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Modeling of the system of regional indicators of the development of a circular economy

Modelización del sistema de indicadores regionales del desarrollo de una economía circular

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ABSTRACT

The purpose of the article is to present a methodological approach to modeling the system of regional indicators in the context of the development of the closed-cycle economy. The employed research methods rely on the provisions of economic and statistical analysis, management theory, situational and adaptive approaches in management, system analysis, simulation modeling, the theory of finance and financial markets, and the theory of taxation. The authors emphasize the importance of accounting for such factors as finance, taxation, entrepreneurial infrastructure, and education for the successful implementation of closed-loop economy strategies at the regional level. The results of modeling the system of regional indicators clarify the estimated forecast of the consequences of the adopted managerial decisions in the financial and industrial policy for the introduction of technologies.

Keywords: sustainable development, circular economy, financing, linguo-combinatorial modeling, development indicators.

RESUMEN

El propósito del artículo es presentar un enfoque metodológico para modelar el sistema de indicadores regionales en el contexto del desarrollo de la economía de ciclo cerrado. Los métodos de investigación empleados se basan en las disposiciones del análisis económico y estadístico, la teoría de la gestión, los enfoques situacionales y adaptativos en la gestión, el análisis de sistemas, los modelos de simulación, la teoría de las finanzas y los mercados financieros y la teoría de la fiscalidad. Los autores subrayan la importancia de tener en cuenta factores como las finanzas, la fiscalidad, la infraestructura empresarial y la educación para aplicar con éxito estrategias de economía de ciclo cerrado a escala regional. Los resultados de la modelización del sistema de indicadores regionales aclaran la previsión estimada de las consecuencias de las decisiones empresariales adoptadas en la política financiera e industrial para la introducción de tecnologías.

Palabras claves: desarrollo sostenible, economía circular, financiación, modelización lingüístico-combinatoria, indicadores de desarrollo.

1. INTRODUCTION

The topicality of developing a system of regional indicators of circular economy development is defined by the need to address the scientific and practical problem of its methodological support in the conditions of sanctions pressure, disruption of supply chains, restricted access to new innovative technologies, as well as the importance of supporting the sustainable development of the region, taking into account the diverse and sometimes incomplete information about economic relations in the region against the background of a dynamic environment and the risks of social, economic, and environmental problems.

The hypothesis put forward in the development of methodological support for the system of regional indicators is formulated as a confirmation of the possibility of the complex application of modern mathematical approaches. This complexity is achieved through the use of linguo-combinatorial algebraic expressions and intellectual technologies for analyzing problem situations in the development of socio-economic relations in the region. In the present study, the region is considered a territory marked by the integrity and interconnection of its constituent elements. In this, consideration is given to the development of the financial sector and the availability of a substantiated assessment of the consequences of decision-making. In order to predict the consequences of implementing circular economy tools, it is necessary to apply the tools of fuzzy logic, soft computing, and the cybernetic approach in general.

1.1. Description of organizational principles for the development of circular economy technologies

The goal-setting process in the development of circular economy technologies in the region should ensure the improvement of living standards through the equalization of economic added value by regional (interregional) links in environment-to-product chains. Vertical integration of environment-to-product chains is realized through the introduction of digital technologies in management and through the application of intelligent socio-psychological solutions in the financial sector (Eskindarov, Maslennikov, 2019; Miroshnichenko, Mostovaia, 2019). As noted in a number of studies, the most important expected result of the introduction and development of the considered technologies is to guarantee a better quality of life (Kirchherr et al., 2017), ecologization of the economy, and import substitution, which, among other things, corresponds to the mobilization aspects of the development of the Russian economy.

The proposed principles of integration, cooperation, specialization, and protectionism in the development of regional financial and industrial policy make it possible to determine the ways of creating new and renewing the previous organizational and technological chains (oriented to the preservation of nature and existing ecosystems and the introduction of waste-free production). Under organizational and technological chains, we understand "a set of elements, links, and stages of the performed type of economic or other activity aimed at achieving a certain or expected result of said activity" (https://iacis.ru/deyatelnost/modelnoe_zakonotvorchestvo/ppz_v_sng_na_20202022gg/I_v_sfere_ekonomiki_i_finansov).

In the organizational aspect, this is achieved by means of the implementation of adaptive management mechanisms by participants in the process of development of circular economy technologies in the region, which is supported by a commission established for this exact purpose (Popova, 2018).

In order to create the conditions for the development of circular economy, i.e. the formation of a comprehensive organization of measures to preserve the natural complex of the region and eliminate the threats of depletion of natural resources, the approved program provides the following measures:

- to verify bottlenecks in the organizational and technological chain;

- to design connections in the regional industrial sector along the environment-to-product chain, which is understood as a type of organizational and technological chain in the industrial sector and presents a set of elements and stages in the production process from raw material extraction to the final product, its use, and utilization;

- to recreate former or construct new promising inter-element connections in the environment-to-product chain (vertical), which assumes changing the ways of managing the production sectors (types) of economic activity in manufacturing, including through digitalization.

The outlined measures promote the transition of the respective industrial sector to a new technological domain by virtue of intellectual and information and communication technologies, which are characterized by comprehensive data collection and analysis, as well as the need to process unstructured information flows for all stakeholders. The instruments recommended for synthesizing managerial decisions in performing the key management functions of planning, organization, coordination, and control in order to establish new organizational and technological (including environment-to-product) chains with the use of large databases and testing complex hypotheses are logico-linguistic modeling and artificial intelligence (Klimenkov, 2016; Kukor, Klimenkov, 2017).

