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THE DEGREE OF DEVELOPMENT OF THE NATIONAL INNOVATION SYSTEM OF UKRAINE AND ITS IMPACT ON THE ENVIRONMENT

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СТУПІНЬ РОЗВИТКУ НАЦІОНАЛЬНОЇ ІННОВАЦІЙНОЇ СИСТЕМИ УКРАЇНИ ТА ЇЇ ВПЛИВ НА НАВКОЛИШНЄ СЕРЕДОВИЩЕ

The article conducts research and examines the degree of development of the national innovation system of Ukraine and its impact on the environment. In the modern world, the development of national innovation systems (NIS) determines the level of national economies. Economic theories are constantly supplemented by factors that influence the development of such systems.

Given the significant negative impact of humanity on the environment, the main factor is to ensure sustainable development by eliminating anthropogenic negative impacts on the environment.

The purpose of the study is to determine the level of development of the national innovation system of Ukraine and its impact on the environment. The authors conducted a retrospective comparative analysis. For comparison, the indicators of Poland, the United States of America and Japan are taken. The factors of the innovative Quintuple Helix model are taken as a basis, which, according to the authors, are the most appropriate for the purpose of the study. To study the NIS of Ukraine, the key indicators of each of the factors of the model of five spirals are analyzed. This approach allows considering the issue of sustainable development and social ecology of Ukraine from an interdisciplinary and transdisciplinary point of view.

The study reveals the interdependence of the factors of the model of fifth spirals. The low level of development of certain factors negatively affects others, which leads to a cumulative negative impact on the environment. For example, insufficient training, weak technology transfer, and insufficient investment in research and development hold back innovative development, which is the basis for the creation of new technologies and eco-innovations.

According to the results of the study, the level of the national innovation system of Ukraine was determined, the mutual influence of the analyzed factors and their impact on the environment was revealed, ways of reducing the negative impact on the environment of the post-war period, restoring the economy of Ukraine and improving the state of its national innovation system were proposed.

The proposed measures to create an environmentally safe, competitive economy and sustainable development of Ukraine require significant resources and time for implementation. However, their implementation is necessary to solve the problems that arose as a result of the deformed development of the country and the negative, destructive impact of the war.

У статті проведено дослідження та розглянуто ступінь розвитку національної інноваційної системи України та її вплив на довкілля. У сучасному світі розвиток національних інноваційних систем (НІС) визначає рівень національних економік. Економічні теорії постійно доповнюються чинниками, які впливають на розвиток таких систем.

Враховуючи значний негативний вплив людства на навколишнє середовище, головним чинником є забезпечення сталого розвитку шляхом усунення антропогенних негативних впливів на навколишнє середовище.

Метою дослідження є визначення рівня розвитку національної інноваційної системи України та її впливу на довкілля. Авторами проведено ретроспективний порівняльний аналіз. Для порівняння взято показники Польщі, Сполучених Штатів Америки та Японії. За основу взято фактори інноваційної моделі Quintuple Helix, які, на думку авторів, є найбільш відповідними меті дослідження. Для дослідження НІС України аналізуються ключові показники кожного з факторів моделі п'яти спіралей. Такий підхід дозволяє розглянути питання сталого розвитку та соціальної екології України з міждисциплінарної та трансдисциплінарної точки зору.

Дослідження виявляє взаємозалежність факторів моделі п'ятих спіралей. Низький рівень розвитку окремих факторів негативно впливає на інші, що призводить до сукупного негативного впливу на довкілля. Наприклад, недостатня підготовка кадрів, слабкий трансфер технологій та недостатні інвестиції в дослідження та розробки стримують інноваційний розвиток, який є основою для створення нових технологій та еко-інновацій.

За результатами дослідження визначено рівень національної інноваційної системи України, виявлено взаємовплив аналізованих факторів та їх вплив на навколишнє середовище, запропоновано шляхи зменшення негативного впливу на навколишнє середовище післявоєнного періоду, відновлення економіки України та покращення стану її національної інноваційної системи.

Запропоновані заходи щодо створення екологічно безпечної, конкурентоспроможної економіки та сталого розвитку України потребують значних ресурсів та часу для реалізації. Проте їх впровадження є необхідним для вирішення проблем, що виникли внаслідок деформованого розвитку країни та негативного, руйнівного впливу війни.

Keywords: *national innovation system, environment, national economy, innovative models, sustainability, competitiveness, the Quintuple Helix innovation model.*

Ключові слова: *національна інноваційна система, довкілля, національна економіка, інноваційні моделі, сталий розвиток, конкурентоспроможність, інноваційна модель п'яти спіралей.*

General statement of the problem and its link with major scientific or practical challenges.

