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INNOVATIVE DEVELOPMENT OF UKRAINE IN WAR CONDITIONS

The article presents a comprehensive study of the key economic and social effects of innovation activity as a determining factor in the structural modernization of the national economy. Ukraine's position in the international arena in terms of innovation development is identified based on a system of integrated indicators: the Global Innovation Index, the Global Sustainable Competitiveness Index, the Composite Innovation Index, the Global Talent Competitiveness Index, the Global Startup Ecosystem Index, and the Brain Drain Index. A detailed comparative analysis of the financial support for scientific and scientific-technical activities in Ukraine has been carried out, particularly the dynamics of expenditures on innovation as a share of GDP, as well as the structure of financing by sources and sectors, in the context of global trends and EU standards. The article examines the directions of Ukraine's international innovation cooperation during the period of full-scale invasion, including participation in the Horizon Europe programme, grant projects, and technology transfer initiatives. The peculiarities of innovation development in export-oriented sectors of the economy are studied, and the role of high-tech exports as a driver of national competitiveness is determined. Special attention is devoted to the innovation potential of Ukraine's defense-industrial complex, in particular the prospects for arms exports as a result of high-technology developments. The preconditions and specific features of innovation activity in the agro-industrial complex are analyzed, and the main stages of agricultural sector development are identified depending on the level of technological modernization. Examples of successful practices of innovation implementation by leading agribusiness companies are provided. Strategic directions for improving the efficiency of Ukraine's innovation policy in the context of wartime and post-war recovery are substantiated.

Keywords: innovation activity, innovation development indices, science financing, international innovation cooperation, full-scale invasion, defense-industrial complex, arms export, export-oriented enterprises, agro-industrial complex.

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ІННОВАЦІЙНИЙ РОЗВИТОК УКРАЇНИ ЗА УМОВ ВІЙНИ

У статті здійснено комплексне дослідження ключових економічних і соціальних ефектів інноваційної діяльності як визначального чинника структурної модернізації національної економіки. Визначено місце України на міжнародній арені за рівнем інноваційного розвитку на основі системи інтегральних показників: Глобального інноваційного індексу, Глобального індексу стійкої конкурентоспроможності, Зведеного інноваційного індексу, Глобального індексу конкурентоспроможності талантів, Глобального індексу екосистеми стартапів та Індексу відтоку людського капіталу. Здійснено ґрунтовний порівняльний аналіз фінансового забезпечення наукової та науково-технічної діяльності в Україні, зокрема динаміки частки витрат на інновації у ВВП, структури фінансування за джерелами та галузевими напрямками, у контексті світових тенденцій і стандартів ЄС. Розглянуто напрями розвитку міжнародного інноваційного співробітництва України в умовах повномасштабного вторгнення. Досліджено особливості інноваційного розвитку експортоорієнтованих секторів економіки, визначено роль високотехнологічного експорту як драйвера зростання національної конкурентоспроможності. Особливу увагу приділено інноваційному потенціалу оборонно-промислового комплексу України, зокрема перспективам експорту озброєння як результату високотехнологічних розробок. Проаналізовано передумови та специфіку інноваційної діяльності в аграрно-промисловому комплексі, визначено основні етапи становлення аграрного сектору залежно від рівня технологічної модернізації. Наведено приклади успішних практик упровадження інновацій провідними компаніями АПК. Обґрунтовано стратегічні напрями підвищення ефективності інноваційної політики України в умовах воєнного та післявоєнного відновлення.

Ключові слова: інноваційна діяльність, індекси інноваційного розвитку, фінансування науки, міжнародне інноваційне співробітництво, повномасштабне вторгнення, оборонно-промисловий комплекс, експорт зброї, експортоорієнтовані підприємства, аграрно-промисловий комплекс.

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STATEMENT OF THE PROBLEM

The war has caused serious changes in all sectors of the Ukrainian economy. According to the National Bank of Ukraine, the economy grew by 2.9% in 2024 compared to a growth rate of 5.5% in 2023, which indicates a slow

recovery from previous losses and demonstrates the challenges that remain relevant for the development of the national economy [1].

Therefore, special attention deserves the innovation sphere, which must quickly adapt to the changed realities of war and contribute to the strategic recovery of the country. Innovations ensure the development of defense technologies, the improvement of public services in crisis conditions, as well as progress in the medical field, including prosthetics and rehabilitation of the wounded. In 2024, the volume of spending on scientific research and development in Ukraine doubled, reaching \$ 191 million, which is primarily due to the growth of investments in defense and high-tech projects [2]. Among the leaders in the implementation of highly effective innovative developments are enterprises of the export-oriented agro-food complex of Ukraine. In the post-war period, innovation activities can increase the efficiency of energy consumption, accelerate the implementation of infrastructure projects and optimize export processes, which increases the country's international competitiveness [3].

Research into trends and problems of innovative development in Ukraine under war conditions allows us to identify effective directions for technological renewal, strengthening defense potential, and ensuring sustainable economic growth of the country.

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

Trends and prospects of innovative activity in Ukraine during the period of military aggression of the Russian Federation were studied in their works by Perminova S.O., Sytnyk N.I., Chuprina M.O. [4] They analyze the adaptation of the scientific and technical sector to extreme conditions, the development of defense technologies and the activation of the startup ecosystem. The results of these scientists' research demonstrate that the war became a catalyst for the accelerated development of innovative areas in the country, in particular in the IT sector and the field of cybersecurity.

Yatskevich I.V. [5], Bila I.S., Posna V.S., Shevchenko O.O. [6] consider innovation policy in the post-war period and innovative development as a critically important factor in post-war reconstruction. Scientists emphasize the strategic role of energy, digital and infrastructure innovations for the restoration of the economy and the integration of Ukraine into the European economic space.