Organization of the mechanism of conscious choice of the structure of product and service flow along the environment-to-product chain (vertical) based on the representation and extraction of knowledge about potential opportunities and public needs of economic systems in the region is possible with the digitalization of management and communication technologies (Iakovleva, Tolochko, 2021). In this case, the environment-to-product vertical of the digital transformation of production as a part of the public administration system ensures “the formation of economic added value in intermediate links united by the realization of final products with the participation of large, medium, and small businesses, including the adjustment and coordination of Russia's monetary, currency, and fiscal policies" (Iakovleva, Tolochko, 2021, p. 416). Ultimately, this serves the goals of improving the quality of life and achieving sustainable development in the region (Eskindarov et al., 2016). The described redistribution can provide regulation of the added value in the environment-to-product chain through the application of intelligent solutions in management.

1.2. Analysis of problematic situations in the region

Russia’s natural resources must not only be rationally used in the national interest (Ivanter et al., 2018) but also utilized in the sphere of high technology both in import substitution and in the process of advancing towards noonomics (Bodrunov, 2021a).

The important problems experienced by Russia in the sphere of natural resource use, greening of the economy, and resource-saving include:

– imperfection of the organizational structure of environmental management;

– ineffective interaction in the sphere of environmental protection and environmental safety between public authorities in the implementation of the region's industrial policy;

– the lack of a comprehensive approach to resolving the region’s environmental problems;

– imperfect legislation (for instance, there is a need to introduce an economic code to systematize the economic relations of economic entities);

– lacking specialized training of staff;

– a deficit of funding (Maslennikov et al., 2017);

– the lack of an efficient mechanism to stimulate resource saving, the introduction of environmentally friendly technologies, and the disposal of production waste in the formation of strategic plans of enterprises (Bodrunov, 2021b).

The described problematic issues are interrelated (see Fig. 1):

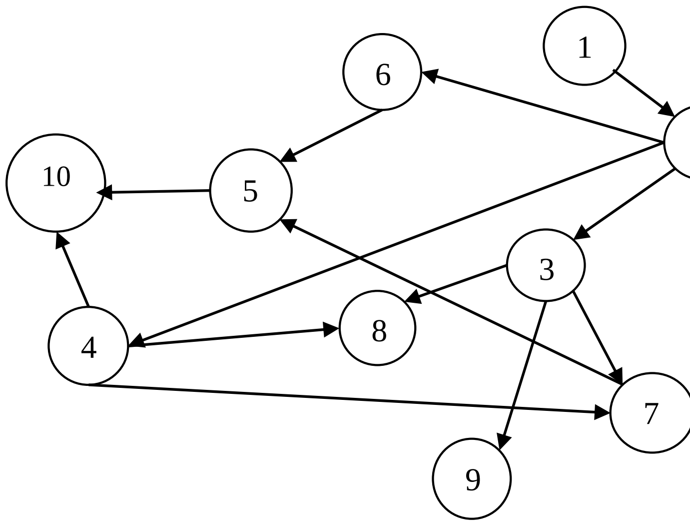

Figure 1. Cause-and-effect model of the problem domain in ecology.
Source: compiled by the authors.

Designations: (1) inefficient interaction in the field of environmental protection and environmental safety between public authorities in the industrial policy of the region (inconsistency of management goals and objectives); (2) lack of an integrated approach to planning and coordination of solutions to environmental problems of the district by sectoral and territorial executive bodies; (3) imperfect organizational structure of environmental management; (4) imperfect legislative base; (5) the need for proactive personnel training; (6) lack of financing, insufficient use of digital financial assets; (7) lack of an effective mechanism to stimulate resource saving, the introduction of environmentally friendly technologies; the problem of production waste in the formation of strategic plans of enterprises; (8) lack of control over objects that pollute the environment; (9) underdeveloped infrastructure; (10) disruption of the ecological balance.

The conducted statistical research on the environmental situation in specific regions of the Northwestern Federal District (Vologda Oblast, Arkhangelsk Oblast, and the Republic of Karelia) reveals general trends and factors that impede entry into a sustainable economic growth trajectory.

Among these is the lack of systemic control over the objects that pollute the environment (Steblianskaia et al., 2019) and over the dynamics of the environmental situation.

Furthermore, the three aforementioned regions demonstrate the following characteristic problematic situations:

– multidimensional and interdependent problems of inflation, demography, security, defense, unemployment, and the environment;

– absence of industry standards for the introduction of modern technologies in general, and those inherent to the circular economy in particular;

– excessive regulation, which slows down the pace of innovative development and leads to the "over-bureaucratization" of documentation;

– the need to redefine the structure and functions of the management of various elements in Russia's financial and educational systems and sectoral institutions in the interests of developing social, innovative, and industrial systems and harmonizing economic relations in order to transition to modern resource-saving technologies;

– inertia in the process of digitalization of the financial and economic sphere;

– high tax burden on the real sector of the economy;

– complex, labor-intensive system of tax control;

– excessive administration and control;

– problems in the production and innovation sphere related to the external and internal environment.

There are also a number of important directions necessary for sustainable development in the environmental sphere, such as: construction of underground crosswalks, multi-level automobile interchanges, and special areas for walking pets; strengthening of the control apparatus for objects that pollute the environment; development of an effective mechanism to stimulate resource conservation; introduction of environmentally friendly technologies; and restoration of the necessary number of green spaces.

The choice of these areas of sustainable development will have a positive impact on the environmental situation in the area, which will ultimately contribute to the improvement of public health and quality of life.

2. METHODS

2.1. Approaches to formalization of the system of regional indicators of the development of circular economy in the region

Formalization of the description of the regional indicators system for circular economy technology development should take into account the periodicity of modeling and forecast calculations on the consequences of managerial decisions of a planning, organizational, and coordination nature. According to the system approach, it is necessary to conduct semantic modeling with the representation of cause-and-effect relationships in the region to describe the characteristics of the object and subject of management and the properties of the control structure. Further, for the viability of the system, it is essential to ensure the structurization of goals with regard to sustainable development and the implementation of a circular economy for the object and the subject of management.

