

# INTERDEPENDENCIES OF INFRASTRUCTURE SYSTEMS AND THE STRATEGY FOR SOCIO-ECONOMIC DEVELOPMENT OF THE NORTH CAUCASUS FEDERAL DISTRICT UNTIL 2030

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## Abstract

*This article analyses the interdependencies between infrastructure systems within the context of implementing the Strategy for the Socio-Economic Development of the North Caucasus Federal District by 2030. It considers the features of the functioning and interaction of various types of infrastructure in the region, including transport, energy, information and communication, and social infrastructure. The mechanisms through which infrastructure interdependencies influence the achievement of the NCFD's strategic development goals are investigated, and critical points and nodes of interaction are identified. Particular attention is paid to analyzing the risks of cascading infrastructure system failures and their potential impact on the region's socio-economic development. The article proposes approaches to optimizing the management of infrastructure interdependencies to ensure the NCFD's sustainable development in accordance with strategic priorities until 2030.*

**Keywords:** infrastructure systems, NCFD, strategic planning, regional development, infrastructure, sustainability

## I. Introduction

Modern regional development is characterized by an increasing complexity of interactions between different infrastructure systems, which requires an integrated approach to strategic planning and management of territorial development. The concept of "infrastructure system" is often used in the literature, and in some cases, they are used as synonyms. Infrastructure as a system object is considered within the framework of several sciences: economics, management, economic geography, regional economy, which determines its properties.

The North Caucasus Federal District (NCFD), characterized by special geographical, geopolitical and socio-economic conditions, is a unique territory where infrastructural interdependencies are manifested with particular acuteness and require in-depth analysis to ensure the sustainable development of the region.

## II. Methods

The methodological basis of the research is a set of general scientific methods (observation, analysis, synthesis, induction and deduction, modeling) and methods of applied research (system approach, statistical and graphical analysis, method of expert assessments, etc.).

## III. Results

The Strategy for the Socio-Economic Development of the North Caucasus Federal District for the Period up to 2030 [7] defines ambitious goals to transform the region into a dynamically developing territory with a diversified economy, a high standard of living of the population and modern infrastructure, which implies the need to create a synergistic effect from the interaction of various infrastructure systems. Transport, energy, information and communication, water management and Social infrastructure should function as a single interconnected complex that provides a multiplier effect for the socio-economic development of the region, which requires a deep understanding of the mechanisms of their interaction and interdependence. The availability of infrastructure facilities, the conditions of their functioning, the level of infrastructure provision affect the parameters of the economic space, changes in its configuration, and act as factors of regional development [6].

The theoretical foundations of the analysis of interdependencies of infrastructure systems are based on the system approach, which involves the consideration of infrastructure as a complex multi-level system, the elements of which are in constant interaction and mutual influence. Conceptual approaches to the study of infrastructure interdependencies include network theory, systems theory, risk management theory, and sustainable development theory, which together provide a methodological framework for understanding the complex processes of interaction between different types of infrastructure. Of particular importance in this context is the concept of critical infrastructure, which considers infrastructure facilities and systems from the point of view of their importance for the functioning of the economy and society, as well as vulnerability to various types of impacts.

The spatial infrastructure system of the region can be presented as a multifunctional dynamically developing complementary structure that forms the spatial framework of socio-economic activity, ensuring the development of interrelated systems, elements, and objects of territories of different hierarchical levels that interact with each other and the external environment on the basis of the principle of complementarity [5].

The methodology for assessing critical infrastructure includes a set of methods and approaches that make it possible to identify key elements of infrastructure systems, assess the degree of their interdependence and impact on the functioning of other systems, as well as identify potential risks and threats to the sustainable development of the territory. System analysis of interdependencies involves the use of mathematical models, simulation modeling, expert assessments and other tools that make it possible to quantitatively and qualitatively assess the nature and intensity of interrelations between different infrastructure systems. An important aspect of the methodology is also taking into account the spatial factor, since infrastructural interdependencies have a pronounced territorial specificity and require a differentiated approach to analysis depending on the characteristics of a particular territory [1].