Migai N.B. and Tarasyuk V.V. [7] highlight aspects of forming an effective innovation policy that contributes to the sustainable development of the country, and the studies of Davymuka S.A. and Paskakoshtiv O.V. [8] analyze social and innovative approaches to ensuring the protection of the population during war. Bobko N. [9] and Nazarovets S. [10] consider the rating of Ukraine's innovation potential and the impact of military actions on scientific and technical cooperation. The results of the studies of Timoshyn D., Grynova T., Kostyuk I. [11] testify to the restoration of scientific infrastructure and Ukraine's contribution to fundamental research even in conditions of military aggression.

Thus, modern scientific literature covers the study of both operational problems of innovation activity during wartime (adaptation, defense technologies, IT sector, startups), and the definition of strategic tasks of post-war development (infrastructure and energy innovations, restoration of financing, international cooperation).

However, in the context of dynamic geopolitical events and the escalation of military confrontation, it is relevant to further monitor trends and problems of innovative development of Ukraine, track and analyze factors that influence its place in the rankings among the leading high-tech countries. Insufficient attention has been paid by domestic scientists to the issue of increasing the efficiency of innovative activity of export-oriented sectors of the country's economy. Filling these gaps will contribute to the formation of a scientific basis for the development and improvement of strategies for innovative development of the state in conditions of military aggression and post-war recovery.

The purpose of this article is a comprehensive study of the features and factors of innovative development of Ukraine in general and export-oriented sectors of the economy in particular under conditions of military aggression.

PRESENTATION OF THE MAIN MATERIAL

At the state level, the effective implementation of innovations is a strategic factor in creating competitive advantages and ensuring sustainable economic development.

Among the key economic and social effects of innovation in the country, it is necessary to highlight: stimulating the structural transformation of the economy through the development of new industries and the formation of innovative products and services, which ensures the growth of national GDP and strengthening economic stability; increasing the competitiveness of the economy due to technological advantage in the world market and integration into global value chains; increasing labor productivity and creating new jobs, especially in high-tech sectors, which contributes to the modernization of the labor market and increasing incomes of the population; improving the quality of life of the population through increasing the efficiency of the provision of social services, the development of medical and educational technologies; forming an attractive investment environment that stimulates the inflow of direct and portfolio foreign investments; adaptability of the economic system to external and internal risks, increasing the efficiency of risk management and preventing the negative consequences of crisis phenomena; activating scientific and technical potential through the development of research and innovation infrastructure; promoting the introduction

of environmentally friendly technologies, reducing harmful emissions and rational use of natural resources, which meets the principles of sustainable development.

Thus, innovation activity serves as a comprehensive tool for the economic, social and technological development of the state, ensuring its strategic stability in the modern conditions of global challenges and military risks.

Analysis of the dynamics of Ukraine's positions according to the three leading international approaches to assessing innovation capacity during 2016–2024 – the Global Innovation Index (GII), the Global Sustainable Competitiveness Index (GSCI) and the Composite Innovation Index (CII) – shows a relatively low level of performance of our country in the world ranking. At the same time, there is a gradual positive dynamics of individual indicators. In particular, in 2024, Ukraine improved its positions in the GICI and CII rankings, taking 47th and 33rd places respectively, while in 2023 these indicators were 57th and 34th places [12].

In 2024, to the top five in the Global Innovation Index (Global Innovation Index , GII) included Switzerland, Sweden, the United States of America, Singapore and the United Kingdom. Among the post-Soviet states, the highest positions are occupied by Estonia (16th place), Lithuania (35th place) and Latvia (42nd place). In the regional dimension, Poland demonstrated positive dynamics, rising one place to 40th place. Ukraine took 60th place, at the same time entering the top four countries among 38 countries from the group with a lower-middle income level (Table 1.1) [13].

Key weaknesses in innovation include unstable business conditions, low labor productivity, and insufficient gross fixed capital formation. Strong factors include the development of useful models, high female employment rates in the relevant sector, investment in software, export of ICT services, and government support in the form of financing [14].

Despite the war conditions, Ukraine retains an innovative potential based on human capital and a developed startup ecosystem. Even before the full-scale invasion, the country had a significant base of technical expertise and entrepreneurial initiatives, such as People.ai , Grammarly , GitLab , and Ahrefs .

Despite a 32% reduction in funding during 2023–2024, by early 2025, Ukraine had risen to 42nd place in the annual *Global Startup Ecosystem Rankings. Startup Ecosystem Index* , compiled by the international startup and innovation research center *StartupBlink* . This means an improvement of seven positions compared to 2023 and eighth place among the countries of Eastern Europe. The country has 646 startups registered (2 units per 100 thousand people) - this is 6% of their total volume in Eastern Europe . Kyiv, Lviv, Kharkiv, Odessa are the leaders of the national ranking of the top 1000 cities according to the Global Startup Ecosystem Index 2025 [15].

A key resource for development is a highly skilled workforce, some of which is temporarily integrated into foreign labor markets. The long-term sustainability of the ecosystem depends on the return of these professionals and the active participation of the diaspora.

In modern conditions, there is a diversification of innovations in the fields of defense and cybersecurity . To stimulate them, the state uses tax breaks, deregulation measures, grant programs. The Brave 1 initiatives and the Ukrainian Startup Fund are important , providing support for projects for both military needs and reconstruction.

The institutional environment is developing through the strategies of the Ukrainian Startup Association, innovation parks like Unit City , as well as public-private partnerships (for example, the activities of Technosystem in cooperation with the Ministry of Digital Transformation).

