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ON THE FORMATION OF NEW RESEARCH INFRASTRUCTURES IN UKRAINE UNDER PRESENT CONDITIONS

Makarov M.V., ORCID 0000-0001-9524-9092[1]

[1]*Scientific and research institute of providing legal framework for the innovative development Kharkiv, Ukraine*

Corresponding author: Makarov M.V., email: kharkovpri@ukr.net

Abstract. The formation of new research infrastructures in Ukraine has become a critical priority due to the ongoing full-scale war and its impact on the country's scientific and technological potential. This paper analyzes the current state of Ukrainian research infrastructures, highlighting the damage to material and technical bases, the outflow of human capital, and disruptions in funding. Drawing on international experience from the European Union, the United States, and France, the study identifies effective models of state, private, and municipal research centers, as well as public–private partnerships and international collaborations. The paper emphasizes the importance of resilient, interdisciplinary, and internationally connected infrastructures to ensure Ukraine's post-war scientific recovery, technological modernization, and global competitiveness. Recommendations focus on creating national science and technology hubs, leveraging international grants, integrating research with industry, and adopting adaptive governance models to enhance the country's innovation capacity.

Keywords: research infrastructures, Ukraine, science policy, innovation, post-war reconstruction, public-private partnerships, international cooperation, high-tech hubs, resilience, technological modernization.

Author Contributions
The author performed the work independently.

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The author have no competing financial, professional, or personal interests from other parties.

INTRODUCTION

The establishment of new research infrastructures in Ukraine represents a critical component of national science and technology policy and has become especially urgent in the context of the ongoing full-scale invasion. Since February 2022, the economic, social, and scientific landscapes of the country have undergone profound transformations. Military actions have caused significant destruction of the material and technical base of scientific institutions, forced many researchers to relocate internally or abroad, and disrupted entire research agendas. These developments have created severe challenges for Ukraine's science and technology sectors, which had already faced structural underfunding and governance problems in the previous decades. At the same time, the contemporary stage of science policy in Ukraine must be directed not only at safeguarding existing capacities but also at strategically developing new research centers that comply with international standards and foster the integration of Ukrainian science into global research ecosystems.

Research infrastructures—including high-technology laboratories, university research centers, scientific clusters, and innovation hubs—constitute the foundation of knowledge generation, technology transfer, and interdisciplinary collaboration. In times of war and post-war reconstruction, such

infrastructures are not only indispensable for immediate needs such as defense technologies, health monitoring, and environmental safety but also for the country's long-term competitiveness and innovation capacity. Consequently, state strategies should address both the restoration of destroyed facilities and the planned development of resilient, modern infrastructures designed for continuity under crisis conditions. According to a UNESCO-commissioned assessment conducted with the Junior Academy of Sciences of Ukraine, as of early 2024 more than 1,443 buildings and laboratories belonging to 177 scientific institutions had been damaged or destroyed, and over 750 scientific and technical equipment items had been damaged, 643 of which were beyond repair. The replacement cost of these assets alone was estimated at US$45.9 million, while the overall cost of restoring Ukraine's public research infrastructure—including universities—amounted to roughly US$1.21–1.26 billion, with about US$980.5 million attributable to higher education institutions. These figures highlight the scale of the losses and the urgency of rebuilding (UNESCO, 2024).

Equally pressing is the human capital dimension. Prior to the war approximately 88,629 researchers were employed in the public research sector; by 2024, more than 10,400 had been forced to relocate either within Ukraine or abroad, resulting in a 5.3% decline in the workforce. Budget cuts have also been severe: gross domestic expenditure on research and development fell by 38.5% between 2021 and 2022, and the National Academy of Sciences of Ukraine experienced a nearly 48% budget reduction (UNESCO, 2024). Yet despite these disruptions, Ukrainian researchers have shown remarkable resilience. The share of internationally co-authored articles produced by Ukrainian universities has increased during wartime, indicating the persistence of scholarly networks and the potential to leverage international partnerships for rebuilding.

