International Journal for Quality Research 18(2) 613–626
ISSN 1800-6450

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Article info:
Received 21.02.2023.
Accepted 29.08.2023.

UDC – 502.131.1
DOI – 10.24874/IJQR18.02-19

THE CONCEPT OF RESILIENCE-DIAGNOSIS OF THE REGIONAL ECOSYSTEM ON THE BASIS OF THE DIGITAL TWIN MODEL

Abstract: *For many researchers the task of assessing the socio-economic security of a region involves using a system of security criteria based on comparng the values of indicators of the regional system with fixed threshold levels. This approach, at best, provides an assessment of the current state of the security of the regional system, but does not allow predicting the reaction of the state of the security system to the negative impact of external factors. For this it is necessary to additionally take into account sustainability - an ability of the regional security system to resist the impact of external threats. Therefore, diagnosing the ecosystem of the region should include steps to assess sustainability. From this point of view, resilience-diagnostics can be considered as a superstructure on the system of diagnostics of the socio-economic security of the region, and for the integration of diagnostic processes, general computational algorithms should be used based on the digital model of the regional security system - a digital twin. The article presents an algorithm for resilience-diagnostics of the ecosystem of the region based on the digital twin model of the ecosystem security, the results of its testing, including graphic visualizations in the form of heat maps, digital portraits of the security and sustainability of the ecosystem of the region.*

Keywords: *Economic security, Regional ecosystem, Digital twin, Indicators, Sustainability indices, Resilience-diagnostics, Heat map, Digital portrait of the economic security of the region, Digital portrait of the regional ecosystem sustainability*

1. Introduction

Digital transformation of all areas of activities expands opportunities and ensures coming to optimal management decisions for cross-functional tasks of the socio-economic development of regions. The region, as a multidimensional dynamic ecosystem, is characterized by a set of specific indicators that form a comprehensive system for assessing its development.

Internal and external challenges, the ability of the region's ecosystem to adequately respond to them determine the importance of sustainability assessment as a component of the regional system security.

With this approach, the primary task is to develop the concept of resilience-diagnostics of the region's ecosystem based on

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interactive algorithmic solutions, including analytical and predictive methods. Resilience-diagnostics of the regional ecosystem should be aimed at studying abilities of the regional system to restore the main parameters of sustainable functioning in response to negative external challenges.

Digital twin models of the security of the regional ecosystem and the system of sustainability indices, characterized by the properties of processability, parametricity, cyclicity and adaptability, have the greatest potential in this aspect.

Close attention to digital twin models is due to their flexibility, interactivity and multifunctionality. So the digital twin is able to perform modeling, economic, predictive, optimization and management functions.

A model of the digital twin of the security of the regional ecosystem and the system of sustainability indices can be used to carry out such diagnostics.

The foregoing determined the purpose of the study: to develop and test an algorithm for resilience-diagnostics of the regional ecosystem in the current period based on the digital twin model. For this, the following steps were taken: collection and preparation of the regional indicators for the formation of a system of indicators of the ecosystem security during the study period; formation of a digital twin model of the ecosystem security in the form of quantitative values of a hierarchical system of indicators and qualitative levels of security; study of the state of security of the ecosystem of the region in the context of the security of other members and in the context of a general security indicator, main projections, subprojections and individual indicators based on heat maps; creation of a digital portrait of the region ecosystem security; formation of a register of risks and threats to the security of the region ecosystem; calculation of ecosystem sustainability indices during the study period; creation of a digital portrait of the sustainability of the region ecosystem; formation of a register of risks and threats to the ecosystem of the region, taking into account sustainability.

2. Model development and testing

The concept of the “economic security of regional systems” underlies the “resilience-diagnostics of the regional ecosystem”. So back in 1994 L.I. Abalkin understood the economic security as a certain set of factors and conditions that ensure the sovereignty of the state economy, its stability as well as the ability to constantly update, develop and improve (Abalkin, 1994). Many researchers have been involved in the study of the economic security at the regional level, for example, V.K. Senchagov et al. (2012). In general, the authors of this study understand the economic security as “an ability of a system to function stably for a long period, including under the negative impact of the external environment… the security of a system is characterized by a certain relationship between its potential and threats from external factors. The potential should be sufficient to neutralize the negative impact of external factors and further sustainable operation. Only in this case it is possible to speak of a high level of the economic security” (Karanina & Karaulov, 2023).