This study investigates the development of Ukraine's national innovation system and its connection to environmental impact. In today's world, a nation's economic prosperity depends heavily on the strength of its innovation system. However, traditional economic theories are evolving to encompass the factors influencing these systems. With humanity's growing environmental burden, achieving sustainable development with minimal negative environmental impact has become a paramount concern.

This directly addresses the critical need to balance economic development with environmental protection. The obtained results can influence political decisions

and contribute to the development of a more sustainable innovation model for Ukraine.

Analysis of recent research and publications.

One of the first scientists who drew attention to innovation as an important component of the development of national economies was Joseph Schumpeter. Such scientists as Robert Solow, Paul Romer, Bengt-Åke Lundvall, Richard Nelson, Henry Etzkowitz, Loet Leydesdorff, Elias J. Karayannis and David F. J. Campbell worked on the study of the phenomenon of national innovation systems.

Among the Ukrainian scientists who were involved in the research of national innovation systems in Ukraine, we can single out O. Amos, Y. Bazhal, V. Geets, I. Makarenko, Y. Pyatakov.

Despite the significant amount of research in this direction, the complexity and importance of interaction between the development of national innovation systems and environmental issues require further study.

The wording of the purposes of article (problem)

The purpose of this article is to assess the current state of the national innovation system of Ukraine using the Quintuple Helix innovation model and determine its impact on the environment. The evaluation is carried out by means of a comparative, retrospective analysis. The result of the study is the development of a recommendation in the direction of restoring the national innovation system of Ukraine.

Presentation of the main research material

The innovative orientation of entrepreneurial activity provides business entities with competitive advantages, strengthens their market positions, and contributes to the economic growth of countries that support the development of innovative entrepreneurship in their country. Innovation entrepreneurship is the driving force behind achieving the desired goals. Science, technology and innovation are crucial for the development of modern society. Countries are developing their own models of innovative development to improve their competitiveness. And if, at the beginning of the XX century, the innovation and evolutionary economic theory

proposed by Joseph Schumpeter [1] mainly took into account only the interests of entrepreneurs, later theories appeared that gradually expanded the range of factors that, according to their authors, influenced economic development. Robert Solow points out the dominant role of technological change compared to capital and labour productivity in economic growth [2]. Paul Romer proposes a model of economic growth in which the main factor is the growth of investment in research and development and investment in human capital [3]. Bengt-Åke Lundvall and Richard Nelson propose to study innovation in the context of societies at the level of nation-states [4,5]. Lundvall also proposes to consider the national innovation system as a set of elements and interconnections that interact in the production, distribution and use process and are usually located within the borders of the nation-state. At the same time, knowledge is the "most important resource", and learning is the "most important process" in the modern economy [4]. Henry Etzkowitz and Loet Leydesdorff propose the Triple Helix model, which symbolizes the interaction between academia (universities), industry and government to promote economic and social development [6]. Later, Elias J. Karayannis and David F. J. Campbell proposed to supplement the Triple Helix model with another factor, the public, the level of which indicates the degree of democracy in society and the use of innovations as a result of the dissemination and use of knowledge. That is how the Quadruple helix appeared [7].

The development of economic theories is impossible without considering the global challenges facing humanity. A significant deterioration of the planet's ecology under anthropogenic influence has become a threat to both the existence of humankind and the planet Earth as a whole. Realizing the fatal consequences of irresponsible human activity can lead to, the United Nations adopted the Sustainable Development Goals (SDGs). They were formulated as a universal call to end poverty, improve health and education, reduce inequality, stimulate economic growth, combat climate change and preserve our oceans and forests. The SDGs emphasize the interconnectedness of environmental, social, political and economic aspects of sustainable development. [8].

The severity of environmental problems also attracts the attention of scientists studying the development of national innovation systems. Elias J. Karayannis and David F. J. Campbell propose the Quintuple Helix innovation model. It complements the Quadruple helix with another factor - the environment. Knowledge also plays a fundamental role in this model. It is transformed into innovations in the movement between social subsystems, provided the society is mature. The Quintuple Helix innovation model points to the interaction of all subsystems (spirals): education system, business, government, civil society based on culture and knowledge, and the environment [9]. The efficient, harmonious development of all factors through interaction by creating, disseminating and using knowledge is the result of the development of national innovation systems. The basis for the physical existence of the entire system is the natural environment.