The approach suitable for modeling the assessment of the consequences of decisions made in the development of the program of circular economy technology development under the conditions of insufficient information, uncertainty of tasks, stochasticity of management processes, and dynamism of the environment is the fuzzy-multiple approach.

The development of the program requires forming a set of knowledge bases on the rules and constraints of the operation of elementary objects in the region, including the criteria of safety and risk protection, integrity, and equilibrium (Kuragin, 2021).

2.2. Composition of the indicator system by elements

The methodology for building a linguo-combinatorial model (LCM_t) is based on the concepts of the algebraic ring, combinatorics, and mathematical linguistics. The fundamental basis of control in the model is the provisions of the linguo-combinatorial approach of M.B. Ignatiev (Ignatev, Katermina, 2018a), which determine the efficiency of the model that is contingent on changes in the number of coefficients. "The adaptation capabilities of a system are the higher the more uncertain coefficients are operating in it. With the help of uncertain coefficients, it is possible to change the trajectory of motion along the given manifolds" (Ignatev, Katermina, 2018b, p. 115).

In forming a linguo-combinatorial model of the economic system of the region, we need to account for the complexity and diversity of links between elements, the incompleteness of information about the state of the system, and the parameters of information flows (Ignatyev, Katermina, 2016).

The element composition of the system of indicators consists of the description of characteristics of the subjects and objects of interaction within the region's socio-economic system, including available resource-industrial complexes, nature, labor resources, the intellectual potential of the region, and its science and education. Since we are dealing with regional indicators, the linguistic variables should characterize the above problematic situations.

Next, let us present a general semantic expression from three variables with two limitations:

$$A_1^1 E_1 + A_2^1 E_2 + A_3^1 E_3 = 0 \quad (1)$$

$$A_1^2 E_1 + A_2^2 E_2 + A_3^2 E_3 = 0 \quad (2)$$

where A_i^j– characteristics, i – number of the characteristic, j – order of the limitation, E_i – change in the i-th characteristic.

In equations (1) and (2), as well as in the following formulas, all values of variables are normalized, since it is important to understand the degree of influence of individual parameters (variables) on changes in the model characteristics when studying the model. In this case, it is acceptable to carry out the procedure of variable denormalization, which can be used for systems described by differential equations, for example, control systems.

Let us present the formulation of a model for creating a regional financial and economic policy focused on stimulating the development of the circular economy, which reflects the indicators necessary for monitoring.

Suppose that we face the task of managing the ecological, resource, production, and intellectual potentials of one of the regions of Northwestern Federal District for the long term within the framework of the policy of implementation of circular economy technologies. From the point of view of creating funding sources in accordance with regional financial and economic policy, all these components are significant and are connected with each other by various economic and management processes. Thus, the situation of lack of adequate financial resources for the region's industrial enterprises prevents them from switching to up-to-date equipment in the process of ecologization and import substitution (thereby increasing the degree of wear and tear of the main production assets and increasing the emission of pollutants into the atmosphere).

Deterioration of the environmental situation in the region, in turn, promotes an increase in the burden on the regional budget, including due to increased expenditures on the health care system (because of a rise in the incidence of heart attacks, strokes, and other dangerous diseases).

Having singled out the principal components of interest, let us form the following equation (3) in the form of an algebraic ring:

$$A_1^1 E_1 + A_2^1 E_2 + A_3^1 E_3 = 0 \qquad (3)$$

where A_1^1 – regional resource potential accounting for the socio-economic and environmental characteristics of economic activity to solve the tasks of development of the circular economy; E_1 – information-analytical description of the region's industrial policy by the structure of resource potential; A_2^1 – characteristics of regional environmental potential; E_2 – information and methodological description of production potential; A_3^1 – characteristics of the regional financial system; E_3 – information and methodological description of the financial and economic policy of the region (Bobylev, Soloveva, 2020). E_i– changes in variables.

The summands in the equation can be negative or positive depending on changes in the variables (E_i).

The development of a circular economy will depend on many qualitative and quantitative characteristics of a particular region (D'Amato et al., 2019). Naturally, the state of environmental and resource (including production) potential is constantly changing, resulting in changes in the dynamics of indicators of regional socio-economic development.

In this case, the matrix should be presented as follows:

$$\begin{matrix} A_1^1 A_2^1 A_3^1 \\ A_1^2 A_2^2 A_3^2 \end{matrix} \qquad (4)$$

In turn, changes E_i of characteristics A_i^j can be described by the determinants of minors:

$$\{E_1 = u_1 D_{23}^1 \; E_2 = -u_1 D_{13}^2 \; E_3 = u_1 D_{12}^3 \qquad (5)$$

Where D_{23}^1– determinant of the minor of matrix (4) when leaving columns 2 and 3; u_1 … etc. – arbitrary mathematical coefficients that allow updating the information and methodological support of the model so that the consequences of the decisions taken in the form of changes in the dynamics of the corresponding indicators are adjusted to the desired characteristics of the region's potentials, which experts can work out in the process of modeling the system.

Index 1 on top of D_{23}^1 is the ordinal number of the equation in the system (5). Thus, the determinants of the matrix minors can be represented as:

$$D_{23}^1 = \left| A_2^1 \; A_3^1 \; A_2^2 \; A_3^2 \right| = A_2^1 \times A_3^2 - A_3^1 \times A_2^2$$

$$D_{13}^2 = \left| A_1^1 \; A_3^1 \; A_1^2 \; A_3^2 \right| = A_1^1 \times A_3^2 - A_3^1 \times A_1^2 \qquad (6)$$

$$D_{12}^3 = \left| A_1^1 \; A_2^1 \; A_1^2 \; A_2^2 \right| = A_1^1 \times A_2^2 - A_2^1 \times A_1^2$$

Developing the theory, it is possible to introduce other variables into the stage model, e.g.:

A_4^1 – characteristics of the region's innovation system (innovation potential, implementation of the latest technologies of artificial intelligence and the Internet of Things) with a focus on qualitative and quantitative models for assessing innovation potential (Ignatiev, Makin, 2017b);
E_3 – information and methodological description of the region's innovation policy.

