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Compliance and corporate culture: Interconnection and impact on business performance

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Abstract. The purpose of the article was to develop practical recommendations for integrating the compliance function into business processes, including the formation of transparent internal control mechanisms, increasing the level of involvement of management at all levels, systematic staff training and implementation of the code of ethics, as well as assessing the effectiveness of compliance programmes through their impact on key business processes such as procurement, sales, recruitment and contractual work. The article explored the relationship between corporate culture and compliance, as well as their impact on business performance in today's global economy, growing competition and increasing regulatory pressure. Attention was focused on the importance of developing an ethical corporate culture as a key element of the successful implementation of compliance programmes, especially in the context of modern global economy, where the level of regulatory pressure on business increases every year. The article analysed scientific publications and industry standards that define corporate culture as an integral part of an effective compliance programme, using the method of average assessment of the compliance function's effectiveness, as well as the cost and revenue function model. The challenges faced by enterprises in integrating compliance procedures into business processes are highlighted, including insufficient support from management, resistance to change, and lack of understanding of the importance of compliance. The article discussed in detail the methods of assessing corporate culture, including questionnaires, analysis of internal documents, focus groups and the dynamics of labour discipline violations. Particular attention was paid to the mechanisms for diagnosing corporate culture through key indicators such as innovation, results orientation, employee support and stability. The article highlighted the theoretical aspects and practical significance of integrating compliance and corporate culture as tools for improving business efficiency, ensuring its stability and competitiveness

Keywords: business processes; risks; ethical standards; internal control; performance assessment; business transparency

Introduction

In modern global economy, with growing competition and increasing regulatory control, the issue of ensuring the efficiency of enterprises is of particular importance. The success of their operations increasingly depends on their ability to adapt to new challenges and implement effective management approaches, one of which is the development of an ethical corporate culture (or so-called compliance culture) as part of the implementation of compliance programmes. Ukrainian businesses need to be prepared for the challenges associated with Ukraine's integration with the

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European Union, as this process will not only provide new business opportunities (such as access to new markets), but will also significantly increase regulatory pressure on entrepreneurs. In practice, many Ukrainian businesses face challenges in integrating compliance procedures into their business processes, including the introduction and development of an appropriate business culture – corporate or compliance culture. A lack of understanding of the importance of compliance, resistance to change on the part of employees and sometimes managers at various levels, insufficient internal organisation and weak management control are just some of the factors that impede effective interaction between these elements. As a result, there are risks of non-compliance with regulatory requirements, deterioration of the internal climate in the company and reduced competitiveness.

Y.L. Pathiranage (2019) investigated the impact of organisational culture on business performance through a literature review and empirical evidence. He argued that corporate culture affects employee behaviour, motivation, engagement, as well as the efficiency, profitability and growth of a company, and that businesses with strong cultures demonstrate better operational and financial performance. The author believes that an effective culture combines a strong (shared values) and a positive (motivation and mutual respect) culture. F. Banning *et al*. (2023) noted that there is a direct correlation between employee job satisfaction and performance, in particular, the level of employee satisfaction determines the employee's adaptive behaviour, which can change under the influence of certain management decisions. The authors also argue that a stable strategy allows for the formation of a sustainable culture, and knowledge of employee values allows for the most effective management style. S.H. Ghumiem *et al*. (2023) concluded that companies with a strong corporate culture have stable and committed employees who work more efficiently. Through a survey of 300 respondents, the authors determined that corporate culture has a direct and statistically significant impact on overall organisational performance, employee satisfaction, and organisational commitment. The authors also found that communication and leadership are the most important aspects of corporate culture that affect performance. In addition, the study found that the impact of corporate culture is stronger among women than among men, and that employees with less experience are more sensitive to the level of corporate culture as it is a source of guidance and motivation for them.

According to C. Coglianese (2024), cultural change in an organisation may indeed be what is needed to improve compliance, as formal implementation of compliance programmes is not effective in itself if the appropriate culture is not implemented. J.R. Graham *et al.* (2023) highlighted that 90% of senior executives consider corporate culture to be very important or important in their company, and that, all other things being equal, a company with a positive corporate culture will demonstrate better business results than a company with a poor corporate culture. According to the study, organisational leaders often describe corporate culture as a set of shared values, norms and beliefs that influence employee behaviour and decision-making in an organisation. The authors also note that a strong corporate culture promotes compliance with ethical standards and regulatory requirements, reducing the need for strict external controls.

Corporate culture is a fundamental element that influences the effectiveness of compliance management systems. C.R. Harvey *et al*. (2023) in their article emphasised that corporate culture is one of the most important factors affecting company performance, although it is often overlooked. Y.S. Hung *et al.* (2022) argued in their study that organisational culture had a significant impact on aspects of labour productivity such as task performance, contextual performance, and counterproductive work behaviour. In all the analysed studies, the concepts of compliance and corporate culture are considered separately. In the opinion of the authors of this article, corporate culture is one of the key elements of effective compliance programmes and should be considered as an element of such programmes. In this case, its effectiveness can be assessed in accordance with industry standards, such as ISO 37001:2025 (2025) or ISO 37301:2021 (2021). The topic of compliance and corporate culture still requires further research, given that it is quite new and, accordingly, the number of studies is significantly limited. Both the relationship between the internal control system and corporate culture and the impact of the compliance system and corporate culture as an integral part of it on the operational efficiency of enterprises and organisations are insufficiently studied. Therefore, the purpose of the article is to study the concepts of compliance and corporate culture, their interconnection, and the impact on business efficiency.

Materials and Methods

Most of the analysed scientific publications were published in the last 5-6 years (Chatman & Choi, 2019; Asikhia, 2020; Ivanenko, 2024). These works were analysed for the impact of the level of corporate culture on the overall performance of the respective companies. From the point of view of this study, the most relevant was the study of the relationship between the implementation and development of corporate culture and the growth of business efficiency. The method of average assessment of the effectiveness of the compliance function was used to assess the difference in the level of material losses of an enterprise without a compliance programme and with one. This method was applied by surveying the management of Fresenius Medical Care Ukraine LLC regarding the level of financial losses before and after the implementation of the compliance function in the company. A total of 12 people took part in the survey – all representatives of the leadership team, six men and six women of different ages – from 29 to 62 years. The survey was conducted on the online platform Google forms. The ethical standards of the ICC/ESOMAR International Code on Market, Opinion and Social Research

and Data Analytics (2016) were followed during the testing. The questionnaire asked for an assessment of the level of financial losses within business processes owned by the relevant management representatives before and after the implementation of the compliance control system. The losses were assessed on a scale from 1 (low losses) to 5 (high losses). The assessment criterion was the amount of losses: low losses – up to one hundred euros per year, high losses – more than five thousand euros per year. The article also analyses approaches to assessing the effectiveness of corporate culture, such as surveys, focus groups, analysis of the dynamics of labour discipline violations, and benchmarking.

The paper used the method of building a model of cost and income functions, which allows assessing the ratio of costs of implementing the compliance function to the benefits received or saved. In order to estimate the costs, the following indicators were taken into account: annual salary and bonus of the compliance officer, cost of medical insurance, annual operating expenses (legal advice, software purchase, etc.) and cost of recruiting relevant personnel. Data from the ACFE report (2024), which identifies average losses from healthcare fraud, was analysed from to estimate the retained benefit. Other potential losses were calculated based on the applicable antitrust and anti-corruption legislation, based on the volume of sales of the company's goods in public procurement. The dynamics of labour discipline violations were also analysed for the relevant period – before and after the implementation of the compliance function. The use of these methods in combination made it possible to assess changes in the management's perception of the state of corporate culture related to the implementation of the compliance programme at the enterprise, as well as the dynamics of losses associated with the launch of the internal control system and changes in the level of labour discipline. The article discusses the key aspects of the industry standards in the field of compliance – ISO 37301:2021 (2021) and ISO 37001:2025 (2025), as they are the main standards that guide businesses in the process of implementing compliance functions in their organisational structure. The analysis of these industry standards helped to form a clear understanding of the definitions of compliance and corporate culture and to assess how to evaluate the effectiveness of compliance programmes in general. This comprehensive approach allowed to draw a reasonable conclusion about the interconnectedness of the concepts of compliance and corporate culture, as well as to assess their impact on business performance.

Results and Discussion

Organisational culture as a concept first emerged in the 1970s and 1980s, but has already become influential and controversial in management research. As of February 2025, there is no single established definition of corporate culture. Some scholars define corporate culture as a system of values that subconsciously motivates people to make choices or decisions (Pathiranage, 2019). Others perceive it as a list of constituent elements that form a favourable microclimate and contribute to the formation of a positive company image (Malyk & Fisenko, 2016). After analysing the definitions available in the scientific literature, it can be concluded that corporate culture is a system of certain values aimed at forming ethical approaches to doing business, creating a favourable and comfortable climate in the team of a company, improving reputation in the eyes of all relevant stakeholders – from employees to customers, partners and regulators, and, as a result, increasing business efficiency in general.

The main elements of corporate culture include the mission, which defines the main reason for the company's existence and reflects the business philosophy. It can be formulated as a statement in a simple and easy-to-understand form (Shveda, 2019). Values are basic beliefs and principles that define standards of behaviour and decision-making, shaping the culture and ethical norms within an organisation. Image is a set of perceptions and impressions that have developed in society about an organisation, its activities, products and services, affecting reputation and perception by external stakeholders. Operational objectives cover short-term tasks aimed at implementing the organisation's day-to-day activities, ensuring its efficient functioning and achieving specific results within the established timeframe. Strategic goals define long-term plans for the development of the organisation, focused on achieving competitive advantages and sustainable development in the future (Zlenko *et al.,* 2023). Rules and norms of behaviour are also important, as they set standards and expectations for the actions and interactions of employees within the organisation, support an ethical culture, professionalism and compliance with the company's mission and values (Shemchuk, 2014). Traditions passed down between generations within an organisation help to strengthen corporate culture and create a unique identity. A code of ethics or code of conduct is an internal regulatory document that publicly sets standards of behaviour for employees, defines minimum requirements for business partners, declares the core values and mission of the organisation, and describes possible consequences for violating its requirements (Malyk & Fisenko, 2016). The effectiveness of a company's corporate culture can be assessed using various methods. These include questionnaires and surveys of employees and managers, group interviews and focus groups, analysis of existing internal regulations and their accessibility for all categories of employees, exit interviews, etc. It is advisable to analyse the dynamics of labour discipline violations, as well as to use benchmarking.

It is necessary to take into account the psychology of people and apply the principle of anonymity in the process of, for example, questionnaires, since if the anonymity of respondents is violated, a significant number of socially desirable answers may arise, which will lead to a decrease in the validity of the data obtained (Hovorukha, 2024). Organisational culture should be diagnosed in the following areas: innovation and risk-taking – assessed in terms of the degree of encouragement to take a certain level of risk,

experimentation and approval of innovations; attention to detail – to what extent does the organisation's management expect its employees to be accurate in performing tasks, meticulous and attentive to details; focus on the end result – to what extent does the organisation's management focus on the end result rather than on the methods and processes used by the staff.

Relevant industry standards, as well as recommendations from US and European regulators, state that corporate culture is an integral part of any effective compliance programme. ISO 37301:2025 (2025) states that an organisation should develop, maintain and promote a compliance culture at all levels of the organisation. The governing body, senior and middle management shall demonstrate an active, visible, consistent and sustained commitment to common standards of behaviour that are required throughout the organisation. Senior management should encourage behaviours that create and sustain a culture of compliance. It should prevent and demonstrate zero tolerance for behaviour that compromises compliance with laws, industry codes and internal regulations. In the U.S. Department of Justice (2024) guidelines for assessing the effectiveness of compliance programmes, there is a paragraph that states the importance of creating and developing a culture of ethics and compliance at all levels of the company. C. Coglianese & J. Nash (2021) pointed out that the effectiveness of a compliance programme requires the involvement of the organisation's top management to implement a culture of compliance at the middle and top management levels. M.M. Towle (2024) emphasised that the development of a compliance culture based on ethical standards complements the formal compliance process and potentially increases the effectiveness of risk management. G. Widjaja (2024) believed that a high level of compliance helps organisations to minimise legal risks and maintain their reputation and stakeholder trust.

If the definitions of this concept provided by various scholars are analysed, O.V. Neizvestina (2017) defined compliance as a set of functions built into each business process of an organisation aimed at complying with internal business standards, corporate ethics, and legal and regulatory requirements in order to achieve the highest efficiency of financial and economic activities. S.J. Griffith (2016) emphasised that "compliance" is a set of internal processes by which firms adapt their behaviour to the established norms. The compliance system establishes internal mechanisms for preventing and detecting violations of legislation and regulatory practices. To summarise, compliance in a broad sense is a system of measures and tools, rules and procedures that aims to ensure that an organisation's activities comply with the requirements of legislation, internal regulations, as well as ethical and industry standards.

In accordance with international standards and regulators' recommendations, the elements of an effective compliance programme include the following: consideration of the context of a particular organisation; involvement of management at all levels to promote a culture of compliance; allocation of roles and responsibilities; planning; availability of necessary resources, autonomy, authority and expertise of compliance officers; an effective internal control system; use of a risk-based approach; effective communication; availability of effective mechanisms for.

The effectiveness of each of these elements can be assessed separately using relevant industry standards: 37301:2021 (2021), 37001:2016 (2016) and the U.S. Department of Justice (2024) guidelines for assessing effective compliance programmes. Accordingly, the overall assessment of the compliance programme will be the sum of the assessments of each of its elements. Additionally, it makes sense to assess the economic impact of the function on the company's operations (Table 1). There are at least a few ways to do this. The first is to compare the level of material losses of the enterprise in the presence of the relevant function and in its absence. The efficiency was assessed by questioning representatives of the company's management (1 – high losses, 5 – low losses):

Table 1. Average assessment of the effectiveness of the compliance function on the example of Fresenius Medical Care Ukraine LLC

Management representatives	Level of financial losses	
	Before the implementation of the compliance function	After implementing the compliance function
General Director	5	2
Chief Financial Officer	5	2
Chief Accountant	4	3
Sales and Marketing Director	4	3
Director of Legal Affairs	5	1
Chief Compliance Officer	5	1
Medical Director	4	3
Director of Logistics	5	3
Service Director	4	3
Quality Director	5	2
CIO	5	3
HR Director	5	3

Source: created by the authors

The results of the survey show that the level of financial losses has significantly decreased with the implementation of the compliance programme at the enterprise. This became possible not only due to the development of an internal control system that allows to reduce compliance risks in the relevant business processes of the company, but also due to the development of corporate culture by introducing internal regulations (Code of Ethics, Supplier Code of Conduct, Conflict of Interest Management Policy, Business Gift Exchange Policy, Third Party Risk Management Policy, etc.), conducting training for staff, demonstrating the benefits of ethical business conduct by top management, and also applying the principle of zero tolerance for violations of compliance requirements.

In addition to the analysis of direct losses, a model for building cost and revenue functions is promising. Such a model takes into account not only the direct costs of the compliance function (creation of a unit, its financing, staff training, support, etc.), but also the lost profit of the company as a result of its refusal to implement the compliance programme. Such lost profits may include a decrease in the capacity of the target market, an increase in the cost of services from suppliers, deterioration of payment terms for goods or services (for example, a shift from post-payment to partial or full prepayment), increased costs for business processes, etc. In order to build a model of cost and revenue functions, the following data are required: data on the company's expenditures on regulatory risks (fines, investigations), the budget for the implementation of the unit (one-time and operating costs), historical data on the company's financial losses due to non-compliance. Based on the example of one company operating in the healthcare sector, a corresponding model was created, taking into account the following data potential fines for violations of antitrust laws – up to 10% of annual turnover (10% of €8,000,000 – €800,000), potential fines for violations of international anti-corruption and sanctions laws – up to 35% of annual turnover, assuming that all public tenders of the enterprise in question were won through corruption offences (35% of €8,000,000 – €2,800,000), according to the ACFE report (2024) the average loss from healthcare fraud is €100,000, the cost of legal support for potential investigations is up to €100,000, and the cost of setting up a compliance function is €43,500 (€30,000 annual salary, €4,500 annual bonus, €1,000 annual health insurance policy, €5,000 annual operating costs of the function, €3,000 recruitment costs to fill the position of Compliance Director). Accordingly, the formula for the cost/income function will be as follows:

$$Return\ of\ Investment\ (ROI) = \frac{(800,000 + 2,800,000 + 100,000 + 100,000)}{(30,000 + 4,500 + 1,000 + 5,000 + 3,000)} = 87.36. \quad (1)$$

That is, for every euro that an enterprise spends on maintaining the compliance function, it potentially saves up to €87.36. It can be argued that the efficiency of implementing the compliance function is very high, given the regulatory environment in which the company operates. As noted above, one of the elements of any effective compliance programme is the internal control system. This element is the most effective in terms of assessing the impact of compliance programmes on overall business performance. The key business processes in which relevant controls are usually built in, as well as the impact of these controls on the efficiency of such processes (Table 2).

Table 2. Areas of corporate culture diagnostics in organisations

Process	Control	Effect
Procurement	Monitoring compliance with the principle of "fair market value"	1. Reducing costs through transparent procurement of goods and services at market prices 2. Reduction of corruption risks
Sales	Monitoring compliance with the principle of "fair market value"	1. Increase revenues by maintaining fair sales conditions for all consumers 2. Reducing corruption risks
Recruitment	Monitoring compliance with the fair employment principle	1. Increase labour efficiency by hiring the most qualified personnel 2. Reducing the risk of conflict of interest 3. Reducing the risk of discrimination against candidates on any grounds
Finance	Control over the process of approving outgoing payments	1. Reducing the risk of unlawful payments
Relations with counterparties	Checking counterparties	1. Reduce financial losses by entering into transactions with unreliable counterparties 2. Reduction of sanctions risks 3. Reduction of corruption risks 4. Reducing fraud risks
Contract work	Approval of contracts / agreements	1. Improve cash flow by managing payment schemes (prepaid/postpaid) 2. Reducing financial losses by including relevant clauses in contracts with risky counterparties (mandatory bank guarantee, the ability to terminate supply in case of late payment, the possibility of early termination of the contract, clarification of the moment of transfer of ownership of goods, etc.) 3. Reducing sanctions and corruption risks by including appropriate compliance clauses
Personnel management	Control over the objectivity of disciplinary proceedings	1. Reduce staff turnover by ensuring objectivity and impartiality in the process of reviewing alleged violations 2. Reducing the risk of lawsuits in connection with potential violations of labour laws

Source: compiled by the authors

This study demonstrates a practical approach to integrating compliance into business processes through the formation of corporate culture, in particular by introducing internal controls, staff training, codes of ethics and performance measurement. These ideas are strongly supported by international sources, where the concept of compliance culture is defined as a critical factor in organisational effectiveness and integrity. In a large-scale study by J.R. Graham *et al.* (2022), which covered more than 1,300 executives, 77% of them recognised corporate culture as a key factor in compliance. The authors emphasised that culture has an impact not only on compliance, but also on productivity, financial results and management decisions, which echoes the findings of the Ukrainian authors on the positive impact of compliance on key business processes. All other things being equal, companies with a strong culture demonstrate higher operational efficiency. This article focuses on corporate culture as an integral part of the compliance programme. This approach is also supported by the study by K.D. Bussmann & A. Niemeczek (2019), which argues that it is the integration of ethical values into the culture of an organisation that is an effective mechanism for preventing corruption and building a sustainable compliance system. They argue that successful anti-corruption programmes are not based on external control, but on the internal adoption of integrity values. This is consistent with the article's conclusion that top management needs to lead by example to demonstrate the benefits of doing business ethically. P. Rea *et al*. (2016) distinguished between the concepts of "ethics" and "compliance", pointing out that focusing solely on formal compliance without developing an ethical culture can limit innovation and promote myopic management. They believed that compliance without a cultural foundation is reduced to formal policies, which is consistent with the approach of Ukrainian researchers who argue that culture is the foundation of effective compliance.

J. Gordon (2018) emphasised that developing a culture of compliance and integrity is the most effective way to protect against regulatory risks, which is illustrated in this article by building an ROI model. This model shows that for every euro of compliance costs, a company potentially saves up to €87.36, demonstrating the high payback of the compliance function – an effect that cannot be achieved without a cultural foundation. G.W.G Bendermacher *et al.* (2019) emphasised that the key to building a culture of quality and integrity is the involvement of all levels of management and continuous training of staff. This is fully consistent with the structure of the recommendations in this article, where the authors mention regular training, active involvement of top management and the creation of internal policies as tools to improve compliance. The authors of this article emphasised the difficulties of integrating compliance into business processes, such as resistance to change and insufficient support from management. These barriers are also noted by F. Banning *et al.* (2023), who emphasised that a stable strategy and employees' understanding of corporate values are critical for the successful establishment of a compliance culture. Thus, the article confirms the existing international trends in the perception of compliance not only as a legal function, but also as a tool for managing value-based behaviour.

The study by J.P. Mendoza *et al.* (2016) theoretically deepens the understanding of how the perception of fairness of complex regulatory requirements can motivate companies to voluntarily learn and comply with regulations. In this context, this article also offers empirical evidence – a decrease in financial losses after the implementation of a compliance function indicates an increase in the level of compliance. Thus, there is a common logic in the works: intrinsic motivation (through culture or perception of fairness) is the basis for effective compliance. Another important work is by L. Andreisova (2018), where the author discussed methods of assessing corporate culture through the analysis of internal documents, focus groups and surveys. The same approaches are reflected in this article, which uses surveys, focus groups, analysis of disciplinary violations, etc. This correspondence confirms the validity of the tools used in the international context.

D.C. Langevoort (2017) discusses the "dark side" of corporate culture: it can be a source of both integrity and violations. The author emphasises the difficulty of implementing a true compliance culture, especially when an organisation tries to "imitate" a culture just to comply with the requirements. This is a warning that complements the thesis of this article on the importance of deep rather than declarative transformation. According to the publication of The Wall Street Journal (2018), a culture of integrity is not just an attribute, but "the centre of an effective ethics and compliance programme" that creates competitive advantage. The authors of this article implement this idea in their analysis, linking corporate culture not only to compliance but also to improving operational efficiency in such processes as procurement, sales and recruitment.

Conclusions

It can be concluded that compliance, as well as the corporate culture that is an integral part of it, directly affects not only the sustainable development of business and its security by reducing relevant risks but is also directly related to the efficiency of the organisation in which the compliance function is implemented. It can be argued that in the process of assessing the effectiveness of compliance programmes, as well as their direct impact on business efficiency, comprehensive approaches should be used, which include the following tools: assessment of the impact of internal control on the efficiency of individual processes in which they are embedded; assessment of the reduction of total losses in the form of fines, operational and other losses from the implementation of certain aspects of compliance control; assessment of the perception of the implementation and operation of the compliance function by the organisation's personnel (through questionnaires, focus groups, etc.). Based on the results of the study, it can be

concluded that in the context of increased regulatory pressure on business, the implementation of a compliance programme at enterprises is effective in terms of cost-benefit analysis. The implementation of a compliance programme is positively perceived by the company's management, as it helps to reduce financial losses by improving corporate culture (through the development of an internal regulatory framework, staff training and communication of the need for ethical business by the management) and the introduction of an internal control system that allows for more effective risk management.

Further research in this area should be aimed at deepening the study of the financial effect of implementing compliance programmes at Ukrainian enterprises. A financial justification for the feasibility of implementing such programmes will help Ukrainian businesses make informed decisions about increasing compliance costs, which in turn will make them more stable, secure and competitive in the European and global markets. Such an integrated approach will allow tracking the real dynamics of changes in the organisation and making appropriate adjustments if necessary.

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Комплаєнс і корпоративна культура: взаємозв'язок та вплив на ефективність бізнесу

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Анотація. Метою статті була розробка практичних рекомендацій щодо інтеграції комплаєнс-функції в бізнес-процеси, включно із формуванням прозорих механізмів внутрішнього контролю, підвищення рівня залученості менеджменту всіх рівнів, систематичне навчання персоналу та впровадження етичного кодексу, а також оцінка ефективності комплаєнс-програм через їхній вплив на ключові бізнес-процеси, такі як закупівлі, продажі, рекрутинг та договірну робота. У статті досліджено взаємозв'язок між корпоративною культурою та комплаєнсом, а також їхній вплив на ефективність бізнесу в умовах сучасної глобальної економіки, зростаючої конкуренції та посилення регуляторного тиску. Акцентовано увагу на важливості формування етичної корпоративної культури як ключового елементу успішного впровадження комплаєнс-програм, особливо в умовах сучасної глобальної економіки, де рівень регуляторного тиску на бізнес зростає щороку. У статті проаналізовано наукові публікації та галузеві стандарти, які визначають корпоративну культуру як невід'ємну складову ефективної комплаєнс-програми, використано метод середньої оцінки ефективності комплаєнс функції, а також модель функції витрат та доходів. Висвітлено виклики, з якими стикаються підприємства під час інтеграції комплаєнс-процедур у бізнес-процеси, включаючи недостатню підтримку з боку менеджменту, опір змінам та брак розуміння важливості дотримання нормативних вимог. У роботі детально розглянуто методи оцінки корпоративної культури, зокрема анкетування, аналіз внутрішніх документів, фокус-групи та динаміку порушень трудової дисципліни. Окрему увагу приділено механізмам діагностики корпоративної культури через ключові показники, такі як інноваційність, орієнтація на результати, підтримка співробітників і стабільність. У статті висвітлено теоретичні аспекти та практичне значення інтеграції комплаєнсу та корпоративної культури як інструментів для підвищення ефективності бізнесу, забезпечення його стабільності та конкурентоспроможності

Ключові слова: бізнес-процеси; ризики; етичні стандарти; внутрішній контроль; оцінка ефективності; прозорість бізнесу

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From threats to growth: How recommence shapes the new economy and reduces the fashion industry's carbon footprint

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Abstract. As one of the most significant sources of environmental pollution, the fashion industry requires a transition from the linear production model to sustainable business approaches, among which recommencement is a key strategy for reducing climate impact. The aim of the article was a comprehensive analysis of recommerce as a key factor in the transformation of the fashion industry. The study theoretically substantiated and empirically examined how this business model contributed to the transition from a linear to a circular economy. Particular attention was paid to studying the economic benefits for brands, reducing the climate footprint, and changing consumer behaviour in the context of sustainable development. The main mechanisms by which recommerce helped achieve this goal were described, including extending the life cycle of clothing, reducing the need to produce new goods, decreasing the volume of waste, and saving resources (water, energy, raw materials). Various formats of recommerce were considered – from second-hand shops to online resale platforms, clothing rental, and brand buyback programs. Special attention was paid to the challenges and opportunities facing the development of recommerce, such as logistical difficulties, issues of quality and hygiene of used goods, and the need to change consumer habits. The advantages of recommerce were substantiated not only for the environment, but also for consumers (affordability, uniqueness, cost savings) and business (new sources of income, strengthening reputation, attracting eco-conscious customers). It was emphasised that to achieve maximum effect, a comprehensive strategy is needed, combining recommerce innovations with a rethinking of clothing design (emphasising durability and the possibility of resale). It was demonstrated that introducing recommerce as a priority model in the fashion industry was not just a trend but an urgent necessity for forming a more sustainable future and significantly reducing the climate footprint

Keywords: economic security; climate footprint; sustainable development; circular economy; green economy; reuse; textile waste; consumer habits

Introduction

The necessity for fundamental changes in the global economy is driven by the urgent need to minimise negative environmental impact. Excessive consumption of natural resources and significant volumes of greenhouse gas emissions resulting from the processing and use of materials create considerable ecological risks. In this context, the fashion industry is one of the most prominent sectors that requires transitioning to more sustainable models. Historically, the fashion industry has operated on a linear model of "production-consumption-disposal", which has led to a massive climate footprint, intensive use of natural resources, and the generation of enormous amounts of waste. The phenomenon of "fast fashion" has only exacerbated these problems by encouraging excessive consumption and reducing the life cycle of clothing to a minimum. According to the Circularity Gap Report, the average consumer buys 60% more items than 20 years ago (World Economic Forum, 2023). At the same time, less than 1% of used clothing is recycled into new fibres (ThredUp, 2024). This prompts the fashion industry to rethink its operational and

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business models. The transition to a circular economy requires environmentally friendly production and systemic changes covering the entire value chain – from initial design and raw material selection to logistics, marketing, sales, consumer use and subsequent disposal. Recognising the complexity and depth of such transformations requires a comprehensive study of global experience and existing scientific developments.

In particular, P. Centobelli *et al.* (2022) emphasised that clothing production is highly resource-intensive and resource-dependent, which is why the fashion industry is recognised as unsustainable and is forced, in the context of a transformation to a "green" economy, to seek a more rational model of functioning. They underlined that the current linear model, built on fast fashion, is economically and environmentally unsustainable in the long run. The paradigm shift requires a systemic approach that includes innovations in production processes and business models. According to S. Mishra *et al.* (2021), such a model is the circular business model, in which the driving forces of a closed fashion value chain are innovations, a waste management system, collaboration with partners, connection with clients, and a change in models of using fashion products. The authors specified that successfully implementing a circular economy requires the integration of technologies and ethical principles at all stages of the product's life cycle. They viewed collaboration between brands, consumers, and suppliers as a key element for closing the loop. A. Kozlowski *et al.* (2019) examined traditional tools to minimise the fashion industry's negative impact on the environment in detail. Their research analysed approaches such as using organic materials, recycling, and implementing ecological labelling systems. Although important, the authors stated that these measures cannot fully solve the problem, since they do not change the fundamental principles of linear production.

However, I. Gardabkhadze (2023) emphasised that traditional tools are not enough and suggests expanding their list by developing digital tools for fashion design. The author proved that using 3D modelling and virtual prototypes allows for a significant reduction in the volume of physical waste during the design and production stages of clothing. This enables optimising processes, reducing the need for materials, and increasing production efficiency. O. Vodzinska & V. Paukova (2023) advocated the appropriateness of using upcycling as a way of reusing things to solve this issue. The authors emphasised that upcycling (transforming old things into new ones) extends the product's life cycle and creates additional value, contributing to the formation of unique products. They noted that this practice is important for reducing pressure on natural resources and forming a creative ecological consciousness.

Researchers A. Gakhova & I. Yeremenko (2021) saw the reduction of the fashion industry's environmental impact by introducing innovative technologies for processing textile waste. The authors focused on the importance of chemical and mechanical processing, which allows for obtaining new fibres from used clothing. They stated that introducing such technologies is critical for closing the material cycle and reducing dependence on primary raw materials. I.I. Bilyk *et al.* (2021) emphasised that the processing of textile waste is not only a guarantee of resource efficiency but also an indication of the ecological responsibility of fashion industry companies. They noted that companies that invest in recycling technologies reduce their ecological footprint and improve their reputation and attractiveness to conscious consumers. This contributes to the formation of a new brand image that corresponds to the principles of sustainable development.

Despite the considerable attention given to sustainable fashion and circular economy practices, previous research has primarily focused on technological innovations, material recycling, and production process optimisation. However, the economic and managerial dimensions of recommerce – as a new business model transforming the fashion industry – have received significantly less scholarly attention. Most studies analysed recycling and upcycling as environmental strategies but overlooked recommerce as a comprehensive economic mechanism that simultaneously addresses sustainability, consumer behaviour, and business profitability. The article sought to deliver an in-depth examination of recommerce as a key force shaping the evolution of the fashion industry.