International support (Google , Network VC , EU programs) demonstrates confidence in Ukraine's innovation potential. The Ukrainian Startup Fund and the Vision 2025 strategy, introduced in 2019, have already provided funding for over 350 projects.

Therefore, despite the crisis conditions, the Ukrainian startup ecosystem retains its adaptability and ability to develop, which forms the basis for recovery and integration into the global innovation space.

According to the results of the 2024 Global Sustainable Competitiveness Index, Ukraine rose ten places to 47th place among 191 countries. The strongest indicators were recorded in the areas of resource efficiency (24th place) and natural capital (38th place), while the country remains in relatively low positions in intellectual capital and quality of governance (80th and 88th places) (Table 1).

Table 1

Ukraine's ranking by Global Index components sustainable competitiveness in 2024

Indicator	Global index sustainable competitiveness	Natural capital	Resource intensity and efficiency	Intellectual capital	Social capital	Economic sustainability	Management
Place in the ranking	47	38	24	80	60	68	88
Mark	47.7	50.5	53.8	41.4	46.7	45.2	49.1

Source: compiled by the author based on [16]

In 2023, Ukraine improved its position in the Global Talent Competitiveness Index, moving from 66th to 64th place (Figure 1) [17]. Growth was recorded in all six components of the index: from 75th place in market and regulatory opportunities to 50th place in the ability to retain talent and the level of global knowledge.

The identified increase indicates a gradual increase in the competitive potential of the national workforce, which may be due to an increase in the educational level, improvement of professional qualifications and expansion of innovative segments of the economy. At the same time, despite positive changes, Ukraine still belongs to the group of countries with a moderate level of talent competitiveness, which highlights the need for further implementation of human capital development strategies, modernization of educational policy and active involvement of highly qualified specialists.

According to the Composite Innovation Index (CII), Switzerland took the lead in 2023, followed by Denmark, Sweden, and Finland. Ukraine, with a CII value of 36.0 (relative to the EU average for 2017), is classified as a “slow innovator.” The current index value for Ukraine (0.18) is more than three times lower than the average level for the European Union countries (0.55) (Fig. 1).

Ukraine demonstrates the most pronounced results in the innovation dimensions "Impact on employment" (indicator "Impact" - 73.7), "Intellectual assets" (indicator "Innovative activity" - 20.0) and "Connections" (indicator "Innovative activity" - 21.4). All of these indicators slightly exceed the results of the previous year (72.8; 17.3 and 21.0, respectively), which indicates the presence of positive trends in the implementation of individual components of innovation potential.

For the first time in recent years, an improvement was recorded in the indicator "Digitalization" (component "Framework Conditions"), which increased to 115.6. At the same time, the indicators "Environmental Sustainability" (component "Impact") and "Human Resources" (component "Framework Conditions") show a decline - to 71.5 and 29.8, respectively, which are lower than the indicators of 2023 (76.7 and 34.9). This indicates the persistence of structural imbalances in the development of the national innovation system and the need for a comprehensive adjustment of the state innovation policy.

