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**СМАРТ-ЕКОНОМІКА,
ПІДПРИЄМНИЦТВО
ТА БЕЗПЕКА**

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ЗМІСТ

Юрасова Ольга, Івашко Лариса, Максимова Юлія, Максимов Олександр ІННОВАЦІЙНІ ТРЕНДИ: ВПЛИВ НА РОЗВИТОК ФІНАНСОВОГО СЕКТОРУ	7
Івашко Лариса ДИДЖИТАЛІЗАЦІЯ СФЕРИ ТУРИЗМУ ТА ГОСТИННОСТІ	15
Булгаков Микола, Мельник Олексій, Коробкова Олена ІНВЕСТИЦІЙНІ ТА ЕКОНОМІЧНІ АСПЕКТИ ПЕРЕХОДУ МОРСЬКОГО ТРАНСПОРТУ ДО НИЗЬКОВУТЛЕЦЕВИХ ТЕХНОЛОГІЙ	29
Лезіна Анастасія ІМПЛЕМЕНТАЦІЯ МЕХАНІЗМУ ЗМІЦНЕННЯ ЕКОНОМІЧНОЇ БЕЗПЕКИ В СТРАТЕГІЮ РОЗВИТКУ ПІДПРИЄМСТВА	36
Шевчук Сергій, Гаврашенко Карина ІНТЕГРОВАНА ЗВІТНІСТЬ ЯК ІНСТРУМЕНТ ПРОЗОРОСТІ ДЛЯ СТАЛОГО РОЗВИТКУ ПІДПРИЄМСТВА	47
Золковер Андрій, Яцентюк Ростислав, Айедогбон Джон О. СТРАТЕГІЧНІ ПРІОРИТЕТИ ДЛЯ БІЗНЕС-ІННОВАЦІЙ ТА ІНВЕСТИЦІЙ У ПОВОЄННІЙ УКРАЇНІ	55
Мягих Ірина, Кохно В'ячеслав, Сопін Євген СЕКТОРНІ РІЗНИЦІ В ЦИФРОВІЙ ТРАНСФОРМАЦІЇ: ПОРІВНЯЛЬНИЙ АНАЛІЗ СЕКТОРІВ ЕКОНОМІКИ УКРАЇНИ З ВИКОРИСТАННЯМ ПІДХОДУ КОМПОЗИТНОГО ІНДЕКСУ	64
Карбекова Азіза Б. СТРУКТУРНІ ОСОБЛИВОСТІ ПОДАТКОВОГО АДМІНІСТРУВАННЯ В КИРГИЗСТАНІ: АНАЛІТИЧНИЙ ОГЛЯД ФІСКАЛЬНИХ ПОКАЗНИКІВ	72

CONTENTS

Iurasova Olga, Ivashko Larysa, Maksymova Julia, Maksymov Oleksandr INNOVATION TRENDS: IMPACT ON DEVELOPMENT OF FINANCIAL SECTOR	7
Ivashko Larysa DIGITALIZATION OF THE TOURISM AND HOSPITALITY SECTOR	15
Bulgakov Mykola, Melnyk Oleksiy, Korobkova Olena INVESTMENT AND ECONOMIC ASPECTS OF THE TRANSITION OF MARITIME TRANSPORT TO LOW-CARBON TECHNOLOGIES	29
Liezina Anastasiia IMPLEMENTATION OF THE MECHANISM FOR STRENGTHENING ECONOMIC SECURITY INTO THE ENTERPRISE DEVELOPMENT STRATEGY	36
Shevchuk Serhii, Havrashenko Karyna INTEGRATED REPORTING AS A TRANSPARENCY TOOL FOR SUSTAINABLE ENTERPRISE DEVELOPMENT	47
Zolkover Andrii, Iatsentiuk Rostyslav, Aiyedogbon John O. STRATEGIC PRIORITIES FOR BUSINESS INNOVATION AND INVESTMENT IN POST-WAR UKRAINE	55
Miahkykh Iryna, Kokhno Viacheslav, Sopin Evgen SECTORAL DISPARITIES IN DIGITAL TRANSFORMATION: A COMPARATIVE ANALYSIS OF UKRAINE'S ECONOMIC SECTORS USING A COMPOSITE INDEX APPROACH	64
Karbekova Aziza B. STRUCTURAL FEATURES OF TAX ADMINISTRATION IN KYRGYZSTAN: AN ANALYTICAL REVIEW OF FISCAL PERFORMANCE	72

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INNOVATION TRENDS: IMPACT ON DEVELOPMENT OF FINANCIAL SECTOR

Abstract. *Modern financial institutions are undergoing significant transformations driven by innovative technologies. This article examines current trends in financial innovations and their impact on the operations of banks, insurance companies, and financial institutions. The research focuses on the digitalization of financial services (FinTech), the application of artificial intelligence, blockchain, big data, new customer service models (mobile banking, online insurance), and risk management strategies.*

The study reviews the works of leading scholars who analyze the transformation of traditional financial services through digitalization and develop conceptual models, such as the “Digital Finance Cube.” The role of financial innovations in supporting economic growth and enhancing the competitiveness of companies is highlighted. The global experience in implementing financial technologies and their potential adaptation in Ukraine, considering regulatory barriers, is also examined.

The research methodology is based on the analysis of scientific literature, statistical data, and applied studies in financial technologies. Special attention is given to the impact of digital tools on financial accessibility, particularly in the context of martial law in Ukraine. The study explores the role of blockchain, crowdfunding, and mobile financial services in addressing economic challenges and improving financial inclusion.

The findings emphasize the necessity of further digital transformation in the financial sector, the expansion of financial technologies, and the development of innovative strategies to ensure the stability and efficiency of financial institutions.

Keywords: *financial innovations, FinTech, digitalization, blockchain, artificial intelligence, banks, financial institutions.*



1. Introduction

Modern financial institutions are experiencing an era of unprecedented changes, driven by the rapid development of technologies and innovative solutions. The subject of the study is the financial system as a set of processes and entities (banks, insurance companies, financial institutions) that use innovative approaches.

The object of the research is innovative processes, technologies, methods and approaches used in financial institutions, namely the digitalization of financial services (fintech); the implementation of artificial intelligence (AI), blockchain, big data (Big Data); new customer service models (mobile banking, online insurance); the use of innovations in risk management or financial analysis.

Transformations not only change traditional business models, but also create new opportunities for market participants. Innovations in finance, banking and insurance are becoming key factors that determine the competitiveness of companies, their ability to adapt to a changing environment and meet consumer needs. In the context of globalization and digitalization, financial institutions face new challenges, such as growing competition from financial technologies, changes in the regulatory environment and the need to improve customer experience. The use of artificial intelligence, blockchain technologies, data analytics and process automation opens up new horizons for optimizing business processes and increasing efficiency.

According to a study in the Google search engine, over 95,000 publications have been published in the last five years. This indicates great public attention and interest in innovations in the field of finance.

The works of scientists Gomber, Koch and Siering consider how the digitalization of the financial sector transforms traditional services, creating new business models. The concept of the "Digital Finance Cube" is presented for the analysis of business functions, technologies and involved institutions [1]. Researchers Laeven and Levine in their scientific works investigated the role of financial innovations in supporting economic growth, developing a model where financiers improve the mechanisms for selecting entrepreneurs. The authors prove that without financial innovations, technological progress and economic growth are impossible [2]. Summerfield R. conducts in his research an analysis of the impact of new technologies on financial services, emphasizing the role of innovation in the transformation of the industry and focuses on the need to integrate advanced technologies, such as artificial intelligence, analytics, robotics, cloud solutions and blockchain [3]. Khan, Bartakova and Almadhor in their research identify the main factors of vulnerability, such as insufficient financial and digital literacy, confidence problems, lack of cooperation between banks and regulatory gaps, and provide recommendations for improving financial inclusion [4]. Sarto, Bocchialini, Gai and Ielasi study the transformational role of social networks in the digital evolution of banks, focusing on strategies used by Italian banks to

maximize their advantages. The study identifies key factors for successful digital transformation, including organizational culture, attracting clients, financial innovations and proactive response to financial companies [5]. Gyau, Appiah, Gyamfi and Achie analyzed the relationship between the introduction of artificial intelligence in the banking sphere and the financial indicators of banks in 20 countries. The study determines the positive impact of innovations and artificial intelligence on the profitability of banks, as well as emphasizes the role of information and communication technologies, economic growth and regulatory factors in this process [6]. Anestiawati, Amanda, Khantinyano, Agatha examines the impact of FinTech on bank credit risk in 40 countries, comparing 20 developed and emerging economies while considering macroeconomic factors, competition, and technological development. They highlight both the benefits and risks of FinTech lending, emphasizing the need for balanced regulation to promote financial inclusion and economic growth [7]. In the work of Hitsan, the world experience in implementing financial innovations is considered, the possibility of their adaptation in Ukraine is analyzed and regulatory barriers to the development of fintech startups in the country are identified [8]. Such scientists as Zaika, Gridin set the main goal of their research on modern approaches to financing innovations, determining the factors influencing the choice of funding sources, identifying key problems and developing proposals for their solution to increase the efficiency of innovation activity and the competitiveness of the economy [9]. Koval conducted research on the impact of innovation on the development of banking and financial institutions in the context of globalization, her research identified key factors of competitiveness, and she also developed approaches to improving innovation strategies and management decisions to ensure the sustainability and efficiency of their activities [10].

2. Materials and Methods

Innovation in finance and banking plays a crucial role in economic development and improving access to financial services for all segments of the population. Over the past decades, technological changes have significantly transformed the banking sector, creating new opportunities for both consumers and financial institutions. Initiatives such as digitalization, blockchain, artificial intelligence, and automation have changed the way banking services are delivered, increasing their efficiency and security.

Financial technology has become a major driver of change in the financial sector. FinTech companies offer new solutions for financial management, lending, investing and payments, which reduce costs, shorten transaction processing times and improve user convenience.

FinTech firms have increased their market share in lending and payments, with digital lending platforms accounting for 35% of total global loans in 2023 [11].

This shift is reshaping traditional banking, forcing institutions to adopt digital-first strategies to remain competitive.

Global investment in FinTech reached \$164.1 billion in 2023, marking a 12.7% increase compared to 2022. The United States remained the leader, attracting \$60 billion, followed by Europe with \$45 billion, and Asia-Pacific with \$38 billion [12].

Over 80% of financial institutions have integrated AI for fraud detection, credit scoring, and personalized banking services [13]. The market for blockchain solutions in finance is projected to grow at a 46.92% CAGR, reaching \$31.8 billion by 2029 [14].

One of the most important innovations is digital technology, which allows to significantly reduce the costs of traditional customer service. The reduction of paper documents, the introduction of mobile applications and online banking have allowed banks to offer convenient services around the clock, reduce transaction processing times and facilitate access to finance for a wide range of individuals, including people who previously did not have access to traditional banking institutions due to geographical or social barriers.

Blockchain and cryptocurrencies are also playing an important role in transforming the banking sector. Blockchain technologies allow for transparent and secure mechanisms for conducting transactions without the need for intermediaries. This not only reduces transaction costs, but also opens up new opportunities for international transfers that are faster and cheaper than traditional methods. In addition, the use of cryptocurrencies creates the potential for greater financial inclusion, providing access to financial services even to those who do not have bank accounts.

Digital technologies have helped transform the financial services industry, changing how we save, borrow, invest, and pay for goods. With increased innovation comes heightened regulatory scrutiny. In 2023, financial institutions faced a 25% rise in compliance costs related to digital transformation [15]. Simultaneously, cyber threats surged, with a 40% increase in financial sector cyberattacks, emphasizing the need for stronger security frameworks.

Financial innovations play an important role in the development of the Ukrainian economy, ensuring transparency, accessibility and efficiency of the

financial sector. They also have an impact on almost all areas of our lives, including business, investments, social services and everyday financial transactions of citizens. Given the martial law in Ukraine, financial innovations such as digital banking services, mobile wallets, online lending and fintech applications help expand access to financial services from anywhere, especially for remote regions. Startups, small businesses and innovative projects are especially important for the development of the Ukrainian economy, and new financial technologies such as blockchain and crowdfunding make the investment process more transparent and accessible. Financial innovations help to quickly adapt to challenges such as the COVID-19 pandemic, war or economic crisis. For example, digital payments have allowed to maintain the continuity of financial transactions during restrictions, and crowdfunding platforms have helped to raise funds for humanitarian needs. A study of innovation activity in Ukraine from 2018 to 2023 was conducted, which is presented in Table 1.

Analyzing Table 1, we can see that significant jumps in Ukraine's innovation activity fall in two periods. The first is 2020–21. It should be noted that the COVID-19 pandemic had a positive impact on the development of innovation, as isolation forced society to adapt to new conditions, which led to the introduction of many innovations in the financial sector. In 2022, the negative impact of the war on the development of innovation activity was observed, which decreased. Thus, in 2023, the number of enterprises engaged in innovation activities decreased to 354 compared to 453 in 2021, which indicates a decrease of 21.9%.

As of July 2023, the market capitalization of publicly traded fintech companies was \$550 billion, double the level in 2019. Additionally, as of the same period, there were over 272 fintech unicorns with a combined valuation of \$936 billion, a seven-fold increase from the 39 companies valued at \$1 billion or more five years ago [7]. Today, given all the challenges, it should be noted that fintech companies can no longer afford to grow rapidly. To remain competitive, they must operate at a slower and more stable pace.

The digital payments market is expanding rapidly, with global transaction volume expected to surpass \$14 trillion by 2027 [12]. Mobile payment adoption is particularly high in China, where over 87% of the

Table 1

Innovation activity in Ukraine 2018–2023

Year	The number of enterprises engaged in innovative activities, units	Own funds, mln. UAH	Innovation expenses, thousand UAH.	Share of loss-making enterprises (%)
2018	351	35656.6	12180072.5	34.5
2019	352	45621.1	14220905.2	26.8
2020	386	47512.2	14406887.0	31.5
2021	453	35646.6	10171650.0	32.5
2022	423	38526.5	7640459.9	27.5
2023	354	42651.5	6989180.0	28.9

Source: compiled by the authors using [16]

population uses digital wallets such as Alipay and WeChat Pay. In contrast, Europe and North America report adoption rates of 65% and 58%, respectively.

The financial sector is undergoing a transformative shift driven by digital innovation, AI, blockchain, and FinTech expansion. While these trends enhance efficiency and accessibility, they also present challenges related to regulation, cybersecurity, and market stability. Policymakers and financial institutions must strike a balance between fostering innovation and ensuring financial security to sustain long-term growth.

3. Results and Discussion

The fintech industry continues to navigate a challenging landscape, yet numerous untapped opportunities remain. Investors are adjusting to a new financial environment characterized by higher interest rates and inflation, reshaping their approach to risk and returns. Simultaneously, a once-in-a-generation technological revolution is unlocking new avenues for value creation. Throughout 2024, the financial technology sector will experience a profound transformation, driven by groundbreaking advancements and key trends. Innovations such as generative artificial intelligence and the expansion of decentralized systems are steering this evolution, pushing financial services toward greater personalization, efficiency, and security. As a result, the fintech market is projected to soar to \$882 billion, growing at an annual rate of 17%. A report by the global consulting firm McKinsey outlines expected revenues in the fintech sector between 2024 and 2028. Figure 1.

Analyzing Figure 1, we can see that North America will be the leading country in fintech revenues by 2028, with Latin America, Africa, and the Middle East also seeing significant growth. The data shows that fintech revenues will grow almost three times faster than traditional banking from 2022 to 2028.

The future of banking is marked by fundamental restructuring. Banks and non-banks compete to meet the diverse needs of customers in five cross-sector areas: everyday banking, investment advice, integrated financing, mass wholesale intermediation and banking as a service.

Since 2021, there has been a rapid development of artificial intelligence (AI), which has also significantly influenced innovations in the banking sector. A study of the development of AI for the period 2022–2032 is presented in Figure 2. Let's consider the key areas where artificial intelligence is commonly used in the financial industry.

After analyzing the above data, we can conclude that the generative artificial intelligence market is currently reaching a historical maximum of 13.8 billion US dollars in 2023. Tracking the dynamics, it is expected that by 2032 it will reach 198.8–208.8 billion US dollars [18]. This indicates a large turn in the development of AI.

Today, robotics and process automation play a leading role in the banking sector. It works through the use of bots that imitate human actions, interacting with digital systems to read what is displayed on the screen, press buttons, copy/paste data, generate reports, etc. The main advantages of applying process automation in banking include:

- time saving — software works faster than people;
- cost reduction — with less manpower, as well as fewer errors, robotic process automation allows for cost savings;
- increased efficiency — RPA prevents repetitive and cumbersome tasks from taking up valuable time;
- error reduction — finance automation tools cope with their tasks with maximum accuracy and efficiency, regardless of the amount of work ahead of them.

For fintech companies, partnering with banks is a promising opportunity to build mutually beneficial

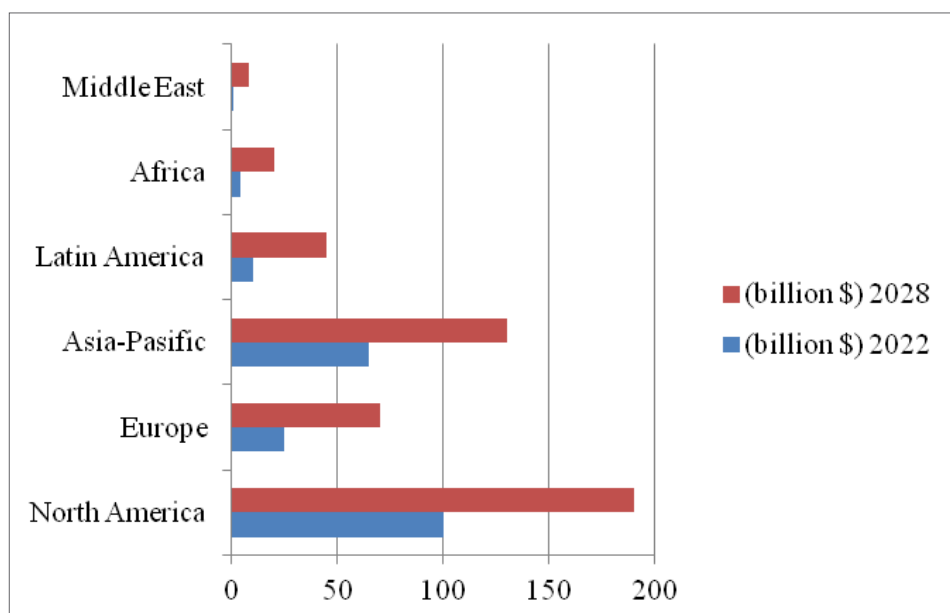


Figure 1. Revenue indicators in the fintech industry 2022–2028

Source: compiled by the authors using [17]

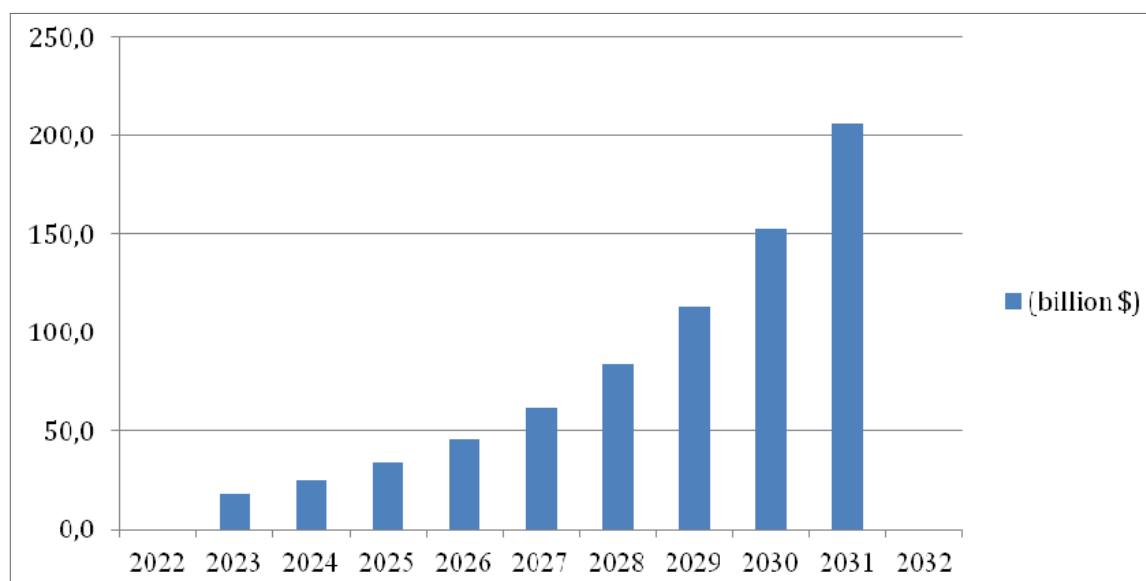


Figure 2. Generative AI market size 2022–2032 (USD billion)

Source: compiled by the authors using [18]

cooperation, expand their geographical presence, and alleviate the burden of complying with market requirements.

The fintech industry has intensified competition and introduced new challenges for commercial banks, contributing to market instability. Fintech companies frequently provide superior services, particularly in online banking. However, commercial banks also have the opportunity to leverage partnerships with fintech firms, allowing them to adopt innovative financial solutions and enhance their offerings.

The digital economy has raised customer expectations, and banks of all sizes around the world are responding by automating their processes. Modern banks are changing their strategies for attracting and retaining customers, from expanding their branch network to creating technically sophisticated services such as mobile banking.

Technological innovations create many benefits for society, companies and banks. One of the main benefits is the increased accessibility of services. In the financial and banking sectors, these include online banking and fintech applications that allow users to carry out transactions anytime and from anywhere in the world, such as remote account opening and micro-lending.

Nowadays, society values its time and is looking for different ways to save it. Therefore, innovations have advantages in this, as chatbots and automated platforms significantly speed up responses to customer requests, and digital platforms provide instant money transfers and purchase of financial products.

The security of society and personal information is also an integral part. Security is also an advantage of innovation, for example, the use of blockchain technologies ensures transparency and the impossibility of forging transactions, and biometric technologies, such as fingerprints or facial recognition, make access to financial services more secure.

Despite the challenges that accompany the introduction of innovations, their advantages undoubtedly outweigh the disadvantages. Countries around the world are investing in the latest technologies, which allows creating new opportunities for society, business and the economy as a whole. According to research by the World Intellectual Property Organization (WIPO), a rating of leading innovative countries for 2021–2024 has been compiled, which is presented in Table 2. In the ranking among innovative countries, Ukraine took 49th place in 2021, but due to the beginning of a full-scale invasion, the country remained in place in the development of financial innovations and took 57th place in 2022, but within a year society adapted to work during martial law and the development of innovations went up, as evidenced by the 55th place that Ukraine took in 2023, in 2024 there was again a decline in innovative activity in Ukraine, it took 60th place in the world ranking [19].

Each country approaches the implementation of innovations differently, which is determined by the level of economic development, technological capabilities, and regulatory features.

Developed countries such as the USA, the UK, Japan, and Germany are actively investing in the development of the fintech industry and the creation of cashless payment platforms. The USA leads in this field thanks to companies like PayPal, Square, and Stripe, which set global trends in mobile payments, lending, and blockchain. The UK, with its financial hub in London, has become a center of regulatory innovation, creating favorable conditions for startups. Japan is gradually transitioning to digital banking, despite its traditional preference for cash transactions. At the same time, the use of digital payments, particularly credit cards, is steadily increasing. Transaction data obtained through digital payments provides banks with valuable insights into customers' financial

Table 2

Ranking of leading innovative countries (2021–2024)

Place	2021	Score	2022	Score	2023	Score	2024	Score
1	Switzerland	66.5	Switzerland	64.6	Switzerland	67.6	Switzerland	67.5
2	Sweden	53.1	USA	61.8	Sweden	64.2	Sweden	64.5
3	USA	51.3	Sweden	61.6	USA	63.5	USA	62.4
...								
49	Ukraine	35.6	Romania	34.1	Brazil	33.6	Qatar	32.9
55	Mexico	34.5	Serbia	32.3	Ukraine	32.8	Mauritius	30.6
57	Brazil	34.2	Ukraine	31.0	Mauritius	32.1	Georgia	30.4
60	Iran	32.9	Montenegro	30.3	Republic of Moldova	30.3	Ukraine	29.5
132	Angola	15.0	Guinea	11.6	Angola	10.3	Niger	11.2

Source: compiled by the authors using [19]

habits and priorities, allowing them to better understand their needs. By leveraging this data, banks can offer personalized recommendations and services that create real value for users. This approach helps position them as trusted financial partners committed to their customers' well-being. Financial institutions in Japan recognize the need to transition to modern, scalable, and future-ready platforms that meet consumers' growing expectations for access to their financial data anytime, anywhere [20].

European countries are pioneers in regulatory innovation. For example, the PSD2 directive implemented by the European Union allows for the development of open banking, where customers can use different platforms to manage their finances. Scandinavian countries (Sweden, Denmark, Norway) are actively moving towards a completely cashless economy, and Estonia has become known for implementing e-residency and blockchain solutions in public administration.

Developing countries (India, China, Brazil) are showing a dynamic growth in financial innovations aimed at providing access to financial services to a wide range of people. China, for example, is a world leader in mobile payments through the Alipay and WeChat Pay platforms, which cover the majority of the population. In India, the Aadhaar program has allowed the creation of unique digital identifiers for over 1 billion people, providing access to banking services even in remote regions.

African countries, despite facing many challenges, are demonstrating successful examples of mobile technology. For example, M-PESA is Africa's most successful mobile money service and the region's largest fintech platform. It was founded on March 6, 2007 by Vodafone's Kenyan partner, Safaricom, and is the leading mobile money service in Africa, with over 660,000 active agents [21]. It should be noted that it became a revolutionary solution that allowed financial transactions to be carried out via mobile phone even in regions without banking infrastructure.

Artificial intelligence (AI) has become a key element of the transformation of the financial sector, especially in the analysis of big data and personalization of

client proposals. In the global context of AI, it allows you to process huge amounts of information in real time, identify patterns and predict customer behavior. In Ukraine, the introduction of AI in financial institutions is of particular significance against the background of economic challenges caused by the war, and the need to optimize resources. For example, in scoring loans, AI has increased the accuracy of risk assessment by 15% compared to traditional methods [22], which is especially relevant for Ukrainian banks striving to minimize default in conditions of instability.

Ukraine is also making strides in financial innovation. The active development of online banking, including applications such as Monobank and Privat24, demonstrates the country's readiness for digital transformation. Privatbank actively uses AI to analyze transactions and combat fraud. The machine learning system, implemented in 2023, made it possible to reduce the number of fraudulent operations by 25% per year, which is equivalent to the savings of about 500 million UAH (approximately \$12 million at the rate of February 2025) [23]. AI analyzes the patterns of customer behavior in real time, identifying anomalies, such as suspicious transfers abroad.

Monobank is one of the leaders of digital banking in Ukraine, uses AI to personalize proposals for credit limits and cashbacks. In 2024, Monobank said that the use of AI increased the retention of customers by 18% due to point offers based on the analysis of more than 10 million transactions monthly [24].

Oschadbank introduced AI to automate the processing of applications for loans for small and medium-sized businesses. According to the bank for 2024, the processing time of applications decreased from 3 days to 4 hours, and the accuracy of assessing solvency increased by 12%, which allowed it to issue additional loans worth 1.2 billion UAH (\$29 million) [25].

For the right choice of an architectural solution and the correct construction of a bank transformation plan, it is necessary to understand at what point of development it is located. Otherwise, you can draw an unrealistic scenario that will show its inefficiency in the first project due to lack of data and lack of infrastructure

for basic information systems that could put this data. For a complete understanding of the situation, it is necessary to give a clear definition of all the processes that exist in the bank and which must be used in the future to achieve the goals of its development.

According to the National Bank of Ukraine for 2024, about 35% of large banks and financial companies use AI in operating activities, which is 10% more than in 2022. The volume of investments in AI in the financial sector of Ukraine in 2024 amounted to about \$50 million, of which 60% were per private banks, and 40% for state initiatives.

According to the Ukrainian FinTech Association report, by the end of 2025, the share of banks using AI can reach 50% with the support of international donors, such as IFC and EBRD [26].

Thus, the implementation of artificial intelligence in Ukrainian financial institutions has significant potential to enhance efficiency and strengthen the sector's stability during a crisis. The experience of PrivatBank, Monobank, and Oschadbank demonstrates that AI can effectively address key challenges, such as preventing financial fraud and supporting small businesses. However, large-scale adoption of this technology is hindered by limited financial resources, an unstable economic situation, and insufficient digitalization of data. Moreover, overcoming ethical challenges and the high cost of AI implementation is crucial for its successful development. This requires the creation of a national strategy that combines state support with international cooperation. For example, participation in joint projects with the EU under the "Digital Europe" program (2021–2027) could accelerate the development of artificial intelligence in Ukraine's financial sector, attracting investments of up to \$100 million by 2027.

Informatization is any process aimed at supporting a team's activities to reduce uncertainty. It is essential for people to synchronize their actions and plans and work in a coordinated manner. This can be achieved by providing each employee with the necessary amount of information. Informatization is not necessarily dependent on technology any form of information exchange, even pigeon mail, is also a type of informatization.

When we are talking about today, automation is a type of informatization made using modern automated systems and computer technology. Automation is aimed at ensuring that the data is processed, transferred and preserved primarily those where the computer is more effective than a person.

Automated system is an automated solution of production processes plus a user as a participant in these processes. That is, a person is an integral part of the approach called automation. Automated systems process data, but a person makes decisions. Man is also a kind of "connecting link" between these systems.

A subtle line between digitalization and automation, it can be said that digitalization is the process of digitizing data not only in areas where the computer is more effective than a person, but also in the maximum number of areas. And even those issues that

are traditionally resolved by people begin to go into digital form. Communications, photos, videos, any notification, sensors and much more are translated into a digital form in order to further analyze and identify correlations that will allow you to effectively manage the business, reaching the very added and significant value for which everything is started.

Automation is "about IT systems", and digitalization is "about data". Digitalization and digital transformation are often used as synonyms. However, it is easy to notice that digital transformation is the result of successful digitalization. In essence, this is a situation in which the achieved digitalization level and the obtained volume of digital data allow you to change the business model, transform it so that it affects the better into counterparties and customers, allow us to offer new banking services, new principles of mutualization and interactions.

Thus, digital transformation is a digitalization aimed at reorganizing the banks business processes, IT cultures and business models of banks, opening up new opportunities for its ecosystem.

4. Conclusions

Innovations in the financial sector, such as digital platforms, fintech applications, blockchain, and process automation, have become an integral part of the modern economy. They not only facilitate access to financial services for citizens and companies, but also contribute to reducing transaction costs, accelerating customer service, and improving the security of financial transactions. At the same time, they create opportunities for personalization of services, which strengthens customer trust and contributes to the formation of loyalty.

The study also identified shortcomings of financial innovation. These include increased risks of cyber threats, insufficient legislative framework for regulating some innovations, such as cryptocurrencies, and the significant cost of implementing new technologies for businesses. Particular attention should be paid to the problem of the digital divide between different regions and social groups, which can exacerbate inequality in access to financial services. Based on the analysis, it can be concluded that the advantages of financial innovation significantly outweigh the disadvantages, especially when properly implemented and properly regulated.

Developed countries such as the United States, the United Kingdom, Japan, and Germany are leading the way in the fintech industry. Their innovations are optimizing business processes, developing cashless payments, and integrating cutting-edge technologies such as artificial intelligence and blockchain. European countries, including Scandinavia and Estonia, are not only actively implementing innovations, but also creating favorable conditions for their regulation, which is an example for other regions.

Developing countries (India, China, Brazil) are showing significant success in applying financial

innovations to improve access to financial services. China is a leader in mobile payments, and India is integrating digital technologies into banking processes with its Aadhaar program. African countries, despite economic challenges, are successfully using mobile financial platforms such as M-Pesa to overcome infrastructure constraints.