The characteristics of the infrastructure complex of the NCFD indicate the presence of significant disproportions in the development of various types of infrastructure and the unevenness of their territorial distribution, which creates special conditions for the formation of interdependencies between infrastructure systems. The transport infrastructure of the region is characterized by insufficient development of federal and regional roads, limited opportunities for railway communication in mountainous areas and underdevelopment of inland waterways, which

creates systemic restrictions for economic development and forms specific interdependencies with other types of infrastructure. The energy infrastructure of the North Caucasus Federal District demonstrates high dependence on external energy supplies with the simultaneous presence of a significant hydropower potential in mountainous areas, which creates prerequisites for the development of interdependencies between energy and transport infrastructure in the context of the delivery of energy resources and the development of renewable energy sources.

The information and communication infrastructure of the region is characterized by the uneven development of digital technologies and telecommunication networks, which creates digital gaps between different territories and social groups, affecting the efficiency of the functioning of other infrastructure systems, which are increasingly dependent on information technologies for their management and monitoring. The social infrastructure of the North Caucasus Federal District is experiencing serious challenges associated with the need to ensure equal access to quality educational, health and cultural services throughout the region, which requires close coordination with the development of transport and information and communication infrastructure to ensure the availability of social services for all categories of the population.

The regional features of the infrastructure development of the NCFD are due to difficult geographical conditions, including mountainous territories, foothills and plain zones, each of which is characterized by specific requirements for infrastructure support and forms special types of interdependencies between infrastructure systems. Mountainous areas are characterized by increased risks for infrastructure facilities associated with natural disasters, difficult conditions of construction and operation, which requires special approaches to ensuring the stability and reliability of infrastructure systems. The ethnocultural diversity of the region also creates specific requirements for the development of social infrastructure, which should take into account the needs of different ethnic groups and ensure the preservation of cultural heritage while ensuring equal opportunities for the socio-economic development of all groups of the population.

The analysis of interdependencies between the infrastructure systems of the NCFD reveals a complex network of interconnections that manifest themselves at different levels and in various forms, determining the nature and intensity of the impact of changes in one infrastructure system on the functioning of other systems. Transport and logistics interrelations in the region are characterized by a high degree of interdependence between different modes of transport, when restrictions in the development of one mode of transport create an additional burden on other modes of transport and affect the efficiency of the entire transport system. Road transport in the mountainous areas of the region is experiencing increased loads due to the limited capabilities of railway transport, which creates additional risks for the transport system and requires increased attention to the condition of roads and their resistance to natural impacts [2].

The interdependencies between transport and energy infrastructure are manifested in the need to ensure energy supply to transport facilities, especially in the context of the development of electric transport and modern traffic control systems, as well as the dependence of the energy system on transport support for the delivery of energy resources and equipment for energy facilities. The development of renewable energy sources in the mountainous regions of the region creates new types of interdependencies, as the location of wind and solar power plants requires appropriate transport accessibility for construction and maintenance, as well as the development of electrical networks to transmit the produced energy to consumers.

Energy and utility interdependencies in the NCFD are characterized by close interdependencies between electricity, heat, gas and water supply systems, where disruptions in the functioning of one system can cause cascading failures in other systems and seriously affect the livelihoods of the population and the functioning of the economy. The heat supply system of many settlements in the region depends on the reliability of power supply for the operation of pumping equipment and automation systems, which creates critical interdependencies, especially in winter, when failures in the heat supply system can have catastrophic consequences for the population. Water supply and sanitation are also characterized by a high dependence on electricity supply for

the operation of pumping stations and treatment facilities, which requires special attention to ensure backup power supply to critical water infrastructure facilities.

Digital infrastructure and information connections form a new type of interdependencies, which is becoming increasingly important for the functioning of other infrastructure systems in the context of digitalization of the economy and society. Modern systems for managing transport, energy, water supply and other types of infrastructure are increasingly dependent on information and communication technologies, which creates new vulnerabilities and risks related to cybersecurity and the reliability of digital systems. The development of smart cities and the digital economy in the region involves the integration of various infrastructure systems based on common digital platforms, which creates both new opportunities for improving the efficiency of infrastructure management and new risks associated with possible failures in digital systems [3].

The impact of infrastructure interdependencies on the implementation of the strategic priorities for the development of the NCFD until 2030 is manifested in the fact that the effectiveness of achieving the goals of the strategy is largely determined by the ability to ensure a synergistic effect from the interaction of various infrastructure systems and minimize the negative consequences of their interdependencies. The impact on the economic development of the region is manifested in the fact that infrastructure interdependencies can both contribute to economic growth through the creation of agglomeration effects and reduce transaction costs, and create restrictions on economic development through the formation of infrastructure barriers and increased risks for business. Industrial development in the region requires the coordinated development of transport, energy and information and communication infrastructure, since deficiencies in any of these systems can significantly reduce the competitiveness of industrial enterprises and limit the opportunities for attracting investment.