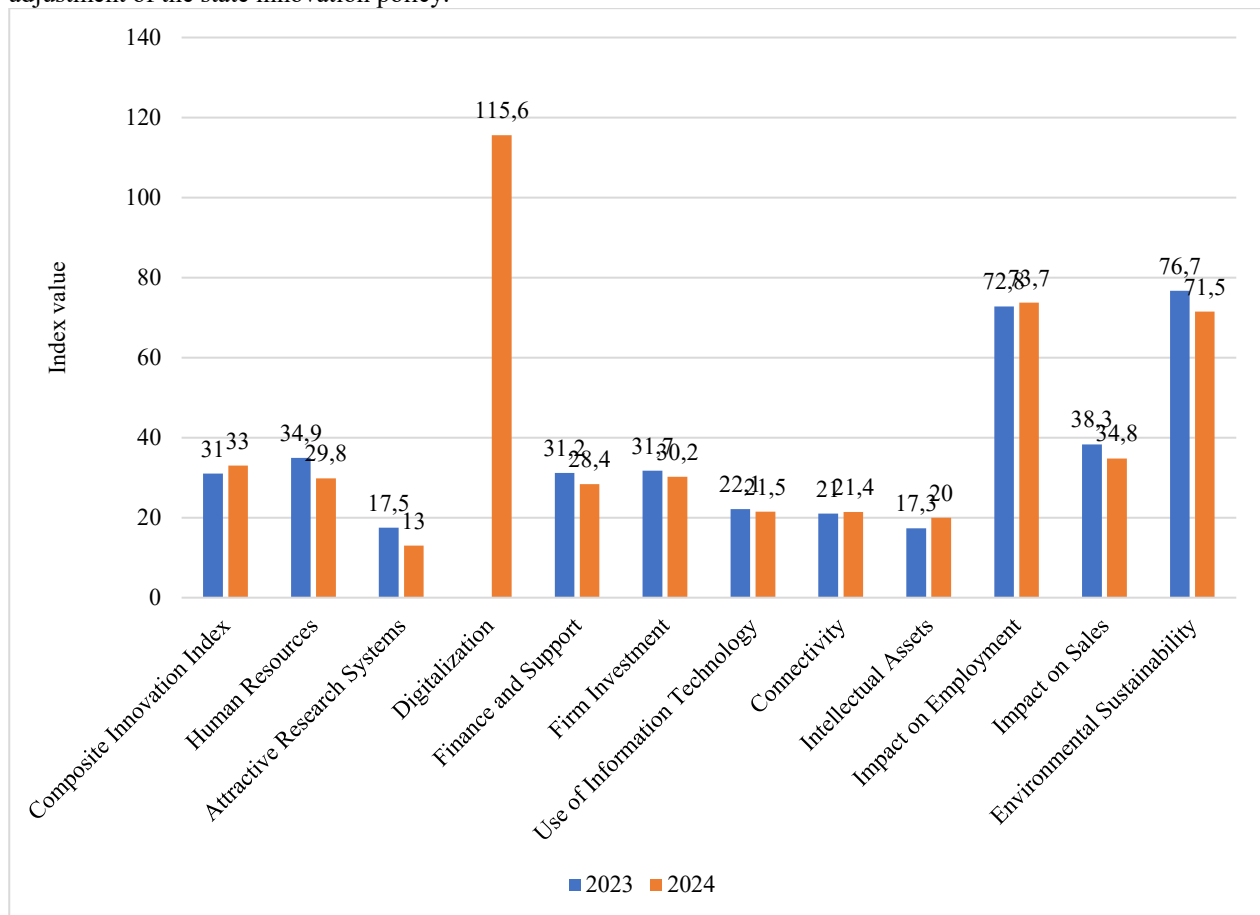


Fig. 1. Ukraine's position by components of the Consolidated Innovation Index in 2023 – 2024

Source: Compiled by the author based on data from [18]

As shown by the results of the analysis of the state of financial support for domestic scientific and scientific and technical activities, the share of expenditures on scientific and technical activities in GDP has been decreasing over the past 10 years and in 2024 amounted to 0.33% (Fig. 2), which is much less than in developed countries of the world.

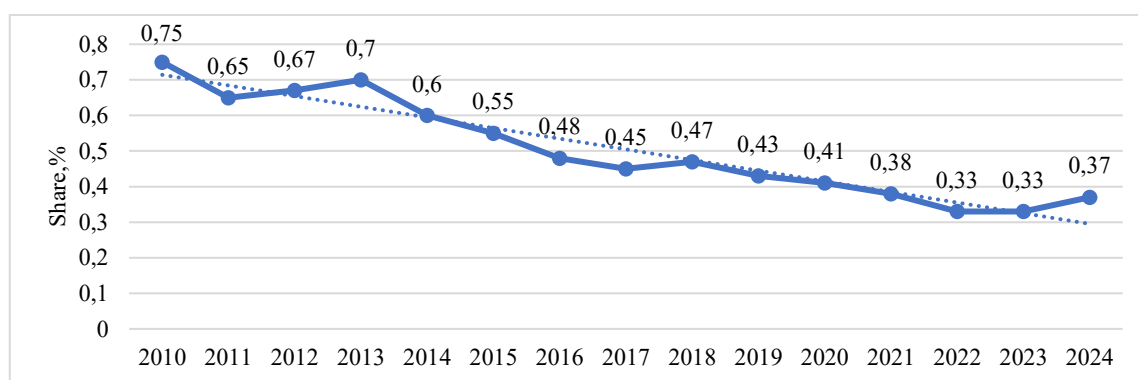


Fig. 2 Expenditures on scientific and technical activities as a percentage of GDP for 2010-2023

Source: compiled by the author based on data from [19]

For example, in 2023, the average share of R&D expenditure in the GDP of the EU-27 countries was 2.13%. Indicators exceeding the average level were recorded in Sweden (3.60%), Belgium (3.32%), Austria (3.29%), Germany (3.11%), Finland (3.09%), Denmark (2.99%) and France (2.19%). At the same time, in a number of countries this indicator is significantly lower than the European average: in particular, in Estonia, Poland, Lithuania, Romania, Latvia, Bulgaria, Cyprus and Malta it ranges from 0.52% to 1.84%[20]. The highest indicators of the share of R&D expenditure in the GDP structure were recorded in Israel (6.35%) and the Republic of Korea (4.96%). Values exceeding the 3% level are also typical for China (3.98%), the United States of America (3.45%) and Japan (3.44%)[21].

Analysis of the share of knowledge-intensive expenditures in Ukraine's GDP shows that it remains almost six times lower than the average level in the EU countries and significantly lags behind the indicators of leading countries, where the share of expenditures on research and development exceeds 3%. This situation indicates the limited competitiveness of the national economy in the field of high-tech products and innovative markets. Accordingly, at the current stage, Ukraine is able to compete effectively mainly with countries that are not leading suppliers of advanced technologies and products with high added value, which determines the strategic need to concentrate efforts on increasing innovation capacity and stimulating knowledge-intensive sectors of the economy.

In 2024, the largest share of budget funds was directed to engineering and technology, which is due to the urgent need for technological support, modernization of the armed forces and restoration of destroyed infrastructure. Such a concentration of funding reflects the strategic priority of the state in the development of critical sectors of the economy and ensuring national security, and also creates the prerequisites for stimulating innovation processes in high-tech industries (Fig. 3).