For Ukraine, the introduction of innovations in the financial sector is an important step on the path to economic growth, increased integration into global markets, and increased competitiveness of the financial sector. But this is possible only if properly implemented, which can significantly change the financial system of Ukraine, making it more flexible, accessible, and secure.

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ІННОВАЦІЙНІ ТРЕНДИ: ВПЛИВ НА РОЗВИТОК ФІНАНСОВОГО СЕКТОРУ

Анотація. Сучасні фінансові установи зазнають значних трансформацій під впливом інноваційних технологій. У статті досліджено актуальні тенденції фінансових інновацій та їхній вплив на функціонування банків, страхових компаній і фінансових установ. Об'єктом дослідження є цифровізація фінансових послуг (FinTech), застосування штучного інтелекту, блокчейну, великих даних, нових моделей обслуговування клієнтів (мобільний банкінг, онлайн-страхування) та управління ризиками.

У статті було розглянуто роботи провідних науковців, в яких проаналізовано як проводилась трансформація традиційних фінансових послуг через цифровізацію та розробляють концептуальні моделі, зокрема «Digital Finance Cube». Визначено роль фінансових інновацій у підтримці економічного зростання та підвищенні конкурентоспроможності підприємств. Досліджено світовий досвід впровадження фінансових технологій та можливості їхньої адаптації в Україні з урахуванням регуляторних бар'єрів.

При написанні статті авторами проведено дослідження, яке базується на аналізі наукової літератури, статистичних даних та прикладних досліджень у сфері фінансових технологій. Особливу увагу приділено впливу цифрових інструментів на доступність фінансових послуг, особливо в умовах воєнного стану в Україні. Зроблено аналіз блокчейну, краудфандингу та мобільних фінансових сервісів у подоланні економічних викликів та підвищенні фінансової інклюзії.

Результати дослідження підкреслюють важливість подальшої цифрової трансформації фінансового сектору, розширення фінансових технологій та розробки інноваційних стратегій для забезпечення стабільності та ефективності фінансових установ.

Ключові слова: фінансові інновації, FinTech, цифровізація, блокчейн, штучний інтелект, банки, фінансові установи.

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DIGITALIZATION OF THE TOURISM AND HOSPITALITY SECTOR

Abstract. *The article examines the impact of digitalization on the tourism and hospitality sector, particularly in the face of modern challenges. The state of the industry in Ukraine in 2024 is analyzed, when, amid economic instability and the aftermath of the war, there was an increase in tax revenues and a gradual recovery of the tourism business. The key obstacles to the development of the tourism and hospitality sector in Ukraine are outlined, including the low level of digital technologies and insufficient infrastructure. The purpose of the study is to analyze the main benefits and barriers associated with the implementation of digital technologies in the tourism and hospitality sector. The task is to highlight the main prospects and challenges of using digital technologies, as well as to formulate a strategy for applying these technologies in the tourism market as a means of revitalizing the tourism and hospitality industry. To this end, theoretical, methodological and systemic approaches to the analysis of the source base, in particular, statistical data and scientific publications, are applied. The role of digitalization is considered, including the application of artificial intelligence, VR, AR, blockchain, Internet of Things and big data, green technologies and sustainable development technologies to the tourism and hospitality sector. A descriptive analysis of the level of digitalization of tourism and the possibilities of its further development was performed. The study identified key areas for implementing digital technologies in tourism and hospitality and their impact on the formation of more diverse and flexible offers in the tourism services market. It was concluded that the implementation of digital technologies contributes to the transparency and quality of tourism services, increasing the security of the industry, which has a positive effect on its profitability.*

Keywords: *digitalization, digital technologies, AI, virtual and augmented reality, blockchain, cloud technologies, green technologies, sustainable development.*

1. Introduction

At a time of deep uncertainty for the entire world and for many industries, in particular, the field of tourism and hospitality, one simple question arises: where to go next?

After several years of decline, the Ukrainian tourism business has begun to actively recover, despite numerous challenges. The tourism and hospitality sector in Ukraine consists of many industries that are closely linked to other sectors of the economy (industry, transport, construction, services, etc.), and is mainly represented by small and medium-sized businesses. 2024 was a turning point for the tourism industry, which suffered serious losses due to hostilities,

energy problems, and infrastructure destruction. In spite of public debates about the appropriateness of vacation during wartime, hotels and resorts became not only a place to restore strength, but also an important source of taxes. According to State Tourism Development Agency, in 2024, tourism activities contributed to the state budget UAH 2 billion 938 million in taxes. This is 43% more than in 2023, when revenues amounted to about UAH 2.049 billion. Compared to 2021, tourism revenue increased by 32%, which indicates a gradual return of the industry to pre-war indicators. In particular, the growth in tax revenues was provided by hotels, which paid UAH 1.954 billion, which is 66.5% of the total amount of taxes. In 2023,



this amount was UAH 1.304 billion, and in 2021 — UAH 1.289 billion [1; 2].

Thus, the tourism industry demonstrates remarkable resilience and has the potential to become an important source of financial revenue for the state in the future.

After the war, Ukraine has the potential to become a major tourist destination, but this will depend on stability in the country and the market. The post-war recovery of Ukraine's tourism and hospitality sector looks like a powerful challenge, but at the same time an opportunity for innovation and development of the country. All development scenarios — from rapid recovery to prolonged instability — require different approaches to investment, digital technology development, infrastructure and adaptation to new conditions [2].

Some of the key obstacles to the restoration and functioning of the tourism sector are: insufficient development of high-quality modern infrastructure, transport, hotel, MICE (meetings, conferences, other events; mainly concerns business tourism) and exhibition, etc.; insufficient development of information, digital technologies and communications and insufficient level of digitalization.

Digitalization is an important trend for modern business. After all, with and according to Gartner's definition, digitalization is the use of digital technologies to change the business model and create new opportunities for profit [3]. Businesses that do not implement digital technologies risk falling behind competitors and losing competitiveness.

Digitalization is the process of introducing digital technologies into all aspects of the tourism and hospitality industry. This includes the use of technologies such as the Internet, artificial intelligence (AI), machine learning and data analytics, etc.

Sector tourism and hospitality industry is experiencing an era of rapid transformation. Innovation, technology and sustainability play a vital role in creating a thriving and resilient industry. It is also worth highlighting the importance of tourism as a driver of cultural exchange, economic prosperity and environmental stewardship.

The travel and hospitality industries are among those industries that are already actively using innovative technologies, including AI, chatbots, VR and AR, blockchain, CleanTech, communication technologies, Internet of Things, BigData, sustainable development technologies and, according to experts, can get incredibly cool benefits from it.

Researchers often discuss: the potential benefits and challenges of the aforementioned technologies in this field; addressing security issues, in particular blockchain; increasing the efficiency and reliability of financial transactions; fostering innovation and improvement; creating new markets and opportunities in the tourism and hospitality industry; the state and implementation of digital technologies for tourism and hospitality in times of crisis and the era of digitalization; aligning digitalization with tourism and

hospitality business goals; customer expectations and market demands.

With the advent of digital technologies, the relationship between the tourism and hospitality sector and digitalization has become a hot research topic. As a result, a number of literature reviews on digitalization in tourism have been published, for example on: AI — Schorn K. [4] and Barten M. [5]; robotics — Barten M. [6] and Webster C. and Ivanov S. [7]; big data — Belias D., Malik S., Mantas C., [Rossidis I.](#) [8]; blockchain — Barten M. [9] and Gaponenko G. and Vasylenko V. [10]; VR — Barten M. [11] and Denzon D. [12]; AR — Barten M. [13]; IoT — Barten M. [14] and Tsukanova T. [15].

The proliferation of research related to digitalization and sustainable development in the tourism and hospitality sector has led to the emergence of a significant number of review articles: Sharpley R. [16]; [Rodrigues V.](#), Eusebio C. and Breda Z. [17]. Sharpley R. [16], reviewing recent changes in the understanding of the concept of sustainable development, as well as modern approaches to sustainable development, he highlighted the controversies surrounding the continued adherence to the principles of economic growth in development policy in general and tourism development; sustainable growth reduction as an alternative approach to development and specific implications for tourism. In particular, [Rodrigues V.](#), Eusebio C. and Breda Z. [17] conducted a review of multiple articles aimed at expanding knowledge on the opportunities presented by digital technologies, the impact of digital transformation in tourism as a driver of sustainable development, and identifying research gaps while suggesting future directions. The findings indicate that the tourism industry has yet to fully integrate the fundamental principles of sustainable development. Although digital technologies serve as valuable management tools, helping to bridge gaps and connect people and places — both physically and virtually — their adoption in tourism destinations and businesses remains in its early stages. This challenge is particularly evident in the sector's dominance by small and medium-sized enterprises, which often face limitations in human, financial, and investment resources, making it difficult for them to engage in the digital transformation process.

It is important to note that the digitalization of the tourism and hospitality sector remains a topic of debate, particularly regarding the opportunities and risks associated with the use of digital technologies. This study specifically aims to examine the perceived benefits and challenges of implementing digital technologies in the industry and to highlight potential directions for future research.

2. Materials and Methods

The main objective of the study is to improve our understanding of the impact of digitalization on the tourism and hospitality sector. The focus is mainly on the potential of digital technologies to create new

values and innovative processes in the digital landscape of tourism and hospitality. To achieve this, the study used methods such as: abstraction (to highlight the most essential aspects of technologies; to focus on key processes); analysis and synthesis (to study individual technologies and synthesize their cumulative impact; to identify the most effective technologies; as well as for decision-making on the effective application of digital technologies and effective investment in innovative technologies); grouping (to identify groups of enterprises implementing innovations). In this sense, the driving motivation is the potential of digitalization to improve business efficiency.

3. Results and Discussion

In 2023, the world witnessed the rapid growth of AI. Everyone is talking about AI these days, and it seems that if a company isn't into it, it's not trendy. The British dictionary Collins has named "artificial intelligence" the word of the year for 2023 [18].

According to GlobalData, the AI market is projected to reach \$383.3 billion in revenue by 2030. In the hospitality sector, the adoption of generative AI is becoming increasingly prominent among industry players. This trend is reflected in a report by SITA, which revealed that 97% of airlines are actively planning initiatives to integrate this technology. Artificial intelligence has significant potential to enhance the customer experience. IDC reports that hoteliers anticipate allocating over 40% of their AI investments next year to predictive AI. Additionally, 86% of airlines, in collaboration with innovation partners, have begun developing AI, machine learning, and computer vision technologies. Among them, 39% have already implemented these technologies, while another 47% plan to do so in the near future [15, 19].

For example, American consulting firm McKinsey recently stated in a report that artificial intelligence has the potential to add \$2–4 trillion in value added per year across various sectors. As for the tourism sector, it will grow by an average of 6% annually over the next 5–7 years thanks to AI. As proof: the share of travel companies' revenues impacted by AI worldwide increased from 9% in 2018 to 21% in 2021. And in 2024, it reached 32%. 25% of companies in the tourism and hospitality sector are already using various innovative technologies. According to report, the AI and hospitality market is expected to grow to over \$1.2 billion by 2026, with a growth rate of over 9.7% [19]. The expansion of this market is driven by several factors, including the swift advancement of infrastructure in airports, seaports, railways, hotels, highways, etc., combined with the introduction of advanced technologies.

The ability of artificial intelligence to perform tasks that traditionally required human cognitive functions has made it particularly useful for those working in the tourism and hospitality industry.

The adoption of AI offers businesses significant time and cost savings while reducing the risk of

human error and enabling tasks to be performed efficiently around the clock. Since exceptional customer service is crucial for hotels and resorts to maintain their reputation, AI can play a key role in enhancing personalization, tailoring recommendations, and ensuring prompt responses — even in the absence of staff. These include:

- Personalized travel recommendations. AI analyzes tourists' preferences and offers personalized options for activities, restaurants, and attractions;
- dynamic pricing: artificial intelligence algorithms monitor data in real time and adjust fares for flights and accommodation;
- Customer service chatbots handle inquiries, facilitate bookings, and offer support. This increases service efficiency and customer satisfaction;
- using AI in transportation to improve passenger safety, reduce road congestion and accidents, reduce carbon emissions, and minimize overall financial costs;
- implementation of artificial intelligence in the hotel sector goes beyond customer service chatbots and encompasses predictive analytics for demand forecasting and personalized guest experience.

The growth of AI-driven travel planning tools from leading companies such as Google, Meta, Expedia, Kayak, Booking.com, and WhatsApp is expected to persist. In July 2023, TUI Group introduced a ChatGPT-powered chatbot in its UK app, taking an initial step toward incorporating generative AI into its technology framework. Likewise, other hotel companies are adopting a similar strategy [15].

For example:

- Hilton has implemented AI-powered chatbots and virtual assistants to offer round-the-clock automated guest support, handling routine inquiries, personalized recommendations, and reservations. This innovation enhances convenience and contributes to a more seamless and autonomous guest experience;
- Additionally, in collaboration with IBM, Hilton introduced Connie, the first AI-powered concierge robot. Connie interacts with guests by providing information on hotel amenities, local attractions, and dining options. With each interaction, she learns and improves, enhancing guest engagement while also helping to reduce staff workload. Connie can answer over 10,000 frequently asked questions about reservations, hotel amenities, maintenance requests, local attractions, restaurant recommendations, and more. She can also alert hotel staff when she is unable to answer a request so they can respond [4];
- Hyatt has integrated AI-powered conversational interfaces into its contact centers, handling over 7 million calls annually. This advancement has significantly improved call processing efficiency, reducing operating costs by \$4.4 million per year while enhancing customer interactions through faster and more accurate responses;

- Additionally, Hyatt leverages AI to analyze guest data, enabling personalized recommendations and services. This technology helps tailor guest experiences — such as room preferences, dining options, and activity suggestions — enhancing satisfaction and fostering loyalty;
- Wyndham Hotels has incorporated an AI-driven messaging system into its operations, allowing guests to receive immediate responses to common inquiries during their stay. This enhances the guest experience while allowing staff to focus on more critical tasks;
- Furthermore, Wyndham's AI-powered guest engagement platform features intelligent mobile check-in and check-out, streamlining the process by verifying credit cards and IDs before arrival. This not only reduces wait times and minimizes fraud risk but also improves housekeeping efficiency by notifying staff when rooms are ready for cleaning. The system has also contributed to a 25% increase in positive reviews at pilot locations;
- Wyndham's AI-driven solutions incorporate predictive analytics for revenue management, leveraging market trends, competitor pricing, and demand forecasts to dynamically adjust room rates, maximize revenue, and enhance overall performance;
- Marriott tested concierge assistants with artificial intelligence, which can have natural conversations with guests in multiple languages. Bots can book services, provide suggestions for destinations based on guests' interests, explain loyalty programs, and much more [4].

Through the integration of AI across various aspects of their operations, these hotel brands have successfully: delivered highly personalized experiences (recommendations and services) to guests and hyperpersonalized marketing based on individual preferences, which is becoming increasingly sophisticated; reduced dependence on physical staff, taking pressure off overburdened customer service agents, enhanced operational efficiency, accelerated revenue growth, and established themselves as pioneers in the digital transformation of the hospitality industry.

According to a study by Revinate, 86% of consumers report that personalization in hospitality influences their purchasing decisions. This level of personalization can significantly increase guest satisfaction and loyalty [20]. As integration deepens, experts predict that it will allow even small hospitality providers to offer customized services.

The growing use of AI-based incentives, along with the use of advanced machine learning (ML) and behavioral science technologies, is helping managers make informed, better, and objective investment decisions, deliver value-added services with greater customer engagement and satisfaction worldwide. AI-driven prompts, which work as cybersecurity prompts in various industries, including tourism, help customers make better security decisions when visiting websites that are experiencing phishing attempts, malicious

content, frequent cyberattacks, or outdated software, and provide personalized recommendations for product selection in the tourism and hospitality industry [19].

For several years now, virtual reality (VR) has been playing an important role in tourism. There is a significant gap between the perception of service consumers and the current service offered by service providers. Customers at a distance are obviously not interested in tourist destinations and the travel experience in that destination. Hotel customers will observe the travel and discovery of tourist destinations before going to the tourist destinations. This is achieved by searching for useful information on the Internet in the form of user reviews, among others. VR technology creates a simulated world that provides a virtual reality experience. In the interactive realm, the 3D customer encounters the environment. The main limitations between the customer and the service provider are solved with this technology. Customers can enjoy the scenic beauty of natural resources, general infrastructure services, and tourist infrastructure destinations by watching augmented reality videos. In order to evaluate the choice of tourist destinations, users can gain detailed first-hand knowledge through VR technology. Travelers use virtual reality headsets to see themselves in specific cities, hotels, or resorts. They can research almost any destination in the world in advance before making a decision about whether to go there or not. VR also helps travelers explore hotel rooms and amenities before booking, making them more confident in their choice.

Augmented reality (AR) has a slightly different effect. Virtual reality seems to transport the user to another place, while augmented reality allows a person to get more detailed information about a particular place using applications on their smartphone. For example, you can point your smartphone at the door of a chosen restaurant and get reviews about it, or you can watch a video of a chef preparing your favorite dish.

AR also allows travelers to take virtual tours of hotels, resorts, museums, etc. to help them decide on their preferred vacation spot. With virtual tours, travelers can explore places without leaving their homes. This allows them to get a realistic idea of the attractions before booking. AR guides provide real-time information via smartphones. They enrich the sightseeing experience by adding cultural knowledge, historical facts, and navigational details to physical landmarks.

If a traveler is in a country whose language they have never even heard in their life, they can use a mobile application that can automatically translate all printed materials — menus, signs, newspapers.

The advantage of VR and AR in the travel industry is that they still have room to grow. The faster the technology develops, the more benefits it will offer users.

Travel companies analyze market trends using big data and analytics to forecast demand, optimize prices, adapt offerings to changing traveler preferences, and increase competitiveness.

Through big data analysis, companies learn who their customers prefer and why. For example, hotels can tailor their offerings to individual needs, such as room temperature, dietary requirements, or entertainment preferences. This allows you to provide personalized service and make customers more satisfied.

Big data and analytics are also used to optimize tourism: finding inefficiencies and improving resource utilization help reduce costs and improve the quality of services.

With the increasing number of travelers, it is important for service providers to differentiate themselves from overly personalized offerings by considering the tastes of visitors. The dynamic method of understanding guest expectations and monetizing the provision of personalized services to guests has progressed with the advent of data analytics. ML (Machine Learning) is an ideal environment for travel businesses to gain basic knowledge and improve operational productivity, meeting consumer needs with cost-effectiveness. A deep understanding of specific consumer needs allows customer service agents or communication staff to recommend products and services that are sure to appeal to the customer. This also contributes to the growth of the market.

Strategic use of data analytics to personalize guest experiences and dynamic pricing strategies is becoming a cornerstone of competitive differentiation in the hospitality industry. Technology packages, which combine AI and data analytics, will enable providers to optimize pricing, more accurately forecast demand, and tailor marketing strategies to individual guest preferences, paving the way for a more personalized and engaging guest journey. A 2023 Deloitte survey found that 85% of hotels using data analytics reported improved customer satisfaction and revenue [20]. According to a Workday report, 51% of hospitality leaders work with data that is at least somewhat siloed within their organization, underscoring the importance of integrated data systems [20].

With facial recognition and fingerprint scanning, travelers can bypass traditional check-in, reducing wait times and simplifying identity verification.

Biometric systems increase security: only authorized persons gain access to restricted areas, and the risk of identity fraud is minimal.

Hotels recognize repeat customers using biometric data and provide personalized service.

In recent years, blockchain technology has gained significant attention across various industries due to its potential to transform the way data is stored and utilized. It enhances transparency, security, and transaction efficiency. Blockchain functions as a public ledger where transactions between participants are recorded. Each entry, known as a “block,” is secured through cryptographic methods.

A key feature of blockchain is decentralization, meaning that information is transmitted through a peer-to-peer (P2P) network. Each block contains transaction details and a timestamp, and once

recorded, the data cannot be altered without the consensus of the entire network and modifying all subsequent blocks. These characteristics — decentralization, immutability, tamper resistance, and transparency — make blockchain more secure, reliable, and resilient against external interference, eliminating a single point of vulnerability [9]. According to a report on the blockchain technology market by Fortune Business Insights, the global market is expected to expand by 59.9% by 2030. In 2023, the market was valued at \$17.57 billion, rising to an estimated \$27.84 billion in 2024. By 2032, it is projected to reach \$825.93 billion, demonstrating a compound annual growth rate (CAGR) of 52.8% from 2024 to 2032 [19].

When it comes to the benefits of blockchain technology in the travel industry, stability and security play a crucial role. Due to its decentralized structure, blockchain ensures that information is never lost, whether due to accidental deletion or cyberattacks. This guarantees continuous availability and traceability of transactions [9]. Under normal circumstances, distinguishing fake passports from genuine ones remains a challenging task. However, with the introduction of blockchain technology, the fear of immutable records has been eliminated. Document verification on blockchain has proven itself with many features such as: immutable records, highest level of security, cheaper transactions, traceability, ownership verification, integrity verification, etc. The document verification process, which uses blockchain innovations and smart contracts, will simply allow the government and other authorized bodies to confirm that the identification process is valid and reliable.

The travel industry depends on seamless information sharing between various companies. For instance, travel agents exchange customer details with airlines and hotels, while travelers’ personal belongings are frequently transferred and tracked across multiple providers. Blockchain enhances the security and accessibility of this data by distributing storage responsibilities across the network, ensuring safer and more efficient management of essential information [9].

Blockchain serves as a guarantee of booking and payment security using smart contracts, reducing the risk of fraud. The booking process takes place transparently in real time without intermediaries.

Blockchain-based loyalty programs provide customers with a secure and transparent way to earn rewards and redeem them across platforms. Such programs increase customer engagement.

Identity services are extremely important to the travel industry. And blockchain could become the industry standard for storing this information, significantly reducing check-in times or queues at the airport, as a simple fingerprint or retina scan could replace showing documents.

Blockchain stores traveler data. This allows for real-time identity verification at checkpoints. Blockchain technologies that incorporate facial recognition offer seamless check-in at airports and all other stations

without any document verification by immigration, customs, etc. Facial recognition software not only offers seamless check-in but also provides digital privacy to visitors and ensures compliance with regulations through blockchain technology. This technology helps travelers avoid queues and fill out the check-in form at the check-in counter. With the help of such terminals, check-in, which usually takes three minutes or more, can be completed in less than a minute. Airlines are not only improving customer service through self-service options. The customer journey process supported by these technologies is positively influencing the growth of the market.

Therefore, the use of blockchain allows:

- during digital identity verification by secure storage of biometric data (e.g. fingerprints, retinal scans) to simplify the verification process, reduce check-in time and queues at the airport;
- securely manage documents (eliminates the need for physical documents, reducing the risks of loss and fraud) by keeping travel documents, visas and identity documents intact;
- during automatic check-in through integration with seamless traveler identification systems in hotels, airports, etc., improve customer interaction through faster and more seamless check-in, securely manage guest data and ensure clear transaction records. Technologies such as mobile check-in, digital room keys, and personalized services have made stays more convenient and enjoyable. According to the 2023 Hospitality Technology Report, 70% of guests prefer hotels that offer digital check-in [20];
- at border control through promoting secure, transparent cross-border identification processes to expedite immigration processes, increasing security and efficiency;
- personalize travel experiences and simplify loyalty program management by creating secure, immutable records of traveler preferences and loyalty points;
- facilitate safe travel and entry into different jurisdictions through health data that can be verified through the secure storage of medical records and vaccination statuses, for example against COVID-19 [9].

It's also quick to use a checkout using facial recognition technology. Travelers identify themselves by scanning their ID, taking a screenshot, and adding their contact information. The computer verifies their knowledge of identification and booking, and issues a room key. For example, Marriott has installed self-service kiosks in its Moxy brand hotels where guests are asked to swipe their credit card, after which the kiosk issues a key to their room.

Blockchain technology could be highly beneficial for monitoring luggage transfers, particularly on international trips. All of a traveler's personal belongings travel with them. Therefore, they are constantly being moved and transported from place to place. Thanks to blockchain, information about all luggage movements

will be available and up-to-date at any time. The use of a decentralized database greatly facilitates the exchange of tracking data between companies.

The Winding Tree platform is a prime example of blockchain-based luggage tracking that also incorporates a booking system. By eliminating third-party involvement, it enables seamless, secure booking and tracking while enhancing transparency [9].

One of the most significant applications of blockchain in the hospitality, tourism, and travel industries is in payments. Its versatility allows it to function as a global ledger, simplifying and securing bank transactions while also enabling travel companies to accept Bitcoin and other cryptocurrencies. A notable example is the BeeToken (Beenest) platform, which connects customers with hosts, facilitating seamless booking and payments without commissions. It also incorporates payment, reputation, and arbitration protocols to enhance user security. Similarly, the LockChain platform serves as a decentralized marketplace for hotels and hospitality businesses, managing payments, property listings, and other booking-related aspects while eliminating intermediaries and commission fees [9].

Additionally, many travel companies are adopting customer loyalty programs to encourage repeat business. Blockchain can streamline these initiatives by making loyalty points more accessible to customers and facilitating the distribution of digital tokens. Moreover, it enhances security by reducing the risk of fraud in loyalty programs.

Therefore, the application of Blockchain technology can help reduce fraud, human error, and provide an efficient and reliable platform for bookings, payments, rewards, and loyalty programs.

It is also worth mentioning the use of CleanTech technologies in tourism:

- the use of solar panels and waste recycling make the premises environmentally friendly, comfortable and do not harm nature;
- the use of environmentally friendly transport, in particular electric vehicles and alternative fuels, reduces carbon dioxide emissions, making travel safe for the environment;
- Intelligent energy management systems (EMS) at tourist facilities optimize energy consumption, reduce costs and environmental impact, i.e. energy-efficient tourism.

Cloud technologies allow businesses to store and process large amounts of data, as well as increase efficiency by automating business processes and expanding opportunities for customer interaction. In particular, integration with tour operators with cloud platforms allows for fast and accurate order processing, allowing customers to book rooms and tables online and receive confirmation in real time.

Cloud computing is enhancing travel companies' CRM systems, enabling them to analyze customer data and provide personalized marketing and services. Property management systems (PMS) integrate various functions such as reservations, billing, and

housekeeping, ensuring seamless operations. In 2023, a McKinsey study found that hotels using an advanced PMS reported a 30% increase in operational efficiency [20].

With cloud-based data analytics, travel companies can tailor travel packages and offer recommendations based on customer preferences.

Using communication technologies:

- tourists can quickly and securely pay for purchases using NFC technology;
- Wi-Fi in tourist destinations allows visitors to receive information and collect data for managing people flows and marketing strategies;
- Travel apps are leveraging 5G networks, private wireless infrastructure, beacon technology, and other tools to provide updates, location-based services, and personalized recommendations.

The tourism and hospitality industry's shift to digital, accelerated by ongoing staff shortages, is driving a surge in contactless services and the adoption of mobile technologies. Mobile apps allow guests to conveniently access services and amenities, from self-service kiosks to digital check-in counters. A significant number of hospitality businesses are adopting a no-staff or minimal-contact model to improve efficiency and guest satisfaction. This digital transformation is helping to create a smoother and more streamlined guest journey from booking to check-out.

Mobile innovation will continue to advance. The growing success of travel-focused mobile tools like Emburse Go, designed to simplify the travel experience, is likely to attract more players to the market. DeepMind co-founder Mustafa Suleiman highlighted that the next phase after generative AI will be interactive AI. Unlike generative AI, which generates content based on input data, interactive AI will enable robots to carry out assigned tasks by collaborating with other programs and individuals. This shift is expected to drive further advancements in mobile concierge technologies, which have been gaining traction in recent years. By 2025 and beyond, we can anticipate a broader range of AI applications and the emergence of new, innovative sectors [15].

For instance, the United mobile app delivers a seamless user experience with features like customized departure times, intuitive baggage tracking, and personalized rebooking options. Skift praised the app for its standout design, calling it "the best digital experience" in a landscape often marked by mediocrity [15].

The term "Internet of Things" more commonly used to refer to everyday physical devices, appliances, and other "things" that are connected to the Internet. The technology allows devices to be remotely controlled or monitored and perform actions automatically [14]. A hotel can become a "smart hotel" with the help of IoT technology. Essentially, a smart hotel is a hotel that uses Internet-connected electronic devices and appliances that are able to communicate or interact with each other by sending or receiving data, which makes them "smart" [21]. The ability of these devices to interact with each other could allow users greater control

and access to information through their phones, as well as control multiple devices from a single control point.

The use of smart devices can help optimize the physical condition of a hotel and its rooms: allows you to manage the room using a mobile application, namely, to adjust lighting, temperature and security; enables personalization by collecting data on guest preferences and adapting services to their needs; enables reduction of electricity costs. It is also worth mentioning about seamless travel: in airports, this could mean using sensors and sending information to passengers' smartphones, alerting them when their luggage is nearby and allowing them to find it more quickly; sensors on planes could alert staff when the alarm level rises above a certain level; hotel check-in could be made seamless (hotels send electronic key cards to guests' phones, which automatically check them in when used, without stopping at the reception desk); sensors could also notify restaurant staff of a guest's arrival, automatically sending them the correct table number; IoT can also be used to collect accurate data on the number of people using certain hotel facilities at different times to optimize staffing [14].

Companies in the travel industry can also use IoT to send location information to customers and collect valuable data. By combining smartphone capabilities with beacon technology or other sensors, it is possible to send messages to tourists at the point where they are most relevant, depending on where they are. For example, this could mean sending messages about: local attractions and tours and the times when they are least busy, which reduces wait times and improves the overall experience of the trip; or real-time recommendations about public transportation.

The Internet of Things can also directly benefit IoT devices by providing valuable real-time information about their current status. This could be vital in the travel and tourism, as it allows major devices to be repaired or replaced before they stop working. For example, hotel staff can be alerted if a radiator or light bulb breaks. Outside of hotels, the Internet of Things can also be deployed to airlines could refuel aircraft more efficiently or replace spare parts in a timely manner, striking the perfect balance between maximizing value and maintaining safety [14].

The trend towards smart rooms is accelerating. Properties like Raus are implementing cutting-edge IoT solutions to offer guests unprecedented control over their stay. These smart home mobile apps, voice controls, and connected devices allow guests to adjust room settings to their preferences, from lighting and temperature to entertainment systems, to create a unique and personalized experience. This level of personalization is becoming the new standard for luxury hospitality:

- apps like Marriott allow guests to customize their ideal room setting before arrival;
- connected Hilton room allows guests to control over 100 features, including streaming their own content to their TV;

- voice control via Amazon Alexa or Google Home allows for hands-free setup;
- smart sensors also detect room occupancy to optimize cleaning and maintenance [22].

Smart technology and the Internet of Things are continuously advancing, leading to the emergence of an increasing number of solutions for smart rooms and smart homes.

For example, SALTO has introduced Smart Locks, an advanced system that enhances traditional mechanical locks by enabling secure, keyless, and mobile access to apartment doors via a smartphone. The system is also compatible with Apple Wallet, offering seamless integration and convenience [15].

Smart bed technology is gaining popularity and receiving higher ratings. At the Lake Nona Wave Hotel in the U.S., guests can experience smart beds that automatically adjust to optimize sleep conditions. These beds monitor and regulate temperature while adapting to relieve pressure points, providing a comfortable and restful night's sleep [15].

These are just a few examples of how IoT solutions provide a high level of convenience and personalization.

A robot is a machine designed to perform specific tasks accurately and automatically. These can be physical tasks, or tasks related to text or speech. They can be fully autonomous or semi-autonomous, working with some human assistance. Modern robots use a variety of technologies: from collision detection to speech recognition and artificial intelligence. According to Global Travel Technologies Business Analysis Report, conducted by Research and Markets, the size of the global hospitality robot market is projected to grow by 25.51% by 2030 [9].