2.1. Theoretical basis

The economic security can be considered from the standpoint of the ecosystem security (ESS) by analogy with natural ecosystems - local communities interacting with each other and the environment; cooperating and competing with each other, these systems develop and adapt under the influence of external conditions. Another used term is "economy"; it includes the concept of rational use of resources in the system of their circulation and expanded reproduction, and the identity of the economic system and the ecosystem lies in the grammatical basis of these concepts of "eco-", which determines their basic features: rationality and complexity. Therefore, the concept of the “ecosystem security” is appled here (Karanina, 2022).

One of the most important characteristics of the ecosystem security is sustainability - an ability of an ecosystem to maintain its functionality under various conditions of the external or internal environment. This property includes resistance (in biology, it means resistance, immunity of the body to the effects of various factors) and resilience-sustainability of the system - an ability to resist the negative effects of the external and internal environment and, at the end of such an impact, return to an acceptable level of system functioning within a short period at least in the medium term. In the first case, this ability of the system can characterize a high level of the system security, and in the latter case, a reduced level of the security with the same nature of the negative impact. An additional characteristic of resilience-sustainability is adaptability - an ability of the system to change locally, but retain the most important components of its structure and functional performance in general under internal/ external negative impact. In the case of a long-term negative impact as a result of adaptation, significant structural changes can occur in the security system. Therefore, assessment of the security status of a large system in a short period reflects only its response to external/ internal impact - the level of sustainability: a negative impact worsens the parameters of the current functioning, and a positive impact improves these parameters. Assessment of the current level of the system security must be carried out in the medium term, and an adequate assessment of changes in the level of system security in most cases can be obtained in the long term, for example, when comparing the economic system security indicators with a time lag of 3–5 years. In general, this corresponds to the concept of diagnosing the economic security and stress resistance of Russian regions (Karanina, 2021; Karanina, 2022b; Karanina & Karaulov, 2023), but the system of indicators used in these publications can only partly be considered as corresponding to indicators presented at Rosstat for diagnosing the state of theveconomic security of Russia taking into account the Economic Security Strategy of the Russian Federation (Decree, 2017).

Translated from English, "resilience" means elasticity, and the traditional representation of this concept characterizes an ability of an arbitrary system to absorb negative internal or external shocks, adapt and restore balance (Walker & Cooper, 2011). In general, this concept has a multidisciplinary character. For example, in ecology, this concept is associated with an ability of "survival" of complex systems (Holling, 1973). Economic research uses the term economic resilience. After the global financial crisis of 2008, studies of the world economic system and regional economies from the standpoint of an ability of the economic system to quickly return to its original state or to the current development trend after exogenous (recessionary) shocks appeared. For example, R. Martin defines the economic resilience as a process - the reaction of the regional system to a shock and includes four stages: resistance, recovery, renewal and reorientation (Martin, 2012).

Various authors dealt with the issues of the economic resilience in domestic science. V.V. Akberdina (Akberdina, 2021), O.A. Romanova, D.V. Sirotin, A.O. Ponamoreva (Romanova et al., 2022).

N.V. Smorodinskaya, D.D. Katukov, E.V. Malygin explore the economic resilience in the context of global value chains and highlight such properties of the system resilience as robustness, flexibility, resource redundancy, dynamic stability and propose to consider the resilience “as an organizational principle for functioning of complex systems, a new element of growth policy and a new standard for risk management under uncertainty” (Smorodinskaya et al., 2021; Smorodinskaya & Katukov, 2021).

V.V. Akberdina proposes two approaches to understanding this concept in the studies of various authors. Within the framework of the first is basen on the equilibrium approach, the key aspect is the rate of return of the economic system to the initial equilibrium state; the second - on the evolutionary approach, the sustainability is seen as a process of continuous adaptation to constantly changing conditions. V.V. Akberdina believes that the sustainability of the economic system reflects the pre-event character, and the specific property of the resilience is the post-event character and gives the following definition: “Economic resilience is an ability of the economy to fully recover from the impact of shocks of various nature due to internal adaptive properties.” Resilience factors are located within the system itself, and among them we can distinguish congenital and acquired factors. The latter factors characterize the property of the adaptability of the economic system (Akberdina, 2021).

Thus, the key point in the analysis of the concept of "resilience" is an ability of the economic system to fully recover from the impact of short-term shocks of various nature. The authors' approach to the concept "resilience" is somewhat broader: an ability of the economic system to maintain a "normal" level of sustainability in the event of negative shocks, an ability to recover to a "normal" level, as well as the speed (or duration until) of such recovery are considered. Therefore, the resilience diagnostics of the regional ecosystem should be aimed at studying an ability of the regional system to restore the main parameters of sustainable functioning in response to negative external challenges. The model of the digital twin of the security of the regional ecosystem and the system of sustainability indices can be used to carry out such diagnostics.