Let us represent algebraically a model of four variables with one constraint, for example, on emissions:

$$A_1^1 E_1 + A_2^1 E_2 + A_3^1 E_3 + A_4^1 E_4 = 0$$

$$A_1^1 A_2^1 A_3^1 A_4^1$$

$$\{E_1 = u_1 D_2^1 + u_2 D_3^1 + u_3 D_4^1 \ E_2 = -u_1 D_1^2 + u_4 D_3^2 + u_5 D_4^2 \ E_3 = -u_2 D_1^3 - u_4 D_2^3 + u_6 D_4^3 \ E_4 = -u_3 D_1^4 - u_5 D_2^4 - u_6 D_3^4 \tag{7}$$

$$D_1^2 = D_1^3 = D_1^4 = A_1^1 D_2^1 = D_2^3 = D_2^4 = A_2^1 D_3^1 = D_3^2 = D_3^4 = A_3^1$$

$$D_4^1 = D_4^2 = D_4^3 = A_4^1$$

Next, we algebraically present a four-variable model with two limitations (let the second limitation be imposed on import substitution):

$$A_1^1 E_1 + A_2^1 E_2 + A_3^1 E_3 + A_4^1 E_4 = 0 A_1^2 E_1 + A_2^2 E_2 + A_3^2 E_3 + A_4^2 E_4 = 0$$

$$A_1^1 A_2^1 A_3^1 A_4^1 A_1^2 A_2^2 A_3^2 A_4^2$$

$$\{E_1 = u_1 D_{23}^1 + u_2 D_{24}^1 + u_3 D_{34}^1 \ E_2 = -u_1 D_{13}^2 - u_2 D_{14}^2 + u_4 D_{34}^2 \ E_3 = u_1 D_{12}^3 - u_3 D_{14}^3 - u_4 D_{24}^3 \ E_4 = u_2 D_{12}^4 + u_3 D_{13}^4 + u_4 D_{23}^4$$

$$D_{23}^1 = D_{23}^4 = \left| A_2^1 \ A_3^1 \ A_2^2 \ A_3^2 \right| = A_2^1 \times A_3^2 - A_3^1 \times A_2^2$$

$$D_{24}^1 = D_{24}^3 = \left| A_2^1 \ A_4^1 \ A_2^2 \ A_4^2 \right| = A_2^1 \times A_4^2 - A_4^1 \times A_2^2 \tag{8}$$

$$D_{13}^2 = D_{13}^4 = \left| A_1^1 \ A_3^1 \ A_1^2 \ A_3^2 \right| = A_1^1 \times A_3^2 - A_3^1 \times A_1^2$$

$$D_{12}^3 = D_{12}^4 = \left| A_1^1 \ A_2^1 \ A_1^2 \ A_2^2 \right| = A_1^1 \times A_2^2 - A_2^1 \times A_1^2$$

$$D_{34}^1 = D_{34}^2 = \left| A_3^1 \ A_4^1 \ A_3^2 \ A_4^2 \right| = A_3^1 \times A_4^2 - A_4^1 \times A_3^2$$

$$D_{14}^2 = D_{14}^3 = \left| A_1^1 \ A_4^1 \ A_1^2 \ A_4^2 \right| = A_1^1 \times A_4^2 - A_4^1 \times A_1^2$$

Further, a third constraint can be introduced into the model, such as measures of protectionism.
A model with four variables and three limitations can be presented as follows:

$$A_1^1 E_1 + A_2^1 E_2 + A_3^1 E_3 + A_4^1 E_4 = 0 A_1^2 E_1 + A_2^2 E_2 + A_3^2 E_3 + A_4^2 E_4 = 0 A_1^3 E_1 + A_2^3 E_2 + A_3^3 E_3 + A_4^3 E_4 = 0$$

$$A_1^1 A_2^1 A_3^1 A_4^1 A_1^2 A_2^2 A_3^2 A_4^2 A_1^3 A_2^3 A_3^3 A_4^3 \tag{9}$$

$$\{E_1 = u_1 D^1_{234}\ E_2 = -u_1 D^2_{134}\ E_3 = u_1 D^3_{124}\ E_4 = -u_1 D^4_{123}$$

$$D^1_{234} = |A^1_2\ A^1_3\ A^1_4\ A^2_2\ A^2_3\ A^2_4\ A^3_2\ A^3_3\ A^3_4\ | = A^1_2 \times A^2_3 \times A^3_4 + A^1_3 \times A^2_4 \times A^3_2 + A^1_4 \times A^2_2 \times A^3_3 - A^1_4 \times A^2_3 \times A^3_2 - A^1_3 \times A^2_2 \times A^3_4 - A^1_2 \times A^2_4 \times A^3_3$$

$$D^1_{134} = |A^1_1\ A^1_3\ A^1_4\ A^2_1\ A^2_3\ A^2_4\ A^3_1\ A^3_3\ A^3_4\ | = A^1_1 \times A^2_3 \times A^3_4 + A^1_3 \times A^2_4 \times A^3_1 + A^1_4 \times A^2_1 \times A^3_3 - A^1_4 \times A^2_3 \times A^3_1 - A^1_3 \times A^2_1 \times A^3_4 - A^1_1 \times A^2_4 \times A^3_3$$