This study aims to assess the national innovation system of Ukraine and the environment as its component. The authors conduct a comparative analysis based on the key indicators of The Quintuple Helix innovation model. For comparison, the indicators of Poland, which shares a border with Ukraine and has much in common in historical and cultural contexts, are used. Poland has a successful experience of development after leaving the Soviet Union also. The United States of America is selected as the country that ranks first in the number of "unicorn companies" [10], and Japan is selected as the country with a unique experience of repeated post-war recovery. The data for 2019-2022 are considered to allow for a retrospective analysis of the development of the selected countries. This timeframe includes 2019 – the period before the coronavirus, 2020-2021 – the period of the pandemic, and 2022 – the beginning of Russia's armed aggression, which had a tremendous negative impact on Ukraine's economy, ecology, demographics and other spheres of development. The study shows the mutual influence of each factor, focusing on the natural environment. The level of development of the national innovation system of Ukraine is determined, the main problems are outlined, and recommendations for their solution are formulated.

Ukraine began to build its economic development model after gaining independence in 1991. At that time, the country found itself in difficult conditions of losing a significant share of its economic potential due to the severance of established economic ties and the destruction of business and production value chains. The institutional vacuum at the beginning of independence, the lack of investment, innovation and technological capital, and the underdevelopment of entrepreneurship all contributed to the economy's low adaptability to new conditions, which led to severe social and economic losses. Miscalculations in the policy of property denationalisation and ineffective antimonopoly control contributed to the concentration of public wealth in a narrow circle of influential large business groups, which subsequently accumulated significant political influence, allowing them to obtain economic preferences, thus forming an oligarchic model of the economy. It has not contributed to the development of fair and competitive economic relations and a holistic business environment of a market economy and has hurt the environment.

To study the national innovation system of Ukraine, we will analyse each of the core indicators according to The Quintuple Helix innovation model [9]. It will make it possible to study the issues of Ukraine's sustainable development and social ecology from a multidisciplinary and transdisciplinary perspective.

Education system

Therefore, considering education as the first factor, the rankings of higher education institutions - organizations that act as catalysts for technology transfer and training future specialists and experts - are used for comparison. The information for comparison is taken from the World University Rankings [11]. This ranking consists of the following indicators: teaching, research, citations, industry revenue, and international perspective. Ten top-ranked universities were selected for each country, and the average rating was calculated. The highest ranking among those under consideration is taken as 1. The second indicator for the study is the lifelong learning indicator, which shows how well countries provide opportunities for lifelong learning

to their citizens. The information for comparison is taken from The Global Talent Competitiveness Index [12].

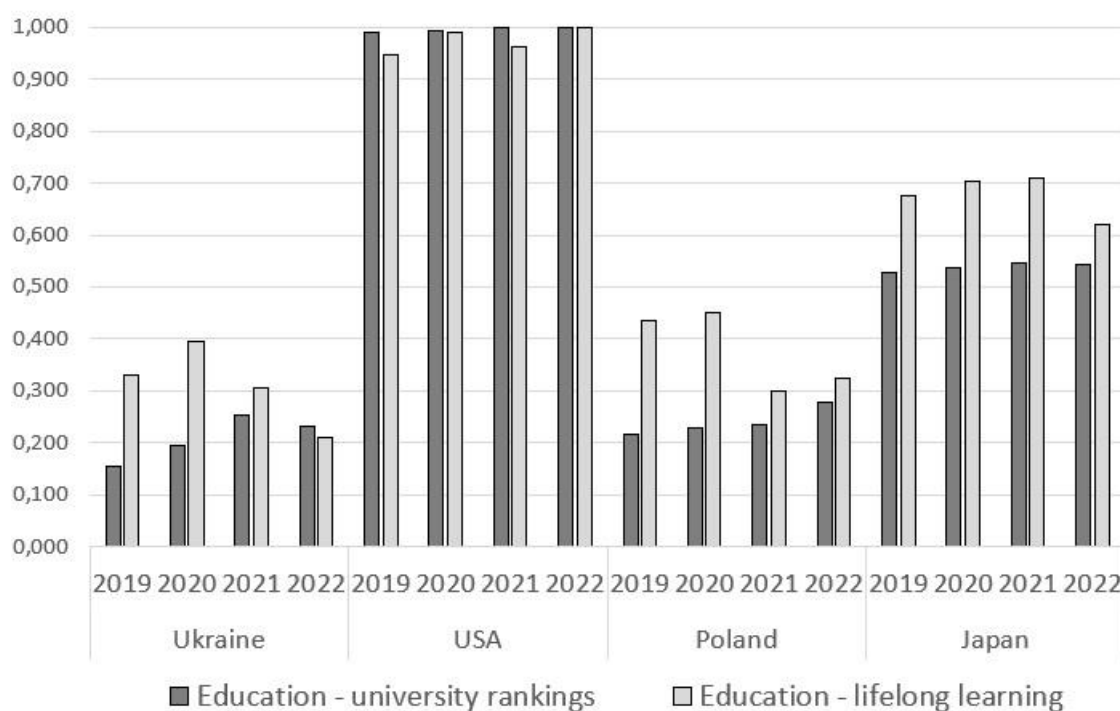


Fig. 1 Comparison of education indicators

Source: formed based on [11,12]

The highest ranking among the countries under consideration is 1. Figure 1, Comparison of Education Indicators, shows information on the selected countries for 2019-2022.