Materials and Methods

A complex set of scientific methods was employed to conduct this research, ensuring a systematic and comprehensive approach to the analysis. The study relied on general scientific and special methods that made it possible to identify the economic and environmental effects of recommerce in the fashion industry. The methods of systematisation and generalisation were used to structure various recommerce formats – from traditional second-hand stores to modern online resale platforms and brand take-back programs implemented by Ralph Lauren, Vans, and Nike**.** This methodological approach enabled the identification of key trends in transforming consumption patterns and business strategies within the sustainable development framework.

The comparative analysis method constituted the core of the research, allowing a systematic comparison between the traditional linear production model ("take-make-use-dispose") and the circular model, which emphasises resource efficiency and waste minimisation. The comparison was carried out according to four key criteria: 1) main goal – defining the strategic objective of production; 2) environmental impact – assessing the level of resource consumption, emissions, and waste; 3) product lifecycle – evaluating product durability and reuse potential; and 4) economic strategy – identifying how business models ensure profitability through recommerce practices. This structured comparison enabled a clear differentiation between the short-term, profit-oriented focus of the linear model and the long-term, sustainability-oriented goals of the circular model.

In addition, the method of content analysis was applied to evaluate academic literature and analytical reports from

leading consulting companies and sustainability organisations (including World Economic Forum (2023), McKinsey & Company (2020), and ThredUp (2024)). This allowed for identifying dominant research directions, conceptual gaps, and practical case studies of successful recommerce integration into corporate strategies. Three criteria guided the selection of sources: 1) relevance – priority was given to publications from the last five years (2019-2025) to reflect current global trends; 2) authority – works by recognised scholars in sustainable fashion and circular economy were included; 3) practical significance – emphasis was placed on empirical data and case studies of internationally known fashion brands that have implemented recommerce. The synthesis of theoretical, empirical, and comparative data allowed the formation of a transparent, evidence-based understanding of how recommerce operates as a transformative mechanism that bridges environmental responsibility with economic efficiency in the fashion industry.

Results and Discussion

Ecological imperative:
From a linear model to a circular economy

The fashion industry is widely recognised as one of the global economy's most resource-intensive and polluting sectors. Its production, distribution, and consumption processes generate substantial environmental impacts throughout the value chain. According to estimates by the World Economic Forum (2023), the fashion industry is responsible for 2-10% of global greenhouse gas emissions, which exceeds the combined emissions from all international flights and maritime transport. This figure reaches about 2.1 billion tons of greenhouse gases annually. Its carbon footprint is more than 10% of global greenhouse gas emissions. In this context, it can be said that the fashion industry annually emits approximately as many greenhouse gases as the entire economies of France, Germany, and the United Kingdom combined. Most of these emissions fall into the third category (Scope 3 emissions), covering the entire value chain – from growing raw materials and producing fabrics to using and disposing of products. This makes decarbonising the industry difficult, as it requires influencing countless disparate suppliers and processes worldwide. Therefore, "fast fashion" companies must be responsible for their own production and the product's entire life cycle.

Researchers O. Vodzinska & V. Paukova (2023) explored upcycling as a design-oriented approach that extends the lifecycle of garments through creative reuse. Their research showed how incorporating upcycling into brand strategies supports environmental sustainability, enhances the uniqueness of products, and strengthens brand identity among environmentally conscious consumers. This perspective was particularly relevant to recommerce, which builds upon the revaluation and resale of pre-owned items as a new and dynamic business direction. In contrast, T. Brydges (2024) critically examined the phenomenon of ultra-fast fashion, noting that the accelerated production and consumption cycles promoted by brands such as Shein and Boohoo undermine efforts to achieve global sustainability. The author argued that such models exacerbate environmental pressures, destabilise market equilibrium, and contradict the principles of circularity. From a managerial point of view, this highlights the necessity for companies to adopt recommerce practices as tools for risk reduction and as drivers of strategic innovation. V. Lisitsa (2025) analysed the contemporary fashion industry's operational and competitive challenges during its transition towards sustainable development. The author demonstrated that digital resale platforms and take-back programmes are not merely ecological measures but also profitable entrepreneurial innovations that restructure traditional value chains. These findings correspond closely with the purpose of the present study, which investigates recommerce as both an environmental and an economic catalyst for transformation. Finally, A.A. Ivashura (2022) examined the relationship between the green economy and the minimalist consumption movement, observing that overproduction and shortened product lifecycles have effectively turned the fashion sector into a "disposable industry". This observation supports the conceptual foundation of recommerce, which seeks to prolong product use, optimise resource efficiency, and promote responsible consumption as an integral part of sustainable business management.

In addition to greenhouse gas emissions, the fashion industry is one of the largest consumers of the world's water resources, absorbing approximately 93 billion m^3 of water annually, equivalent to five million people's annual needs. The production of one cotton T-shirt can require up to 2,700 litres of water, and a pair of jeans up to 10,000 litres, creating a significant burden on water resources, especially in deficit regions. The fashion industry is also a colossal generator of waste: about 92 million tons of textile waste are produced worldwide annually, the volume of which has almost doubled over the last decade and a half due to the further evolution of "fast fashion" into "ultra-fast" – Ultra Fast Fashion, where trends for fashionable goods change even faster, as does their production, promotion, and sale (for example, brands Shein, Boohoo, and Cider). For instance, Gap and H&M introduce 12,000 and 25,000 new products yearly, while Shein introduces 1.3 million items over the same period. Most "fast fashion" clothing ends up in landfills, thus turning the fashion industry into a "terrible disposable industry" that produces countless useless items of clothing (McKinsey & Company, 2020; Brydges, 2024).

This ecological imperative dictates the urgent need for the transformation of business models of fashion industry companies from business models based on the "extract-produce-use-dispose" principle to circular business models, based on three key principles (Gakhova & Yeremenko, 2021):

- Circular design, which means not just "eco-design", but a profound rethinking of the product creation process, taking into account its impact on the environment throughout its entire life cycle, which is reflected in the "Cradle to Cradle" concept. This involves transitioning

from traditional resource-intensive and polluting materials (such as conventional cotton with intensive water, pesticides, or primary polyester based on fossil fuels) to environmentally friendly alternatives. These include organic cotton (GOTS certified), linen, hemp, which require less water and chemicals, recycled polyester (from plastic bottles or textile waste), Tencel (lyocell) from environmentally responsible forests (produced in a closed loop where solvents are recovered), as well as innovative biomaterials (for example, leather from mushrooms, fibres from algae, plant waste such as pineapple leaves or banana stalks, or even bacterial cellulose). That is, it is about creating clothing that is not only easy to repair, update, and reuse, but also, after the end of its long-life cycle, can be effectively recycled into new materials or safely returned to the biological cycle (composted). In addition to the choice of materials, designers should focus on design for durability and versatility, creating high-quality, long-lasting clothing that does not go out of fashion in one season and can withstand repeated use and washing.

- Design for recycling involves developing clothing made of mono-materials or easily separable components, which significantly simplifies further processing into new fibres. This avoids complex fabric blends, such as cotton-polyester, which are virtually impossible to economically and effectively recycle into quality secondary fibres.
- Zero-waste design, which minimises fabric scraps during cutting and sewing (up to 15% of fabric traditionally goes to waste (Galushka & Kondratenko, 2020)), and the use of innovative technologies (for example, 3D printing that creates clothing layer by layer, or knitting a "whole" item without seams) helps to reduce waste directly in production.

Companies have viewed circularity as improving traditional processes (Ishchuk & Ivanishena, 2025). However, circular practices like resource recovery create more productive, sustainable, resource-saving, closed supply chains, strengthening resilience and stimulating economic growth. For clarity, a comparison of the linear and circular models is presented in Table 1.

Table 1. Comparison of key characteristics of the linear and circular models in the fashion industry

Characteristic	Linear model	Circular model
Main goal	Maximising production volume and profit from the first sale.	Minimising environmental impact, extending product lifecycles, and diversifying revenue streams.
Environmental impact	High resource consumption, significant climate footprint, and generation of a considerable amount of waste.	Reducing resource consumption and emissions, minimising waste, and creating closed-loop systems.
Product lifecycle	Short, single-use, rapid disposal.	Extended, with multiple uses, repair, resale, and recycling.
Economic strategy	Low prices, fast assortment updates, and stimulating excessive consumption.	Creating new revenue sources (resale, rental), increasing customer loyalty, and attracting investment.

Source: developed by the author based on O. Vodzinska & V. Paukova (2023)

Therefore, the data in Table 1 clearly demonstrates the fundamental differences between the linear and circular models in the fashion industry. While the traditional model focuses on maximising production volume and profit from the first sale, which leads to significant resource consumption and waste, the circular model aims to extend a product's life cycle, reduce the environmental footprint, and diversify revenue streams. This comparative analysis emphasises that the transition to a circular economy is an ecological choice and a radical change in business strategy that ensures long-term sustainability. In particular, resource recovery and material regeneration create more productive, resilient, resource-saving, and closed supply chains, enhancing sustainability and stimulating economic growth (Fig. 1).

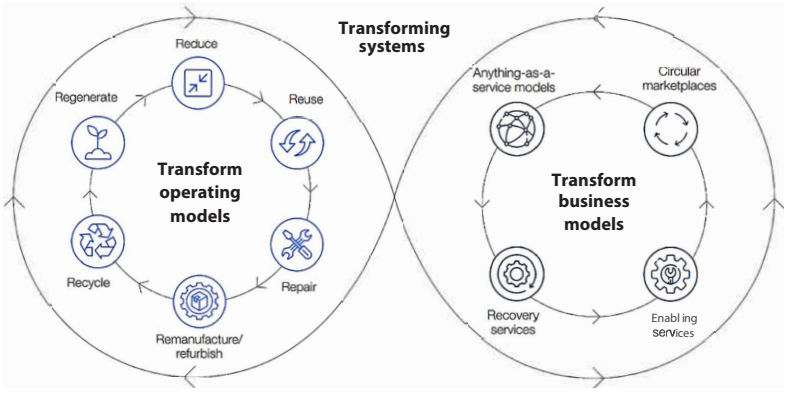

Figure 1. Transition to a circular economy: the need for operational changes and new business models
Source: Driven automotive industry powered by circular economy (2023)

The transformation of business models in the fashion industry has also significantly improved brand image and customer loyalty. As A. Koriakina *et al.* (2024) argued, sustainable fashion represented not only an environmental or aesthetic movement but also a crucial aspect of creative brand strategy. Their research examined the practices of Ukrainian and international clothing brands that incorporated sustainability principles into design and production. The authors demonstrated that environmentally conscious branding fostered stronger emotional connections with consumers, particularly among millennials and Generation Z, who were more inclined to associate themselves with brands that reflected their ethical and ecological values. They highlighted that sustainable fashion brands benefitted from increased visibility, positive word-of-mouth, and a growing base of loyal customers willing to pay premium prices for responsible production. The study also emphasised that integrating sustainable creativity into brand development enhanced long-term competitiveness and differentiation in an increasingly saturated market. Therefore, the findings of A. Koriakina *et al.* (2024) supported the argument that adopting circular and ethical practices strengthened customer trust and brand reputation, which are essential to modern entrepreneurial success in the fashion industry.

In addition, a strong brand reputation positively influenced the companies' investment attractiveness and financial stability. C. Jaynes (2024) investigated the economic dynamics of the second-hand clothing market in the United States. They revealed that it grew seven times faster than the general retail clothing sector in 2023. This growth indicated a broader global trend towards sustainable consumption and demonstrated that resale and recommerce models were becoming mainstream in the fashion economy. The author observed that this shift reflected a change in consumer behaviour, where environmental responsibility was increasingly associated with social prestige and rational economic choice. Moreover, C. Jaynes suggested that sustainable fashion brands participating in the circular economy through resale and take-back programmes became more appealing to investors seeking alignment with ESG (Environmental, Social, and Governance) principles. Such enterprises attracted "green" investments and gained access to financing on more favourable terms. These findings reinforced the conclusion that sustainability and transparency were not merely ethical imperatives but strategic business advantages that improved financial resilience, reduced operational risks, and expanded opportunities for partnership and innovation in the fashion industry.

Economic drivers and barriers of circular transformation in the fashion industry

The transition to a circular business model is not just about environmental responsibility but also about significant economic and social benefits that can turn these challenges into opportunities, ensuring the long-term sustainability and competitiveness of enterprises (Gerasymenko *et al.*, 2023):

- Cost reduction is an obvious advantage. The optimisation of resources (water, energy, materials) and the minimisation of waste in production lead to a direct reduction in operating costs. For example, implementing closed water cycles or transitioning to renewable energy sources can significantly reduce utility bills in the long term. Introducing repair and reuse programs can also be economically beneficial, turning potential waste into valuable resources and reducing disposal costs.
- New sources of income are opening up. Recommerce, clothing rental, and repair services create new market segments previously ignored by traditional business models. Brands can profit from goods that have already been sold (for example, through commissions from resale or rental fees), doubling their potential income from one item of clothing and creating more stable and diversified profit flows.
- The transparency and traceability of the product creation chain have direct consequences for reputation and compliance. Reporting and certification through obtaining recognised ecological certificates (for example, GOTS, OEKO-TEX, Cradle to Cradle Certified) and the regular publication of detailed, independently verified sustainability reports are key to building trust, improving reputation, and accessing "green" investments.
- The creation of new jobs. Developing a circular economy requires new skills and specialists in textile processing, repair, secondary use logistics, recommerce platform management, ecological design, sustainability auditing, and certification. This can contribute to the development of local economies, improving the qualifications of the workforce and creating more stable and diverse employment, often with better working conditions.

A lesser dependence on primary resources and the diversification of business models make companies more resilient to external shocks, such as fluctuations in raw material prices (for example, cotton or oil), geopolitical crises, trade barriers, or disruptions in global supply chains. They become less vulnerable to resource scarcity and can better adapt to changes in market conditions and the regulatory environment, ensuring stability in the long term. This can also improve relations with regulatory bodies and local communities, creating a favourable operational environment.

Despite the apparent benefits and urgency, transforming business models in the fashion industry is a complex, multifaceted process. It comes with significant challenges and barriers that pose direct business risks and require coordinated efforts to overcome them. The principal barriers hindering the transition towards circularity are summarised in Table 2, which provides an overview of the main challenges identified through the literature review and case study analysis.

Table 2. Main barriers to circular transformation in the fashion industry

Barrier	Description / Explanation
Defining "circularity" and understanding its full potential	Many companies consider themselves circular if they incorporate recycled materials into a well-established, fully optimised supply chain. Leaders often see this as an expensive step, and it frequently is. Adding circular elements to a modern linear economic model usually does not improve a company's performance or create enough momentum for change. To achieve fundamental transformation, leadership teams must completely redesign their operational and business models, customer engagement methods, product development processes, and supply chain structures to support a new way of doing business. Making minor adjustments to an existing model only leads to gradual changes. New operational and business models that are circular by design can provide the necessary transformative change.
High initial investment	The transition to new, eco-friendly production technologies (e.g., waterless dyeing), investment in new materials (biomaterials are often more expensive initially), and the development and implementation of circular models (creating re-commerce platforms, logistics infrastructure for reverse flows) all require significant financial investment. The fashion industry is characterised by extremely fragmented and geographically scattered supply chains, involving hundreds of suppliers, factories, and contractors worldwide. Making such a chain fully transparent, traceable, and controlled for environmental and social standards is a huge task.
The need for a change in consumer behaviour and mentality	Despite growing environmental awareness, widespread adoption of circular models requires profound consumer habits and preferences changes. For many, a psychological barrier or social stigma exists around buying used clothing. Additionally, the appeal of "fast fashion", with its low prices and constant collection updates, remains strong. Persuading consumers to choose durable, more expensive or pre-owned items that do not align with the latest "microtrends" is a difficult task that requires effective educational and marketing strategies.
Lack of standardisation and uniform regulatory frameworks	The absence of these creates confusion and complicates the implementation of sustainable practices. Specifically, a lack of unified international standards for "green" fashion, methods for calculating carbon footprints, and certification of circular materials and processes can lead to "greenwashing" and hinder fair competition.
Technological limitations in recycling	While mechanical and chemical textile recycling technologies are developing, large-scale, cost-effective, and high-quality recycling of complex fibre blends and clothing with accessories and other additives remains a difficult challenge.

Source: developed by the author based on O. Vodzinska & V. Paukova (2023)

As shown in Table 2, the barriers to circular transformation in the fashion industry are closely interrelated and reveal the structural complexity of the sector. The main challenge lies in the limited understanding of circularity: many companies still perceive it as an optional improvement rather than a strategic foundation. This results in incremental rather than systemic change, preventing the full potential of circular models from being realised. The high initial investment required for new technologies, materials, and recommerce infrastructure remains a critical obstacle, particularly for small and medium-sized enterprises. This highlights the need for financial incentives, "green" investment tools, and collaborative funding mechanisms to support sustainable transformation. Equally significant are behavioural barriers. Consumer attachment to fast fashion and persistent social stigma around pre-owned clothing hinder mass adoption of circular practices. Overcoming these obstacles requires educational campaigns and marketing strategies promoting the appeal and value of reuse and durability. The lack of regulatory consistency creates further uncertainty, as the absence of common standards for carbon accounting and eco-certification allows greenwashing and limits comparability across markets. Technological challenges also persist: despite progress in recycling, large-scale, cost-effective processing of blended fibres and complex garments remains problematic. Overcoming these challenges requires a comprehensive and coordinated approach that includes innovation, investment, government support (through tax incentives and subsidies), a shift in consumer culture, and close cooperation among all stakeholders. For clarity, the main barriers and ways to overcome them are presented in Table 3.

Table 3. Main barriers and ways to overcome them on the path to a circular economy in the fashion industry

Barrier	Description	Ways to overcome
Insufficient understanding of circularity	Companies are limited to partial changes without transforming their business model.	Complete redesign of operational models and business processes; strategic partnerships.
High investment costs	Significant initial investments in new technologies, materials, and infrastructure.	Government support (tax incentives, subsidies); attracting "green" investments and ESG funds.
Consumer resistance	The existing psychological barrier toward used clothing, and the appeal of "fast fashion".	Educational and marketing campaigns; collaboration with influencers; emphasis on the uniqueness and quality of recommerce items.
Lack of uniform standards	Difficulties in certification, calculating footprints, and combating "greenwashing".	Development of unified international standards; government regulation (EPR); industry coalitions.
Technological limitations	Difficulties in recycling blended fibres and clothing with accessories.	Investment in R&D; development of new chemical and mechanical recycling technologies; design for recycling (mono-materials).

Source: developed by the author based on O. Vodzinska & V. Paukova (2023)

The data in Table 3 suggests that the challenges of the fashion industry's circular transformation extend beyond technological or financial aspects. Other significant barriers include an insufficient understanding of circularity, consumer resistance, and the lack of unified regulatory standards. However, Table 3 shows that comprehensive measures can overcome these challenges. These range from completely redesigning business models and attracting "green" investments to implementing educational campaigns and developing standardised regulations. Thus, the content of Table 3 illustrates that a successful transformation requires the coordinated efforts of all stakeholders. For businesses, this means the need for strategic planning, a readiness to adapt, and the ability to turn challenges into opportunities (Fig. 2).

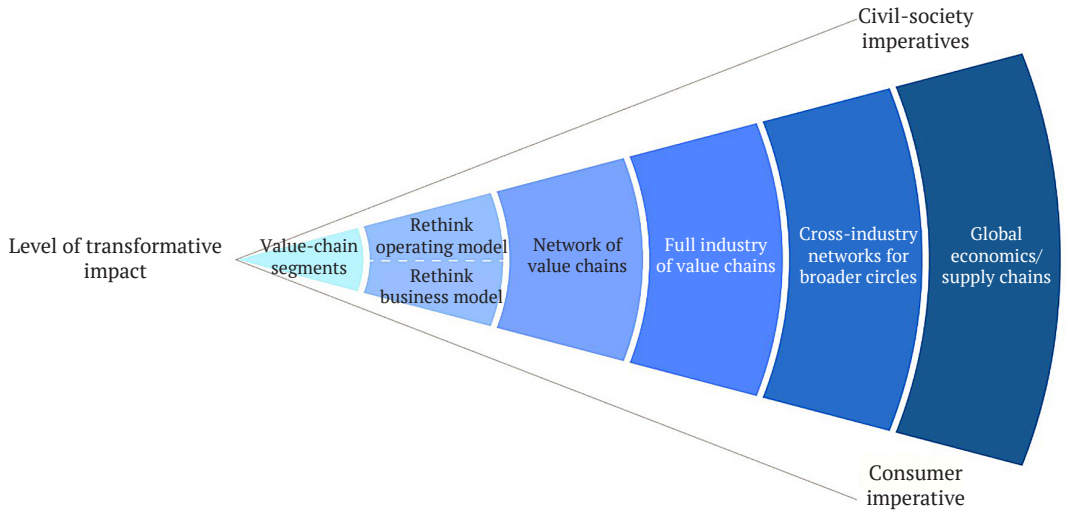

Figure 2. Amplifying Circular Transformations through Systems Thinking
Source: V.I.C. Belchior (2023)

Figure 2 illustrates that a successful circular transformation in the fashion industry requires a phased expansion of influence, moving from local changes to global integration. It shows how transitioning from rethinking individual business models and operational processes to forming industry-wide networks and coalitions significantly increases transformative impact. The ultimate goal is to create circular networks that meet the demands of both consumers (Consumer imperative) and civil society (Civil-society imperatives). Thus, Figure 2 emphasises that achieving sustainable change requires a systemic approach, not a fragmented one. This approach will facilitate successful circular transformation, enhance competitiveness in international markets, expand product ranges, and create socially responsible businesses. This will enable Ukraine to strengthen its position in the fashion industry and ensure the sector's sustainable development, even in the face of modern challenges.

Forward-thinking strategies and the role of recommerce in a sustainable future

Successful leaders begin their journey with self-reflection and developing a profitable circular business model, transforming operations accordingly and at scale. Ralph Lauren, for example, addressed this challenge through a partnership with the resale platform Vestiaire Collective (alongside the World Economic Forum and Bain & Company), creating a digital architecture for reselling authenticated products. This partnership, which uses digital ID technology developed by Digimarc (formerly EVRYTHNG), has benefited all parties. Ralph Lauren expanded its brand reach, enhanced brand equity, and pioneered a new resale market. Vestiaire Collective increased its customer base and reduced the risks and costs of counterfeit products. Consumers also benefited, as they can confidently purchase authenticated second-hand products. Partnerships offer the opportunity to elevate and scale circular models beyond a single product, value chain, or company. Governments should encourage companies to account for their negative impact on the environment and take responsibility for their inputs, outputs, and practices. The EU has led this process with its Extended Producer Responsibility (EPR) programs, which require manufacturers to manage their products at all stages of their lifecycle, shifting financial and operational responsibility from governments and consumers to businesses. Similar frameworks are being implemented worldwide (including in the US, China, and Kenya), but they must be expanded and harmonised across regions and materials to maximise their impact. Specifically, the EU estimates that its circular transformation legislation will lead to €600 billion in cost savings, €1.2 trillion in other economic benefits (about 10% of the EU's 2022 GDP), and create approximately 2 million additional jobs (Vodzinska & Paukova, 2023).

To build a network of connected value chains and self-sustaining ecosystems, industry coalitions must understand the economic fundamentals that support circular models at scale. This requires:

- *Promoting new standards and certifications*. Developing circular-oriented capabilities within companies and among suppliers and consumers, and supporting new regulatory frameworks. Company coalitions can define the "rules of the game", creating an ecosystem with standardised industry metrics – and rely on governments to integrate rapid policies that support the implementation of circular practices (Kozlowski *et al.*, 2019) and the manufacturing of clothing that is safe for both the environment and consumer health (Tilna, 2024).
- *Scaling the secondhand market*. With over half of all consumers buying used clothing last year, it is clear that resale is now firmly embedded in the fashion landscape. Secondhand shopping transcends generations, and the role of resale changes throughout consumers' lives. Younger buyers turn to secondhand for self-expression and to help build their personal style; parents rely on secondhand to outfit their families cost-effectively and eco-consciously; and older generations turn to secondhand for accessible, high-end brands and the thrill of the hunt. Secondhand's flexibility in meeting such diverse needs is a key reason it has become popular and has a promising growth trajectory. On average, the secondhand apparel market is expected to grow three times faster than the overall apparel market (Tkanko & Tkanko, 2019). In addition to clothing, soft toys also require a secondhand system, which is currently being implemented in EU countries, particularly in the Czech Republic (Kriuchkova *et al.*, 2024).
- *Harnessing the opportunities of the metaverse*. Harnessing the opportunities of the metaverse involves several innovative strategies that combine digital engagement with consumer experience. One such approach is metaverse launches, which involve releasing products in the digital world to gauge audience interest and demand before manufacturing them physically. Users can then purchase these products online and use them in the real world. This method, the Direct-to-Consumer (D2C) model, enables brands to test market reactions efficiently. For instance, Balenciaga created its video game, Afterword, to showcase its 2021 autumn collection. Another approach includes virtual events, which help brands attract attention and strengthen audience engagement. Companies also experiment with "meta-events", such as establishing virtual stores in the metaverse to present new collections, foster direct communication with users, and study their preferences in real time. Furthermore, gaming-based advertising is gaining traction as brands shift from traditional formats to more interactive, game-oriented experiences. Modern consumers often ignore conventional advertisements, while gamified promotion methods offer higher engagement and entertainment. This trend is evident in the sports industry: in 2021, footwear and apparel manufacturer Vans created its virtual skatepark within the metaverse platform Roblox, where users could perform tricks, earn bonuses, and buy or customise skateboards and sneakers. Nike took this concept further by developing its own immersive sports world, NIKELAND, where users can explore different sports activities and visit various branded stores (Kozlowski *et al.*, 2019).
- *Implementing circular design*. This involves creating closed loops of production and consumption to eliminate waste entirely through reuse, repair, upcycling, and material recycling. Products created with circular design principles should be durable, modular, and suitable for refurbishment or complete disposal without harming the environment (Chornostan & Myrhorodska, 2025).

Therefore, the future development of the fashion industry requires a comprehensive approach that combines technological innovation, economic incentives, and environmental requirements (Fig. 3).

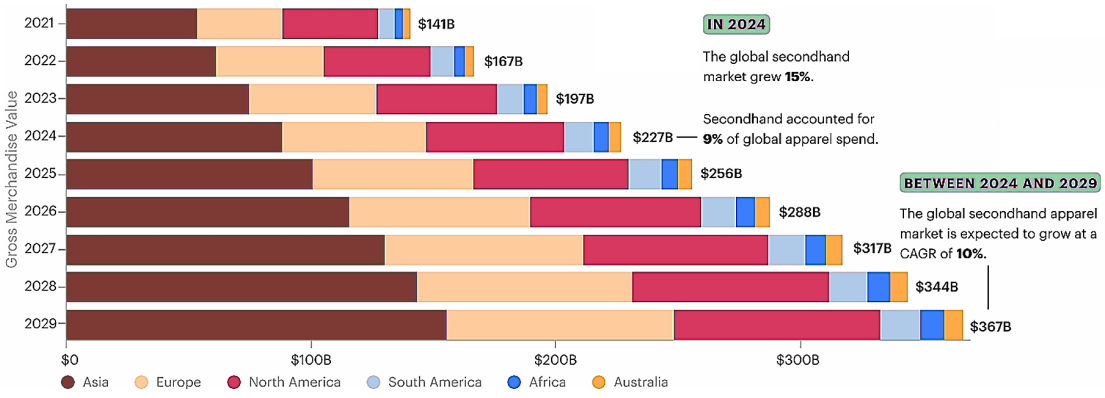

Figure 3. Expected growth in the second-hand market by 2029

Source: N. Silberstein (2025)

Figure 3 illustrates the global secondhand apparel market dynamics by region between 2021 and 2029, expressed in gross merchandise value (GMV). The data show a steady upward trend, confirming the growing economic significance of the secondhand fashion segment within the global apparel industry. In 2021, the market was valued at $141 billion, dominated by Asia and North America, with smaller shares contributed by Europe, South America, Africa, and Australia. Over the following years, the market demonstrated rapid expansion, reaching $197 billion in 2023 and

$227 billion in 2024. Notably, in 2024, the global secondhand market grew by 15%, accounting for 9% of total global apparel spending. The figure also highlights the projected trajectory between 2024 and 2029, during which the secondhand apparel market is expected to grow at a compound annual growth rate (CAGR) of 10%, reaching approximately $367 billion by 2029. This sustained growth reflects structural shifts in consumer behaviour, driven by increasing environmental awareness, affordability concerns, and the expanding accessibility of digital resale platforms. Regionally, Asia maintains the most significant share throughout the period, followed by Europe and North America, suggesting a diversification of recommerce activity across developed and emerging economies. The gradual increase in contributions from South America and Africa indicates the diffusion of sustainable consumption models beyond traditional fashion markets. Overall, the data in Figure 3 reinforce that recommerce is evolving from a niche trend into a global economic driver, offering both environmental and business benefits. The continuous growth trajectory underscores the potential of the secondhand sector to become a central element of the circular economy within the fashion industry.

Thirty per cent of the top 20 global fashion brands have already implemented specialised resale programmes, integrating circular business models into their core operations (Fig. 4). These initiatives reflect a growing strategic shift within the fashion industry toward sustainability-driven innovation and consumer engagement. By creating digital resale platforms and take-back systems, leading brands seek to reduce textile waste, extend product lifecycles, and build long-term customer relationships based on shared environmental values.

Figure 4. Brands that, as of 2023, offer specialised resale programs

Source: IPMARK (2023)

Figure 4 presents the top 20 global fashion brands that have adopted resale or recommerce initiatives, indicating the increasing normalisation of circular business practices among mainstream fashion companies. Brands such as Patagonia, Levi's, The North Face, Madewell, and Lululemon have been pioneers in this domain, developing comprehensive programmes for product take-back, refurbishment, and resale through in-house and third-party platforms. For instance, Patagonia's "Worn Wear" initiative and Levi's "SecondHand" platform illustrate how resale systems can become profitable while promoting environmental responsibility. Similarly, The North Face's "Renewed" programme extends the lifespan of outdoor apparel through professional repair and repackaging. At the same time, brands like Madewell and Lululemon focus on online resale ecosystems that attract younger, sustainability-conscious audiences. The remaining 70% of brands represented in the figure, including major fast fashion companies such as Zara and Free People, have yet to integrate recommerce strategies fully. However, many are experimenting with limited sustainability initiatives or pilot projects. This gap highlights the uneven progress of circular transformation within the global fashion industry, revealing that while some brands have already institutionalised circularity, others remain bound by traditional linear models of production and consumption (IPMARK, 2023).

Figure 4 thus demonstrates a clear trend toward diversification of business models and strategic innovation in sustainability. Resale programmes have evolved from marginal experiments into mainstream business practices, driven by growing environmental awareness, regulatory pressures, and consumer demand for authenticity and responsibility. As the recommerce sector expands, the brands that proactively embrace these changes will likely gain a competitive advantage through enhanced brand reputation, customer loyalty, and operational efficiency.