The question of forming new research infrastructures in Ukraine thus extends beyond a purely technical or scientific matter; it represents a strategic challenge central to the nation's future as a high-technology and innovation-driven state. Creating modern, resilient, and internationally connected research facilities will be crucial to post-war reconstruction, economic recovery, and Ukraine's global competitiveness. This requires a comprehensive and multi-stakeholder approach that integrates government support, international cooperation, private investment, and adaptive planning under uncertainty.

THEORETICAL REVIEW

The theoretical foundation for studying the formation of new research infrastructures in Ukraine under current conditions is grounded in international and national studies on science policy, innovation systems, and post-crisis reconstruction of research capacity. The concept of research infrastructures as a strategic resource for national development has been extensively developed in the European Union through initiatives such as the European Strategy Forum on Research Infrastructures (ESFRI), which defines them as facilities, resources, and services used by the scientific community to conduct cutting-edge research and foster innovation (European Commission, 2024). Such infrastructures serve as key nodes in global knowledge networks, enabling countries to strengthen competitiveness and integrate into the international research space (Kuhlmann, S., & Rip, A., 2018).

Ukrainian scholars have also examined the dynamics of research infrastructures in the context of limited resources and the need for modernization. Studies by Kovalenko and collaborators (Kovalenko O., 2023) emphasize that the Ukrainian system of research institutions inherited from the Soviet period shows a high level of fragmentation, insufficient coordination between state, private, and university sectors, and chronic underfunding, all of which necessitate the development of new organizational models and public–private partnerships. The importance of rebuilding research infrastructure under conditions of war has been analyzed in UNESCO's report (2024), which provides a quantitative basis for estimating damage, losses of human capital, and potential areas for innovation in reconstruction.

In international practice, the development of research infrastructures has been linked to regional innovation ecosystems and to the concept of smart specialization. For example, Karo and Kattel (2016) demonstrate how small and medium-sized countries use targeted investments in research infrastructures to align national innovation strategies with global technological trends. This approach can be applied to Ukraine, where concentrating new infrastructures in resilient regions may help balance regional disparities while maintaining scientific excellence.

Innovative tools and metrics to evaluate the performance of research infrastructures have also emerged. The European Commission (2022) and OECD (2023) stress that beyond input indicators such as funding and staff, performance must include knowledge transfer, interdisciplinarity, and international collaboration. In this context, bibliometric analyses and digital tools (e.g., Scopus, Web of Science, Google Trends) are increasingly used to track scientific productivity, collaboration networks, and public interest in specific research fields (Menter M. & Frickel S., 2020). This digitalization of monitoring enables policymakers to respond dynamically to changes in the science landscape, including those caused by crises.

Furthermore, theoretical models of resilience and risk management are increasingly applied to research infrastructure planning. Scholars such as Linkov et al. (2018) argue that resilience-based design can help institutions prepare for and adapt to disruptions, including conflicts, natural disasters, and pandemics. For Ukraine, this theoretical perspective underscores the importance of decentralization, modularity, and adaptability in new research infrastructures.

The literature also highlights the role of international partnerships and donor funding in post-conflict reconstruction. Experience from the Western Balkans and Eastern Europe shows that integrating national infrastructures into pan-European networks accelerates recovery, increases quality standards, and attracts skilled researchers back to the country (Balázs, K. & Kárpáti, T., 2021). Given Ukraine's participation in EU research programs such as Horizon Europe, these theoretical insights are directly applicable to its present challenges and opportunities.

Thus, the theoretical review reveals a consistent emphasis across studies: research infrastructures are not merely physical assets but also complex socio-technical systems embedded in innovation networks. Their successful formation depends on combining state policy, international cooperation, private sector involvement, and adaptive management. This theoretical background frames the present study's analysis of how Ukraine can create resilient and competitive research infrastructures during and after the ongoing war.