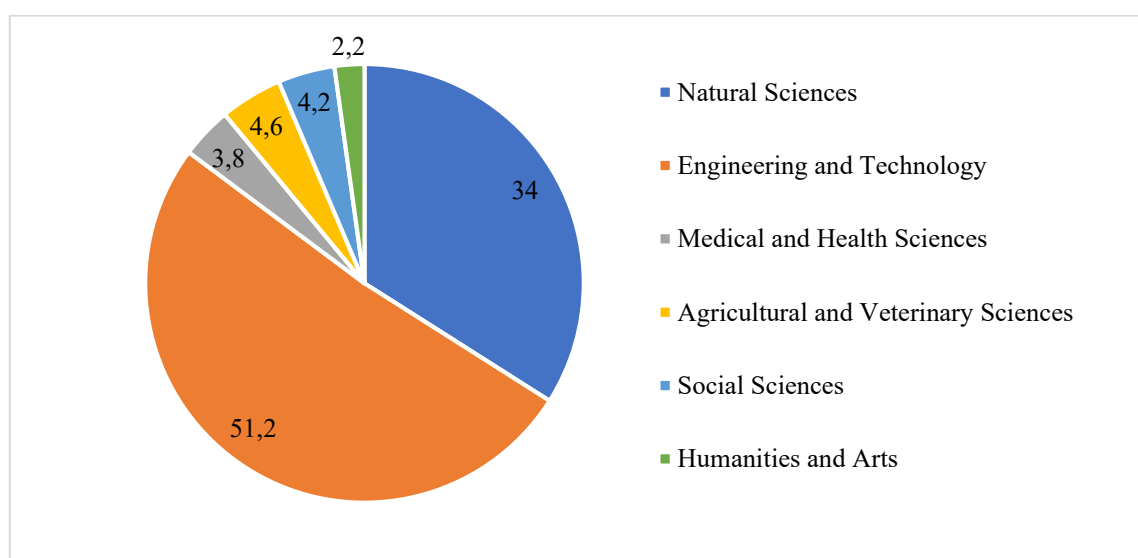


Fig. 3. Expenditures on scientific research and development by field of science in 2024

Source: compiled by the author based on data from [19]

Compared to the previous year, the burden on the state budget increased to 64.2% of the total amount of funding for scientific activities. In 2023, this indicator returned to the level of 2021. The increase in support for Ukrainian science from international organizations allowed, after a period of uncertainty at the beginning of the full-scale war, to increase the share of funding from foreign sources to 16.4% of the total amount, which practically

corresponds to the pre-war level (Table 2). At the same time, recently, the largest share of resources for research and development has been directed by the business sector, ahead of other sectors of the economy, which indicates a gradual intensification of private innovation activity and a strengthening of the role of business in the formation of the country's scientific and technological potential.

Table 2

Expenditures by sources of funding for scientific research and scientific and technical (experimental) developments (S&T) in Ukraine in 2021-2024

Year	Total, UAH million	Including at the expense of funds,%						
		own	public sector organizations	business sector	Higher education sector organizations	Private non-profit organizations	Foreign sources	Other sources
2021	20973.8	19.2	46.3	13.9	0.1	0	19.7	0.7
2022	17117.8	9.8	66.6	11.8	-	-	10.8	0.7
2023	21348.1	27.8	43.1	11.5	0.1	0	16.4	1
2024	28328.2	30	40.1	11.6	0.1	0	15.9	1.0

Source: compiled by the author based on data from [19]

The share of the Ukrainian state budget for financing research and development in 2023–2024 significantly decreased compared to 2022, but remained above the level typical for most developed countries of the world, where state funding for R&D accounts for less than 30% of total expenditures. This indicates that the national research sector remains significantly dependent on state support, despite the gradual increase in the role of private and international funding (Fig. 4).

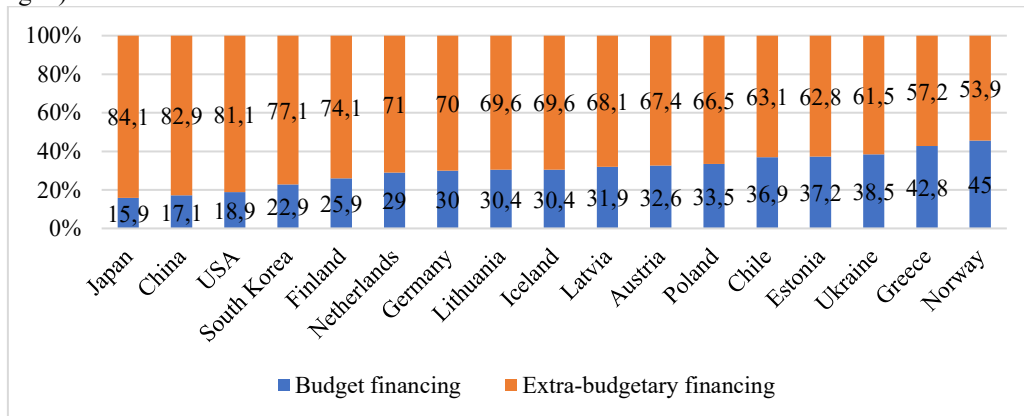


Fig. 4. Ratio of shares of budgetary and extra-budgetary financing of D&D in the countries of the world and Ukraine, %

Source: compiled by the author based on data from [22], [19]

Intellectual emigration has the most negative impact on the economy of a state in conditions of military conflict. During the first year of the war, Ukraine's position on the Brain Drain Index deteriorated from 81st place in 2022 to 4th, putting it on a par with countries such as Palestine, Jamaica, and Samoa [23]. This indicates a sharp reduction in the availability of highly qualified personnel and a weakening of the potential of the national economy's intellectual resources (Table 3).

Table 3

Dynamics of the Brain Drain Index of the world's countries in 2022–2024*

Country	2022		2024	
	Rating	Rating	Rating	Rating
Australia	177	0.4	175	0.3
Sweden	176	0.6	173	0.6
Canada	174	0.8	172	0.7
Denmark	172	1.0	170	0.8
Singapore	167	1.6	168	1
USA	163	1.8	166	1.4
Austria	164	1.7	160	1.6
Great Britain	157	2.4	155	2.3
South Korea	143	3.4	140	3.1
China	137	3.5	134	3.3
Poland	115	4.6	115	4.3
Ukraine	81	5.9	7	8.4
Palestine	3	8.9	2	9.4
Jamaica	2	9.5	3	9.2
Samoa	1	10	1	10

* Rating scale: 0-10, the lower the value, the lower the level of brain drain. A total of 177 countries are ranked.