Based on the above, it can be stated that the fashion industry is facing an urgent need for radical transformation. The traditional linear model of production and consumption, which is based on a constant increase in volume and rapid trend changes, generates a significant climate footprint, depletes resources, and creates a tremendous amount of waste. This threatens the environment and the economic security of the businesses themselves. Increasing regulatory pressure, changing consumer preferences, and reputational risks force businesses to seek practical and sustainable alternatives. In this context, recommerce acts not just as a trend but as a strategic imperative for ensuring

the sustainable development of the fashion industry. The adoption of sustainability by brands, the reduction of fast fashion, and the promotion of mindful consumption and a caring attitude toward items and nature are beginning to significantly impact the fashion industry at both the production and consumption stages (Cherkach, 2023).

The current study results were consistent with previous research highlighting the importance of sustainability and circularity as fundamental drivers of transformation in the global fashion industry. I. Budnikevych *et al.* (2024) argued that sustainable development had evolved from a theoretical framework into a practical mechanism for restructuring the light industry in Ukraine and beyond. Their findings confirmed that environmental responsibility, social awareness, and innovation served as interconnected factors that determined the competitiveness of fashion enterprises. In line with this view, the present study demonstrated that recommerce – a business model integrating resale, reuse, and upcycling – represented an ecological necessity and an economic opportunity that enhanced brand resilience and adaptability. O.I. Garafonova *et al.* (2021) examined sustainable business models in the circular economy context and emphasised that long-term success required systemic innovation across value chains. They highlighted the need for collaboration between producers, consumers, and intermediaries to achieve closed-loop production and distribution systems. Current research findings complemented those conclusions by empirically illustrating how leading brands had begun to embed recommerce into their operational and marketing strategies. In doing so, they moved from isolated ecological initiatives to comprehensive circular systems that simultaneously reduced waste and generated new revenue streams. I. Soloviy (2025) examined how global principles of sustainable fashion are adapted in Ukraine, showing that local designers reinterpret sustainability through regional materials, traditional crafts, and community-based production. However, she noted that many initiatives remain largely declarative rather than systemic. Compared with international brands such as Patagonia and Levi's, which have successfully implemented *recommerce* and circular models, the Ukrainian context still reflects an early stage of practical transformation. I. Soloviy's findings thus highlight the gap between theory and practice, reinforcing that true circularity requires design innovation, economic incentives, technological infrastructure, and changes in consumer culture.

Researchers O.D. Gerasymenko *et al.* (2023) analysed upcycling and minimalism as cultural and behavioural trends that moderated the overconsumption typical of fast fashion. His research underscored that the success of sustainable fashion depended not only on technological and managerial innovation but also on a paradigm shift in consumer consciousness. This observation corresponded with the present study's conclusion that changes in consumer behaviour – particularly among younger generations – played a decisive role in expanding the global recommerce market. By perceiving pre-owned clothing as a symbol of ethical consumption rather than social stigma, consumers contributed to redefining fashion value. Similarly, O. Kolosnichenko *et al.* (2021) viewed sustainable fashion as an evolving aesthetic and ethical movement that reshaped design philosophy and business practice. They identified sustainability as a modern trend that reflected the growing interdependence between creative innovation and environmental accountability. These insights supported the current study's assertion that circularity could be a unifying principle linking creativity, production efficiency, and responsible consumption. I.M. Mytsenko & I.V. Khadzhynov (2022) examined the conceptual foundations of circular business models adopted by leading European companies. Their study revealed that the effectiveness of circular transformation largely depended on how deeply sustainability principles were integrated into corporate strategy rather than being treated as peripheral initiatives. They identified that successful companies prioritised innovation in logistics, product design, and customer engagement while fostering cross-sectoral collaboration. These findings complement the results of the present study by confirming that recommerce, as part of the circular model, functions not only as an environmental solution but also as a strategic management tool for enhancing competitiveness and mitigating operational risks.

N. Lytvynenko *et al.* (2022) examined the principles of secondary material use in clothing design, emphasising the artistic and functional dimensions of sustainable fashion. Their research explored how designers could creatively integrate previously used materials into new garments without compromising aesthetic quality or consumer appeal. The authors argued that the reuse of textiles reduced waste and encouraged innovation in design thinking, fostering a culture of conscious production and consumption. Importantly, they demonstrated that material reuse could bridge environmental responsibility and creative expression, allowing fashion brands to align sustainability goals with artistic distinctiveness. These findings resonated strongly with the current study, which positioned recommerce as a business-level extension of the same philosophy. While N. Lytvynenko *et al.* focused primarily on design processes, the present research expanded this perspective to the economic and managerial level, analysing how recommerce operationalised the principles of reuse and circularity within corporate strategy. Both approaches underscored the importance of prolonging product lifecycles and redefining the value of clothing in the context of sustainable development. Consequently, the study by N. Lytvynenko *et al*. and colleagues reinforced the view that the future of fashion depends not only on technological or economic transformation but also on the reconfiguration of cultural and creative paradigms in design practice.

The report by J. Reinhart (2025) provided up-to-date empirical evidence on the rapid expansion of the global second-hand market. The report showed that resale grew fifteen times faster than traditional retail in 2023, indicating a fundamental shift in consumer behaviour and brand

strategy. These data supported the current study's findings that recommerce was no longer a niche activity but a mainstream business model reshaping the fashion industry's value chains. The report also highlighted the increasing involvement of major brands in developing take-back programmes and digital resale platforms, confirming that circularity had become a new vector of growth, profitability, and brand differentiation. These studies reinforced the argument that recommerce represented a crucial stage in the evolution of circular business models. It bridged the gap between sustainable production and responsible consumption, creating new opportunities for innovation and long-term economic resilience within the global fashion industry.

The findings outlined above demonstrate that the transformation of the fashion industry through circular and recommerce models is not merely a temporary trend but a structural shift in global business logic. While only a portion of leading brands have fully embraced circularity, the growing diffusion of resale initiatives signals an irreversible movement towards sustainable production and consumption. This transformation is supported by both market dynamics and societal expectations, indicating that environmental responsibility has become a key component of competitiveness.

Conclusions

The transformation of business models in the fashion industry is an inevitable and vital process in the transition to a green economy. It is no longer just a matter of following trends or engaging in "greenwashing", but a strategic imperative for survival and prosperity in the face of growing environmental and regulatory demands and a fundamental shift in consumer values. The move from the traditional linear model – based on the "take-make-use-dispose" principle – to a circular one is key to achieving sustainable development goals. This transition is built on foundational principles like eco-design, production optimisation, and expanding consumption models, including recommerce, renting, repairing, and upcycling.

While the path to significant decarbonisation and circularity comes with significant challenges—high initial investments, complex logistical solutions, overcoming consumer barriers, and technological limitations in recycling – the potential economic, environmental, and social benefits are enormous. Businesses that successfully make this transformation will gain substantial competitive advantages. They will reduce their climate footprint and minimise environmental risks, boost customer loyalty, attract new, valuable market segments, and improve access to sustainable and ESG-focused financing. Furthermore, adopting circular practices will strengthen a brand's reputation and resilience to external economic shocks. Thus, companies that become leaders in shaping a new, more sustainable, responsible fashion industry will secure long-term prosperity. Conversely, those who ignore these changes risk facing a series of serious problems. These include rising waste disposal costs, reputational damage from criticism by environmentally conscious consumers, a shrinking market share, and a threat to the business's existence as regulatory requirements become stricter. Implementing recommerce as a priority model is not just a trend but an urgent necessity for ensuring the industry's long-term viability and achieving the overarching objective of sustainable fashion transformation – aligning economic development, social well-being, and the preservation of the planet. Given the dynamic nature of this field, further research will focus on studying the effectiveness of new textile recycling technologies, analysing the efficiency of marketing strategies aimed at popularising recommerce, diagnosing the long-term economic impact of recommerce programs on brand profitability, and examining the factors that influence changes in consumer behaviour and the overcoming of psychological barriers to buying used clothing.

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Conflict of Interest

None.

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Від загроз до зростання: як рекомерція формує нову економіку та зменшує кліматичний слід індустрії моди

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Анотація. Індустрія моди, яка є одним із найбільших джерел забруднення довкілля, потребує переходу від лінійної моделі виробництва до сталих бізнес-підходів, серед яких рекомерція виступає ключовою стратегією зниження кліматичного впливу. Метою статті був комплексний аналіз рекомерції як ключового чинника трансформації індустрії моди. У роботі теоретично обґрунтовано та емпірично досліджено, як ця бізнес-модель сприяє переходу від лінійної до циркулярної економіки. Особливу увагу приділено вивченню економічних переваг для брендів, зменшенню кліматичного сліду та зміні споживацької поведінки в умовах сталого розвитку. Охарактеризовано основні механізми, за допомогою яких рекомерція сприяє досягненню цієї мети, включаючи подовження життєвого циклу одягу, скорочення потреби у виробництві нових товарів, зменшення обсягів відходів та економію ресурсів (води, енергії, сировини). Розглянуто різні формати рекомерції – від секонд-хендів до онлайн-платформ для перепродажу, оренди одягу та програм зворотного викупу товарів брендами. Особливої уваги приділено викликам та можливостям, що стоять перед розвитком рекомерції, таким як логістичні складнощі, питання якості та гігієни вживаних товарів, а також необхідність зміни споживчих звичок. Обґрунтовано переваги рекомерції не лише для навколишнього середовища, але й для споживачів (доступність, унікальність, економія коштів) та бізнесу (нові джерела доходу, посилення репутації, залучення еко-свідомих клієнтів). Підкреслено, що для досягнення максимального ефекту необхідна комплексна стратегія, яка поєднує інновації у рекомерції з переосмисленням дизайну одягу (з акцентом на довговічність та можливість перепродажу). Доведено, що запровадження рекомерції як пріоритетної моделі в індустрії моди є не просто трендом, а нагальною необхідністю для формування більш стійкого майбутнього та значного скорочення кліматичного сліду

Ключові слова: економічна безпека; сталий розвиток; циркулярна економіка; «зелена економіка»; повторне використання; текстильні відходи; споживчі звички

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Development of bioenergy enterprises as a sustainable energy solution for urban micro-methanisation

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Abstract. A serious argument for the need to develop bioenergy enterprises and micro-methanisation of cities is, first of all, the need to quickly rebuild the energy sector and fulfil commitments regarding the transformation to clean energy. Second, it is the fact that Ukraine, like most European Union countries, has significant areas of low-yield land that could potentially be used for growing perennial energy crops and, consequently, for replacing energy imports with biofuel. The purpose of the article was to conduct theoretical research and practical testing of approaches to forming directions for the development of bioenergy enterprises as sustainable energy solutions for micro-methanisation of cities. The results of this study were obtained using the following methods: analysis and synthesis for problem formulation, research task formulation, and identification of promising technologies for the production of electrical and thermal bioenergy; scientific abstraction, comparison, and generalisation for defining a roadmap for the development of bioenergy enterprises and urban micro-methanisation. Timely completion of tasks related to the development of bioenergy enterprises and urban micro-methanisation is only possible if state support policies and incentives for energy decentralisation are revised. The article discussed theoretical and practical aspects of implementing technologies for producing electrical and thermal bioenergy. It systematised the use of biomass-fired thermal power plants and combined heat and power plants in European countries. A roadmap for the development of bioenergy enterprises and micro-methanisation of cities has been developed, which includes such key areas as the creation of a regulatory framework for micro-methanisation of cities, the demonopolisation and decentralisation of heat and power supply, intensification of international cooperation and partnership, development of bioenergy infrastructure, establishing dialogue with stakeholders, financial support and subsidies, creation of public information platforms, risk insurance, and state guarantees. The advantages of switching to alternative fuels have been identified. The achievement of the expected result in energy and heat supply to territories and cities has been substantiated. The study has high practical value and can be used in the formation of a sustainable development strategy for communities and as a strategic alternative for bioenergy supply

Keywords: management; sustainable development strategy; decarbonisation; biomass; generation; sustainable development; technological development

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Introduction

In the context of adhering to the principles of sustainable development, growing challenges to ensuring energy security, overcoming environmental instability due to active hostilities, and the need to decarbonise Ukraine's economy, the development of bioenergy enterprises and the micro-methanisation of cities are of particular importance. Micro-methanisation is one of the promising areas in the process of converting organic waste into biogas and its subsequent use as a source of thermal and/or electrical energy. The introduction and application of innovative micro-methanisation technologies in cities allows several pressing issues to be addressed: first, reducing waste volumes; second, reducing greenhouse gas emissions; third, enabling local energy production; and fourth, increasing the energy independence of cities and urban communities. Bioenergy enterprises can become catalysts for sustainable economic development through innovative technological development, job creation, and diversification of energy supplies. From this perspective, justifying the need to introduce modern mechanisms for the effective functioning of such enterprises, assessing their potential in the current conditions of Ukrainian cities and communities, and developing a roadmap and models of support from the state and local government are relevant in both scientific and practical terms. The need to develop a roadmap is dictated by the importance of phased implementation of micro-methanisation technologies in cities, investment planning and searching for funding, coordinating the actions of state authorities, businesses and the public, reducing risks by taking into account legal, technical, and economic aspects, as well as the need to communicate with international partners and adapt best practices.

Ukraine faced serious consequences of the destruction of the country's energy sector due to the destruction of most of its power generation facilities, namely thermal power plants and power stations (Order of the Cabinet of Ministers of Ukraine No. 1082-r, 2023). According to O. Sikorska *et al*. (2023), there are four objective factors contributing to the sustainable development of the bioenergy sector in Ukraine: significant biomass resources generated by the agricultural sector and vast land areas; favourable climatic conditions; the availability of labour resources that can quantitatively and qualitatively solve the tasks of developing bioenergy; the availability of an extensive transport and logistics network integrated with the EU.

The issue of developing bioenergy enterprises and urban micromethanisation is becoming particularly relevant. M.R. Errera *et al*. (2023) made a forecast for the supply of primary bioenergy until 2050 and determined its place in the global energy matrix. The characteristics of bioenergy generation and energy use have shown that the global supply of primary bioenergy could increase sixfold by 2050, accounting for 37% of demand. A full adaptation scenario could meet 100% of global energy demand, and bioenergy can and should play an important role in the global energy supply. This will result in a shift in the composition of bioenergy supplies, from wood to energy crops and biowaste. The available technical potential for fuel and electricity largely matches the trends in primary bioenergy supplies and takes into account the potential for avoiding greenhouse gas emissions. The heuristics and level of transparency of the new model will allow for adjustments and exploration of other scenarios over time. The results of the study by S. Manikandan *et al*. (2023) on the biochemical conversion of biomass waste into bioenergy prove that energy is traditionally produced first, by wood biomass combustion and second, using anaerobic oxidation, enzymatic hydrolysis and microbial fuel cells. The circular economy preserves the value of its by-products, anaerobic digestion and microbial fuel cells help achieve sustainable biomass use. Moreover, alternative fuels are increasing energy demand worldwide.

E.B. Ramirez *et al*. (2024) investigated the potential of renewable energy generation in plant-based microbial fuel cells through metabolic reactions of microorganisms in their interaction with a substrate. Microbial fuel cells, in addition to direct energy production, have a stable and self-sustaining workflow, as microorganisms are self-generated and demonstrate resistance to environmental stress factors. The production of energy from non-traditional sources is a matter of social utility, public interest and national economy, which enables global energy demand to be met and constantly increases interest in the development of new technologies that provide access to alternative, inexpensive energy with minimal impact on the environment. According to O. Ovcharenko *et al*. (2021), taking into account the conditions of sustainable development, the importance of developing bioenergy enterprises and micro-methanisation in Ukrainian cities, which are the subject of this study, is significantly increasing. It is the development of bioenergy enterprises and micro-methanisation of cities that will make it possible to maintain and increase a certain level of economic security by enabling economic entities to choose the most effective of the available development alternatives, which will allow them to effectively withstand internal and external threats.

Despite the significant attention of scientists to this issue, the problems of developing bioenergy enterprises as a sustainable energy solution for urban micromethanisation remain unresolved. The aim of the article was to develop a theoretical and methodological approach to the formation and development of opportunities, mechanisms and prospects for the creation and development of enterprises in the bioenergy industry that implement micromethanisation technologies through local processing of organic waste into biomethane directly within urban areas.

Materials and Methods

The study covered the period from 2010 to 2023, which made it possible to track the dynamics of renewable energy development and, in particular, the bioenergy segment. It should be noted that the data used in the graphics was

only available up to and including 2022, as the official statistical series for 2023 had not yet been published in full as of the time of writing. Another limitation of the study was that data for 2024 could not be taken into account, as it was still preliminary and unverified by the time the study was conducted.

The study used a set of materials covering regulatory and legal acts of Ukraine and the EU in the field of renewable energy, waste management and tariff setting, in particular documents Order of the Cabinet of Ministers of Ukraine No. 1082-r (2023), Order of the Cabinet of Ministers of Ukraine No. 373-r, Global bioenergy statistics report (2023), Bioenergy Europe (2022), as well as reporting data on the volume of organic waste generated in cities and towns (Garbage processing in Ukraine, 2024; Prospects of micromethanisation in cities, 2024), municipal waste management programmes and energy strategies (Order of the Cabinet of Ministers of Ukraine No. 587-r, 2024). In addition, statistical data series on the share of renewable energy sources and biomass power generation in previous periods were taken into account, as well as data on the technical characteristics of the world's leading biomethane and micro-biogas plants.

Various methods were used to achieve the set objectives. The roadmap method was used to determine the sequence of actions for creating a favourable environment for the development of bioenergy enterprises and micro-methanisation of cities, and made it possible to structure a set of measures in key areas such as regulatory and legal support, infrastructure, financing, international partnerships, insurance, communications and legislative analysis. The analysis method was used to process statistical data on electricity production from renewable sources, the share of electricity produced from biomass, electricity generation capacity and the structure of biomass potential in Ukraine and EU countries. The synthesis method was used to integrate the energy, environmental, economic and social aspects of micro-methanisation to ensure the formation of sustainable, decentralised solutions for the development of energy-efficient cities. The generalisation method made it possible to compile a list of promising technologies for the production of electrical and thermal bioenergy, while the comparison method was used to compare the rates of bioenergy development in Ukraine and EU countries, as well as to assess the cost of energy carriers and equipment. To quantitatively assess development trends, a forecasting method based on building trend models using the least squares method was used, which made it possible to extrapolate existing statistical series and assess the reliability of models using the coefficient of determination (R^2). In addition, tabular and graphical methods were used to ensure clarity and visualisation of the results.

Results and Discussion

Micro-methanisation of cities is the reconstruction of the energy sector in Ukraine and European Union countries in accordance with the declared Sustainable Development Goals (Transforming Our World..., 2015) and the Paris Agreement (2015), which have increased attention to bioenergy and gradual transition of thermal power plants (TPPs) and combined heat and power plants (CHP plants) to biomass. The Sustainable Development Goals (SDGs) are a universal framework adopted by the UN General Assembly in 2015 as part of the 2030 Agenda, which includes 17 goals and 169 targets and integrates the economic, social and environmental dimensions of human development. The SDGs are being implemented through national strategies and local policies, and monitoring is ensured by a system of global and national indicators, which makes it possible to assess progress and compare results. Micromethanisation is possible with the implementation of technological solutions that combine circular economy approaches, decarbonisation, energy efficiency improvements, resource recovery and reuse, greenhouse gas emission minimisation, local energy balance optimisation, and the integration of renewable energy sources into municipal infrastructure.

Micro-methanisation projects should be aligned with relevant SDG indicators, namely Goal 7, "Affordable and clean energy", with a direct contribution to targets 7.2 (increasing the share of renewable energy), 7.3 (improving energy efficiency), 7.a and 7.b (investment and infrastructure for modern energy services). In addition, micro-methanisation of cities is supported by Goal 11, "Sustainable cities and communities" (11.6, 11.b), Goal 12, "Responsible consumption and production" (12.2, 12.5), Goal 13 "Climate Action" (13.2), as well as related Goal 6.3 (reuse of wastewater and sludge) and Goal 9 "Industry, Innovation and Infrastructure" (9.4). Alignment with the SDGs also facilitates inter-municipal cooperation and scalability of solutions, reducing transaction costs for implementation. For the reconstruction of the energy sector in Ukraine and EU countries, this means local, flexible energy generation, increased energy resilience of communities, and reduced dependence on fossil gas. In the reconstruction phase, such a link forms the basis for prioritising investments, accessing green financing and assessing the social value of projects within the principles of the circular economy (Global bioenergy statistics report, 2023). Figure 1 illustrates the growing role of bioenergy. Based on the share of electricity from biomass, a linear trend line has been constructed with a forecast for future periods, which shows that there is an 87.47% probability that its share in all other renewable energy sources will grow. An example of successful and systematic micro-methanisation is Belgium, where all thermal power plants have been completely converted to biomass. A striking example is the CHP plant in Ghent, which has been converted to use biomass, in particular wood pellets and other organic waste (Geletukha, 2021). Austria is another example of a European country that is actively developing the use of biomass. Many small and medium-sized towns in Austria have already switched to using wood chips and waste for centralised heat supply. The country uses its large forest resources to produce biomass, replacing fossil fuels (Pechenyuk, 2024).

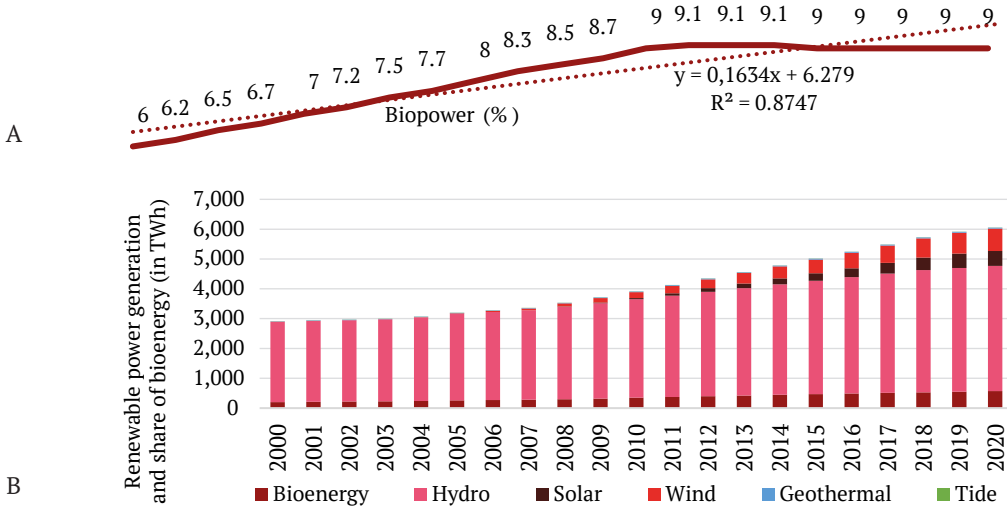

Figure 1. Electricity generation from RES (a) and share of electricity from biomass (b), TWh/year
Source: Global bioenergy statistics report (2023)

Finland also demostrated a successful transition from coal-based energy to biomass. A significant portion of electricity and heat in Finland is produced by biomass power plants that use wood from the country's forests (The largest biomethane plants in Europe, 2022). Denmark's thermal power plants and combined heat and power plants are not lagging behind in the transition to biomass. In particular, the Avedøre TPP, which has been converted to biomass, provides 90% of the electricity and heat supply for Copenhagen, with a population of over 1.4 million (Epik, 2021). The United Kingdom has also successfully transformed its coal-fired power plants. Drax Power Station, formerly the largest coal-fired power station in the country, has largely switched to biomass. Instead of coal, the station now uses wood pellets (Epik, 2021; The largest biomethane plants in Europe, 2022). The growth in biomass power generation capacity between 2000 and 2022 contributed to a nearly fourfold increase in electricity production. Further growth is confirmed by a linear trend line, which predicts further growth in biomass power generation capacity with a probability of 96.81%, which is a significant factor and highlights the relevance of the study (Fig. 2).

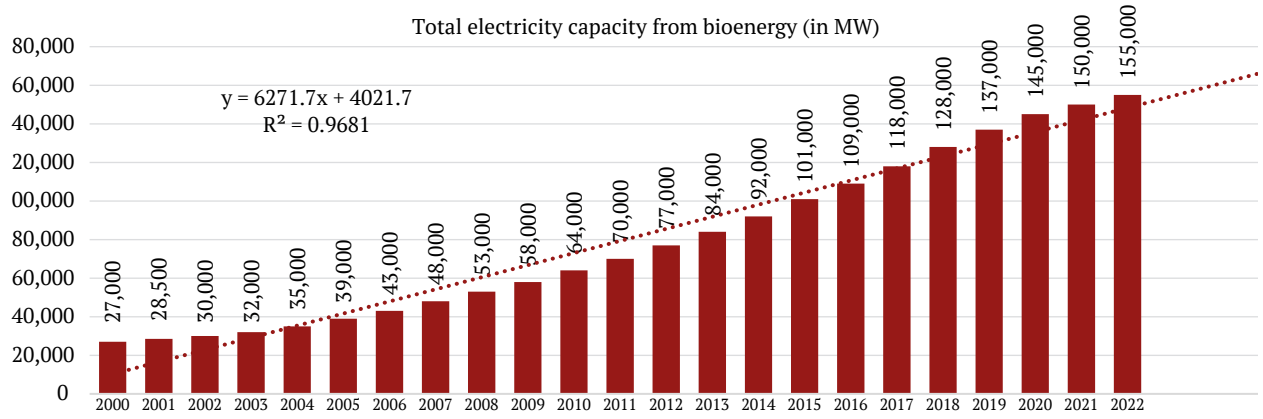

Figure 2. Biomass power generation capacity during 2000-2022, MW
Source: Global bioenergy statistics report (2023)

A serious argument for the need to develop bioenergy and micro-methanisation of cities in Ukraine and worldwide is not only the need for rapid reconstruction of the energy sector and the commitment to transform to "clean" energy, but also the fact that as of early 2022, Ukraine had almost 8 million hectares of low-yield land that could potentially be used for growing perennial energy crops. According to calculations by G. Geletukha (2021), using just 3 million hectares of low-yield land for energy crops could completely replace energy imports with biofuel, and this is only 37% of the available unused low-yield land. However, the potential of bioenergy is not merely measured by the amounts of energy crops grown. Ukraine is an agrarian country, so it has significant volumes of agricultural waste, which is a universally recognised important component of the bioenergy potential in any country.

The opinion of the European Biogas Association (EBA) needs to be taken into account, namely that the deployment of biomethane to replace fossil fuels does not require investment in additional resources for the development of new infrastructure. The existing gas infrastructure is ready for biomethane. This is key to accelerating decarbonisation and ensuring affordable renewable energy in the form of heat, electricity or transport fuel for industry and households. Indeed, anaerobic fermentation of organic materials from plant by-products, animal manure, and bio-waste from households or industry in a biogas reactor in the absence of oxygen releases a mixture of gases: 45-85 vol. % methane (CH4) and 25-50 vol. % carbon dioxide (CO2). The renewable gas obtained can be used for cooking, electricity generation, and heating, replacing compressed natural gas for use in vehicles and displacing carbon dioxide at local CHP plants (Biomethane..., 2024). The total annual technically achievable energy potential of biomass in Ukraine is 37.8 million tonnes of oil equivalent (Prospects of micromethanisation in cities, 2024). According to estimates and forecasts by the Bioenergy Europe association (2022), forest wood currently accounts for 71.37% of the biomass used for bioenergy in Europe (Fig. 3a), but forecasts for 2050 show an increase in the use of agricultural biomass and waste, as well as waste streams, as shown in Figure 3.

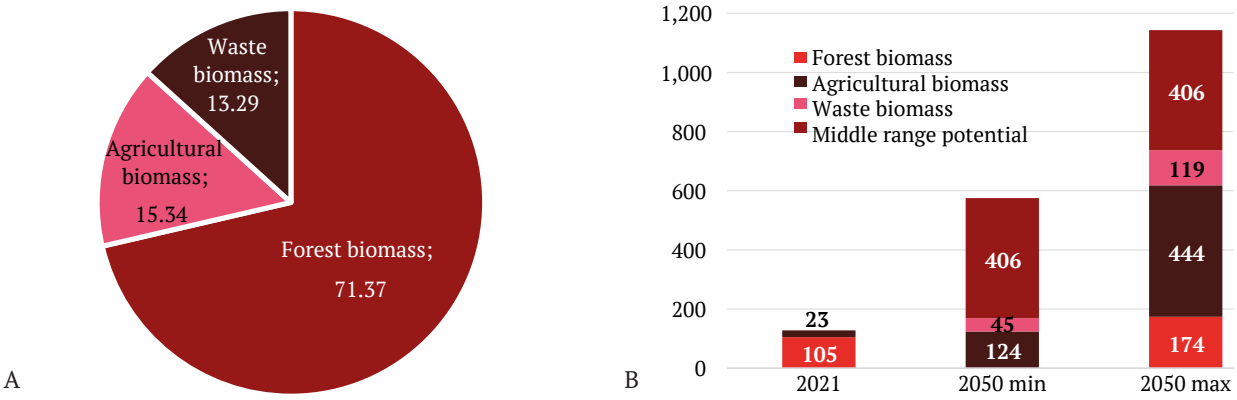

Figure 3. Biomass potential structure for the EU27 + UK (in Mtoe)

Note: a – distribution of the various biomass feedstock for energy in 2021 (%); b – Gross inland energy consumption of biomass in 2021 and potential in 2050 for the EU27 + UK (in Mtoe)

Source: Bioenergy Europe (2022)

The introduction of technologies for the production of electrical and thermal bioenergy by increasing the share of bioenergy in Ukraine's energy balance, the development of distributed generation and energy storage facilities are recognised as one of the priority vectors of the country's Energy Strategy (ESU) for the period up to 2050 (Energy Strategy of Ukraine, 2023) and the National Renewable Energy Action Plan for the period up to 2030 (Order of the Cabinet of Ministers of Ukraine No. 587-r, 2024). According to the National Energy and Climate Plan (2024), it is expected that, thanks to promising technologies, the generation of electrical and thermal bioenergy in the medium and long term will change as follows (Table 1).