Graph 1 shows that while the indicators of Ukraine and Poland are comparable, US universities are several times ahead of Ukrainian and Polish universities. An analysis of the university ranking indicators shows that the United States ranks first worldwide. Therefore, it makes sense to take the US higher education system as a benchmark and, after careful study, to use its strengths as indicators for the Ukrainian education system to follow. Japanese universities occupy strong positions in the ranking but are significantly inferior to the US. Thus, we can conclude that Japanese universities, like US universities, occupy a worthy place in the Japanese national innovation system. Despite the COVID-19 pandemic, we see positive dynamics in Ukraine until 2022. Obviously, in 2022, the indicator was negatively affected by Russia's military aggression. Poland shows a steady

development in 2021 and 2022, while the United States and Japan have stable indicators for all years.

In terms of lifelong learning, which shows the extent to which countries provide lifelong learning opportunities for their citizens, Ukraine unfortunately lags far behind the comparator countries. Figure 1 shows that Ukraine's performance is mostly below Poland's and several times lower than that of the US and Japan, with the US being the undisputed leader. It indicates that Ukrainians are not well adapted to new technologies and innovations. The acceleration of technological cycles and the creation and dissemination of innovations significantly affect the labour market. The emergence of new industries and professions requires employees to undergo ongoing training and, in some cases, change their occupations. Obviously, in Ukraine, the peak of the COVID-19 pandemic in 2021 and the military aggression by Russia in 2022 hurt the trend of this indicator. But in 2019, we also had the lowest rate among the countries under consideration.

Thus, the education system in Ukraine has comparable indicators with the region's countries but lags far behind the world leaders and shows a low level of adaptation to technological and sectoral changes. Low awareness of sustainability has a negative impact on behavioural scenarios towards environmental protection.

Business

Business plays a significant role as one of the helices (spirals). It represents the sector of the economy that produces goods or provides services. Business includes companies and institutions that create innovations, manufacture goods and provide services. It further encompasses research, development, production, marketing, sales and distribution.

To assess the Business factor, which is also responsible for knowledge and technology exploitation, the first indicator to be compared is the level of capital investment as a percentage of GDP [13,14]. It shows what part of the country's gross domestic product is spent on the purchase, manufacture or modernization of fixed assets, other non-current assets and intangible assets.

Thus, we can assess the degree of renewal of production facilities, innovation and competitiveness of the country's economy. A high level of capital investment contributes to GDP growth, while a low level indicates an outdated and declining economy.

Figure 2 shows that in 2019, this indicator was the highest in Ukraine over the period under review. That is due to the absence of negative factors such as the COVID-19 pandemic and the war. However, compared to other countries, it is still insufficient and much lower than Poland's, which in almost every year under review is higher than even the US.

