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THEORETICAL APPROACHES TO THE INTERPRETATION OF CRITICAL INFRASTRUCTURE AS AN ECONOMIC CATEGORY

ТЕОРЕТИЧНІ ПІДХОДИ ДО ТРАКТУВАННЯ КРИТИЧНОЇ ІНФРАСТРУКТУРИ ЯК ЕКОНОМІЧНОЇ КАТЕГОРІЇ

The article is devoted to approaches to the interpretation of critical infrastructure as an economic category under hybrid threats and systemic uncertainty. The relevance is determined by the growing role of critical infrastructure in ensuring economic continuity, macroeconomic stability, institutional resilience, and national security amid geopolitical instability, military conflicts, cyber threats, and technological disruptions. It focuses on the evolution of approaches to the concepts of "infrastructure" and "critical infrastructure" and substantiates the transformation of critical infrastructure from a narrowly technical category into a multidimensional socio-economic system. The methodological basis includes theoretical generalization, comparative analysis, semantic mapping, and systematization of scientific approaches presented in contemporary economic and resilience-oriented discourse.

Keywords: *critical infrastructure, economic category, economic resilience, national economic stability, hybrid threats, infrastructure governance.*

У статті досліджено теоретичні підходи до трактування критичної інфраструктури як економічної категорії в умовах гібридних загроз та системної невизначеності. Актуальність дослідження зумовлена зростанням ролі критичної інфраструктури у забезпеченні безперервності економічних процесів, макроекономічної стабільності, інституційної стійкості та національної безпеки в умовах геополітичної нестабільності, воєнних конфліктів, кіберзагроз і технологічних ризиків. Основну увагу приділено еволюції наукових підходів до трактування понять «інфраструктура» та «критична інфраструктура», а також обґрунтуванню трансформації критичної інфраструктури з вузькотехнічної категорії у багатовимірну соціально-економічну систему. Методологічною основою дослідження стали методи теоретичного узагальнення, порівняльного аналізу, семантичного картування та систематизації наукових підходів, представлених у сучасному економічному та resilience-орієнтованому дискурсі. У межах дослідження проаналізовано класичні та сучасні підходи до трактування інфраструктури, сформовані представниками економічної теорії, міжнародними організаціями та сучасними дослідниками проблем стійкості критичної інфраструктури. Додатково використано семантичний аналіз та частотне картування дефініцій для визначення домінуючих концептуальних дескрипторів і трансформації змістових акцентів у науковому дискурсі. У результаті дослідження встановлено, що традиційні підходи до трактування інфраструктури переважно були пов'язані із забезпеченням виробництва, економічного розвитку, наданням послуг та територіальною інтеграцією. Водночас сучасні наукові підходи дедалі більше акцентують увагу на категоріях стійкості, безпеки, безперервності функціонування, адаптивності та управління ризиками. Проведений семантичний аналіз засвідчив, що концептуальна структура дефініцій критичної інфраструктури значною мірою концентрується навколо категорій захисту, стійкості, стабільності та безперервності економічного функціонування. В умовах посилення взаємозалежності інфраструктурних секторів стійкість критичної

інфраструктури стає однією з ключових детермінант економічної стабільності держави та безперервності економічних процесів.

Ключові слова: *критична інфраструктура, економічна категорія, економічна стійкість, економічна стабільність держави, гібридні загрози, управління інфраструктурою.*

Problem statement. The increasing scale of geopolitical instability, hybrid threats, military conflicts, cyberattacks, and technological disruptions has significantly intensified scientific and practical interest in critical infrastructure as a strategic component of national economic systems. Under conditions of systemic uncertainty, critical infrastructure plays a key role in ensuring economic continuity, institutional stability, public service delivery, and national security. The experience of contemporary crises, particularly the full-scale war in Ukraine, has demonstrated that disruptions of energy systems, transport networks, logistics chains, digital communications, and financial infrastructure generate not only technical failures but also large-scale macroeconomic destabilization, production interruptions, inflationary pressures, and increasing fiscal burden on the state.

In modern economic conditions, critical infrastructure is no longer perceived solely as a technical or engineering system supporting economic activity. Instead, it increasingly functions as a multidimensional economic category that combines production, institutional, technological, organizational, security, and resilience-related components. The growing interdependence between infrastructure sectors substantially increases the vulnerability of national economies to cascading disruptions and systemic crises, thereby transforming infrastructure resilience into one of the key determinants of economic stability and adaptive development.