Table 1. Promising technologies for the production of electrical and thermal bioenergy

Technologies	Capital expenditure, €/kW						Efficiency (electrical), %	Installed capacity utilisation factor, ICUF %	Heat production coefficient
	2,025	2,030	2,035	2,040	2,045	2,050			
Wood biomass TPPs	2,750	2,700	2,650	2,600	2,550	2,500	24	50	30
Share of capital expenditures for converting TPPs to wood biomass in total expenditures, %	6.98	15.47	15.36	15.20	15.22	15.15	-	-	-
Waste incineration TPPs	2,850	2,800	2,750	2,700	2,650	2,600	23	50	30
Share of capital expenditures for converting TPPs to household waste incineration in total expenditures, %	7.23	7.11	6.98	6.85	6.73	6.60	-	-	-
Biogas TPPs	3,200	3,200	3,200	3,200	3,200	3,200	42	50	30
Share of capital expenditures for converting TPPs to biogas in total expenditures, %	8.12	8.12	8.12	8.12	8.12	8.12	-	-	-
Wood biomass TPPs + Carbon capture	3,650						24	50	30

Table 1. Continued

Technologies	Capital expenditure, €/kW						Efficiency (electrical), %	Installed capacity utilisation factor, ICUF %	Heat production coefficient
	2,025	2,030	2,035	2,040	2,045	2,050			
Share of capital expenditures for converting TPPs to wood biomass + Carbon capture in total expenditures, %	9.26	20.92	21.16	21.35	21.79	22.12	-	-	-
Biogas TPPs + Carbon Capture	5,350						42	50	30
Share of capital expenditures for converting TPPs to biogas + Carbon capture in total expenditures, %	13.58	30.66	31.01	31.29	31.94	32.42	-	-	-
Energy crop TPPs + Carbon capture	3,750						24	50	30
Share of capital expenditures for converting TPPs to energy crops + Carbon capture in total expenditures, %	9.52	21.49	21.74	21.93	22.39	22.73	-	-	-
Wood biomass CHP plants	2,850	2,800	2,750	2,700	2,650	2,600	20	50	35
Share of capital expenditures for converting CHP plants to wood biomass in total expenditures, %	7.23	16.05	15.94	15.79	15.82	15.76	-	-	-
Biomass waste-fired CHP plant	2,950	2,850	2,850	2,900	2,750	2,700	19	50	35
Share of capital expenditures for converting CHP plants to biomass from waste in total expenditures, %	7.49	16.33	16.52	16.96	16.42	16.36	-	-	-
CHP plant using energy crops	3,150	3,100	3,050	3,000	2,950	2,900	20	50	35
Share of capital expenditures for converting CHP plants to energy crops in total expenditures, %	7.99	17.77	17.68	17.54	17.61	17.58	-	-	-
Wood biomass CHPP + Carbon capture	4,450						20	50	35
Share of capital expenditures for converting CHP plants to wood biomass + Carbon capture in total expenditures, %	11.29	25.50	25.80	26.02	26.57	26.97	-	-	-
CHP plants using energy crops + Carbon capture	4,450						20	50	35
Share of capital expenditures for converting CHP plants to energy crops + Carbon capture in total expenditures, %	11.29	25.50	25.80	26.02	26.57	26.97	-	-	-
Total costs, €/kW	39,400	17,450	17,250	17,100	16,750	16,500	25	50	32

Source: supplemented by Order of the Cabinet of Ministers of Ukraine No. 587-r (2024)

A significant increase in production electricity from biomass is planned by 2030. Its total capacity is to be approximately 876 MW (Order of the Cabinet of Ministers of Ukraine No. 373-r, 2023). However, it is already clear that the pace of bioenergy development in Ukraine has been significantly behind schedule, which is explained not only by the full-scale invasion of the Russian Federation, but also by limited development due to a number of obstacles. The difficulties include insufficient funding for the sector, unregulated legislation, lack of effective incentives, technological and infrastructure constraints, complex and unstable regulatory conditions for doing business, etc. (Pechenyuk, 2024). The situation is further aggravated by the remoteness of bioenergy facilities from cities, which is typical for most EU countries and Ukraine. The facilities are mainly located in areas where there is access to agricultural waste, wood or energy crops, i.e. in rural areas and around farms. These are large closed tanks, anaerobic digestion reactors that convert biomass into energy, and biogas plants (Thermal alternative…, 2022).

The Vinnytsia region stands out in Ukraine for its large number of biogas plants that generate energy from agricultural biomass. In terms of generation volumes, it is followed by the Lviv, Ivano-Frankivsk, Volyn and Zakarpattia regions, where, due to large forest areas, bioenergy companies have significant potential with wood and forest waste (Kramar, 2023). However, most bioenergy enterprises are located far outside cities, which significantly complicates their micro-methanisation. However, everything can be changed if the value of municipal solid waste (MSW), which accumulates daily in urban landfills (Prospects of micromethanisation in cities, 2024), is taken into account and favourable conditions for micromethanisation of cities are created. In Ukraine, about 7% of the territory is polluted with MSW, and there are practically no bioenergy enterprises that can generate energy from it. Meanwhile, Sweden recycles over 99% of its waste annually, Germany over 60%, and Poland almost 43% (Garbage processing in Ukraine, 2024). A roadmap for the development of bioenergy enterprises and micro-methanisation of cities has been created. For a clear understanding

of the sequence of actions aimed at creating a favourable environment for the development of bioenergy enterprises and micro-methanisation of cities, one can follow the proposed Roadmap, which includes the creation of a favourable regulatory and legal framework, the demonopolisation of heat supply, the development of bioenergy infrastructure, the promotion of international cooperation, and combines technical, economic and institutional instruments, including financial support, the creation of information platforms and an investment insurance system (Table 2).

Table 2. Roadmap for creating a favourable environment for the accelerated development of bioenergy enterprises and micro-methanisation of cities

Actions	Description and direction
Creating a regulatory framework for the development of micro-methanisation in cities	Legislative consolidation of tariff regulation for electricity and heat energy, creation of a favourable investment climate, etc. It is envisaged that producers of heat energy from alternative energy sources will be able to obtain tariffs on general terms and operate at economically justified tariffs.
Demonopolisation and decentralisation of heat supply	Transformation of state-owned heat supply companies into joint stock companies, minimisation of state participation and political influence, expansion of bioenergy producers and consumers of electricity and heat supply services.
Enhancing international cooperation and partnership	Consolidation of opportunities for international cooperation and partnership. Transposition and implementation of existing regulatory acts governing the trans-European energy network to facilitate Ukrainian projects obtaining the status of "project of mutual interest".
Development of bioenergy infrastructure	Construction of micro-biogas plants and installation of direct pipelines connecting plants for the production and consumption of thermal energy. Arrangement of organic waste collection.
Establishing dialogue with stakeholders	Developing stakeholder engagement policies, including dividend policy, investment policy, planning and decision-making policy.
Financial support and subsidies	Development and legislative consolidation of mechanisms and timeframes for state support for the development of bioenergy enterprises and micro-methanisation of cities. Preferential loans, state guarantees, tax and customs discounts, avoidance of multiple subsidies and tax preferences.
Establishment of public information platforms	Creation of special online resources where communities, businesses and municipal authorities can obtain information about micro-methanisation technologies, as well as opportunities for receiving state support or investments. Integration with smart city systems.
Insurance and state guarantees	Creation of state or municipal guarantee funds that will cover the financial risks of investing capital in the development of bioenergy enterprises and urban micromethanisation.

Source: developed by the authors

The advantage of using this roadmap is a comprehensive approach, promoting energy independence, attracting investment, increasing the sustainability of the energy system and environmental benefits. Disadvantages include the high cost of implementation, the need for significant changes in legislation, bureaucratic delays. The estimated implementation period in Ukraine is 3-5 years, provided that there is positive political support and stable financing. The prospect for further development of bioenergy enterprises and micro-methanisation is the transition to alternative fuels, which will reduce the vulnerability of the energy system, as damage to the gas infrastructure can immediately deprive a significant number of consumers (in some cases, part of a city or more) of heat, and the use of boiler rooms and local resources reduces such risks (Zamazeyeva, 2023); this will also reduce dependence on natural gas and, accordingly, reduce the cost of its purchase; scale up and multiply projects to install biomass boiler rooms and bio-CHP plants in communities, attract new investments, create new jobs, generate additional budget revenues, etc.

Therefore, by developing bioenergy enterprises and implementing micro-methanisation of cities, economic security of enterprises, regions and countries is achieved in terms of counteracting exogenous and endogenous factors of influence; risks are minimised or eliminated, and ecological development is ensured with the achievement of sustainable development goals (Tiutchenko *et al.*, 2024). The key recommendations for the development of bioenergy enterprises in Ukraine are improving the regulatory framework by ensuring clear rules for bioenergy production, tariff regulation, a transparent licensing procedure, and the integration of European Directives. Accelerating the demonopolisation of heat supply and creating conditions for attracting a greater number of private and state-owned biomass heat and electricity producers. Developing infrastructure through the design and construction or procurement of micro-biogas plants, heat pipelines and organic waste collection systems. Attracting international financing to obtain investments, loans or guarantees from the EBRD, Energy Community, Ukraine-Germany Energy Partnership. Attracting investment should be based on guaranteeing stable rules and compliance with long-term energy purchase agreements; introducing public-private partnership mechanisms; providing preferential lending and investment return guarantees through state funds; attracting international donors and financial institutions that do not support fossil fuels and actively invest in RES.

Support national producers through preferential lending, tax breaks, and investment insurance; give priority to public procurement for Ukrainian producers of bioenergy equipment. Create a biomass exchange and a transparent biofuel market with quality control and supply guarantees from the state. Provide information support and training by developing public online platforms for communities and businesses, as well as training programmes for plant operators. These measures will enable the achievement of Sustainable Development Goals and generate economic benefits through energy independence, reduced imports

of natural gas and oil, a stable energy system, decentralised power generation, and the creation of new jobs in the regions through the development of the agricultural sector due to increased demand for energy crops and further GDP growth. The environmental effect will be manifested through a reduction in greenhouse gas emissions and organic waste disposal, while innovative development will be achieved through the introduction of advanced waste processing and energy storage technologies (BESS).

When making decisions on the development of micro-methanisation in Ukrainian cities, it is necessary to take into account the possible negative consequences: high investment levels and long project payback periods; risks of legislative incompleteness that reduces attractiveness for investors; significant competition for raw materials between bioenergy and other sectors of the economy (food industry, livestock farming); potential negative impact on agricultural land due to the large-scale cultivation of energy crops. Further development should be based on international experience by integrating the strategies of countries that already have successful bioenergy practices, similar climatic conditions and raw material bases, as well as common goals for decarbonisation and energy independence (Denmark, Austria, Finland, Great Britain). Good practices include setting economically sound tariffs; introducing guaranteed long-term contracts; developing local biofuel markets; and combining bioenergy with smart heating networks and energy storage facilities.

A notable achievement by M.R. Errera *et al*. (2023) was the development of a new model, whose heuristics and level of transparency allow for adjustments to be made and other scenarios to be explored over time. The author identified three future scenarios for bioenergy supply in 2050: business as usual (BUS), optimistic trends (OPT) and full adaptation (FAR). The forecast was based on four adjustment factors. Uncertainty analysis was performed using the Monte Carlo method. Bioenergy production forecasts for 2050 were compared with other forecasts available in the literature. The FAR scenario showed that it would be possible to produce 21 times more than the current supply of primary bioenergy and even meet the entire global demand for primary energy in 2050, mainly through energy crops. The assumptions made for the BUS and OPT scenarios make these forecasts more probable.

O. Evstegneeva (2024) studied the state and prospects of bioenergy use in Ukraine, identified the potential for producing biofuels from agricultural waste and biomass to replace imported natural gas and coal, and analysed the technical possibilities for attracting resources, overcoming existing barriers, determining economic feasibility, and an impact on the country's energy security. Based on the results of the study, the author outlined that Ukraine has significant technical potential for bioenergy resources, especially from agricultural waste, and that the effective use of these resources could replace a significant portion of energy imports. The effect can be seen in reduced dependence on fossil fuels, preservation of currency reserves, and development of domestic production. The most successful cases of biomass use in heat and power generation in Ukraine have proven that bioenergy is a realistic and promising component of Ukraine's energy security, especially in conditions of war and energy shortages. Significant results in this area can be achieved by reforming the regulatory framework and mechanisms to accelerate the implementation of bioenergy projects; supporting investment in biomass processing technologies and the development of relevant infrastructure; implementing decarbonisation, creating jobs and developing local communities.

The researchers A.I. Orekhova *et al*. (2024) emphasised that the potential of bioenergy in Ukraine involves replacing imported energy resources (gas, coal) with biomass and biofuel from agricultural and forestry waste and organic waste. The study covered the economic, technical and environmental aspects of the implementation, as Ukraine has the technical potential to replace a significant portion of imported fuel (up to 20 billion m^3 of gas equivalent annually). The authors argue that bioenergy can provide stable heat and electricity for communities, especially during energy crises, and provide examples of successful regional projects that have already reduced dependence on fossil fuels by using local biomass and created new jobs. These results can be achieved by involving investors and biofuel producers, stimulating decarbonisation and sustainable development in the regions. In order to strengthen Ukraine's energy independence through the use of bioenergy tools, it is necessary to remove administrative and regulatory barriers and simplify the procedure for connecting bioenergy facilities to the grid. These aspects were addressed in the article by O. Tregub (2024), who analysed tax incentives as an economic and legal tool for supporting bioenergy, in particular the possibility of a zero tax rate for CO_2 emissions from biofuel combustion. The author focused on the adequacy of the regulatory and legislative framework to the wartime crisis, which exacerbates the need for rapid adaptation of the industry despite restrictions due to martial law and the reform of EU climate legislation. The results of the study highlighted that the ecotax rate for CO_2 emissions increased from 0.41 UAH/tonne in 2018 to 30 UAH/tonne in 2022. The proposed zero rate for biomass energy production in the draft laws requires amendments to the Tax Code and the creation of a register of bioenergy plants. At the same time, an anti-corruption assessment has identified risks such as the creation of a register of plants under a resolution of the Cabinet of Ministers to prevent the non-transparent selection of beneficiary companies. The main conclusions are that the zero tax rate is a viable option during martial law to quickly boost bioenergy and support recovery. It is desirable to develop a gradual transition to the introduction of the exemption, but it is not advisable to link it to sustainability criteria due to their insufficient implementation.

M.B. Palasevich & P.A. Murdza (2024) emphasised that Ukraine has the potential to replace imported gas and coal with bioenergy by using local biomass (straw, corn stalks,

sunflower husks, wood waste, municipal organic waste). According to the authors' estimates, Ukraine's technical biomass potential is about 23 million tonnes of fuel equivalent per year, which is equivalent to approximately 20 billion m^3 of natural gas. Using this resource will reduce gas imports by 60-70% in thermal power generation. The researchers cite successful examples of biomass boiler rooms in Kamianets-Podilskyi, which provide over 60% of the heat for centralised heating, and in Trostyanets, where biofuel boiler rooms have reduced the cost of heat by 25-30%. The transition to biofuel will allow the country to save approximately $2 billion annually, which was previously spent on energy imports. The study concludes that bioenergy technologies contribute to reducing CO_2 emissions, create thousands of jobs in the regions, and that bioenergy can replace a significant portion of imported energy resources and increase Ukraine's energy independence. This is possible through the introduction of government incentives such as preferential loans, tax breaks, and simplified procedures for connecting to power grids.

Based on retrospective and forecast data, Ya. Demchenkov (2023) argues that Russia's full-scale war against Ukraine has affected the energy independence of other countries and accelerated the global energy transition. Currently, Ukraine has the potential to replace some of the energy, which the EU previously received from Russia, by creating new energy security architecture. The author's findings show that Ukraine has demonstrated better energy reform rates than other countries applying for EU membership, despite the ongoing war. All technical conditions for acquiring full ENTSO-E membership have been met, which will ensure stable electricity exchange with Europe in the future. A promising area is the development of nuclear energy and the creation of universal nuclear fuel for VVER-440 reactors, which is applicable to all reactors in the EU. Projects of common interest (PCI) for the EU include a hydrogen corridor connecting Ukraine, Slovakia, the Czech Republic, Austria and Germany. The war has turned energy into a tool of hybrid warfare and accelerated the global energy transition. Ukraine has the potential to become Europe's green energy hub, capable of producing not only clean energy, but also equipment and technologies for energy transformation. Ukraine's prospective membership in the EU will ensure that its energy will never be used against common European interests. The development of joint projects with the EU and the US (Holtec, Westinghouse, Rolls-Royce SMR; hydrogen and renewable energy projects) will increase continental security and accelerate Europe's energy independence. The Ukrainian experience can serve as an example for countries in the Global South showing that green transformation is possible even during periods of armed conflict and is beneficial for all countries. I.V. Furman & D.O. Ksenych (2024) studied the state, problems and prospects of bioenergy development in Ukraine in the context of ensuring energy security. The authors analysed the stages of the industry's development, compared Ukrainian and European experience, considered successful examples of bioenergy clusters, and assessed the potential for using local bioresources. The study identifies the main challenges: imperfect legislation, technological limitations, insufficient funding, high competition with imported energy sources, logistical problems with raw material supply, and the need to take environmental and social aspects into account. Ukraine has significant potential for producing biofuels, biogas and electricity from biomass due to its considerable agricultural and forestry resources. It has been found that the creation of bioenergy clusters of agro-industrial enterprises and households can ensure the efficient use of resources, reduce dependence on energy imports, reduce greenhouse gas emissions, stimulate the development of rural areas and create additional jobs. The EU's experience confirms that this model promotes innovation, investment attractiveness and sustainable development. The authors conclude that the successful development of bioenergy in Ukraine requires a comprehensive approach that includes financial support (subsidies, grants, investment programmes), a stable regulatory framework, technological modernisation, infrastructure expansion, international cooperation and government incentives for the industry. Bioenergy is seen as a strategic direction that can strengthen the country's energy independence, improve environmental safety, and support regional economic development.

The results obtained are consistent with broader studies that emphasise the role of renewable energy in strengthening energy security. In particular, O. Semenenko *et al.* (2025) demonstrated that energy security has become a key factor in ensuring Ukraine's economic stability during the war. This approach reinforces the relevance of expanding the network of bioenergy enterprises and introducing micro-methanisation technologies, which simultaneously contribute to the sustainable development of cities and increase the country's ability to withstand external challenges. The findings are also consistent with international studies on the use of agricultural biomass as a promising resource for bioenergy. S. Anvari *et al*. (2024) used the example of Tunisia to prove that the effective use of agricultural waste and by-products can significantly increase energy independence and promote sustainable development. This is in line with the Ukrainian context, where significant agricultural potential could form the basis for expanding bioenergy production and introducing micro-methanisation technologies.

J. Plotkin *et al.* (2023) investigated the role and prospects of thermal power plants and combined heat and power plants in Ukraine's energy system in the context of international climate commitments, national plans to reduce emissions, and the transition to renewable energy sources. The researcher have identified four key factors that justify the need to continue the operation of TPPs/CHP plants: insufficient number of electrical substations for stable reception and distribution of electricity; the inability of nuclear power plants to quickly regulate load, which creates a need for flexible generation sources, such as TPPs/CHP plants; limitations of renewable energy sources (solar, wind, etc.) due to

instability, low conversion efficiency, and the need for large land areas; the importance of CHPs for the simultaneous production of electricity and heat, as well as difficulties in financing the modernisation and gasification of these facilities. The authors concluded that the complete decommissioning of TPPs/CHP plants in the short term could threaten Ukraine's energy security, especially in the context of war. The most realistic model is a combination of renewable energy, hydroelectric power plants, modernised CHPs and new safe nuclear technologies. At the same time, effective financial mechanisms need to be developed for modernisation and reduction of emissions from thermal generation in order to meet international and national climate commitments without affecting the stability of the energy system.

By simplifying the procedures for state approval of boiler house construction projects, approval of project documentation, environmental impact assessment, land allocation, identifying of connection conditions, obtaining a licence for heat energy production, approval of tariffs, etc., it will be possible to commission up to 500 MW of distributed thermal generation capacity running on biomass and natural gas within 6-8 months. The above proposal did not receive due attention from the government and local authorities, which highlights the need for further scientific research in this area. Given the difficult situation in Ukraine's energy sector, one of the most promising ways to restore it in conditions of instability is to develop decentralised biogeneration and micro-methanisation systems in cities. Decentralised biogeneration is the main direction of strategic development during the Russian Federation's military aggression, due to the fact that it is a solvable task to physically protect the distributed generation facilities and associated substations (Ukrinform, 2024).

The study demonstrated a comprehensive approach to assessing the potential for micro-methanisation in Ukrainian cities, by combining legal, economic, technical and social aspects. The methods of analysis, forecasting and comparison used by the authors made it possible to quantitatively confirm the positive trends in the development of bioenergy and identify prospects for the expansion of technology at the local level. The results obtained substantiated the need for the phased implementation of a roadmap as a tool for coordinating the efforts of the government, businesses and the public.

Conclusions

The study provides a theoretical justification and practical testing of approaches to the development of bioenergy enterprises as a sustainable solution for micro-methanisation of urban areas. Ukraine has sufficient amounts of low-yield land; the use of additional areas for energy crops could completely replace energy imports with biofuel. The total technically achievable energy potential of biomass is estimated at 37.8 million tonnes of oil equivalent. European practices for conversion of TPPs/CHP plants to biomass (Belgium, Austria, Finland, Denmark, and Great Britain) have been systematised and aligned with the UN Sustainable Development Goals (Goals 7, 11, 12, 13, 6.3, and 9.4). The trend lines show that the share of bioenergy in green energy production is highly likely (87.47%) to grow, and global bioenergy capacity is even more likely to increase (96.81%). According to forecasts, electricity production from biomass in Ukraine will grow to 876 MW by 2030. A list of promising technologies and capital expenditure ranges has been compiled: wood biomass TPPs – €2,500-2,750/kW; wood biomass CHP plants – €2,600-2,850/kW; biogas TPPs – €3,200/kW; options with CO_2 capture – €3,650-5,350/kW.

A roadmap has been developed for a sequence of actions aimed at creation of a favourable environment for accelerating the development of bioenergy enterprises and micro-methanisation of cities. Subject to changes in legislation and state support, up to 500 MW of distributed heat generation from biomass/gas could be introduced within 6-8 months; given that there are more than 100 specialised companies in the country, this would allow up to 30% of lost generation to be partially restored within a year. Key barriers to the development of bioenergy enterprises and micro-methanisation of cities have been identified, including underfunding, regulatory uncertainty, technological and logistical constraints, and low waste processing rates in cities.

Decentralised bioenergy and micro-methanisation of cities have been proven to be a realistic and rapidly scalable way to increase the energy sustainability of communities, reduce gas imports and achieve climate goals. The proposed sequence of actions and agreed technological and financial benchmarks could also form the basis for state policy and local strategies. Prospects for further research consist of deepening the quantitative assessment of micro-methanisation potential at the level of specific communities (organic waste flows, heat loads, connection points); modelling financial schemes (tariff and non-tariff incentives, guarantees, BESS integration) taking into account wartime risks; assessing socio-environmental effects (jobs, emission reductions, budget revenues); and preparing packages of model solutions for rapid launch of pilots in cities.

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Розвиток підприємств біоенергетики як стале енергетичне рішення мікрометанізації міст

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Анотація. Серйозним аргументом необхідності розвитку підприємств біоенергетики та мікрометанізації міст є, по-перше, потреба у швидкій відбудові енергетичного сектору та виконанні зобов'язань щодо трансформації до чистої енергетики. По-друге, той факт, що Україна, як і більшість країн Європейського Союзу, має значні площі низькопродуктивних земель, які потенційно можуть бути використані для вирощування багаторічних енергетичних рослин, а відтак, і для заміщення імпорту енергоносіїв біопаливом. Метою статті було теоретичне дослідження та практична апробація підходів до формування напрямів розвитку підприємств біоенергетики як сталих енергетичних рішень мікрометанізації міст. Результати даного дослідження отримано шляхом використання таких методів: аналізу і синтезу – при постановці проблеми, формулюванні завдань дослідження, визначення перспективних технологій виробництва електричної та теплової біоенергії; наукової абстракції, порівняння та узагальнення – для визначення дорожньої карти розвитку підприємств біоенергетики та мікрометанізації міст. Своєчасне виконання поставлених завдань з розвитку підприємств біоенергетики та мікрометанізації міст можливе лише за умови перегляду політики державної підтримки та стимулювання децентралізацій енергетики. У статті розглядалися теоретичні та прикладні аспекти впровадження технологій виробництва електричної та теплової біоенергії. Систематизовано застосування теплових електростанцій і теплоелектроцентралей на біомасі в країнах Європи. Розроблено дорожню карту розвитку підприємств біоенергетики та мікрометанізації міст, яка включає такі основні напрями, як створення нормативно-правового поля з регулювання розвитку з мікрометанізації міст, демонополізація та децентралізація теплоенергопостачання, активізація міжнародного співробітництва та партнерства, розбудова біоенергетичної інфраструктури, встановлення діалогу із зацікавленими сторонами, фінансова підтримка та субсидування, створення публічних інформаційних платформ, страхування ризиків та державні гарантії. Визначено переваги переходу на альтернативні види палива. Обґрунтовано досягнення очікуваного результату у енерго- та теплозабезпеченні територій та міст. Дослідження має високу практичну цінність та може бути використане при формуванні стратегії сталого розвитку громад та як стратегічна альтернатива забезпечення біоенергією

Ключові слова: менеджмент; стратегія сталого розвитку; декарбонізація; біомаса; генерація; сталий розвиток; технологічний розвиток

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Research on the role of cross-border trade in the economic growth of border regions of Central Asia

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Abstract. The aim of this study was to determine how trade flows and integration processes influenced the socio-economic development of the border regions of Central Asia. The methodology was based on the analysis of official statistics and the application of a correlation approach to identify dependencies between investments and export flows. The results of the study demonstrated that trade between Kazakhstan and Kyrgyzstan remained structurally asymmetric: in 2019, Kyrgyzstan's exports amounted to 327 million USD, and by 2023-2024 they had increased to 559 million USD, yet imports from Kazakhstan were considerably higher, generating a persistent deficit. Kazakhstan's exports comprised grain and flour (in 2023 alone – 40.4 thousand tonnes of grain and 53.2 thousand tonnes of flour), gold, tobacco products and mineral waters, while more than 90% of Kyrgyz exports consisted of precious metal ores and petroleum products. In the Talas region, investments rose from USD 36.6 million in 2020 to USD 127.9 million in 2022, before declining to USD 107.1 million in 2024. Correlation analysis confirmed a strong relationship between investment activity and exports (coefficient 0.84). In the Zhetysu region of Kazakhstan, in 2024, gross regional product increased by 5.6%, investments reached USD 641.4 million, and foreign trade turnover approached USD 3 billion, accompanied by a low unemployment rate of 4.7%. The findings could be applied by state authorities, regional administrations and international organisations in designing strategies aimed at enhancing the efficiency of cross-border trade and investment policy

Keywords: transport corridors; investment; infrastructure; logistics; export; import

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Introduction

The transformation of border areas in Central Asia has unfolded against the backdrop of expanding international trade and the region's strengthening role within global supply chains. The intensification of transport corridor development and increasing investment inflows have created new opportunities for economic advancement; however, these processes are simultaneously associated with uneven regional progress and potential threats to socio-economic stability. S. Golunov & A. Bitabar (2025) demonstrated that most studies focused on European and North American experiences, while a systematic analysis of local specificities was lacking. The authors identified the potential for adapting international practices to enhance the integration capacities of the region. They emphasised that despite the existence of individual works on local issues – such as informal trade, demographic processes and water resources management – there was no overarching vision of the development of cross-border cooperation in the region.

B.K. Kuanshaliev (2025) summarised the results of studies on the interaction of border states, their economic security and infrastructure projects, highlighting patterns in the evolution of relations between neighbouring countries. The author found that comparative analysis of socio-economic processes makes it possible to identify new areas of cooperation and their potential. G. Bodaubayeva *et al*. (2025) analysed the institutional and infrastructural factors of cooperation, with particular attention to transport corridors, industrial and logistics zones, and non-tariff barriers that hinder the movement of goods. The authors concluded that sustainable development is possible only with the harmonisation of legislation, the establishment of joint regulatory bodies and the digitalisation of processes. G. Tekir (2025) examined Uzbekistan's strategic participation in Chinese infrastructure projects, showing that the modernisation of the transport system, the development of digital networks and the attraction of foreign investment have significantly altered the country's economic landscape. The author emphasised that Uzbekistan was able to deepen its integration into regional markets and strengthen transit potential, but at the same time financial risks, reliance on external creditors and challenges in the field of digital security increased.

B. Kadyrov & B. Kuantkan (2024) conducted a comprehensive regression analysis of export-import flows in the agricultural and livestock sectors for 2018-2022, finding that the volume of agricultural exports did not significantly affect their value, while imports demonstrated a strong correlation with dollar indicators. B.K. Yeleussizova *et al.* (2024) examined the role of the de minimis threshold in shaping low-value parcel flows, showing that its adjustment partly influenced the growth of e-commerce imports and a reduction in misdeclared goods. The authors concluded that the fiscal impact remained limited, while access to cheaper and better-quality goods was of greater importance for consumers.

I. Bastanifar *et al.* (2024) applied the Morris Economic Stability Index and the Granger causality test to data for 2000-2021, considering inflation, unemployment, private and public debt, as well as the trade-to-GDP ratio. The study concluded that the average level of stability in Kyrgyzstan was 63%, while in Tajikistan it was 65%; since 2013 Tajikistan has demonstrated higher figures due to demographic factors and changes in the structure of trade. The results indicated that trade relations with China increase economic stability in Kyrgyzstan, while no significant effect was observed for Tajikistan. A. Ibyzhanova *et al.* (2024) investigated the dynamics of agri-food trade between the two countries for 2012-2022, showing that China, as the world's second largest importer of agricultural products, occupies one of the leading positions among Kazakhstan's trading partners, yet Kazakhstan's share in the Chinese market remains marginal at only 0.1%. The authors found that the main export commodities are grains, seeds and vegetable oils, while the potential for diversification and expansion is much greater. They highlighted the importance of developing transport infrastructure, harmonising standards and pursuing technological modernisation to enhance competitiveness.

Existing studies underscore the lack of quantitative analysis, statistical evidence and systematic assessments, which complicates the evaluation of the long-term effects of cross-border interaction on economic security, social stability, competitiveness and environmental sustainability. In addition, labour mobility plays a crucial role in shaping regional economic activity. As noted by A. Makyev & N. Zairova (2023), the movement of labour in Kyrgyzstan substantially affects the level of economic activity and income formation in border regions, highlighting the importance of demographic processes in trade and integration dynamics. The purpose of this study was to examine the impact of trade flows and integration processes on the socio-economic development of the border regions of Central Asia. To achieve this aim, the study set the following tasks: to investigate the dynamics and structure of cross-border trade flows in the region, with particular focus on the role of transport corridors and logistics infrastructure; and to analyse the interrelationship between investment activity, economic growth and trade turnover in border territories.

Materials and Methods

This study was empirical in nature and covered the period 2018-2024, focusing on the dynamics of cross-border trade between the border states of Central Asia, primarily Kazakhstan and Kyrgyzstan. The starting point of 2018 was selected as a baseline year preceding the global shocks of the COVID-19 pandemic and the subsequent structural adjustments in regional trade. This allowed the research to capture the pre-crisis state of bilateral trade flows and to compare it with the ensuing dynamics. The period 2020-2024 was examined in order to trace transformations in cross-border trade under the influence of the pandemic, post-crisis recovery and integration projects, such as the modernisation of transport corridors and logistics hubs.

The analysis investigated the general tendencies of trade flows between Kazakhstan and Kyrgyzstan, identifying their structure and long-term dynamics. It considered the role of key transport corridors and border checkpoints that form the backbone of trade. The Trans-Caspian International Transport Route (TITR) (n.d.), also known as the Middle Corridor, was studied as a multimodal route linking China and Europe through Central Asia, with rail and maritime components ensuring reduced delivery times (Kyrgyzstan plans to use TITR, 2024). In parallel, the Bedel Corridor project through the Bedel Pass (Kwan, 2025a; 2025b) into China's Xinjiang region was analysed as part of the One Belt, One Road initiative (One Belt, One Road..., n.d.), with emphasis on its modern customs infrastructure, logistics hubs and potential to improve Kyrgyzstan's transit role. The research also assessed Kazakhstan's logistics policy, in particular the expansion of southern railway lines and the construction of an industrial trade and logistics complex on the Kazakhstan-Kyrgyzstan border. The introduction of "green corridors" for agricultural products, simplified customs procedures and sanitary measures was investigated to evaluate institutional mechanisms for trade facilitation.