Digital transformation is a key vector in the development of modern society. Digitalization, networking, data-datification, eco-systematicity provide the emergence of new concepts and strategies for the socio-economic development of various structures and relationships between systems and their objects.

One of the dynamically developing concepts is the concept of the digital twin. The essence of the concept of the digital twin lies in a new paradigm of digital modeling, which makes it possible to represent an object or system not only in the form of a physical, but also a digital (virtual) model.

Digital modeling provides a reflection of links between a physical object or system and its digital (virtual) model, providing a possibility to continuously predict the behavior and modification of the object (system). This is one of the biggest benefits of using the digital twin model.

In the field of multimedia technologies, the digital twin is defined as "a digital copy of a living or inanimate physical entity." Combining the physical and virtual world through multimedia technologies, data (parameters) and technologies are the key elements that allow the virtual model to exist simultaneously with the physical object (El Saddik, 2018).

K.S. Ponomarev, A.N. Feofanov, T.G. Grishina consider the possibilities of the digital twin in industrial production, defining it as a mathematical model of a production or an object in the digital environment associated with a database of the parameters of this object. (Ponomarev, Feofanov, Grishina, 2019).

A similar position is presented in the study of M. Hindsbo, who considers the process of numerical modeling as the basis for creating digital twins. (Hindsbo, 2018).

Bolton et al. (2018) focus on the social context of the use of the digital twin and defines it as “a dynamic virtual representation of a physical object or system throughout its entire life cycle using real-time data to understand, study and reason” (Bolton et al., 2018).

For our study, the concept of the digital twin in the economic sphere is of interest. M. A. Garanin (2018) describes the consequences of the introduction of "digital twins" in the economy of the public sector, drawing attention to the importance of the possibility to predict economic processes.

It is information exchange as a two-way data transmission channel from a physical object to a digital twin that is the basis for optimizing models of the economic sector.

Analyzing and summarizing the definitions of the "digital twin", it can be concluded that there are two basic methodological approaches that reveal its essence and characteristics: systemic and information-cybernetic. The provisions of the systems approach (Yudin et al., 1997) allow us to consider the digital twin in the context of a holistic, complex impact of the ecosystem of a physical object on a digital model.

The ideas of the information-cybernetic approach (Khutorskoy, 2010) emphasize the need to collect, analyze and manage information links between a physical object (system) and a digital twin model, which determine the possibility of taking into account changes of a physical object and predicting its behavior.

Based on the above concept of the digital twin and the analysis of sources on the studied issues (El Saddik, 2018; Ponomarev et al., 2019; Shpak et al., 2020), we will designate its key properties and functions.

Properties of the digital twin:

Processability. Digital twins are determined mainly by the development of modern technologies (Internet of things, artificial intelligence, machine learning).

Parametricity. The digital twin model is created on the basis of data (parameters) transferred from a physical object to a virtual one. At the same time, changing one of the indicators provides a change in other parameters associated with them.

Cyclicity (updating). The digital twin describes the state of a physical object (system) throughout its entire life cycle.

Adaptability as a possibility to adapt the digital twin model to the external and internal challenges of the environment in which the physical object or system is located.

Functions of the digital twin.

Modeling: allows simulating events that occur with a real object or system under certain conditions under the influence of various factors.

Economic: Minimizes costs and risks associated with implementing innovations in the real world.

Predictive: provides a continuous forecast of the state of a real object or system; allows tracking, based on a comparison of actual and predicted data, the reaction of an object or system to critically significant challenges, to identify problem stages without bringing them to a critical state.

This function is key, since the presence of sustainaility properties of the security system makes it possible to predict the preservation of the security level in response to external challenges, and the absence of such sustainaility - possible threats to the functioning of the regional ecosystem.

Optimizational: involves the optimization of various types of resources for testing innovations in relation to a real object or system in the current conditions.

Managemental: allows making informed multifactorial management decisions regarding the development of a particular object or system.

The functional scope of the digital twin is largely determined by its level of technological development. There are four levels of digital twins: pre-digital twin, digital twin, adapted digital twin, smart digital twin.

