CRITICAL INFRASTRUCTURE SUSTAINABILITY IN THE CONTEXT OF THE WELL-BEING OF THE COUNTRY'S POPULATION

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Abstract

The article analyses and summarizes theoretical approaches to the concepts of "sustainability," "resilience," "system sustainability," "critical infrastructure sustainability," and "population well-being." Using content analysis and a systems approach, existing definitions of the term "system sustainability" are conditionally systematized according to classification characteristics. A bibliometric and trend analysis of scientific publications was conducted to identify the relationships between the concepts of "critical infrastructure sustainability," "population well-being," and "quality of life of the population." The paper proposes an original approach to defining the term "critical infrastructure sustainability" in the context of the well-being of the country's population.

Keywords: *sustainability, resilience, population well-being, quality of life of the population, critical infrastructure*
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Introduction

Critical infrastructure as a set of processes, networks, objects is of great importance for the development of the national economy and the well-being of the country's population. It should be noted that critical infrastructure as an economic system operates in conditions of instability, uncertainty and threats, that is, under the influence of many external factors that cannot be foreseen and predicted in advance. They are disturbances in this system and cause its deviation from the state of equilibrium. In this regard, an important property of critical infrastructure as a system is its ability to return to a state of equilibrium as a result of the action of these disturbances, that is, the stability of strategic infrastructure objects.

Therefore, in the modern globalized world, the problem of ensuring the stability of critical infrastructure to threats of various natures is becoming increasingly relevant, especially when these threats are transformed and acquire new hybrid forms, and also negatively affect various spheres of life. One of such spheres is recognized as social, the key element of which is ensuring the well-being of the population. In this regard, ensuring resilience is a necessary and important basis and prerequisite for the effective development of critical infrastructure.

Analysis of recent publications and research

As the analysis shows, determining the relationship between the development of critical infrastructure, sustainability, resilience, stability, and ensuring the well-being of the population is among the leading foreign scientists (C. Axon & S. Roberts [1]; A. Azami & M. Razavian [2]; C.-W. Chen [3]; M. Das [4]; G. Helgadóttir et al. [5]; N. Santero et al. [6]; F. Santos et al. [7]; Z. Turskis et al. [8]; F. Zhang & H.Qian [9]).

According to scientists Z. Turskis et al. [8], critical information infrastructure exists in different sectors of each country. Its loss or disruption of sustainability will lead to a negative impact on the provision of vital services, as well as on the social or economic well-being of the population. It may also even pose a threat to human health and life. Therefore, it is advisable to address the problem of ensuring sustainable development of EU countries from the point of view of identifying critical information infrastructures. For this purpose, a model of identifying critical

information infrastructures taking into account the sustainable development of countries is proposed.

Researchers A. Azami & M. Razavian [2] pay attention to studying the role of factors that are usually associated with achieving sustainable development in urban areas, including quality of life, productivity, infrastructure, justice and environmental sustainability.

The issues of the well-being of the population of the world, the level and quality of life of the population are considered by many researchers, including: K. Cooper, M. Fabian & C. Krekel [10]; M. Kruzslicika [11]; J. Thoma [12]; W. Tov [13]; S. Waddock [14] and others.

Despite the wide range of scientific research on the chosen topic, the multifaceted nature and debatability of individual issues require further scientific development.

Research purpose

The purpose of this article is to study the relationship between the concepts of "critical infrastructure sustainability", "population well-being" and "population's quality of life" using bibliometric and trend approaches, as well as to clarify the essence of the term "critical infrastructure sustainability" in the context of ensuring the well-being of the country's population.

Research methodology

The theoretical and methodological basis of the study is the provisions of the theories of systems, globalization, infrastructure; concepts of strategic management, sustainable development, resilience.

The following general scientific methods were used in the research process: dialectical, historical, formal-logical, axiomatic, hypothetical-deductive, analysis and synthesis, induction and deduction, bibliometric analysis, trend analysis, comparative analysis, analogy, classification, structural-logical generalization.

Based on the results of the analysis of coincidences and closeness of the relationship of 66 keywords of the selected sample of 239 publications, a network visualization map was constructed (*Figure 1*), on the basis of which 5 clusters on the topic under study were identified and characterized.

The first cluster (red colour) contains the largest number of terms (namely 19 items), among which the following can be mentioned: ecosystem service, environmental sustainability, green space, green infrastructure, infrastructure, urban policy, urban growth, urbanization. It is worth noting the keyword "Urban development", the frequency of its co-use in the studied sample is 15, and the strength of the connection is 96.