The study further traced long-term regional trade trends and the growing role of China as an external partner. The consequences of the COVID-19 pandemic for cross-border flows were examined, with emphasis on prolonged border crossing times, the introduction of quarantine inspections and rising transport expenses (Kim *et al.*, 2025). In addition, the effects of Kyrgyzstan's accession to the Eurasian Economic Union (EAEU) were examined, as this integration process reduced tariff barriers and expanded access to regional markets (Barnes, 2025).

Quantitative methods were applied to track the dynamics of bilateral trade volumes. Official trade statistics were collected for Kazakhstan's exports to Kyrgyzstan and Kyrgyzstan's exports to Kazakhstan for 2020-2024 (QazTrade, 2020a; 2020b; Observatory of economic complexity: Kazakhstan/Kyrgyzstan, 2023; Kyrgyzstan, Kazakhstan aim to significantly..., 2024). These data were used to monitor changes in the structure of exports and imports and to highlight the asymmetry in bilateral trade. Complete statistical data were available for the Talas region of Kyrgyzstan and the Zhambyl region of Kazakhstan, which enabled a quantitative assessment of investment dynamics and export flows. For the other regions – Zhetysu and Almaty in Kazakhstan, and Naryn and Issyk-Kul in Kyrgyzstan – statistical information was limited. This restricted the possibility of making comprehensive comparisons at the regional level and necessitated reliance on data for mutual export volumes at the national level as a basis for generalisation. A separate analytical focus was placed on the correlation between investment activity and export flows. Data on the dynamics of investments in Kyrgyzstan's Talas region and the country's exports to Kazakhstan in 2020-2024 were employed (Foreign direct investment..., n.d.). The relationship was tested using the Pearson correlation coefficient, calculated as:

$$r = \frac{\sum(xi-x)(yi-y)}{\sqrt{\sum(xi-x)^2(yi-y)^2}}, \quad (1)$$

where xi – represented investment volumes and yi – export values; x – denoted the arithmetic mean of investments over the period, and y – the arithmetic mean of export indicators. This method was applied to determine whether growth in investments in border regions was associated with an increase in cross-border trade flows.

The study also examined the factors of growth and risks for the sustainable development of border territories. For this purpose, official strategic documents were reviewed, including the State Program for Regional Development of the Republic of Kazakhstan for 2020-2025 (Kazakhstan: Strategic development plan..., 2018) and the National Development Strategy of Kyrgyzstan "Unity. Trust. Creation" (2018-2022) (Kyrgyzstan: Development Program..., 2018). The analysis of these programs made it possible to assess the institutional foundations of trade facilitation, infrastructural development, and regional competitiveness.

Results and Discussion

Dynamics and structure of cross-border trade flows in Central Asia

Trade relations between Kazakhstan and Kyrgyzstan have been determined by the presence of a system of major transport corridors and border checkpoints that ensure the movement of goods and contribute to regional interconnectivity. A central element of this network is the Middle Corridor, a multimodal route that links China with Europe through Central Asia. Combining rail connections with ferry crossings over the Caspian and Black Seas, the corridor shortens delivery times to approximately 20-25 days and indirectly supports bilateral trade by expanding available transit opportunities. At the same time, Kyrgyzstan has invested in the construction of the Bedel Corridor through the Bedel Pass towards China's Xinjiang province (Kwan, 2025b). This initiative has strengthened Kyrgyzstan's transit function, offering a faster and more reliable alternative to the Irkeshtam and Torugart routes, which often remain closed during winter. The Bedel project, integrated into the Belt and Road Initiative (One Belt, One Road..., n.d.), is financed through substantial Chinese investment and envisages the creation of advanced customs infrastructure, cargo control areas and services for transport operators. By reducing travel time by more than 12 hours and the overall distance by around 500 kilometres, the project is expected to deliver significant logistical and economic advantages (Kyrgyzstan plans to use TITR, 2024).

Kazakhstan's logistics policy complements these efforts by focusing on the expansion of southern railway lines to increase efficiency in cross-border flows. At the bilateral level, the Kazakhstan-Kyrgyzstan border hosts checkpoints such as Karasu and Ak-Tilek, where a large Industrial Trade and Logistics Complex is under construction. This hub is designed to be one of Central Asia's largest cargo distribution centres, enabling the consolidation, processing and transit of goods. In addition, "green-light" corridors have

been introduced for perishable agricultural goods, such as early-season fruit and vegetables, ensuring smooth delivery from Kyrgyzstan to Kazakhstan. Simplified customs procedures, health protocols and disinfection systems are applied to maintain the resilience of trade flows. Kazakhstan's geographical location provides a transit advantage, connecting not only Kyrgyzstan but also trade routes extending to Uzbekistan, Afghanistan and further south. This strengthens regional integration and supports Kazakhstan's ambition to expand bilateral trade with Kyrgyzstan to 3 billion USD annually by 2030. A significant share of this growth is expected to come from agriculture, particularly grain and flour exports from Kazakhstan, alongside Kyrgyzstan's role as a re-exporter of Chinese goods (Kwan, 2025a).

Similar dynamics can be observed in Kazakhstan-Uzbekistan trade, which is underpinned by the modernisation of transport corridors and border checkpoints. The TITR (n.d.), or the Middle Corridor, links Central Asia with Europe through Kazakhstan, the Caspian Sea, the South Caucasus and Turkey. Uzbekistan actively engages in this network whilst also diversifying its routes to the Indian Ocean via Afghanistan, Iran and Pakistan, thereby reducing dependency on northern transit lines. In 2024, bilateral trade between Kazakhstan and Uzbekistan surpassed 4 billion USD, with grain representing a major export from Kazakhstan. Investments in logistics hubs and checkpoints have supported these flows, strengthening regional trade integration.

The broader picture of long-term regional trade shows that, after the global crisis of 2008-2009, Central Asian exports began to recover around 2010, with Kazakhstan's exports growing at a compound annual rate of about 23%. However, structural barriers such as geographical remoteness, lack of direct access to seaports and underdeveloped infrastructure limited the region's full trade potential. Nevertheless, cooperation and integration initiatives gradually developed, focusing on trade facilitation, corridor expansion and the reduction of tariff and non-tariff barriers (Kazakhstan, Uzbekistan to open four..., 2025). Figure 1 demonstrates the TITR.

Figure 1. Trans-Caspian International Transport Route

Source: J.C.K. Daly (2025)

By 2024, trade dynamics in Central Asia were heavily shaped by China as the dominant partner. Trade turnover between China and Central Asia reached approximately 95 billion USD, more than triple the volume of 2014, with Kazakhstan accounting for 43.8 billion USD and Kyrgyzstan for 22.7 billion USD. China mainly exports manufactured goods, machinery and technology, whilst importing energy resources, metals and an increasing volume of agricultural products (Kazakhstan ranks first among China's Central..., 2025). Land-based transport rose from 19.9% of trade in 2020 to 51.8% in 2024 due to improved infrastructure. Despite this growth, challenges remain: Kazakhstan runs a trade deficit with China of around 12 billion USD, and Kyrgyzstan also faces a deficit despite a sharp increase in exports, as imports of consumer goods remain dominant. These trends underline both the opportunities and vulnerabilities of regional economies, showing that although China is a crucial driver of trade expansion, structural imbalances and infrastructure gaps persist (China, Central Asia witness deepened..., 2025).

In summary, the development of transport corridors such as the Middle Corridor and the Bedel project, the modernisation of checkpoints and logistics hubs, and the intensifying trade with China reflect the dual trajectory of Central Asia's cross-border trade: continuous growth alongside persistent asymmetries. Kazakhstan maintains a strategic advantage as a transit hub and exporter of diversified goods, whilst Kyrgyzstan strengthens its role through

re-exports and targeted infrastructure projects. Together, these processes highlight the region's gradual integration into Eurasian trade networks and its increasing dependence on external partners, especially China.

Between 2020 and 2022, cross-border trade in Central Asia encountered serious disruptions as a result of the COVID-19 pandemic, which led to longer delays, higher expenses and declining trade volumes. The average time required to cross borders rose by 23.7%, increasing from 12.2 hours in 2019 to 15.1 hours in 2020, largely due to quarantine procedures and mandatory testing. In states with more stringent restrictions, the clearance period for imported goods expanded by up to 40%, whilst export operations were indirectly hindered by broader regional "spill-over effects". This was accompanied by an increase in transport costs: road transport costs rose by 1.8%, rail transport by 1.9%. In a landlocked environment, this further increased the cost of trade for the region (Kim *et al.*, 2025).

A separate factor influencing trade dynamics was Kyrgyzstan's accession to the EAEU in 2015. Kazakhstan is one of Kyrgyzstan's key trading partners within the integration association: in 2016, it accounted for about 14.8% of Kyrgyzstan's total trade turnover, and in 2025, about 7.3% of Kazakhstan's trade with the EAEU countries. Participation in the union has provided a reduction in customs barriers, simplification of procedures and duty-free access to markets, which has contributed to the growth of trade in non-raw-material sectors. Kyrgyzstan has benefited from tariff preferences for Russian gas, which reduced energy costs compared to countries that are not EAEU members (Foreign trade turnover of the Republic..., 2025).

An additional factor was the use of the so-called "sanctions arbitrage" after 2022, when Kyrgyzstan began to play the role of a transit hub for the re-export of machinery and cars, which brought additional budget revenues of up to 3.3% of GDP. On average, in 2015-2023, Kyrgyzstan's GDP growth was 3.9% per year, which is partly explained by participation in the integration bloc. At the same time, the expected benefits were offset by external crises: the fall in oil prices and the impact of sanctions, which led to a reduction in intra-union trade by 26% in 2015. Kyrgyz exports lost competitiveness due to the devaluation of neighbouring currencies, and the country's political weight in decision-making remained limited. Labour migration also creates additional challenges: on the one hand, simplified access to the EAEU labour markets, and on the other, pressure on the social sphere and problems with informal employment (Barnes, 2025).

The dynamics of bilateral trade between Kazakhstan and Kyrgyzstan during 2018-2024 demonstrate both cyclical fluctuations and gradual growth. In 2018, the trade structure returned to the usual regional pattern: Kazakhstan maintained a stable surplus whilst Kyrgyzstan operated under a deficit. Kyrgyz exports to Kazakhstan reached around 327 million USD, dominated by precious metal ores, petroleum products and ferrous metals, whilst Kazakhstan exported 699 million USD worth of goods, led by gold, mineral waters and tobacco products. Despite positive growth rates over the subsequent five years – 11.3% annually for Kyrgyz exports and 9.23% for Kazakh exports – the beginning of 2018 was marked by a contraction in trade, with turnover for January-May decreasing by 10.5% compared to 2017. The year 2019 preserved these trends, as Kazakhstan continued to run a surplus and Kyrgyzstan a deficit. Trade volumes in mid-2019 were about 318 million USD, reflecting an 11% decline from the previous year. Kyrgyz exports consisted primarily of ores, dairy products and grains, but imports from Kazakhstan remained substantially higher (Observatory of economic complexity: Kazakhstan/Kyrgyzstan, 2023).

The COVID-19 pandemic in 2020 disrupted trade flows significantly. From January to August, turnover dropped to 489.2 million USD, 17.9% lower than in 2019. Kazakhstan's exports fell by 14% to 338.7 million USD, whilst Kyrgyzstan's exports decreased by 25.4% to 150.5 million USD. Although Kazakhstan preserved a positive balance of approximately 188.3 million USD, the surplus narrowed considerably (QazTrade, 2020b). Recovery began in 2021, when trade gradually stabilised, albeit with notable contributions from informal exchanges – estimated at 20-30% of total flows, particularly in petroleum products and grain. The year also witnessed an exceptional episode in June, when Kyrgyzstan temporarily registered a surplus of 230.5 million USD, the highest on record (Kyrgyzstan Trade Balance, n.d.). By 2022, mutual trade volumes expanded again, with Kazakhstan's exports reaching 600-700 million USD and Kyrgyzstan's 382 million USD. Kazakhstan's surplus was sustained by energy, food, engineering goods and metals, whilst Kyrgyzstan remained in deficit (Kyrgyz Republic trade balance, exports..., 2022). The upward trajectory strengthened in 2023 as bilateral trade turnover amounted to 1.317 billion USD, an 11.6% increase from the previous year. Kazakhstan exported 1.09 billion USD in goods, primarily gold (214 million), mineral waters (86.8 million) and tobacco products (54.2 million). Kyrgyz exports to Kazakhstan rose to 559 million USD, driven mainly by precious metal ores (159 million), petroleum products (46.3 million) and ferrous metals (42.1 million). As a result, Kazakhstan secured a surplus of about 530 million USD (Daryo, 2024).

In 2024, positive dynamics continued, with trade turnover for the first eleven months reaching approximately 1.6 billion USD. Kazakhstan's exports amounted to 772.5 million USD, whilst Kyrgyzstan's reached 382 million USD, leaving Kazakhstan with a positive balance and Kyrgyzstan facing a deficit of – 662 million USD in December 2024 (Seilkhanov, 2025). Figure 2 presents the dynamics of Kazakhstan-Kyrgyzstan trade for the years 2018, 2020, 2022-2024. The year 2018 is included as a reference point before the pandemic, 2020 reflects the sharp decline in trade flows caused by COVID-19 restrictions, whilst 2022-2024 illustrate the subsequent recovery and gradual expansion of bilateral trade.

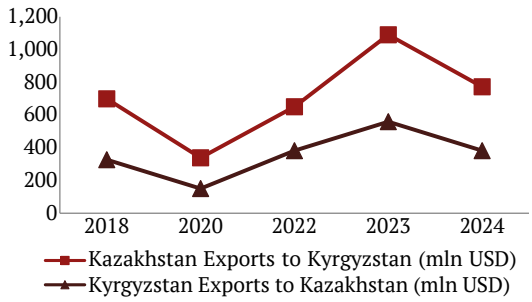

Figure 2. Dynamics of bilateral trade: Key years reflecting pre-COVID, pandemic, and post-COVID trends

Source: compiled by authors based on QazTrade (2020a; 2020b), Observatory of economic complexity: Kazakhstan/ Kyrgyzstan (2023), Daryo (2024), A. Seilkhanov (2025), Kyrgyzstan Trade Balance (n.d.)

The graph demonstrates the dynamics of mutual trade between Kazakhstan and Kyrgyzstan during 2018-2024, highlighting both cyclical declines and subsequent recovery. Kazakhstan consistently maintained higher export volumes, ensuring a trade surplus throughout the entire period. The lowest point was observed in 2020, when the COVID-19 pandemic led to a sharp contraction in bilateral flows, after which both countries experienced steady growth, peaking in 2023. In 2024, exports slightly decreased compared to the previous year but remained significantly higher than in the pre-pandemic period. Overall, the data confirm a stable upward trend in trade turnover with structural asymmetry, as Kazakhstan dominates bilateral trade due to its more diversified export base, whilst Kyrgyzstan's exports remain comparatively limited. Thus, during 2018-2024, bilateral trade between Kazakhstan and Kyrgyzstan showed a stable trend: Kazakhstan maintained a trade surplus due to a more diversified economy and exports of energy, metals and food, whilst Kyrgyzstan remained dependent on imports and recorded a deficit, with the exception of isolated episodes. Despite the imbalance, the dynamics of indicate an increase in trade volumes and the desire of both states to strengthen economic integration.

A number of studies have found a common view that cross-border trade is one of the key drivers of economic development. In particular, both this study and the work of Y. Chen (2024) confirmed that the growth of external flows contributed to the integration of countries into global value chains, but at the same time created additional risks. Both approaches emphasised the importance of regulatory reforms and infrastructure development, yet the difference lay in the scope of consideration: whilst this study focused on transport corridors and the impact of crisis events in Central Asia, Y. Chen examined digitalisation and the role of e-commerce in the growth of Chinese exports. Similar parallels were also found in the work of T. Zhu (2023). Both studies emphasised that cross-border e-commerce is a powerful catalyst for trade and requires updated regulatory mechanisms. However, in this case, the focus was on the logistics routes and structural challenges of Central Asia, whilst T. Zhu analysed the deeper changes in China's service sector, where the integration of e-commerce was accompanied by the need for harmonisation of rules and standards. The meaningful combination of logistics and digital tools became a point of intersection between this study and the work of H.Z. Ping *et al.* (2024). Both approaches emphasised the positive impact of Cross-Border E-Commerce (CBEC) on the economy and its role in opening up new markets. Nevertheless, whilst the focus of this study was on transport and customs processes in Central Asia, H.Z. Ping *et al*. concentrated on the economic effects for China, especially in less developed regions, where technological investment could be a crucial factor for growth.

A similar contrast was observed in the work of W. Wang *et al*. (2025). Both works recognised that cross-border trade and e-commerce required digitalisation and institutional support, yet the focus was significantly different. This study highlighted integration processes through the development of Central Asian transport corridors, whilst W. Wang *et al.* focused on the functioning of e-commerce pilot zones in China, showing their impact on reducing financial barriers for companies. A somewhat different dimension of analysis was presented by H. Paul *et al.* (2025). Whilst this study examined specific trade flows between Kazakhstan and Kyrgyzstan, the work of H. Paul *et al*. was global in nature. It systematised research on border economies, outlined conceptual approaches and highlighted gaps in the scientific literature, which made it possible to relate the local empirical dimension of Central Asia to the broader academic discourse.

A comparison with the work of L. Yang *et al.* (2024) demonstrated another plane of differences. The common understanding was that CBEC required digitalisation and institutional support. However, whilst this study focused on cross-border trade between Kazakhstan and Kyrgyzstan, L. Yang *et al*. employed the Global Entrepreneurship Monitor (GEM) model to quantitatively measure the competitiveness of different regions in China, revealing disparities between eastern and western provinces. No less revealing was the comparison with L. Wang (2020). In both cases, e-commerce was regarded as a factor of economic growth that reduced costs and facilitated integration into global markets. However, L. Wang concentrated on China's macroeconomic challenges – increasing competition, a crisis of confidence and the need to integrate online and offline formats – whilst this study focused on the regional logistics processes of Central Asia. The results of S. Li *et al.* (2025) showed that the high-quality development of CBEC depended on a combination of internal and external factors. Their analysis through fuzzy-set Qualitative Comparative Analysis enabled them to identify configurations that ensured the resilience of Chinese companies. In this sense, their work differed from the present study, which focused on interstate trade flows in Central Asia, but both approaches demonstrated a shared belief in the key role of digitalisation, logistics and institutional support for the effective development of cross-border trade.

Overall, the analysis showed that cross-border trade in Central Asia developed dynamically, relying on the expansion of transport corridors and the modernisation of customs infrastructure. Kazakhstan strengthened its position as a key transit hub, whilst Kyrgyzstan actively formed the role of an intermediary through new routes and projects within the framework of the "One Belt, One Road" initiative. Alongside positive trends, the region's vulnerability was also observed – dependence on China, structural imbalances and the impact of external crises. Taken together, these processes reflected the dual nature of development: the growth of trade volumes was combined with asymmetries and challenges to the sustainability of economic integration.

The impact of cross-border trade on the economic development of border regions

Cross-border trade between Kazakhstan and Kyrgyzstan in 2020-2024 was characterised by a stable positive balance for Kazakhstan and a chronic deficit for Kyrgyzstan. At the same time, the key direction remained cooperation between the Talas region of Kyrgyzstan and the Zhambyl region of Kazakhstan, where joint programmes for optimising cargo flows and developing agricultural partnerships were being implemented in 2024. Despite the lack of detailed regional data for other regions (Zhetysu, Almaty, Naryn, Issyk-Kul), national trade trends allow one to trace a certain correlation between the growth of mutual trade volumes and the dynamics of key economic indicators of border territories.

Thus, Kyrgyzstan is characterised by a high dependence on imports from Kazakhstan, which determines its persistent trade deficit. At the regional level, the most illustrative example is the Talas region, where investment volumes increased from USD 36.6 million in 2020 to a peak of USD 127.9 million in 2022, after which there was a gradual decrease to USD 107.1 million in 2024. The dynamics of these indicators indicate a close relationship with general trade trends: the period of active investment growth coincides with the phase of growth of Kyrgyzstan's exports to Kazakhstan (from USD 170.5 million in 2020 to USD 559 million in 2023-2024) (Kyrgyzstan, Kazakhstan aim to significantly..., 2024). Table 1 demonstrates the dynamics of investments in the Talas region and Kyrgyzstan's exports to Kazakhstan, 2020-2024.

Table 1. Dynamics of investments in Talas region and Kyrgyzstan's exports to Kazakhstan, 2020-2024

Year	Investments (mln USD)	Exports to Kazakhstan (mln USD)
2020	36,581.40	170.5
2021	81,845.50	382
2022	127,900.80	411
2023	117,547.80	559
2024	107,162.10	559

Source: compiled by authors based on Foreign direct investment by territory (n.d.), QazTrade (2020a; 2020b), Daryo (2024), Kyrgyzstan, Kazakhstan aim to significantly boost trade turnover (2024)

Correlation analysis of the data obtained showed a close positive relationship between the dynamics of investments in the Talas region and the volume of exports from Kyrgyzstan to Kazakhstan. The calculated correlation coefficient for the period 2020-2024 is 0.84, which indicates a strong dependence of the growth of foreign trade flows on the scale of investment activity in the border region (formula 1). For Kazakhstan, a similar dynamic is illustrated by the Zhetysu region, formed in 2022. In the first half of 2024, its gross regional product grew by 5.6% compared to 2023, the volume of investments reached USD 641.4 million, and foreign trade turnover amounted to almost USD 3 billion. The average wage exceeded USD 330 per month, and the unemployment rate remained relatively low – about 4.7% (Abuova, 2024). Such indicators demonstrate the growing economic activity of the region and confirm the direct connection between the expansion of the investment base, an increase in the gross regional product and the intensification of cross-border trade flows, in particular with Kyrgyzstan.

In summary, the results of the correlation analysis confirm that in the border regions of Kyrgyzstan, particularly Talas Oblast, the growth in investment is directly related to the increase in exports to Kazakhstan, reflecting the mutual stimulation of trade and regional development. In the border regions of Kazakhstan, such as Zhetysu Oblast, a similar trend is observed: the growth in investment and gross regional product is accompanied by the revival of foreign trade operations. This indicates that the effects of cross-border trade extend beyond macroeconomic indicators, creating tangible changes at the level of regional economies and laying the foundations for further deepening of integration processes in Central Asia.

Between 2020 and 2024, the development of border territories of Kazakhstan and Kyrgyzstan was shaped by a combination of favourable growth drivers and persistent structural risks. Among the decisive factors stimulating regional progress were national programmes directed at strengthening border economies. In Kazakhstan, the State Programme for Regional Development of the Republic of Kazakhstan for 2020-2025 (Kazakhstan: Strategic development plan..., 2018) allocated resources for infrastructure modernisation, the improvement of transport corridors, and the attraction of investment flows into strategically important areas such as Zhambyl and Zhetysu. These measures created the prerequisites for expanding cross-border trade with Kyrgyzstan by enhancing logistical capacity and production potential.

In Kyrgyzstan, a comparable role was performed by the National Development Strategy of Kyrgyzstan "Unity. Trust. Creation" (2018-2022) (Kyrgyzstan: Development Program..., 2018), which prioritised regional economic competitiveness and resilience. The strategy facilitated improvements in the business environment for small and medium-sized enterprises located in the border zones and stimulated growth in agriculture and entrepreneurship. These processes were directly connected with the intensification of exports to Kazakhstan, as border regions strengthened their capacity to integrate into bilateral trade flows. Other growth factors include increased investment flows, the expansion of agricultural production, and the development of infrastructure and tourism in the border regions. However, there are also significant risks: Kyrgyzstan's high dependence on energy imports from Kazakhstan, extensive informal trade, and the vulnerability of the regions to external shocks, including price fluctuations and logistical constraints. Thus, the analysis confirms that the implementation of state development programmes in both countries contributes to strengthening the economic potential of the border areas, whilst maintaining the need to reduce structural risks and increase the resilience of these regions to external challenges.

A comparison of this study with a number of works by foreign authors showed that what they had in common was the recognition of cross-border trade as a key factor in economic development. Both the work of A. Karagkouni & D. Dimitriou (2025) and this study emphasised the need for modern infrastructure, digitalisation and regulatory reforms. However, whilst for Central Asia transport corridors, customs reforms and China's external influence were crucial, in the European context the focus was on the micro level – barriers to small businesses, innovation and environmental practices. A similar difference was also observed in a comparison with the work of C. Gao *et al.* (2025). Both approaches emphasised the importance of infrastructure investments and state support for the economic and social development of border regions. However, whilst in Central Asia the resilience of trade in times of crisis was crucial, a Chinese study based on machine learning methods found a direct effect of rail trade on urbanisation in ethnic regions. A different perspective was provided by a comparison with the work of J. Xiong & X. Wang (2023). All studies emphasised the importance of institutional support and reforms, but whilst in Central Asia the focus was on logistics and cross-border flows, in China integration was viewed through the transformation of enterprises and their adaptation to global competition.

Digitalisation as a factor of development became a point of intersection between this study and the work of J. Liu & G. Chen (2025). Both approaches considered it a driver of economic growth, although the directions of analysis differed: in Central Asia it was transport corridors and customs reforms, whilst in China it was the impact of the digital economy on the agricultural sector and export growth. A similar logic was demonstrated by the work of D.G. Borojo & H. Weimin (2025). Like this study, it focused on reducing trade costs through digitalisation and logistics development. However, the difference was in scale: for Central Asia, regional corridors and interaction with China were analysed, whilst in the case of China and Africa, the key factor was the combination of digital platforms with differing levels of institutional quality across African states.

Regional contrasts became even more pronounced when compared with the work of Z.M. Gnoleba (2022). Both approaches confirmed that cross-border trade stimulated integration into global value chains, but whilst in Central Asia the main drivers were infrastructure and Chinese influence, for West Africa the decisive elements were currency regimes, population incomes and demographic factors. A different set of challenges was highlighted by the work of C. Mendoza & J. Domínguez-Mujica (2025). In both cases, the importance of cross-border cooperation was emphasised, but in Central Asia it was determined by infrastructure projects and geopolitical factors, whereas in the border regions of Spain the main problem was depopulation and the need to attract migrants who could support the local economies. Similarly, the work of P. Chamusca (2024) highlighted the positive impact of cross-border cooperation on development, but emphasised the European experience. Whilst in Central Asia the priority was transport projects and the growing dependence on China, in Portugal and Spain EU programmes played a key role in promoting employment, innovation and cohesion in border areas.

In 2020-2024, the development of cross-border trade between Kazakhstan and Kyrgyzstan displayed stable dynamics, but remained structurally asymmetric: Kazakhstan maintained a stable surplus, whilst Kyrgyzstan was characterised by a chronic deficit. At the same time, the examples of Talas and Zhetysu regions demonstrated that the growth of investments was directly correlated with the revival of exports and the expansion of economic activity in border areas, which is confirmed by the high level of correlation between indicators. State development programmes, which focused on infrastructure modernisation, support for small and medium-sized enterprises, and stimulation of agricultural production, were among the factors influencing this process.

Conclusions

The findings of this study confirmed that the development of border trade between Kazakhstan and Kyrgyzstan in 2018-2024 was stable but structurally asymmetric. Kazakhstan maintained a consistent positive balance, whilst Kyrgyzstan demonstrated a chronic deficit. In 2019, its exports to Kazakhstan amounted to only USD 327 million, whilst in 2023-2024 they increased to USD 559 million, but remained significantly lower than imports. The structure of exports remained relatively stable: on the Kazakh side, grain and flour prevailed (in 2023 – 40.4 thousand tonnes of grain and 53.2 thousand tonnes of flour), as well as gold, tobacco products and mineral waters, whilst more than 90% of imports from Kyrgyzstan comprised precious metal ores and petroleum products.

In Kyrgyzstan's Talas region, investment inflows rose from USD 36.6 million in 2020 to a maximum of USD 127.9 million in 2022, followed by a decline to USD 107.1 million in 2024. The correlation analysis revealed a strong positive linkage between investment dynamics and export performance (correlation coefficient of 0.84), underscoring the reciprocal reinforcement of trade expansion and regional economic growth. Comparable tendencies were identified in Kazakhstan's Zhetysu region, where in 2024 the gross regional product increased by 5.6%, the volume of investments amounted to USD 641.4 million, and foreign trade turnover approached USD 3 billion, whilst unemployment remained at a relatively low level of 4.7%.

Thus, the results confirmed that the development of transport corridors, the modernisation of customs infrastructure and government programmes contributed to the intensification of cross-border trade. A limitation of this study was that it relied mainly on official statistics for 2018-2024 and had limited regional data for border areas. Future research could expand the analysis to other border regions of Central Asia and take into account the impact of digitalisation and new e-commerce formats on trade development.

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Дослідження ролі транскордонної торгівлі в економічному зростанні прикордонних регіонів Центральної Азії

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Анотація. Метою цього дослідження було визначити, як торговельні потоки та інтеграційні процеси вплинули на соціально-економічний розвиток прикордонних регіонів Центральної Азії. Методологія ґрунтувалася на аналізі офіційної статистики та застосуванні кореляційного підходу для виявлення залежностей між інвестиціями та експортними потоками. Результати дослідження продемонстрували, що торгівля між Казахстаном і Киргизстаном залишалася структурно асиметричною: у 2019 році експорт Киргизстану становив 327 мільйонів доларів США, а до 2023-2024 років він зріс до 559 мільйонів доларів США, але імпорт із Казахстану був значно вищим, що спричиняло постійний дефіцит. Експорт Казахстану включав зерно та борошно (лише у 2023 році – 40,4 тис. тонн зерна та 53,2 тис. тонн борошна), золото, тютюнові вироби та мінеральні води, тоді як понад 90 % киргизького експорту складалося з руд дорогоцінних металів і нафтопродуктів. У Талаській області інвестиції зросли з 36,6 млн доларів США у 2020 році до 127,9 млн доларів США у 2022 році, перш ніж знизитися до 107,1 млн доларів США у 2024 році. Кореляційний аналіз підтвердив сильний зв'язок між інвестиційною активністю та експортом (коефіцієнт 0,84). У Жетисуській області Казахстану у 2024 році валовий регіональний продукт збільшився на 5,6 %, інвестиції досягли 641,4 млн доларів США, а зовнішньоторговельний обіг наблизився до 3 мільярдів доларів США, що супроводжувалося низьким рівнем безробіття у 4,7 %. Результати можуть бути використані державними органами, регіональними адміністраціями та міжнародними організаціями при розробці стратегій, спрямованих на підвищення ефективності транскордонної торгівлі та інвестиційної політики

Ключові слова: транспортні коридори; інвестиції; інфраструктура; логістика; експорт; імпорт

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Development of startup ecosystems in Ukraine and the European Union: Challenges and opportunities

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Abstract. The relevance of the researched problem is determined by the role of startup ecosystems as key drivers of innovation and economic development, fostering technological progress and addressing global challenges through sustainable practices and entrepreneurial activity. The article aimed to analyse the challenges and opportunities for the development of startup ecosystems in Ukraine and the European Union, with emphasis on their comparative strengths, barriers, and growth strategies. To achieve this aim, comparative analysis, a systems approach, and the synthesis of data from official reports, academic sources, and industry surveys were applied. It was found that the EU has a mature, diverse, and well-funded ecosystem with leading hubs in Berlin, Paris, and Amsterdam, supported by institutional programmes such as Horizon Europe. The EU ecosystem was shown to grow from around 60,000 startups and 50 unicorns in 2020 to 75,000 startups and 110 unicorns in 2023, with investments amounting to approximately $20 billion. In contrast, the Ukrainian ecosystem was characterised by dynamism and significant IT expertise, with 30% of startups concentrated in Software/SaaS and 15% in FinTech, but its development was constrained by political instability, limited access to capital, and challenges in scaling to global markets. It was established that the agility and innovative capacity of Ukraine's technology sector can complement the EU's structured markets and regulatory framework. Mutual benefits were highlighted through the combination of institutional support and market access with Ukraine's resourceful and cost-effective talent pool. Emerging sectors such as GreenTech, AI, and FinTech were identified as promising areas for collaboration, while cross-border cooperation, coherent policies, and targeted investments were emphasised as crucial strategies for sustainable growth and resilience. The practical significance of the research lies in its applicability for policymakers, investors, and entrepreneurs in designing strategies to foster collaboration, enhance startup ecosystem development, and unlock the economic potential of partnerships between Ukraine and the EU

Keywords: economic development; innovation; technology; venture capital; entrepreneurship; collaboration

Introduction

The development of startup ecosystems is a key factor in ensuring innovation-driven growth, enhancing economic competitiveness, and integrating national markets into the global space. For Ukraine, this topic is of particular importance in the context of post-war reconstruction, attracting investment, and accelerating the processes of European integration. For the European Union, the relevance of studying startup ecosystems is driven by the need to overcome internal barriers, strengthen regional cohesion, and create conditions for sustainable development under global competition. The rapid expansion of sectors such as GreenTech, FinTech, and artificial intelligence (AI) underscores the transformative role of startups in shaping future economic trajectories. At the same time, the resilience of startup ecosystems has become a decisive factor in responding to global crises, fostering adaptability, and sustaining long-term growth.