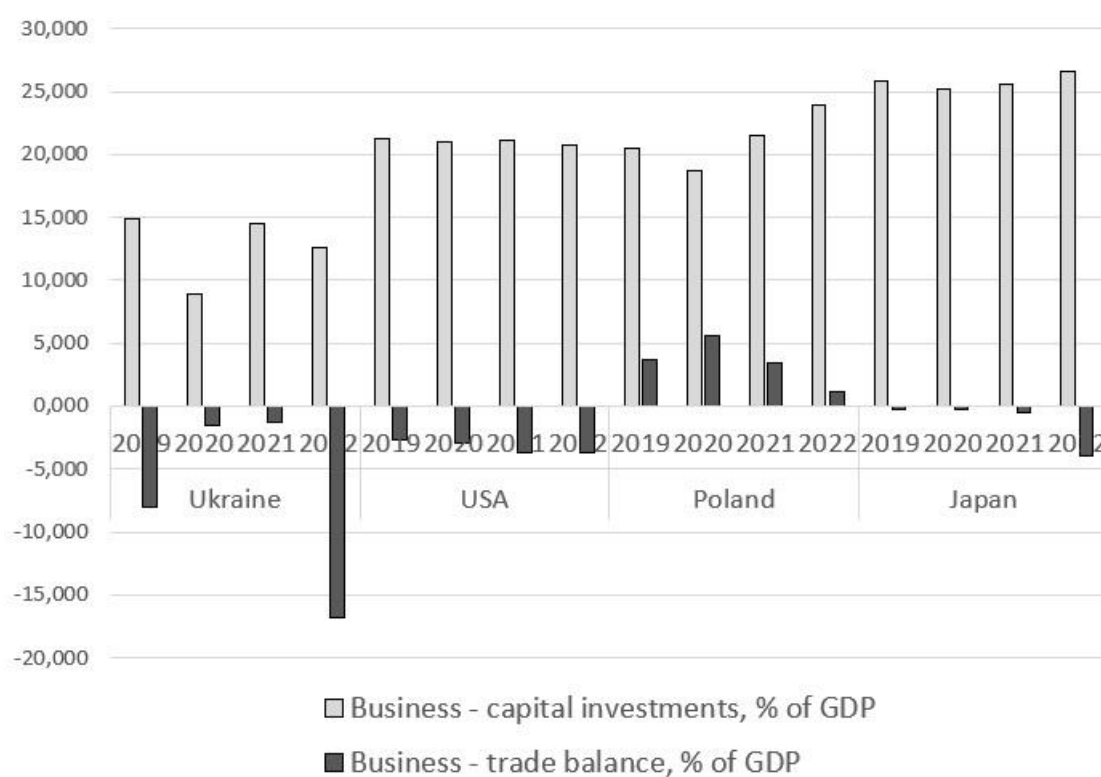


Fig. 2 Comparison of business performance

Source: formed based on [13,14,15]

It suggests that the neighbouring country pays a lot of attention to modernizing production, making significant investments to increase the productivity of enterprises and improve competitiveness.

The second indicator is the trade balance as a percentage of GDP [15]. In a country's economy, the trade balance relative to GDP shows the extent of the difference between exports and imports of goods and services. A country's

participation in international trade is carried out to receive funds for exported goods and services. At the same time, when it imports goods and services, it has to pay for them. Such payments for exports and imports of goods and services form the country's trade balance. The trade balance is the difference between the value of exports and imports. As we can see, Ukraine has the most significant trade deficit in 2019 and 2022 due to low competitiveness of production and low quality of products. At the same time, Poland has a trade surplus, reflecting its internationally recognized level of competitiveness. The US also has a trade deficit caused by high consumption: the US generally spends more money than it earns, leading to a current account deficit. The US also imports more goods than it exports abroad. That is due, among other things, to the transfer of production to China. Japan also has a trade deficit. That is due to the large volume of imports, a feature of an "island economy" where most raw materials and fuel are imported. In 2022, Japan has a significant negative balance due to higher prices for imported energy. At the same time, the large volume of exports with a high level of processing and added value allows almost completely covering imports in all years except 2022.

Consequently, we can state that Ukraine has the lowest level of capital investment among the countries under comparison, leading to the use of outdated technologies, low competitiveness, and a negative trade balance. At the same time, the neighbouring country of Poland has a high level of capital investment, which is on par with the leading countries, which also positively affects its balance of payments.

Government

The third factor is the government, responsible for creating favourable conditions for innovation, regulating the legal and financial environment, ensuring national security and social justice, and cooperating with other spiral actors.

For each of the countries in the period under review, the following indicators were taken: judicial system efficiency [16], corruption index [17], and the index of freedom to do business [18]. All the indices are reduced to a single format, where the highest score is taken as 1. The information is shown in Figure 3.

Ukraine has the worst values for each of the indicators. It has the lowest efficiency of the judicial system, which has negative dynamics, unlike other countries, and the highest level of corruption. Only the index of freedom to do business in Ukraine is relatively similar to the indicator of Poland. However, in 2022, Poland showed a significant improvement, which allowed it to reach the level of the United States and Japan, unlike Ukraine, which deteriorated in 2022. The deterioration occurred under martial law when the government was supposed to focus on creating conditions for doing business, but unfortunately, we see the opposite result.