The second cluster (16 concepts, green) combines such terms as critical infrastructure, climate change, economic development, economic and social effects, resilience, sustainable infrastructure, environmental impact, urban transportation, sustainable cities. In this cluster, the keyword "Sustainable development" has the highest frequency – the ratio is 58, while the strength of the association is 393.

The third cluster (13 elements, blue colour) describes the relationship between the development of critical infrastructure and the well-being of the population with the following terms: sustainable development goals, energy utilization, information management, investments, life cycle.

The main key term in this cluster is “Energy efficiency”, the frequency of its co-use in the studied sample of scientific publications is 12, and the strength of the association is 56.

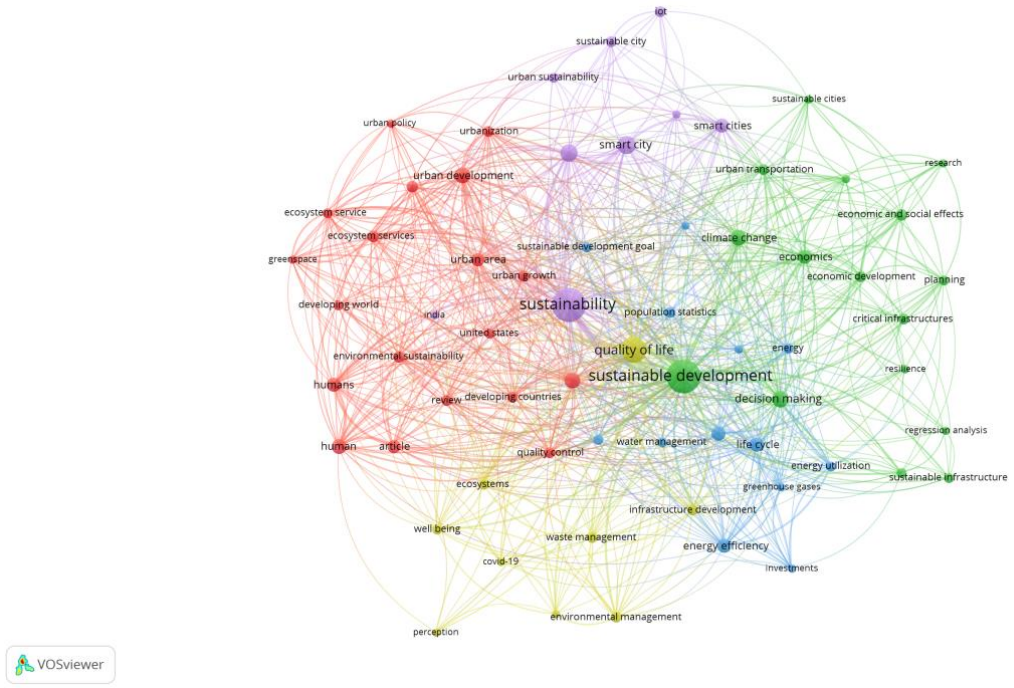


Figure 1. Map visualization of bibliometric analysis of publications devoted to issues of the relationship between the critical infrastructure sustainability and the well-being of the population

Source: built on the basis of data from the Scopus scientometrics database using the VOSviewer program

The fourth cluster (9 elements, yellow colour) is associated with the following categories: ecosystems, environmental management, infrastructure development, waste management, well-being. The keyword “Quality of life” has the highest frequency of co-use – 41, while the strength of association – 202.

The fifth cluster (9 elements, purple colour) covers the following categories: smart city, sustainable city, urban planning, urban sustainability. The frequency of co-use of the main keyword “Sustainability” in this cluster is 72, and the strength of association – 246.

Thus, based on the constructed terminological map of categories and the highlighted most significant keywords related to the issues of critical infrastructure development in the context of ensuring the well-being of the population, it can be stated about the multidimensionality and cross-dependence of the studied areas, since there are numerous connections between the terms, as well as their high prevalence in research.

In order to determine the temporal patterns of the development of the views of scientists who study the relationship between the sustainability of critical infrastructure and the well-being of the population in countries around the world, the trend analysis tool – Google Trends is used. Based on trend analysis over the past 5 years (2021-2025), a high level of interest in the topic “Quality of life” was found worldwide (average score 67) (*Figure 2*). However, the popularity level of topics related to the concepts “Critical infrastructure sustainability” and “Population well-being” was 0 points. That is, no user search queries were found in countries around the world for these keywords.