At the same time, despite the growing number of studies devoted to critical infrastructure protection and resilience, the scientific understanding of critical infrastructure as an economic category remains fragmented and insufficiently systematized. Existing approaches predominantly focus on technical protection mechanisms, legal regulation, or security aspects, while the conceptual and economic foundations of critical infrastructure are often considered indirectly. In addition, scientific discourse demonstrates significant variability in the interpretation of the categories “infrastructure” and “critical infrastructure,” reflecting the ongoing transformation of theoretical approaches under conditions of global instability and hybrid threats.

Therefore, the need to systematize scientific approaches to the interpretation of critical infrastructure and to determine its economic essence under contemporary conditions determines the relevance of this research.

Analysis of recent research and publications. The theoretical foundations of infrastructure research were formed within classical economic theories that considered infrastructure as a prerequisite for industrial development, economic growth, and market integration. One of the earliest conceptual approaches was proposed by P. Rosenstein-Rodan, who associated infrastructure development with the theory of the “Big Push” and emphasized its role in overcoming structural economic backwardness and stimulating large-scale economic modernization [9]. A significant contribution to the development of infrastructure theory was also made by R. Jochimsen, who interpreted infrastructure as a fundamental basis for the functioning of a market economy and territorial economic cohesion [4].

Contemporary scientific approaches substantially expand the interpretation of infrastructure beyond its traditional technical understanding. B. Frischmann considers infrastructure as a socially significant shared resource that creates conditions for economic interaction, innovation, and long-term societal development [2]. Similar approaches are reflected in analytical studies conducted by the Organisation for Economic Co-operation and Development (OECD), where infrastructure is interpreted through the prism of resilience, sustainability, and adaptive economic development [6]. Analytical reports prepared by

Gordon and Dion for the OECD additionally emphasize the growing relationship between infrastructure protection, national security, and investment policy under conditions of increasing global instability [3].

The development of the concept of critical infrastructure became particularly intensive under conditions of increasing hybrid threats, technological risks, cyberattacks, military conflicts, and global crises. Contemporary scientific discourse increasingly focuses on the resilience of interconnected infrastructure systems and their role in ensuring national security and macroeconomic stability. B. Rathnayaka, C. Siriwardana, D. Robert, D. Amaratunga, and S. Setunge emphasize that critical infrastructure resilience has become one of the key determinants of societal and economic stability under conditions of disasters and systemic disruptions [7]. D. Rehak, M. Hromada, V. Onderkova, N. Walker, and C. Fuggini investigate the robustness of energy infrastructure systems as an important component of energy security and economic continuity [8]. L. Shen, J. Li, and W. Suo focus on the growing complexity of interdependent infrastructure risks and the cascading effects generated by disruptions within interconnected infrastructure systems [10].

A significant contribution to the development of theoretical approaches to critical infrastructure in the context of national security and economic stability was also made by Ukrainian researchers. In particular, M. Kyzym, V. Khaustova, and N. Trushkina interpret critical infrastructure as a strategic component of national security and emphasize its systemic role within the functioning of the national economy [5]. Their research highlights the transformation of critical infrastructure from a narrowly technical category into a multidimensional socio-economic and security-related phenomenon.

At the same time, the existing scientific approaches remain fragmented and primarily concentrated on security-oriented, technical, or legal aspects of infrastructure protection. Insufficient attention is devoted to the conceptualization of critical infrastructure specifically as an economic category integrating economic continuity, institutional stability, resilience, and adaptive governance under conditions of systemic uncertainty. This determines the necessity for further theoretical systematization and conceptual clarification of the economic essence of critical infrastructure in contemporary scientific discourse.

Statement of the task. The purpose of the article is to investigate theoretical approaches to the interpretation of critical infrastructure as an economic category and to determine its role in ensuring national economic stability under conditions of hybrid threats and systemic uncertainty.

Presentation of the main research material. The concept of infrastructure has undergone a significant transformation throughout the evolution of economic thought. Initially, infrastructure was predominantly interpreted as a set of material and technical facilities ensuring the functioning of production processes, transport systems, and public utilities. Early economic approaches considered infrastructure primarily as an auxiliary component of economic development aimed at supporting industrial production and territorial integration. One of the first systematic economic interpretations of infrastructure was proposed within the framework of development economics. P. Rosenstein-Rodan emphasized the importance of large-scale infrastructure investments as a prerequisite for overcoming structural economic backwardness and stimulating industrial modernization [9]. Within the concept of the “Big Push,” infrastructure was regarded as a fundamental basis for economic growth, industrialization, and market formation.