$$D^1_{124} = |A^1_1\ A^1_2\ A^1_4\ A^2_1\ A^2_2\ A^2_4\ A^3_1\ A^3_2\ A^3_4\ | = A^1_1 \times A^2_2 \times A^3_4 + A^1_2 \times A^2_4 \times A^3_1 + A^1_4 \times A^2_1 \times A^3_2 - A^1_4 \times A^2_2 \times A^3_1 - A^1_2 \times A^2_1 \times A^3_4 - A^1_1 \times A^2_4 \times A^3_2$$

$$D^1_{123} = |A^1_1\ A^1_2\ A^1_3\ A^2_1\ A^2_2\ A^2_3\ A^3_1\ A^3_2\ A^3_3\ | = A^1_1 \times A^2_2 \times A^3_3 + A^1_2 \times A^2_3 \times A^3_1 + A^1_3 \times A^2_1 \times A^3_2 - A^1_3 \times A^2_2 \times A^3_1 - A^1_2 \times A^2_1 \times A^3_3 - A^1_1 \times A^2_3 \times A^3_2$$

From the procedure of normalization of these variables follows the need to bring the rest (characteristics of objects and actors) into compliance with the norms according to the theory of adaptive management of the regional industrial complex (planning, organization, coordination, and control) (Kukor, Klimenkov, 2017). The development of these potentials of the region depends on the availability of experience in managing projects on similar topics, the possibility of using expert systems, the formation of a map of events to achieve management goals, etc.

As demonstrated in the model, it is possible to change the number of keywords when specifying the conditions or the number of limitations within the framework of structuring the indicators of the implementation of a circular economy (Ignatiev, Makin, 2017b) when managing the policy and program. In accordance with the conclusions of M.B. Ignatiev, the number of arbitrary coefficients determines the adaptive capacity of the system (Ignatiev, Makin, 2017a).

3. MODELING RESULTS

For the convenience of modeling, it is advisable to use the developed templates for describing variables and their characteristics (Table 1).

Table 1. Denotations in the lingo-combinatorial model.

No.	Alphanumeric abbreviation	Characteristic of objects (actors)	Alphanumeric abbreviation	Dynamic transformation of the characteristic
1	A_1	Resource potential of the region	E_1	Using the results of SWOT analysis to identify further optimal directions for the development of circular economy
2	A_2	Environmental potential of the region	E_2	Analysis of the identified threats and opportunities. Changes to strategic development plans, budgets, and acts, including in view of the destructive influence of sanctions
3	A_3	Financing system	E_3	Reorganization of approaches to

				financial support
4	A_4	Innovation potential of the region	E_4	Formation of conditions for the use of innovations and environmentally friendly technologies
5	Results	Target norms for key policy characteristics	Allowable value range	Adaptation of parameters for the work of the regional commission

Source: compiled by the authors.

Using the MatLab software package, we created a discrete model that allows predicting the results of the achievement of the circular economy development program in coordination with financial and economic policy measures (Fig. 2).

The model is built for four variables under two limitations; all signals in it are discrete, but, in principle, can also be analog.

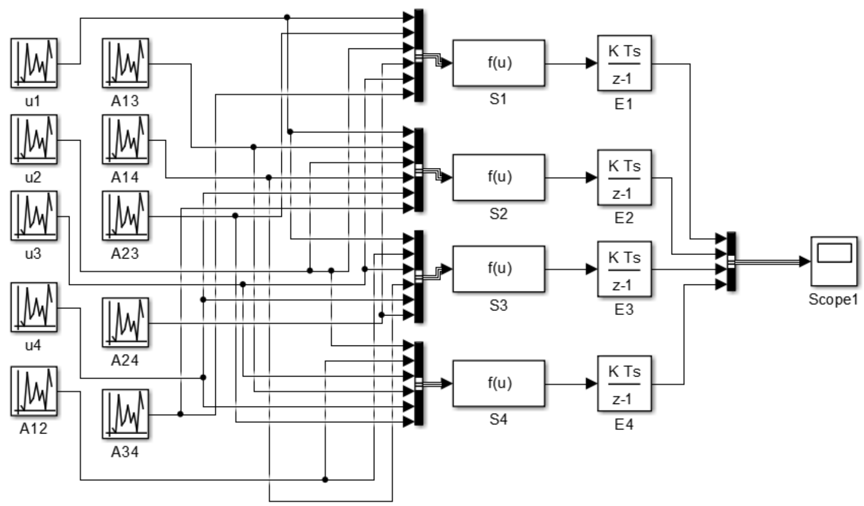

Figure 2. Graphical depiction of the model for the system of regional indicators of circular economy development.
Source: compiled by the authors.

The dynamic transformation of parameters and characteristics over time in the proposed model looks as demonstrated in Fig. 3.

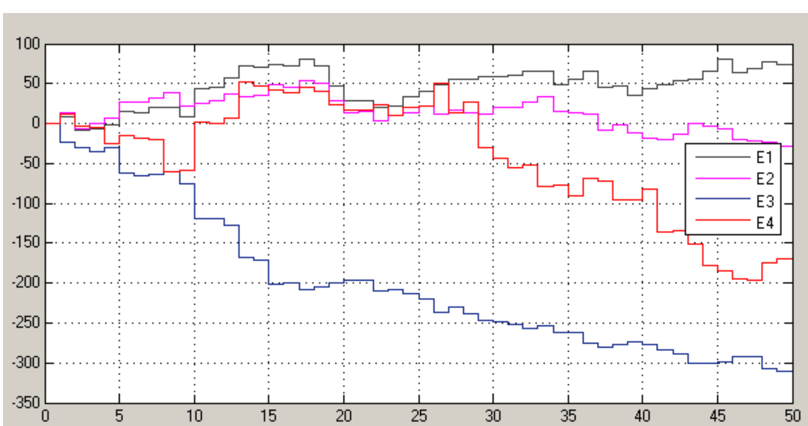

Figure 3. Change of parameters of the indicator system model by templates of dependence on the time

factor.
Note: on the abscissa axis – time in notional seconds of the MatLab system; on the ordinate axis – value of the variable in notional units of the MatLab system.
Source: compiled by the authors.