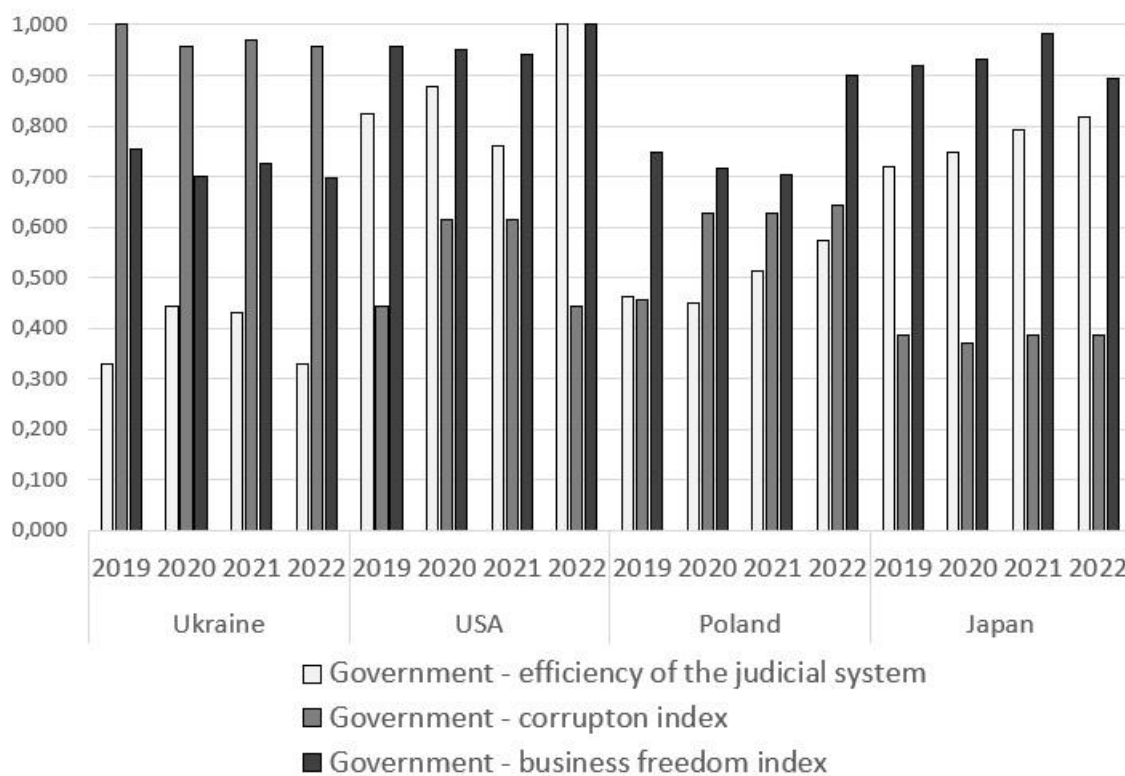


Fig. 3 Comparison of government performance

Source: formed based on [16,17,18]

Society

The next factor is Society, which shows the role of citizens, NGOs, media, culture and values in shaping the innovation process. This factor influences the demand for innovation, expresses its needs and expectations, and is involved in

knowledge and technology creation. It also affects the government and industry, contributing to social inclusion and democratization of innovation.

To assess this factor, for each of the countries for the period under review, we took the following indicators: the Human Rights Index [19] and the Press Freedom Index [20]. All the indices are reduced to a single format, where the highest score is taken as 1. The information is shown in Figure 4. As can be seen from the graph, Ukraine has the lowest human rights index scores, with a sharp deterioration in 2022. The United States and Japan have the highest benchmark scores, while Poland is midway between Ukraine and the benchmark countries. The situation with the Press Freedom Index is similar. In 2022, there is a significant deterioration in all countries.