A substantial contribution to infrastructure theory was also made by R. Jochimsen, who interpreted infrastructure as a fundamental component of the market economy ensuring territorial cohesion, economic interaction, and balanced regional development [4]. His approach significantly expanded the understanding of infrastructure beyond purely technical functions and highlighted its systemic economic role. Over time, scientific approaches to

infrastructure became considerably broader and more multidimensional. Contemporary researchers increasingly interpret infrastructure not only as a physical or engineering system but also as a complex socio-economic category integrating institutional, organizational, communication, technological, and service-related components. In particular, B. Frischmann emphasizes the social and economic value of infrastructure as a shared resource that creates conditions for economic interaction, innovation, and long-term societal development [2]. Modern international organizations, particularly the OECD, additionally interpret infrastructure through the prism of sustainability, resilience, and adaptive economic development [6]. Such approaches reflect the growing understanding that infrastructure forms the basis for economic continuity, accessibility of essential services, institutional stability, and macroeconomic resilience under conditions of uncertainty.

Therefore, the evolution of scientific approaches demonstrates the gradual transformation of infrastructure from a narrowly technical category into a multidimensional economic system that performs strategic functions within the national economy.

The transformation of global economic systems, technological development, digitalization, geopolitical instability, and the growing scale of hybrid threats significantly contributed to the emergence and development of the concept of critical infrastructure. Unlike traditional infrastructure approaches focused primarily on economic support functions, the concept of critical infrastructure emphasizes security, resilience, continuity, and protection against systemic disruptions [1].

Initially, critical infrastructure was interpreted mainly within national security discourse and was associated with strategically important facilities whose destruction could threaten state security and public safety. However, contemporary scientific approaches substantially expand this understanding by emphasizing the economic and systemic importance of critical infrastructure for ensuring national stability and continuity of economic processes.

Modern studies increasingly define critical infrastructure as a complex system of interconnected physical, digital, institutional, and organizational elements whose disruption may generate large-scale economic, social, technological, and security consequences [5]. Under such conditions, critical infrastructure becomes not only an object of protection but also a strategic determinant of economic resilience and macroeconomic stability.

Particular attention within contemporary scientific discourse is devoted to the interdependence of infrastructure sectors and the emergence of cascading risks. Rathnayaka et al. emphasize that the resilience of critical infrastructure systems has become one of the key prerequisites for societal and economic stability under conditions of disasters and large-scale crises [7]. Similar approaches are reflected in the studies of Rehak et al., who investigate the robustness of energy infrastructure systems as a critical component of energy security and economic continuity [8].

Shen, Li, and Suo additionally focus on the growing complexity of interdependent infrastructure risks and demonstrate that disruptions within one infrastructure sector may rapidly spread across interconnected systems, thereby generating systemic economic instability [10]. Consequently, contemporary approaches increasingly interpret critical infrastructure not as a set of isolated facilities but as an interconnected adaptive system ensuring the continuity of national economic functioning.

Under current geopolitical conditions, particularly in the context of the full-scale war in Ukraine, the role of critical infrastructure has become significantly more important. Attacks on energy systems, transport networks, communication infrastructure, and logistics facilities have demonstrated that infrastructure disruptions rapidly transform into macroeconomic destabilization, production interruptions, fiscal pressure, and investment decline. Therefore, modern scientific discourse increasingly conceptualizes critical infrastructure through the categories of resilience, economic security, adaptive governance, and continuity of economic processes.

The analysis of scientific approaches to the interpretation of infrastructure and critical infrastructure demonstrates a substantial transformation of conceptual priorities within contemporary economic discourse. In order to identify the dominant semantic characteristics of both categories, a semantic mapping and frequency analysis of scientific definitions were conducted. The semantic structure of infrastructure definitions is primarily concentrated around categories associated with economic functioning, development, production support, services, interaction, networks, and resources. Such conceptual approaches reflect the traditional perception of infrastructure as a system ensuring the operational continuity of economic activity and supporting market functioning (fig. 1).

The semantic analysis additionally demonstrates that infrastructure is increasingly interpreted not only as a technical or engineering category but also as a socio-economic system integrating institutional and organizational components. Dominant conceptual descriptors such as "system," "services," "development," "economic functioning," and "interaction" indicate the growing complexity and multidimensionality of infrastructure research.

At the same time, the semantic structure of critical infrastructure definitions demonstrates a substantial shift in scientific discourse toward categories associated with security, resilience, stability, risk, continuity, disruption, and protection. Such transformation reflects the increasing significance of critical infrastructure within contemporary economic and security systems (fig. 2). The comparative analysis of semantic structures indicates the transformation of infrastructure from a category primarily associated with economic development toward a category increasingly connected with resilience, adaptive capacity, and national economic security. The frequency analysis demonstrates that contemporary scientific discourse increasingly emphasizes the ability of critical infrastructure to maintain continuity of economic processes under conditions of uncertainty, hybrid threats, military conflicts, and technological disruptions.