Advanced robotics is constantly improving customer loyalty and customer service quality by providing innovative services and offering assistance in the tourism and hospitality sectors:

- In hotels and airports, robots help navigate: check in customers, answer their questions about help desks, hotel rooms, restaurants and hours, hotel maps, flights, and other related tasks. This provides 24/7 support and improves the guest experience;
- Robot guides conduct interactive tours of museums and tourist attractions: they provide information and engage visitors with dynamic presentations;
- automated transportation: self-driving shuttles and baggage handling robots reduce waiting times, increase safety, and simplify trips for passengers;
- Butler robots and porter robots in hotels assist customers by escorting them to their hotel rooms, delivering luggage to their rooms, maintaining cleanliness, and serving food and snacks;
- customer service chatbots: automatic responses to customer inquiries are available on websites or in applications;
- registration/deregistration work: automated kiosks for self-service check-in and check-out at hotels;

- cleaning robots: automatic machines for washing floors, windows, and public places;
- security work: robots patrol premises to detect and report unusual activity [6].

In particular, brands such as Hilton, Marriott, Henn-na are examples of the implementation of this technology.

Thus, robots delight consumers by offering unexpected services, maintaining constant customer engagement, creating a fresh and exciting atmosphere in their minds. This has a positive impact on the positioning of brands in the market.

Overall, robots offer greater consistency and precision than humans and often perform tasks more quickly, particularly those involving calculations. Unlike employees, robots never experience fatigue or boredom, require no motivation or salary, are not bound by labor regulations, and can operate 24/7, year-round, without breaks or holidays. However, there are also disadvantages: overreliance on robots can lead to “*automation crises*”, when robots will replace humans, leading to a shortage of jobs; robots cannot adapt to unforeseen events, malfunctions, and have high initial and long-term maintenance costs. But there are situations where robots are necessary. A great advantage of their use is their ability to work in dangerous conditions where humans cannot work safely [6].

Automation tools, robotics, and smart home solutions increase work efficiency by:

- reducing dependence on human labor to perform repetitive tasks;
- simplify maintenance with predictive analytics powered by the Internet of Things;
- optimizing utility costs through resource-efficient systems.

These savings allow hotels to invest in improving guest amenities, creating a better overall experience [21].

Digital marketing tools allow hotels to reach a wider audience and personalize their marketing efforts. Social media, email campaigns, and targeted advertising can attract more guests and build brand loyalty. According to a 2023 Statista report, hotels that invested in digital marketing saw a 25% increase in bookings.

Sustainable tourism is a form of tourism that takes into account its economic, social, and environmental impacts, both in the present and the future, while meeting the needs of travelers, the industry, the environment, and local communities. Its core principles focus on balancing environmental, economic, and socio-cultural aspects to ensure long-term sustainability [23].

Green technologies and sustainability include advanced environmental solutions that are applied to protect natural resources and the atmosphere, mitigate or minimize the undesirable impact of anthropogenic activities on the environment, and enhance sustainable development. The main goal of implementing these technologies is to protect and sustain the environment and restore past damage. In 2023, the

global green technologies and sustainability market was estimated at \$17.21 billion.

The market is projected to expand from \$20.90 billion in 2024 to \$105.26 billion by 2032, with an expected CAGR of 22.4% throughout the forecast period [24]. “Digital technologies can accelerate progress towards achieving sustainable development goals, going beyond compliance to help enterprises achieve goals, create new business models, and unlock revenue streams”, said Moyer [3]. According to Gartner, digital technologies play a critical role in achieving both financial and sustainability outcomes.

Now sustainable development is a key part of brand identity and strategy in the tourism and hospitality industry. The use of smart thermostats and lighting to save energy, artificial intelligence and the Internet of Things to reduce food loss and waste, plastic-free policies and digital tools such as apps are helping to make accommodation, restaurants and travel more sustainable, while the closed economy market can create new revenue and reduce waste.

These efforts reduce the industry’s environmental impact and support important ESG goals. Embracing sustainability responds to growing consumer demand for environmentally friendly practices and positions brands as responsible, forward-thinking leaders [21].

While the initial investment in digital technology can be high, the long-term savings are significant. Automation reduces labor costs, and energy-efficient systems reduce utility bills. For example, according to a 2024 report by the International Energy Agency, smart thermostats and lighting systems could reduce energy consumption by up to 20% [20].

Digitalization can also contribute to the sustainability efforts of the hotel industry. Smart technologies, such as energy-efficient lighting and heating systems, help reduce energy consumption and operating costs. For example, hotels can monitor and optimize energy use through smart sensors and automation. This not only reduces costs, but also attracts environmentally conscious guests. According to ABI Research, 6.4 million smart hotel room devices are expected to be shipped worldwide by 2027, more than double the 3.2 million shipped in 2022 [20].

Green technologies refer to environmentally friendly technologies and tools that improve business operations. These technologies also facilitate the use of consumer applications such as charging systems, electric vehicles, smart homes, and other applications powered by IoT sensors. The Internet of Things is an important aspect of the green technology industry and sustainable development. IoT in green technologies enables sensor-based solutions, minimizes the need for human intervention, and provides rich analytical information so that service providers can continuously improve their services. In recent years, the combination of IoT and green technologies has promoted the use of renewable energy. Ecological networks in IoT can provide emission and pollution reduction by using observations and minimizing operational costs and

consumption. The Green Internet of Things (G-IoT) is expected to initiate significant changes that will contribute to the realization of the idea of a green intelligent environment. For example, according to GSMA Intelligence, the tourism and hospitality industry is expected to see massive clusters of sensors, devices and things communicating via high-speed technologies such as 5G within a few years. This growing adoption of IoT technology is likely to propel the green and sustainability market onto a higher growth trajectory.

But traditional technologies are cheaper than green technologies. The high cost of green technology solutions is the environmental cost that is externalized in many conventional manufacturing procedures. In addition, since the technology is still new, training and development costs are expected to be higher compared to existing technologies. High initial deployment costs are likely to limit the adoption of green technologies among enterprises. For example, when using air quality monitoring instruments to analyze and test air quality indicators, detecting biological and chemical parameters in the air requires the use of advanced technologies such as gas sensors, radio frequency identification, and PCR-based biosensors, all of which are expensive.

Furthermore, the estimated benefits of green technologies depend on factors such as technological readiness, human resource capacity, geographical elements, and the availability of supporting infrastructure. Therefore, to deploy green technologies, tourism and hospitality enterprises must satisfy all the requirements mentioned above. However, inadequate infrastructure is likely to hinder the growth of the market [24]. The surge in demand for green and sustainable technologies is attributed to the desire of consumers to be more environmentally conscious. The segmental growth is also significantly driven by government efforts to promote green technologies.

As for customers, the bar for capabilities and service requirements is higher than ever. They demand immediate, fast, and hassle-free service. This trend is sometimes described as the “Amazonization” of the consumer, as Amazon has established high standards for fast delivery, leading to disappointment when other companies fail to meet those expectations. Reflecting on this shift in priorities, Salesforce research highlighted in Tiffany Rowe’s book *The Experience Mindset* found that “88% of customers believe that the experience a company provides is as important as its product or service. In a world where there are many “things”, experience becomes a more valuable currency [25].

It is also worth taking a closer look at the difficulties and obstacles to digitalization in the tourism and hospitality sector:

- high initial investment: Implementing digital solutions requires significant upfront investments in technology and infrastructure. Hotels need to invest in software and hardware, and train staff to effectively use these new systems. This can be

a financial burden, especially for small and independent hotels with limited budgets. A 2023 PwC report found that 40% of small hotels cited financial constraints as a barrier to digitalization. However, the long-term benefits of increased efficiency and guest satisfaction often outweigh the initial costs. As noted Jennifer Kosar — PwC Head of AI Assurance — “Successful AI governance will increasingly be defined not only by reducing risk, but also by achieving strategic objectives and high return on investment” [26; 27];

- Security and privacy concerns: The growing reliance on digital tools increases the risk of data breaches and cyberattacks. Hotels handle vast amounts of personal data, making them prime targets for cybercriminals. Implementing strong cybersecurity measures and adhering to data protection regulations are essential for safeguarding guest information. According to a SiteMinder report, 45% of hotels acknowledge that fragmented technology and data hinder their ability to gain a comprehensive view of customers and operations, emphasizing the importance of integrated and secure systems [28];
- With the increase in digital transactions and data collection, hotels are becoming more vulnerable to cyberattacks. A 2024 study by Cybersecurity Ventures forecasts that cybercrime losses will amount to \$10.5 trillion per year by 2025, emphasizing the critical need for strong security measures. Therefore Enterprises should: develop and systematically update a comprehensive cybersecurity strategy that includes both technical and organizational security measures; use AI technologies to increase the effectiveness of protection and identify potential threats; use blockchain technologies, in particular, to protect confidential and important business data; conduct ongoing professional training of personnel on cybersecurity issues [29];
- reduction in human interaction: While digitalization can increase efficiency, it can also reduce human interaction. This is a key aspect of the hospitality industry. Automated check-ins, chatbots, and smart rooms can lead to fewer face-to-face interactions between guests and staff. This can impact the personalized approach that many guests value in their hotel. Hotels need to find a balance between automation and personalized service to maintain guest satisfaction;
- technological dependence: The adoption of digital technologies can make hotels vulnerable to system failures and technical issues. Any disruptions to digital services can lead to operational issues and negatively impact the guest experience. A 2023 Gartner survey found that 60% of hotels experienced at least one major system failure each year [3]. Hotels should have contingency plans in place to address potential technical issues and ensure smooth operations;
- moving work: Automation and digital tools can lead to job displacement, especially for jobs that

involve repetitive and routine tasks. While digitalization creates new opportunities, it also requires workers to adapt and acquire new skills. According to a 2023 World Economic Forum report, 50% of all workers will need to be retrained by 2025 due to technological advances [30];

- digital divide: Not all travelers are comfortable with digital technology. Some may prefer traditional service methods, and hotels need to accommodate these preferences to avoid alienating a certain demographic. A 2023 PeW Research Center study found that 25% of adults over 65 don't feel comfortable using digital services [30].

4. Conclusions

So, digitalization is a key trend in the modern tourism business. The tourism and hospitality industry is rapidly changing under the influence of technological progress. The latest developments in software and hardware, as well as digital solutions, are fundamentally transforming the guest experience and facilitating the management of hotels, resorts, restaurants and tourism.

The industry is becoming more efficient and guest-centric with the introduction of travel and hospitality software, artificial intelligence, and smart devices. From contactless service to personalized services based on data analytics, these innovations are changing the way we do business. Companies that do not implement digital technologies risk losing their competitive advantage and losing their market position. The range of applications of technology in tourism and hospitality is huge.

Digitalization of the tourism and hospitality industry offers numerous benefits:

- enhancing efficiency and productivity: Automating tasks frees up time and resources for more strategic activities. This includes streamlining HR processes such as recruitment, training, and performance evaluation, allowing employees to focus on creative and high-level tasks. Automation also improves task accuracy, minimizes errors, optimizes workflows, and increases overall operational speed;
- boosting sales and revenue: Digital technologies enable businesses to offer unique and enhanced experiences that set them apart from competitors. By maintaining high customer service standards, leveraging technology to complement rather than replace human strengths, and adopting a personalized approach, businesses can improve service quality and strengthen their competitive edge;
- reducing costs: Automation and optimization help cut unnecessary expenses caused by errors and inefficiencies. By lowering operational costs, improving resource utilization, and uncovering new cost-saving opportunities, businesses can achieve greater financial efficiency;
- informed decision-making: Data collection and analysis provide businesses with deeper insights into customer behavior and market trends, enabling smarter, data-driven decisions;

- improving customer interactions: simplifying access to information, i.e. the ease with which companies and customers can communicate with each other; providing customers with access to information and services 24/7; creating a personalized experience for each customer; collecting and analyzing information about customers to better understand their needs.
- creating new business opportunities: for doing business online; entering new markets; creating new products and services, in particular, those that meet the needs of digital consumers; Attracting tech-savvy guests who value convenience and innovation; Increasing market share and ensuring strong customer loyalty through, for example, investing in user-friendly design, fast professional support and early, flexible adoption of digital technologies; Increasing competitiveness.

But digitalization also creates problems, such as: high initial costs, security issues and confidentiality, job relocation, ongoing staff training, digital divide, reduction of human interaction, technological dependence.

In such a competitive industry, it is crucial to carefully weigh the cost of investing in digital technologies against their long-term benefits or ROI. These innovations come with significant upfront costs

but promise significant operational efficiencies and savings.

By understanding both the benefits and drawbacks of digitalization, tourism and hospitality businesses can better develop business strategies and implement technologies that improve their services while reducing potential risks.

Thus, the digitalization of the tourism and hospitality sector is an important process in the modern world, which allows enterprises in this sector to achieve greater efficiency, reduce costs, improve customer service and occupy a larger market share. The implementation of digital technologies can be a key factor in the success of a business in the face of constant changes in the market. Therefore, it is important to prepare for digital transformation by using new technologies to improve business processes and ensure competitiveness. In 2025 and beyond, the key challenge for the Ukrainian tourism and hospitality sector will be to combine safety, service quality, and digital technologies, which will allow the industry to develop even in conditions of instability.

In the tourism and hospitality sector, companies are also actively testing other innovative technologies that will help them better meet the needs of travelers, generate financial benefits for themselves, and contribute to sustainable development.

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ДИДЖИТАЛІЗАЦІЯ СФЕРИ ТУРИЗМУ ТА ГОСТИННОСТІ

Анотація. У статті досліджено вплив цифровізації на сферу туризму та гостинності, зокрема в умовах сучасних викликів. Проаналізовано стан галузі в Україні у 2024 році, коли, при економічній нестабільності та наслідках війни, спостерігалось збільшення податкових надходжень та поступове відновлення туристичного бізнесу. Окреслено ключові перешкоди розвитку сфери туризму та гостинності в Україні, серед яких низький рівень цифрових технологій та недостатня інфраструктура. Мета дослідження — аналіз основних переваг і бар'єрів, пов'язаних із упровадженням цифрових технологій у сферу туризму та гостинності. Завдання полягає у висвітленні основних перспектив та викликів використання цифрових технологій, а також у формулюванні стратегії застосування цих технологій на туристичному ринку як засобу відновлення індустрії туризму та гостинності. Для цього застосовуються теоретичні, методологічні та системні підходи до аналізу джерельної бази, зокрема, статистичних даних і наукових публікацій. Розглянуто роль диджиталізації, зокрема застосування штучного інтелекту, VR, AR, блокчейну, Інтернет-речей та великих даних, зелених технологій та технологій сталого розвитку на сферу туризму та гостинності. Виконано описовий аналіз рівня цифровізації туризму та можливостей її подальшого розвитку. У результаті дослідження визначено ключові напрямки упровадження цифрових технологій у туризм і гостинність та їх вплив на формування різноманітніших і гнучкіших пропозицій на ринку туристичних послуг. Дійшли висновку, що упровадження цифрових технологій сприяє прозорості та якості туристичних послуг, підвищенню безпеки галузі, що сприятливо позначається на її прибутковості.

Ключові слова: диджиталізація, цифрові технології, III, віртуальна та доповнена реальність, блокчейн, хмарні технології, зелені технології, сталий розвиток.

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INVESTMENT AND ECONOMIC ASPECTS OF THE TRANSITION OF MARITIME TRANSPORT TO LOW-CARBON TECHNOLOGIES

Abstract. *The article discusses the investment and economic aspects of transitioning maritime transport to low-carbon technologies within the framework of global climate initiatives and the evolving regulatory environment. It analyzes the costs associated with fleet modernization, financing mechanisms for environmental solutions, and the impact of the CII indicator and carbon taxation on maritime transportation expenses. An investment model is presented that considers operational savings, emission reductions, and the payback period. Scenario modeling shows that adopting a slow sailing strategy, combined with technical measures, can lower the total voyage cost while also reducing the carbon footprint. Key implementation risks, such as high CAPEX, insufficient infrastructure, and technological uncertainty, are identified, and policy and financial recommendations are provided to encourage the green transformation of the maritime sector. These results can contribute to developing a national strategy for decarbonizing shipping and advancing green logistics.*

Keywords: *shipping, low-carbon technologies, maritime transport, decarbonization, CO₂ emissions, energy efficiency, slow motion, investment model, ESG, carbon pricing, green logistics, foreign economic activity, port infrastructure, cargo transportation.*



Relevance. In the context of global climate challenges and the intensification of the green transformation of the transport sector, shipping is becoming one of the key elements of the decarbonization of international logistics. The introduction of the Carbon Intensity Indicator (CII), the expansion of IMO requirements, and growing investor expectations regarding ESG indicators are shaping a new paradigm for maritime carriers. At the same time, the transition to low-carbon technologies is a technical upgrade and a comprehensive economic transformation that includes investments, operating costs, regulatory risks, price competition, and financial sustainability of market players. These aspects require in-depth analysis in the Ukrainian and international context.

Literature review. Recent research in the field of maritime transport decarbonization covers a wide range of aspects, from strategic planning and policy to technical implementation and socio-economic impacts. Sources [1, 10, 17] highlight systemic approaches to the transition, emphasizing the importance of national and global strategies, overcoming carbon lock-in, and addressing hard-to-decarbonize transport segments. Modeling of energy scenarios, including island systems and analysis of climate policies, is presented in detail in [2, 3, 8], where optimization models are proposed and climate instruments are evaluated.

The technical aspects of the transition are discussed in [7, 9, 11, 14], which analyze the characteristics of alternative fuels (LNG, methanol, ammonia, HVO) and their impact on emissions and the economy. Sources [4, 6, 16] focus on selecting environmental solutions based on multi-criteria optimization and address barriers to implementation. The issues of market instruments, particularly ETS, carbon pricing, just transition, and carbon revenues, are analyzed in [5, 12, 13, 15].

Ukrainian researchers' works [17, 18] stand out distinctly. They are applied in nature and focus on implementing environmental solutions at the level of machinery and marine fuels under real operating conditions.

Problem statement. Despite the growing pressure from international environmental initiatives, financial markets and regulators, the process of transition of maritime transport to low-carbon technologies remains uneven, fragmented and economically controversial. Most shipping companies face a lack of clear investment mechanisms, long-term access to green capital, and risks of losing competitiveness in the face of increasing regulatory pressure (e.g., due to the introduction of CII, ETS, FuelEU Maritime). At the same time, market incentives for switching to alternative fuels, new energy installations, or digital monitoring remain weak or unpredictable. There is a significant lack of evidence-based approaches to assessing the cost-effectiveness and investment feasibility of low-carbon solutions in the maritime sector, particularly in the face of growing risks and uncertainty. The challenge is to develop a coherent economic model of the transition that considers the costs, benefits, risks, and systemic constraints of infrastructure, public policy, and the capital market.

Research objective. To assess the economic impacts and investment needs of the transition of maritime transport to low-carbon technologies, considering global environmental trends, regulatory challenges, and financial instruments for decarbonization.

Statistical aspects of global decarbonization of maritime transport. Maritime transport generates a significant amount of CO₂ emissions every year. According to the OECD and IEA, in 2022, international shipping emitted about 858 million tons of CO₂, which is higher than the level of aviation OECD, 2023 IEA, 2023. The breakdown of emissions by ship type (Fig. 1) shows that tankers (28.55%), dry bulk carriers (27.52%), and container ships (24.03%) account for the largest share of pollution.

At the same time, according to Statista, the global shipping industry consumed 8.7 exajoules of energy in 2021, mainly from fossil fuels. Forecasts until 2050 (Fig. 2) show a gradual decline in the share of oil to 50%, with an increase in the use of ammonia (15%), LNG (20%) and biofuels (10%) Statista, 2024.

The presented statistics show that maritime transport remains one of the largest sources of greenhouse gas emissions in global logistics. The largest contribution to total CO₂ emissions comes from tankers, dry bulk carriers, and container ships, due to their scale of

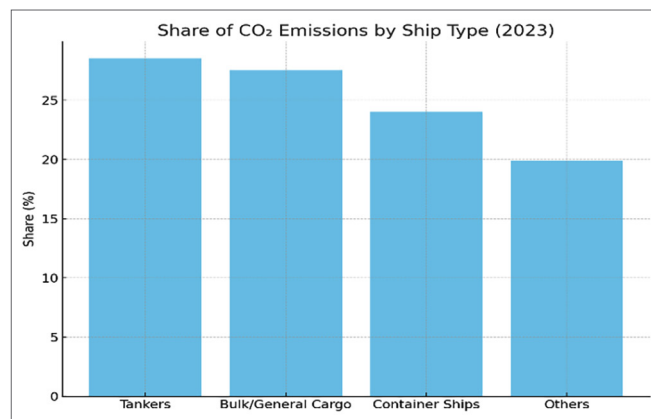


Figure 1. Share of CO₂ emissions by vessel type (2023)

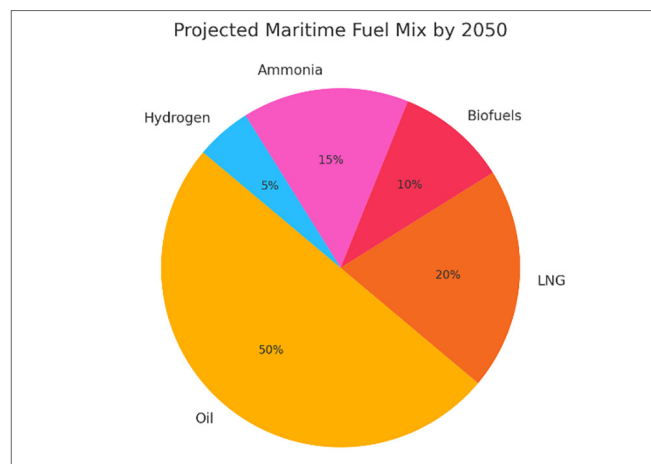


Figure 2. Projected structure of fuel use in maritime transport by 2050

transportation and energy intensity. At the same time, the sector's energy intensity is gradually decreasing, and there is growing interest in the introduction of alternative fuels such as LNG, biofuels, ammonia, and hydrogen. Forecasts to 2050 show a change in the fuel mix, in which fossil fuels, while still dominant, will be complemented by low-carbon solutions. This creates both opportunities and challenges — related to the need for large-scale infrastructure modernization, development of fuel production chains and adaptation of regulatory policies to the new energy reality of maritime transport.

Theoretical and methodological basis of the study. The transition of maritime transport to low-carbon technologies is part of a broader paradigm of decarbonization of the global economy, which the Paris Agreement is shaping, European Union strategies (Green Deal, Fit for 55), initiatives of the International Maritime Organization (IMO), and the green finance market. As part of this transition, key concepts include carbon pricing, emissions externalities, ESG criteria, and institutional support for innovation.

One of the central elements is the carbon pricing system, which, through the CII (Carbon Intensity Indicator), SEEMP, and mechanisms such as the EU ETS, puts financial pressure on ship owners with high emissions. This transforms the cost structure of enterprises and stimulates investment in energy-efficient solutions. The decarbonization economy considers such investments to be long-term, with the effect of strategic protection against future regulatory threats.

From a methodological point of view, the study is based on the principles of institutional economics (analysis of the role of regulators, norms, and incentives), innovation economics (assessment of the impact of technological progress), and applied financial analytics (cost-benefit modeling, sensitivity analysis, NPV/IRR). Basic tools for assessing investment attractiveness are used: calculation of net present value (NPV), internal rate of return (IRR), payback period, and scenario and sensitivity analysis to assess the uncertainty of the regulatory environment, fuel prices and the pace of technological change.

The impact of ESG indicators (environmental, social responsibility, corporate governance) on access to capital is also considered, as shipping companies are increasingly being evaluated according to sustainability criteria. Accordingly, the low-carbon transition is

viewed not only as a technical modernization but also as a strategic investment in companies' competitiveness in the context of global logistics transformation.

Investment model for the transition to low-carbon technologies. The transition to low-carbon technologies in maritime transport involves complex investment decisions that encompass both modernizing the technical base and adapting operational strategies. The primary elements of the investment process are initial capital expenditures (CAPEX), anticipated operating savings (OPEX savings), payback period, and the potential to reduce greenhouse gas emissions. This section evaluates the effectiveness of the key technological solutions that shipping companies can implement as part of their decarbonization strategy.

Table 1 presents a selection of essential technologies with potential for reducing carbon footprints, along with their basic investment parameters, cost savings, and environmental impact.

As can be seen from the table, the most capital-intensive option is the conversion of the engine to a dual-fuel mode using LNG (CAPEX — \$8.5 million), but also the highest level of emission reduction — up to 22 thousand tons of CO₂ per year. At the same time, the slow-running strategy requires minimal investment (\$0.6 million), demonstrates the fastest payback period (0.75 years) and allows for significant emission reductions (15 thousand tons/year), making it extremely attractive in the short and medium term. Other technologies, such as air cushion, hull grinding, or shore power, have moderate investment attractiveness parameters and require a developed infrastructure.

To comprehensively assess the feasibility of implementing such solutions, an integrated environmental and economic efficiency coefficient is used:

$$E_{eco} = \frac{B_{OPEX} + \theta \cdot B_{CO_2}}{CAPEX}, \quad (1)$$

where: B_{OPEX} — is the annual savings in operating costs; B_{CO_2} — is the annual emission reduction converted to a value equivalent (e.g. €85/ton in the ETS system); θ — carbon value coefficient (depending on the region's policy); $CAPEX$ — the amount of initial investment.

The proposed model allows for a comparative analysis of alternatives, taking into account not only the payback period but also the environmental effect integrated

Table 1

Low-carbon maritime technology investments

Technology	Initial CAPEX (USD million)	Expected OPEX savings per year (USD million)	Payback period (years)	CO ₂ reduction potential (tons/year)
Dual-fuel LNG engine retrofit	8.5	1.7	5.00	22000
Installation of air lubrication system	2.2	0.5	4.40	8000
Slow steaming strategy implementation	0.6	0.8	0.75	15000
Hull cleaning & coating optimization	0.9	0.3	3.00	5000
Onshore power supply integration	3.0	0.6	5.00	12000

into the financial assessment. This is becoming increasingly important in the context of the transition to the ESG paradigm and sustainable investments.

Case study: The economics of a low-carbon voyage. To illustrate the practical implications of implementing low-carbon measures in maritime shipping, we have conducted a scenario modeling of the cost of a voyage in two variants: a traditional voyage (baseline scenario) and a green voyage with elements of slow running, the use of energy-saving technologies (ESD) and connection to onshore power supply in the port (OPS). Both scenarios assume a fixed route with the same cargo and tariff. The results are shown in Table 2.

The results indicate that, despite the extension of the voyage duration from 7 to 9 days, implementing low-carbon solutions allows for a 17.9% reduction in total costs (from \$155,400 to \$127,550). This was achieved by lowering fuel consumption by 25% and decreasing CO₂ emissions by 330 tons, which corresponds to \$28,050 in carbon tax savings (calculated at €85/ton of CO₂, reflecting the average level in the EU ETS system).

The overall economy of the flight improves even with a slight increase in operating costs (+\$500) due to the extended duration. This confirms the effectiveness of slow sailing in conjunction with technical measures as a strategy to simultaneously reduce costs and emissions.

Thus, the scenario analysis illustrates the financial feasibility of green transformation even in the short term, provided there is a regulatory incentive (carbon tax) and support for energy infrastructure in ports.

Risks and barriers to the implementation of low-carbon technologies. Despite the growing relevance of decarbonizing maritime transport, the adoption of low-carbon technologies faces several systemic barriers that impede the large-scale implementation of environmentally efficient solutions. These barriers are both technological, economic and institutional in nature.

1. High initial CAPEX. One of the main obstacles is the high cost of modernizing ships (dual-fuel engines, emission treatment systems, digital monitoring, etc.) In most cases, the payback period exceeds 5 years, which does not correspond to small and medium-sized operators' average financial planning horizon. Access to cheap loans or green financing is limited.

2. Infrastructure constraints. The lack of developed coastal infrastructure (shore power, LNG refueling stations, hydrogen terminals) in many ports limits the ability to effectively use new technologies, even in the

case of fleet modernization. This is especially true for developing countries and transit ports.

3. Technological uncertainty. The rapid evolution of IMO standards, the emergence of alternative fuels (ammonium, hydrogen, methanol), and the still unstable regulatory environment lead to a wait-and-see effect: operators postpone investments for fear of obsolescence of already installed solutions.

4. Risks of regulatory fragmentation. There are discrepancies between global IMO requirements and regional systems (EU ETS, FuelEU Maritime). This creates asymmetries in costs and competitiveness between shipping companies operating in different jurisdictions.

5. Shortage of qualified personnel and digital competence. The implementation of most low-carbon technologies requires new competencies of the crew, technical staff and operators — from energy management to working with LNG or hydrogen systems.

Thus, the transition to sustainable maritime transport requires coordinated efforts by the state, the private sector and international organizations, covering not only financing but also standardization, infrastructure development and educational support.

The introduction of low-carbon technologies in maritime transport is a systemic transformation that involves significant costs, changes in business models, and adaptation to new technical and regulatory conditions. For a comprehensive understanding of the problem areas, we propose a framework (Figure 1) that categorizes the main challenges into five key groups: financial barriers, infrastructure constraints, technological uncertainty, human resource gaps, and the need for coordinated policies.

As can be seen from the figure, the central barrier is the high initial CAPEX cost, exacerbated by limited access to green finance, long payback periods and high fleet modernization costs. Infrastructure constraints are particularly critical in developing countries with no LNG/hydrogen terminals or onshore power sources. Technological uncertainty is associated with the emergence of new fuels, rapid changes in IMO requirements, and the risk of obsolescence of implemented solutions. The lack of digital and energy management skills among crew and technicians makes it challenging to integrate modern systems, especially in the LNG and H₂ equipment field. Ultimately, fragmented regulations lead to cost disparities and legal ambiguity, diminishing shipowners' investment incentives.

Table 2

Comparison of flight costs in traditional and low-carbon scenarios

Parameter	Traditional voyage	Low-carbon voyage
Voyage duration (days)	7	9
Fuel consumption (tons)	420	315
Fuel cost (USD)	25,200	18,900
CO ₂ emissions (tons)	1320	990
Operational cost (USD)	18,000	18,500
Emission tax (€85/t CO ₂)	112,200	84,150
Total voyage cost (USD)	155,400	127,550

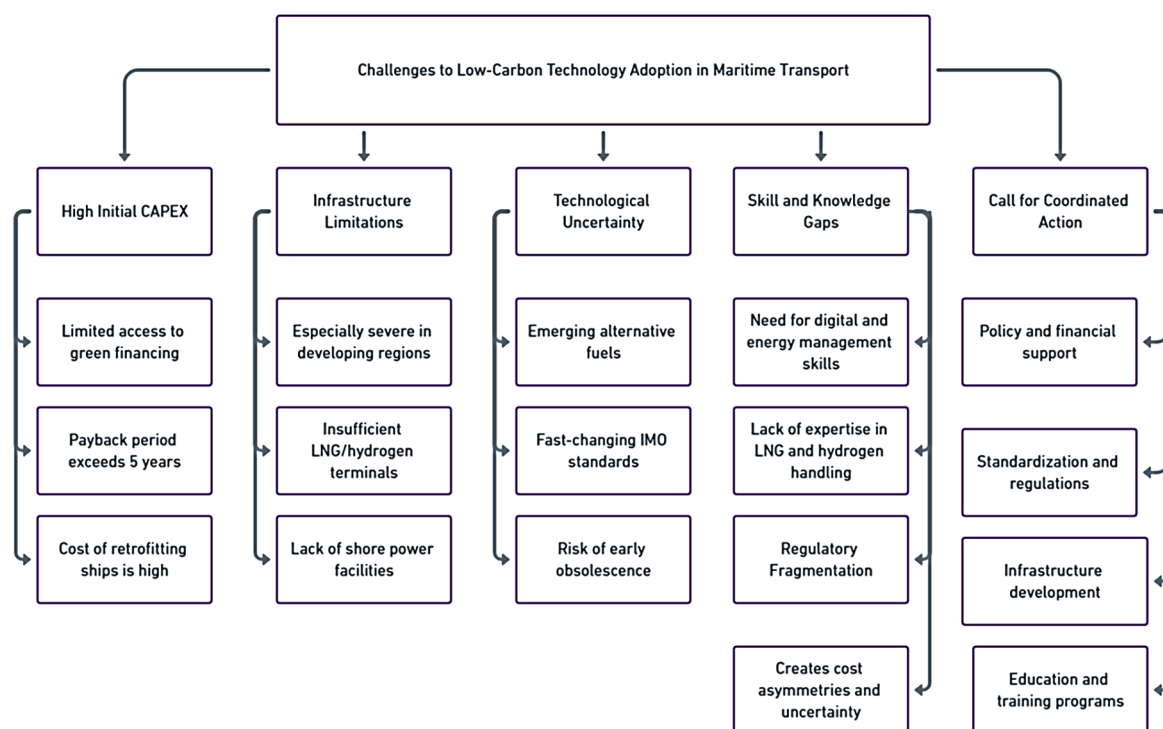


Figure 2. Key challenges to implementing low-carbon technologies in maritime transport

In view of this, implementing low-carbon solutions requires coordinated actions between the state, businesses, and international organizations, including political and financial support, infrastructure development, standardization, and the creation of educational programs. Only if these barriers are removed can the green transformation of maritime transport become systemic and effective.