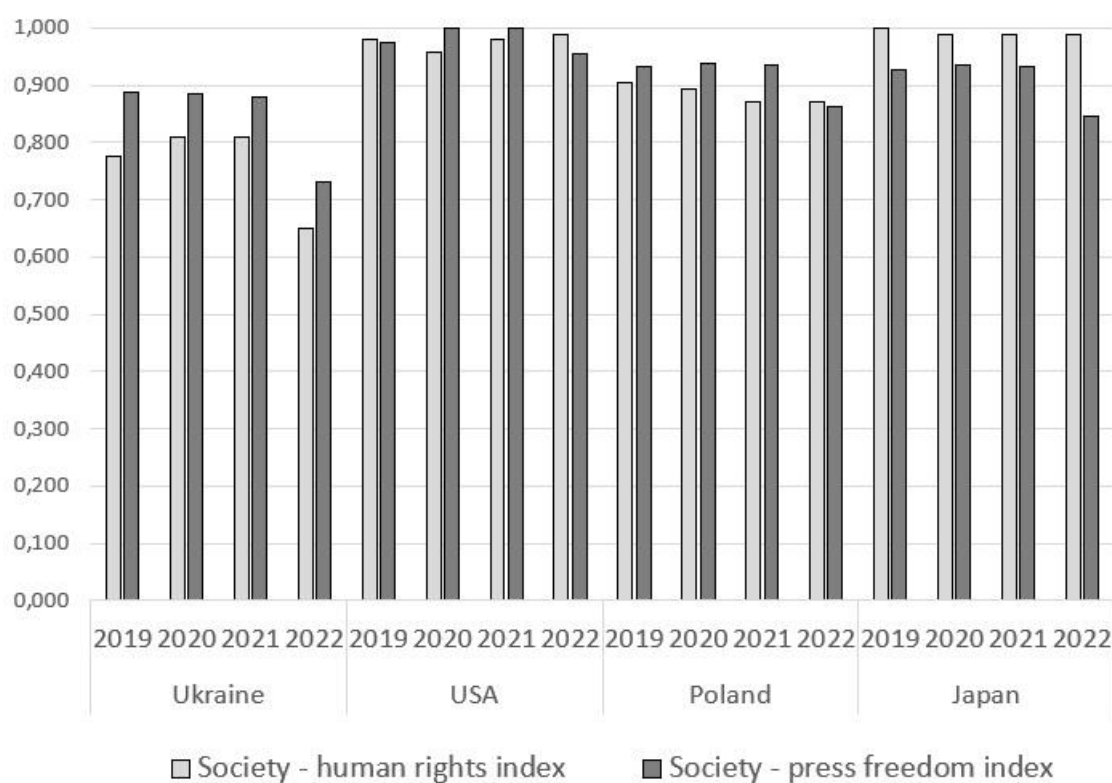


Fig. 4 Comparison of public indicators

Source: formed based on [19,20]

Thus, according to the civic sphere factor, Ukraine has the lowest human rights index scores and low but comparable press freedom index scores. At the same time, all countries show a deterioration in 2022. As for Ukraine, this is explained by

the need for centralized control of the information space, movement, and actions under martial law.

Environment

This factor reflects the interaction between humans and nature, as well as the impact of humans on the environment. Its state is determined by the level of development of the factors discussed earlier. To assess this factor, for each of the countries for the period under consideration, we took the following indicators: the air pollution index [21] and the environmental performance index [22], which ranks 180 countries in terms of climate change efficiency, environmental health and ecosystem viability. The indexes under consideration are reduced to a single format, where the highest score is taken as 1. The information is shown in Figure 5. As can be seen from the graph, Ukraine has the most polluted air. It significantly affects the health of all segments of the population. At the same time, there is a significant improvement in air quality in 2022. These changes are most likely due to the martial law in the country, which resulted in the closure of enterprises, production cuts, Ukrainian citizens leaving the country and, consequently, a decrease in transport use. Therefore, the improvement in the indicator is not due to the equipment and vehicle upgrades but to the reduction of emissions of harmful substances into the air. The high level of air pollution in Poland is also noteworthy. It is caused by two main factors: a significant increase in cars on city roads and an outdated heating system that uses solid fuels.

At the same time, the United States and Japan have much better indicators, indicating effective environmental policies of both governments and local authorities in those countries. A similar situation is observed when analysing the environmental performance index. Ukraine has the worst indicators, followed by Poland, the United States and Japan.

It indicates the ineffectiveness of Ukraine's environmental policy and the lack of efforts to achieve the UN Sustainable Development Goals and move society towards a sustainable future.