Thus, the semantic evolution of scientific approaches confirms that critical infrastructure should be interpreted not merely as a technical subsystem but as a multidimensional economic category integrating security, institutional stability, resilience, and continuity of national economic functioning.

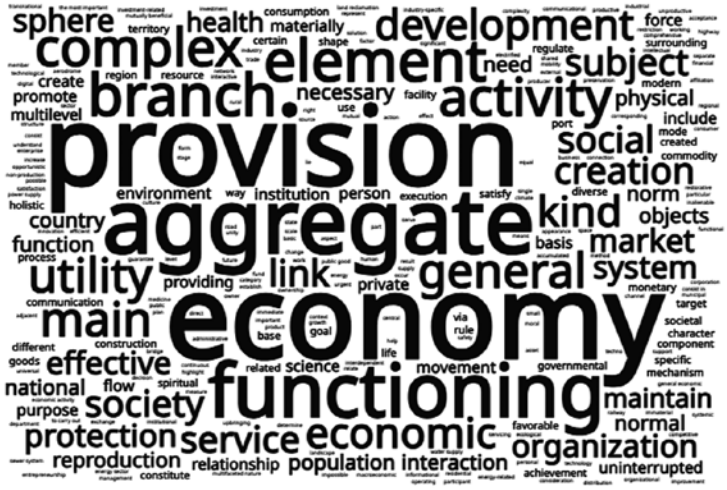

Figure 1. Semantic structure of infrastructure definitions

Source: developed by the author

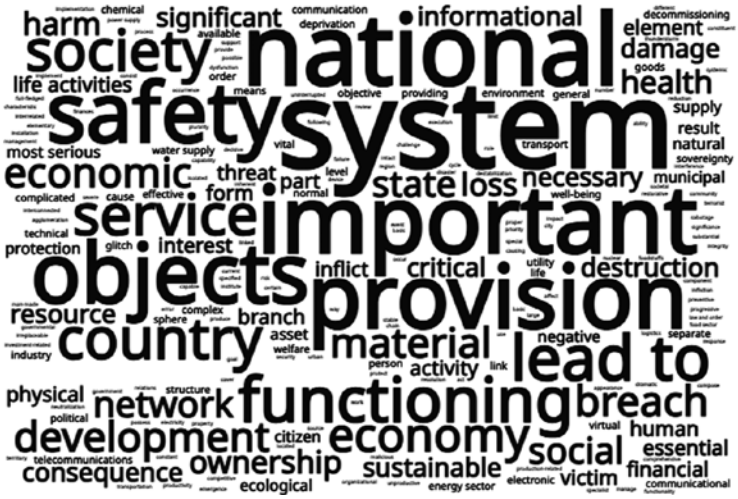

Figure 2. Semantic structure of critical infrastructure definitions
Source: developed by the author

Conclusions. The conducted research demonstrated that the evolution of scientific approaches to infrastructure and critical infrastructure reflects substantial transformations in the understanding of their role within contemporary economic systems. Traditional interpretations of infrastructure as a supporting technical component of economic activity gradually evolved toward multidimensional approaches that integrate economic, institutional, technological, organizational, and resilience-related characteristics. It was established that contemporary scientific discourse increasingly interprets infrastructure not only as a system ensuring production support and service provision but also as a strategic basis for economic continuity, institutional stability, and adaptive development. The analysis of theoretical approaches additionally confirmed the gradual transformation of the concept of critical infrastructure from a narrowly security-oriented category into a complex socio-economic system ensuring the stability and resilience of national economies under conditions of systemic uncertainty and hybrid threats.

The semantic analysis of scientific definitions revealed significant differences between the conceptual structures of "infrastructure" and "critical infrastructure." Infrastructure definitions are primarily concentrated around categories associated with economic functioning, services, development, interaction, and production support. In contrast, the semantic structure of critical infrastructure definitions is increasingly focused on resilience, security, continuity, protection, stability, and risk management. Such transformation reflects the growing importance of critical infrastructure within the system of national economic security and macroeconomic stability.

The research additionally confirmed that the growing interdependence between infrastructure sectors substantially increases the vulnerability of national economies to cascading disruptions and systemic crises. Under conditions of geopolitical instability, cyber threats, military conflicts, and technological disruptions, critical infrastructure resilience becomes one of the key determinants of economic continuity and adaptive capacity.

Therefore, critical infrastructure should be interpreted as a multidimensional economic category integrating economic, institutional, technological, and security-related components and ensuring the continuity and stability of national economic systems under conditions of uncertainty. Further research should focus on the development of methodological approaches to assessing critical infrastructure resilience, modeling systemic economic risks, and improving adaptive governance mechanisms within the field of critical infrastructure protection.

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