Next, let us consider the changes occurring in a system of four variables with two limitations when some variable increases. For this purpose, we will manipulate the uncertain coefficients in the system so that, for example, the variable A_4 increases. The result of such manipulations is a set of equations in which all variables change synchronously and their influence on each other can be traced (Fig. 4).

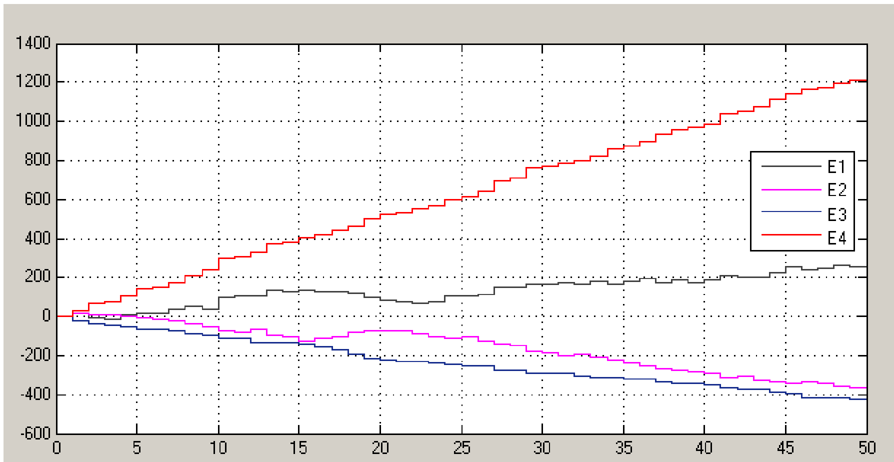

Figure 4. Graphical depiction of control over the logical-linguistic model with increasing variable A4 (innovation potential of the region).
Note: on the abscissa axis – time in notional seconds of the MatLab system; on the ordinate axis – value of the variable in notional units of the MatLab system.
Source: compiled by the authors.

4. DISCUSSION

4.1. Description of recommended solutions in the sphere of finance

As a way to solve the tasks of financial and economic policy we can point to the organization of planned work on building organizational and production chains as part of the work of a specially established commission under the executive body of state power in the region. This provides for the creation of a competence center – a state-authorized body that provides expert, analytical, and methodological support in the region for the program of organizing activities for the introduction of circular economy technologies. The key tasks of this center are the development and introduction of a regional mechanism for implementing a coordinated policy in the implementation of plans and (or) projects in the field of green economy.

Furthermore, additions should be made to the geoinformation system of the region regarding:

– available technological solutions and their providers in the region;

– assessment of the needs and opportunities for finding a component base for technological solutions in case of substituting foreign partners;

– requirements for patenting (Zhdanova et al., 2021).

Coordination with the education policy in relation to the training of specialists is a critical prerequisite for the introduction of technologies.

Preferences in taxation developed at the legislative level will allow enterprises that introduce circular economy technologies to reimburse the falling out costs of the ecologization of production, the regulation of labor remuneration at the level of modern relations, and the renewal of means of production, as well as to achieve normalized values of profitability, cost recovery, capital-labor, and resource provision.

The financial system is required to provide for:

– the creation of conditions for expanding the channels of access to affordable credit financing for enterprises of the studied type, for example, by compensating a part of interest expenses, creating industry funds, applying special financial instruments (tokens, Islamic banking as one of the ways to organize project financing, digital currencies) (Luzgina, 2021);

– the development of the necessary entrepreneurial infrastructure for the emergence of new types of companies of resource-efficient economy, including venture funds, business incubators, and other economic blocks (Li et al., 2017) capable of adequately assessing and interacting with the increased level of risk when testing a new business model;

– funding for the process of advanced training of the required personnel who possess technical, environmental, economic, and other knowledge essential for the successful operation of enterprises that are following the concepts of green economy;

– the allocation of funds from the regional budget for backbone enterprises that are flagships for the development of circular economy by establishing a development fund or within the framework of sectoral funds;

– creating socio-economic conditions to ensure the smooth operation of circular economy enterprises, e.g. by reducing administration and control;

– the intensification of investment processes in the greening of the economy through low-cost credit or digital financial currencies for green economy development programs and the creation of favorable conditions for export-import operations by enterprises that introduce new technologies (Andreeva et al., 2020).

At the moment, those responsible for the implementation of circular economy technology development organize the management of all its priority areas in the established order, which enables the transition from the current state of the region's socio-economic system to the desired one. Verification of the workability of the proposed hypotheses for solving the identified problems of the region is provided with the help of the linguo-combinatorial model.

In addition to the environmental agenda, priority is given to geopolitical issues, import substitution, access to innovative developments and high-tech, and redistribution of logistics and organizational and production chains. Ignoring these circumstances poses threats to economic and product security, demographics, and medicine, and a number of other negative consequences. Due to global climate change, the economy will lose much more than the amount of the potential costs of minimizing a negative human impact on the planet. Therefore, the key guideline of circular economy and public policy in this area is to create a favorable environment for the sustainable long-term development of the region's economic system. In the face of sanctions and the transition to a new economic model, it is advised to minimize the losses arising from the destructive impact of environmental disasters and threats (Aleksandrova, 2019).