For the pre-digital twin, as a rule, only a virtual prototype is characteristic. The digital twin differs from the pre-digital one by the presence of a digital model and an ability to receive data from a physical object (system). The adapted digital twin implies an adapted interface, real-time updates and model management. The smart digital twin, in addition to an adapted interface, is characterized by the possibility of learning and improvement.

In our study, under the model of the digital twin of the security of the regional ecosystem, we will understand a copy of the regional ecosystem that has real properties, exists on the basis of information exchange of data (security indicators) and performs modeling, predictive, economic and management functions.

2.2. Data and Methods

Taking into account the outlined approaches, the principles for developing a system for diagnosing the sustainability of the regional ecosystem based on the digital twin model were laid down:

- Use of numerical data from open sources over a long period.
- System for diagnosing the sustainability of the regional ecosystem should be consistent with the national strategy for the economic security.
- Hierarchical structure of the regional ecosystem sustainability indices should be similar to the structure of security indicators and be based on security indicators.
- Formation of the integral index from component indices and individual system indices by means of convolution similar to the security indices.
- Assessment of sustainability in general and its components is carried out on the basis of sustainability indices, threshold levels and sustainability zones.
- Finding indices of ecosystem stability in the corresponding zones of stability allows assessing the level of sustainability-resistance.
- State of indices of sustainability of the regional ecosystem and its component allows revealing the structure of sustainability: to form sustainability maps of ecosystem components (projections, subprojections, individual indicators), to rank the components and elements of the ecosystem according to the level of sustainability and security threats.

2.3. Diagnostic Model

The digital security model of the regional ecosystem (the digital twin of the security system) can be represented as a hierarchical structure of numerical indicators and threshold levels, at the top level of which there are many projections that reveal the state of the most important components of the security. For example, many researchers single out social, resource, financial, technical and technological and other components. Comparing numerical indicators with threshold levels makes it possible to obtain a qualitative characteristic of the state of security, and comparing indicators with their indications in previous periods allows us to assess the development of ecosystems and their response to external challenges and threats. Thus, the resilience-diagnostics of the regional ecosystem can be carried out.

Taking into account the Economic Security Strategy of the Russian Federation, a system of indicators was developed in the form of a hierarchical model for diagnosing the security of the regional ecosystem (Karanina, 2022). At the first level, there are 6 main elements-indicators of the ecosystem security (ESS) of the region - projections: SED - "Security of economic development", FS - "Financial security", SEEI - "Security of external economic integration", TTS - "Technical and technological security" , ERMS - "Energy and Raw Material Security", SS - "Social Security".

At the second level of the hierarchical diagnostic model, there are subprojections that characterize certain aspects/ specifics of the main projections of ESS. Each projection includes two to three subprojections. In general, the hierarchical model for diagnosing the security of regional ecosystems in the Russian Federation consists of 58 indicators which are at the third level of the hierarchy. They are grouped into 15 subprojections located on the second level of the hierarchy. The latter are included in 6 main projections of the first level of the hierarchy (table 1).

Table 1. The structure of projections and subprojections of the model for diagnosing the security of the ecosystem of the region

	Projections		Subprojections
1	SED - Security of economic development	1.1	LSD- level and structure of development
		1.2	DED - general dynamics of economic development
2	FS - Financial security	2.1	LSFS - level and sustainability of financial security
		2.2	DPD - domestic public debt
		2.3	EPD - external public debt
3	SEEI - Security of external economic integration	3.1	IEC - import / export of capital
		3.2	LEEI - level of external economic integration
		3.3	DEEI - dynamics of external economic integration
4	TTS - Technical and technological security	4.1	LInvD - level of investment development
		4.2	LInnD - level of innovative development
5	ERMS - Energy -raw material security	5.1	RMS - raw material security
		5.2	EnB - energy security
6	SS - Social security	6.1	SL - standard of living
		6.2	CS - consumer security
		6.3	PS - personnel security

Sources: compiled by the authors

Relative indicators of the model express the essence of the structure, dynamics or efficiency of functioning; absolute - the scale of functioning per capita, per unit of a fixed set of goods and services, etc. This approach makes it possible to compare the state of the ESS of members in different periods and among themselves.

The result of the assessment is a set of values of indicators and levels of ESS, taking into account the structure of security, transferred into a point scale and qualitative interpretations of security levels (low, medium and high): the general (integral) indicator of EES - IIESS, security indicators of the projections of SED, FS, SEEI, TTS, ERMS and SS, as well as their subprojections and individual indicators.

The initial indicators are trensferred into a point scale from 1 point to 100 points using the piecewise linear scaling method. The projection indicators are calculated as an additive convolution of the individual indicators included in it. The final (integral) ESS indicator is calculated as the geometric mean of the projections.