Policy and management recommendations. Successful implementation of the maritime transport transition to low-carbon technologies requires a systematic, multi-level policy that covers not only financing and regulation, but also infrastructure modernization, training and innovation. This section presents specific recommendations for government policy makers, investors, and industry players, organized into five key areas (Table 3).

First of all, Ukraine needs to adopt a national maritime decarbonization strategy that will be in line with IMO and EU requirements and serve as a basis for regulatory, financial, and infrastructure policies. At the same time, domestic legislation should be harmonized

with European mechanisms (EU ETS, FuelEU Maritime) to avoid barriers to access to international markets. To reduce financing barriers, green support instruments, such as subsidies, insurance, tax benefits, and government guarantees, should be created.

In terms of infrastructure, investments are needed in alternative fuel terminals (LNG, methanol, hydrogen), as well as incentives for port electrification, including connecting ships to an onshore power supply (OPS). It is also advisable to develop training programs for crew and managers in digital monitoring, ESG reporting, and energy management.

Market mechanisms, such as introducing carbon pricing or accession to international emissions trading systems (ETS), should be emphasized as they create clear incentives for reducing emissions and investing in clean technologies.

Conclusions. The study results confirm that introducing low-carbon technologies in maritime transport is strategically feasible in terms of both environmental

Table 3

Policy and investment recommendations for low-carbon maritime transition

Category	Recommendation
Policy and Regulation	Adopt a national maritime decarbonization strategy aligned with IMO and EU targets
Policy and Regulation	Harmonize national legislation with ETS and CII requirements
Finance and Investment	Create green financing instruments (e.g., subsidies, credit guarantees)
Finance and Investment	Develop public-private partnerships (PPPs) for fleet modernization
Infrastructure	Invest in LNG, methanol, and hydrogen terminal infrastructure
Infrastructure	Provide incentives for port electrification (OPS) and ESD deployment
Education and Skills	Implement training programs in alternative fuels and digital monitoring
Education and Skills	Integrate ESG skills into maritime education programs
Market Instruments	Introduce carbon pricing mechanisms or emissions trading schemes

impact and economic efficiency. Despite the high start-up costs, the scenario analysis demonstrates a reduction in total operating costs and greenhouse gas emissions with the transition to slower speeds, the introduction of alternative fuels, shore power, and energy-saving systems. At the same time, the identified barriers — financial, infrastructural, human resources, and regulatory — require a comprehensive support

policy. Creating the conditions for attracting green capital, harmonizing legislation with European standards, developing port infrastructure, and training specialists are key prerequisites for a successful transition. The green transformation of maritime transport should be viewed as a multisectoral investment strategy for sustainable development that combines technological innovation, market mechanisms, and public policy.

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ІНВЕСТИЦІЙНІ ТА ЕКОНОМІЧНІ АСПЕКТИ ПЕРЕХОДУ МОРСЬКОГО ТРАНСПОРТУ ДО НИЗЬКОВУГЛЕЦЕВИХ ТЕХНОЛОГІЙ

Анотація. У статті розглядаються інвестиційні та економічні аспекти переходу морського транспорту до низьковуглецевих технологій у контексті глобальних кліматичних ініціатив та трансформації регуляторного середовища. Проведено аналіз витрат на модернізацію флоту, механізмів фінансування екологічних рішень, впливу індикатора СІІ та вуглецевого оподаткування на вартість морських перевезень. Представлено інвестиційну модель з урахуванням операційної економії, скорочення викидів та періоду окупності. Сценарне моделювання демонструє, що стратегія повільного ходу у поєднанні з технічними заходами дозволяє зменшити загальні витрати рейсу при зниженні вуглецевого сліду. Визначено ключові ризики впровадження (високий CAPEX, нестача інфраструктури, технологічна невизначеність), а також сформульовано політичні та фінансові рекомендації для стимулювання зеленої трансформації морського сектору. Результати можуть бути використані для формування національної стратегії декарбонізації судноплавства та розвитку екологічної логістики.

Ключові слова: судноплавство, низьковуглецеві технології, морський транспорт, декарбонізація, викиди CO₂, енергоефективність, повільний хід, інвестиційна модель, ESG, вуглецеве ціноутворення, зелена логістика, зовнішньоекономічна діяльність, портова інфраструктура, вантажні перевезення.

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IMPLEMENTATION OF THE MECHANISM FOR STRENGTHENING ECONOMIC SECURITY INTO THE ENTERPRISE DEVELOPMENT STRATEGY

Abstract. Sustainable development of the enterprise through the implementation of a reliable strategy is a significant factor in competitiveness and increasing the level of profitability. Against this background, strengthening economic security is only a guarantee and support for this direction. At the same time, in the modern scientific world there are not enough methods and tools that allow for the successful implementation of the processes of strengthening the economic security of enterprises in its development strategy. In this direction, it is important to consider the initial conditions of the level of economic security of the enterprise and, accordingly, choose the direction of strategic development (aggressive, compromise or conservative) that would satisfy both the increase in the level of security and would help create conditions for long-term planning. The study used a system of methods and tools that allowed solving the tasks of the article: quantitative (statistical), qualitative (expert), abstraction, deduction, mathematical modelling and induction. The database used to confirm the effectiveness of the implementation of the processes of strengthening economic security in the enterprise development strategy is official statistical sources of financial activity of enterprises and expert assessment of employees.

It is proven that strengthening the economic security of enterprises plays an important role both in the effective functioning of the enterprise and in its further strategic development. Therefore, the implementation of the two components, with constant control of implementation, has a synergy effect. The methodology of priority placement (SMART), additive weighting (SAW), “ideal” points (LINMAP) and ideal positive solution (TOPSIS) is proposed to establish adaptive interaction of the processes of strengthening economic security and the development of strategic planning of enterprises.

The recommendations received on the proposed strategies for the development of enterprises of the Unified Economic System-U indicate an increased need for the formation of a new type of internal management, which fully reflects the long-term development plans of enterprises. The proposed methodology will be useful for both internal and external stakeholders of enterprises, and can also be implemented in various industries.

Keywords: economic security, development, strategy, model, SMART criteria, enterprise.



1. Introduction

The development strategy of any enterprise is the key to its continuous development, choosing the right path and, above all, making the right decisions in a timely manner and with the best use of all resources. Currently, a correctly chosen strategy is the vector of development, the formation of the enterprise and obtaining the desired level of competitiveness. Today, enterprises do not exist separately from the system, but themselves create a system of relationships in which they function. At the same time, having a desire to constantly develop and improve. The development of the theory of strategic management has its roots in the middle of the last century, but at present, digitalization and the widespread use of artificial intelligence dictate the conditions and contribute to the environment of all factors of the enterprise's management in order to obtain the desired result. In this direction, economic security, as a component that allows you to adjust the vector of movement in time, is a significant component. Accordingly, the improvement of the strategic management of the enterprise has its dependence on the correctly chosen mechanism for managing the economic security of the enterprise.

The purpose of this article is to determine the methodology for the successful implementation of the mechanism for strengthening the economic security of an enterprise in conditions of uncertainty in the enterprise's development strategy.

Not many scientific works are devoted to the issue of implementing a mechanism for strengthening the economic security of enterprises in the strategy of its development. And currently, it is inherent in scientists to characterize economic security at the state level and form a general picture of creating conditions for security guarantees in the economic context by isolating various components. Thus, according to Pryimak et al. [1], the system of socio-cultural indicators in the state is of great importance. Their formation can ensure the proper level of development of the population and the country as a whole. But the authors do not single out the formation of such a system at the enterprise level and, accordingly, do not cover the issue of the development of economic entities. The results obtained in the work of scientists are general and can serve to develop macroeconomic potential. In this direction, it is also worth noting the work of Popławski [2], who develops the specified issues and analyzes data on the implementation of a multifactor model of socio-cultural security, using the example of Poland. The author suggests that correctly identified threats and risks can help predict the standard of living of the territory being analyzed. The presented model covers a wide range of indicators for analysis, it contains clearly distinguished cause-and-effect relationships, but it is also aimed at the state and population levels. As for individual enterprises, this approach is not effective, due to the fact that it does not reflect all components of economic activity. This type of research will be more favorable for determining demographic characteristics of development.

In the direction of development and strategic thinking, scholars such as Saba [3] have good achievements, highlighting the economic prosperity of African countries. In the work, the author, as a result of the study, proves the relationship between economic prosperity and security, which confirms our opinion about the right trajectory for strategic planning. It is also worth noting Shigeaki [4], who describes in detail the example of Japan, where since 2022, tracking the level of economic security of the state has been adopted at the level of legislative regulation. That is, Japan accepts the fact of mandatory formation of the country's development on the basis of economic security. In this case, we again have confirmation of the macro-level manifestation of the introduction of economic security tracking, but the connection between strategy and this direction is already traced. Another Asian country also directs its achievements towards development through the prism of economic security. It is worth noting the opinion of Yuan [5], who proposes to train workers so that they can create security conditions for their country abroad at any time. And also, Koyu et al. [6] form the historical background and development regarding the countries of the East. As for the instrumental base of research, the field of application of the tools is quite wide. Mora et al. [7] apply the strategy of smart specialization (C3), the results of which testify to the effectiveness in the direction of implementing innovations. Walsh & Lannon [8] pay attention to the strategy of knowledge management, and in the development of this direction it is worth noting Andriushchenko et al. [9], who prove the methodological application using the example of analyzing the aviation sector of the economy.

Regarding the methodology of economic security, many scientists pay attention to defining the components of this concept. They analyze different approaches and methods of factors that make up the general system of indicators of economic security of enterprises. These include the studies of Zhao & Yue [10] and Wu et al. [11], which introduce analysis and comparison tools to determine added value, as a component of economic security, which can be traced through the instrumentation of uncertainty and fuzzy sets. The results are quite important, but are not unified for different industries, but focused on construction, which has its own specifics of functioning. On the other hand, there are studies that indicate the multifaceted nature of economic security factors. Thus, the works of Andriushchenko et al. [12] and Liezina et al. [13] expand the list of indicators and prove their relevance and reliability of calculations in various sectors of the economy. Scientists most often use point (Leal et al. [14]), indicator (Font et al. [15]), integral (Renthlei & George [16] and Chen et al., [17]) and expert methods (Qazi & Simsekler [18]). All of them are quite popular, but have drawbacks. These include the subjectivity of the results, given the involvement of experts who express their own opinions; unreliability of the data, because along with statistical data, there is also a point assessment, which neutralizes the general results; the formation of a general result, which does

not reveal the details of its creation, and accordingly does not provide opportunities for the necessary recommendations. Given this, it can be formed that during the strategic planning of the development of the enterprise, there are no factors and methods that are supported by the instrumental base of economic security.

In general, the implementation of the mechanism for strengthening the economic security of enterprises is carried out by all employees in the process of conducting entrepreneurial activity, which is most often the object of planning. It is obvious that achieving an appropriate level of own economic security by enterprises is the result not only of establishing the “rules of the game” for its provision and strengthening, but also of developing clear algorithms for their observance and integration into strategic and tactical plans. This opinion is supported by scientists Hu et al. [19] and Fayoumi & Loucopoulos [20] in their works.

With due respect to the scientific developments of the authors, we note a certain fragmentation in the consideration of the implementation of mechanisms for strengthening the economic security of enterprises in the strategy of its development. Within the framework of our research, it will be useful to use the means, methods and tools of the above-mentioned authors, which can be partially used for our scientific research.

2. Materials and Methods

Regarding the issues of our research, the NAO-MIE management process life cycle model attracts attention, the stages of which successfully reflect the logic of developing an enterprise’s economic security strategy. In the specified model (Table 1), it is possible to conditionally distinguish 3 zones of responsibility for its implementation by economic activity subjects. These are the NAE, MIO, MEA triangles.

In the process of strategy development, the planning boundaries are expanded and the goals (tasks, priorities, etc.) of the enterprise are clearly set within each of the components of economic security, taking into account its general level. Based on this, the strategy for strengthening the economic security of the enterprise should be a plan of coordinated actions that concerns all its components. For this, it is advisable to distinguish the following strategies: aggressive, compromise and conservative. In order to implement the process of strengthening the economic security of enterprises in the strategy of its development (in accordance with the selected type of strategy), the use of “intellectual” methods and criteria is provided. These are SMART criteria, which provide that any strategy, including the one we are studying, must be: specific, measurable, attainable, relevant, time-bound. Obviously, these criteria have different meanings for each of the components of economic security due to their objective features. To do this, it is necessary to take into account all the SMART criteria when choosing an enterprise’s economic security strategy, which requires the use of combined methods of their assessment, which harmoniously combine the entire toolkit. This group includes the following methods: priority ranking (SMART), additive weighting (SAW), “ideal” points (LINMAP), ideal positive solution (TOPSIS). It is worth noting that, despite the similarity of individual calculation algorithms, each of these methods differs in the implementation mechanism and approach to compiling a matrix for choosing an enterprise’s economic security strategy.

In the most general sense, the implementation of these methods comes down to modeling the impact of SMART criteria assessments on the choice of a particular economic security strategy using the following formulas that take into account the uncertainty factor:

Table 1

Essential characteristics of the NAOMIE model for application in enterprise strategy

An element of the model		Areas of responsibility and stages of implementation of model elements		Information needs when implementing model elements
<i>N</i> <i>(needs)</i>	The need and prerequisites for strategy development	MNEO: Strategy implementation entity		Information about existing and potential threats to the economic security of the enterprise
<i>A</i> <i>(aim)</i>	The goal of strategy development			Information on the dynamics of activities, available resources, indicators reflecting the current and desired level of economic security of the enterprise
<i>O</i> <i>(objectives)</i>	Tasks and directions of strategy development	Δ MIO: Heads of structural divisions	Δ NEA: Owner and/or senior management of the enterprise	Information on the advantages and disadvantages of using different strategy development methods
<i>M</i> <i>(methods)</i>	Strategy development methods and their alternatives			Information on the progress of implementation of measures provided for by the strategy
<i>I</i> <i>(implementation)</i>	Strategy implementation			
<i>E</i> <i>(evaluation)</i>	Evaluation and control of strategy implementation	Δ MEA: Business owner		Information on the presence of deviations of actual indicators from planned ones

Source: author’s development

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{j=1}^m a_{kj}^2}}, \quad (1)$$

$$S_i = \sqrt{\sum_{j=1}^m w_j * (x_{ij} - x_j^+)^2}, \quad (2)$$

$$S_{j=1}^+ = \sqrt{\sum_{j=1}^m (x_{ij} - x_j^+)^2}, \quad (3)$$

$$S_{j=1}^- = \sqrt{\sum_{j=1}^m (x_{ij} - x_j^-)^2}, \quad (4)$$

$$S = \frac{S_j^-}{S_j^- + S_j^+}, \quad (5)$$

where x_{ij} — normalized values of SMART criteria scores;

a_{ij} — SMART criteria score;

S — integral score of SMART criteria;

w_j — SMART criterion weight;

x_j^+ — maximum value of SMART criteria score;

x_j^- — minimum value of SMART criteria score;

S_j^+ — distance to ideal positive solution;

S_j^- — distance to ideal negative solution.

Given the fact that the above formulas are universal and can be used to solve various problems related to the assessment of certain criteria, there is a need to adapt them to the scope of our study.

3. Results and Discussion

Thus, the method of prioritization, the calculation logic of which is presented in Table 2, involves obtaining expert assessments (often on a 100-point scale), adjusted for the weight of each SMART criterion. In other words, we are talking about the calculation and further analysis of the integral expert assessment obtained by normalizing the primary results. This method allows you to move from any expert assessment system to a unified matrix (normalized) through conversion to a 100-point scale.

Thus, the values obtained in the normalized matrix (Table 2) are adjusted to the weight of each of the SMART criteria and added to obtain an integral assessment of each strategy for strengthening economic security. The strategy, the integral assessment of which is greater than the others, is better for implementation. However, it is also necessary to take into account individual assessments of individual criteria that are a priority for a particular component of economic security. The method of assessing alternatives (SAW), unlike the previous one, involves the use of a different type of normalized matrix. The result of the criteria assessment is the construction of a normalized matrix with values in the range from 0 to 1 (Table 3), since each assessment is divided by the maximum of the selected set of values. For greater accuracy, the weight of the SMART criteria can be used.

A distinctive feature of this method is that the SMART criteria cannot be evaluated equally. This condition is additionally stipulated during expert assessment. This leads to the fact that one strategy is

Table 2

Calculating the assessment of SMART criteria using the method of determining priorities

Strategies	Criteria					Integral assessment
	S	M	A	R	T	
Aggressive	$S_1 * S_0$	$M_1 * M_0$	$A_1 * A_0$	$R_1 * R_0$	$T_1 * T_0$	$S_1 * S_0 + M_1 * M_0 + A_1 * A_0 + R_1 * R_0 + T_1 * T_0$
Compromising	$S_2 * S_0$	$M_2 * M_0$	$A_2 * A_0$	$R_2 * R_0$	$T_2 * T_0$	$S_2 * S_0 + M_2 * M_0 + A_2 * A_0 + R_2 * R_0 + T_2 * T_0$
Conservative	$S_3 * S_0$	$M_3 * M_0$	$A_3 * A_0$	$R_3 * R_0$	$T_3 * T_0$	$S_3 * S_0 + M_3 * M_0 + A_3 * A_0 + R_3 * R_0 + T_3 * T_0$
Criterion weight	S_0	M_0	A_0	R_0	T_0	$S_0 + M_0 + A_0 + R_0 + T_0$

Note: S_0, M_0, A_0, R_0, T_0 — the weight of SMART criteria in the integral assessment;
 $S_0 + M_0 + A_0 + R_0 + T_0 = 1$;
 $S_{01,2,3}, M_{1,2,3}, A_{1,2,3}, R_{1,2,3}, T_{1,2,3}$ — expert assessment of SMART criteria on a 100-point scale

Source: author's development

Table 3

Calculation of SMART criteria scores using the adaptive weighting (SAW) method

Strategies	Criteria					Integral assessment
	S	M	A	R	T	
Aggressive	$S_1/100$	$M_1/100$	$A_1/100$	$R_1/100$	$T_1/100$	$(S_1 * S_0 + M_1 * M_0 + A_1 * A_0 + R_1 * R_0 + T_1 * T_0)/100$
Compromising	$S_2/100$	$M_2/100$	$A_2/100$	$R_2/100$	$T_2/100$	$(S_2 * S_0 + M_2 * M_0 + A_2 * A_0 + R_2 * R_0 + T_2 * T_0)/100$
Conservative	$S_3/100$	$M_3/100$	$A_3/100$	$R_3/100$	$T_3/100$	$(S_3 * S_0 + M_3 * M_0 + A_3 * A_0 + R_3 * R_0 + T_3 * T_0)/100$
Criterion weight	S_0	M_0	A_0	R_0	T_0	$S_0 + M_0 + A_0 + R_0 + T_0$

Note: S_0, M_0, A_0, R_0, T_0 — the weight of SMART criteria in the integral assessment;
 $S_0 + M_0 + A_0 + R_0 + T_0 = 1$;
 $S_{01,2,3}, M_{1,2,3}, A_{1,2,3}, R_{1,2,3}, T_{1,2,3}$ — expert assessment of SMART criteria on a 100-point scale

Source: author's development

necessarily the best according to a certain criterion. Obviously, this method makes it possible to better identify the advantage of a particular criterion in different economic security strategies, which is especially important when combining them for its various components and taking into account uncertainty conditions. However, for a combination of economic security strategies of an enterprise, it is not enough to take into account the weight of the criteria assessment when compiling a normalized matrix. For this, according to the method of “ideal” points (LINMAP), it is necessary to adjust the initial criteria assessments using formula 4 (Table 4).

The next step is to select the “ideal” points, in the case of maximum values of the adjusted scores of the SMART criteria. Next, the distances to the “ideal” points for each criterion are determined based on formula 2 (Table 5). The strategy whose integral score is smaller than the others is the best for implementation.

However, in practice, it is often difficult to unambiguously evaluate a particular SMART criterion using the “ideal” point method by choosing only one of them. This is due to the fact that several values can be approximately the same and claim to be “ideal”. To

overcome this situation, it is advisable to implement the TOPSIS method, which will allow simultaneously taking into account the distance from the ideal positive and ideal negative value of the criteria assessment within each of them. This method is a logical continuation of the previous one, since on the basis of calculating the adjusted values of SMART criteria using the “ideal” point method, their normalization occurs depending on the weight of each of them (Table 6).

Having adjusted the values of the SMART criteria, their ideally positive (maximum) and ideally negative (minimum) evaluations are then determined with the simultaneous calculation of the distance from each other. This distance, calculated on the basis of formulas 3 and 4 (similar to the calculations given in table 5), is the basis for the final integral evaluation of the SMART criteria according to formula 5. The strategy, the integral evaluation of which is greater than the others, is better for implementation.

Confirmation of the feasibility of implementing adapted methods for assessing SMART criteria when choosing a strategy for strengthening economic security in conditions of uncertainty was facilitated by their testing at enterprises. The companies of the Unified

Table 4

Calculation of SMART criteria score using the “ideal” points method (LINMAP)

Strategies	Criteria				
	S	M	A	R	T
Aggressive	$\frac{S_1}{\sqrt{\sum S_i^2}}$	$\frac{M_1}{\sqrt{\sum M_i^2}}$	$\frac{A_1}{\sqrt{\sum A_i^2}}$	$\frac{R_1}{\sqrt{\sum R_i^2}}$	$\frac{T_1}{\sqrt{\sum T_i^2}}$
Compromising	$\frac{S_2}{\sqrt{\sum S_i^2}}$	$\frac{M_2}{\sqrt{\sum M_i^2}}$	$\frac{A_2}{\sqrt{\sum A_i^2}}$	$\frac{R_2}{\sqrt{\sum R_i^2}}$	$\frac{T_2}{\sqrt{\sum T_i^2}}$
Conservative	$\frac{S_3}{\sqrt{\sum S_i^2}}$	$\frac{M_3}{\sqrt{\sum M_i^2}}$	$\frac{A_3}{\sqrt{\sum A_i^2}}$	$\frac{R_3}{\sqrt{\sum R_i^2}}$	$\frac{T_3}{\sqrt{\sum T_i^2}}$

Note: $S_{1,2,3}$, $M_{1,2,3}$, $A_{1,2,3}$, $R_{1,2,3}$, $T_{1,2,3}$ — expert assessment of SMART criteria on a 100-point scale

Source: author's development

Table 5

Calculation of SMART criteria score using the “ideal” points method (LINMAP)

Strategies	Integral assessment
Aggressive	$\sqrt{S_0 * (S_1 - S_{\max})^2 + M_0 * (M_1 - M_{\max})^2 + A_0 * (A_1 - A_{\max})^2 + R_0 * (R_1 - R_{\max})^2 + T_0 * (T_1 - T_{\max})^2}$
Compromising	$\sqrt{S_0 * (S_2 - S_{\max})^2 + M_0 * (M_2 - M_{\max})^2 + A_0 * (A_2 - A_{\max})^2 + R_0 * (R_2 - R_{\max})^2 + T_0 * (T_2 - T_{\max})^2}$
Conservative	$\sqrt{S_0 * (S_3 - S_{\max})^2 + M_0 * (M_3 - M_{\max})^2 + A_0 * (A_3 - A_{\max})^2 + R_0 * (R_3 - R_{\max})^2 + T_0 * (T_3 - T_{\max})^2}$

Note: S_0 , M_0 , A_0 , R_0 , T_0 — the weight of SMART criteria in the integral assessment;

$S_0 + M_0 + A_0 + R_0 + T_0 = 1$;

$S_{1,2,3}$, $M_{1,2,3}$, $A_{1,2,3}$, $R_{1,2,3}$, $T_{1,2,3}$ — expert assessment of SMART criteria on a 100-point scale

$S_{\max}$, $M_{\max}$, $A_{\max}$, $R_{\max}$, $T_{\max}$ — the meaning of “ideal points”

Source: author's development

Table 6

Calculation of SMART criteria score using the “ideal” points method (LINMAP)

Strategies	Criteria				
	S	M	A	R	T
Aggressive	$\frac{S_1}{\sqrt{\sum S_i^2}} * S_0$	$\frac{M_1}{\sqrt{\sum M_i^2}} * M_0$	$\frac{A_1}{\sqrt{\sum A_i^2}} * A_0$	$\frac{R_1}{\sqrt{\sum R_i^2}} * R_0$	$\frac{T_1}{\sqrt{\sum T_i^2}} * T_0$
Compromising	$\frac{S_2}{\sqrt{\sum S_i^2}} * S_0$	$\frac{M_2}{\sqrt{\sum M_i^2}} * M_0$	$\frac{A_2}{\sqrt{\sum A_i^2}} * A_0$	$\frac{R_2}{\sqrt{\sum R_i^2}} * R_0$	$\frac{T_2}{\sqrt{\sum T_i^2}} * T_0$
Strategies	$\frac{S_3}{\sqrt{\sum S_i^2}} * S_0$	$\frac{M_3}{\sqrt{\sum M_i^2}} * M_0$	$\frac{A_3}{\sqrt{\sum A_i^2}} * A_0$	$\frac{R_3}{\sqrt{\sum R_i^2}} * R_0$	$\frac{T_3}{\sqrt{\sum T_i^2}} * T_0$

Note S_0, M_0, A_0, R_0, T_0 — the weight of SMART criteria in the integral assessment;
 $S_0 + M_0 + A_0 + R_0 + T_0 = 1$;
 $S_{1,2,3}, M_{1,2,3}, A_{1,2,3}, R_{1,2,3}, T_{1,2,3}$ — expert assessment of SMART criteria on a 100-point scale

Source: author's development

Energy System of Ukraine (UES-U) were selected for the analysis, namely JSC NNEGC Energoatom, NEC Ukrenergo, JSC Ukrhydroenergo, JSC NJSC Naftogas Urkayny, PJSC DTEK Kyiv Regional Electric Networks, JSC DTEK Zakhidenergo, JSC DTEKDni-proenergo, PJSC Centrenergo. Thus, the corresponding results of calculations of SMART criteria when choosing a strategy are presented in Fig. 1.

The results of the calculations of SMART criteria when choosing a strategy for strengthening the economic security of enterprises of the Unified Energy System of Ukraine using the adaptive weighting (SAW) method are presented in Fig. 2.

The results of the calculations of SMART criteria when choosing a strategy for strengthening the economic security of enterprises of the Unified Energy

System-U using the method of “ideal” points (LINMAP) are presented in Fig. 3.

The results of the calculations of SMART criteria when choosing a strategy for strengthening the economic security of enterprises of the Unified Energy System (UES) using the method of ideal positive solutions (LINMAP) are presented in Fig. 4.

The results of the simulation and analysis show almost complete coincidence of the results of the assessment of SMART criteria using the methods of prioritization and additive weighting (SAW). The differences are associated with the revision of the assessments of SMART criteria during the implementation of the second method, since, according to it, their identical values are unacceptable. In addition, the results of the implementation of the specified methods allow

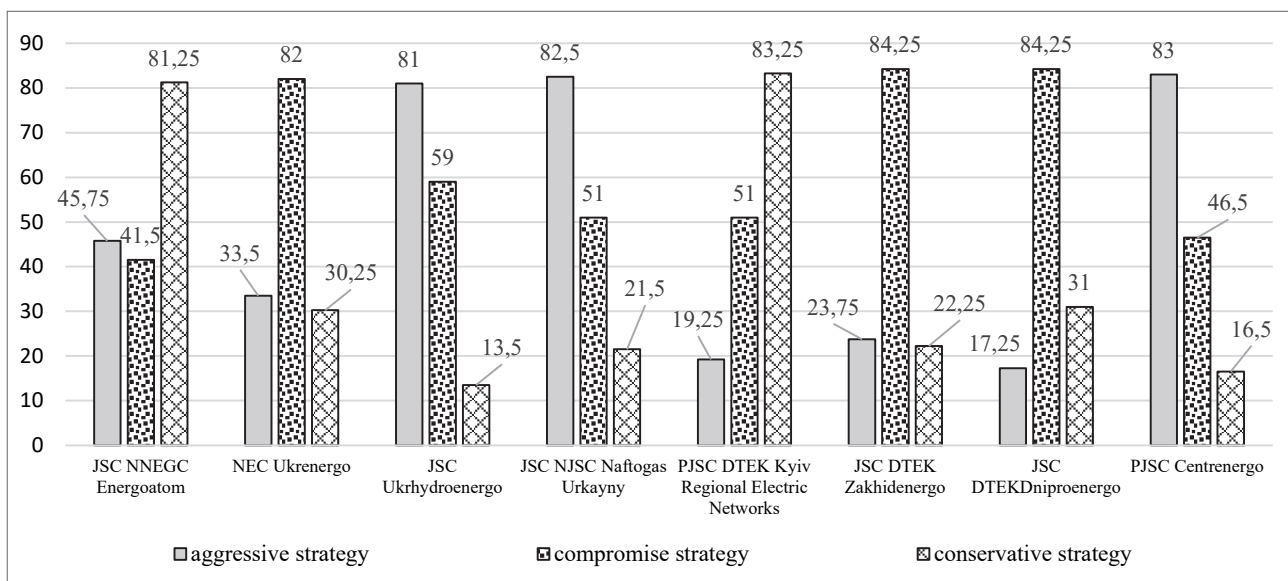


Figure 1. Results of the assessment of SMART criteria when choosing a strategy for strengthening the economic security of the UES-U enterprise

Source: calculated by the author

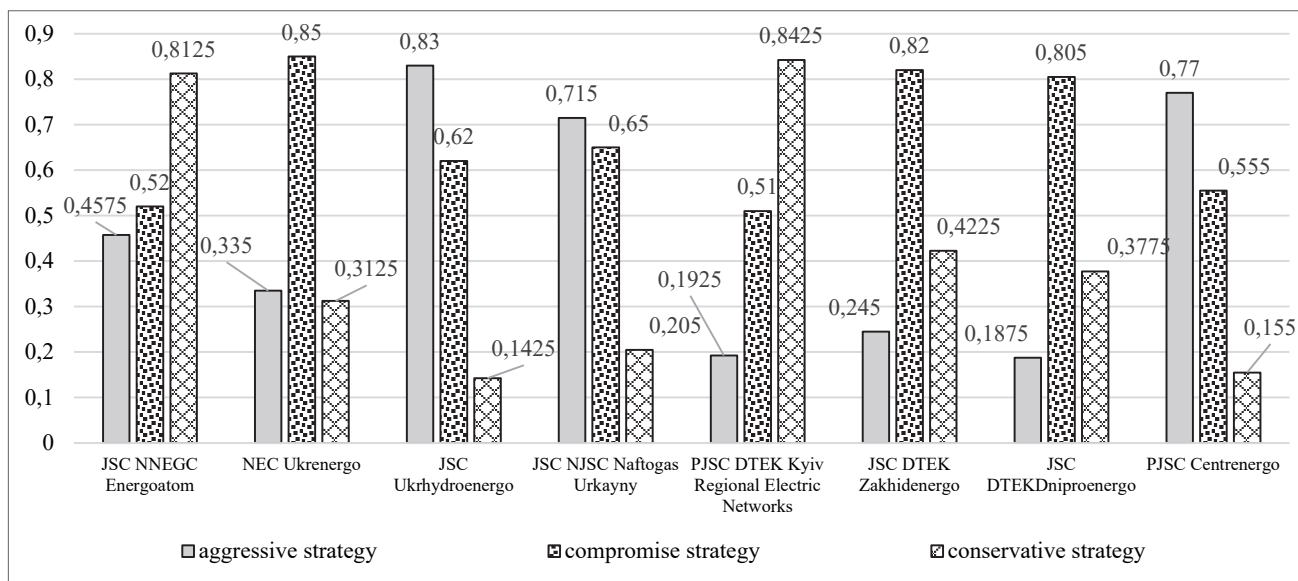


Figure 2. Results of the evaluation of SMART criteria when choosing a strategy for strengthening the economic security of enterprises of the UES-U enterprise using the adaptive weighting method (SAW)

Source: calculated by the author

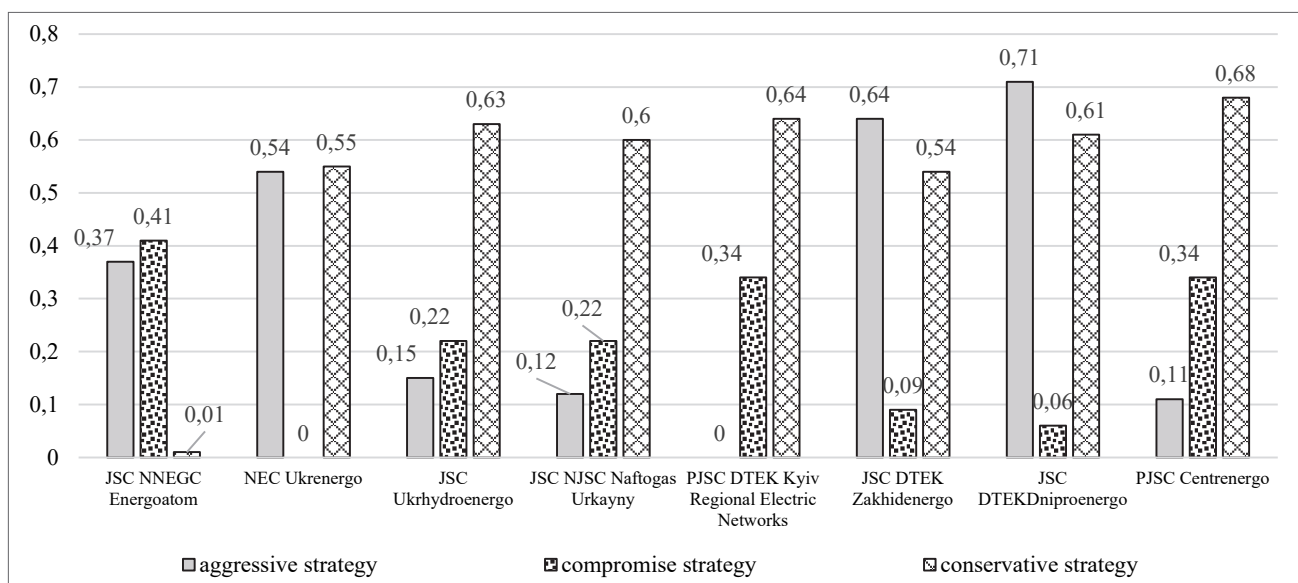


Figure 3. Results of the evaluation of SMART criteria when choosing a strategy for strengthening the economic security of enterprises of the UES-U enterprise using the method of “ideal” points (LINMAP)

Source: calculated by the author

us to conclude that the results are excessively “rigid”. This leads to the fact that it is only possible to accurately determine the choice between an aggressive and conservative strategy for strengthening economic security, which corresponds to a low or high level of it at enterprises, respectively. Thus, according to Fig. 1 and Fig. 2, the connection between the low level of economic security and the relevance of implementing an aggressive strategy for ensuring it is clearly visible. In some cases (JSC Ukrhydroenergo, JSC NJSC Naftogas of Ukraine) it was found that there is a need to apply a compromise strategy for strengthening economic security, especially for the criteria attainable (achievable) and time-bound (limited by time frames).