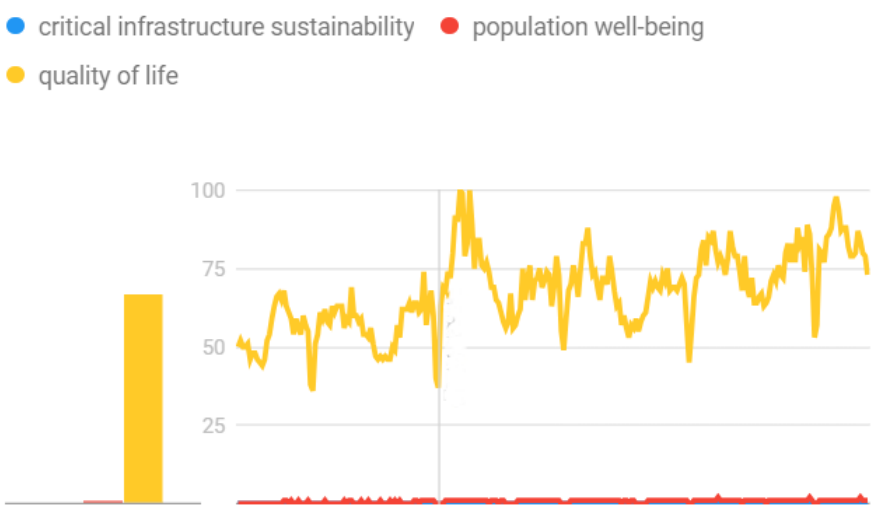


Figure 2. Dynamics of search frequency changes in the context of the definitions "Critical infrastructure sustainability" (blue colour), "Population well-being" (red colour), "Quality of life" (yellow colour) in the world

Source: constructed using Google Trends tools

If we consider Moldova and Ukraine, then in these countries the most common user search query can be attributed only to "Quality of life". Therefore, the topics related to the problems of ensuring the stability of critical infrastructure and the well-being of the population remain insufficiently resolved and require thorough research.

Research results

Recently, a lot of scientific literature has appeared on the problems of developing critical infrastructure. In scientific sources, this concept is mostly defined as: a complex system; its key components or elements; critically important infrastructure objects; network structure; physical structure; organizational structures; institutions; institutions; a set of assets; an object of administrative and legal protection; an object of cyber protection; a security direction; a component of national infrastructure; a set of objects, technologies, state and scientific structures; an object of public administration; a component of information security; an element of the system for ensuring the national security of a state or region, etc.

In [15], the term "critical infrastructure" refers to a set of facilities, systems, and networks that are priority and strategically important for the development of a competitive national economy and ensuring an adequate level of national security, the neutralization or disruption of which may harm the national interests of the state, lead to the emergence of possible threats and risks, significant damage and losses (economic, transport, logistics, environmental, financial, investment, information, etc.).

The development of critical infrastructure can be understood as the process of transformational changes in priority and strategically important facilities, systems, and networks for the economy by transferring key infrastructure components to a qualitatively new level of functioning due to adaptation to the variability and instability of the exogenous environment, taking into account the impact of possible threats, risks, and modern challenges [16].

It is worth noting that the development of critical infrastructure affects the quality of life of the population and its well-being. Thus, a critical infrastructure facility is an engineering structure, a public service, and an information system in the critical infrastructure sector, the disruption or destruction of which has negative consequences for the performance of the economic and social functions of the state, and therefore for the quality of life of residents in terms of protecting their lives, health, safety, property, and the environment.

For the most part, scientists understand the welfare of the population as an indicator of the effectiveness of state policy, which reflects the level of people's provision with material and spiritual benefits, as well as the quality of their lives [17-20].

The welfare of the population is the main indicator of assessing the effectiveness of the implementation of the state's socio-economic policy [21]. The growth of the population's social welfare depends on meeting the needs of people, the level of which is rapidly growing and qualitatively changing. It is the totality of material, social, and spiritual conditions that reflects the level and quality of life of the population. The process of meeting the needs of society with material and spiritual benefits is the ultimate goal of the functioning of any economic system [21].

At the current stage of social development, well-being is interpreted as a complex category that includes not only material, but also social, psychological, legal, political and other components both at the individual level and at the level of the entire society [22].

According to O. Chechel [23], the welfare of the population as a basic category of the state's economic policy is a multifaceted phenomenon. The level of the population's welfare is a factor that restrains or promotes human development.