Threshold levels were used to transfer to a point scale, when they aere determined various approaches were used: taking into account target / normative values, etc., as well as those used in the world practice and by leading scientists (Senchagov & Mityakov, 2011), (Avdiyskiy & Senchagov, 2014). Additionally, the average values of the indicators and their standard deviations for the Russian Federation in 2010-2014 and the dynamics of the indicators themselves for 2000-2020 were studied. (Karanina, 2022).

The formation of sustainability indices was carried out by analogy with the basic indices. First, the average security indicator of individual indicators for 2010-2014 was determined as the arithmetic mean of indicators over five years, which was then transferred into a point scale. The average value is assigned a stability index of 100 points. If the current value of the indicator is better than the average base level, then the index becomes more than 100 points, and if it becomes worse then it is below 100. Changing the security indicator by 1/99 of the share between the security thresholds changes the security index by one point. The sustainability index is estimated in the range from 1 to 200 points. Outside the sustainability index, the corresponding limit values of 1 or 200 points are assigned. The group and integral sustainability indices are calculated by the convolution method as security indicators.

For annual indicators of sustainability (individual, sub-projections, projections and final), a qualitative scale of sustainability of the regional ecosystem is used. If the sustainability indicator:

- less than 50 - critical level of sustainability of the regional ecosystem;
- from 50 to 75 – low level of sustainability of the regional ecosystem;
- from 75 to 90 - average level of sustainability of the regional ecosystem;
- from 90 to 100 – normal level of sustainability of the regional ecosystem;
- from 100 to 110 - increased level of sustainability of the regional ecosystem;
- more than 110 – high level of sustainability of the regional ecosystem.

The normal and higher levels of sustainability of the considered secuirity aspect is assessed only when this secuirity aspect is formed - the coefficient of variation of the sustainability index for 2010-2014 does not exceed 10%.

The average level of sustainability can be assessed for a partially or formed security aspect - the coefficient of variation of the sustainability index should not exceed 25%.

The lack of formation of the considered aspect of security indicates the presence of high uncertainty and risks.

The algorithm for resilience-diagnostics of the region's ecosystem in the current period based on the digital twin model includes the following steps:

1) Collecting regional indicators for the formation of a system of ecosystem security indicators during the study (current) period;
2) Forming a model of a digital twin of the ecosystem security in the study period in the form of quantitative values of a hierarchical system of indicators and qualitative (fixed) levels of security;
3) Studying the state of security of the ecosystem of the region in the context of the security of other subjects and in the context of a general security indicator, main projections, subprojections and individual indicators based on heat maps;
4) Creating a digital portrait of the security of the ecosystem of the region;
5) Forming a register of risks and threats to the security of the ecosystem of the region;
6) Calculating the ecosystem sustainability indices in the study period;
7) Creating a digital portrait of the sustainability of the regional ecosystem.
8) Forming a register of risks and threats to the ecosystem of the region, taking into account sustainability.

2.4. Research results

The results of testing the algorithm are presented below. In particular, Figure 1 shows the heat map of the security of the constituent entities of the Russian Federation in the "Social Security" projection in 2020, which makes it possible to assess the level of security of the regional ecosystem comparatively to other constituent entities. Figure 2 shows the digital portrait of the security of the Kirov region ecosystem, which is a visualization of the quantitative and qualitative characteristics of the digital model. This portrait allows creating a register of risks and threats to the security of the region. Table 2 presents a register of risks and threats to the security of the ecosystem of the Kirov region in 2020 using subprojections as an example. The color scheme of the subprojections characterizes the degree of the security system development, and the security and threat indicators characterize the qualitative level of danger (low, medium, or high). Comparison of the current level of the security of the regional ecosystem with the baseline reflects the state of stability and makes it possible to assess the change in the security of the regional ecosystem compared to the base period. Figure 3 presents the digital portrait of the sustainability of the ecosystem of the Kirov region in 2020 and, on its basis, the register of risks and threats to the sustainability of the ecosystem of the Kirov region was compiled (table 3).