Developing the previously expressed opinion about the relationship between individual SMART criteria and some components of economic security, we can conclude that in this case we are talking about the need to apply a compromise strategy for the financial and intellectual and personnel components.

Thus, enterprises with a low level of economic security support the logic of implementing aggressive and compromise strategies for its provision and choosing it among others, linking the dominants of its implementation with attracting additional funds and reviewing the resources already available to the enterprise (especially material, not labor), and systematic verification of employees.

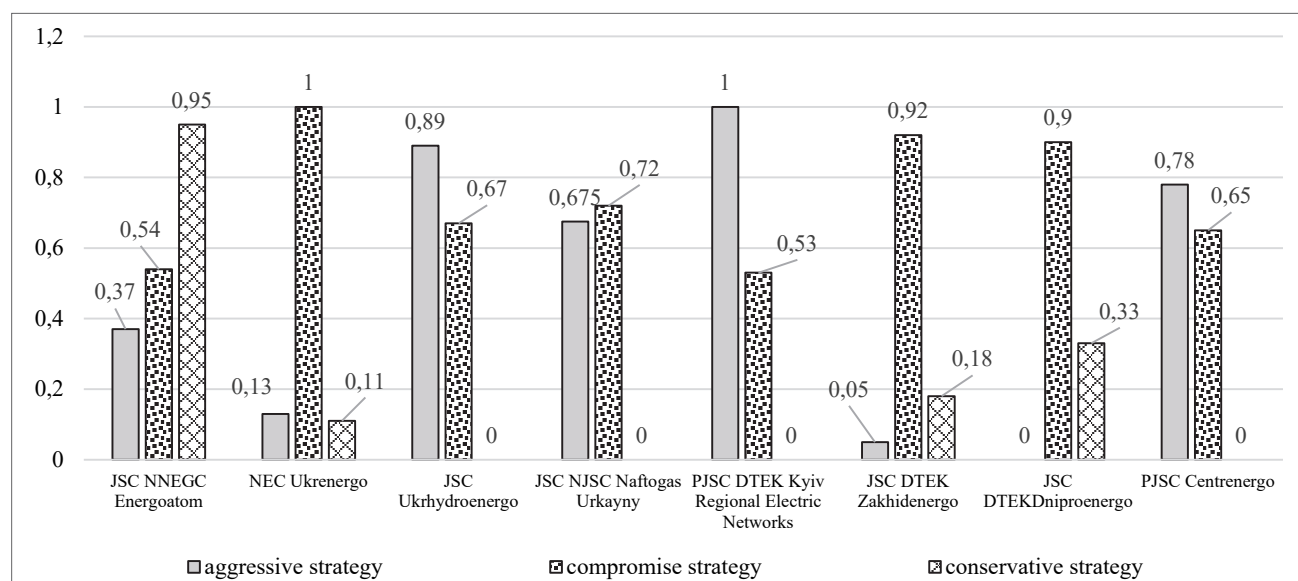


Figure 4. Results of the evaluation of SMART criteria when choosing a strategy for strengthening the economic security of enterprises of the UES-U enterprise using the method of ideal positive decision (LINMAP)

Source: calculated by the author

A similar situation is observed in expert assessments of SMART criteria at enterprises with a high level of economic security, which in the absolute majority corresponds to an exclusively conservative strategy for its provision. However, assessments of individual SMART criteria, for example, JSC NNEGC Energoatom and PJSC Centrenergo, indicate the relevance of implementing a compromise strategy for strengthening economic security.

Implementation of the methods of prioritization and additive weighting (SAW) does not allow establishing the need to apply a compromise strategy for strengthening economic security associated with optimizing or adapting its level. That is why for a more detailed selection of strategies it is advisable to use the method of “ideal” points (LINMAP), which was demonstrated practically (Fig. 3).

It is worth paying special attention to the fact that for some enterprises the value of the integral assessment of the SMART criteria is 0 (for example, in Fig. 3, a compromise strategy for NEC Ukrenergo or in Fig. 4, a conservative strategy for JSC Ukrhydroenergo), which is associated with the lack of alternatives in choosing a strategy for strengthening economic security. The absence of a special alternative in strategies is primarily characteristic of enterprises with an extremely low or rather high level of economic security. In turn, for enterprises whose level of economic security was assessed as average, the value of the integral assessment and its proximity to an aggressive or conservative strategy are of particular importance. Thus, in the first case, we are talking about a compromise optimization strategy, and in the second, adaptation of the level of economic security of the enterprise. Thus, taking into account the above, the implementation of a compromise optimization strategy is of particular relevance for NEC Ukrenergo. At the same time,

according to the obtained assessments of the SMART criteria and their comparison with the components of economic security, special attention should be paid to motivating employees to increase the level of economic security of the enterprise, as well as monitoring the implementation of management decisions (especially regarding operational activities: production of products, sale of goods, provision of services).

In turn, for JSC DTEK Zakhidenergo, JSC DTEK Dniproenergo, it is recommended to use a compromise strategy for adapting the level of economic security. This is due to the fact that the level of economic security of the specified enterprises is assessed as higher than average, however, its individual components require serious “strengthening”. For this, special attention should be paid to: improving automated management systems, their individual elements in order to protect access to information or restrict it; organizing interaction with financial institutions to attract additional funds.

It is impossible not to notice that the results obtained during the implementation of the ideal positive solution method (TOPSIS) and presented in Fig. 4, confirm the above in terms of choosing a compromise strategy for optimizing or adapting the level of economic security. However, it is worth noting that the value of the integral assessment of some strategies (conservative in JSC Ukrhydroenergo, JSC NJSC Naftogaz of Ukraine, PJSC DTEK Kyiv Regional Electric Grids, PJSC Centrenergo) is equal to 0. This state of affairs indicates that their application does not fully correspond to the existing level of economic security, which clearly demonstrated this.

In turn, the value of the integral assessment of strategies for ensuring economic security, equal to 1, indicates a special lack of alternatives for their choice (according to the results presented in Fig. 4, we are

talking about an aggressive or conservative strategy). In other words, it is the application of the ideal positive solution method (TOPSIS) that allows us to maximally substantiate the choice of strategies for strengthening economic security or their combination for its various components. This is done by taking into account the mutual influence of both the maximum and minimum assessments by experts of the SMART criteria and determining their integral value, which clearly demonstrates the quantitative difference between them. The difference between such values, according to the results in Fig. 4, can be significant, which simplifies the choice of a particular strategy for strengthening economic security. Based on the above, it is quite logical that, according to the results of implementing all methods for assessing SMART criteria, for enterprises with a high level of economic security, a conservative strategy for ensuring it is preferable. Thus, the main attention should be paid to: regular explanatory work with employees in order to prevent deviations from work regimes; systematic coordination of goals and objectives of activities with real financial capabilities and key indicators of financial stability (especially in conditions of reduced solvency of individuals and legal entities).

However, taking into account the SMART criteria when implementing a particular strategy for strengthening economic security without its detailed plan minimizes the value of efforts to select it using the methods considered earlier. According to the NAOMIE model (Table 1), the choice of a strategy should be supported by the development of a plan of measures for their implementation in the context of not only each component of economic security, but also the planned results within each of them. To understand and further take into account the fact that the results of the implementation of measures envisaged by the selected strategy for strengthening economic security can be extremely different, it is advisable to differentiate them through the prism of at least three levels: initial, sufficient, advanced.

Accordingly, an important aspect for further resolution remains the issue of determining the level of decision-making for the selected strategies, that is, including an action plan aimed at solving at the tactical (initial level) and strategic (sufficient and advanced levels) levels. However, if the solution of tactical tasks within the framework of the strategy is mainly associated with the economic effect (quantitative efficiency criteria), then the implementation of strategic ones is also associated with the social (qualitative efficiency criteria).

Such differentiation of the levels of implementation of the strategy for strengthening the economic security

of the enterprise not only stimulates the solution of the maximum number of tactical and strategic tasks, but also orients to a more detailed elaboration of the relevant measures in the conditions of uncertainty of the future.

It should be understood that the number of planned and implemented measures is a conditional criterion for determining the levels of implementation of the strategy. However, when developing a detailed plan of measures for the implementation of the strategy for the collision of the economic security of the enterprise, for each of its components there will be different criteria for attributing the “general” result to the initial, sufficient or advanced level. For example, a 5% reduction in staff turnover can be considered the initial level of strategy implementation for the intellectual and human resources component, 10% — sufficient, 15% — advanced. In turn, the totality of the results achieved within each component of economic security indicates the real level of implementation of the strategy for its strengthening.

4. Conclusions

Thus, we have determined that the processes of strengthening the economic security of enterprises are easily introduced and implemented in the operational activities of enterprises under the condition of choosing an appropriate strategy of action. In addition, using SMART methods, it was determined that in accordance with the initial determined level of economic security, an important aspect is the choice of the desired strategy: aggressive, compromise or conservative. That is, the more exaggerated the economic security of the enterprise, the less aggressive the methods of its further development should be. And based on the proposed methodological approach to the SMART assessment criteria, additive weighting (SAW), “ideal” points (LINMAP) and ideal positive solution (TOPSIS), it was established that most of them are adaptive and create a basis for a new direction of development for each of the studied enterprises of the Unified Economic System. As a result, it was recommended to choose the following strategies for further development and strengthening of economic security: aggressive for JSC Ukrhydroenergo, PJSC DTEK Kyiv Regional Electric Networks, PJSC Centrenergo; compromise — NEK Ukrenergo, JSC NJSC Naftogaz of Ukraine, JSC DTEK Zakhiden-ergo and JSC DTEK Dniproenergo; conservative — JSC NNEGC Energoatom. In conclusion, it is worth noting that the processes of strengthening the economic security of enterprises are easily integrated into the general concept using the proposed methods.

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ІМПЛЕМЕНТАЦІЯ МЕХАНІЗМУ ЗМІЦНЕННЯ ЕКОНОМІЧНОЇ БЕЗПЕКИ В СТРАТЕГІЮ РОЗВИТКУ ПІДПРИЄМСТВА

Анотація. Сталий розвиток підприємства за рахунок реалізації надійного стратегії є вагомим фактором конкурентоспроможності та підвищення рівня дохідності. На тлі цього зміцнення економічної безпеки є лише запорукою та підтримкою даного спрямування. Водночас у сучасному науковому світі недостатньо методів та інструментів, що дозволяють провести вдалу імплементацію процесів зміцнення економічної безпеки підприємств в його стратегію розвитку. У такому спрямуванні важливо розглядати первісні умови рівня економічної безпеки підприємства та відповідно обирати той напрям стратегічного розвитку (агресивний, компромісний чи консервативний), який задовільнив би і підвищення рівня безпеки і допоміг би створити умови для довгострокового планування. У дослідженні використано систему методів та засобів, які дозволили вирішити задачі статті: кількісного (статистичного), якісного (експертного), абстракції, дедукція, математичного моделювання та індукція. Базою даних, що використовується для підтвердження дієвості імплементації процесів зміцнення економічної безпеки в стратегію розвитку підприємства, є офіційні статистичні джерела фінансової діяльності підприємств та експертна оцінка працівників.

Доведено, що зміцнення економічної безпеки підприємств відіграє важливу роль як в ефективному функціонуванні підприємства, так і в його подальшому стратегічному розвитку. Отже, імплементація двох складових, при постійному контролі реалізації, має ефект синергії. Запропоновано методологію розташування пріоритетів (SMART), адитивного зважування (SAW), «ідеальних» точок (LINMAP) та ідеального позитивного рішення (TOPSIS) для налагодження адаптивної взаємодії процесів зміцнення економічної безпеки та розвитку стратегічного планування підприємств.

Отримані рекомендації щодо запропонованих стратегій розвитку підприємств ОЕС-У свідчать про посилення потреби у формуванні нового типу внутрішнього управління, який повністю відображає довгострокові плани розвитку підприємств. Запропонована методологія буде корисною як для внутрішніх, так і для зовнішніх стейкхолдерів підприємств, а також може бути реалізована в різних галузях діяльності.

Ключові слова: економічна безпека, розвиток, стратегія, модель, SMART критерії, підприємство.

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INTEGRATED REPORTING AS A TRANSPARENCY TOOL FOR SUSTAINABLE ENTERPRISE DEVELOPMENT

Abstract. *Integrated reporting (IR) has emerged as a crucial tool for enhancing transparency and driving sustainable development within enterprises. By consolidating financial and non-financial information, IR provides a comprehensive view of an organization's long-term performance, strategy, and impact on society and the environment. This paper explores the role of integrated reporting as a transparency mechanism, assessing its influence on corporate decision-making, stakeholder engagement, and sustainability practices.*

The study examines the benefits and challenges of implementing IR in various sectors and offers recommendations for businesses aiming to adopt or enhance their reporting frameworks. The findings highlight the importance of aligning corporate strategies with sustainable development goals, improving trust with stakeholders, and fostering a more responsible business environment.

Keywords: *Integrated reporting, transparency, sustainable development, corporate social responsibility, business ethics, stakeholder engagement, corporate governance.*

1. Introduction

In the last five years, the concept of integrated reporting has been actively developing, originating at the beginning of this millennium. This concept represents a process in which an organization presents information in the form of a periodic report that combines both financial and non-financial information, and introduces a fundamentally new approach to disclosing capital and value creation by the company. It is also characterized by a strategically focused information disclosure approach. Integrated reporting, according to the definition established in the International Integrated Reporting Standard, is a concise representation of how an organization's strategy, governance, performance, and prospects in the context of the external

environment lead to value creation in the short, medium, and long term.

Integrated reporting has garnered significant attention in recent academic research, particularly concerning its role in enhancing transparency and fostering long-term sustainable development. Numerous studies highlight the potential of integrated reporting to bridge the gap between financial performance and sustainability efforts (Velte, 2022) [1]. A major focus of recent works has been its ability to provide a comprehensive view of an organization's overall value creation process, aligning financial results with environmental, social, and governance (ESG) factors (Sierra-Garcia, 2021) [2]. For example, Cruz & Galvão [3] conducted a comprehensive literature review on integrated



reporting, confirming its growing importance in sustainable development business models. Similarly, Cunha & Duncan [4] explore the relationship between integrated reporting and group decision-making within the framework of sustainable development goals.

The concept of integrated reporting is closely related to the notion of corporate transparency. Integrated reporting allows for the most accurate and clear disclosure of crucial information about an organization's ability to create value over the short, medium, and long term. Achieving transparency is also facilitated by the fact that the company discloses information not only about financial capital but also about its production, human, natural, intellectual, and social-reputational capitals, their interconnections, and interactions, which, in turn, influence the organization's ability to create value for itself and its stakeholders over different periods.

Recent studies confirm the growing role of integrated reporting (IR) in enhancing business transparency and supporting sustainable development strategies. For instance, de Villiers [5] emphasizes the importance of the relationship between non-financial indicators and long-term performance. Lai and Stacchezzini [6] address issues of accountability and the role of report preparers. Such research highlights the increasing academic interest in IR and its relevance in modern corporate governance. The study by Manes-Rossi, Cohen, and Nicolò [7] stresses that investors are increasingly expecting companies to provide comprehensive disclosures on social and environmental aspects of their operations, which enhances the role of IR in transparency strategies.

2. Materials and Methods

For this research, a combination of qualitative and case study research methods was employed to explore the role of integrated reporting as a transparency tool for sustainable enterprise development. The primary sources of data were secondary, including academic articles, corporate reports, and publicly available documents. Sources were instrumental in gathering information on the implementation and effectiveness of integrated reporting in various industries. The data collected helped identify trends, challenges, and best practices related to the adoption of integrated reporting frameworks. A case study approach was used to examine organizations that have successfully implemented integrated reporting. A selection of companies from different sectors was chosen for detailed analysis. The case studies provided insights into the broader implications of integrated reporting for enhancing corporate transparency and supporting sustainable development. The research was guided by several well-established reporting frameworks, including the International Integrated Reporting Council's (IIRC) Integrated Reporting Framework and the Global Reporting Initiative (GRI) standards. In contemporary academic literature, considerable attention is given to the research methodology of integrated reporting (IR). De Villiers, Venter, and Hsiao [5], for instance, emphasize the relevance

of case studies as a means of analyzing changes in corporate reporting under the influence of external factors. Lai, Melloni, and Stacchezzini [6] propose the use of content analysis of integrated reports to identify the level of narrative accountability of companies, which allows for a deeper assessment of the quality of management practices. Additionally, Navarrete-Oyarce [8] and Benameur [9] apply bibliometric analysis to explore the dynamics of IR research in a global context, highlighting the growing interdisciplinary interest in the topic. Accordingly, the selection of a combination of qualitative, comparative, and case-based analysis in this study aligns with current academic approaches.

Furthermore, Manes-Rossi [7] points out that transparency in communication with stakeholders is critically important for the effective implementation of integrated reporting. Therefore, researchers combine content analysis of reports with the study of companies' communication strategies.

3. Results and Discussion

The modern world is characterized by the rapid development of all spheres of activity, largely due to the widespread implementation of information technologies. Global transformational processes are observed in the business sector, including in the field of accounting and financial reporting. Currently, there is a modernization of the "government — business — society" communication system to ensure more transparent interaction among all participants.

In the era of digitalization, the technology for preparing and presenting all types of organizational reports—financial, tax, statistical, and prudential—is undergoing significant changes. The business world is experiencing a need for a new approach to data collection and processing, enabling the systematization of both financial and non-financial information characterizing a company's activities. Stakeholders are interested in obtaining detailed information about business processes to conduct comprehensive analysis and make rational economic decisions [2].

Today, the digital format for presenting corporate reporting, known as eXtensible Business Reporting Language (XBRL), is widely used in global practice. According to Kourtis [10], it is the technological foundation, including XBRL, that ensures the transparency of non-financial information and facilitates the automated audit of integrated reports. This electronic business reporting standard emerged in the late 1990s. Currently, the XBRL format is applied in more than 50 countries worldwide for preparing various types of reports, including in most BRICS and G20 countries [11].

The adoption of XBRL (eXtensible Business Reporting Language) has become a significant trend among BRICS and G20 countries, reflecting a global shift towards digital and standardized financial reporting. China has been at the forefront of adopting XBRL. The China Securities Regulatory Commission (CSRC) mandated the use of XBRL for financial reporting by listed companies. This move aims to enhance transparency

and facilitate data analysis in the capital markets. India's Securities and Exchange Board (SEBI) introduced XBRL filing for the top 100 listed companies, aiming to improve the quality and accessibility of financial data. The Reserve Bank of India (RBI) also adopted XBRL for regulatory reporting, enhancing data consistency and comparability. Brazil's Securities and Exchange Commission (CVM) has been exploring the implementation of XBRL for corporate disclosures. While adoption is still in progress, the move aligns with global trends towards digital reporting. South Africa has been a pioneer in adopting XBRL, with the Johannesburg Stock Exchange (JSE) requiring listed companies to file financial statements in XBRL format. This initiative aims to streamline data processing and enhance investor confidence [12].

The U.S. Securities and Exchange Commission (SEC) mandated the use of XBRL for financial reporting by public companies, aiming to improve the accessibility and usability of financial data. The EU has adopted XBRL for regulatory reporting, with the European Securities and Markets Authority (ESMA) requiring financial statements to be submitted in XBRL format. Japan has implemented XBRL for corporate disclosures, with the Financial Services Agency (FSA) requiring listed companies to file financial statements in XBRL format. Australia has adopted XBRL for financial reporting, with the Australian Securities and Investments Commission (ASIC) encouraging companies to submit financial statements in XBRL format. The widespread adoption of XBRL among BRICS and G20 countries demonstrates a collective move towards standardized, transparent, and efficient financial reporting. This trend not only facilitates better decision-making for stakeholders but also aligns with global efforts to enhance financial transparency and accountability [12].

The digital format for presenting reports, XBRL, contributes to the improvement of the process of accumulating, structuring, exchanging, and analyzing information about an enterprise's performance. It is important to note that XBRL is a tool that meets the accounting and analytical needs of any organization, as it allows for the electronic presentation of all forms of corporate reporting, containing both financial and non-financial data. In the context of business process automation and the active use of technological innovations, stakeholders are raising new demands for the information contained in corporate reports. In order to make an objective assessment of the enterprise's performance and prospects for development, they need not only financial indicators but also extensive non-financial data [12].

In the modern world, the role of socially responsible investors is growing. These investors are interested not only in generating profit but also in fostering a fair and sustainable economy. Therefore, it is important for them that corporate reporting discloses detailed information about the economic, social, and environmental aspects of an organization's activities. Increasing informational demands from stakeholders are prompting companies to improve their accounting and reporting

systems. As a result, more and more enterprises in different regions of the world are introducing integrated reporting into their accounting practices. Integrated reporting is a document that presents, in a summarized form, both financial and non-financial data, characterizing the business model of the economic entity, as well as its ability to create value in the short, medium, and long term. The value of the organization can be divided into two interconnected elements: the value created for the company and the value created for the stakeholders of the enterprise and society as a whole [13].

According to data from XBRL International, by 2023, more than 60% of public companies in the United States, the European Union, and Asian countries use XBRL for financial reporting. In the United States, over 90% of large public companies already use XBRL to submit their financial reports. This became possible after the U.S. Securities and Exchange Commission (SEC) mandated that all public companies submit their reports in this format starting in 2009. According to the SEC, implementing XBRL has reduced the time for processing reports by 35%, significantly lowering costs for both companies and regulators. For example, one of the major investors, BlackRock, has noted that the use of digital reporting formats has halved the time required to analyze financial reports of companies they invest in [14].

In the European Union, according to the European Commission, approximately 70% of public companies have started using integrated reporting, which includes financial, environmental, and social indicators. This process is particularly active in the United Kingdom and Germany, where over 80% of large companies already integrate non-financial data into their reports. In comparison, in 2015, this figure was only around 45%, indicating significant progress in adopting new reporting standards. In the BRICS countries, such as India and Brazil, integrated reporting practices are gaining momentum, with over 30% of publicly traded companies in these regions beginning to publish reports that include social and environmental aspects. For instance, in Brazil, mining companies began submitting reports in 2021 using the Global Reporting Initiative (GRI) standards, which cover environmental impact, labor conditions, and social responsibility [13].

Large multinational corporations are also increasingly adopting integrated reporting, with over 60% of companies in the Fortune 500 using integrated reporting to provide comprehensive information about their activities. A review of contemporary literature indicates that these trends are also reflected in the work of Navarrete-Oyarce [15], who systematizes approaches to the application of GRI standards in public reports. According to a survey by PwC, 72% of investors consider not only financial data but also social and environmental indicators when evaluating companies for investments, highlighting the growing role of socially responsible investors. The number of companies using integrated reporting continues to rise. According to the Global Reporting Initiative (GRI), by 2022, over 7,000 companies worldwide publish reports containing

Table 1

Adoption of XBRL and Integrated Reporting across Different Regions [6]

Region	Percentage of Companies Using XBRL/Integrated Reporting (%)	Adoption Year	Main Sector Affected
United States	90	2009	Public Companies
European Union	70	2022	Public Companies
BRICS	30	2022	Public Companies
United Kingdom	80	2020	Large Corporations
Germany	80	2020	Large Corporations
Brazil	20	2021	Mining
India	10	2022	Public Companies

Source: [13]

financial, social, and environmental information. In 2010, this figure was only around 3,500 companies, demonstrating significant growth in the adoption of integrated reporting practices [13]. Adoption of XBRL and Integrated Reporting across Different Regions is presented in Table 1 and in figure 1.

The U.S. has been a pioneer in the adoption of XBRL for corporate reporting, with over 90% of public companies already using it. The mandate by the Securities and Exchange Commission (SEC) since 2009 has significantly contributed to this widespread adoption. The adoption of XBRL in the U.S. reflects a mature system of digital reporting that simplifies the process of financial reporting and enhances transparency, which is critical for both investors and regulators. In the European Union, 70% of public companies have adopted integrated reporting by 2022. This shows a strong commitment to improving corporate transparency. The EU has seen significant progress in both financial and non-financial reporting, with a particular focus on environmental, social, and governance (ESG) issues. This adoption rate suggests that companies in the EU are increasingly aware of the need to provide a holistic view of their performance [6].

The BRICS countries, including Brazil, Russia, India, China, and South Africa, are in the early stages of

adopting integrated reporting, with only 30% of public companies in these regions using it. This lower adoption rate reflects the slower pace of regulatory reforms and the need for capacity building in these regions. However, as sustainability issues become more pressing globally, this trend is expected to grow. The UK and Germany show a high rate of adoption, with 80% of large corporations using integrated reporting by 2020. This reflects their strong commitment to both corporate transparency and sustainability reporting. These countries are leading the way in the EU in terms of adopting integrated reporting as a standard business practice, especially for large corporations that face increased scrutiny from investors and regulatory bodies [13].

In Brazil, the adoption rate is much lower at 20%, but it has been growing since 2021, especially in sectors like mining. Brazil is focusing on sustainability reporting, particularly in industries that have significant environmental impacts. As companies in Brazil face increasing pressure from both domestic and international investors, integrated reporting is expected to become more widespread. India, with only 10% of companies adopting integrated reporting by 2022, still has a long way to go in this area. The relatively low percentage could be attributed to limited regulatory frameworks and lower awareness of the need for

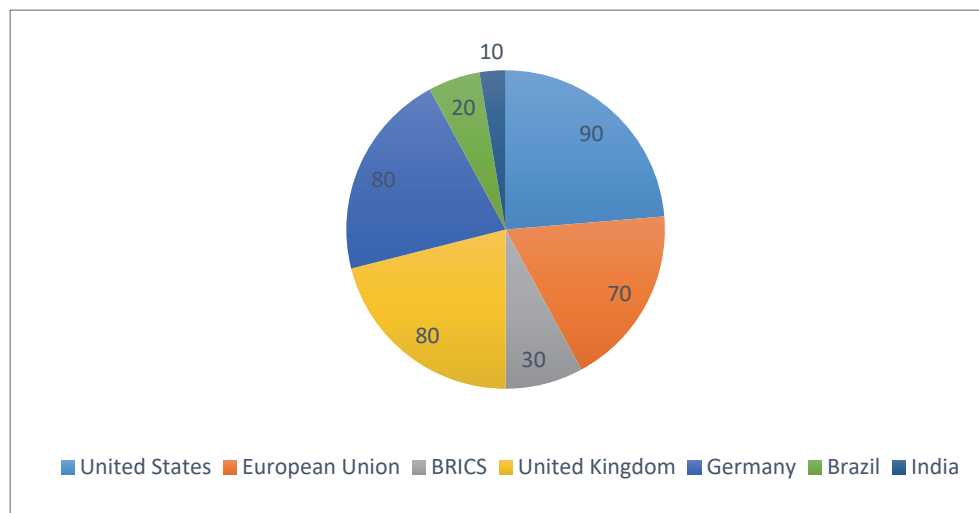


Figure 1. Percentage of Companies Using XBRL/Integrated Reporting (%) [13]

comprehensive non-financial reporting. However, the adoption rate is expected to increase as demand for sustainability information grows and as India becomes more integrated into global markets [13].

The global adoption of XBRL and integrated reporting varies significantly by region, with developed markets like the United States and the European Union leading the way. In these regions, XBRL and integrated reporting have become essential tools for increasing transparency and facilitating more informed decision-making by investors. Meanwhile, emerging markets like BRICS, Brazil, and India are still in the early stages of adoption, but as global interest in sustainable and transparent business practices grows, it is expected that these regions will follow suit. In the context of the domestic economic system, it is worth noting, firstly, the underdevelopment of social partnership between the state and private business. If the state is perceived as the sole guarantor of social support, it leads to budget overloads and a lack of free funds for innovation, such as investments in promising areas of activity [16].

Secondly, private business often pursues its own interests, which may not align with the goal of regional and national economic development. For example, the presence of a large number of intermediary organizations contributes to higher final product prices and the diversion of funds to organizations and individuals dependent on the owner. A significant portion of intermediary organizations does not provide real added value and negatively affects the competitiveness of the product due to increased production costs [16].

Indeed, the integrated reporting (IR) model can be effectively used in the implementation of state economic policy at both federal and local government levels, as the indicators of integrated reporting allow for the assessment and further consideration of the impact of organizations' activities on industrial, human, intellectual, social, and natural capital in the region, reflected in the organizations' reports.

