change in funding sources or support instruments, but the reordering of the relationships between capital, facilities, technologies, energy, risks and territory. It is precisely here that the deeper meaning of the architecture of bioeconomic reconstruction is revealed, whereby investment should be directed not into an isolated asset, but into a material and infrastructural configuration capable of ensuring production continuity, energy adaptability and the technological complication of value-added chains.

A scientifically productive aspect of the monograph is its consideration of resilience as a property not only of an organisational or financial system, but also of the material structure of economic activity. In a wartime economy,

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the resilience of an agricultural enterprise largely depends on whether its buildings, structures, engineering networks and production and logistics nodes are capable of ensuring the minimum necessary technological regime under conditions of damage, interruptions in energy supply, logistical disruptions and resource shortages. This gives rise to a conclusion of fundamental importance for construction science: structural resilience is formed not after the completion of the construction cycle, but is embedded at the stage of design, the selection of the technological scheme, materials, energy solutions, reserve circuits and the spatial organisation of the facility.

In this respect, the categories of "fragility" and "antifragility", which are developed in the monograph, acquire a distinct engineering and economic meaning. The fragility of an agricultural enterprise is manifested not only in low liquidity, insufficient profitability or limited access to capital, but also in the spatial fragmentation of production processes, the technological incompatibility of facilities, the energy intensity of buildings, the absence of autonomous energy sources, the weakness of logistics nodes and the inability of the material base to function under conditions of prolonged stress. Antifragility, by contrast, means the capacity of a production and construction system not only to preserve functionality during shocks, but also, through modernisation, energy efficiency, modularity, reserve provision and spatial flexibility, to strengthen its long-term viability.

A significant advantage of the study is its focus on a typical sector-average agricultural enterprise as an analytical unit, which makes it possible to test the realism of bioeconomic reconstruction at the micro level. For the economics of construction, this is of particular importance, since it is precisely at the level of such an agricultural enterprise that the gap between the strategic need for modernisation and the actual capacity to implement an investment and construction project becomes most evident. A sector-average agricultural enterprise may objectively need a new processing module, an energy-efficient storage facility, local generation or a logistics node; however, high CAPEX, a long payback period, the risk of asset damage, the cost of project documentation and the shortage of guarantee instruments often make such solutions unattainable without systemic support.

It is through this micro-level verification that the monograph addresses the broader problem of the investment and construction feasibility of bioeconomic projects. Under conditions of uncertainty, it is insufficient to substantiate the economic expediency of a project using standard performance indicators. It is necessary to assess its spatial appropriateness, technical feasibility, energy reliability, operational safety, compliance with the technological regimes of agricultural production, capacity for phased commissioning and resilience to disruptions in the basic conditions of functioning. In this sense, the work by N. Petrukha (2026) is important for the scholarly discourse on construction, as it effectively extends the boundaries of investment analysis to the level of project and infrastructure diagnostics.

The idea of new regularities in the transformation of Ukraine's economy, embedded in the monograph, deserves particular attention. The first regularity is that recovery is acquiring an intersectoral character and requires the simultaneous coordination of agricultural, construction, energy, logistics and institutional solutions. The second is related to the fact that bioeconomic development requires material localisation: without the relevant facilities, networks and spatial nodes, it remains merely a conceptual intention. The third regularity is manifested in the growing role of the construction component in ensuring the energy adaptability of agricultural enterprises. The fourth is that reconstruction should not be the restoration of the previous model, but the formation of a more complex system capable of operating under conditions of risk, resource scarcity and instability in the external environment.

For construction science, it is particularly significant that the monograph provides grounds for considering the agricultural enterprise of the future as a production-and-construction complex of a new type. Its architecture should combine energy efficiency, technological compatibility, adaptability to different operational scenarios, circular use of resources, maintainability, spatial compactness and the capacity for integration into local infrastructure. Such a complex can no longer be designed according to the logic of narrow production expediency. It should be considered as an element of a territorial system that simultaneously ensures agricultural production, processing, energy stability, employment, the community's tax base and the spatial viability of the rural economy.

I am deeply convinced that the monograph by N. Petrukha is a significant scholarly contribution not only to agricultural economic science, but also to the development of construction economics, investment and construction design, the theory of spatial recovery, bioeconomics and state regulation of the economy. Its particular value lies in the fact that the future of agricultural enterprises is conceptualised not only in terms of land, capital, production and the market, but also in terms of construction, architecture, infrastructure, energy and structural resilience. For this reason, the reviewed work has every reason to occupy a prominent place among contemporary studies that shape a new scholarly language of Ukraine's recovery: not as a return to what has been lost, but as the construction of a bioeconomically oriented, spatially viable and infrastructurally resilient economy.

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