Source: compiled based on [24].

According to the Law of Ukraine “On the State Budget of Ukraine for 2025”, the share of financing for digital transformation will be UAH 4 billion, science – UAH 14.5 billion, which is UAH 3.1 and 2.6 billion more than in 2023 [25, 26].

Increasing the pace of Ukraine's international cooperation in the field of innovation is a key factor in its development and adaptability (Table 4).

Table 4

International innovation cooperation of Ukraine in 2022-2024

Date	Partner	Object of cooperation	Projects and the essence of cooperation
from June 9, 2022	EU	Horizon Europe	<ul style="list-style-type: none"> • MSCA4Ukraine (25 million euros) – scholarships for relocated researchers from Ukraine to the EU and associated countries; • EIC4Ukraine (20 million euros) – consulting for startups in the field of deep technologies; • ERC4Ukraine – 500 grant-related vacancies; • Accelerated access for Ukrainian researchers in the fields of healthcare, ecology, and digitalization; • 5 million euros to Ukrainian cities to integrate carbon neutrality; • Human Frontier Science Program for scientists from Ukraine; • The “Centers of Excellence” initiative is a competition for Ukrainian organizations on an innovation “mentoring scheme”
May 3, 2024	Great Britain	Innovate Ukraine	<ul style="list-style-type: none"> • MicroHubs – production of electricity, heat and hydrogen using biomass; • CHEPro – energy-efficient landfill power plants; • FireDragon Fuel – supply of dry fuel; • H2U – hydrogen energy; • OMM-Ukraine – optimized management; • CERU – critical energy resilience; • AIRFUSE – supply of redox batteries; • Expanded biomethane production from microalgae; • METTLE – supply of mobile energy storage devices with replaceable batteries; • S3RU – safe, sustainable and rapid reconstruction
June 4-6, 2024	NATO	NATO-Ukraine Defense Innovators Forum	<ul style="list-style-type: none"> • Presentation of projects (including more than 100 launches) by 400 participants from 17 countries; • Automated Visual Guidance Hackathon and the total winnings of Ukrainians were 65 thousand US dollars; • First-time access to the Defense Innovation Accelerator; • Receiving feedback from the NATO Innovation Fund
August 5, 2024	NATO	NATO-Ukraine Innovation Cooperation Roadmap	<ul style="list-style-type: none"> • Mechanisms of innovation policy and innovation ecosystems; • Pilot events for permanent exchange of participants; • Joint Analysis, Training and Education Center

Source: compiled by the author based on [27,28,29,30]

Martial law and the need to ensure the state's priority needs redirect scientific research and development to the national security of Ukraine, which is enshrined in the relevant amendments to the Laws of Ukraine "On Priority Areas of Development of Science and Technology" and "On Priority Areas of Innovation Activity in Ukraine" [31].

The priority task is to increase the production of the Ukrainian defense industry under the conditions of attracting foreign investment and joint ventures. It is predicted that in 2025 the production potential of the private and public sectors of the defense industry will be \$ 20 billion, which is 3 times more than in 2023.

Among the advantages of Ukrainian weapons is the low cost of production [32], in addition, the state budget for the purchase of weapons in 2024 amounted to 6 billion dollars, which is three times less than the production capabilities of domestic manufacturers. Due to the lack of orders, and as a result, working capital, manufacturers are forced to close production or relocate it abroad. Therefore, opening and increasing the volume of exports of surplus military equipment and weapons can be an alternative solution for replenishing the state budget and strengthening the Armed Forces of Ukraine [33].

In order to ensure effective coordination between military structures, government agencies, defense equipment companies (defence tech), volunteer funds, media and investors, as well as to accelerate the development and implementation of technological solutions in favor of approaching victory, a defense support cluster was created in Ukraine tech developments " Brave 1" at the initiative of military and state bodies. As a result of the cluster's activities, more than 1,600 developments have been registered, of which 60 are ready for codification and procurement, and about 1,000 Ukrainian manufacturers have been involved in their participation. In addition, a grant program has been implemented, within the framework of which 186 grants were provided during the year for the equivalent of 3.2 million USD. For 2024, financing of the defense sector through " Brave 1" in the amount of 1.5 billion UAH is envisaged. The permanent international partners of the platform are the United Kingdom, France, the United States, Denmark, the Czech Republic, Italy, Belgium and Estonia, as well as their highly qualified developers of relevant technologies [34].

Despite the ongoing military aggression, Ukraine continues to play a key role in ensuring global food security, supplying food to approximately 400 million people in the world (Melnyk , Tunitska , Banas , 2023 [35]). At the same time, the share of the agricultural sector in the gross domestic product is decreasing due to the faster recovery of other sectors, in particular industry and construction. However, the agro-industrial complex retains leading positions in foreign trade, generating more than 40% of export revenue, which significantly exceeds the indicators of such sectors as metallurgy and mechanical engineering [36].

Full-scale military aggression has created unprecedented challenges for agriculture: infrastructure has been destroyed, logistics chains have been disrupted, and significant areas of agricultural land have been lost. Total direct and indirect losses of Ukraine's agro-industrial complex are estimated at 80 billion USD (Table 5). At the same time, the sector's ability to restore and maintain competitiveness is largely ensured by the introduction of innovative technologies. Digitalization, precision agriculture, automation of production processes, and optimization of logistics chains allow for increased productivity, reduced losses, and adaptation of production to the difficult conditions of wartime, which is critically important for maintaining food security at the national and international levels.