The decision made by many modern organizations to implement integrated reporting in their accounting practices is driven by the fact that such reporting serves an important informational function. An integrated report ensures greater transparency and accountability of the company, which in turn increases business sustainability and stakeholder trust. Disclosure of data about the company's positive results, used resources, existing problems, implemented strategies, and activities aimed at developing technologies and human resources contributes to reducing investment risks and increasing the value of the organization. For key stakeholders, it is crucial to present information in the integrated report about the significance of their interests and needs for the company, as well as the actions the company is taking to meet the needs of its stakeholders [16].

Integrated reporting contains information about the factors that play a significant role in creating value for the organization and its environment. The company's ability to create value for itself ensures financial

capital providers with a return on their investments. The value created for the stakeholders of the company and society as a whole determines the long-term competitiveness of the organization. The quality of management is influenced by the development of the business strategy and the effectiveness of its implementation. To successfully implement the strategy in practice and ensure long-term sustainability, the company needs to have highly professional staff with unique knowledge and skills. The improvement of employee competencies is achieved through large-scale investments in their education and activities aimed at fostering cooperation among different departments within the organization. These processes are managed by top-level executives.

Management's understanding of the situation in a specific industry and the market overall influences the business's competitiveness and allows for adjustments to the company's strategy and tactics. Consumer satisfaction is determined by the quality of the products or services produced, as well as the frequency of product line updates [17].

The business model plays a significant role in the process of value creation for the organization, as it serves as the link connecting the company's resources, corporate strategy, risks, and opportunities, and showing how they transform into final products. The business model is a key element that influences the company's success. It provides a clear understanding of the organization's positioning in the value creation chain within a specific sector of the economy. A poorly chosen business model can lead to the company's bankruptcy. Stakeholders pay special attention to studying and analyzing the company's business model since it determines the organization's investment attractiveness. Information about the functioning business model, contained in the integrated report, shows how the company uses its available capital, increases or decreases its volume over time, with the aim of maintaining the sustainable development of the enterprise and the economy as a whole. To ensure the growth of the organization's value in the future, the management must have an understanding of potential threats both within the internal and external environments. Stakeholders need to be informed about the measures the company's management is taking to mitigate existing risks [17].

Integrated reporting in Ukraine has a significant impact on businesses, contributing to increased transparency and sustainable development. One striking example is the activities of major Ukrainian companies such as "Miryonsky Hliboproduct" (MHP) and "Ukrzaliznytsia". These companies actively implement integrated reporting, which allows them to not only report financial results but also provide data on environmental and social initiatives [12].

"Miryonsky Hliboproduct", one of the leaders of Ukraine's agricultural sector, began publishing integrated reports in 2016, showcasing not only financial performance but also information about its impact on the environment and social issues. In its reports,

the company provides information on CO2 emission reductions, energy-efficient technologies, and efforts to improve labor conditions for its employees. Such transparent reporting helped the company improve its reputation in the international market and attract investment. For instance, in 2020, MHP received a positive assessment from international investors, reflecting the growing interest in the company due to its responsible approach to ecology and social aspects [12].

Another example is “Ukrzaliznytsia”, which began publishing integrated reports in 2019, containing not only financial information but also data on the company’s social and environmental initiatives. These include efforts to modernize infrastructure, reduce energy consumption, and implement environmentally friendly technologies in transportation. As a result, “Ukrzaliznytsia” was able to increase trust from international partners and attract investments for infrastructure development [12].

The introduction of integrated reporting also positively affects corporate culture. For example, “Kyivstar” actively applies the principles of sustainable development and corporate social responsibility in its operations. In the company’s reports, apart from financial results, issues such as energy conservation, CO2 emissions reduction, and the implementation of programs aimed at supporting local communities are thoroughly addressed. This approach allows “Kyivstar” not only to improve its image among consumers and partners but also to demonstrate its commitment to sustainable development and social responsibility. Examples illustrate how integrated reporting helps Ukrainian companies not only enhance transparency and attract investment but also effectively respond to contemporary economic and environmental challenges. Integrated reporting allows companies to present their overall sustainable development strategy, increase trust from stakeholders, and strengthen their market position.

In today’s conditions of globalization and digitalization, Ukrainian enterprises need to adapt to new business requirements, which requires a transformation of approaches to reporting. One of the key tools that can significantly affect transparency and promote sustainable development is integrated reporting. In Ukraine, this approach is becoming an important tool that allows not only to increase the efficiency of enterprise management, but also to meet the growing requirements of both internal and external stakeholders.

One of the main problems limiting the spread of integrated reporting in Ukraine is the lack of sufficient regulatory support. While international standards, such as GRI (Global Reporting Initiative), are already actively used in many countries, such practices are not yet standard in Ukraine. In particular, the lack of legislative initiatives that promote the implementation of integrated reporting complicates the process of its implementation at the state level. To solve this problem, it is necessary to develop clear legislative norms that would establish requirements for reporting containing both financial and non-financial indicators. Since integrated reporting

is important for interacting with investors and other stakeholders, creating a legal framework that would support this process will be an important step towards improving corporate transparency in Ukraine [18].

Companies need to change their attitude towards integrated reporting, as many of them still consider it only an additional burden without real benefits. As global practice shows, integrated reporting not only increases trust from stakeholders, but can also help companies create long-term value. Drawing attention to non-financial aspects of a company’s activities — such as environmental impact, social responsibility, management practices — can have a positive impact on the company’s reputation. For example, companies that actively apply the principles of sustainable development have a higher chance of attracting investment. Stakeholders, including investors and regulatory authorities, are increasingly paying attention to aspects that were previously not taken into account in traditional financial reporting. The use of modern information systems and software products that allow you to automate the process of collecting and processing data significantly reduces the cost of time and human resources. Automation systems also reduce the likelihood of errors that may occur during manual collection and analysis of information. Automated platforms provide high data accuracy and allow for greater transparency of processes, which is critical for maintaining trust from investors and other stakeholders [18].

Thanks to integrated reporting, enterprises are able not only to improve the effectiveness of management decisions, but also to clearly forecast their long-term prospects. Part of integrated reporting is a business model that describes the enterprise’s strategy, resources used and methods for their effective management. Reporting that includes such data allows stakeholders to understand how the company plans to ensure its growth and adapt to changes in the market environment.

In Ukraine, the main step to improve the effectiveness of integrated reporting is to intensify cooperation between government agencies, business and public organizations. Initiatives to increase transparency and introduce integrated reporting should become part of state economic policy.

Integrated reporting has enormous potential for the development of enterprises in Ukraine, contributing not only to increasing transparency but also to the development of sustainable economic practices. To realize this potential, it is necessary to create an appropriate legal and technological infrastructure, as well as to raise awareness among enterprises about the importance of this tool.

4. Conclusions

Integrated reporting is a powerful tool for increasing the transparency of enterprises, contributing to sustainable development and improving interaction with all stakeholders. In Ukraine, this approach is gaining increasing importance, as it allows enterprises not only to respond to the growing demands of

stakeholders, but also to create long-term value for their organization and the economy as a whole. The use of integrated reporting makes it possible to collect both financial and non-financial data, which allows for a more complete picture of the enterprise's activities, as well as its impact on the environment, social and economic aspects.

For the effective implementation of integrated reporting in Ukraine, a number of problems need to be solved. This includes the development and implementation of relevant regulatory and legal acts regulating reporting standards, as well as increasing the technological readiness of enterprises to automate the processes of data collection and analysis. It is

recommended to raise awareness among Ukrainian companies about the importance and advantages of this approach, which will not only increase their competitiveness at the international level, but also make a significant contribution to the overall development of sustainable economic practices in Ukraine.

The introduction of integrated reporting in Ukraine can be a step towards creating a more transparent and efficient economic system, where enterprises work for long-term development, taking into account the interests of all stakeholders. Therefore, it is necessary to continue working on the popularization of this tool and provide the necessary conditions for its widespread use in the practice of Ukrainian companies.

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ІНТЕГРОВАНА ЗВІТНІСТЬ ЯК ІНСТРУМЕНТ ПРОЗОРОСТІ ДЛЯ СТАЛОГО РОЗВИТКУ ПІДПРИЄМСТВА

Анотація. Інтегрована звітність (ІЗ) стала вирішальним інструментом для підвищення прозорості та стимулювання сталого розвитку підприємств. Консолідуючи фінансову та нефінансову інформацію, ІЗ надає комплексне уявлення про довгострокову ефективність, стратегію та вплив організації на суспільство та навколишнє середовище. У статті досліджується роль інтегрованої звітності як механізму прозорості, оцінюється її вплив на прийняття корпоративних рішень, залучення зацікавлених сторін та практики сталого розвитку. У дослідженні розглядаються переваги та проблеми впровадження ІЗ у різних секторах та пропонуються рекомендації для підприємств, які прагнуть запровадити або вдосконалити свої системи звітності. Результати дослідження підкреслюють важливість узгодження корпоративних стратегій з цілями сталого розвитку, підвищення довіри із зацікавленими сторонами та сприяння більш відповідальному бізнес-середовищу.

Ключові слова: інтегрована звітність, прозорість, сталий розвиток, корпоративна соціальна відповідальність, бізнес-етика, взаємодія із зацікавленими сторонами, корпоративне управління.

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STRATEGIC PRIORITIES FOR BUSINESS INNOVATION AND INVESTMENT IN POST-WAR UKRAINE

Abstract. *This article delves into the strategic imperatives shaping business innovation and investment development in Ukraine during its post-war recovery phase. Recognizing the immense economic disruptions caused by conflict, it identifies key hurdles impeding private sector revitalization, including large-scale infrastructure devastation, financial instability, capital flight, and a weakened capacity for technological advancement. The study leverages both global best practices and Ukraine's unique socio-economic landscape to formulate a comprehensive framework for determining innovation-investment priorities across various sectors, regions, and enterprise scales.*

Special emphasis is placed on the role of public-private partnerships (PPPs), adaptive financing mechanisms, and institutional restructuring in fostering a resilient and competitive business environment. The research underscores how targeted investments in digital transformation, green technology, and industrial modernization can serve as catalysts for sustainable economic revival. Additionally, it explores the significance of policy coherence, government incentives, and international collaboration in reinforcing Ukraine's long-term economic reintegration and market positioning.

To bridge the gap between policy ambition and business execution, the paper presents a phased implementation roadmap, ensuring alignment between national recovery strategies and corporate innovation trajectories. By outlining actionable steps and sector-specific investment pathways, it offers strategic guidance to policy-makers, investors, and business leaders seeking to navigate post-war economic reconstruction with agility and foresight.

Keywords: *innovation, investment, business development, post-war recovery, Ukraine, strategic priorities, economic resilience.*



1. Introduction

Ukraine's post-war economic recovery requires a strategic focus on rebuilding not only physical infrastructure but also business capacity and innovation potential. In this context, business revitalization becomes a cornerstone of sustainable growth, employment, and competitiveness. The war has severely impacted the private sector, yet it has also opened opportunities for structural transformation and technological renewal. This paper aims to define innovation and investment priorities that can accelerate business recovery and contribute to long-term economic resilience.

Innovation and investment are widely recognized as key drivers of post-crisis economic development. The Schumpeterian view of "creative destruction" supports the idea that crises create space for new models and technologies to emerge. Investment in innovation — particularly in digital technologies, energy efficiency, and knowledge-based industries — enhances a country's adaptive capacity.

International experience (e.g., the Balkans, Georgia, and post-WWII Europe) illustrates that coordinated innovation-investment strategies are essential for post-conflict renewal, especially when paired with institutional reforms and integration into broader economic blocs (e.g., EU).

The formulation of innovation and investment priorities for post-war recovery has been explored across several domains of economic, regional, and development literature. The academic discourse emphasizes that innovation and investment serve as critical levers in restoring economic functionality, ensuring resilience, and enabling long-term transformation in post-crisis environments.

Schumpeter's concept of "creative destruction" underscores the role of innovation in overcoming economic downturns and crises by replacing obsolete structures with advanced technological systems [13]. In a similar vein, Fagerberg and Verspagen argue that innovation plays a pivotal role in achieving structural change, especially in developing and transitioning economies [5]. Innovation is increasingly viewed not just as a technological endeavor but as a broader social and institutional process [4].

Studies on post-crisis countries such as the Balkans, Rwanda, and Georgia suggest that targeted innovation policies accelerate recovery when integrated with macroeconomic reforms and institutional stabilization [14–15]. In the Ukrainian context, Bilorus and Heiets emphasize that crisis periods can catalyze a pivot towards knowledge-based and high-tech sectors, provided there is coordinated state support and access to financing [1; 6–7].

Investment decisions in post-conflict countries are shaped by high uncertainty, limited credit markets, and institutional weakness. According to Collier, attracting both domestic and foreign investment requires a secure environment, credible governance reforms, and donor coordination [3]. The OECD (2021) stresses the importance of de-risking mechanisms, blended

finance models, and public-private partnerships (PPPs) for stimulating investment in fragile contexts.

Empirical studies confirm that strategic public investment — especially in infrastructure, energy, and education — has strong multiplier effects in post-war economies [2]. Ukraine's recovery architecture, according to the National Recovery Plan (2023), must mobilize both international and local capital through transparent and innovation-oriented mechanisms.

The Ukrainian research field highlights both systemic constraints and emerging opportunities in the post-2022 environment. Mazur and Lukach argue that the war has accelerated digitalization and the growth of resilient sectors (e.g., IT, agro-processing), which could anchor future innovation strategies [9]. Kaleniuk et al. point to the role of EU integration, particularly through Horizon Europe and the Ukraine Facility, in fostering a more innovation-friendly ecosystem [8].

Institutional documents, such as the Strategy for the Development of Innovation Activity in Ukraine (2021–2030) and the SME Development Strategy (2020), emphasize regional innovation hubs, startup financing, and science-business linkages. However, implementation has been uneven, and coordination remains a challenge.

Gaps and Research Focus

While the theoretical and empirical literature offers rich insights, there is a gap in integrated frameworks that align innovation policy, investment planning, and post-war reconstruction. Specifically, few studies focus on how to prioritize business sectors for innovation-investment support based on resilience, technological readiness, and regional disparities — a gap this study seeks to address. Additionally, sectoral and regional prioritization methodologies remain underdeveloped in Ukraine's recovery discourse.

Ukraine's business environment in the post-war phase is characterized by both crisis and opportunity. Key challenges include:

- Infrastructure and facility destruction because over 30% of businesses in conflict-affected regions lost access to production facilities.
- Limited investment inflows as investor uncertainty and security risks remain high.
- Human capital loss due to brain drains and displacement have reduced labor and innovation capacity.
- Supply chain disruptions means that businesses face logistical challenges, especially in exporting goods.
- Reduced R&D capacity because of spending on innovation declined during wartime due to survival priorities.

Despite these, sectors such as IT, agro-industrial processing, green energy, and defense-tech show high adaptive potential.

2. Materials and Methods

This study employs a mixed-methods approach combining qualitative expert evaluation and quantitative multi-criteria analysis to determine strategic innovation and investment priorities for Ukrainian businesses in the post-war recovery period.

2.1. Research Design

The research was conducted in three stages:

1. Exploratory analysis: a review of national and international policy documents, academic literature, and statistical data was conducted to identify key sectors affected by war and their potential for innovation and investment.

2. Expert evaluation: semi-structured interviews and surveys were conducted with 24 Ukrainian and international experts from academia, government agencies, business associations, and investment institutions. Experts assessed sectoral recovery potential, innovation readiness, and investment attractiveness.

3. Multi-criteria prioritization model: A scoring system was developed to classify business sectors based on key indicators. The results were used to rank sectors and propose tailored policy recommendations.

2.2. Data Sources

The study relies on the following data sources: statistical data from State Statistics Service of Ukraine, Ministry of Economy of Ukraine, National Bank of Ukraine, Eurostat and World Bank open databases. Policy and strategy documents such as Ukraine's National Recovery Plan (2023); Strategy for Innovation Development of Ukraine (2021–2030); SME Development Strategy (2020); EU and OECD reports on post-conflict investment also were used to this research.

2.3. Multi-Criteria Scoring Model

To assess innovation-investment priorities, a scoring matrix was constructed based on five key criteria (table 1).

Table 1

Key criteria for scoring matrix

Criteria	Weight (%)
Sectoral Resilience & Recovery	25%
Innovation Readiness	20%
Investment Attractiveness	20%
Export Orientation & EU Integration	20%
Regional Clustering Potential	15%

Each criterion was rated on a 1–5 scale for each sector. Weighted scores were calculated to rank sectors as high, medium, or low priority for innovation-investment support.

2.4. Regional and Sectoral Breakdown

To reflect regional disparities and post-war impacts, the analysis was disaggregated by:

- Macro-regions (e.g., West, Central, East, and South Ukraine)
- Enterprise size (e.g., micro, small, medium, and large businesses)
- Industry sectors (e.g., ICT, agro-tech, manufacturing, green energy)

This allowed for the identification of regional hubs and sectoral clusters with the highest potential for targeted innovation and investment policies.

2.5. Longitudinal Survey Design

To assess the evolution of business perspectives on innovation and investment during the war and post-war periods, the study integrates a longitudinal survey component. Two rounds of structured surveys were conducted:

- First wave (July–September 2022) during active hostilities and uncertainty;
- Second wave (January–March 2024) during the early phase of stabilization and recovery planning.

The survey covered 120 businesses across diverse sectors and regions of Ukraine. It included both closed and open-ended questions grouped into the following thematic blocks (table 2).

A Likert scale (1–5) was used to measure attitudes and expectations, with some questions enabling direct year-over-year comparisons. All survey responses were anonymized. Participants were informed about the research purpose and gave consent for data use. The study adhered to ethical standards of academic social research.

Certain indicator questions (e.g., investment activity, digital maturity, optimism about the future, access to finance) were repeated across both 2022 and 2024 waves to allow direct comparison. Differences were statistically analyzed using **paired t-tests** and **cross-tabulations**.

2.6. Comparative Analysis Approach

The survey data from both waves were analysed using:

- Descriptive statistics to summarize sectoral and regional trends;
- Cross-tabulation to identify changes in perceptions over time;
- Mean comparison (t-tests) to highlight significant differences between 2022 and 2024 responses;
- Cluster analysis to group businesses with similar adaptation patterns.

This longitudinal design enables the identification of trends in resilience, recovery expectations, and the reorientation of investment and innovation strategies among Ukrainian businesses.

2.7. Limitations

The research acknowledges the following limitations:

- Data constraints due to incomplete post-war statistics and displacement of enterprises.
- Expert subjectivity in scoring, mitigated through triangulation and weighted averages.
- Dynamic conditions of war and recovery, which may require ongoing updates to the model.

Despite these limitations, the methodology offers a flexible, evidence-based approach to support policy and funding prioritization for Ukraine's business sector recovery.

3. Results and Discussion

3.1. Evolution of Business Perceptions (2022 vs. 2024 Survey Findings)

To evaluate the dynamics of innovation and investment readiness among Ukrainian businesses during

Table 2

Structured Survey Instrument by Thematic Blocks

Thematic Block	Question Type	Sample Question
1. Business Status and Operational Capacity	Closed-ended	What is your current operational status?
	Closed-ended	Rate your operational stability on a scale from 1 (very unstable) to 5 (very stable).
	Open-ended	Please describe the key operational challenges your business has faced since 2022.
2. Investment Activity and Access to Capital	Closed-ended	Did your business make any capital investments in 2022? In 2024?
	Closed-ended	Rate your access to the following sources of finance on a scale of 1 to 5: bank loans, private investors, public support schemes, foreign investment.
	Open-ended	What kind of financial instruments would be most useful to your investment planning?
3. Innovation Readiness and Digitalization Level	Closed-ended	Is your business currently implementing or planning to implement any innovations?
	Closed-ended	On a scale of 1–5, rate your digital transformation level: from no digital tools (1) to fully integrated systems (5).
	Open-ended	Describe any innovations (product, process, business model) adopted since 2022.
4. Public Policy and Support Instruments	Closed-ended	How effective do you find national-level recovery programs? (1–5)
	Closed-ended	Have you received any form of state support since 2022?
	Open-ended	What policy measures would most effectively support your business's innovation and investment plans?
5. Priority Needs and Recovery Expectations	Closed-ended	What is your current top business priority? (e.g., finance, digitalization, infrastructure, policy stability)
	Closed-ended	How optimistic are you about your sector's recovery by 2026? (1–5)
	Open-ended	In your view, what should be the government's top three priorities in supporting business recovery?

Source: built by authors

the post-war recovery period, a comparative survey was conducted in 2022 and 2024. The responses of 120 businesses from diverse regions and sectors were analyzed for each year. The survey included key indicators measured using a 5-point Likert scale across the following domains: operational stability, access to

finance, digital transformation, perceptions of recovery policy, and optimism about future recovery.

Table 2 presents the mean scores and standard deviations for the key variables in 2022 and 2024.

These results indicate a general upward trend in all key areas, suggesting improved resilience and

Table 2

Descriptive statistics for the key variables in 2022 and 2024

Indicator	2022 Mean (SD)	2024 Mean (SD)
Operational Stability	~3.0 (±1.3)	~3.5 (±1.1)
Access to Finance	~2.8 (±1.4)	~3.3 (±1.2)
Digital Transformation Level	~3.2 (±1.2)	~3.8 (±1.0)
Effectiveness of Recovery Programs	~2.5 (±1.5)	~3.1 (±1.3)
Optimism about Recovery	~2.9 (±1.4)	~3.7 (±1.1)

Source: calculated by authors

Table 3

Descriptive statistics for five indicators

Indicator	t-test results	p-test results
Operational Stability	$t \approx -2.7$	$p < 0.01$
Access to Finance	$t \approx -2.5$	$p \approx 0.01$
Digital Transformation	$t \approx -3.0$	$p < 0.005$
Effectiveness of Recovery Programs	$t \approx -2.2$	$p \approx 0.03$
Optimism about Recovery	$t \approx -3.6$	$p < 0.001$

Source: calculated by authors

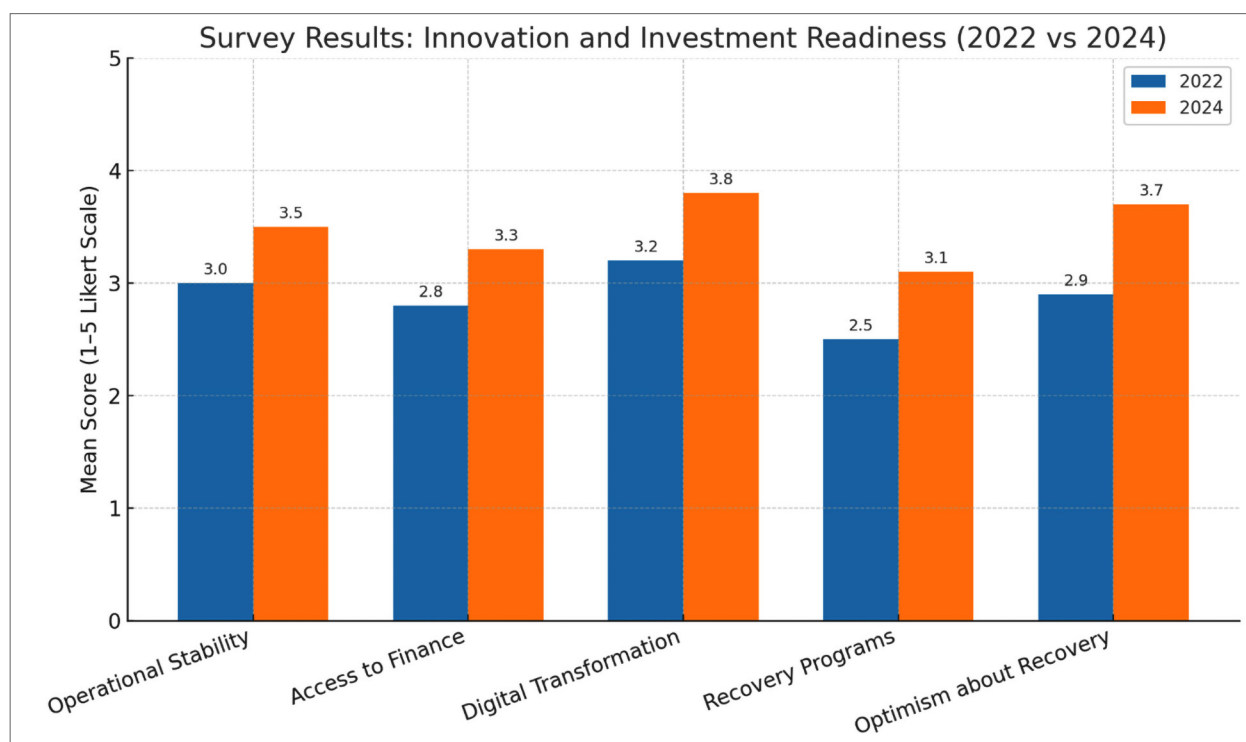


Figure 1. Survey results: Innovation and Investment Readiness (2022 vs 2024)

Source: built by authors

confidence among businesses as the recovery period progresses.

Independent samples t-tests were performed to assess whether the observed differences between 2022 and 2024 were statistically significant. The results revealed statistically significant improvements ($p < 0.05$) across all five indicators (table 3).

These findings support the hypothesis that businesses in Ukraine are becoming more optimistic and better positioned for growth, driven by improvements in access to finance, digital capabilities, and evolving support policies.

The upward trend in digital transformation and innovation readiness suggests that businesses are actively adapting to post-crisis realities by leveraging technology. The modest increase in perceived policy effectiveness and access to capital reflects initial progress in recovery programming, though further targeted support is warranted.

Of particular note is the substantial improvement in optimism about recovery, which may be associated with clearer EU integration pathways and the stabilization of certain macroeconomic indicators.

The comparative analysis of survey data from 2022 and 2024 reveals significant shifts in business

sentiment, investment behaviour, and innovation readiness across sectors and regions.

In 2022, only 27% of surveyed businesses reported stable operations, with high levels of uncertainty and a defensive stance on investment. By early 2024, 62% of respondents reported partial or full recovery of operational capacity, especially in Western and Central Ukraine. Export-oriented sectors like IT and agro-tech showed the fastest return to growth.

Innovation readiness improved markedly from 2022 to 2024 (table 4).

This reflects both internal adaptation and increased external support (e.g., Horizon Europe pilot schemes, regional recovery grants).

Investment appetite rose from 18% in 2022 to 46% in 2024, especially among SMEs in IT, agro-processing, and green energy. However, major barriers remained:

- Access to affordable finance (reported by 64% in 2024)
- Uncertainty in legal and regulatory frameworks (52%)
- Insufficient government guarantees for private investors (47%)

This comparative analysis reinforces the importance of sustained innovation-investment support mechanisms. Tailored policy tools — such as digital

Table 4

Innovation adoption readiness

Indicator	2022 (%)	2024 (%)
Active implementation of digital tools	38	71
Interest in green and energy-efficient tech	19	54
Participation in innovation grants	12	33

Source: calculated by authors

Table 5

Sectoral prioritization based on scoring matrix

Sector	Resilience	Innovation Potential	Export Focus	Priority Group
IT & Digital Tech	High	High	High	High
Agro-tech	High	Medium	Medium	High
Green Energy	Medium	High	Medium	High
Light Manufacturing	Low	Medium	Low	Medium
Heavy Industry	Low	Low	High	Low

Source: calculated by authors

grant platforms, regional technoparks, and targeted recovery funds — should continue to be prioritized. In parallel, alignment with EU standards and frameworks (e.g., Horizon Europe, InvestEU) will be essential to maintain momentum.

3.2. Sectoral Prioritization Based on Scoring Matrix

Using the multi-criteria scoring matrix (resilience, innovation potential, export focus, and EU compatibility), sectors were grouped into priority tiers for innovation-investment support.

This classification highlights the need to focus innovation funding, tax incentives, and EU alignment efforts on IT, agro-tech, and green energy — sectors that combine resilience, innovation capacity, and growth potential.

3.3. Regional and Clustering Insights

Survey and policy data confirm that regional disparities in recovery and innovation are pronounced. Western and Central regions (e.g., Lviv, Ternopil, Vinnytsia) demonstrate stronger innovation dynamics due to a higher concentration of SMEs, relocation of firms, and better infrastructure.

Respondents identified potential cluster development zones for each priority sector:

- IT and creative industries — Lviv, Kyiv, Ivano-Frankivsk.

- Agro-tech and bioeconomy — Vinnytsia, Poltava, Khmelnytskyi.

- Green energy and circular economy — Zakarpattia, Dnipro, Mykolaiv.

These findings support targeted regional innovation and investment strategies aligned with local strengths and EU cross-border programs.

3.4. Strategic Instruments and Policy Recommendations

Based on empirical results, the following tools are proposed to stimulate innovation-investment activity in priority sectors:

- Public-Private Partnerships (PPPs) for infrastructure and green energy initiatives.
- Innovation Grants & Recovery Funds with co-financing from EU, EIB, and multilateral donors.
- Loan Guarantees & Tax Incentives to lower investment risk.
- Technoparks and Innovation Hubs in high-potential regions.
- Digital Investment Platforms to match local firms with international capital and diaspora networks.

The success of these instruments depends on integration with EU frameworks such as Horizon Europe, InvestEU, and the Ukraine Facility. This alignment will unlock funding, enhance institutional credibility, and promote cross-border collaboration.

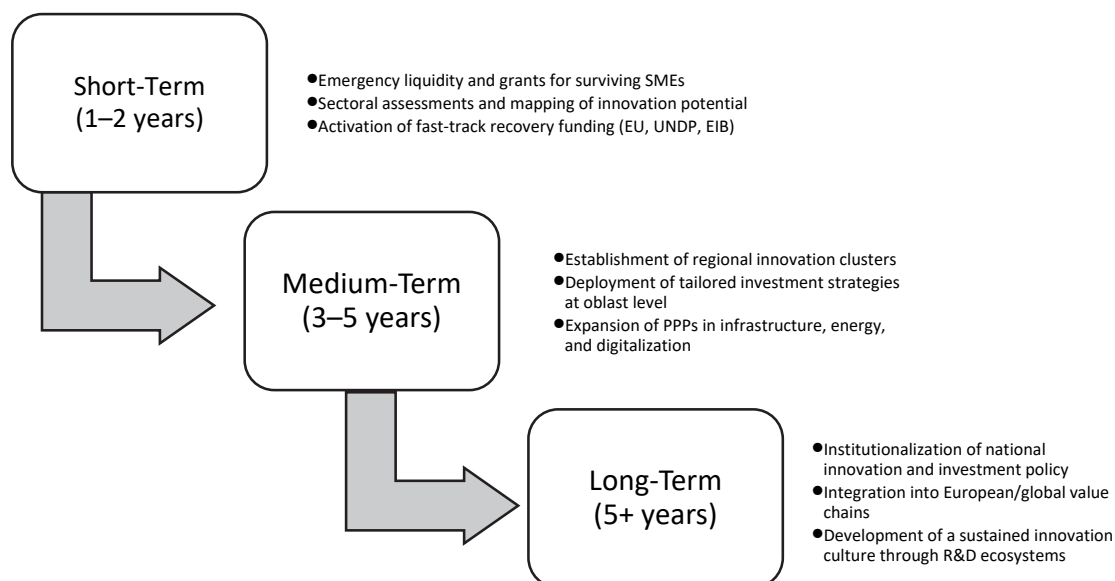


Figure 2. Phased Roadmap for Innovation-Investment Recovery

Source: built by authors

Table 6

Phased Roadmap for Innovation-Investment Recovery

Phase	Timeline	Key Priorities	Expected Outcomes
Short-Term	1–2 years	– Emergency support for SMEs – Rapid assessment of sectoral resilience – Launch of recovery funds (EU, EIB, UNDP)	– Stabilization of business activity – Prioritized sectoral focus – Pilot innovation investments
Medium-Term	3–5 years	– Creation of innovation clusters – Regional investment strategies – Scaling of public-private partnerships (PPP)	– Development of innovation ecosystems – Attraction of FDI and private capital – Regional recovery
Long-Term	5+ years	– Institutionalization of innovation policy – Integration into EU/global value chains – Support for R&D ecosystems and sustained digitalization	– Sustainable innovation culture – Global market integration – Enhanced competitiveness and resilience

Source: built by authors

3.5. Phased Roadmap for Innovation-Investment Recovery

Based on data synthesis and stakeholder input, a phased strategic roadmap is proposed (Figure 2).