Academic literature demonstrates growing interest in the study of startup ecosystems in Ukraine and the EU. V. Tropina & N. Yevtushenko (2023) analysed the current

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state of innovation cooperation between Ukraine and the EU, emphasising the importance of creating favourable organisational and institutional conditions for integrating Ukraine's innovation system into the European space. The authors outlined promising directions for such cooperation but did not address the practical mechanisms of adapting Ukrainian startups to European standards. A. Kuzior *et al.* (2022) examined the specifics of EU innovation policy and assess the national innovation ecosystems of member states and Ukraine, drawing on data from the European Innovation Scoreboard (2025). The authors provided several policy recommendations for Ukraine; however, their findings required further elaboration in terms of practical tools for post-war recovery and strengthening startup competitiveness.

C. Ziakis *et al.* (2022) introduced the StUpEco conceptual model, which explained the structure and functioning of EU startup ecosystems. Their research identified institutional and network factors that determined ecosystem success and provided a valuable theoretical framework for analysing startup development. However, the question of how this model could be adapted to the Ukrainian context, particularly in the framework of European integration and candidate country aspirations, remained open and required further applied research. T. Kharchuk *et al.* (2025) examined the reproduction of Ukraine's business potential under wartime conditions and in the context of European integration. Their research highlighted strategies of business adaptation to crises but paid limited attention to long-term approaches for sustainable startup sector development and underestimated the role of startups as key drivers of innovation in these processes. Researchers O. Kolodiziev *et al.* (2024) investigated the phenomenon of "refugee startups" and their economic adaptation in host countries. Their analysis demonstrated how displaced entrepreneurs designed business models to integrate into new markets and support host economies, but it did not explore the potential of reintegrating such ventures into Ukraine's post-war economy. M. Diha *et al.* (2024) described the dynamic growth of Ukrainian startups in IT, blockchain, agritech, and medicine. They emphasised multimillion-dollar investments, the importance of strong teams, and effective risk management, but left unresolved the issue of how Ukrainian startups could meet the requirements of European investors under infrastructural and regulatory constraints. A.M. Tkachenko *et al.* (2020) emphasised the economic significance of energy saving as a strategic component in the development of Ukrainian enterprises. Their work demonstrated how energy efficiency contributes not only to cost reduction but also to long-term competitiveness. However, the study did not explicitly address how such strategic approaches can be linked to the start-up ecosystem or to broader innovation-driven growth.

V. Menshikov *et al.* (2024) analysed the development of startup ecosystems across selected countries, with a particular focus on case-based comparisons. They underlined the importance of institutional support, access to finance, and entrepreneurial culture as decisive factors in ecosystem performance. Yet, their analysis did not fully consider the specific challenges faced by emerging ecosystems, such as Ukraine's, in aligning with European models. E. Skawińska & R. Zalewski (2020) investigated the success factors of startups within the European Union, offering a comparative perspective on what drives their growth and resilience. The authors highlighted factors such as innovation capacity, managerial flexibility, and adaptability to regulatory environments. While valuable, their findings remain primarily at the EU level, leaving open the question of how these insights can be applied to transition economies undergoing structural transformation. Z. Zavarská *et al.* (2024) focused on innovation systems and policies in Central and Eastern European EU member states, analysing their capacity for innovation-driven growth. The report stressed the role of policy coherence, research and development investment, and cross-border collaboration in fostering innovative capacity. Nevertheless, the study concentrated on EU members and provides limited attention to non-member states like Ukraine, which face unique integration and resilience challenges. A summary of the results of these studies indicates a number of unresolved issues: insufficient development of practical mechanisms for integrating Ukrainian start-ups into the European innovation space, lack of comprehensive approaches to forming cross-border cooperation networks, and the need for strategic decisions for long-term development in the context of post-conflict reconstruction.

Startup ecosystems have become an essential driver of economic growth, innovative solutions, and integration into global markets. For Ukraine and the European Union (EU), this topic is particularly relevant, as the development of entrepreneurial initiatives determines economic competitiveness, stimulates technological breakthroughs, and creates new opportunities for cooperation. At the same time, both regions are affected by common and specific challenges, which highlights the need for a comprehensive analysis of their ecosystems, identification of intersections, and pathways for further integration. The purpose of this article was to identify common and specific problems of the startup ecosystems of Ukraine and the European Union, outline prospects for development, and formulate proposals for organisational and political mechanisms that can ensure their sustainable functioning and mutual integration.

Materials and Methods

The study uses a wide range of sources that provide comprehensive coverage of the development of start-up ecosystems in Ukraine and the European Union. The main sources were analytical reports from consulting companies and industry associations (Consortium of Ukraine's leading..., 2020; Civitta, 2025; Digital Tiger 2024, 2025), which provided up-to-date statistics on the number of start-ups, venture capital investment volumes and sector

dynamics. In addition, several official EU and Ukrainian documents were used, including the European Commission (n.d.a), European Commission (n.d.b) and Digital Europe Programme (n.d.), as well as legislative initiatives such as the Startup Law in Spain (2022, December). Statistical data were also derived from international organisations and open databases, including the European Innovation Scoreboard (2025) and the Global Innovation Index (2025). Other sources were scientific articles in peer-reviewed publications, which helped identify key concepts, success factors and barriers to the development of innovative ecosystems. The study employed a corpus of scholarly publications devoted to the development of innovation and start-up ecosystems. In particular, works by M. Schrijvers *et al.* (2024), S. Primario *et al.* (2024), and R. Kumari *et al.* (2025) were utilised to construct the theoretical framework of the research. These studies provided conceptual approaches for assessing the performance of entrepreneurial ecosystems, understanding modes of interaction among ecosystem participants, and evaluating the contribution of entrepreneurial ecosystems to regional economic development. They served as the basis for identifying key success factors, structural characteristics, and parameters for the subsequent comparative analysis. They were selected based on three main criteria: relevance of the topic (works directly related to startups, innovation ecosystems, and economic integration between Ukraine and the EU); scientific novelty and relevance (sources from 2020-2024 reflecting the latest trends); reliability and representativeness of data (use of official statistics and internationally recognised sources).

The methodological basis of the study relied on a review, analytical, and comparative approach, which made it possible to compare the indicators of startup ecosystem development in different EU countries such as Germany, France, Netherlands, Sweden, Spain, Portugal, Ukraine and UK. Elements of resource-based theory of strategic management were used to interpret competitive advantages, which made it possible to identify key intangible resources (intellectual capital, innovation potential, entrepreneurial competencies). The structure of the study was built around three blocks: 1) barriers to development (access to financing, talent drain, regulatory complexity, market fragmentation); 2) transformation trends (GreenTech, digitalisation, DeFi, development of regional hubs); 3) opportunities and prospects (joint investment programs, integration into European clusters, creation of joint innovation projects). The limitations of the analysis lied in its dependence on available statistical data, which sometimes has a time lag (for example, investment statistics for 2022-2023 may not fully reflect the situation in 2024-2025), as well as the lack of access to micro-level data on individual startups due to commercial confidentiality. In order to include an empirical component, the study used statistical indicators illustrating the dynamics of the number of startups in the EU, the sectoral structure of Ukrainian startups, examples of successful companies such as Grammarly (n.d.) and GitLab (n.d.), Revolut (n.d.) and Klarna (n.d.), which illustrate the potential of ecosystems to create globally competitive players. Thus, the combination of theoretical analysis, a comparative approach, and the use of empirical data made it possible to form a comprehensive picture of the state and prospects of the development of startup ecosystems in Ukraine and the European Union.

Results

A comprehensive study and in-depth understanding of startup ecosystems played a key role in making countries more attractive to international investors. This, in turn, facilitates capital inflows that spur economic growth and accelerate technological innovation. Thriving startup ecosystems foster job creation, entrepreneurship, and economic development. The impact of the ecosystem on the growth and sustainability of startups allowed us to evaluate different strategies for strengthening innovation hubs, creating an environment that supported long-term economic sustainability and social progress. In order to determine the level of development of the competitive potential of startups, it was necessary to identify not only the characteristic features of startup businesses, but also, first of all, their key success factors. The resource-based approach of strategic management theories assumes that this advantage was the result of key tangible and intangible resources. Based on the analysis of literature A.V. Karpenko & R.V. Sevastyanov (2022) and Z. Zavarská *et al.* (2024), eight types of competitive advantages as success factors were systematised, namely: innovation, entrepreneurial, resource, competence, intellectual capital, sustainable development, content management, and information advantages. It was also suggested that there are differences in the situation in catching-up countries and more developed EU member states.

By addressing these interconnected challenges and leveraging emerging opportunities, Ukraine and the EU can enhance their ecosystems, driving innovation and fostering economic resilience (Table 1). The startup ecosystems of Ukraine and the European Union (EU) were undergoing significant transformations, driven by global trends and regional dynamics that create new opportunities for growth. Among these, the development of green technologies has attracted particular attention as a key area of innovation. The increasing demand for sustainable solutions presented vast potential for startups focused on renewable energy, the circular economy, and ESG-driven innovations. Ukraine, with its rich natural resources and skilled workforce, had the capacity to become a key player in renewable energy, particularly in wind and solar power. Meanwhile, the EU continued to lead the way in green technology thanks to ambitious initiatives such as the European Commission (n.d.b.) and funding programs such as Horizon Europe, which prioritised sustainable innovation. Joint investments by Ukraine and the EU, tax incentives, and knowledge-sharing platforms could further accelerate progress in this sector.

Table 1. Key challenges for start-ups in the EU and Ukraine

Barrier	EU startups	Ukrainian startups
Access to funding	Most money goes to rich regions; smaller areas don't get much	Very little investment; war and risks make it worse
Talent shortages	Big companies hire most skilled workers; rules make moving workers across countries hard	Many skilled workers leave the country
Regulatory complexity	Different laws in each country make it hard to grow	Rules are unclear and not flexible
Market fragmentation	Different languages and cultures make cross-border growth hard	Same problem – hard to grow across regions

Source: developed by the author based on M. Greenacre (2025), A. Zaikin (n.d.)

Access to funding remained a critical barrier for start-ups, impacting their ability to scale and compete in global markets. In Ukraine, early-stage funding was particularly limited due to a nascent venture capital ecosystem and an over-reliance on external investors. This dependency often led to challenges in retaining intellectual property and skilled talent within the country, creating vulnerabilities in long-term innovation and economic growth. Conversely, while the EU benefits from substantial investment volumes, disparities in funding distribution were a persistent issue. Established hubs such as Berlin and Paris attracted a disproportionate share of capital, leaving startups in peripheral regions underserved. This imbalance restricted opportunities for less-developed areas to fully participate in the global startup landscape, undermining regional equity and cohesion. Talent shortages further exacerbate these challenges, as human capital was fundamental to the success of any startup ecosystem. Ukraine faced significant brain drain, with skilled professionals emigrating to pursue better opportunities abroad. This migration diminished the local talent pool, limiting the capacity of startups to grow and innovate. In the EU, while the region boasts a highly educated workforce, startups often struggled to compete with multinational corporations offering higher salaries and superior benefits. Additionally, bureaucratic obstacles to hiring international talent constrain efforted to build diverse, competitive teams, further limiting the dynamism of the ecosystem. Regulatory and market fragmentation posed additional hurdles for startups. In Ukraine, inconsistent enforcement of regulations and bureaucratic inefficiencies delayed business operations and inflated operational costs, deterring both domestic and foreign entrepreneurs. In the EU, despite efforts at harmonisation, the regulatory landscape remained fragmented, with each member state maintaining distinct legal frameworks and compliance requirements. This lack of uniformity created barriers for startups seeking to scale across borders, imposing significant financial and administrative burdens that stifle innovation and growth.

Digital transformation was another pivotal trend, with AI, fintech, and health tech driving innovation globally. Ukraine's robust IT industry aligned well with these trends, positioning the country as a hub for AI development, software outsourcing, and fintech solutions. The skilled and cost-effective workforce was a significant advantage. In parallel, the EU benefited from well-structured regulatory frameworks and digital initiatives, such as the Digital Europe Programme (n.d.), which supported the adoption of advanced technologies. Enhanced market access for Ukrainian startups, targeted upskilling programs, and public-private partnerships in health tech could deepen the impact of digital transformation in both ecosystems. Decentralised Finance (DeFi) and blockchain were also gaining traction in Ukraine and the EU, offering innovative solutions in financial inclusion, digital identities, and payment systems (Blockchain Observatory & Forum: Conclusion report, 2024). Ukraine's proactive approach to cryptocurrency and blockchain adoption positions was as a regional leader, while the EU provided a secure regulatory environment for blockchain startups. Collaborative frameworks and pilot projects for blockchain applications, particularly in public services, could strengthen these advancements.

Emerging regional hubs were reshaping the innovation landscape. In Ukraine, cities like Lviv and Kyiv were becoming vibrant tech ecosystems, driven by concentrated talent and growing international interest, though infrastructure and funding access remain challenges. Similarly, non-traditional hubs in the EU, such as Barcelona, Stockholm, and Lisbon, were diversifying the region's startup environment with competitive tax regimes and dynamic entrepreneurial networks (How European tech hubs..., 2025). Strengthening infrastructure in Ukrainian hubs and fostering collaborations between EU and Ukrainian cities could further enhance these ecosystems. Cross-border collaboration between Ukraine and the EU offered immense potential for mutual growth. Ukraine's technical expertise and cost-effective workforce complement the EU's structured markets, regulatory support, and funding opportunities. By co-financing joint projects, creating innovation clusters, and streamlining mobility for startup founders and talent, the two regions could leverage their strengths to foster a more integrated and resilient startup ecosystem (EIIT, 2023). This collaborative approach promised not only to drive innovation but also to contribute to sustainable economic development and global competitiveness.

Infrastructure deficiencies also hinder the development of robust startup ecosystems. In Ukraine, the shortage of incubators, accelerators, and coworking spaces outside major cities like Kyiv and Lviv restricted access to critical resources such as mentorship, funding, and collaboration networks. While the EU generally offered more developed infrastructure, significant disparities persist between core

and peripheral regions. Startups located outside established centres faced a lack of resources, which limited their competitive potential and exacerbated existing inequalities in the ecosystem. Addressing these gaps in infrastructure was essential to fostering a more inclusive and dynamic startup environment (Horban & Bilenko, 2025).

Several promising sectors were driving growth opportunities for startups in Ukraine and the EU, despite the challenges faced by these ecosystems. A. Kuzior *et al.* (2022) noted that sustainable innovation has become a strategic priority for both regions, with GreenTech emerging as a critical area of innovation, fuelled by global sustainability goals of the European Commission (n.d.b) and a rising demand for eco-friendly solutions from consumers and industries alike. In Ukraine, a similar emphasis on energy efficiency and environmentally responsible production is reflected in research on the economic significance of energy saving for enterprise competitiveness (Tkachenko *et al.*, 2020). Startups in this sector were advancing renewable energy technologies, circular economy innovations, and environmentally sustainable practices. Similarly, AI and financial technology (FinTech) were dominating the innovation landscape, with significant progress in automation, data analytics, and decentralised finance. HealthTech was also a rapidly growing field, propelled by increased demand for telemedicine services, wearable health devices, and personalised healthcare solutions, particularly in the wake of global health crises. These sectors presented significant opportunities for both regions to drive technological progress and address critical societal needs.

Cross-border collaborations between Ukrainian and EU startups offered substantial benefits for both parties. According to I.G. Lukianenko & Y.S. Sova (2024), Ukraine's tech ecosystem demonstrated strong adaptability and competitiveness even under wartime conditions, which made it an attractive partner for European companies. A. Kuzior *et al.* (2022) also emphasised that the growing complementarity between the Ukrainian and EU innovation ecosystems supports sustainable development and deepens economic integration. As a result, Ukrainian startups gained access to larger, structured markets in the EU, enabling them to scale their operations and attract international investors. In turn, EU companies benefited from Ukraine's highly skilled workforce and cost-effective technical expertise, which enhanced their ability to develop innovative solutions. Joint ventures, shared innovation projects, and strategic partnerships were facilitating greater economic integration, fostering mutual growth, and strengthening ties between the two regions.

Policy reforms were playing a pivotal role in shaping a more favourable environment for startups. In Ukraine, the government had prioritised digital transformation, streamlining administrative processes to make it easier for entrepreneurs to establish and operate businesses, as highlighted by M. Diha *et al.* (2024). Reforms in areas such as taxation and intellectual property rights were further enhancing the startup climate, supporting the reproduction of business potential even amidst wartime challenges (Kharchuk *et al.*, 2025). The EU was similarly advancing regulatory harmonisation, with initiatives like the Digital Single Market aiming to eliminate cross-border barriers and created a unified space for innovation. These policy advancements were fostering conditions conducive to entrepreneurial activity and enabling startups to thrive in an increasingly interconnected global economy.

Spain's startup ecosystem has experienced considerable growth but continues to face structural challenges in securing early-stage funding. Venture capital activity, while on the rise, was characterised by comparatively smaller ticket sizes than those found in more mature ecosystems across Northern and Central Europe. This limitation restricted the scaling potential of high-growth ventures. Nevertheless, policy interventions from the Spanish government, in collaboration with the European Investment Fund, were increasingly improving access to capital and supporting the development of the innovation economy. Across the European Union, disparities in investment levels remained evident. Countries such as Germany, the Netherlands, and the Nordic states continued to dominate venture capital inflows, while Southern and Eastern European countries struggled to attract comparable levels of investment. This imbalance undermined cohesion across the EU's innovation landscape. Accelerators were strategically aimed at narrowing these gaps by incentivising cross-border investments and supporting startups in less capitalised regions. Talent availability in Spain was shaped by a combination of strengths and limitations. The country benefited from a well-educated workforce, but faced a shortfall in experienced professionals in high-demand fields such as AI, deep technology, and advanced software engineering. Moreover, Spain's tax treatment of stock options discouraged equity-based compensation strategies, thereby hindering talent retention. Despite these challenges, the country's relatively low cost of living and high quality of life continued to attract foreign professionals, partially offsetting domestic talent shortages. Within the EU, labour mobility has improved through initiatives such as the EU Blue Card system, yet it was still hindered by bureaucratic and legal fragmentation. Differences in national taxation, employment regulation, and residency procedures complicated the movement of skilled labour, particularly in innovation-intensive sectors. In addition, many Eastern European countries faced a constant outflow of skilled workers, as specialists moved to more economically developed regions, exacerbating the imbalance in human capital within the Union (Font-Cot *et al.*, 2023).

Spain's regulatory framework remained a significant obstacle to entrepreneurial activity. Cumbersome administrative procedures, including delays in company registration and complex tax compliance requirements, contributed to inefficiencies that slow startup formation and scaling. In response, the Law of Spain No. 28 (2022) has introduced targeted reforms to reduce bureaucratic burdens, incentivise innovation, and attract international

entrepreneurs through favourable visa regimes. These policy developments suggested a move toward a more supportive business environment, though implementation challenges remain. At the EU level, regulatory heterogeneity continued to present barriers to the creation of a unified digital economy. Startups faced difficulties navigating the varied legal environments, particularly with respect to data protection (GDPR), labour laws, and taxation. In an effort to address these challenges, the European Commission has introduced the Digital Markets Act and is actively pursuing regulatory harmonisation through the Single Digital Market strategy, aimed at streamlining cross-border operations and enhancing legal coherence. Spain offered a sizable domestic market, yet startups were frequently dependent on international expansion to achieve scalable growth. However, limited English proficiency among the population and business leaders may constrain global outreach. Conversely, Spain's strong cultural and linguistic connections with Latin America provided a distinct comparative advantage for internationalisation, offering access to high-growth emerging markets that share institutional and linguistic affinities.

Throughout the EU, startups encountered a fragmented market environment shaped by divergent consumer preferences, legal systems, and linguistic diversity. These factors can obstruct the realisation of pan-European business strategies. Nevertheless, the Single European Market offered substantial opportunities for cross-border growth by reducing trade and regulatory barriers among member states, positioning the EU as one of the most accessible and integrated economic blocs globally. Spain continued to underperform in research and development investment relative to other major EU economies. Both public and private sector contributions to R&D remained low, and collaboration between academic institutions and industry actors was often limited. However, the country increasingly benefited from EU-level funding instruments, particularly Horizon Europe (European Commission, n.d.a), which promote knowledge transfer and transnational research initiatives. Innovation performance across the EU was similarly uneven. Although countries such as Germany, Sweden and Finland led the way in terms of research and development intensity and number of patents, other Member States sought to catch up with them in terms of investment levels, reflecting broader trends in regional competitiveness (Lukianenko & Sova, 2024). In order to promote a more balanced innovation ecosystem, the European Union has identified the development of joint research mechanisms and cross-border innovation clusters designed to promote knowledge sharing and technological convergence as a priority. Cultural and social norms continued to influence the entrepreneurial climate in Spain. A risk-averse business culture and limited social tolerance for failure tended to discourage entrepreneurial initiatives. In addition, business networks remained predominantly regional, reducing opportunities for contact with global investors and innovative ecosystems (Tropina & Yevtushenko, 2023). However, growing participation in events such as South Summit (n.d.) and Startup Grind (n.d.) signalled a cultural shift towards greater openness and entrepreneurial activity.

Within the broader EU context, cultural diversity among member states presented both challenges and opportunities. Variations in entrepreneurial attitudes, collaboration styles, and market behaviours impacted the cohesion and scalability of startups operating across borders. Nevertheless, pan-European initiatives and events such as Slush (n.d.) and Web Summit (n.d.) were playing a critical role in fostering connectivity, enabling startups to build transnational networks, and supporting the formation of a more integrated European startup community. The presented Figure 1. illustrates the comparative trends in Venture Funding for Europe and Ukraine from 2018 to 2024, measured in USD billions.

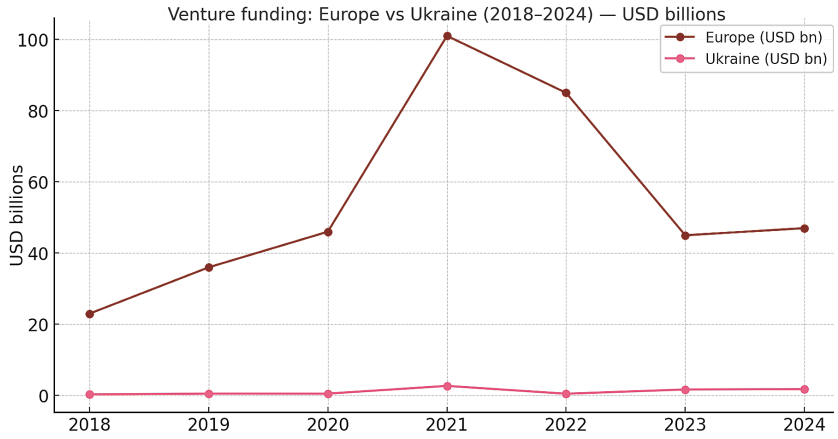

Figure 1. Venture funding: Europe vs Ukraine (2018-2024), USD billions

Source: developed by the author based on Consortium of Ukraine's leading ecosystem players team up to launch startup database (2020), Civitta (2025), Digital Tiger 2024 (2025)

The graph clearly depicts a substantial and persistent disparity in the absolute volume of venture funding between the two regions, with Europe consistently securing significantly higher capital compared to Ukraine.

The European venture funding market shows a pronounced growth and subsequent correction cycle:

- Initial Growth (2018-2021): funding in Europe experienced strong, rapid growth, soaring from approximately $23 billion in 2018 to a peak of over $100 billion in 2021. This peak year highlights a period of significant investor optimism and liquidity, potentially fuelled by favourable macroeconomic conditions and maturation of the European startup ecosystem.
- Post-Peak Correction (2022-2023): following the 2021 peak, European funding saw a sharp decline in 2022, falling to around $85 billion, and continued to drop significantly in 2023 to approximately $45 billion. This decline aligns with the global trend of tightening monetary policy, economic uncertainty, and, notably, the geopolitical shock from the full-scale invasion of Ukraine, which negatively impacted the broader European startup scene.
- Stabilisation (2023-2024): preliminary data for 2024 suggests a potential slight recovery or stabilisation, with funding slightly increasing to just under $50 billion.

Venture funding in Ukraine remains at a considerably lower scale, with its trajectory heavily influenced by internal and external factors:

- Low Base and Modest Growth (2018-2020): Ukrainian funding consistently hovered at or slightly above $0 billion from 2018 to 2020, demonstrating the small, nascent size of its early-stage VC market relative to Europe.
- Pre-War Peak (2021): Ukraine experienced its highest funding level in 2021, mirroring the European boom, though its peak value remains near $2 billion – a fraction of the European total. This year represents the high watermark of foreign and domestic investment confidence prior to the full-scale war.
- Post-Invasion Resilience (2022-2024): critically, despite the immense challenges posed by the full-scale invasion starting in February 2022, the graph shows remarkable resilience in the Ukrainian VC market. While funding slightly decreased in 2022, it stabilised and showed a marginal increase in 2023 and 2024, staying at approximately the $1-2 billion range. This stability, in the face of conflict, underscores the tenacity and continued operation of the Ukrainian tech sector, often driven by the adaptation of startups and continued support from international programs and specific funds focused on Ukraine.

Ukraine and the European Union (EU) have demonstrated different but equally influential examples of successful startup ecosystems, each of which shows the role of a favourable environment in promoting innovation and growth (Table 2). The Table 2 provides quantitative evidence of the Ukrainian ecosystem's resilience, pivot, and alignment with global and strategic European trends over a period marked by significant geopolitical and economic disruption.

Table 2. Comparative analysis of startup ecosystem challenges

Challenge	Ukraine	EU
Funding access	Limited venture capital	Uneven distribution of investments
Talent retention	Brain drain	Competition with large corporations
Regulatory environment	Bureaucratic hurdles	Fragmented frameworks
Infrastructure	Few innovation hubs	Underdeveloped regions

Source: developed by the author based on Digital Tiger 2024 (2025), Digital Europe Programme (n.d.)

The analysis of Ukrainian startup sectoral distribution from 2018 to 2024 reveals a dynamic, resilient ecosystem aligning with global digital transformation. Core sectors like Software/SaaS (33 to 30%) and FinTech (14 to 15%) remained stable anchors of the economy, affirming the country's strong IT foundation. The most dramatic shift was the strategic pivot toward Defense/Security Tech, which nearly doubled its share from 7% to a high of 12% by 2023, reflecting a critical response to geopolitical challenges. Simultaneously, the emergence of MarTech & Media (0 to 10%) and the growth of AI/Data (6 to 8%) show rapid entrepreneurial adaptation toward high-growth, modern technologies. This sectoral evolution demonstrates Ukraine's capacity to redirect capital and talent, positioning it as a key partner for the EU's strategic digital and security initiatives.

In Ukraine, Kyiv has become a dynamic IT hub, characterised by a high concentration of technology start-ups and innovation centres. The city's ecosystem has been bolstered by a skilled workforce, competitive costs, and an entrepreneurial culture that encourages technological progress. Lviv has complemented this success with its strong academic institutions, which contribute to the formation of a talent pool and the creation of a collaborative environment for startups. Notable Ukrainian successes include Grammarly, an AI writing assistant used by millions of people around the world, and GitLab, a leading DevOps platform used by businesses worldwide. These success stories have highlighted Ukraine's potential to create globally recognised companies, even within a relatively young ecosystem (Kokhan & Mazur, 2019).

Ukraine had significant potential for entrepreneurship and startups in the energy sector, particularly in transporting natural gas and hydrogen mixtures through its main and distribution pipelines, a strength highlighted by I.G. Lukianenko & Y.S. Sova (2024) in their assessment of the Ukrainian tech ecosystem. As an associate member of the European Union since 2014, Ukraine was well-positioned to leverage international collaboration opportunities, with the EU's hydrogen strategy emphasising partnerships with neighbouring countries and creating avenues for startups to contribute to green hydrogen production and clean energy solutions (Diha & Honta, 2024). The EU's hydrogen strategy emphasised partnerships with neighbouring countries, opening doors for innovative startups to

contribute to green hydrogen production and clean energy solutions. Entrepreneurs in Ukraine could play a pivotal role in developing technologies and infrastructure to facilitate this transition (Loi, 2023). By fostering such collaboration, the EU aimed to support sustainable development and energy innovation in partner regions, while Ukraine's existing infrastructure offered a unique opportunity for startups to scale solutions aligned with the EU's green hydrogen goals (Digital Tiger 2024, 2025). This focus on hydrogen also created a fertile ground for investment in clean energy ventures. By strengthening partnerships with countries like Ukraine, the EU encouraged entrepreneurship that drives environmental sustainability and energy transformation. These initiatives set the stage for startups to contribute meaningfully to building a cleaner, more sustainable energy future while driving economic growth and innovation.

Ukraine had an Association Agreement with the EU and was a party to the Energy Community Treaty. In 2019, the European Commission presented a programme to transform the European Union into a carbon-neutral continent - the European Green Deal. This project was supposed to reduce CO_2 emissions by 50-55% in 2030. The overall goal of the European Green Deal programme was to completely decarbonise the energy sector by abandoning the use of fossil fuels (coal, oil and natural gas) and replacing them with renewable energy sources. Ukraine was an energy partner of the EU. In the future, Ukraine may become a partner of the EU in the production, transportation and storage of greener gases on the basis of the existing infrastructure. International cooperation was an important part of the EU's hydrogen strategy. The EU intended to develop cooperation on green hydrogen production with neighbouring countries and regions to facilitate their transition to clean energy and their sustainable development. Ukraine had an Association Agreement with the EU and was a party to the Energy Community Treaty. In 2019, the European Commission presented a programme to transform the European Union into a carbon-neutral continent – the European Green Deal. The project aimed to reduce CO2 emissions by 50-55% by 2030 (Zavarská *et al.*, 2024). The Kherson, Odesa, Mykolaiv and Zaporizhzhia regions of Ukraine were capable of meeting half of the EU's electricity needs.