Table 5

Straight losses AIC and land resources because of War with the russian federation in 2022-2024

Types of losses	One . ex.	Initial number of objects	Number of damaged objects			Loss assessment, m million dollars		
			2022	2024	Abs. deviation, +/-	2022	2024	Abs. deviation, +/-
Total direct infrastructure damage	-	-		-	-	8.7	10.3	1.6
<i>Destroyed</i>								
Agricultural machinery	units	764323	109601	130603	21002	4.3	5.43	1.13
Granaries	capacity, thousand tons	75084	8198	11351	3153	1.2	1.7	0.5
Dead animals (including poultry)	thousand heads	203292	2230	1899	-331	0.1	0.1	0
Destroyed apiaries	bee colonies	2272740	86902	86902	0	0.0	0.0	0
Perennial crops	Ha	197100	20104	16364	-3740	0.5	0.4	0
Destroyed and stolen factors of production	so.	962951	135993	135993	0	0.1	0.1	0
Destroyed and stolen finished agricultural products	so.	25486613	4037542	4037542	0	1.9	1.9	0
Aquaculture and fishing facilities	units	2102	-	228	228	-	0.03	0.03
<i>Damaged</i>								
Slaughter of animals due to the impossibility of keeping them	thousand heads	203292	14072	11963	-2109	0.1	0.1	0
Dead and missing bees	bee colonies	2272740	192526	192526	0	0.0	0.0	0
Agricultural machinery	units	764323	50749	50749	0	0.4	0.4	0
Granaries	capacity, thousand tons	75084	3249	3249	0	0.1	0.1	0

Source: compiled based on data from the Agrocenter of the Kyiv School of Economics (Center for Food and Land Use Research) [37]

There are five key stages in the development of the agricultural sector from the beginning of the 20th century to the present day (Table 6). Each stage is characterized by specific technological and organizational innovations that significantly increased the efficiency of agricultural production. The mechanization of the early 20th century provided an increase in labor productivity through the use of tractors and manual labor. In the 1950s, the “Green Revolution” promoted the use of new agricultural technologies, mineral fertilizers and pesticides, which increased yields. At the “Precision Farming” stage of the 1990s, the use of autopilots, yield monitoring and data-based management began. In the 2010s, digital farming was introduced, including FARM management and real-time analytics. The modern “Integration of Technologies” stage is characterized by the widespread use of artificial intelligence, robotics, IoT and big data analytics, which ensures the optimization of production processes and precise management of resources.

Modern agribusiness operates in the context of a number of structural and environmental challenges, including global climate change, depletion of natural resources, soil degradation and increasing environmental pressure. Eco-innovation is a key mechanism for overcoming these problems, ensuring the transformation of the agricultural sector into a modern, sustainable and competitive industry that combines economic efficiency, social welfare and the preservation of natural capital. The use of resource-efficient technologies, energy-saving solutions, digitalization and circular economy principles contributes to increasing productivity, minimizing environmental

impact and optimizing production processes, which is the basis for sustainable development of the agricultural sector [39].

Table 6

Stages of development of the agricultural sector in the world depending on the degree of application of technologies

1900s Agriculture 1.0	1950s Agriculture 2.0	1990s Agriculture 3.0	2010s Agriculture 4.0	2020s Agriculture 5.0
Mechanization	Green Revolution	Precision farming	Digital farming	Technology integration
The emergence of tractors Improving efficiency Manual labor Low level of production, only enough to meet the needs of one family	New agronomic practices Use of mineral fertilizers and pesticides Improving seed quality Increasing yield	Using autopilot Yield monitoring Differential fertilization and sowing Data-driven management	FARM management Real-time data analysis Value-added services Optimization of resource usage	Artificial Intelligence and Machine Learning Use of robotic technology Internet of Things (IoT) Wireless Sensor Networks (WSN) Agrobiotechnologies Big Data Analytics and Decision Support Systems (DSS)

Source: compiled by the author based on [38]

Digitalization processes are increasingly integrated into the functioning of the agricultural sector, in particular into the electronic document management system and precision agriculture technologies, which include the use of unmanned aerial vehicles (UAVs), satellite monitoring, mobile applications, and big data analysis methods (Big Data). Data) and intelligent chatbots; these tools are considered in modern reports as key elements in increasing the operational sustainability and productivity of agricultural enterprises [40, 41].

From the perspective of transforming consumer preferences, the prospects for the development of the food industry are determined by the intensification of personalized nutrition - approaches based on genomics data, microbiome analysis and biomarkers (blood indicators) - and the spread of flexitarian practices, i.e. partial replacement of rational animal products with plant-based alternatives; clinical and review studies in 2023–2024 confirm the growing effectiveness of genome-oriented and personalized diets on cardiometabolic and other health indicators, which creates demand for accordingly adapted food chains [42, 43].

In terms of state and international regulation, the policies of the European Union, in particular the European Green Deal, are becoming a determining factor . Green Deal) and carbon farming initiatives (carbon farming), which formulate requirements for increasing the environmental sustainability of agricultural production and reducing the carbon footprint; non-compliance with these requirements increases the risk of complicating Ukrainian exporters' access to developed solvent EU markets, which has been confirmed by both EU analytical reports and assessments of recent reforms in the field of agricultural policy [44, 45].

At the same time, external shocks and military actions affected the structural parameters of the domestic agricultural sector: national and international surveys and assessments for 2024 record a decrease in sown areas and changes in the economic behavior of enterprises, which reinforces the importance of state support instruments, financial programs of international financial organizations (World Bank, FAO), and the need for investments in digital infrastructure and innovative management to restore exports [46, 47].