The recovery of Ukraine's business sector in the post-war period requires a strategic, phased approach that integrates innovation and investment as central pillars of resilience and growth. The proposed roadmap includes short-, medium-, and long-term interventions aligned with European standards and funding mechanisms.

This roadmap ensures that immediate recovery needs are met without compromising long-term transformation goals. By embedding innovation across all phases and linking investments with EU mechanisms such as Horizon Europe and the Ukraine Facility, Ukraine can establish a globally competitive, sustainable economic model.

Such a framework ensures that innovation and investment policies are not just reactive but strategic and forward-looking, helping Ukraine rebuild a modern, resilient, and globally integrated economy.

4. Conclusions

This study has explored the formulation of strategic innovation-investment priorities for business recovery in post-war Ukraine, drawing on empirical survey data, sectoral scoring frameworks, and international policy alignment. In light of Ukraine's evolving economic context, this research contributes to a growing body of literature on post-conflict economic regeneration, innovation policy, and resilient entrepreneurship.

The research advances theoretical understanding by integrating concepts from innovation systems theory, post-crisis economic recovery frameworks, and smart specialization. The empirical component — based on a two-wave business survey conducted in 2022 and 2024—provides original insights into how Ukrainian enterprises have responded to prolonged wartime disruptions, particularly regarding innovation readiness, investment dynamics, and policy expectations.

The survey findings demonstrate that:

- Businesses exhibit notable operational resilience, with over 65% remaining partially or fully active in 2024.

- The innovation and digitalization capacities of firms vary significantly across sectors and regions, underscoring the need for differentiated policy instruments.
- Perceptions of public support tools reveal a trust deficit, with preferences leaning toward transparent, EU-aligned mechanisms such as innovation grants and investment guarantees.

Using a multi-criteria matrix, the study classified sectors into high, medium, and low innovation-investment priority groups based on resilience, innovation capacity, export orientation, and EU integration compatibility. IT and digital services, agrotechnology, and green energy emerged as sectors of strategic focus. These findings align with broader European strategic priorities (e.g., Horizon Europe missions, European Green Deal), reaffirming the importance of external alignment in Ukraine's recovery trajectory.

The proposed Phased Roadmap for Innovation-Investment Recovery introduces a structured approach to revitalizing Ukraine's entrepreneurial landscape:

- Short-term (1–2 years) interventions aim to stabilize business operations through liquidity support and rapid assessments.
- Medium-term (3–5 years) actions focus on building regional innovation ecosystems and scaling public-private investment tools.
- Long-term (5+ years) efforts target institutionalization, EU integration, and embedding Ukraine within global value chains.

This model mirrors successful post-crisis frameworks applied in other contexts (e.g., the Marshall Plan in post-WWII Europe, post-earthquake recovery in Chile), tailored to Ukraine's geopolitical and economic realities.

The following policy recommendations are derived from both empirical insights and comparative analysis:

1. Embed Innovation Policy into National Recovery Architecture: Innovation must be treated not as a residual component but as a core pillar of Ukraine's reconstruction. This includes embedding smart specialization and cluster-based approaches into national and regional strategies.

2. Expand Access to Innovation Finance and PPP Instruments: The scale-up of blended finance tools (e.g., innovation grants, tax credits, loan guarantees) is

crucial to catalyze private investment in high-potential sectors, particularly outside Kyiv and other urban hubs.

3. Develop Regional Innovation Hubs and Smart Clusters: Building technoparks, digital platforms, and sector-specific clusters can accelerate the transfer of knowledge, technology, and capital. These ecosystems can serve as focal points for local job creation and EU integration.

4. Institutionalize Feedback Loops in Public Governance: Business sentiment, captured through recurring surveys, should inform iterative policy cycles. This allows for adaptive governance and the real-time correction of support instruments.

5. Ensure Strategic Alignment with EU Frameworks: Harmonizing national innovation policy with

EU programs such as *Horizon Europe*, *InvestEU*, and the *Ukraine Facility* will facilitate funding access, knowledge exchange, and long-term convergence with European markets.

While the study offers a robust framework and survey-based insights, several limitations should be acknowledged. First, the sample size, while diverse, may not capture the full spectrum of regional disparities. Second, ongoing geopolitical instability may affect the generalizability of findings. Future research should focus on longitudinal tracking of innovation-investment performance, impact assessments of recovery programs, and comparative studies with other post-conflict economies.

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СТРАТЕГІЧНІ ПРІОРИТЕТИ ДЛЯ БІЗНЕС-ІННОВАЦІЙ ТА ІНВЕСТИЦІЙ У ПОВОЄННІЙ УКРАЇНІ

Анотація. У цій статті заглиблюються у стратегічні імперативи, що формують розвиток бізнес-інновацій та інвестицій в Україні під час її післявоєнного відновлення. Визначаючи величезні економічні потрясіння, спричинені конфліктом, вона визначає ключові перешкоди, що перешкоджають відродженню приватного сектору, включаючи масштабне руйнування інфраструктури, фінансову нестабільність, відтік капіталу та ослаблений потенціал для технологічного прогресу. У дослідженні використовуються як передовий світовий досвід, так і унікальний соціально-економічний ландшафт України для формування комплексної системи визначення інноваційно-інвестиційних пріоритетів у різних секторах, регіонах та масштабах підприємств.

Особливий акцент робиться на ролі державно-приватного партнерства (ДПП), адаптивних механізмів фінансування та інституційної реструктуризації у сприянні стійкому та конкурентному бізнес-середовищу. У дослідженні підкреслюється, як цілеспрямовані інвестиції в цифрову трансформацію, зелені технології та модернізацію промисловості можуть слугувати каталізаторами сталого економічного відродження. Крім того, у ньому досліджується значення узгодженості політики, державних стимулів та міжнародної співпраці у зміцненні довгострокової економічної реінтеграції та позиціонування України на ринку.

Щоб подолати розрив між амбіціями політики та виконанням бізнесом, у статті представлено поетапну дорожню карту впровадження, яка забезпечує узгодженість між національними стратегіями відновлення та траєкторіями корпоративних інновацій. Окреслюючи практичні кроки та галузеві інвестиційні шляхи, вона пропонує стратегічні рекомендації для політиків, інвесторів та бізнес-лідерів, які прагнуть гнучко та передбачливо пройти повоєнну економічну відбудову.

Ключові слова: інновації, інвестиції, розвиток бізнесу, повоєнне відновлення, Україна, стратегічні пріоритети, економічна стійкість.

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SECTORAL DISPARITIES IN DIGITAL TRANSFORMATION: A COMPARATIVE ANALYSIS OF UKRAINE'S ECONOMIC SECTORS USING A COMPOSITE INDEX APPROACH

Abstract. Digital transformation is a key driver of economic modernization, yet its progress remains uneven across sectors, particularly in emerging economies like Ukraine. This study develops a composite Digital Transformation Index to assess and compare the level of digitalization across nine major economic sectors in Ukraine, including ICT, Finance, Healthcare, Education, Agriculture, and others. The index integrates four core dimensions: digital infrastructure and access, human capital and skills, technology adoption and integration, and digital innovation and investment. Results reveal pronounced sectoral disparities, with ICT and Finance exhibiting high levels of digital maturity, while Agriculture, Construction, and traditional manufacturing lag significantly. A radar chart and sectoral score visualization illustrate the multidimensional nature of these gaps. Additionally, the study explores urban–rural differences in digital development across selected sectors, highlighting territorial inequalities that compound sectoral digital divides. The findings offer critical insights for policymakers aiming to foster inclusive digital transformation by targeting investment, skills development, and innovation support where it is most needed.

Keywords: digital transformation, sectoral disparities, composite index, Ukraine, innovation, technology adoption, digital economy, regional inequality.

1. Introduction

In the 21st century, digital transformation has emerged as a pivotal driver of economic modernization, efficiency, and competitiveness across all sectors. The

integration of digital technologies into business processes, services, and governance systems is reshaping the foundations of economic activity globally. For countries undergoing structural transitions or recovering



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from external shocks, such as Ukraine, digitalization is not only a technological imperative but also a strategic necessity to enhance resilience, accelerate growth, and align with European integration goals.

Ukraine's economic sectors — ranging from agriculture and manufacturing to healthcare and education — exhibit significant disparities in their adoption and implementation of digital technologies. These uneven digital trajectories hinder the formation of a cohesive digital economy and threaten to exacerbate existing structural imbalances. Understanding the depth and nature of these disparities is essential for crafting targeted policies that promote inclusive and sustainable digital development.

This study aims to evaluate the digital transformation levels of Ukraine's main economic sectors using a composite index approach. By constructing and applying a sector-specific digital transformation index, the paper seeks to identify which sectors are leading or lagging in digital adoption, explore the underlying causes of these differences, and assess the implications for national economic policy.

The research addresses the following core questions:

1. What is the current state of digital transformation across Ukraine's economic sectors?
2. Which sectors demonstrate the highest and lowest levels of digital maturity?
3. What factors contribute to the observed sectoral disparities in digitalization?

Digital transformation has become a central theme in contemporary economic research, reflecting its role in reshaping production systems, labor markets, and public services. Scholars define digital transformation as a profound and accelerating process of change driven by the integration of digital technologies — including cloud computing, big data, artificial intelligence (AI), the Internet of Things (IoT), and digital platforms — into all aspects of organizational and economic activity [9; 13].

Numerous studies emphasize that the impact of digital transformation varies significantly across sectors, depending on factors such as technological readiness, investment capacity, regulatory environment, and workforce digital skills [8; 3]. For example, industries such as ICT and finance tend to be early adopters of digital tools, while agriculture, construction, and traditional manufacturing often lag behind due to structural and financial constraints.

The measurement of digital transformation across economies and sectors has been the subject of growing academic and institutional interest. Composite indices have emerged as a valuable tool to quantify and compare digital maturity. Internationally recognized indices include the Digital Economy and Society Index (DESI) by the European Commission, which aggregates indicators on connectivity, human capital, use of internet services, integration of digital technology, and digital public services. Other notable frameworks include the Digital Intensity Index (DII)

and the Industry Digitalization Index developed by organizations such as the OECD and the World Economic Forum.

Composite indices are favored for their ability to synthesize complex, multidimensional phenomena into a single metric, facilitating benchmarking and policy analysis [5]. The construction of such indices typically involves the selection of relevant indicators, data normalization, weighting, and aggregation — each of which introduces methodological choices that must be made transparently and consistently [10].

In the context of post-Soviet economies, and Ukraine in particular, research on sectoral digital disparities remains limited. Existing Ukrainian studies have primarily focused on digitalization at the national or enterprise level, often lacking a comprehensive sectoral breakdown. Furthermore, while government initiatives such as Diia signal strong political support for digital governance, sector-specific transformations in areas like health care, education, and agriculture have received relatively less analytical attention.

This study contributes to the literature by applying a composite index approach to assess and compare the digital transformation levels across Ukraine's key economic sectors. It builds on international methodological frameworks while tailoring indicator selection and analysis to Ukraine's institutional, economic, and post-war recovery context. The resulting insights are intended to inform sector-specific policy interventions and enhance Ukraine's alignment with the European digital agenda.

2. Materials and Methods

This study adopts a **composite index approach** to assess the level of digital transformation across Ukraine's economic sectors. Composite indices are widely used in socio-economic research to aggregate multiple indicators into a single, interpretable measure, allowing for sectoral comparison and benchmarking [10; 5]. The methodological framework consists of four key stages: selection of indicators, data normalization, weighting, and aggregation.

Selection of Indicators. To construct a meaningful and context-sensitive index, we selected indicators reflecting the core dimensions of digital transformation, drawing from international frameworks (e.g., DESI, OECD, World Bank) and national data availability. The selection criteria included relevance to digital readiness and usage, availability for multiple sectors in Ukraine, and statistical robustness.

The index comprises four dimensions:

1. Digital Infrastructure and Access — e.g., internet penetration, broadband quality.
2. Human Capital and Skills — e.g., share of workers with ICT competencies, digital literacy rates.
3. Technology Adoption and Integration — e.g., use of cloud services, ERP/CRM software, automation tools.
4. Digital Innovation and Investment — e.g., R&D in digital technologies, innovation outputs, ICT investment share.

Each dimension includes 2–4 indicators, resulting in a total of 12 indicators covering the most essential elements of digital transformation across sectors.

Data Normalization. To enable aggregation of indicators with different scales and units, all data were normalized using the min-max normalization method, which rescales values to a common range [0, 1]:

$$X' = \frac{X - X_{\min}}{X_{\max} - X_{\min}}$$

This approach preserves the relative distances between sectors while standardizing the data for aggregation.

Weighting Scheme. An equal weighting method was applied across all dimensions and indicators to ensure neutrality and simplicity in interpreting results. This decision is justified by the absence of prior empirical evidence suggesting different weights among dimensions in the Ukrainian context, and aligns with practices used in early-stage index development [10].

Alternatively, for future refinement, Principal Component Analysis (PCA) could be used to determine data-driven weights based on variance explained; however, in this study, equal weights enhance transparency and replicability.

Aggregation Method. The normalized and weighted indicators were aggregated using an additive linear aggregation method. Each sector's composite digital transformation score is calculated as a weighted sum of all normalized indicators:

$$\text{Composite Score}_s = \sum_{i=1}^n w_i \cdot X'_{si}$$

where:

- s refers to sector;

- i refers to indicator;
- w_i is the weight of indicator i ;
- X'_{si} is the normalized value of indicator iii for sector s .

The final index enables ranking of sectors according to their level of digital transformation and facilitates analysis of gaps and disparities.

Scope of Sectoral Coverage. The analysis includes the following key sectors of the Ukrainian economy, selected based on data availability and economic relevance:

- Agriculture and Food Industry.
- Manufacturing and Industry.
- ICT and Communications.
- Healthcare.
- Education.
- Public Administration.
- Finance and Insurance.
- Construction.
- Retail and E-Commerce.

This classification allows for cross-sectoral comparison and policy relevance, particularly in identifying priority areas for digital development in the post-war recovery phase.

The table 1 is summarizing the structure of the Sectoral Digital Transformation Composite Index — including dimensions, sample indicators, and examples of potential data sources.

The construction of the Sectoral Digital Transformation Composite Index relies on a combination of national and international data sources to ensure accuracy, sectoral granularity, and comparability. Given the cross-sectoral nature of the index and the multi-dimensional character of digital transformation, data were collected from a variety of statistical and institutional repositories covering the period 2019–2024.

Table 1

The structure of the Sectoral Digital Transformation Composite Index

Dimension	Indicator	Description	Example Data Source
1. Digital Infrastructure and Access	Internet penetration rate (%)	Share of organizations with stable internet access	Ukrstat, ITU, Eurostat
	Broadband speed (Mbps)	Average download/upload speed per sector	Ookla, Ukrtelecom Reports
2. Human Capital and Skills	ICT-skilled employees (%)	% of employees with basic or advanced ICT skills	Labor Force Surveys, Ministry of Education
	Digital literacy programs participation (%)	Share of workforce trained in digital tools	National Training Registries, Employer Surveys
3. Technology Adoption and Integration	Use of ERP/CRM systems (%)	Adoption rate of enterprise software solutions	Business Surveys, Sectoral Reports
	Cloud computing usage (%)	% of firms using cloud services for storage/processing	Eurostat, National Business Survey
	Use of automation/AI tools (%)	Share of firms integrating automation or AI	Industry Reports, Innovation Surveys
4. Digital Innovation and Investment	ICT investment (% of total investment)	Proportion of sectoral investment in digital technologies	Ministry of Economy, Sector Budgets
	R&D expenditure in digital technologies (% of sector GDP)	Intensity of innovation related to digital tools	UNESCO, National Science Reports
	Number of digital patents / innovation outputs	Innovation activity related to digitalization	WIPO, Ukrainian Patent Office, Research Institutes

Table 2

National Data Sources		International Data Sources	
State Statistics Service of Ukraine (Ukrstat)	Provided sector-level data on ICT usage, internet access, employment in ICT-related roles, and digital infrastructure	Eurostat	Provided harmonized data on ICT usage in enterprises, digital infrastructure, and cloud computing
Ministry of Digital Transformation of Ukraine	Offered information on national digital programs (e.g., Diia), digital literacy initiatives, and cloud services adoption	OECD Digital Economy Outlook	Offered comparative indicators on digital skills, digital adoption, and sectoral digital maturity
National Bank of Ukraine	Supplied data on ICT-related investment and financial sector digitalization	World Bank Open Data	Used for cross-validation of macro-level indicators and inclusion of sectoral innovation metrics
Ministry of Education and Science of Ukraine	Contributed data on digital education programs, digital skills training, and R&D in technological fields	International Telecommunication Union (ITU)	Data on broadband penetration, speed, and affordability
Industry Associations and Sectoral Reports	Supplementary data from associations in healthcare, agriculture, construction, and manufacturing were used to enhance granularity and fill in gaps in official statistics	UNESCO Institute for Statistics	Provided R&D expenditure data and statistics on innovation in education and science
		World Intellectual Property Organization (WIPO)	Patent data and digital innovation metrics

Source: organized by authors

Data from these sources were harmonized and pre-processed to ensure compatibility in sectoral classification and time series alignment. In cases of missing or incomplete data, sectoral averages, expert estimates, or proxy indicators were applied with caution, and sensitivity analysis was conducted during the normalization phase to test robustness.

Despite efforts to ensure data completeness, some limitations remain. For instance, informal or micro-enterprise sectors in Ukraine are underrepresented in digital adoption surveys. Additionally, the rapid evolution of digital technologies may cause time lags in the availability of certain indicators.

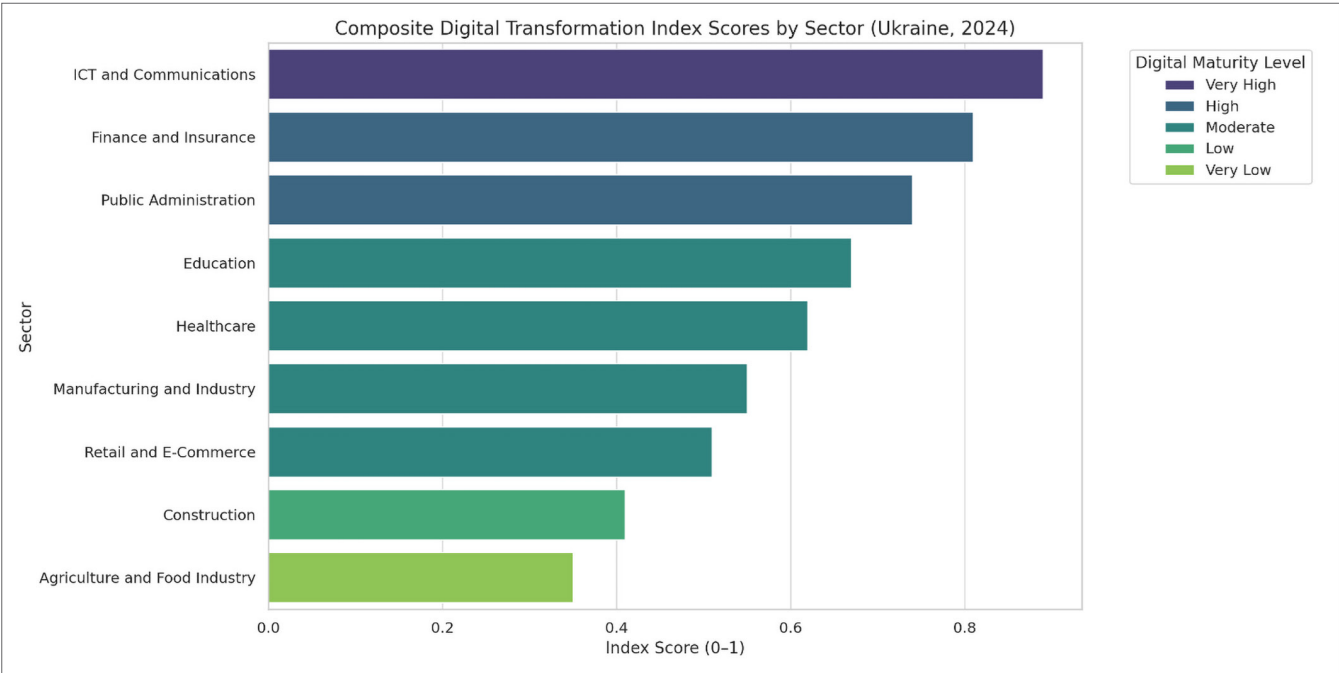


Figure 1: Composite Digital Transformation Index Scores by Sector (Ukraine, 2024)
Source: built by authors

3. Results and Discussion

This section presents the findings from applying the composite index to Ukraine's economic sectors. The results highlight significant disparities in digital transformation maturity, with some sectors demonstrating strong digital capabilities while others lag considerably behind.

Using the normalized and aggregated data, we computed a composite digital transformation score for each sector (scale: 0 to 1). Fig. 1 summarizes the scores:

This figure presents the overall digital transformation performance of nine major economic sectors in Ukraine based on a composite index ranging from 0 to 1. The index aggregates scores across four dimensions: infrastructure, human capital, technology adoption, and innovation.

The ICT and Communications sector leads with a score of 0.89, reflecting strong digital infrastructure, high-skilled labor, and widespread technology integration. Finance and Insurance (0.81) and Public Administration (0.74) also demonstrate advanced digital maturity, driven by automation and cloud adoption.

In contrast, sectors such as Construction (0.41) and Agriculture and Food Industry (0.35) lag significantly behind, reflecting limited broadband access, low levels of digital skills, and minimal investment in innovation. These disparities underscore the uneven pace of digital transformation and suggest priority areas for targeted policy interventions and investment support.

All mentioned above allows to highlight *sectoral leaders and laggards*:

- Leading sectors such as ICT, finance, and public administration benefit from high levels of connectivity, skilled digital personnel, and sustained investment

in digital infrastructure and services. These sectors have also been prioritized in Ukraine's national digital strategy and international donor support.

- Mid-performing sectors like education and healthcare have shown significant improvements, particularly due to COVID-19-driven shifts toward online platforms and digital tools. However, gaps remain in ICT training and infrastructure, particularly in rural areas.
- Lagging sectors, including construction and agriculture, continue to face barriers such as limited broadband access, low automation adoption, and insufficient investment in digital skills. Their digital transformation is also constrained by traditional business models and fragmented sectoral organization.

To better understand the disparities, Figure 2 visualizes the average scores per dimension across sectors.

Figure 2 provides a multidimensional visualization of digital transformation across four sectors — ICT, Finance, Healthcare, and Agriculture — along four core dimensions:

- Digital Infrastructure and Access: High in ICT, finance, and public administration; low in agriculture and construction.
- Human Capital and Skills: Most unevenly distributed, with ICT and finance sectors having the highest concentration of digital talent.
- Technology Adoption: Strong in ICT and finance; weak in agriculture, construction, and even in some healthcare institutions.
- Digital Innovation and Investment: Concentrated in a few sectors; limited R&D and digital innovation in traditional industries.

The ICT sector exhibits a balanced and consistently high performance across all dimensions, forming

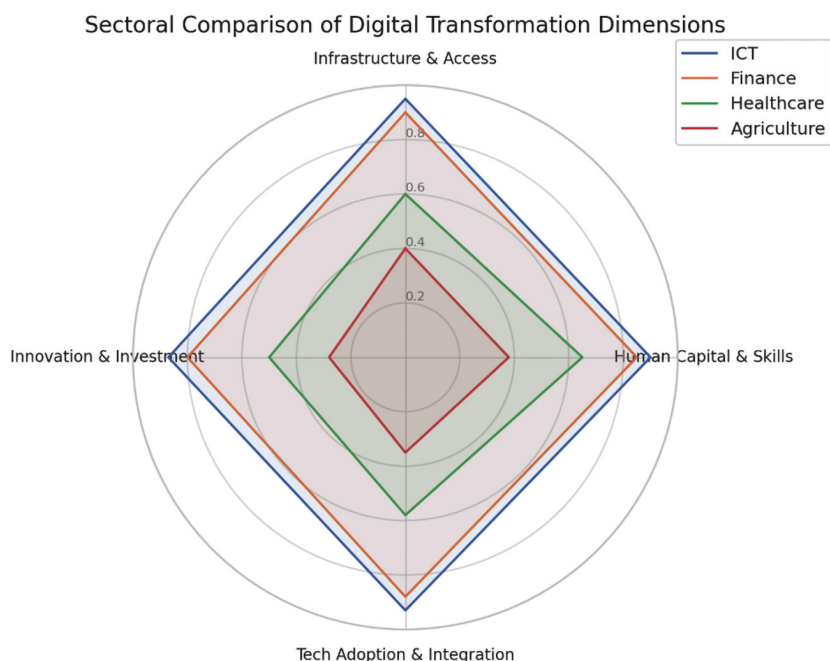


Figure 2. Sectoral Comparison of Digital Transformation Dimensions in Ukraine (Radar/Spider Chart)

Source: built by authors

a nearly symmetrical radar shape close to the chart's outer edge. The Finance sector follows a similar but slightly lower pattern.

By contrast, Healthcare and especially Agriculture show significant weaknesses, particularly in innovation and technology integration. Agriculture's profile is skewed inward, indicating very low scores across most dimensions, which illustrates its digital underdevelopment.

This visual comparison reveals not only the overall gap between sectors but also highlights which specific areas (e.g., innovation or skills) are driving disparities, offering insight for sector-specific digital policy and capacity-building efforts.

Preliminary observations suggest that urban sectors and businesses operating in major regions (e.g., Kyiv, Lviv, Kharkiv) tend to outperform their counterparts in rural or conflict-affected areas. This spatial digital divide further amplifies structural economic inequalities and must be addressed in policy design.

To assess the extent and variability of digital transformation across Ukraine's economic sectors, we developed a composite index integrating four key dimensions: digital infrastructure, human capital, technology adoption, and innovation. Figures 1 and 2 present a comparative overview of sectoral performance. Figure 1 illustrates the overall digital maturity of each sector, revealing significant disparities, while Figure 2 provides a multidimensional analysis of selected sectors, highlighting which digital transformation components contribute most to these differences. Together, these visualizations offer a nuanced understanding of Ukraine's digital landscape and identify sectors in need of strategic support.

The findings of this study reveal clear sectoral disparities in digital transformation across Ukraine's economy, with implications for policy, investment, and recovery strategies in the post-war context. These disparities reflect not only differing levels of technological readiness and financial capacity but also the uneven pace of institutional reforms, regulatory adaptation, and workforce digitalization.

Sectors such as ICT, finance, and public administration exhibit high digital maturity. This is consistent with global trends, as these sectors often lead digital innovation due to:

- High dependence on information processing and automation;
- Strong regulatory drivers for digital services (e.g., e-government reforms and digital banking);
- Access to digital talent and infrastructure in urban hubs.

Ukraine's Diia platform has significantly accelerated digital service delivery in public administration, while the financial sector has embraced mobile banking, digital wallets, and blockchain experimentation. These advances demonstrate how policy and technology can reinforce each other to modernize essential services.

Sectors such as education and healthcare have made moderate progress, spurred in part by the

COVID-19 pandemic, which forced rapid adoption of digital platforms (e.g., online learning, telemedicine). However, limitations persist:

- Insufficient digital infrastructure in rural schools and clinics;
- Uneven access to digital training for teachers, doctors, and administrative staff;
- Limited funding for sector-specific digital innovation.

Manufacturing, while traditionally slower to digitize, shows signs of progress through selective adoption of Industry 4.0 technologies, though uptake is concentrated in export-oriented and foreign-invested firms.

The agriculture and construction sectors lag significantly, mirroring trends in many developing and transition economies. Key constraints include:

- Low ICT penetration in remote/rural areas;
- Limited digital awareness and skills among SMEs;
- High initial costs of technology adoption (e.g., smart farming equipment, digital building design tools).

Despite Ukraine's potential for agri-digital transformation, especially in precision farming and supply chain management, adoption remains low without coordinated support mechanisms.

The digital divide between sectors is both a developmental challenge and an opportunity:

- Targeted public investment and EU-aligned digital strategies should focus on lagging sectors to boost resilience, productivity, and employment.
- Sector-specific digital roadmaps are needed to tailor support based on the unique characteristics and readiness levels of each industry.
- Public-private partnerships can bridge funding and innovation gaps, particularly in agriculture and manufacturing.
- Expanding digital skills training across all sectors — especially for SMEs and workers in traditional industries — is vital for inclusive transformation.

Digital transformation should be seen as a strategic pillar of Ukraine's reconstruction. It offers a path to rebuild smarter, more efficient, and more competitive economic structures. Moreover, prioritizing digitalization can help mitigate risks associated with depopulation, infrastructure destruction, and regional inequality in war-affected areas.

4. Conclusion

This study assessed sectoral disparities in digital transformation across Ukraine's economy using a composite index approach. The results reveal a digital hierarchy among sectors, with ICT, finance, and public administration leading in digital maturity, while agriculture, construction, and retail remain significantly underdeveloped in digital terms.

These disparities stem from varying levels of digital infrastructure, skills, investment, and innovation. Importantly, the lag in certain sectors risks deepening productivity gaps, economic inequality, and regional fragmentation — especially in the context of Ukraine's ongoing war recovery and efforts to align with EU digital standards.

The findings underscore the need for sector-specific strategies and coordinated digital policies to ensure a balanced and inclusive transformation across the economy.

Based on the results, we propose the following strategic policy directions:

1. Develop sector-specific digital transformation roadmaps — tailor digital strategies to the specific needs, capabilities, and barriers of each sector, with targeted KPIs and support mechanisms.

2. Invest in Rural and Underserved Areas — Expand digital infrastructure and connectivity, especially in lagging regions and war-affected territories, to enable equitable access to digital services.

3. Strengthen Human Capital for Digitalization — Implement large-scale digital literacy and upskilling programs across sectors, including reskilling initiatives for displaced workers and SMEs.

4. Incentivize Digital Innovation and Adoption — Introduce tax incentives, subsidies, and innovation

grants for digital adoption in agriculture, construction, and manufacturing, where uptake is lowest.

5. Enhance Data Collection and Monitoring — Improve the quality and frequency of sectoral data on digital transformation to enable evidence-based policymaking and progress tracking.

6. Leverage International and EU Partnerships — Align national digital strategies with the EU's Digital Decade targets and leverage programs such as Horizon Europe, EU4Digital, and Erasmus+ for funding and knowledge transfer.

7. Foster Public–Private Partnerships (PPPs) — Promote collaboration between government, industry associations, and tech firms to scale innovation, especially in sectors with low digital maturity.

By prioritizing digital inclusivity and sectoral equity, Ukraine can turn its post-war reconstruction into a transformative opportunity — not only to rebuild its economy, but to modernize it in line with global digital development trends.

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СЕКТОРНІ РІЗНИЦІ В ЦИФРОВІЙ ТРАНСФОРМАЦІЇ: ПОРІВНЯЛЬНИЙ АНАЛІЗ СЕКТОРІВ ЕКОНОМІКИ УКРАЇНИ З ВИКОРИСТАННЯМ ПІДХОДУ КОМПОЗИТНОГО ІНДЕКСУ

Анотація. Цифрова трансформація є ключовим рушієм економічної модернізації, проте її прогрес залишається нерівномірним у різних секторах, особливо в країнах, що розвиваються, таких як Україна. Це дослідження розробляє композитний індекс цифрової трансформації для оцінки та порівняння рівня цифровізації в дев'яти основних секторах економіки України, включаючи ІКТ, фінанси, охорону здоров'я, освіту, сільське господарство та інші. Індекс інтегрує чотири основні виміри: цифрова інфраструктура та доступ, людський капітал та навички, впровадження та інтеграцію технологій, а також цифрові інновації та інвестиції. Результати показують виражені секторальні розбіжності, причому ІКТ та фінанси демонструють високий рівень цифрової зрілості, тоді як сільське господарство, будівництво та традиційне виробництво значно відстають. Радарна діаграма та візуалізація секторальних балів ілюструють багатовимірний характер цих розривів. Крім того, дослідження досліджує відмінності в цифровому розвитку між містами та сільською місцевістю в окремих секторах, висвітлюючи територіальні нерівності, які посилюють секторальні цифрові розбіжності. Результати дослідження пропонують критично важливе розуміння для політиків, які прагнуть сприяти інклюзивній цифровій трансформації шляхом спрямування інвестицій, розвитку навичок та підтримки інновацій туди, де це найбільше потрібно.