METHODOLOGY

To examine the current state and development of research infrastructures in Ukraine, the study employed a desk-based analysis of open government sources, including official documents, policy papers, and reports from the Ministry of Education and Science of Ukraine, the National Academy of Sciences of Ukraine, and the European Commission. Statistical and analytical data were also drawn from international platforms and publicly available datasets to ensure comparability with European standards. By applying comparative and trend analysis methods, the research identified key priorities, challenges, and opportunities for integrating Ukrainian research infrastructures into the European Research Area. This methodological approach allowed for assessing not only the existing infrastructure and policy framework but also the dynamics of ongoing reforms and international cooperation trends.

RESULTS AND DISCUSSION

One of the key challenges of the Ukrainian research infrastructure is its material and technical base. A significant portion of scientific equipment is outdated, which severely limits the possibilities for conducting advanced research. For example, in 2019 the average age of scientific equipment in

institutions of the National Academy of Sciences of Ukraine exceeded 20 years, and the rate of renewal of research facilities remained critically low. This shortfall has been partially mitigated by international cooperation, particularly through Ukrainian researchers' access to foreign laboratories and participation in joint scientific projects.

Among the successful examples of research infrastructures in Ukraine are the V. M. Bakul Institute for Superhard Materials of the National Academy of Sciences of Ukraine, which specializes in the development and production of artificial diamonds and hard alloys, as well as the Institute for Condensed Matter Physics in Lviv, which actively cooperates with European partners in the field of nanotechnologies. Another noteworthy institution is the National Science Center "Kharkiv Institute of Physics and Technology," which, before the war, was a major hub for nuclear physics and energy research but has suffered significant damage as a result of military actions.

At present, technology parks also function as important elements of the scientific ecosystem. In particular, the UNIT.City Innovation Park in Kyiv remains one of the most promising hubs for technological start-ups, although the war has altered its operations. Similar structures exist in Lviv (Tech StartUp School), Kharkiv (Synergy Science Park), and other cities. However, their effectiveness largely depends on the stability of the investment environment, which is currently under significant pressure due to the ongoing hostilities.

The role of international partners in supporting Ukrainian research infrastructures is also significant. European programs such as Horizon Europe provide funding for scientific research, while cooperation with CERN grants Ukrainian scientists access to state-of-the-art equipment in high-energy physics. Despite these opportunities, the war has considerably complicated Ukraine's participation in such initiatives, forcing many researchers to work from abroad.

Thus, the current state of Ukraine's research infrastructure is highly uneven. Alongside preserved scientific potential and international opportunities, there are significant problems with financing, physical preservation of institutes and laboratories, and the outflow of personnel. This situation requires not only adapting the existing system to the conditions of wartime but also developing a long-term strategy for its development and modernization.

The creation of new research infrastructures in Ukraine is a complex and multi-component process that depends on the form of ownership, sources of funding, and the level of interaction between the public, private, and municipal sectors. Considering the current challenges, including war, brain drain, and limited financial resources, a strategic approach to their formation is essential.

The establishment of state research infrastructures is regulated by Ukrainian legislation, in particular the Law of Ukraine "On Scientific and Scientific-Technical Activities," as well as sectoral regulatory acts. The main mechanism of financing is the state budget through the Ministry of Education and Science of Ukraine, the National Research Foundation, and sectoral ministries.

State research infrastructures in Ukraine have the advantages of stable funding and strategic development but often face bureaucratic procedures, insufficient flexibility, and limited adaptability to changes in the scientific environment.

The private sector plays an increasingly important role in establishing modern research centers focused on innovation, commercialization of scientific developments, and the growth of high-tech business. The creation of private research infrastructures is regulated by general entrepreneurial legislation as well as by specific provisions on innovation activities. Among the successful examples of private research infrastructures in Ukraine are UNIT.City, Radar Tech, and other technology hubs actively working in the fields of IT, biotechnology, energy, and artificial intelligence. Private research centers are characterized by high mobility, market orientation, and rapid implementation of new technologies but often struggle with financing issues and regulatory constraints.