#### IV. Discussion

The tourism industry, which is considered as one of the priority sectors of the NCFD economy, is especially sensitive to the state of infrastructure systems and their interdependencies, since the quality of tourism services directly depends on the reliability of transport links, energy supply, water supply and information and communication services. The development of the agro-industrial complex of the region also requires taking into account infrastructural interdependencies, since the efficiency of agricultural production depends on the state of transport infrastructure for the delivery of products to markets, energy infrastructure for ensuring technological processes and information systems for managing agronomic processes and logistics.

The social aspects of infrastructure interdependencies in the NCFD are related to the impact of the state of infrastructure systems on the quality of life of the population, the availability of social services and opportunities for social mobility, which is of particular importance for a region with a high level of social differentiation and uneven development of territories. The availability of quality education in the region largely depends on the state of the transport infrastructure, which provides the opportunity to attend educational institutions, and the information and communication infrastructure, which allows the use of distance learning technologies, especially in the context of a pandemic and other emergencies. The region's health system is highly dependent on transport infrastructure to ensure the availability of medical services in remote areas, energy infrastructure for the functioning of medical equipment, and information systems for coordinating the activities of medical institutions and exchanging medical information.

The risks of cascading failures and threats to the sustainable development of the NCFD associated with infrastructure interdependencies are a serious challenge to ensure the stable functioning of the regional economy and society, requiring the development of comprehensive measures to prevent and minimize the consequences of systemic failures in infrastructure systems. The identification of critical interaction nodes between infrastructure systems shows that the most

vulnerable facilities are those that ensure the intersection and interaction of different types of infrastructure, such as large transport hubs, power substations that supply many consumers, and information and communication centers that provide control of various infrastructure systems. Infrastructure facilities located in high-risk areas of natural disasters typical for the mountainous areas of the North Caucasus Federal District are particularly dangerous, where earthquakes, landslides, floods and other natural phenomena can simultaneously affect several infrastructure systems and cause cascading failures.

Scenarios for the spread of system failures in the infrastructure systems of the North Caucasus Federal District can develop along different trajectories depending on the nature of the primary impact and the characteristics of interdependencies between the systems, which requires the development of comprehensive plans for the prevention and elimination of emergency situations that take into account the specifics of infrastructure interdependencies. The most dangerous scenarios are those associated with failures in the energy system, which can cause the shutdown of transport systems, life support systems, information and communication systems and social infrastructure, which can lead to the paralysis of the life of large areas and the creation of humanitarian crises. Climate change poses additional risks to the region's infrastructure systems, as changes in precipitation patterns, temperature conditions and the increased frequency of extreme weather events can significantly affect the reliability and resilience of infrastructure facilities, especially when they are highly interdependent.

In accordance with the Strategy, the goal of spatial development of the Russian Federation is to ensure sustainable and balanced spatial development of the Russian Federation, aimed at reducing interregional differences in the level and quality of life of the population, accelerating the pace of economic growth and technological development, as well as ensuring the national security of the country [8]. In this regard, strategic approaches to the management of infrastructure interdependencies in the NCFD should be based on the principles of consistency, complexity and sustainability, which involve the consideration of infrastructure systems as a single interconnected complex that requires coordinated management and development. Mechanisms for coordinating the development of infrastructure systems should include institutional, organizational and methodological tools that ensure coordinated planning, financing and implementation of infrastructure projects, taking into account their interdependencies and synergistic effects (Fig. 1).