The study presents a methodological approach to modeling the system of regional indicators of circular economy development. The hypothesis put forward is confirmed, as the modeling systems based on the principles of fuzzy logic combine the possibilities of simple and logically understandable transformation of the available numerous disparate numerical data into normalized linguistic concepts that are suitable for further use in reasoning modeling systems. Such systems based on the methods of fuzzy logical inference and situational management allow to interpret the available expert knowledge with the highest degree of plausibility and implicitly take into account the actions and interests of all participants in the form of an assessment of the consequences of decisions. It is possible to further transform the results into a clear numerical form suitable for later use in forecasting and management, for example, in the form of input of additional regional indicators and characteristics (Teece, 2018a, 2018b).

5. CONCLUSION

The study demonstrates the construction of flexible control models of behavior of a complex socio-economic system of the region, which can form a sequence of desired target states on the basis of target normalization of linguistic variables and network graphs of problem situations resolution. The applied linguistic variables serve as a basis for the formation of a slot structure and frame representation of domain-specific knowledge for artificial intelligence.

Thus, the modeling of the consequences of policy management and implementation of the development program for circular economy technologies is carried out through the elaboration of qualitative (linguistic) and quantitative variables by matching them to the given objectives and expected results. The system of indicators of circular economy development is integrated into the characteristics of the proposed model, which can change in dynamics.

As a result of the modeling, it is possible to define a range of target regulations for the successful implementation of circular economy technologies and innovations, for the greening of the economy, in order to elaborate further scenarios and evaluate the consequences of the decisions taken by the regional commission.

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REFERENCES

Aleksandrova, V.D. (2019). Sovremennaia kontseptsiia tsirkuliarnoi ekonomiki [Modern concept of circular economy]. International Journal of Humanities and Natural Sciences, 5-1 Ekonomicheskie nauki, 87- 93. https://doi.org/10.24411/2500-1000-2019-10867

Andreeva, O.V., Melekhova, M.A., Turichenko, L.P., Chernobai, O.S. (2020). Finansovye instituty i instrumenty "zelenoi" ekonomiki [Financial institutions and instruments of the green economy]. Fundamental Research, 8, 7-11.

Bobylev, S.N., Soloveva, S.V. (2020). Tsirkuliarnaia ekonomika i ee indikatory dlia Rossii [Circular economy and its indicators for Russia]. The World of the New Economy, 14(2), 63-72. http://dx.doi.org/10.26794/2220-6469-2020-14-2-63-72

Bodrunov, S.D. (2021a). Genezis noonomiki: NTP, diffuziia sobstvennosti, sotsializatsiia obshchestva, solidarizm [Genesis of noonomics: Scientific and technical progress, diffusion of property, socialization of society, solidarism]. Economic Revival of Russia, 1(67), 5-14. https://doi.org/10.37930/1990-9780-2021-1-67-5-14

Bodrunov, S.D. (2021b). Sovremennaia strategiia razvitiia trebuet povorota k planirovaniiu [Contemporary development strategy requires a turn to planning]. Economic Revival of Russia, 3(69), 5-13. https://doi.org/10.37930/1990-9780-2021-3-69-5-13

D'Amato, D., Korhonen, J., Toppinen, A. (2019). Circular, green, and bio economy: How do companies in land-use intensive sectors align with sustainability concepts? Ecological Economics, 158, 116-133. http://dx.doi.org/10.1016/j.ecolecon.2018.12.026

Eskindarov, M.A., Abramova, M.A., Maslennikov, V.V., Goncharenko L.I., Zvonova E.A., Krasavina L.N., Lavrushin O.I., Larionova I.V., Rubtsov B.B., Solyannikova S.P., Fedotova M.A. (2016). Ustoichivoe razvitie rossiiskoi ekonomiki: Sovershenstvovanie denezhno-kreditnoi, valiutnoi i biudzhetno-nalogovoi politiki [Sustainable development of the Russian economy: Improvement of the monetary, forex and fiscal policies]. Bulletin of the Financial University, 20(6), 6-18.

Eskindarov, M.A., Maslennikov, V.V. (Eds.). (2019). Novye traektorii razvitiia finansovogo sektora Rossii [New trajectories of development of the financial sector of Russia]. Moscow: Cogito-Center Publishing House, 368 p.

Gamidullaeva, L.A., Tolstykh, T.O., Shmeleva, N.V. (2020). Metodika kompleksnoi otsenki potentsiala promyshlennoi ekosistemy v kontekste ustoichivogo razvitiia regiona [Method of integrated assessment of the potential of the industrial ecosystem in the context of sustainable development of the region]. Modeli, sistemy, seti v ekonomike, tekhnike, prirode i obshchestve, 2(34), 29-48. https://doi.org/10.21685/2227-8486-2020-2-3

Iakovleva, E.A., Tolochko, I.A. (2021). Instrumenty i metody tsifrovoi transformatsii [Tools and methods of digital transformation]. Russian Journal of Innovation Economics, 11(2), 415-430. https://doi.org/10.18334/vinec.11.2.112016

Ignatyev, M.B., Katermina, T.S. (2016). Chaos control and uncertainty. In Proceedings of 2016 XIX IEEE International conference on soft computing and measurements (SCM), May 25-27, 2016, St. Petersburg, Russia (pp. 449-452). Saint Petersburg: Institute of Electrical and Electronics Engineers Inc. https://doi.org/10.1109/SCM.2016.7519810

Ignatev, M.B., Katermina, T.S. (2018a). Miagkoe prognozirovanie i planirovanie razvitiia slozhnykh sistem na osnove lingvo-kombinatornogo podkhoda [Soft forecasting and planning of complex systems development on the basement of the linguo-combinatorial approach]. In International conference on soft computing and measurement (IEEE SCM 2018) (Vol. 2, pp. 397-400). St. Petersburg: St. Petersburg State Electrotechnical University "LETI" named after V.I. Ulyanov (Lenin).