Summarizing various approaches to determining the criteria for assessing the welfare of the population, we note that, in our opinion, the main components of the welfare of the population are “quality of life” (standard and conditions of life) and “way of life” (labour activity, demographic and migration activity), through which it is advisable to develop a system of criteria for assessing the welfare of the population. According to O. Chechel [23], the quality of life is a set of conditions of human existence that ensure the acquisition of necessary life benefits, material wealth and spiritual values.

T. Pavlyuk et al. [24] formulate the welfare of the population as the basis for the development of the state, and the quality of life is considered as a complex characteristic of a person in different social conditions, which reflects the degree of his freedom, the possibility of comprehensive development and implementation of abilities and life plans. This is the totality and quality of material, social, cultural and spiritual values provided by society to a person to satisfy his needs and realize his interests. That is, this category demonstrates the extent to which a person satisfies his needs in current social conditions and achieving a high quality of life is the goal of social policy and evidence of the social well-being of society [24].

As H. Sytnyk and Y. Taran [25] argue, the well-being of the population and food security directly depend on the competitiveness of the state. Therefore, in order to realize opportunities and minimize threats in Ukraine, it is necessary to develop a strategy that should be based on the principles of a guaranteed minimum level of well-being, ensuring equal opportunities, improving the quality of life, strengthening social cohesion, strengthening social security, social responsibility and social integration [25].

In addition, it is worth emphasizing that the development of critical infrastructure is closely related to the categories of "sustainability" and "resilience". The concept of "sustainability" is multifaceted and is used in different areas, having different meanings.

Based on the analysis of various research approaches to the content of the interdisciplinary concept of resilience, it can be concluded that it is built around the ability of complex systems to respond to negative influences in a way that allows them not to lose their functionality and ability to develop [26].

At the same time, the following characteristics are of fundamental importance for understanding resilience and further conceptualization: the field of research; the object in relation to which resilience is considered; external factors/influences in relation to which the object must be resilient; the goal of achieving resilience of a certain object; parties interested in the corresponding result; subjects/factors capable of influencing the achievement of such a result. That is, in a generalized form, the concept of "resilience" characterizes the reaction of an object to certain external stimuli, its ability to adapt to their influences without significant loss of functionality [26].

In the European Union, sustainability is defined as the ability of an individual, an individual economy, a society, a country or a region to withstand, adapt and recover quickly from stresses and shocks [27].

As noted by O. Firsova [28], in the classical theory of system sustainability (stability), three main forms are distinguished: 1) inertia (resistance) – the ability of a system to maintain its state unchanged for a certain period of time under external influences; 2) elasticity (recoverability) – the ability of the system to return to its original state after the cessation of external influences; 3) plasticity (flexibility) – the presence of several normal or permissible states in the system and its ability to transition from one state to another under the influence of adverse factors, while maintaining the necessary invariant – the mode of functioning, development trajectory, structural connections, etc.

O. Bazhenova [29] states that sustainability is the ability of a system to move from different initial states to some equilibrium (stationary) state.

From the point of view of I. Vysotskaya [30], sustainability is the ability of an object to function normally and resist various inevitable disturbances. The researcher conventionally systematized the interpretation of stability into 3 groups: system state; system property; system behaviour characteristic. In her opinion, the stability of an economic system is not just a property or state of the system, but a property that manifests itself in the state of the system, which depends on its relations with the external environment. The development of an economic system is possible provided that dynamic stability is ensured. The dynamic stability of an economic system is manifested in the reaction of the system and its elements to the action of external and internal factors, which leads to the restoration of the system [30].

In the scientific literature, there is such a concept as economic stability. This is a complex concept associated with the ability to maintain integrity and balance in conditions of negative and positive influences of various internal and external factors due to the effective use of enterprise resources [31].

From the position of S. Tkachenko [32], economic stability can be considered as the ability of a system to maintain its operational state in order to achieve planned results in the presence of various disturbance influences. Disturbances can cause temporary deviations of the coordinates of

the state of the system within predetermined tolerances, but with the cessation of influences, a stable system must return to its original position.

So, it turns out that stability is a dynamic concept, that is, it involves the development of an economic system. Therefore, sustainability is closely related to the concept of "system" and is one of its main properties.

As scientists V. Vasylenko et al. [33] argue, there is a close connection between such concepts as functional stability and reliability, survivability and fault tolerance. At the same time, we must understand the fundamental difference between these concepts: the main components of functional stability are aimed not at reducing the number of failures and violations, but at ensuring the performance of particularly important functions in which these violations have already occurred.