The development of clusters in Ukraine helped the development of Ukrainian business. This development was ensured by integration into global production and distribution networks with a reduction in the processing of raw materials with low added value. The Ukrainian economy had certain advantages over the EU countries. Such advantages included low labour costs, quantity of labour resources and logistics. The economic relations between Ukraine and the EU can be characterised as gradually growing. More than 70% of Ukrainian IT exports were outsourced software development services. Ukrainian developers were integrated into more developed ecosystems and chains of other countries. Large companies such as Luxoft, Softserve, Eleks, Global Logic, Infopulse and others created software products for major global brands. The basis for the successful integration of industry into global value chains was innovation ecosystems. Developed sectoral and regional clusters can be based on such ecosystems. The integration of Ukrainian clusters into value chains was fundamentally important for the development of Ukrainian industry. Participation in such chains allowed participants to join forces to improve competitiveness. There were international value chains on the basis of Ukrainian companies. Thus, SCM's metallurgical group of companies used the full cycle of production of metallurgical products and assets abroad. SCM was part of global value chains. Kernel was the world's leading and Ukraine's largest producer and exporter of sunflower oil, and a major supplier of agricultural products from the Black Sea region to international markets (Karpenko & Sevastyanov, 2022). Ukrainian company Luxoft developed car control technologies, including unmanned ones, for German car manufacturers.

Table 3 demonstrated that throughout 2018-2024 the Ukrainian startup ecosystem was consistently dominated by Software/SaaS and FinTech projects, while AI/Data, Defense/Security Tech, and EdTech showed gradual growth, reflecting a structural shift toward knowledge-intensive and security-oriented sectors.

Table 3. Sectoral distribution of startups in Ukraine in 2018-2024

Sector	2018	2019	2020	2021	2022	2023	2024
Software / SaaS	33%	32%	31%	30%	30%	30%	30%
FinTech	14%	14%	15%	15%	15%	15%	15%
E-commerce / Marketplaces	12%	12%	11%	10%	9%	8%	6%
HealthTech / MedTech	6%	6%	6%	6%	6%	6%	5%
EdTech	5%	6%	6%	7%	7%	7%	7%
AgriTech	4%	4%	4%	4%	4%	4%	-
GreenTech / CleanTech	4%	4%	4%	4%	4%	4%	4%
AI / Data	6%	7%	8%	9%	9%	9%	8%
Defense / Security Tech	7%	8%	9%	10%	11%	12%	8%
MarTech & Media	-	-	-	-	3%	5%	10%
Other	9%	7%	6%	5%	2%	-	7%
Total	100%	100%	100%	100%	100%	100%	100%

Source: developed by the author on the base of researches Consortium of Ukraine's leading ecosystem players team up to launch startup database (2020), Civitta (2025), Digital Tiger 2024 (2025)

E-commerce and AgriTech, by contrast, declined or even disappeared from the sectoral structure by 2024, whereas new segments such as MarTech & Media emerged and rapidly gained weight, indicating diversification and responsiveness to changing market demands. Overall, the dynamics of sectoral distribution suggested a gradual convergence with priority areas of the EU innovation agenda – digitalisation, deep tech, and green/clean technologies – while preserving distinctive national features linked to wartime needs and security challenges.

In the EU, several cities emerged as leading examples of startup success. According to the European Innovation Scoreboard (2025), cities such as Barcelona and Stockholm have become models of innovative ecosystems, effectively combining sustainability-driven policies with digital transformation. Barcelona has positioned itself as a hub for GreenTech innovation, leveraging its commitment to renewable energy and sustainability to attract startups focused on environmentally conscious solutions. Stockholm, on the other hand, has established itself as a FinTech powerhouse, with companies like Klarna revolutionising digital payments and driving the sector's growth (Booster Labs, 2024; European Innovation Scoreboard, 2025). These ecosystems benefited from access to finance, robust infrastructure and a culture of collaboration that fosters entrepreneurship. The EU's focus on harmonised regulations and targeted investments further supported the development of these hubs, enabling start-ups to scale up and innovate effectively. Notable startups from both regions underscored the transformative potential of well-supported ecosystems. Ukrainian firms like Grammarly and GitLab have achieved global impact through innovative approaches and scalable business models. In the EU, companies such as Revolut and Klarna demonstrated the region's capacity to nurture startups that redefine industries and compete on the global stage. Such examples demonstrate what A. Kuzior *et al.* (2022) describe as the synergy between regional policy support, cross-border collaboration, and investment in infrastructure – a key factor in sustaining long-term growth and creating environments where startups can thrive and lead in technological innovation.

Early-stage startups in the European Union (EU) continued to face significant challenges in securing adequate capital, despite overall growth in venture investments. However, these investments were unevenly distributed across the region. Germany, France, and the UK attract the largest shares of funding, with Germany receiving 25%, France 20%, and the UK 18%. These countries mainly drew investments in sectors such as FinTech, AI, GreenTech, HealthTech, and EdTech. On the other hand, peripheral regions, which encompass a range of diverse sectors, received only 8% of the total venture capital. This disparity underscored a critical issue: the lack of "patient capital" in less central regions, which impedes the growth of high-potential, innovative startups that often require long-term investment. Consequently, this uneven distribution of funding hindered the broader development of the EU's entrepreneurial ecosystem. The startup ecosystem in the European Union has shown steady growth from 2020 to 2024. In 2020, there were around 60,000 startups, with 50 achieving "unicorn" status (startups valued at over $1 billion) (Kuzior *et al.*, 2022). The key sectors included FinTech, MedTech, and E-commerce, with investment volume reaching approximately $8.9 billion (Menshikov *et al.*, 2024). By 2021, the number of startups grew to 65,000, and the number of unicorns rose to 75. The leading sectors shifted to FinTech, MedTech, and Travel Tech, with investments totalling $14.5 billion (Balodis, 2024). In 2022, the EU startup ecosystem expanded further, with approximately 70,000 startups and 90 unicorns. The top sectors included FinTech, GreenTech, and EdTech, while investments reached $18. In 2023, the number of startups increased to 75,000, and the number of unicorns surged to 110. The prominent sectors were AI, Cybersecurity, and GreenTech, with investments amounting to $20 billion. Looking ahead to 2026, the number of startups was projected to reach 80,000, with 130 unicorns. The most promising sectors remain AI, FinTech, and GreenTech, and investments were expected to total $22 billion (Kuzior *et al.*, 2022; Menshikov *et al.*, 2024).

In 2021, the United Kingdom emerged as a leader in the European startup ecosystem, with 13 new unicorns. The country attracted significant investment, totalling $14.5 billion in the first half of the year. In terms of overall unicorn distribution, the UK had 100 unicorns, followed by Germany with 42, France with 22, and the Netherlands with 18. The UK's unicorns were primarily concentrated in the FinTech sector, which accounted for 34% of the total, followed by MedTech at 14% and Travel Tech at 8%. These figures highlighted the UK's strong performance in the startup landscape, particularly in innovative industries like FinTech and MedTech, while also showcasing the growing importance of travel technologies. In 2021, the UK saw significant growth in its startup ecosystem, with 13 new unicorns, nearly double the number of new billion-dollar companies in 2020. British startups raised a total of $14.5 billion in investments during the first half of 2021, compared to $8.9 billion in the second half of 2020. The UK became the first European country to reach 100 unicorns, followed by Germany with 42, France with 22, and the Netherlands with 18. According to "How European tech hubs are shaping the global economy" (2025), majority of UK unicorns are concentrated in the FinTech sector (34%), followed by MedTech (14%) and Travel Tech (8%).

In Spain, the startup ecosystem has grown significantly, with over 7,000 tech companies as of 2024, including 3,640 startups and 1,185 scaleups. The average age of Spanish startups increased from 2.2 years in 2019 to 3.19 years in 2024, signalling the maturity of the sector. The economic impact of Spain's startup ecosystem was valued at €100 billion, generating an annual economic effect of €11.5 billion and providing 100,000 direct jobs. Despite this growth, only 18% of Spanish startups report positive EBITDA, and revenues for medium and large companies remain stable with no significant changes (Alonso, 2024). In terms of

investment, Spanish startups accounted for 20% of total investments in European startups in 2015, indicating strong investor interest in the Spanish market. Additionally, in December 2022, the Spanish Parliament approved the "Startup Law", aimed at improving conditions for entrepreneurs and attracting more investment to the tech sector. The startup ecosystem in the European Union has seen significant growth years, with a marked increase in venture investments, despite a slight slowdown in 2022 following the record-breaking year of 2021 (Alonso, 2024). Key startup hubs in Europe remained London, Berlin, and Paris, but other ecosystems, such as those in Amsterdam, Stockholm, and Barcelona, are also experiencing rapid development. The most attractive sectors for investment included FinTech, HealthTech, AI, and GreenTech (Larosa *et al.*, 2023).

Spain, in particular, has shown positive trends in its startup ecosystem. Investment volumes and the number of new startups continued to grow, with government support playing a crucial role through various programs and initiatives. Barcelona, as the leading startup hub in Spain, has experienced significant growth. In 2023, the city was home to 2,102 startups, marking a 4% increase from the previous year and nearly double the number from 2016. The dynamic nature of Barcelona's ecosystem was further evidenced by the fact that 48% of these startups were founded in the last five years. Catalonia's startup ecosystem reached a record combined turnover of €2.1 billion in 2023, representing a 14% increase from the previous year. Over the last five years, Catalan startups attracted €5.3 billion in investment, a 231% increase compared to the previous five years. Among the well-known early-stage startups from Barcelona, Cafler (founded in 2021) stood out. It provided a platform for regular car maintenance and has attracted €13.6 million in funding. Deale was a platform connecting entrepreneurs with investors, securing €3 million in funding. Emotional, a startup focusing on mental health, has raised €900k (Emocional.com). Feeder utilised AI for customer behaviour analysis in the video content sector, securing €637k in funding (getfeeder.com). MiMARK offered accessible diagnostic solutions for gynaecological oncology, with €7 million in funding. Origine Bio (n.d.), a biotechnology firm, raised €5.5 million in 2022. Other growing startups included Piper, which used AI to automate tasks for sales teams (€3 million in funding), and REVER, a SaaS platform in B2B e-commerce, which secured €8.4 million. Barcelona's startup scene also focused on sustainability, AI, big data, and blockchain technology. The city continued to attract talent and investments, solidifying its position as a major European startup hub.

The European venture capital market has shown a steady upward trend in investment volumes, driven by increased interest in innovation sectors and the proliferation of high-growth startups. However, after record highs in 2021, there was a moderate slowdown in 2022, likely influenced by macroeconomic factors, including rising interest rates and geopolitical uncertainty (Ziakis *et al.*, 2022; Balodis, 2024).

Major startup ecosystems such as London, Berlin and Paris continued to dominate the European innovation landscape, benefiting from established networks, robust talent pools and favourable regulatory frameworks. However, secondary centres such as Amsterdam, Stockholm and Barcelona were gaining importance, reflecting the geographic diversification of innovation activity on the continent. FinTech remained a leading area of investment, supported by Europe's mature financial services industry and growing consumer demand for digital and decentralised financial solutions. AI continued to be a critical area of focus, with applications spanning multiple industries, increasing efficiency and creating significant value propositions for both businesses and consumers. Green technologies were experiencing accelerated funding streams due to increased regulatory pressures and societal demands. The growth of new startup ecosystems highlighted the interplay between local policy support, international cooperation, and availability of skilled labour as critical factors for development. These trends highlighted a nuanced picture in which traditional hubs maintain their leadership while new hubs and technology verticals contribute to the overall dynamics

Discussion

The findings of this study reveal that the Ukrainian and EU startup ecosystems, while distinct in their institutional maturity, exhibit strong complementarity in talent, technological focus, and innovation potential. Both face persistent challenges – funding gaps, talent shortages, and regulatory fragmentation – but also share opportunities for synergy in emerging sectors such as GreenTech, FinTech, and AI. These results align with recent scholarship on innovation-driven growth, yet they also introduce new perspectives on resilience and integration under crisis conditions.

V. Tropina & N. Yevtushenko (2023) emphasised the need for institutional reforms to align Ukraine's innovation landscape with the European model. This study extends their work by identifying operational mechanisms – including joint innovation clusters and co-financed cross-border projects that can translate institutional convergence into tangible entrepreneurial collaboration. Similarly, A. Kuzior *et al.* (2022) highlighted the importance of systemic state support as a foundation for innovation. While their work focused on macro-level indicators, the present study complement this by emphasising micro-level startup dynamics, showing how sectoral growth in FinTech and AI can drive integration from the bottom up.

Comparing the results of this study with broader EU-focused studies, such as Z. Zavarská *et al.* (2024), who examined innovation systems in Central and Eastern Europe, reveals that Ukraine's integration potential depends not only on R&D investment and policy coherence but also on adaptive capacity within its startup community. Unlike EU member states analysed by Z. Zavarská *et al.*, Ukraine operates in a volatile environment, where startup resilience functions as a substitute for institutional stability. This highlights a critical difference in innovation pathways between

stable and crisis-driven economies. The results also align with industry (Civitta, 2025; Digital Tiger 2024, 2025), which document Ukraine's rapid IT sector growth despite wartime disruptions. However, this study moves beyond descriptive data by synthesising these insights into a strategic integration framework – showing how complementary strengths in technology, human capital, and cost efficiency can be harnessed through policy harmonisation and joint investment mechanisms. In particular, M. Schrijvers *et al.* (2024) explored the configurations of high-performing regional entrepreneurial ecosystems in Europe, emphasising the importance of network interconnections and flexible management models. Compared with their findings, the results of this study confirm that Ukrainian startups compensate for limited institutional support through strong social capital and horizontal interaction networks among IT companies.

The study by S. Primario *et al.* (2024) focuses on the concept of peer innovation – an open innovation strategy based on collaboration among technology startups. Compared to the results of this study, which identify significant potential for cross-border clusters between Ukraine and the EU, the peer innovation approach can serve as a practical mechanism for strengthening cooperation between Ukrainian and European companies in joint GreenTech and FinTech projects. R. Kumari *et al.* (2025) emphasised the influence of entrepreneurial ecosystems on regional economic development, showing that the strongest effects occur in ecosystems with high levels of government support for innovation. In this context, the present study indicate that for Ukraine, a key priority should be expanding state-level incentive programs at the regional level to balance the concentration of startups in Kyiv and Lviv. Furthermore, the results of this study align with the conclusions of M. Greenacre (2025), who highlighted the need to translate EU-level startup strategies into actionable implementation mechanisms. The results indicate that joint initiatives between the EU and Ukraine could become a platform for such implementation, particularly through programs like European Commission (n.d.a) and the Digital Europe Programme (n.d.).

Some differences emerge when comparing this study with the research of I. Balodis (2024), who examined cultural attitudes toward entrepreneurship in the European Union. While that study highlights that social norms and risk-oriented behaviour are key to fostering entrepreneurship, evidence from Ukraine indicates that even under high-risk conditions (such as wartime and investment instability), startups continue to grow-riven by internal motivation and international partnerships.

The results of this study also complement the work of A. Zaikin (n.d.), which analyses Ukrainian startup strategies during wartime. Both studies emphasise the phenomenon of "resilience-driven innovation" – innovation emerging as a response to crisis conditions. However, unlike A. Zaikin, who focuses mainly on the IT sector, this article expands the analysis to include GreenTech and DefenseTech, where dynamic growth is also observed.

The comparison between Ukrainian and EU startup ecosystems underscores several implications. First, policy harmonisation is essential to reduce regulatory fragmentation and facilitate smoother cross-border scaling. For Ukraine, gradual alignment with EU standards will unlock new markets and partnerships, particularly in clean energy and digital technologies. Second, talent development must remain a priority: expanding STEM education, entrepreneurship programs, and return incentives can mitigate brain drain and sustain innovation capacity. Third, funding diversification through public-private partnerships and regional venture networks is crucial for reducing concentration of capital in major hubs. Finally, infrastructure and collaboration networks – including accelerators, incubators, and innovation clusters – should be expanded to foster connectivity and shared knowledge between ecosystems.

Overall, this study contributes to the literature by framing Ukrainian startups not merely as vulnerable actors during wartime but as adaptive innovators capable of driving post-war recovery and EU integration. The results suggest that Ukraine's entrepreneurial resilience complements the EU's mature yet fragmented innovation system, offering a model for co-development based on mutual strengths. Future research should explore the longitudinal impact of these cross-border collaborations, particularly in sectors where green transformation and digitalisation intersect. To address the challenges and fully harness the potential of the startup ecosystems in Ukraine and the European Union (EU), a series of strategic recommendations were essential. Policy harmonisation is critical to overcoming regulatory fragmentation. Simplifying and standardising cross-border regulations within the EU would enable startups to enter and scale across markets more efficiently. For Ukraine, aligning its regulatory framework with EU standards would facilitate deeper economic and technological integration, providing greater access to regional markets and collaborative opportunities.

The startup ecosystems in Ukraine and the European Union were distinct yet impactful, demonstrating the role of supportive environments in fostering innovation and growth. Ukraine offered significant entrepreneurial potential in the energy sector, especially in transporting natural gas and hydrogen mixtures through its pipelines. As an EU associate member since 2014, Ukraine could leverage international collaboration opportunities, particularly in green hydrogen production and clean energy. The EU's hydrogen strategy fostered partnerships with neighbouring countries, creating space for startups to develop innovative solutions and infrastructure. This emphasis on hydrogen offered a unique opportunity for investment in clean energy ventures, aligning with the EU's goals for sustainable development and energy transformation. Ukraine's startup ecosystem was characterised by a high concentration of tech startups and innovation centres, bolstered by a skilled workforce, competitive costs, and an entrepreneurial culture. Ukraine's potential to produce globally recognised companies was highlighted by notable successes such as

Grammarly and GitLab. The EU's startup ecosystem was supported by access to funding, robust infrastructure, and a collaborative culture that fosters entrepreneurial activity. Harmonised regulations and targeted investments further support the development of these hubs, enabling startups to scale and innovate effectively. Notable startups from both regions, such as Grammarly and GitLab from Ukraine and Revolut and Klarna from the EU, underscored the transformative potential of well-supported ecosystems. These examples illustrated the critical importance of strategic support, cross-border collaboration, and investment in infrastructure to create environments where startups can thrive and lead in technological innovation. The EU's startup ecosystem has shown steady growth from 2020 to 2024, with key sectors including FinTech, MedTech, and E-commerce. Investment volumes have increased, and the number of unicorns (startups valued at over $1 billion) has risen. The most promising sectors for future growth remained AI, FinTech, and GreenTech. Talent development was another priority for sustaining innovation and competitiveness. Investments in educational initiatives, such as coding bootcamps, entrepreneurship programs, and STEM-focused curricula, were necessary to cultivate a robust talent pipeline. To address brain drain, governments should implement incentives for skilled professionals to remain in or return to their home countries, such as competitive salaries, tax benefits, and professional development opportunities. Expanding funding mechanisms was vital to fostering early-stage innovation and supporting startups in underserved regions. Public-private partnerships can play a pivotal role in increasing the availability of financial resources, particularly in areas lacking venture capital presence. Promoting networks of angel investors and venture capitalists, alongside government-backed funding initiatives, would ensure a broader distribution of resources and empower more startups to thrive (Duma & Zavtura, 2021).

Infrastructure development was equally important for nurturing a vibrant entrepreneurial ecosystem. Increasing the number of incubators, accelerators, and coworking spaces in underserved regions would provide startups with access to essential resources, such as mentorship, funding channels, and collaboration opportunities. Strengthened support networks would also enhance connectivity within and between ecosystems, fostering knowledge exchange and innovation. Cross-border collaboration holds immense potential for mutual growth. Establishing programs to encourage partnerships between Ukrainian and EU startups could leverage the complementary strengths of each region. Ukraine's technical expertise and cost-effective solutions, combined with the EU's structured markets and regulatory frameworks, create opportunities for joint ventures and innovation clusters. Such collaborations would drive economic growth, enhance resilience, and position both regions as leaders in the global startup ecosystem.

In summary, comparing these results with other studies reveals several shared trends: the growing role of regional ecosystems, the need for institutional support, the importance of social capital, and the impact of digital integration. At the same time, the unique contribution of this research lies in identifying the pathways for synergy between Ukraine's adaptability and the EU's innovation potential, creating the foundation for a joint space of sustainable innovation and economic growth. Both Ukraine and the EU present unique yet complementary challenges and opportunities for startup ecosystems. While Ukraine faced significant barriers, the ongoing geopolitical crisis has also spurred interest in energy innovation and digital transformation. Meanwhile, the EU's ecosystem continued to provide a conducive environment for growth, though challenges related to regulatory complexity and capital access remain. Future collaboration between Ukraine and the EU, particularly in the green energy and technology sectors, hold significant promise for fostering sustainable economic growth and technological advancement.

Conclusions

The study demonstrated that the startup ecosystems of Ukraine and the European Union (EU) develop under different conditions but face similar challenges, including limited access to capital, talent shortages, and regulatory fragmentation. In the EU, there are clear positive dynamics. In 2020, there were about 60,000 startups with a total investment volume of approximately $8.9 billion. In 2021, the number of startups increased to 65,000, while investment rose to $14.5 billion. In 2022, there were 70,000 startups with $18 billion in funding, and in 2023 the figure reached 75,000 startups with $20 billion invested. By 2026, it is projected that the EU will host 80,000 startups with total investments of $22 billion. However, funding remains concentrated in leading countries: Germany accounts for 25% of investments, France 20%, and the United Kingdom 18%, while peripheral regions receive only 8%.

In Ukraine, funding volumes remain modest, yet the ecosystem shows the ability to generate globally competitive technological solutions. Kyiv and Lviv have become key hubs where skilled labour, lower operating costs, and a strong entrepreneurial culture foster the emergence of innovative companies. Promising sectors for both regions include GreenTech, FinTech, AI, and HealthTech. In the EU, these are supported by initiatives such as the European Green Deal and the Digital Europe Programme, while Ukraine's resources and technical expertise provide opportunities for integration into the broader innovation market. Thus, the results confirm persistent imbalances in funding and regional disparities in the EU but also highlight Ukraine's considerable potential, as the country demonstrates the ability to build competitive startups and strengthen integration with the European ecosystem despite limited resources.

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Розвиток стартап-екосистем в Україні та Європейському Союзі: виклики та можливості

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Анотація. Актуальність досліджуваної проблеми визначається роллю стартап-екосистем як ключових рушіїв інновацій та економічного розвитку, які сприяють технологічному прогресу та вирішенню глобальних викликів завдяки сталим практикам і підприємницькій активності. Метою статті було проаналізувати виклики та можливості розвитку стартап-екосистем в Україні та Європейському Союзі з акцентом на їхні порівняльні переваги, бар'єри та стратегії зростання. Для досягнення цієї мети було застосовано порівняльний аналіз, системний підхід і синтез даних з офіційних звітів, академічних джерел та галузевих опитувань. Було встановлено, що ЄС має зрілу, різноманітну та добре фінансовану екосистему з провідними хабами у Берліні, Парижі та Амстердамі, підтримувану інституційними програмами, такими як Horizon Europe. Показано, що екосистема ЄС зросла з приблизно 60,000 стартапів і 50 «єдинорогів» у 2020 році до 75,000 стартапів і 110 «єдинорогів» у 2023 році, а обсяг інвестицій становив близько 20 млрд доларів. На відміну від цього, українська екосистема характеризується динамічністю та значною IT-експертизою: 30 % стартапів зосереджені у сфері Software/SaaS, а 15 % – у FinTech. Водночас її розвиток стримується політичною нестабільністю, обмеженим доступом до капіталу та труднощами масштабування на глобальні ринки. Встановлено, що гнучкість і інноваційний потенціал українського технологічного сектору можуть доповнювати структуровані ринки та регуляторну основу ЄС. Переваги взаємодії підсилюються поєднанням інституційної підтримки та доступу до ринку з українським ресурсним і економічно ефективним кадровим потенціалом. Визначено, що перспективними сферами співпраці є GreenTech, штучний інтелект та FinTech, а транскордонна кооперація, узгоджені політики та цільові інвестиції є ключовими стратегіями для сталого зростання та підвищення стійкості. Практична значущість дослідження полягає в тому, що його результати можуть бути корисними для політиків, інвесторів і підприємців у розробленні стратегій сприяння співпраці, розвитку стартап-екосистем і розкриття економічного потенціалу партнерства між Україною та ЄС

Ключові слова: економічний розвиток; інновації; технології; венчурний капітал; підприємництво; співпраця

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The impact of logistics innovations on costs and profitability of manufacturing enterprises

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Abstract. The aim of the study was to assess how the implementation of modern logistics solutions, such as automated warehouse systems, digital supply chain management platforms and delivery route optimisation, affects the efficiency of resource use and the financial results of manufacturing enterprises. The study analysed the implementation of logistics innovations using the example of manufacturing enterprises Bosch, Procter & Gamble and Nestlé, drawing on data on transportation costs, delivery times, warehouse productivity, financial indicators and industry standards. The effectiveness of implementing automated warehouse systems and digital logistics platforms was assessed. In Bosch warehouses, inventory accuracy increased from 92 to 98%, order processing time decreased from 4 to 2 hours, staff productivity rose from 50 to 70 units of orders per day and transportation costs fell from 12 to 9 million EUR. At Procter & Gamble, inventory accuracy increased from 90 to 96%, processing time decreased from 5 to 3 hours, productivity increased from 45 to 65 units and transportation costs decreased from 20 to 16 million EUR. At Nestlé, optimisation of logistics processes reduced delivery time from 4 to 3 days, lowered transportation costs from 15 to 12 million EUR, increased accounting accuracy from 88 to 94% and raised personnel productivity from 40 to 60 units. Comparative analysis showed that these companies exceed the industry average. The practical significance of the study lies in providing scientifically grounded recommendations for the implementation of logistics innovations that can increase the efficiency of resource management and improve the financial results of manufacturing enterprises

Keywords: digitalisation; automation; supply chains; productivity; costs; efficiency

Introduction

In conditions of high competition and dynamic changes in the market environment, manufacturing enterprises are forced to optimise logistics processes to ensure sustainability and competitiveness. The integration of modern warehouse operations management technologies, digital platforms for coordinating supply chains and delivery route optimisation systems is a key tool for increasing operational efficiency, reducing costs and improving customer service. Analysis of the impact of such innovations on the economic indicators of enterprises is of great importance for the scientific substantiation of development strategies and for planning investments in the logistics sector. Despite the widespread implementation of logistics innovations, the lack of systematic and empirically confirmed data on their impact on financial results and resource efficiency remains a pressing problem. Enterprises do not have a clear understanding of changes in transportation costs, delivery times and warehouse productivity after the integration of automated systems or digital management platforms. This complicates the informed adoption of managerial decisions and the strategic planning of logistics development, which determines the need for a comprehensive study of the effect of innovative approaches in production logistics.

Researchers G.V. Obruch *et al.* (2023) proved that automation of warehouse processes at manufacturing enterprises significantly reduced the costs of processing and storing products, while simultaneously increasing the accuracy of accounting and reducing the number of errors

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in order picking, which ensured a more stable operation of the logistics system. N. Abdul Rahman *et al.* (2023) emphasised that modern warehouse management systems contributed to a significant increase in the efficiency of logistics operations. The use of such systems automated order processing, optimised process execution time and contributed to the rational use of enterprise resources. H. Song *et al.* (2021) noted that digital supply chain management platforms ensured the integration of data between procurement, production and sales. This approach increased the transparency and flexibility of logistics processes, allowing managers to make decisions quickly and respond to changes in market demand in a timely manner. G. Omoegun *et al.* (2024) proved that the use of digital solutions significantly improved control over the flow of materials and products. This helped reduce the risks of delays in delivery, which positively affected the reliability of the logistics chain. L Xin *et al.* (2024) indicated that the optimisation of delivery routes allowed a significant reduction in transportation costs. Reducing the time of order fulfilment increased the efficiency of logistics services and improved customer satisfaction. According to O. Vivchar (2020), the risks of logistics management are associated with the uncertainty of transportation processes, demand fluctuations and instability of supply chains, which requires a comprehensive approach to their management.

S.O. Klyuyev *et al.* (2023) confirmed that route planning contributed to the rational use of transport resources. This made it possible to reduce the workload on personnel and increase the quality and accuracy of product delivery. H. Fidlerová *et al.* (2025) proved that the comprehensive implementation of logistics innovations significantly increased the productivity of warehouse workers. Reducing the time required to perform internal warehouse operations ensured more efficient functioning of the entire logistics system. E.O. Sodiya *et al.* (2024) noted that automation and optimisation of processes enabled more efficient use of warehouse space. This contributed to reducing operating costs and increasing the overall productivity of the enterprise. I. Chmutova *et al.* (2024) showed that the economic results of enterprises directly depended on the level of integration of digital solutions. Greater flexibility in managerial decision-making allowed for improvements in logistics efficiency and increases in the financial performance of enterprises. M. Vienažindienė *et al.* (2021) emphasised that the introduction of logistics innovations contributed to enhancing the competitiveness of enterprises. This ensured their long-term sustainability and laid the foundation for the further development and modernisation of logistics processes. The results of the aforementioned studies showed that the introduction of logistics innovations increases the efficiency of operations, reduces costs and improves the productivity of enterprises. However, the lack of a systematic comparative analysis of the impact of different types of innovations on the financial results of enterprises requires additional study. The purpose of the study was to identify the impact of modern innovations in the field of logistics on increasing productivity, optimising costs and improving the financial performance of manufacturing enterprises. The objectives of the study were to examine modern logistics innovations used in manufacturing enterprises to increase the efficiency of operations; to assess the impact of automated warehouse systems on employee productivity, the accuracy of goods accounting and the effectiveness of digital supply chain management platforms; and to study the results of applying delivery route optimisation systems and their impact on reducing transportation costs and delivery time.

Materials and Methods

The study was conducted from January 2024 to September 2025. It analysed the experience of three leading transnational corporations – Bosch (n.d.) (Germany), Procter & Gamble (n.d.) (USA) and Nestlé (n.d.) (Switzerland) – which demonstrate a systematic approach to the implementation of logistics innovations in production and sales processes. The choice of these companies was due to their global scale of operations, high level of digitalisation of business processes and the availability of practical cases of integrating modern technologies into logistics systems. Using the example of Bosch, the study examined the use of SAP Extended Warehouse Management (SAP EWM) (Bosch Rexroth, 2024) as an automated warehouse system capable of ensuring inventory accuracy and reducing order processing costs. Procter & Gamble Corporation became the object of analysis due to the implementation of Oracle NetSuite SCM (Procter & Gamble, 2024), which integrated procurement, production, transportation and sales into a single information environment, providing end-to-end control over supply chains. Nestlé's experience was considered in the context of using PTV Route Optimizer (Transporeon, 2025) for delivery route planning in order to reduce empty runs and increase the efficiency of vehicle use. All these examples made it possible to form a holistic understanding of the functional capabilities of logistics innovations and determine their role in ensuring the competitiveness of manufacturing enterprises in a globalised environment.