<b>MECHANISMS FOR COORDINATING THE DEVELOPMENT OF INFRASTRUCTURE SYSTEMS</b>		
<p><b>INSTITUTIONAL LEVEL</b></p> <ol style="list-style-type: none"> <li>1. Interregional Coordination Council for Infrastructure Development of the North Caucasus Federal District</li> <li>2. Working groups in industry areas</li> <li>3. Interdepartmental Commission for the Assessment of Interdependencies</li> </ol>	<p><b>ORGANIZATIONAL LEVEL</b></p> <ol style="list-style-type: none"> <li>1. Unified Project Management Center (USCM)</li> <li>2. Interregional Planning System (Integrated Territorial Planning Schemes)</li> <li>3. Advance planning mechanism (corridors of the Infrastructure development)</li> </ol>	<p><b>METHODICAL LEVEL</b></p> <ol style="list-style-type: none"> <li>1. Integrated Project Appraisal System</li> <li>2. Scenario planning model</li> <li>3. Digital modeling tools (creation of digital twins of infrastructure systems, simulation)</li> </ol>
<p><b>FINANCIAL AND ECONOMIC LEVEL</b></p> <ol style="list-style-type: none"> <li>1. Mechanism for co-financing interregional projects</li> <li>2. Public-Private Partnership Tools</li> <li>3. Tariff Regulation System</li> </ol>	<p><b>INFORMATION AND ANALYTICAL LEVEL</b></p> <ol style="list-style-type: none"> <li>1. Unified Monitoring Information System</li> <li>2. Feedback mechanism</li> <li>3. Best Practices Exchange System</li> </ol>	

**Figure 1.** Mechanisms for coordinating the development of infrastructure systems in the NCFD

International cooperation in the field of infrastructure development can become an important factor in improving the efficiency of management of infrastructure interdependencies in the North Caucasus Federal District, especially taking into account the border location of the region and its role in international transport corridors. The development of cross-border infrastructure creates new opportunities for the economic development of the region, but at the same time creates new types of interdependencies that transcend national borders and require international coordination to ensure their effective management.

The economic and geographical position of the North Caucasian Federal District at the intersection of transit directions to the countries of Transcaucasia and sublatitudinal routes between the Black Sea and Caspian basins, along with the peculiarities of the settlement system, determined the high density of transport infrastructure in the North Caucasian Federal District with a large number of transport hubs [7]. The strategic importance of the NCFD in the context of international transport corridors is determined not only by its geographical location, but also by its potential for creating integrated infrastructure complexes capable of ensuring the uninterrupted functioning of logistics chains connecting various regions of Eurasia. The formation of such complexes requires the coordination of efforts to standardize technical solutions, harmonize regulatory approaches and create unified risk management mechanisms at the cross-border level.

Of particular relevance is the development of digital infrastructure, which can serve as the basis for the creation of intelligent systems for managing cross-border traffic flows. The introduction of modern information technologies makes it possible not only to optimize logistics processes, but also to create mechanisms for a prompt response to changes in the functioning of the infrastructure systems of neighboring states. The development of energy infrastructure within the framework of international cooperation opens up opportunities for the creation of regional energy hubs that can ensure the energy security of not only the North Caucasus Federal District itself, but also neighboring regions. Such projects require long-term planning and the establishment of mechanisms to manage the technical and economic risks associated with the integration of different energy systems.

Social infrastructure can also be developed through cross-border cooperation, especially in education and health. The creation of joint educational and medical centers can contribute to the formation of a single space of knowledge and competencies, which in the long term will become an important factor in the sustainable development of the region. Financing international infrastructure projects requires innovative mechanisms that include public-private partnerships, international investment funds and multilateral development banks. Effective management of such projects involves the creation of specialized institutions capable of ensuring coordination between various actors and minimizing the risks associated with the cross-border nature of infrastructure interdependencies.

At the same time, the most important from the point of view of ensuring the effectiveness of the implementation of socio-economic policy belongs to the determination of its priorities that are adequate to the current conditions of territorial development, as well as corresponding to the main trends, the manifestation of which will take place in the strategic perspective [4].

The prospects for optimizing infrastructure interdependencies in the NCFD until 2030 are associated with the implementation of an integrated approach to infrastructure development based on a deep understanding of the mechanisms of interaction between various infrastructure systems and taking into account their impact on the achievement of strategic goals of the region's socio-economic development.

Directions for further research in the field of infrastructure interdependencies in the NCFD should include the development of better methods for modeling and predicting the behavior of complex infrastructure systems, the study of the impact of new technologies on the nature of infrastructure interdependencies, as well as the study of social and environmental aspects of infrastructure development.

The development of digital twins of infrastructure systems can be an important tool for a deeper understanding of infrastructure interdependencies and the development of optimal strategies for managing them, but it requires significant investment in the development of appropriate technologies and competencies.

International experience in managing infrastructure interdependencies in difficult geographical and socio-economic conditions can also become a serious source of knowledge for improving approaches to managing infrastructure development in the NCFD, which requires intensifying international cooperation in the field of infrastructure research and the exchange of best practices.

#### CONFLICT OF INTEREST.

Authors declare that they do not have any conflict of interest.

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