Municipal research infrastructures are established by local authorities or on the basis of municipal institutions. They are oriented toward regional needs, the development of education, science, and innovation activities. A notable example of successful municipal initiatives is the creation of regional

scientific centers within Smart City programs, where science is combined with applied technologies for the development of urban infrastructure. Municipal research infrastructures have significant potential for the development of regional science, the attraction of young specialists, and integration with local businesses, yet they remain dependent on the financial policies of local authorities and the level of managerial competence.

Within the European Union, effective mechanisms for establishing new research centers include transnational projects, national investment programs, and public-private partnerships. A prominent example is the European XFEL in Germany, launched in 2017. This unique X-ray laser was created through the cooperation of 12 EU countries and financed by an international consortium that included state institutions and research foundations. The success of this project stems from its ability to combine the capacities of academic institutes, industry, and government bodies, thereby creating unique conditions for experimental research in physics, materials science, and biology.

Another significant example is CERN, which has recently begun construction of the Future Circular Collider to replace the Large Hadron Collider. This two-decade project is financed jointly by EU countries and international partners, combining budget funds, private contributions, and European Commission grants. It stands as a classic example of how transnational scientific collaboration enables the creation of world-class research facilities.

France demonstrates a different approach by implementing a state strategy for the development of artificial intelligence through the creation of specialized centers in Paris, Lyon, Grenoble, and Toulouse. The program, launched in 2020, provides funding of €1.5 billion supplied both through state grants and with the support of European Union funds. This initiative focuses on applied research in artificial intelligence and its integration into industrial and commercial projects.

The United States is also actively developing new research infrastructures, combining government programs and private investments. In 2023, the Argonne Leadership Computing Facility became operational — one of the most powerful computing centers in the world conducting research in quantum technologies, bioinformatics, and climate change modeling. Funding is provided by the U.S. Department of Energy as well as through cooperation with technology giants such as IBM, NVIDIA, and Intel. This model is distinguished by a high level of commercialization of scientific results, making it particularly attractive for business.

Another landmark U.S. project is the Quantum Technology Laboratory at Oak Ridge National Laboratory, under construction since 2022. Half of its budget is supported by government programs and the other half by leading technology corporations. This allows research results to be rapidly implemented in industry and in defense and digital security domains.

An important example of science-business integration is MIT.nano, the nanotechnology center at the Massachusetts Institute of Technology. It was financed through government grants, philanthropic contributions, and investments from corporations such as Apple, Samsung, and Intel. This model demonstrates that cooperation among universities, the state, and commercial actors is key to establishing successful research infrastructures.

Analysis of international experience makes it possible to outline key directions that could be adapted in Ukraine. First and foremost is the creation of science and technology hubs at leading universities, enabling the integration of research with business needs. Another promising direction is the construction of national research centers in strategic areas such as artificial intelligence, quantum computing, materials science, and biotechnology. Financing for such centers should rely on public-private partnerships and the attraction of international grants, including programs such as Horizon Europe and USAID.

An effective strategy could also include Ukraine's active participation in international scientific projects, which would allow the country to access external funding, exchange experience with leading research institutions worldwide, and integrate Ukrainian scientists into global research processes. Establishing dedicated research platforms and training centers for participation in international

programs would enhance the nation's scientific potential and ensure competitiveness in high-tech sectors.

Global experience shows that the development of research infrastructures is a powerful driver of an innovation-based economy. For Ukraine, it is critically important not only to restore damaged scientific facilities but also to build new, modern centers that could serve as the foundation for a technological breakthrough. The implementation of such initiatives requires consolidated efforts of the state, business, and international partners, as well as the effective use of available financial and organizational tools.

Building new research infrastructures in Ukraine under present conditions is not only a challenge but also an opportunity for qualitative renewal of the scientific sphere and its integration into global processes. In the context of war and economic instability, traditional mechanisms for developing scientific facilities have been severely constrained, necessitating new strategies and models of financing, organization, and management of research centers. Analysis of the current state of research infrastructures reveals significant losses but also demonstrates the potential for modernization and transformation through the implementation of international best practices.