The main feature of functionally stable systems is their ability to degrade at the structural level to complete system failure, i.e. to remove failed elements from the structure, rebuild the structure, adjust the system parameters for adaptation to new operating conditions [33]. Thus, based on the generalization of existing scientific approaches to the definition of the concept of "stability", it was established that, as a rule, this category is understood as the ability of an object (system), a universal property, function, state of equilibrium, capabilities, inertia, recoverability, system capability, and a characteristic of system behaviour. At the same time, some authors identify stability with stability.

It should be noted that in recent years, the concept of "resilience" has been introduced into scientific circulation in economic literature, which is closer in essence and meaning of sustainability, stability, resistance, flexibility, recovery, etc.

For the most part, scientists understand the concept of "resilience" as the balancing of risk factors and protective factors; the ability to quickly restore resources; a dynamic process; the process of combating shocks and changes; the ability of the system; the ability or capacity of the economy; the fundamental basis; the concept; the paradigm; the strategy, etc.

In the context of civilizational subjectivity, resilience is a strategy that is able to maintain balanced development and successfully withstand external and internal challenges; through the efforts of the political and intellectual elite to anticipate and neutralize these challenges [34].

In [35], two approaches to understanding resilience are identified. According to the first approach, "resilience" is considered as a return to an already existing equilibrium point; according to the second, as a constant adaptation to changing conditions. The criterion of resilience according to the first approach is the rate of return to the initial state (a significant role in this process is played by the "strength" of the shock – the intensity and duration of the impact on the economic system), according to the second approach – the elasticity of the economic system. But both approaches determine that resilience implies the internal ability of the economic system to change ("bend") and recover after a negative impact (shock) as a result of structural adaptation [35].

Thus, "resilience" is considered as a property of an economic system that has a post-event nature, which allows it to absorb or mitigate losses, reconfigure, restore its state due to internal adaptive properties after the impact of shocks of various natures [35].

Conclusions

Based on the above, the following conclusions can be drawn. In today's world, critical infrastructure is the backbone of any country's national economy. Disruption of critical systems and

essential services, such as telecommunications, energy and water supply, transport and financial systems, can lead to significant economic and social losses [36]. These systems are highly vulnerable to a variety of shocks, from climate and geological hazards to industrial accidents, terrorist attacks, cyber threats, armed conflicts and hostilities, which can have cascading negative impacts at the local, national and even global levels.

Therefore, ensuring the resilience of critical infrastructure is of utmost importance. The concept of "system sustainability" should be considered from the perspective of a transformational economy, taking into account the significant impact of exogenous and endogenous factors and the emergence of new challenges of the time. Among them, we can mention such things as the intensification and deepening of the processes of globalization and European integration, transformation, digitalization [37], infrastructure provision and the transition to network forms of interaction and partnership, the use of public investment tools and the green financing mechanism [38-40] for the restoration and modernization of strategically important infrastructure facilities, etc.

Thus, the concept of "critical infrastructure sustainability" is proposed to be interpreted as the ability of infrastructure facilities to maintain their functioning in conditions of shock, to recover and adapt to the impact of threats, risks, challenges and adverse shocks of various nature in order to ensure effective socio-economic development of the economy and an adequate level of well-being of the population.

Currently, in the European Union, the resilience of critical infrastructure is recognized primarily as a national responsibility of each country. As shown by the analysis [36], the resilience of critical infrastructure encompasses the ability to prevent, protect, respond, resist, mitigate, absorb, adapt and recover from crises and emergencies, armed conflicts, military events that may disrupt the provision of essential services. This is particularly important for critical infrastructure, as complete protection is usually not possible.

In this context, ensuring the critical infrastructure sustainability can be based on a combination of several key qualities:

- ✓ reliability (the ability to continue operating or remain resilient. This involves designing structures or systems that are robust enough to withstand foreseeable shocks. It also involves investing in and maintaining critical infrastructure elements so that they can withstand low-probability but high-consequence events);
- ✓ redundancy (the ability to continue operations through replacement or backup systems that can be activated if something important fails or stops working);
- ✓ resourcefulness (the ability to skilfully manage an event as it unfolds. It includes identifying options, prioritizing what needs to be done to control the damage and begin to mitigate it, as well as communicating decisions to the people who will implement them);
- ✓ adaptability (the means to learn new lessons that can be learned from a disaster. It involves reviewing plans, modifying procedures, and implementing new tools and technologies necessary to increase reliability, resourcefulness, and the ability to recover from the next crisis).

Prospects for further research are to generalize foreign practice in identifying infrastructure threats to ensure the resilience of the quality of life of the country's population.

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