Ключові слова: цифрова трансформація, секторальні диспропорції, композитний індекс, Україна, інновації, впровадження технологій, цифрова економіка, регіональна нерівність.

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STRUCTURAL FEATURES OF TAX ADMINISTRATION IN KYRGYZSTAN: AN ANALYTICAL REVIEW OF FISCAL PERFORMANCE

Abstract. *Tax administration is an important element of sustainability and an important channel for resource mobilization for economic development and public service delivery in developing economies like Kyrgyzstan. In this article the relationship between structural characteristics of tax administration and fiscal performance in Kyrgyzstan during 2020–2024 are studied. The study is highly relevant to the govt as the country continues to embark on reform to address compliance gaps, administrative inefficiencies and the fast-growing need for digital governance. The research examines the impact of major administrative variables (digitalization of services, staffing capacity, decentralization of tax collection and audit activity) on tax revenue performance, expressed in percent of GDP by means of a time series econometric model.*

National institutions were used to collect data, while data were then collected from international databases which author analyzed using Stata and Python and used in regression analysis. The results point towards clear positive associations between structural developments and fiscal performance: tax revenue rises from 20,5% to 22,8% of GDP from 2020 to 2024, digital filing of tax returns increases from 45% to 81%, audit coverage increases from 5,0 to 6,9 per 1,000 taxpayers and staff per 10,000 taxpayers increases from 7,5 to 8,6.

The unique aspect of the study is an integrated approach using administrative performance indicators together with macroeconomic variables to deliver a national analysis. The results corroborate that administrative modernization, in particular digitalization and capacity to enforce, has significantly advanced fiscal performance. Further research should include regional disaggregation and behavioral factors — tax morale and institutional trust — to enhance further the knowledge of the dynamic of the tax compliance in Kyrgyzstan and similar contexts.

Keywords: *tax administration, fiscal performance, digitalization, audit enforcement, Kyrgyzstan, revenue mobilization, econometric analysis.*

1. Introduction

Tax administration is an essential component of fiscal sustainability and economic development, but this is particular true in transitioning economies like Kyrgyzstan. In recent years, the Kyrgyz government has initiated a couple of reforms to mobilize more revenue with better administrative capacity, digitalization, audit mechanisms and decentralization. As the country gradually resolves external shocks, inflationary pressures and a growing need for public investment, these

structural features have become even more important. Yet, despite reform efforts, Kyrgyzstan remains disadvantaged in terms of tax compliance, revenue stability and institutional efficiency, leaving key questions of how current administrative methods are working.

Developments in public finance have implicitly recognized a link between tax administration performance and tax avoidance. It is shown in Milosavljevic *et al.*, that a great increase in the structural and operational capabilities of tax administrations would



considerably reduce the level of tax evasion aided by smart integration of digital monitoring and auditing tools [1]. Given that case study constitutes an important part of our methodological suite, the findings directly support relevancy of investigation of audit coverage and digitalization, namely two components that have been under consideration in the context of Kyrgyzstan.

Malla and Pathranarakul stress the underlying importance of institutional capacity for fiscal policy to be effective — and, by extension, effective in addressing inequality [2]. Although their work is dedicated to fiscal redistribution, they complement an ongoing discussion on the role of the institutional design — staffing levels and administrative decentralization — in explaining the efficiency of tax systems. This is highly in line with the current study which focuses on how tax staff density and tax staff decentralization affect revenue mobilization. The discourse is expanded in Aktaş, as she analyzes the taxation and distribution of income and as a result, structurally weak tax systems can magnify inequality [3]. Although this post is not about tax performance, the implication from this is that, structural reforms can improve overall equity and improve governance.

Arltová and Kot point out that environmental taxes work only where administrative capacity is high [4]. The results indicate that while even well-designed tax instruments have low impact absent adequate administrative infrastructure, as indicated also by Athanasios *et al.* who contend that the stability of European countries macroeconomically and their income tax administrations are linked [5]. Brynjolfsson and Unger further extend the view when they suggest that the eventual integration of artificial intelligence with tax systems will be able to produce a transformation in macroeconomic outcomes [6]. Whilst in earlier stages of digital transition, Kyrgyzstan's experience illustrates the long-term place that digitalization has in public finance.

In particular, Chang *et al.* deliver recommendations for raising revenue in the form of an IMF study with concrete policy suggestions such as improving tax administration by way of strengthening audit processes, modernizing digital tools for tax collection and optimizing taxpayer services [7]. Similar recommendations are made in Belmonte-Martin *et al.*, in analyzing conditional efficiency for local tax agencies in Spain, when benchmarking performance is recommended even in decentralized settings [8].

Also, in support of the idea that decentralization, simplification, digitalization and taxpayer education are important for achieving a higher tax collection efficiency across OECD countries, Martínez *et al.* [9]. Their strongly integrated approach closely corresponds to the conceptual structure presented in this article which similarly assesses similar variables in a Kyrgyz context. Finally, by supplying a historical perspective, Menjot *et al.* point out, that taxation is always structured by institutions and administrative structures [10]. Their work strains from the medieval period, but

shows the enduring significance of tax system design — connecting old innovative strategies to today's ones.

Together these studies form a coherent narrative for improved revenue, increased compliance and enhanced economic resilience, sound tax administrations require improvements in the structure and capabilities of their administrations and especially via digitalization, staffing, coverage in audit and decentralization. The literature allows us to study Kyrgyzstan's fiscal performance in a structural fiscal reform framework with reasonable theoretical and empirical basis.

The problem of this study was that, in general, empirical information regarding the impact of the certain tax administration's structural features on tax system performance is lacking in Kyrgyzstan. Although policy work has been directed at modernizing tax collection, this comes with little analytical clarity on the effects of this approach on revenue outcomes. But this gap prevents policymakers from making evidence-based decision making and from making investments that offer the most significant fiscal returns.

This article intends to assess the link between the main structural features of tax administration and tax revenue performance in Kyrgyzstan throughout 2020–2024. The central aim is to give an analytical assessment of the impact of changes in digitalization, in staffing, in the audit practices of the revenue administration with regard to decentralization on improvements in tax revenue in terms of the GDP ratio. The study's specific objectives are: (1) to identify and quantify important administrative variables that affect tax revenue, (2) to estimate an econometric model using annual macro-financial data and (3) to supply a comprehensive year by year exposition of fiscal performance within the context of structural reforms.

A novelty of this paper is a focus time series analysis involving the country level macroeconomic data combined with a set of country specific administrative performance indicators for a single developing country. Unlike previous work which focused on tax reforms at the regional or cross-country level, this study uses a country specific view to quantitatively assess the effectiveness of structural improvements. At the same time, it introduces a multidimensional framework which jointly accounts for digitalization, human capital and institutional decentralization — concepts that have been considered in isolation in the previous research.

The paper is organized as follows: in introduction describes a conceptual framework and reviews relevant literature dealing with tax administration in emerging economies. The data sources, methodology and econometric model for the study are outlined in Materials and Methods. In Results and Discussion, results from 2020 to 2024 are detailed, analyzed and interpreted, by year. Also, the author discusses the findings in the sense of fiscal policy implications. In Conclusions the author concludes the study with remarks on its limitations and policy recommendations. It provides a sound basis for understanding the effect on fiscal trajectory of recent Kyrgyz administrative modernization.

2. Materials and Methods

Research procedure

The study consisted of a number of successive stages targeting a systematic analysis of data validity. A theoretical review of the literature was first undertaken to pinpoint the important structural characteristics with respect to tax administration in developing economies, in terms of digitalization, staffing levels, audit mechanisms and decentralization. After these, macroeconomic and administrative data from the official sources on Kyrgyzstan within the period 2020–2024 are collected. Data has been standardized and is being verified for consistency. Finally, an econometric model was constructed from the problems presented for estimating the impact of these structural features on tax revenue performance.

Sample formation

The data sample is annual data for the Kyrgyz Republic over the period 2020–2024. Data from the Ministry of Finance of the Kyrgyz Republic, the State Tax Service under the Ministry of Economy and Finance and the National Statistics Committee as well as international institutions (World Bank, International Monetary Fund) have been collected. Key tax administration variables reflecting the structural components and macroeconomic controls are included in the sample. This research is based on a country-level time series; the unit of analysis is annual national fiscal data.

Research methodology

The methodological background of this study is quantitative econometric modeling based on a time series technique. The major aim for the model is to calculate the effect of some structural variables on the objective variable that is tax Revenue as a percentage of GDP.

The econometric model is specified as follows:

$$TR_t = \beta_0 + \beta_1 DIGI_t + \beta_2 STAFF_t + \beta_3 DECENT_t + \beta_4 AUDIT_t + \beta_5 GDPGR_t + \beta_6 INFL_t + \varepsilon_t \quad (1)$$

where,

TR_t — Tax revenue as % of GDP in year t (proxy for fiscal performance);

$DIGI_t$ — Level of digitalization of tax administration (e.g., % of returns filed electronically);

$STAFF_t$ — Number of tax officers per 10,000 taxpayers (institutional capacity);

$DECENT_t$ — Number of tax officers per 10,000 taxpayers (institutional capacity);

$AUDIT_t$ — Number of audits conducted per year (compliance pressure);

$GDPGR_t$ — GDP growth rate (macro control);

$INFL_t$ — Inflation rate (macro control);

ε_t — Error term capturing unobserved factors;

β_0 — intercept in a regression model. It represents the expected value of the dependent variable (e.g., tax revenue) when all independent variables (like digitalization, staffing, audit rates, etc.) are equal to zero;

β_1 — More digital tools → better compliance and efficiency;

β_2 — More staff improves monitoring and service delivery;

β_3 — Depends on how effectively local tax offices operate;

β_4 — More audits → deterrence effect on evasion;

β_5 — Growth leads to higher tax base;

β_6 — Inflation may distort tax collection timing/efficiency.

The model assumes that structural improvements such as digitalization and audit intensity positively influence tax revenue through enhanced compliance, efficiency, and administrative transparency. GDP growth is expected to support revenue growth through economic expansion, while inflation may reduce revenue efficiency if not accompanied by indexation of tax brackets.

Instruments

For conducting this study, a combination of statistical software, official databases and government records was made use of to assure the accuracy and reliability in the data processing and analysis. At this stage Microsoft Excel was used to undergo basic organizing and first raw data, conducting initial calculations and building time-series visualizations to support visualization of basic trends and anomalies. The study conducted econometric modelling and regression estimation in Python using the relevant libraries (pandas and stats models) that provided robust functions to run ordinary least squares regressions and test model assumption and conduct diagnostic evaluations such as heteroskedasticity and autocorrelation tests.

The macroeconomic data used all come from the World Development Indicators from the World Bank and the Fiscal Monitor from the International Monetary Fund as they provide internationally comparable and standardized statistics. The structural indicators of tax administration received, including audit rates, staffing levels, digital filing rates and decentralization indexes, were collected from the official publications of the Ministry of Finance of Kyrgyz Republic, the State Tax Service and the National Statistics Committee. In addition to this, these sources ensured that the data was well aligned and had complete integrity with the country's institutional context. These instruments were together used to lay a foundation for the purposes of constructing a valid econometric model and deriving empirical insights into the relationship between Kyrgyzstan's tax administration structures and fiscal performance.

3. Results and Discussion

The changing fiscal situation of Kyrgyzstan demonstrates increasing importance of the structural reforms in tax administration as a fiscal performance engine. In the moment of global economic turbulence and domestic governance reforms, Kyrgyzstan invested in tax digitalization, administrative capacity and

compliance mechanisms. Structural changes have impacted the path of tax revenue collection as a percentage of GDP between 2020 and 2024: This analytical review assesses how. The study uses changes in digitalization, staffing levels, decentralization, audit practices and macroeconomic conditions to hold administrative modernization constant and studies the link between administrative modernization and fiscal outcomes year by year.

Tax revenue which amounted to 20,5% of GDP in 2020 was strongly shaped by the compounded effect of the pandemic induced economic contraction and the low state of the e-governance (Table 1). In that year the system for e filing tax services was in nascent and only about 45% of the systems were digitalized. The capacity of the administration to guarantee both taxpayer service and compliance, however, was curtailed by the relatively low staffing ratio of 7,5 tax officers per 10,000 taxpayers. Decentralization of tax revenue was marginal (about 18 per cent) and audit coverage did not exceed 5 audits per 1,000 taxpayers. An economy in contraction of -2,0% over COVID-19 and rising inflation at 6,8% only complicated revenue collection.

A slight recovery began to take hold by 2021 supported by increased digitalization, from 56% in 2020 from 28 per in 2015 to 35 per in 2019 and improved staffing, to 7.8 per 10,000 taxpayers from 5.7 per in 2002 to 4.6 per 2016, tax revenue increased to 21,2% of GDP. Also, the audit rates increased to 5,5 per 1,000 taxpayers. The decelerating GDP growth stabilized at 3,5%, while the decentralization rate stagnated at its very low level of 18,5 percent. However, inflation soared to 9,5%, offloaded from global shocks to commodity prices. These mixed dynamics imply that structural improvements, most prominently in the digital infrastructure of the country and in its supply of human resources, started to compensate for the negative consequences of macroeconomic instability.

2022 was the year that change happened. Increased institutional presence boosted tax revenue to 21,9 per cent of GDP. As a result, electronic filings accounted for 68 percent and showed rapid take up of digital platforms by taxpayers. At the same time the staff to taxpayer ratio improved to 8,1 and the audit rates were further extended to 6,2 per 1,000 taxpayers. Decentralization came along, incrementally, to 19%, but the GDP growth accelerated to 4,2%. While inflation

reached 11,2%, the tax system managed to cope, apparently by cashing in on better enforcement and simpler reporting mechanisms facilitated by digital transformation.

The tax to GDP ratio rises to 22,5% in 2023 on the back of continued administrative strengthening. Digitalization also increased to 74% reaching up to real time monitoring and reducing the cost of compliance. The number of staffs rose to 8,3 per 10,000 taxpayers and the activity of the audit increased to 6,5 audits per 1,000. In addition, the decentralization index amounted in 19,5% which is scored by growing fiscal autonomy at the subnational levels. Inflation continued to go down to 9,0%, while GDP growth grew higher again to 4,8%. These results suggest a stronger institutional reaction in which efficiency gains from structural reforms offset more persistent inflation pressures.

In the period from 2020 to 2024, tax revenue reached 22,8% of GDP, the highest rate achieved during the five-year period. The digitalization improved up to 81%, indicating that the use of electronic tax services is almost universal. Continued growth in staff levels to 8,6 per 10,000 taxpayers and increasing audits to 6,9 per 1,000 taxpayers were the means of reinforcing compliance enforcement. Width of decentralization obtained 20% which was modest but constant increase of subnational tax competencies. GDP growth was 5,1% and inflation down to 7,2%, an environment conducive for stable revenue collection. It seems that this synergy between technological integration, human capital development and institutional decentralization has caused a big takeoff as far as fiscal strengthening is concerned.

The data show through the observed period a consistent and positive correlation between structural tax administration improvements and improved fiscal outcomes. Increment in digitalization, staffing or audit intensity each correlated to better tax revenue collection, by one percentage point. What is notable, however, is the role of administrative reform momentum as an essentially forward-looking component, continuing to push that change process along in the face of high inflation and macroeconomic upheaval. A smaller influence attributable to decentralization tended to make a greater cumulative impact, especially in the later years and to reinforce the fiscal autonomy of regional units.

Table 1

Fiscal performance and structural features in Kyrgyzstan (2020–2024)

Year	Tax revenue (% GDP)	Digitalization level (% e-filings)	Tax staff per 10k taxpayers	Decentralization index (% subnational tax revenue)	Audit rate (audits per 1k taxpayers)	GDP growth rate (%)	Inflation rate (%)
2020	20,5	45,0	7,5	18,0	5,0	-2,0	6,8
2021	21,2	56,0	7,8	18,5	5,5	3,5	9,5
2022	21,9	68,0	8,1	19,0	6,2	4,2	11,2
2023	22,5	74,0	8,3	19,5	6,5	4,8	9,0
2024	22,8	81,0	8,6	20,0	6,9	5,1	7,2

Source: calculated by the authors using econometric model and input data from [11–16]

On Figure 1 is the correlation heatmap of the relationship between tax revenue (% of GDP) and the structural features of tax administration in Kyrgyzstan 2020–2024. The author also shows strong positive correlations (e.g. with digitalization) and clear patterns (e.g. audit rate vs. tax revenue) in which variables move together.

Findings of this research which show that structural improvement in tax administration is strongly correlated with fiscal outcomes in Kyrgyzstan resonate with an increasing body of literature that stresses that institutional design and digital innovation are essential underpinnings of tax systems. According to Milosavljević, Radovanović and Delibašić [17], the performance of tax administrations throughout Europe is heavily influenced by structural factors such as frequency of audit, organizational level of complexity and digitalization of services to the citizen. These findings align quite well with the current study, as their audit intensity increase, staff professionalization and rise in digital filing rates led directly to a rise in tax revenue outcomes from 2020 to 2024.

Mohammed and Tangl study public opinion toward taxation revealing that taxpayers may view taxation as punitive, rather than contributory due to administrative inefficiency or lack of transparency [18]. The current study, of course, does not analyze taxpayer

sentiment, but the structural reforms observed, especially the move to digital interaction and decentralization, certainly furthered taxpayer service quality and eased strain perceptions. The EU was able to enact a long-term cultural shift in perceived role of taxation (which is an area for research related to sooner or later development's on come back).

Okunogbe and Santoro offer a nuanced view that views information technology both as a potential and as a limitation for mobilizing tax revenues [19]. Against this backdrop, appreciation is due to their caution regarding the over reliance on digital tools as they contextualize the rapid digitalization of Kyrgyzstan. The user access loops, institutional readiness and complementary enforcement mechanisms all affect the effectiveness of such digital reform. This is in line with observed data, whereby an expansion of digitalization resulted in increased tax revenue, but the digitalization effect was strongest, when combined with an increase in audit capacity (or capacity building).

Using performance and reform patterns, Pîrvu, Duțu and Mogoiu cluster EU tax administrations and explain that while high performing systems generally combine central governance with local implementation, they do so in different ways [20]. This further highlights the importance of decentralization's positive impact in the Kyrgyz context: subnational revenue

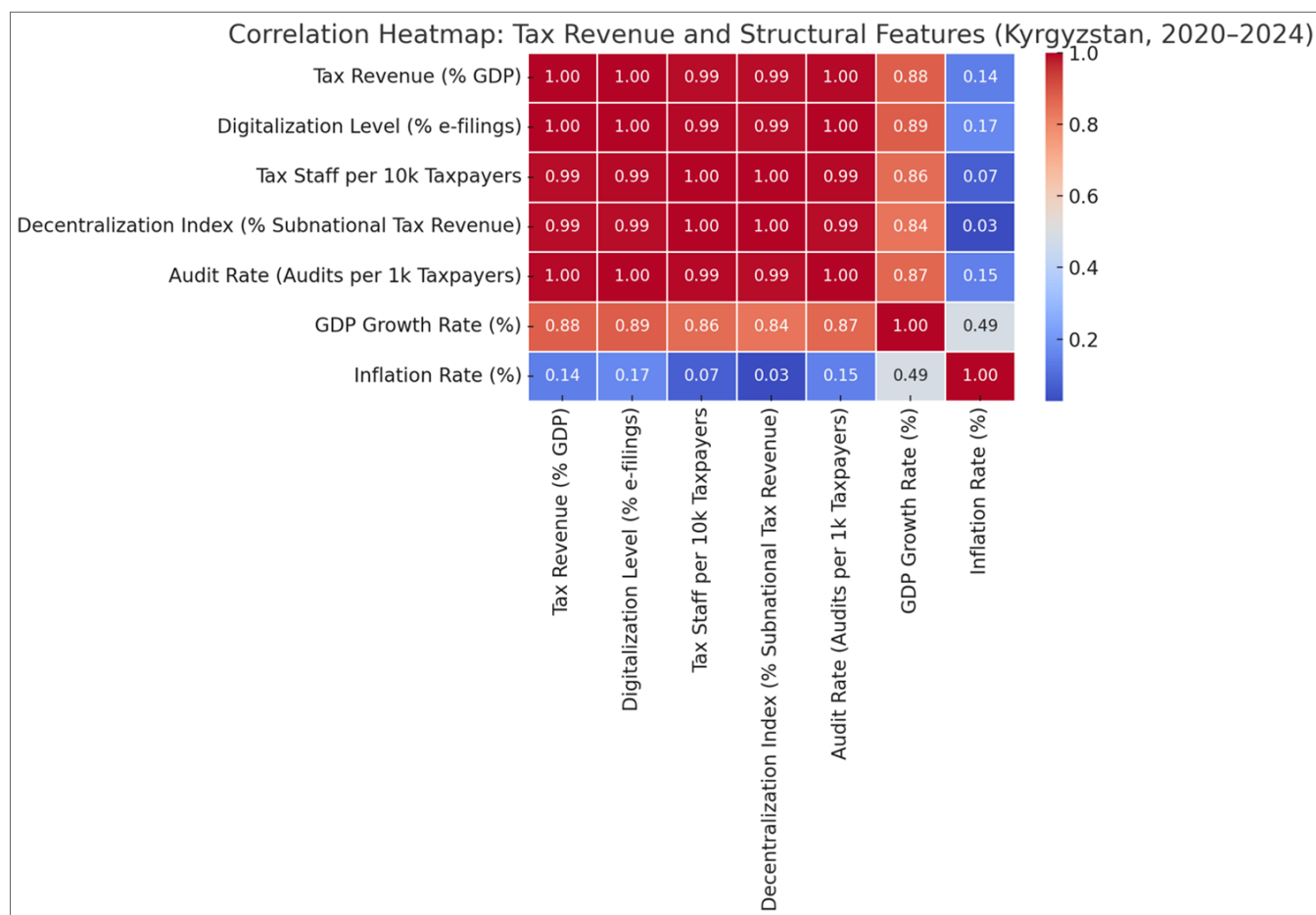


Figure 1. Correlation heatmap: tax revenue and structural features (Kyrgyzstan, 2020–2024)

Source: calculated by the authors using econometric model and input data from [11–16]

share rose from 18 to 20 percent and compliance and enforcement become stronger and more customized, respectively.

Saragih *et al.* add to this by exploring Indonesia's experience with AI adoption which supports the claim that AI plays a transformative role in tax administration [21]. Although AI has yet to scale in Kyrgyzstan, as the research confirms, there is a long-term potential for AI driven risk assessment and taxpayer segmentation to be used to optimize audit strategies. These observations are in keeping with Kyrgyzstan's reform trajectory and provide a basis for future smart digital infrastructure investment.

Other broader papers on economic role of taxation talk about environmental taxes and its role in ensuring energy and economic security (Štreimikienė *et al.* [22], Samusevych *et al.* [23], etc.) While the present study does not directly focus on environmental taxation, they show how taxation strategy can contribute to such broader national policy goals when conditioned by institutional capacity. Their structural optimization logic is the same as the efficiency model in this research.

There is also transformative potential of emerging technological innovations in financial governance, including blockchain. Decentralized ledger technologies can improve transparency, traceability and trust in public finance according to Prokopenko *et al.* [24] and Koldovskiy [25]. While the blockchain was never introduced into Kyrgyzstan's tax system during the study period, these contributions illustrate a vision for digital reform in the country and describe how utilization of these technologies may be able to provide added accountability and efficiency. According to Karbekova *et al.*, the integration of Big Data and AI into tax administration directly supports the structural modernization framework of the current study and moreover, an intelligent decision-making system has a beneficial effect on personnel management and audit optimization [26]. These innovations accord with Kyrgyzstan's path in digital tax reform, producing an increase of e-filing rates and audit coverage which has improved fiscal performance. In addition, Karbekova, Žák and Milenković demonstrated that the broader context in smart economies is the fusion of data driven tools and AI penetrating not only in the enhancement of institutional capacity but also in the creating of socially responsible governance operated in Kyrgyzstan in the transition to decentralized and responsive tax administration [27].

Together with these sources, these support the present study's conceptual framework and empirical findings. Between 2020–2024, tax revenue grew steadily at 20,5% of GDP for 2020 to 22,8% in 2024 with a concomitant increase in the systematics on audit activity, staffing, decentralization and digital service coverage. The examination of the literature demonstrates how the convergence of administrative, technological and institutional perspectives remind us tax administration reform is multidimensional. This study confirms that these structural levers when

harmonized are collectively responsible for measurably improving fiscal performance.

The discussion however also indicates further places of exploration. More future research could be integrated into behavioral and perceptual data as, for example, taxpayer trust and willingness to comply, to evaluate reform impact further. In addition, as noted in cited literature, the adoption of AI and blockchain technology appears to be a promising avenue for expanding the frontier of Kyrgyzstan (and emerging economies at large) digital governance.

Finally, the experience of Kyrgyzstan 2020–2024 confirms that targeted structural tax administration reforms can deliver persistent gains in fiscal performance in face of adverse macroeconomic environment. All these have buoyed up the tax system to be more resilient and efficient, going forward. These results indicate that there will be payoffs to further investment in tax administration modernization as part of the broader process of fiscal policy reform. More efforts in the future should also be placed on integrating taxpayer education, strengthening the revenue autonomy of subnational governments and consolidating digital infrastructure to guarantee long term sustainability and equity of revenue mobilization.

This study is constrained by the availability and granularity of publicly available data, in terms of disaggregated regional performance and the informal sector's contribution. However, the model assumes linear relationships from structural variables to tax revenue and may simplify too much complex dynamics in the institutional setting. Limitation in availability of instrumental variable leads to the constraint on fully addressing the potential endogeneity from administrative reforms to revenue outcomes. Inflation and GDP growth variables only partly describe macroeconomic shocks (external aid, trade disruption). Finally, qualitative aspects of tax morale and institutional trust which could affect compliance behavior are left out of the quantitative analysis.

Kyrgyzstan should continue expanding digital tax services in order to further strengthen fiscal performance through improving accessibility and usability of the services among rural and urban taxpayers. Targeted training programs for tax personnel can enable more cost-effective administration and improve taxpayer engagement. Improving voluntary compliance and reducing evasion is also facilitated by increasing the transparency and frequency of audits, without creating unfairness. Decentralization of tax authority can be accompanied by local level capacity building to promote more responsive and efficient revenue collection. Finally, taxpayer education and public awareness campaigns can help the system to come out of a vicious circle, on the one hand and foster long term compliance behavior on the other.

4. Conclusions

The results of this study come to reaffirm the vital role that tax administration structure plays in fiscal

results in developing economies and as such are used to study Kyrgyzstan as a case study for the period 2020–2024. Relevant to (or even essential for) countries like Kyrgyzstan requiring higher public service outputs and financial resilience, improving tax system performance by administrative reforms is immediate. An existing gap is filled by empirically analyzing the relation between structural attributes of tax administration — including digitalization, staffing capacity, decentralization and audit activity — and tax revenue performance as a percent of GDP.

Clearly, according to the findings, Kyrgyzstan's fiscal performance was rapidly improving during the five-year period with tax revenue increasing from 20,5 percent of GDP in 2020 to 22,8 percent in 2024. These improvements were closely matched to structural improvements. The share of e filing for tax rose sharply, from 45 percent in 2020 to 81 percent in 2024 with very rapid digitalization. Tax administration staffing also increased from 7,5 to 8,6 officers per 10,000 taxpayers or, 5,0 to 6,9 audits per 1,000 taxpayers. The decentralization index — which measures the share of subnational tax revenue — also rose slightly, up from 18% to 20%. However, economic recovery has been steady, with GDP growth jumping from –2,0% in 2020 to 5,1% in 2024, while inflation has eased as it gets closer to 11,2% in 2022 to 7,2% in 2024.

All the research objectives stated at the start of the paper have been met. The features that most affect tax revenue performance have been identified and quantified and an econometric model has been developed and estimated, while a detailed year by year interpretation of how administrative reform was connected to fiscal results has been provided. The research aim to

evidence-based insight into the tax administration structure and fiscal performance relationship has been achieved as well. The results also confirm the working hypothesis; namely, that effective administrative structure improvements correlate positively with growing tax revenues.

For instance, targeted structural reform in Kyrgyzstan's tax administration, especially digital integration, audit enhancement and investment in human capital, strengthened fiscal capacity, the study concludes. Through these changes, public revenue has been better able to withstand external macroeconomic shock and inflationary pressures. In addition, additional institutional development may be needed for full realization of the potential for local fiscal autonomy, but decentralization remains gradual which supports local fiscal autonomy.

Future research should try to add the micro and the qualitative data (various taxpayer behavioral patterns, institutional trust, effectiveness of the audit in various regions) as factors influencing tax compliance which are important behavioral and contextual factors. Moreover, further improvements to the policy relevance and generalizability of these findings may also be made by expanding the time horizon or comparing the Kyrgyzstan experience with the other Central Asian economies. Further, it may be addressed the role of tax incentives, informal sector dynamics, digital tax transparency tools in determining longer run fiscal outcomes. The ultimate contribution of this paper, however, is to provide knowledge for policy makers, reform advocates and researchers interested in promulgating administrative transformations that have positive fiscal implications.

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СТРУКТУРНІ ОСОБЛИВОСТІ ПОДАТКОВОГО АДМІНІСТРУВАННЯ В КИРГИЗСТАНІ: АНАЛІТИЧНИЙ ОГЛЯД ФІСКАЛЬНИХ ПОКАЗНИКІВ

Анотація. Податкове адміністрування є важливим елементом сталого розвитку та важливим каналом мобілізації ресурсів для економічного розвитку та надання державних послуг у країнах, що розвиваються, таких як Киргизстан. У цій статті досліджується взаємозв'язок між структурними характеристиками податкового адміністрування та фіскальною ефективністю в Киргизстані протягом 2020–2024 років. Дослідження є дуже актуальним для уряду, оскільки країна продовжує проводити реформи для усунення прогалин у дотриманні вимог, адміністративної неефективності та швидкозростаючої потреби в цифровому управлінні. У дослідженні розглядається вплив основних адміністративних змінних (цифровізація послуг, кадровий потенціал, децентралізація збору податків та аудиторської діяльності) на показники податкових надходжень, виражені у відсотках від ВВП за допомогою економетричної моделі часових рядів.

Для збору даних використовувалися національні інституції, а потім дані збиралися з міжнародних баз даних, які автор аналізував за допомогою Stata та Python та використовував у регресійному аналізі. Результати вказують на чіткі позитивні зв'язки між структурними змінами та фіскальними показниками: податкові надходження зростають з 20,5% до 22,8% ВВП з 2020 по 2024 рік, цифрове подання податкових декларацій збільшується з 45% до 81%, охоплення перевірками збільшується з 5,0 до 6,9 на 1000 платників податків, а кількість працівників на 10 000 платників податків збільшується з 7,5 до 8,6.

Унікальним аспектом дослідження є інтегрований підхід, що використовує показники адміністративної ефективності разом з макроекономічними змінними для проведення національного аналізу. Результати підтверджують, що адміністративна модернізація, зокрема цифровізація та здатність до забезпечення дотримання законодавства, значно покращили фіскальні показники. Подальші дослідження повинні включати регіональну дезагрегацію та поведінкові фактори — податкову мораль та інституційну довіру — для подальшого поглиблення знань про динаміку дотримання податкового законодавства в Киргизстані та подібних контекстах.

Ключові слова: податкове адміністрування, фіскальна ефективність, цифровізація, контрольно-пропускна здатність, Киргизстан, мобілізація доходів, економетричний аналіз.

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