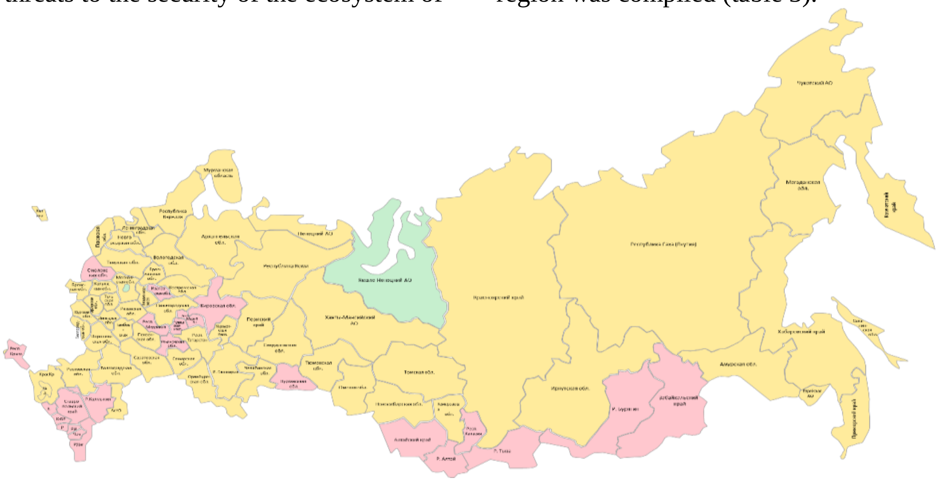

Figure 1. Heat map according to the projection "Social security" in the context of the members of the Russian Federation for 2020 (Sources: compiled by the authors)

the Kirov region in 2020. LRESS = 43														
SED 37		FS 72			SEEI 52			TTS 53		ERMS 29		SS 30		
LSD 26	DED 49	LSFS 59	DPD 63	EPD 100	IEC 52	LEEI 37	DEEI 67	LInvD 29	LInnD 78	RMS 34	ES 24	SK 45	CS 15	PS 30

Figure 2. Digital portrait of the security of the ecosystem of the Kirov region for 2020
Sources: compiled by the authors

Table 2. Register of risks and threats to the security of the ecosystem of the Kirov region in 2020 in the context of sub-projections

Indicator / sub-projection	Security level	Threat level
Consumer security	15	86
Energy security	24	77
Level and structure of development	26	75
Level of investment development	29	72
Personnel security	30	71
Raw material security	34	67
Level of external economic integration	37	64
Standard of living	45	56
Import-export of capital	48	53
Dynamics of economic development	49	52
Level and sustainability of financial security	59	42
Domestic public debt	63	38
Dynamics of external economic integration	67	34
Level of innovative development	78	23
External public debt	100	1

Sources: compiled by the authors

the Kirov region in 2020 LSRESS = 100														
SED 98		FS 114			SEEI 84			TTS 97		ERMS 120		SS 93		
LSD 108	DED 87	LSFS 140	DPD 89	EPD 100	IEC 93	LEEI 103	SEEI 60	LInvD 68	LInnD 126	RMS 133	ES 106	SL 122	CS 67	PS 89

Figure 3. Digital portrait of the sustainability of the ecosystem of the Kirov region for 2020

Table 3. Register of risks and threats to the sustainability of the ecosystem of the Kirov region in 2020 in the context of sub-projections

Indicator / sub-projection	Sustainability index	Threat level
Dynamics of external economic integration	60	41
Consumer security	67	34
Level of investment development	68	33
Dynamics of economic development	87	14
Domestic public debt	89	12
Personnel security	89	12

Sources: compiled by the authors

3. Conclusion

The concept of resilience-diagnostics of the regional ecosystem based on the digital twin model is presented. The concept is based on the authors' approach to the concept of sustainability as an ability of an economic system to maintain a "normal" level of stability in the event of negative shocks, an ability to recover to a "normal" level, as well as the speed of such recovery.

The digital security model of the regional ecosystem (digital twin of the security system) is presented as a hierarchical structure of numerical indicators and threshold levels, at the top level of which there are many projections that reveal the state of the most important components of the security.

Based on the concept, an algorithm for resilience-diagnostics of the regional ecosystem in the current period was developed using the digital twin model that performs modeling, predictive, economic and management functions.

Approbation of the specified algorithm was reflected in the compilation of the heat map and the digital portrait of the security of the ecosystem of the Kirov region, which makes it possible to form a register of security risks and threats to the security of the region (using subprojections as an example).

Acknowledgment: The study was carried out within the framework of the project "Development and justification of the concept, the integrated model of resilience-diagnostics of risks and threats to the security of regional ecosystems and technology for its application based on the digital twin" (grant of the President of the Russian Federation NSh-5187.2022.2 for state support of leading scientific schools of the Russian Federation).

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