Ignatev, M.B., Katermina, T.S. (2018b). Sistemnyi analiz zadach prognozirovaniia i planirovaniia razvitiia slozhnykh struktur: Lingvo-kombinatornyi podkhod [System analysis of the tasks of forecasting and planning the development of complex structures: A linguo-combinatorial approach]. In System analysis in engineering and control: Proceedings of the XXII International scientific and practical conference, May 22-24, 2018 (Part 1, pp. 115-118). St. Petersburg: Polytechnic University Publishing House.

Ignatiev, M.B., Makin, P.I. (2017a). Adaptive capabilities of complex systems. In Proceedings of 2017 XX IEEE International conference on soft computing and measurements (SCM), May 24-26, 2017, Saint-Petersburg, Russia (pp. 681-683). Saint-Petersburg: Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/SCM.2017.7970688

Ignatiev, M.B., Makin, P.I. (2017b). The phenomenon of an adaptive maximum in socioeconomic systems. In Proceedings of 2017 XX IEEE International conference on soft computing and measurements (SCM), May 24-26, 2017, Saint-Petersburg, Russia (pp. 715-717). Saint-Petersburg: Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/SCM.2017.7970700

Ivanter, V.V., Porfirev, B.N., Sorokin, D.E., Eskindarov M.A., Maslennikov V.V., Shirov A.A., Abdikeev N.M., Abramova M.A., Bogachev Yu.S., Goncharenko L.I., Govtvan' O.D., Gusev M.S., Dubova S.E., Ershov M.V., Zubets

A.N., Kolpakov A.Yu., Ksenofontov M.N., Kuvalin D.B., Fedotova M.A., Mikheeva N.N., Moiseev A.K., Potapenko V.V., Solyannikova S.P., Stroev P.V., Tolkachev S.A., Uzyakov M.N. (2018). Kak pridat impuls razvitiiu rossiiskoi ekonomiki: Prioritety deistvii (predlozheniia k osnovnym napravleniiam deiatelnosti Pravitelstva RF do 2024 g.) [How to boost the development of the Russian ewconomy: Priority actions (suggestions for the main activities of the state until 2024)]. Finance: Theory and Practice, 22(S7), 4-15. https://doi.org/10.26794/2587-5671-2018-0-0-4-15

Kirchherr, J., Reike, D., Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, 127, 221-232. http://dx.doi.org/10.1016/j.resconrec.2017.09.005

Klimenkov, G.V. (2016). Postroenie sistemy adaptivnogo upravleniia na baze logiko–lingvisticheskogo modelirovaniia [Building systems of adaptive control based on logic-linguistic modelling]. Bulletin USPTU. Science, Education, Economy. Series Economy, 16(2), 66-70.

Kukor, B.L., Klimenkov, G.I. (2017). Adaptivnoe upravlenie promyshlennym kompleksom regiona: Teoriia, metodologiia, praktika [Adaptive management of the industrial complex of the region: Theory, methodology, practice]: Monograph. Ekaterinburg: Institute of Economics, Ural Branch of RAS, 305 p.

Kuragin, A.V. (2021). Issledovanie metodov i algoritmov otsenki ekologicheskikh riskov [Research of methods and algorithms for environmental risk assessment]. Era of Science, 28, 390-395.

Li, C., Whalley, J. (2017). How close is Asia already to being a trade bloc? Journal of Comparative Economics, 45(4), 847-864. https://doi.org/10.1016/j.jce.2016.08.001

Luzgina, A. (2021). Zelenyi banking: Sushchnost, instrumenty, perspektivy razvitiia [Green banking: Essence, instruments and prospects of development]. Bankovskiy Vestnik, 3(692), 31-42.

Maslennikov, V.V., Fedotova, M.A., Sorokin, A.N. (2017). Novye finansovye tekhnologii meniaiut nash mir [New financial technologies change our world]. Finance: Theory and Practice, 21(2), 6-11.

Miroshnichenko, O.S., Mostovaia, N.A. (2019). "Zelenyi" kredit kak instrument "zelenogo" finansirovaniia [Green loan as a tool for green financing]. Finansy: Teoriia i praktika [Finance: Theory and Practice], 23(2), 31-43. https://doi.org/10.26794/2587-5671-2019-23-2-31-43

Popova, A.G. (2018). K voprosu o soderzhanii regionalnoi politiki kak sovokupnosti vzaimosviazannykh komponentov: Ekonomicheskogo, sotsialnogo, ekologicheskogo [To the question of the content of regional policy as a set of interrelated components: Economic, social, environmental]. Regional Economy and Management: Electronic Scientific Journal, 2(54), 5409.

Steblianskaia, A.N., Vang, D., Bragina, Z.V. (2019). Teoriia obespecheniia ustoichivosti finansovogo rosta kak rezultata vzaimodeistviia s energeticheskimi, ekologicheskimi i sotsialnymi protsessami (na primere neftegazovoi industrii) [Financial sustainable growth theory as a result of interaction with energy, environmental and social processes (evidence from oil and gas industry)]. Finance: Theory and Practice, 23(2), 134-152. https://doi.org/10.26794/2587-5671-2019-23-2-134-152

Teece, D.J. (2018b). Dynamic capabilities as (workable) management systems theory. Journal of Management & Organization, 24(3), 359-368. https://doi.org/10.1017/jmo.2017.75

Teece, D.J. (2018a). Business models and dynamic capabilities. Long Range Planning, 51(1), 40-49. https://doi.org/10.1016/j.lrp.2017.06.007

Zhdanova, E.N., Suloeva, E.S., Filippov, M.M., Minina, A.A. (2021). Printsipy organizatsii baz geodannykh dlia izucheniia sekvestratsionnogo potentsiala karbonovykh territorii [Geodatabases organization principles for studying the sequestration potential of carboniferous territories]. Mezhdunarodnaia konferentsiia po miagkim vychisleniiam i izmereniiam, 1, 290-293.