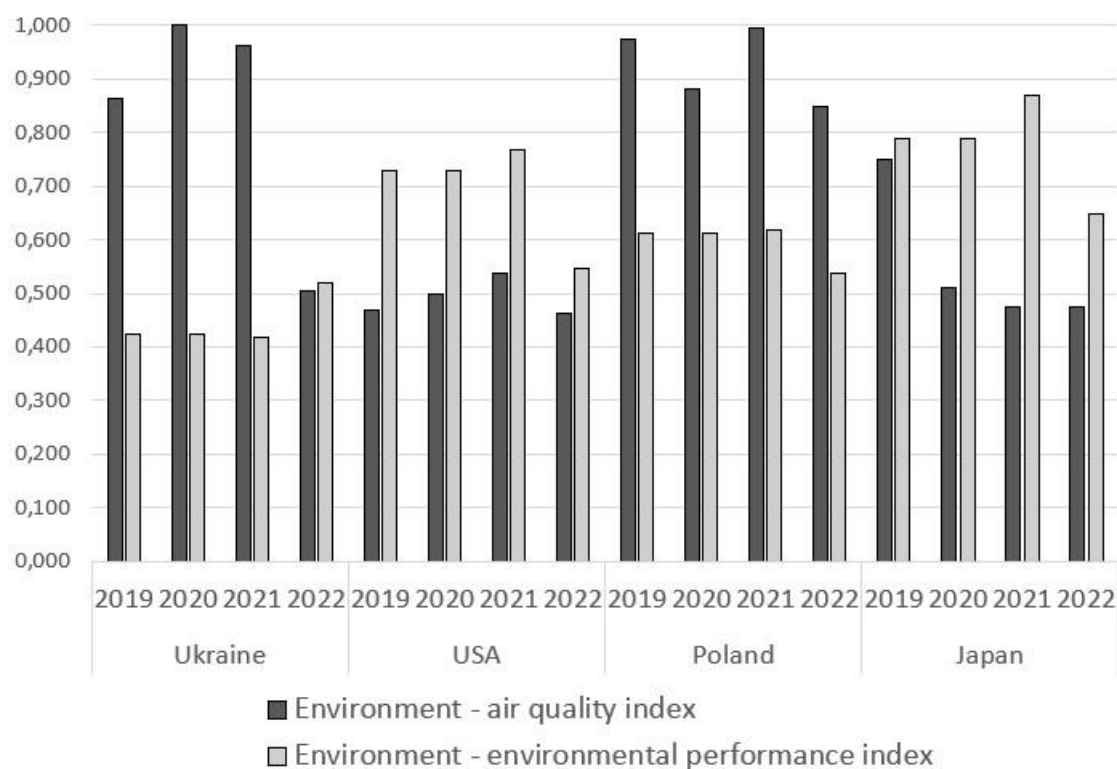


Fig. 5 Comparison of environmental indicators

Source: formed based on [21,22]

Conclusions and recommendations in this direction

Based on the study results, we can conclude that Ukraine has a low degree of national innovation system development compared to the leading countries. The biggest problems are observed in such factors as the environment, government, public and business.

The war in Ukraine has brought additional negative changes to the development of the national innovation system. First and foremost, this was manifested in a significant deterioration in the performance of the government and public factors. Given that the government was focused on solving wartime problems, this led to less attention to innovation and environmental development. The public sphere was restricted in its rights and freedoms, affecting the innovation process.

According to the study, there is an evident interdependence of the factors. Low levels of development of anthropogenic factors negatively affect each other, resulting in a cumulative negative impact on the environment. For example, insufficient knowledge production, poor technology transfer, and insufficient research and development have led to delays in innovative development, as they are the basis for

creating new technologies and eco-innovations. Uneducated people have fewer employment opportunities. They are less creative, and are less interested in protecting the environment. If a society has a low level of knowledge, does not use innovations or does not understand their significance, it leads to a decrease in innovation activity and conscious consumption. The example of Ukraine shows that a society with a low quality of education tends to make decisions in elections based on populist information without critical analysis. It leads to low-quality government leadership. An ineffective government, in turn, cannot provide favourable conditions for business development and innovation, nor can it effectively protect the environment. The lack of funding for science and innovation and the absence of an effective government policy on eco-innovation led to a decline in environmental research and commercialization of eco-innovations. The low quality of the government's expertise and integrity has led to Ukraine having the lowest judicial system efficiency and the highest level of corruption. Corruption, in turn, negatively affects business, leading to distrust on the part of entrepreneurs and, thus, low levels of capital investment, resulting in outdated technologies that negatively impact the environment. In addition, companies that do not invest in innovation are less competitive and have an increased negative influence on the environment.

Insufficient development of eco-innovation, poor waste and recycling management lead to negative environmental impacts. It has long-term negative consequences for human health and biodiversity. As a result, Ukraine has the highest level of air pollution and the lowest level of environmental efficiency. It indicates the need for a greater focus on environmental issues and sustainable development.

Consequently, Ukraine's NIS needs significant improvements to achieve more innovation and environmental protection. It includes reforming the government, strengthening civil society, improving environmental sustainability and promoting knowledge sharing.

Ukraine must develop and implement new environmental regulations and standards that meet European requirements to improve the situation. It applies in particular to the following areas:

waste: sorting, utilization and recycling of waste, reducing its amount;
air: controlling air pollution from industrial, motor vehicle and municipal waste;
water: water pollution control from industrial, municipal and agricultural waste;
land resources: control over the use of land resources, prevention of soil erosion, and deforestation.

It is necessary to increase funding for environmental programmes and allocate more funds for such measures as cleaning rivers and reservoirs, eliminating the consequences of technological disasters, and preserving protected areas.

Businesses must implement environmental standards such as ISO 14001, EMAS, FSC, and PEFC. It will help reduce their negative impact on the environment. Companies should invest in the environment, for example, in the construction of sewage facilities, waste recycling equipment, etc.

Environmental awareness of the population should be raised, specifically through education and propaganda. Ukrainian citizens can consciously reduce their consumption of resources, such as electricity, water, paper, etc. Thus, every citizen can contribute to improving the environment.

The measures proposed to create an environmentally protected, competitive economy and sustainable development of Ukraine require significant resources and time to implement. However, their implementation is necessary to address the problems that have arisen due to the country's deformed development and the highly negative impact of the war.

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