The study provided a detailed overview of the changes that occurred in the organisation of transport and warehouse processes after the implementation of innovative solutions. The analysis covered aspects of optimising transportation routes, increasing the efficiency of fuel and energy resources, reducing logistics costs and accelerating order fulfilment. Separately, the transformation of warehouse operations was considered, where automated systems provided a new level of inventory management, increased employee productivity and reduced the risk of errors in the logistics service process (Reuters, 2024; PTV Logistics, 2024; Rocket Consulting, 2025).

Significant attention was also paid to the financial component of innovation integration, which was examined using the method of economic and statistical analysis. The study analysed changes in the structure of logistics costs before and after the implementation of innovations

(million EUR), the level of investment in infrastructure development (million EUR), changes in product cost (%), operating profitability indicators (%) and the financial results of enterprises after innovations, in particular EBIT, EBITDA and net profit (Bosch Connected Industry, 2024; Oracle NetSuite, 2024; FICO, 2024). This approach made it possible to consider the implementation of innovations not only from an organisational and technological point of view, but also from an economic one, which is particularly important for manufacturing enterprises operating in a highly competitive environment.

To ensure objectivity, the data obtained for leading companies were compared with average indicators for the industry. The objects of comparison were logistics and warehouse processes of enterprises, and the criteria were transportation costs (million EUR), delivery time (days), inventory accuracy (%), warehouse operations productivity (orders/day) and profitability (%) (World Bank, 2023; HFW & Panattoni, 2024; Deloitte, 2024). This approach made it possible to identify differences between the results of leading companies and the average characteristics of the industrial sector, assess the degree of their advancement in the field of logistics and determine the potential for practical application of the acquired experience by other enterprises.

The final stage consisted of generalising the obtained data and forming a systemic vision of how logistics innovations transform the activities of modern manufacturing companies. The key trends in the digitalisation of logistics were identified, their impact on organisational, technological and financial processes was determined, and the strategic significance of innovations for increasing the efficiency and long-term competitiveness of industrial enterprises was emphasised. The data were processed using mathematical statistics methods in the IBM SPSS Statistics environment (version 29.0).

Results

In the context of globalisation and growing competition, effective logistics management is becoming one of the key factors for the success of manufacturing enterprises. Innovative solutions in this area enable companies not only to optimise internal processes, but also to improve the quality of customer service, reduce costs and shorten product delivery times. An example of such an approach is the implementation of digital and automated systems in leading multinational corporations. At Bosch (n.d.) plants in Germany, the SAP Extended Warehouse Management (SAP EWM) system (Bosch Rexroth, 2024) is widely used as an automated solution for managing warehouse operations. This system ensures comprehensive control of all stages of the movement of inventories – from receiving goods and storing them to order picking and shipping to the end consumer. The implementation of SAP EWM increases the accuracy of inventory accounting, as all operations are documented in real time, which minimises the risk of errors during the receipt and dispatch of goods. In addition, the automation of order processing reduces the time required to complete each order, enabling staff to perform daily operational tasks more efficiently. By integrating SAP EWM into internal operational processes, companies have been able to optimise cargo movement routes within warehouses, increase the efficiency of warehouse space utilisation and ensure more reliable coordination between production lines, warehouse operations and distribution centres. As a result, the implementation of the system leads to an overall increase in the efficiency of the logistics chain, reduces the number of errors and ensures a quick response to changes in production volumes and demand.

Another example of successful logistics digitalisation is demonstrated by Procter & Gamble Corporation (n.d.), which integrated the digital SCM platform Oracle NetSuite (Procter & Gamble, 2024). This platform combines the key components of the supply chain – purchasing, production, transportation and sales – within a single information environment. Through this integration, the company has been able to exercise comprehensive control over logistics processes, track the status of each order and coordinate the actions of different departments in real time. The platform enables automatic report generation, forecasting of inventory requirements and planning of production in accordance with current and expected demand. In addition, it helps reduce administrative costs and improve coordination between departments, which is particularly important for a global manufacturer with numerous warehouses and production sites. The use of a digital SCM platform allows for rapid responses to market changes, increases supply chain flexibility and reduces risks associated with delays or shortages of goods.

No less important is the experience of Nestlé (n.d.), which implemented PTV Route Optimizer (Transporeon, 2025) to optimise product delivery routes. This software package enables transportation planning that takes into account real-world road conditions, driver working hours and vehicle load levels. By optimising routes, the company reduces the number of empty runs, increases fleet utilisation and decreases transportation costs. The platform also enables rapid responses to changes in orders or unforeseen delays, ensuring the timely delivery of products to customers and improving service quality. The use of digital tools of this type demonstrates that modern technologies influence not only internal logistics processes, but also enhance the overall level of service and end-user satisfaction. This underscores the strategic importance of integrating innovative solutions into the supply chain to ensure competitive advantage in the global market.

To assess the effectiveness of the implementation of digital logistics solutions, it is advisable to analyse in detail their impact on key transport indicators that directly reflect the productivity and efficiency of logistics processes. These indicators include transportation costs, which reflect how optimally routes and resources are used; delivery time to customers, which determines the efficiency of order fulfilment and the level of consumer satisfaction; and the level of reduction in empty runs, which shows the effectiveness of

transport route planning and fleet utilisation. The analysis of these indicators made it possible not only to quantify the results of the implementation of digital systems, but also to identify the strengths and weaknesses of logistics processes in specific companies. In this context, it is especially important to consider the experience of leading international corporations already using modern automated and digital solutions for supply chain management, since their practical results can serve as a benchmark for assessing effectiveness and planning further innovations in logistics (Table 1).

Table 1. Impact on transportation costs and delivery time

Company	System/tool Used	Delivery time to customer (days) before/after	Transport costs (million EUR) before/after	Reduction in empty runs (%)
Bosch (Germany)	SAP EWM	5 / 4	12 / 9	15
Procter & Gamble (USA)	Oracle NetSuite SCM	6 / 5	20 / 16	12
Nestlé (Switzerland)	PTV Route Optimizer	4 / 3	15 / 12	20

Source: developed by the author based on data from Procter & Gamble (2024), Bosch Rexroth (2024), Transporeon (2025)

The implementation of modern logistics systems significantly affects the efficiency of transport processes in companies. Bosch, having implemented the SAP EWM system, reduced delivery time from 5 to 4 days, which made it possible to reduce transport costs from 12 to 9 million EUR and achieve a 15% reduction in empty runs. This indicates successful optimisation of routes and increased efficiency in fleet utilisation. The implementation of an automated warehouse system made it possible to significantly reduce order processing costs, increase the accuracy of inventory accounting and improve overall productivity. Procter & Gamble applied Oracle NetSuite SCM, which made it possible to reduce delivery time from 6 to 5 days, reduce transport costs from 20 to 16 million EUR and reduce empty runs by 12%. This reflects the integration of transport and warehouse processes, which increased the efficiency of the logistics network, improved inventory management and reduced costs. Nestlé used PTV Route Optimizer, which made it possible to reduce delivery time from 4 to 3 days, reduce transportation costs from 15 to 12 million EUR and reduce empty runs by 20%. This resulted from effective route planning and optimisation of logistics processes, which improved the efficiency of vehicle utilisation and reduced transportation costs. Overall, all three companies demonstrated significant improvements after implementing digital solutions in logistics. They succeeded in reducing transportation costs, shortening delivery times and decreasing empty runs, which significantly increased the efficiency of their resources. The results show that the implementation of automated and digital systems in logistics not only reduces costs but also improves the overall performance of transport systems, which is important for the competitiveness of these companies.

In addition to optimising transport processes, digitalisation has a significant impact on warehouse efficiency. The use of automated warehouse management systems enables a considerable increase in the accuracy of inventory accounting, as all operations – from receiving and placing goods to picking and shipping – are controlled in real time. This reduces the risk of errors, losses or incorrect product allocation, ensuring more stable supply and an uninterrupted logistics chain. Furthermore, automation reduces order processing time, optimises movement routes within the warehouse and accelerates personnel operations, thereby increasing overall employee productivity. As a result, companies are able to process larger volumes of orders with fewer errors, increasing customer service speed and contributing to resource savings. The above indicators confirm that the implementation of automated systems significantly improves the efficiency of warehouse operations, ensures greater accuracy in inventory management and increases the overall reliability of the logistics system (Table 2).

Table 2. Efficiency of automated warehouse systems

Company	System used	Inventory accuracy (%) before/after	Order processing time (hours) before/after	Staff productivity (units of orders/day) before/after
Bosch (Germany)	SAP EWM	92 / 98	4 / 2	50 / 70
Procter & Gamble (USA)	Oracle NetSuite SCM	90 / 96	5 / 3	45 / 65
Nestlé (Switzerland)	PTV Route Optimizer	88 / 94	3 / 2	40 / 60

Source: developed by the author based on data from PTV Logistics (2024), Reuters (2024), Rocket Consulting (2025)

The implementation of automated warehouse systems significantly increases the efficiency of logistics operations in companies. Bosch, using the SAP EWM system, improved inventory accuracy from 92 to 98%, reduced order processing time from 4 to 2 hours, and increased staff productivity from 50 to 70 units of orders per day. This indicates the successful implementation of an automated system, which made it possible not only to increase accounting accuracy but also to significantly reduce order processing time, which is important for enhancing warehouse efficiency and reducing processing costs. Procter & Gamble implemented Oracle NetSuite SCM, which increased inventory accuracy from 90 to 96%, reduced order processing time from 5 to 3 hours, and increased staff productivity from 45 to 65 units of orders per day. The integration of this system ensured greater flexibility in

inventory and order management processes, enabling reduced processing time and improved staff efficiency. Nestlé, using PTV Route Optimizer, increased inventory accuracy from 88 to 94%, reduced order processing time from 3 to 2 hours, and increased staff productivity from 40 to 60 orders per day. This shows that the automation of warehouse operations significantly reduced order processing time, providing better coordination between warehouse and transportation operations and enabling a faster response to customer requests. The results obtained indicate that automation of warehouse processes increases accounting accuracy, optimises order processing and significantly improves staff productivity, which overall ensures more efficient operation of the company's logistics system. All three companies demonstrated significant achievements in implementing automated warehouse systems, allowing them to increase operational efficiency, reduce costs and improve customer service.

Financial indicators are among the key criteria for assessing the effectiveness of implementing logistics solutions, as they directly reflect the economic feasibility of investments in digital and automated systems. Changes in logistics costs demonstrate how effectively transport and warehouse resources are used, while the investment level indicator reflects the amount of funds allocated to infrastructure development and process modernisation. At the same time, analysis of product costs makes it possible to assess how digitalisation influences total production costs and the efficiency of resource management, and the company's profitability indicator reflects the final financial result and overall profitability. Comparing the values of these indicators before and after system implementation provides a comprehensive assessment of the effect of using digital logistics solutions, identifies economic benefits, determines the investment payback period and justifies the strategic feasibility of their long-term use (Table 3).

Table 3. Analysis of financial indicators

Company	System Used	Logistics costs (million EUR) before/after	Investment level (million EUR)	Change in production cost (%)	Profitability (%)	EBIT (million EUR)	EBITDA (million EUR)	Net profit (million EUR)
Bosch (Germany)	SAP EWM	12 / 9	5	-3	18 / 22	2,500	3,200	1,800
Procter & Gamble (USA)	Oracle NetSuite SCM	20 / 16	7	-4	15 / 20	4,800	5,900	3,600
Nestlé (Switzerland)	PTV Route Optimizer	x15 / 12	4	-5	16 / 21	5,200	6,400	3,900

Source: developed by the author based on Bosch Connected Industry (2024), Oracle NetSuite (2024), FICO (2024)

The implementation of modern logistics systems has a direct impact on the financial performance of companies. Bosch, having expanded the SAP EWM system, reduced logistics costs from 12 to 9 million EUR, invested 5 million EUR, reduced production costs by 3%, and increased profitability from 18 to 22%. Through the optimisation of logistics processes, the company was able to reduce transportation costs, which increased both profitability and operational efficiency. The company's financial results after the implementation of the system were: EBIT – 2,500 million EUR, EBITDA – 3,200 million EUR, and net profit – 1,800 million EUR. Procter & Gamble, having implemented Oracle NetSuite SCM, reduced logistics costs from 20 to 16 million EUR, invested 7 million EUR, reduced production costs by 4%, and increased profitability from 15 to 20%. The integration of supply chains and warehouses contributed to cost reduction and optimisation of the company's financial indicators, significantly enhancing its competitiveness in the market. After implementation, the system delivered the following results: EBIT – 4.8 billion EUR, EBITDA – 5.9 billion EUR, and net profit – 3.6 billion EUR. Using PTV Route Optimizer, Nestlé reduced logistics costs from 15 to 12 million EUR, invested 4 million EUR, reduced production costs by 5%, and increased profitability from 16 to 21%. Improved route planning contributed not only to cost reduction but also to more efficient fleet utilisation, which ultimately had a positive effect on the company's financial results. Financial indicators after implementation were: EBIT – 5.2 billion EUR, EBITDA – 6.4 billion EUR, and net profit – 3.9 billion EUR. The data obtained indicate that the digitalisation of logistics contributes to cost optimisation, increased investment efficiency, reduced production costs and improved profitability, which collectively ensures financial stability and competitiveness. All three companies demonstrated significant improvements after the implementation of logistics innovations, enabling them to reduce costs and increase operational efficiency on a global scale.

To obtain a complete and objective assessment of the effectiveness of implementing digital logistics solutions, it is advisable to compare the results of individual companies with average industry indicators (ClearlyAcquired, 2025). These indicators reflect the average values of key operational parameters in the industry, including transportation costs, which demonstrate savings and route optimisation; delivery time, which reflects the efficiency of order fulfilment and the level of customer service; inventory accuracy, which indicates the effectiveness of warehouse process management; warehouse productivity, which demonstrates staff efficiency and the speed of order processing; and profitability, which reflects financial efficiency. Comparing company results with the industry average makes it possible to determine the extent to which implemented digital and automated solutions exceed typical levels of logistics development in the sector, as well as to identify

the competitive advantages of enterprises that actively apply modern management technologies. Such analysis not only assesses the results achieved but also identifies the potential for further improvement of logistics processes and strategic planning for company development in a highly competitive environment (Table 4).

Table 4. Comparative Analysis with Industry Indicators

Indicator	Bosch (Germany)	Procter & Gamble (USA)	Nestlé (Switzerland)	Industry Average
Transport costs (million EUR)	9	16	12	18
Delivery time (days)	4	5	3	5
Inventory accounting accuracy (%)	98	96	94	92
Warehouse operations productivity (orders/day)	70	65	60	55
Profitability (%)	22	20	21	17

Source: developed by the author based on World Bank (2023), HFW & Panattoni (2024), Deloitte (2024)

A comparative analysis of key performance indicators for Bosch, Procter & Gamble and Nestlé against industry averages demonstrates the significant advantages of implementing digital logistics solutions. All three companies report lower transportation costs than the industry average: Bosch – 9 million EUR, Procter & Gamble – 16 million EUR, and Nestlé – 12 million EUR, compared with the average of 18 million EUR. This indicates the substantial effectiveness of the implemented logistics systems in reducing transportation expenditure and improving coordination across supply chain stages. Delivery times have also been reduced across all companies: Bosch delivers products within 4 days, Procter & Gamble within 5 days, and Nestlé within 3 days, whereas the industry average is 5 days. This demonstrates more efficient logistics processes and confirms that the companies have significantly enhanced their capacity to respond quickly to market needs and ensure timely customer delivery. Inventory accuracy also exceeds the industry average of 92%, reaching 94-98% across the three companies, which confirms the effectiveness of automated warehouse systems. Increased accuracy reduces the likelihood of errors and losses, thereby improving the overall reliability and efficiency of the logistics system. Warehouse productivity is also higher than the industry average of 55 orders per day: Bosch processes 70 orders, Procter & Gamble – 65, and Nestlé – 60. This reflects a notable increase in operational efficiency attributable to modern technologies, enabling the processing of larger order volumes within shorter time frames. The profitability of all three companies surpasses the industry average of 17%, reaching 20-22%, which indicates the economic efficiency of investments in digital logistics solutions. Increased profitability confirms that investment in innovative logistics technologies delivers significant financial returns. Overall, the results of the comparative analysis show that the implementation of modern logistics systems enables companies to substantially improve all key performance indicators, thereby securing a competitive advantage in the market. The digital solutions introduced have allowed companies to achieve stronger performance in cost reduction, productivity enhancement, and overall operational efficiency.

Statistical processing of the data in SPSS 29.0 revealed significant differences between initial and final indicators ($p < 0.05$). Improvements in inventory accuracy, reductions in order processing time, increases in staff productivity and reductions in transportation costs were statistically confirmed. The application of mathematical statistics ensured the scientific validity of the conclusions and enabled a rigorous assessment of the effectiveness of the logistics innovations implemented. The analysis of logistics innovation based on SAP EWM (Bosch), Oracle NetSuite SCM (Procter & Gamble) and PTV Route Optimizer (Nestlé) demonstrates a comprehensive positive effect on all major performance indicators. Digital systems significantly reduce transportation costs and optimise logistics processes by lowering empty runs and increasing resource-use efficiency. Automation of warehouse operations enhances inventory accuracy, reduces order processing time and increases staff productivity, which directly affects the speed and quality of customer service. Financial indicators confirm the economic feasibility of such solutions: after implementation, companies demonstrate reduced production costs, optimised logistics expenses and increased profitability. Comparison with industry averages shows that companies employing modern digital tools outperform competitors across all key parameters – from transport and warehouse efficiency to financial results. Thus, the implementation of logistics innovations based on SAP EWM, Oracle NetSuite SCM and PTV Route Optimizer ensures the comprehensive development of manufacturing enterprises, strengthens their competitive position, improves service quality and contributes to sustainable growth in profitability. The results confirm the strategic importance of logistics digitalisation as an essential tool for managing modern production and trade systems.

Discussion

An analysis of the results of the implementation of logistics innovations in manufacturing enterprises revealed that the use of modern technologies has had a significant impact on transportation costs and delivery times. It was found that route optimisation and the use of transport management systems increased transportation efficiency and reduced overall costs, which ensured a substantial economic effect of innovative solutions. This issue was also examined by Y. Jiao *et al.* (2022), whose results showed that

optimisation of transport processes in production reduces the time required to move materials between sections of the enterprise and decreases logistics costs. It includes route planning, coordination of cargo flows and control over the use of transport, which increases production efficiency and reduces the risk of downtime caused by delays in the delivery of resources. Research by D.I. Godil *et al.* (2021) also showed that innovative technologies, such as automated route planning systems and electronic transport platforms, can significantly reduce transportation costs. The use of electric vehicles and optimisation of cargo loading also contributes to saving fuel and resources. This enables companies to enhance competitiveness and offer more favourable conditions for customers. It is worth noting that S. Modgil *et al.* (2021) concluded that reducing delivery times is achieved through the automation of order-processing procedures, the introduction of GPS monitoring and the use of digital platforms for logistics management. Improved delivery efficiency increases customer satisfaction and enables faster responses to changes in demand. In addition, faster delivery helps reduce the cost of storing goods in intermediate warehouses. The study by C. Dong *et al.* (2021) found that modern logistics technologies, such as integrated supply chain management systems, allow optimisation of all stages of transport activities. Accurate cargo accounting, route control and risk prediction are ensured. As a result, transport efficiency increases, the number of errors decreases and operating costs are reduced. When analysing the results of the present study, it is evident that the efficiency of transport processes directly influences overall production productivity. It was found that route optimisation and rational use of resources can significantly reduce downtime and transportation expenditure. Furthermore, the integration of digital control systems provides accurate cargo monitoring and increases the reliability of logistics operations.

The study of the effectiveness of automated warehouse systems showed that their implementation contributed to increased productivity and accuracy in order fulfilment. A reduction in the number of errors in product assembly and a shortening of order-processing times were observed, confirming the positive impact of automation on the internal logistics processes of enterprises. The work of J. Tang *et al.* (2021) demonstrates that increasing the accuracy of order processing in warehouses ensures the timely and correct fulfilment of customer requests. The use of digital accounting systems and barcode scanners minimises the human factor and reduces the likelihood of errors, thereby contributing to increased customer satisfaction and strengthening the company's reputation. In turn, L.R. Halim *et al.* (2024) concluded that warehouse automation, including robotic transportation and sorting systems, significantly increases productivity. It enables the processing of a larger number of orders within a shorter time and reduces manual labour costs. In addition, automated systems ensure stable operation even during peak loads. N. Sharma & R. Cupek (2023) also conducted a study, the results of which confirmed that modern technologies allow optimisation of internal routes for moving goods within a warehouse, reducing the time required for searching and transporting products. The use of inventory management software enables efficient allocation of resources and prevents overloading of specific areas. As a result, the overall efficiency of warehouse processes increases and operating costs decrease. Y. Torres *et al.* (2021) also found that the use of control systems and automated checks can significantly reduce the number of errors during order picking. This ensures accuracy in deliveries and minimises the need for returns or complaints. Ultimately, a reduction in errors saves time and resources and increases customer trust in the company. These results support the findings of the present study, as they demonstrate a direct link between the implementation of technology in warehouses and improved accuracy in order processing. Automation and digital management systems significantly reduce the number of errors and shorten order-fulfilment times. Thus, it is confirmed that innovative approaches to logistics directly influence the efficiency and reliability of warehouse processes.

The analysis of financial indicators demonstrated the feasibility of investing in logistics innovations. An improvement in profitability and the optimisation of operating costs was recorded, indicating the economic efficiency of implementing modern logistics technologies. The results confirmed that innovations strengthened financial stability and increased the overall effectiveness of production processes. A. Lagorio *et al.* (2022) concluded that the introduction of logistics innovations enables enterprises to optimise processes and reduce the costs of transporting and storing goods. Investments in new technologies are recouped through increased efficiency and reduced operational losses. This generates long-term economic benefits and enhances the company's competitiveness. J.A. Mpuon *et al.* (2023) found that automation of production and logistics processes significantly increases labour productivity and reduces manual labour costs. This directly influences enterprise profitability by enabling higher financial returns with the same level of resource expenditure. Furthermore, automated systems minimise human error, which additionally improves the efficiency of financial operations. The study by O.J. Oteri *et al.* (2023) confirmed that modern technologies allow companies to optimise internal processes, reduce inventories and shorten delivery times. Digital platforms and analytical systems contribute to improved cost control and forecasting of enterprise needs. As a result, operating expenses decline and resources are allocated more efficiently. Research by Z. Hao *et al.* (2022) also showed that the introduction of logistics innovations and process automation reduces the risks of financial losses and unforeseen costs. Greater stability of income is ensured through more accurate planning, demand forecasting and reduced downtime. This enables enterprises to maintain competitive positions and develop sustainably in the market. It is important to highlight that logistics innovations not only reduce costs but also increase overall

operational efficiency. They improve the accuracy of demand forecasting and resource allocation, which reduces the risk of financial losses. Thus, the economic feasibility of innovations is confirmed both through cost reduction and through increased profitability.

Comparative analysis with industry indicators demonstrated that enterprises implementing logistics innovations achieve a higher level of organisation of transport and warehouse processes. These enterprises are characterised by improved accuracy in order processing and more efficient resource management, which creates a noticeable competitive advantage. F. Taques *et al.* (2021) concluded that innovative approaches in logistics enable companies to surpass traditional industry standards of efficiency and service speed. The adoption of modern technologies, automated systems and analytical tools ensures more accurate planning and process control. This allows enterprises to achieve superior results using fewer resources compared to conventional methods. A study by R. Richey *et al.* (2022) found that innovations facilitate the implementation of integrated supply chain management systems, which enhances coordination across all stages of logistics. This reduces the risk of delays, optimises routing and ensures timely delivery of goods. Consequently, overall enterprise efficiency increases while the workload on personnel decreases. The findings of Z. Abidin *et al.* (2023) also demonstrated that the introduction of new technologies enables companies to offer improved conditions for customers by reducing delivery times and lowering the likelihood of errors. This increases consumer trust and loyalty, directly influencing market competitiveness. Companies that quickly adopt innovations gain a strategic advantage over other industry participants. Similarly, G. Anwar & N. Abdullah (2021) concluded that innovative logistics solutions allow for more accurate inventory management, optimised transport utilisation and reduced storage costs. This enhances resource management efficiency compared with market averages. As a result, enterprises become more flexible and are able to respond quickly to changes in demand. These findings correspond to the results of the present study, confirming that the introduction of innovations in logistics processes significantly increases both the efficiency and accuracy of enterprise operations. Improvements were observed in the organisational level of processes and in the reduction of order-fulfilment times. This indicates that innovative approaches provide competitive advantages and improve adaptation to dynamic market conditions.

The results demonstrated that the implementation of logistics innovations at manufacturing enterprises had a positive impact on key dimensions of operational activity: optimisation of transportation costs, reduction in delivery times, improvement in warehouse efficiency and enhancement of financial performance. Comparison with industry standards confirmed the increasing importance of innovations for long-term competitiveness and enterprise development. The findings are consistent with the study by C. Baah *et al.* (2023), which confirmed that logistics innovations allow enterprises to significantly increase the efficiency of supply chain management and internal processes. Faster order processing, more accurate planning and the optimal use of resources are ensured, enabling companies to obtain a comprehensive advantage across all areas of activity. Similar conclusions were drawn by N. Batarlienė & A. Jarašūnienė (2024), who found that the introduction of modern technologies into transport and warehouse operations contributes to shorter delivery times and increased accuracy in cargo handling. Automated control and routing systems reduce the risk of errors and prevent staff overload. This ensures the stability and reliability of processes, which is particularly important under conditions of high order volumes. T.R. Akash *et al.* (2024) concluded that logistics innovations reduce operating costs, increase productivity and minimise resource losses. This has a direct positive effect on the financial results of enterprises, ensuring profit growth and increased profitability. In addition, effective resource management enables companies to reliably fulfil commitments to customers and partners. According to Ł. Brzeziński *et al.* (2023), innovations in logistics are becoming a key factor in the long-term development and competitiveness of companies. They enable rapid adaptation to changing market conditions and evolving consumer demands. Consequently, enterprises are able to plan strategic initiatives more effectively and ensure sustainable market performance. In comparing the data obtained in this study, it can be stated that logistics innovations exert a comprehensive positive influence on enterprise operations. The introduction of modern technologies increases the efficiency of transport and warehouse processes, reduces costs and shortens order-fulfilment times. Thus, the findings confirm that innovative approaches are a key factor in improving both the financial and operational performance of manufacturing companies.

Conclusions

In globalised and increasingly competitive environment, effective logistics management has become one of the key determinants of success for manufacturing enterprises. Innovative solutions in this field enable companies not only to optimise internal processes, but also to enhance customer service, reduce costs and shorten product delivery times. The experience of leading multinational corporations confirms the strategic importance of digital and automated systems for the development of efficient supply chains.

At Bosch plants in Germany, the implementation of SAP Extended Warehouse Management (SAP EWM) resulted in a significant increase in inventory accuracy (from 92% to 98%), a reduction in order processing time (from 4 to 2 hours), and an increase in staff productivity (from 50 to 70 orders per day). These improvements strengthened the coordination between production, warehouse operations and distribution. In the transport sector, SAP EWM reduced delivery times from 5 to 4 days, lowered transportation costs from 12 to 9 million EUR, and decreased empty runs by 15%. Procter & Gamble integrated the Oracle

NetSuite digital SCM platform, enabling the consolidation of purchasing, manufacturing, transportation and sales within a single information environment. Following implementation, inventory accuracy increased from 90% to 96%, order processing time decreased from 5 to 3 hours, and staff productivity rose from 45 to 65 orders per day. Delivery times were reduced from 6 to 5 days, transportation costs decreased from 20 to 16 million EUR, and empty runs were reduced by 12%.

Nestlé's use of PTV Route Optimizer ensured more efficient planning of delivery routes. As a result, delivery times fell from 4 to 3 days, transportation costs decreased from 15 to 12 million EUR, empty runs were reduced by 20%, inventory accuracy increased from 88% to 94%, order processing time declined from 3 to 2 hours, and staff productivity increased from 40 to 60 orders per day.

Financial indicators across all three companies also demonstrated substantial improvements. Bosch increased profitability from 18% to 22%, Procter & Gamble from 15% to 20%, and Nestlé from 16% to 21%. Correspondingly, logistics costs were reduced to 9 million EUR, 16 million EUR and 12 million EUR, respectively. Comparative analysis with industry averages further confirmed that these companies outperform typical sector benchmarks: transportation costs remain lower than the industry average of 18 million EUR, delivery times are shorter than the sectoral average of 5 days, and both inventory accuracy and warehouse productivity exceed standard levels. Profitability indicators are consistently 3-5% higher than average.

Overall, the implementation of digital logistics solutions – SAP EWM, Oracle NetSuite SCM and PTV Route Optimizer – provides a comprehensive positive effect, including cost optimisation, improved productivity, reduced delivery times, enhanced service quality and higher profitability. These findings confirm the strategic relevance of logistics digitalisation for modern manufacturing enterprises.

A limitation of this study is that the analysis draws upon data from only three leading multinational corporations, which may not fully reflect the situation of medium-sized or small enterprises. Further research is required to assess the impact of digital logistics systems on the environmental performance of supply chains, including their contribution to reducing CO_2 emissions.

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Вплив логістичних інновацій на витрати та прибутковість виробничих підприємств

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Анотація. Метою дослідження було оцінити, як впровадження сучасних логістичних рішень, таких як автоматизовані складські системи, цифрові платформи управління ланцюгами постачання та оптимізація маршрутів доставки, впливає на ефективність використання ресурсів і фінансові результати виробничих підприємств. В рамках дослідження проведено аналіз впровадження логістичних інновацій на прикладі виробничих підприємств Bosch, Procter & Gamble та Nestlé з використанням даних про транспортні витрати, час доставки, продуктивність складів, фінансові показники та галузеві норми. Було оцінено ефективність упровадження автоматизованих складських систем та цифрових логістичних платформ. На складах Bosch точність обліку запасів підвищилася з 92 до 98 %, час обробки замовлень скоротився з 4 до 2 годин, продуктивність персоналу зросла з 50 до 70 одиниць замовлень на день, а транспортні витрати зменшилися з 12 до 9 млн євро. У Procter & Gamble точність обліку запасів зросла з 90 до 96 %, час обробки скоротився з 5 до 3 годин, продуктивність підвищилася з 45 до 65 одиниць, а транспортні витрати знизилися з 20 до 16 млн євро. У Nestlé оптимізація логістичних процесів дала змогу скоротити час доставки з 4 до 3 днів, знизити транспортні витрати з 15 до 12 мільйонів євро, підвищити точність обліку з 88 до 94 % і збільшити продуктивність персоналу з 40 до 60 одиниць. Порівняльний аналіз засвідчив, що ці компанії перевищують середньогалузеві показники. Практичне значення дослідження полягає у наданні науково обґрунтованих рекомендацій щодо впровадження логістичних інновацій, які можуть підвищити ефективність управління ресурсами та поліпшити фінансові результати виробничих підприємств

Ключові слова: цифровізація; автоматизація; ланцюги постачання; продуктивність; витрати; ефективність

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