In the context of the organizational structure of modern agricultural corporations, the position of innovation officer (director) is finally formalized as a necessary component of the management team, comparable in importance to the position of agronomist; this is due to the need to coordinate digital transformations, adapt to external regulatory requirements, and implement technologies that ensure compliance with environmental sustainability standards and market expectations of partners in the EU.

Most modern agricultural innovations are based on digital technologies. In 2025, the AgroTech development strategy was presented as part of the WINWIN Digital Innovation Strategy until 2030 [48]. It provides for the introduction of IT solutions, artificial intelligence, drones, robotic systems to optimize agriculture and the food industry. The achievement of these goals will be ensured by integrating artificial intelligence technologies, the Internet of Things, unmanned aerial vehicles and robotic systems aimed at optimizing production processes and rationalizing the use of resources. The introduction of these tools not only creates new prerequisites for sustainable economic growth and strengthens Ukraine's competitive position in the global economic system, but also forms the potential for the transition from a raw material export model to the production of innovative products with high added value. In addition, the use of these technologies can compensate for the personnel shortage caused by military losses, as well as contribute to the demining of territories and increase the productivity of agricultural lands.

An analysis of current innovation cases of large Ukrainian companies in the agro-industrial complex has shown their use of various innovative approaches - from deep processing of raw materials and production of bioenergy resources to the use of robotic systems and agricultural drones (Table 7). Despite the expected challenges, the implementation of the latest technologies contributed to increasing the added value of products, reducing the carbon footprint, developing human capital, and optimizing the production processes of the companies studied.

Table 7

Experience of implementing innovation by leading companies in the Ukrainian agribusiness sector in 2024–2025

Company / Project	Type of innovation	Main effects	Challenges / comments
Astarta	Construction of a soy protein concentrate production plant	Increasing the added value of exports; creating new jobs (~3,000 direct and indirect); diversifying the agricultural portfolio; strengthening the country's export competitiveness.	The need for modern equipment, technologies; ensuring the supply of raw materials; investment risks due to the variability of conditions; the need for state support / incentives.
MHP	Bio-LNG production from waste (poultry and agricultural waste)	Turning waste into a valuable energy resource; reducing carbon footprint; first export of such a product to the EU; positioning the company as an innovative leader in the field of "green" technologies.	The need to ensure logistics, standardization; potential regulatory barriers; competition in the energy market; capital expenditures.
MHP	Solar power plants, cogeneration, wind farm planning (60 MW)	Reducing dependence on external energy; increasing energy efficiency; reducing production costs; a step towards sustainable/green production.	Investment costs; difficulties in connecting to networks, stability of supply; regulatory and technical permits; potential risks due to climate change or weather conditions.
DroneUA	Drone sprayers, agricultural drones, robotic technologies in crop cultivation, service provision, personnel training	Reduction in pesticide use (up to ~30% or more), fuel and water savings (up to 90-95% in relevant processes); increased accuracy and timeliness of cultivation; spread of precision agriculture; increased technological culture among farmers.	Barriers to access to drones/equipment; legislative/regulatory issues; need for qualified personnel; limitations in active combat environments or in restricted access areas.
IT Ukraine Association	Strategic partnership in the implementation of the AgroTech direction in the WINWIN strategy	Supporting innovation; scaling technologies; integrating them into related industries and exporting technical solutions.	The need for financing; coordination between government agencies, business and scientific institutions; ensuring sustainable development and adaptation to changing market conditions.

Source: created by the author based on [49, 50, 51, 52, 53, 54].

CONCLUSIONS

Thus, the innovative development of Ukraine in wartime conditions acquires strategic importance both for maintaining economic stability and for building competitiveness in the global economic space. Despite the significant challenges caused by full-scale aggression, Ukraine maintains notable positions in international rankings. In particular, according to *the Global Innovation Index* The state continues to be among countries with an average level of innovation potential, which indicates the presence of significant reserves for building the scientific and technological base.

Research into innovation trends in export-oriented sectors of the economy demonstrates the heterogeneity of processes. On the one hand, the agro-industrial complex continues to actively implement digital technologies, precision farming tools, and biotechnological solutions that increase productivity and allow maintaining competitive positions in international markets. On the other hand, the defense-industrial sector demonstrates the rapid development of innovations, in particular in the field of unmanned systems, cybersecurity, and high-precision weapons, which have become an important factor not only in national security, but also in the future growth of exports of military products.

At the same time, innovation dynamics remain fragmented, which necessitates the formation of systemic approaches to stimulating research and development (R&D), integrating university science into the production sector, and developing an effective innovation infrastructure.

In order to increase the efficiency of innovation activity in Ukraine, it is advisable to highlight the following strategic areas: improving the legislative framework regulating innovation activity, as well as creating a favorable investment environment for venture capital and startups; deepening international cooperation with the EU and other partners in the field of scientific and technical programs, including Ukrainian companies in global innovation value chains; technological modernization of the agro-industrial complex by supporting projects in the field of agrotechnology that combine digitalization, environmental sustainability and increased resource efficiency; development of defense innovations through institutional stimulation of defense startups and creation of mechanisms for the commercialization of dual technologies that will be in demand both in domestic and foreign markets; formation of highly qualified personnel through the integration of STEM education with the practical needs of business and the public sector.

Thus, the innovative development of Ukraine in wartime appears not only as a tool for economic survival, but also as a key resource for the restoration and long-term modernization of the national economy. The systematic implementation of these areas can ensure increased efficiency of innovation processes, contribute to the establishment of Ukraine as a significant subject of the global innovation ecosystem and strengthen its position in world competitiveness rankings.

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