Global experience confirms that effective research infrastructures are built upon interdisciplinary cooperation, public–private partnerships, and the attraction of international funding. The examples of the European XFEL, CERN, the Argonne Leadership Computing Facility, and MIT.nano demonstrate that successful projects rely on long-term development strategies, flexible financial mechanisms, and active business engagement. In Ukraine, these approaches could be adapted through the establishment of specialized science and technology hubs, start-up support programs, and the integration of research into the real economy.

National and international initiatives for the restoration and creation of new research infrastructures should become a top priority of public policy. Ukraine already has access to international scientific funds such as Horizon Europe, USAID, and NATO's Science for Peace and Security program, which can serve as key sources of funding for new projects. It is essential not only to build new laboratories and technology parks but also to create conditions for their sustainability by attracting international partners, fostering interaction between science and business, and promoting the commercialization of scientific developments.

The strategic development of research infrastructures in Ukraine should involve not only construction and restoration but also a transformation in management approaches. Successful global models demonstrate the effectiveness of autonomous governance of research centers, the introduction of flexible grant mechanisms, and the support of interagency and international cooperation. Such practices ensure sustainable funding and help create a competitive scientific ecosystem capable of generating innovation and attracting talented researchers.

Thus, the creation of new research infrastructures in Ukraine must follow the principles of international integration, technological modernization, and partnerships between science, business, and the state. Drawing on best practices from the EU and the U.S., managing resources effectively, and applying a strategic approach to the development of the scientific sphere can ensure not only its recovery but also Ukraine's transformation into a regional leader in high technologies and scientific research in Eastern Europe.

CONCLUSIONS

The analysis of global and Ukrainian trends demonstrates that the sustainable development of research infrastructures requires a systemic and long-term approach. For Ukraine, this means not only the restoration and modernization of facilities damaged or outdated due to external factors but also the adoption of new management models that ensure autonomy, transparency, and effective allocation of resources. International experience shows that research infrastructures become drivers of innovation

when they operate as open, interdisciplinary platforms connecting science, business, and government. In the Ukrainian context, it is crucial to develop mechanisms for integrating national research infrastructures into European and global networks, attracting private investment alongside public funding, and strengthening cooperation with international financial institutions and grant programs. Strategic steps should also include the creation of scientific and technological hubs, support for start-ups and spin-offs, and the introduction of flexible grant systems to stimulate collaboration and commercialization of research results. By aligning national priorities with best international practices, Ukraine can transform its research infrastructure into a catalyst for technological modernization, economic growth, and the country's stronger positioning in the global innovation ecosystem.

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ПРО ФОРМУВАННЯ НОВИХ ДОСЛІДНИЦЬКИХ ІНФРАСТРУКТУР В УКРАЇНІ ЗА СУЧАСНИХ УМОВ

Анотація. Формування нових дослідницьких інфраструктур в Україні стало критичною пріоритетною задачею через триваючу повномасштабну війну та її вплив на науковий і технологічний потенціал країни.

У статті проаналізовано сучасний стан українських дослідницьких інфраструктур, висвітлено шкоду матеріально-технічній базі, відтік людського капіталу та порушення фінансування. На основі міжнародного досвіду Європейського Союзу, США та Франції визначено ефективні моделі державних, приватних та муніципальних наукових центрів, а також державно-приватного партнерства й міжнародної співпраці. У роботі підкреслюється важливість стійких, міждисциплінарних та міжнародно інтегрованих інфраструктур для забезпечення післявоєнного наукового відновлення України, технологічної модернізації та її глобальної конкурентоспроможності. Рекомендації зосереджено на створенні національних науково-технологічних хабів, використанні міжнародних грантів, інтеграції досліджень у промисловість та впровадженні адаптивних моделей управління для підвищення інноваційного потенціалу країни.

Ключові слова: дослідницькі інфраструктури, Україна, наукова політика, інновації, післявоєнне відновлення, державно-приватне партнерство, міжнародна співпраця, високотехнологічні хаби, стійкість, технологічна модернізація.

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